It's all in the milk: The development of cattle breeding and arable farming ensured that there was a simple, reliable supply of meat and grain. The milk from cows, sheep and goats also proved especially valuable.

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# Change That Came from the Plowed Field

The transition to agriculture changed human society more drastically than almost any other innovation. Scientists at the **Max Planck Institute for the Science of Human History** in Jena are investigating this revolution from very different perspectives.

#### TEXT CLAUDIA DOYLE

arming. That means getting up early and going to bed late, never going on vacation and always being there for the farm. Living on the edge and at the source. People have devoted themselves to agriculture for more than 10,000 years. Once upon a time, we were all farmers. But before our ancestors discovered agriculture, they roamed the land as hunters and gatherers. They lived together in small groups. There was no cause for warlike conflicts; the concept of social status was alien to them and possessions were shared. In the daily lives of our ancestors, there was no room for many things that we take for granted.

Anthropologist Robert Spengler, who will leave New York University to begin working at the Max Planck Institute for the Science of Human History in Jena in the fall of 2017, calls the change to an agricultural way of life "an unstoppable snowball." Arable farming brought the opportunity to store grain and thus to feed large families, resulting in rapid population growth. Not all members of the community were needed for agricultural work, which meant that some of them were able to indulge in intellectual, spiritual or artistic pursuits – but they also began to wage wars. Human communities became ever more complex with the development of professions, and changes increased exponentially. However, we still don't know exactly what got this snowball rolling. Researchers at the Institute in Jena are using a wide array of approaches to explore this question.

## AGRICULTURE BROUGHT MORE PLANT-BASED FOODS

The transition from the nomadic way of life of hunters and gatherers to the sedentary farming lifestyle is fluid. There were, and still are, pure hunter-gatherer cultures that neither keep farm animals nor cultivate the fields. Coexisting with them were peoples who wandered the land with their herds and, to a limited extent, also indulged in arable farming. Added to the mix were the farmers, the most sedentary of the groups, who nevertheless still fished and hunted. It's clear that, over the course of the millennia, in many regions of the world, the sedentary farming way of life gradually and increasingly displaced that of the hunters, gatherers and nomads.

Those who study this transition and the cultural changes it brought about repeatedly encounter one anomaly. All over the globe, it was agriculture that set off wide-ranging social changes. The exception is the area that is today's Mongolia, Western China and Eastern Russia: the textbook opinion since the 1930s has been that people there ignored the innovations in agriculture, continued to live as nomadic shepherds and still developed a complex form of society.

For around ten years now, this worldview has been showing cracks. The man stirring up trouble – in a positive sense – is Robert Spengler. He joined archaeological digs in Central Asia and searched for evidence of early agricultural activity. While everyone around him was staring at skeletons, he scratched the ash



**Above** In excavations in Tasbas, Kazakhstan in northern Central Asia, Robert Spengler found the earliest evidence to date of grain cultivation. The early inhabitants of the region had long been regarded as exclusively nomadic.

**Below** Crops spread with merchants and migrants – for instance via the legendary Silk Road. This is evidenced by chickpeas from around 1100 CE found in excavations in Uzbekistan.



from 5,000-year-old hearths and found carbonized plant seeds.

Spengler can tell simply by their appearance under the microscope what plant they come from. The scientist found different types of wheat, millet, barley, peas, lentils and beans, all of them plants more often cultivated in fields than gathered in the wild. "The societies there are therefore no exception to the rule. Although they hunted, fished and gathered plants, they definitely also farmed the land," says Spengler. "It was simply that no one had ever investigated it."

One of the radical changes occasioned by the transition to agriculture was the supply of food. Nomadic peoples set off every day in search of something to eat and always follow their herds as far as they can walk. In addition to the meat from their herds, their menu also contains roots, fruit, bark and other edible parts of plants, but only to a small extent. Diet changed substantially when nomads discovered arable farming more than 10,000 years ago in the area known as the Fertile Crescent, which stretches from present-day Iraq to Syria. Vegetable nourishment slowly but surely acquired a much higher status.

Christina Warinner, a Research Group Leader at the Institute in Jena, has been interested in the diets of our Stone Age ancestors for many years. She wants to determine exactly what delicacies people in those days enjoyed and where they derived the majority of their calories.

#### ISOTOPES IN BONES REVEAL EATING HABITS

One good way to learn something about the diets of our ancestors is to analyze isotopes in bones or teeth. Nitrogen isotopes reveal whether a person consumed a lot of meat or tended to eat more plant-based foods. The ratios of the various carbon isotopes indicate whether their menu consisted mainly of C<sub>3</sub> plants, such as wheat, rice and potatoes, or C<sub>4</sub> plants, such as maize and millet. However, the analysis of isotopes doesn't supply precise information as to which  $C_3$  or  $C_4$  plants were important for the diet. Archaeologists must rely on other methods to obtain this information.

For a long time, the biggest problem for Warinner's research was that plants rot too quickly. Although animal bones can be found en masse at archaeological sites, the remains of vegetable meals are usually missing. The discovery of bones also tells us next to nothing about the purpose for which people once domesticated these animals. Did they harness their cow to the plow, milk it for its milk, or did they simply want to eat its meat?

In 2010, while still in Zurich, Christina Warinner began to apply a completely new method to tackle these questions. The object of her research was plaque. The tartar that dentists scrape from our teeth today as a matter of course consists of various calcium phosphate compounds. But does it contain more information? Are bacteria, pollen or proteins trapped inside it? That is precisely what Warinner believed. She began using scientific methods to examine the plaque on the teeth of our ancestors.

Initially, her colleagues didn't know what to make of this idea. What could be present in plaque? "I found it pretty discouraging," the researcher recounts. But she didn't give up. She procured skulls from archaeological digs as well as a few dental instruments that she used to carefully scrape the plaque from the teeth. With the aid of a fluorometer, she tested whether it contained DNA. Her measuring device initially showed an error message - not because there was no DNA to be found, but because the sample contained too much. "I never realized that that could be a problem," Warinner recalls, laughing.

The DNA in dental plaque stems largely from bacteria. No matter how thoroughly we brush our teeth, our oral cavity is teeming with billions of them. Warinner calls this community the "oral microbiome." Just like the microbiome in the gut, it has a unique composition in every person. There has simply been far too little research on it to date. Currently, Christina Warinner is analyzing bacteria populations from the plaque of Stone Age skeletons. She has already gained insights into diseases. Now she is hoping for clues about our ancestors' diets.

#### MILK IS A KIND OF CLEAN WATER

Warinner has already learned more about another mystery from the plaque. What she wanted to know was when and where people began dairy farming. People have been using the milk from animals as nourishment for at least 8,500 years. This is evidenced by proteins that have survived for millennia trapped in the plaque. One protein was found in a particularly large number of plaque samples: -lactoglobulin (BLG), which is present in the milk of cows, sheep and goats but not in human breastmilk. BLG is virtually indestructible. While other proteins collapse when exposed to heat or acid, BLG survives undamaged.

And even more important for Warinner's analyses was the fact that BLG has a different amino acid sequence for every animal. She can therefore tell exactly what kind of milk was consumed in a particular culture, and even when people first began to drink milk or eat dairy products far beyond childhood.

Humans are an exception when it comes to the consumption of milk. Although all other mammals tolerate milk in their early years, they lose this ability in adulthood. After the period of breastfeeding is over, the body stops producing the enzyme lactase. Without lactase, we are unable to digest lactose. A gene mutation is responsible for the fact that lactase continues to be produced in some people after infancy. Many adults are therefore able to



Useful deposits: Plaque contains valuable information on diseases and the diets of past eras, and it is preserved on teeth for centuries. Researchers use normal dental instruments to take samples (bottom).



Historical research by means of microbiology: Christina Warinner examines fossil skeletons to determine whether people in the past consumed milk products. β-lactoglobulin (right), a protein preserved in the plaque, even reveals which animal the milk came from.

drink milk without any problem, especially in Europe.

Milk supplies protein, fats, vitamins and minerals and is also a kind of "clean water." Camels, for example, can drink saltwater, which is undrinkable for humans, and pass on the liquid to humans in the form of milk. It is assumed that milk drinkers enjoyed an evolutionary advantage: people who could digest milk became stronger, lived longer and had more offspring. The mutation won out.

This so-called lactase persistence originated independently at least five times. It is most widespread today in Scandinavia. Around 80 percent of people there can drink milk without a problem, even as adults. Christina Warinner wants to find out more about how populations without lactase persistence used milk. Today's farmers in Mongolia, who should be genetically unable to digest lactose, in fact drink milk regularly and process the lactose differently than Europeans, for example. Their specialized dairy production processes, which include cultivation and consumption of large quantities of probiotic dairy bacteria, appear to allow them to digest lactose in the absence of a genetic mutation for lactase persistence.

#### EARLY CROP FARMERS WERE THE FIRST WHITE EUROPEANS

The advent of arable farming brought with it a further visible change in Europeans that has lasted to this day: their unusually fair skin. Our ancestors and their nearest relatives, from Neanderthals to Denisovans, were all darkskinned. "Unfortunately, this insight has yet to reach museums," says Johannes Krause, Director of the Archaeogenetics Department at the Max Planck Institute for the Science of Human History. "The Neanderthals and Stone Age people there are always portrayed with pale skin and red hair." The hunters and gatherers as well as the first farmers in the Fertile Crescent also carried predominantly genes for dark skin.

Mutations in these genes that cause the color of the skin to become fairer were first found by researchers in the skeletons of early farmers in Europe. Initially, these mutations occurred only occasionally; then they prevailed. Today, they are fixed in 99 percent of the population of Central Europe. It is thought that Europeans would suffer from vitamin D deficiency without this adaptation. We humans, however, have two ways of acquiring this vitamin: we can absorb it through food, as meat and fish are a plentiful source of vitamin D, or our body can form it on its own with the aid of sunlight.

The dark-skinned farmers were unable to tap into either of these sources efficiently. They ate little meat, as we now know from analyzing isotopes in their bones, and they had ventured far into northern latitudes where the sun shines much more weakly than at the equator. Fair skin saved them. It allows substantially more sunlight to penetrate, with the result that vitamin D can still be produced when the radiation from the sun is less intense.

#### ANIMAL HUSBANDRY LED TO NEW DISEASES

As people began to cultivate the fields, they became sedentary. As a result, they also began to live in much greater proximity to their animals: farm animals such as pigs, cattle, goats and sheep lived in fields and barns right beside their own homes. This proximity to their animals produced one major winner – but it wasn't either humans or animals, but pathogens. Pathogens love it when individuals live together in close communities. Viruses and bacteria need hosts – that is, people or animals – so they can multiply. The more hosts they can infect, the better for them.

"It's a recognized theory, but so far we lack the evidence that early farmers were really exposed to more germs than hunters and gatherers," says Johannes Krause. "Unfortunately, the pathogens didn't leave any direct fossils behind." There are, however, clear indications that support the theory. For example, many of the pathogens related to measles, smallpox and whooping cough also infect farm animals, and were presumably transmitted from these to humans. Tuberculosis is an exception. It was humans that infected their cattle with this bacterium. It is still unknown who transmitted tuberculosis to humans.

Johannes Krause researches the evolution of pathogens. He wants to find out where they appeared for the first time, how they spread and how they adapted to new conditions. To do so, he needs first and foremost genetic material from ancient germs. One rich source for this is mass graves in which the victims of epidemics were buried. The DNA of the pathogens can be isolated from the bones and teeth of these old skeletons.

However, their genome is by no means intact, but has decayed into tiny fragments of only around 50 base pairs.

**Right** Mongolian shepherds process milk in such a way that lactose is largely broken down. Milk products are dried on yurt roofs to make them last longer.

**Below** Whether adults can digest milk is determined by the DNA component thymine at a particular location on the genome (highlighted T). If cytosine (C) is present there, the person will be lactose intolerant.

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Dizzying search: Scientists found 6,000-year-old grains of barley in a cave near the Dead Sea. The entrance to the cave is located in an almost vertical cliff face around four meters above a path. Thanks to the aridity of the desert region, the grains are so well preserved that their genome can be reconstructed.





To find the pathogens' DNA at all among the human DNA, Krause has developed a method that is as simple as it is effective. He employs single-stranded DNA from modern pathogens as bait and uses it to fish the genome scraps of old pathogens from the samples. Then he washes off all of the DNA that isn't on the hook and that therefore stems, not from the pathogen, but from the human host itself or organisms in the soil. Using this method, the researcher has been able to reconstruct, for instance, the DNA of the plague virus Yersinia pestis with unprecedented accuracy. The bones came from a cemetery in London where only plague victims were buried in the 14th century.

The oldest plague germs examined, however, are much older. Scientists from the University of Copenhagen discovered them in 5,200-year-old skeletons from the Central Asian steppe. This may be where the disease originated. It's possible that it spread in all directions of the compass together with the very mobile inhabitants of the Central Asian steppe.

Johannes Krause and his colleagues also examined old skeletons and discovered that there was massive migration from the Central Asian steppe toward Central Europe at that time. More precisely, it was again their DNA that put the researchers on the right track. An analysis of the genome of more than 250 skeletons from various archaeological sites in Europe proves that there were two major population upheavals.

The earlier wave of migration began because the first farmers from the area of the Fertile Crescent were extremely successful. They enjoyed good harvests, always had food in abundance, their population grew and the first trade routes slowly developed. "Only when agriculture appeared did people have time for specialized crafts, standardized mass production and warlike disputes," says Krause.

In search of fertile land, some farmers migrated west and settled in Central and Western Europe, from Bulgaria to Spain, around 7,500 years ago. They didn't drive out the hunter-gatherer societies in these areas, but rather lived side-by-side with them until the hunters and gatherers gradually adopted a rural way of life and merged with the new migrants. Other early farmers left the Fertile Crescent for the East and settled the areas of the Asian steppe. They would later reach Europe in a second wave of migration.

### WAVE OF MIGRATION FROM THE ASIAN STEPPE

This began around 4,800 years ago. In one fell swoop, an incredible number of people pushed toward Europe from the West Asian steppe. The migrants replaced the local population almost completely, as the scientists in Jena discovered in collaboration with an international team. This time, agriculture and the population growth that went with it can't have triggered this event,



as both populations engaged in farming. So what was the reason for it?

"That's precisely the question we're asking," says Johannes Krause. "How does it happen that one population is so successful?" One theory could be that the migrants brought the plague virus to Europe, against which they themselves had already developed resistance. By studying early outbreaks of disease and the evolution of germs more closely, the researchers are hoping to arrive at a better understanding of the dangers these germs pose and of ways of combating them.

Farming changed the world in many respects. It gave humankind food in great quantity and variety, but it also imparted new pathogens; it triggered waves of migration and allowed art and culture to flourish, yet it also encouraged war. By studying these comprehensive changes, scientists at the Max Planck Institute for the Science of Human History are gaining ever greater insights into how our present societies originated. ◄

#### TO THE POINT

- Diet changed with the advent of agriculture: people began to eat more plantbased foods and less meat.
- As a consequence, there was less vitamin D in their diet, resulting in genes for fair skin prevailing among the originally dark-skinned Europeans. This way, the body can produce vitamin D itself with the aid of sunlight.
- Genes that allowed adults to digest milk also proved to be beneficial; farmers increasingly kept dairy cattle.
- Animal husbandry brought people into close contact with pathogens, and their immune systems had to adapt.
- More food and a better diet led to population growth and migration.

#### GLOSSARY

**Isotopic analysis:** Almost every element has different isotopes, meaning that their atomic nuclei contain differing numbers of neutrons. This can be measured using mass spectrometry. Information such as the age or origin of samples can be derived from the ratio of isotopes. In finds of historical skeletons, isotopes reveal information about their diet. Nitrogen isotopes point to a diet of predominantly meat, and the ratio of different carbon isotopes to the consumption of certain plants.

Lactase persistence: To enable it to digest the milk sugar lactose present in milk, the body needs the enzyme lactase, which isn't normally produced in adults. Genetic changes in farmers and settlers in Europe led to their bodies continuing to produce lactase after infancy. This lactase persistence is the opposite of lactose intolerance, the inability to tolerate milk.