VINCENT J. MUSI

Grains were on the menu more than 11,000 years ago at Göbekli Tepe in Turkey, even before crops were domesticated.

THE ANCIENT CARB REVOLUTION

Well before people domesticated crops, they were grinding grains for beer and hearty dishes. **By Andrew Curry**

On a clear day, the view from the ruins of Göbekli Tepe stretches across southern Turkey all the way to the Syrian border some 50 kilometres away. At 11,600 years old, this mountaintop archaeological site has been described as the world's oldest temple — so ancient, in fact, that its T-shaped pillars and circular enclosures pre-date pottery in the Middle East.

The people who built these monumental structures were living just before a major transition in human history: the Neolithic revolution, when humans began farming and domesticating crops and animals. But there are no signs of domesticated grain at Göbekli Tepe, suggesting that its residents hadn't yet made the leap to farming. The ample animal bones found in the ruins prove that the people living there were accomplished hunters, and there are signs of massive feasts. Archaeologists have suggested that mobile bands of hunter-gatherers from all across the region came together at times for huge barbecues,

and that these meaty feasts led them to build the impressive stone structures.

Now that view is changing, thanks to researchers such as Laura Dietrich at the German Archaeological Institute in Berlin. Over the past four years, Dietrich has discovered that the people who built these ancient structures were fuelled by vat-fulls of porridge and stew, made from grain that the ancient residents had ground and processed on an almost industrial scale[1]. The clues from Göbekli Tepe reveal that ancient humans relied on grains much earlier than was previously thought – even before there is evidence that these plants were domesticated. And Dietrich's work is part of a growing movement to take a closer look at the role that grains and other starches had in the diet of people in the past.

The researchers are using a wide range of techniques – from examining microscopic marks on ancient tools to analysing DNA residues inside pots. Some investigators are even experimentally recreating 12,000-year-old meals using methods from that time. Looking even further back, evidence suggests that some people ate starchy plants more than 100,000 years ago. Taken together, these discoveries shred the long-standing idea that early people subsisted mainly on meat – a view that has fuelled support for the palaeo diet, popular in the United States and elsewhere, which recommends avoiding grains and other starches.

The new work fills a big hole in the understanding of the types of food that made up ancient diets. "We're reaching a critical mass of material to realize there's a new category we've been missing," says Dorian Fuller, an archaeobotanist at University College London.

A garden of grinding stones

Dietrich's discoveries about the feasts at Göbekli Tepe started in the site's 'rock garden'. That's the name archaeologists dismissively gave a nearby field where they dumped basalt grinding stones, limestone troughs and other large pieces of worked stone found amid the rubble.

As excavations continued over the past two decades, the collection of grinding stones quietly grew, says Dietrich. "Nobody thought about them." When she started cataloguing them in 2016, she was stunned at the sheer numbers. The 'garden' covered an area the size of a football field, and contained more than 10,000 grinding stones and nearly 650 carved stone platters and vessels, some big enough to hold up to 200 litres of liquid.

"No other settlement in the Near East has so many grinding stones, even in the late Neolithic, when agriculture was already well-established," Dietrich says. "And they have a whole spectrum of stone pots, in every thinkable size. Why so many stone vessels?" She suspected that they were for grinding grain to produce porridge and beer. Archaeologists had long argued that stone vats at the site were evidence of occasional ceremonial beer consumption at Göbekli Tepe, but thought of it as a rare treat.

Teasing answers from the stones there and at other sites is not a simple process. In archaeology, it is much easier to spot evidence of meat meals than ones based on grains or other plants. That's because the bones of butchered animals fossilize much more readily than do the remains of a vegetarian feast. The fragile nature of ancient plant remains makes archaeobotany – the study of how ancient people used plants – tricky, time-consuming work. Researchers use sieves, fine mesh and buckets to wash and separate debris from archaeological sites. Tiny bits of organic material such as seeds, charred wood and burnt food float to the top, while heavier dirt and rocks sink.

The vast majority of what emerges amounts to the raw ingredients, the bits that never made it into a pot. By identifying and counting grass seeds, grain kernels and grape pips mixed into the soil, archaeobotanists can tell what was growing in the area around the settlement. Unusual amounts of any given species offer circumstantial evidence that those plants might have been used, and perhaps cultivated, by people in the past.

Some of the earliest evidence for plant domestication, for example, comes from einkorn wheat grains recovered from a site near Göbekli Tepe that are subtly different in shape and genetics from wild varieties[2]. At Göbekli Tepe itself, the grains look wild, suggesting that domestication hadn't taken place or was in its earliest stages. (Archaeologists suspect that it might have taken centuries for domestication to alter the shape of grains.)

Direct proof that plants landed in cooking pots is harder to come by. To work out what people were eating, archaeologists are turning to previously ignored sources of evidence, such as charred bits of food. They're the mistakes of the past: stews and porridge left on the fire for too long, or bits of bread dropped in the hearth or burnt in the oven. "Anyone who's cooked a meal knows sometimes it burns," says Lucy Kubiak-Martens, an archaeobotanist working for BIAX Consult Biological Archaeology & Environmental Reconstruction in Zaandam, the Netherlands.

Until the past few years, these hard-to-analyse remnants of ruined meals were rarely given a second look. "It's just a difficult material. It's fragile, ugly stuff," says Andreas Heiss, an archaeobotanist at the Austrian Academy of Sciences in Vienna. "Most researchers just shied away." Pottery sherds encrusted with food remains were cleaned off or discarded as 'crud ware', and charred bits of food were dismissed as unanalysable 'probable food' and shelved or thrown out.

The first step towards changing that perception was to go back to the kitchen. That was the inspiration of Soultana Valamoti, an archaeobotanist at the Aristotle University of Thessaloniki in Greece who, not coincidentally, is also a passionate home cook. Valamoti spent the early years of her career toting buckets and sieves from one excavation site to another across Greece, all while combing museum storerooms for ancient plant remains to analyse. The work convinced her there was an untapped wealth of evidence in burnt food remains – if she could find a way to identify what she was looking at.

> **"That's revolutionary. It's an unprecedented source of information."**

More than 20 years ago, Valamoti decided to turn her lab into an experimental kitchen. She ground and boiled wheat to make bulgur, and then charred it in an oven to simulate a long-ago cooking accident (see 'Fast food of the Bronze Age'). By comparing the burnt remains to 4,000-year-old samples from a site in northern Greece, she was able to show that the ancient and modern versions matched, and that this way of preparing grain had its roots in the Bronze Age[3].

Over the decade that followed, she continued experimenting. Beginning in 2016, a European Research Council grant allowed her to create a crusty, charred reference collection of more than 300 types of ancient and experimental samples. After making bread dough, baked bread, porridge, bulgur and a traditional food called trachana from heirloom wheat and barley, Valamoti chars each sample in an oven under controlled conditions.

She than magnifies the crispy results by 750 to 1,000 times to identify the tell-tale changes in cell structure caused by different cooking processes. Whether boiled or fresh, ground or whole, dried or soaked, the grains all look different at high magnification. Baking bread leaves tell-tale bubbles behind, for example, whereas boiling grain before charring it gelatinizes the starch, Valamoti says. "And we can see all that under the scanning electron microscope."

Comparing the ancient samples with her modern experiments, Valamoti has been able to go beyond identifying plant species to reconstruct the cooking methods and dishes of ancient Greece. There is evidence that people in the region have been eating bulgur for at least 4,000 years[4]. By boiling barley or wheat and then drying it for storage and quick rehydration later, "you could process the harvest in bulk and take advantage of the hot sun", Valamoti says. "Then you can use it throughout the

year. It was the fast food of the past."

Other researchers are also pursuing ancient cooking mistakes. Charred food remains "are providing us with direct evidence of food", says Amaia Arranz-Otaegui, an archaeobotanist at the Paris Museum of Natural History. "That's revolutionary. It's an unprecedented source of information."

In the past, it has been difficult for researchers to find hard evidence that our distant ancestors ate plants. "We've always suspected starch was in the diet of early hominins and early *Homo sapiens*, but we didn't have the evidence," says Kubiak-Martens.

Genetic data support the idea that people were eating starch. In 2016, for example, geneticists reported[5] that humans have more copies of the gene that produces enzymes to digest starch than do any of our primate relatives. "Humans have up to 20 copies, and chimpanzees have 2," says Cynthia Larbey, an archaeobotanist at the University of Cambridge, UK. That genetic change in the human lineage helped to shape the diet of our ancestors, and now us. "That suggests there's a selective advantage to higher-starch diets for *Homo sapiens*."

To find supporting evidence in the archaeological record, Larbey turned to cooking hearths at sites in South Africa dating back 120,000 years, picking out chunks of charred plant material — some the size of a peanut. Under the scanning electron microscope, she identified cellular tissue from starchy plants[6] — the earliest evidence of ancient people cooking starch. "Right through from 120,000 to 65,000 years ago, they're cooking roots and tubers," Larbey says. The evidence is remarkably consistent, she adds, particularly compared with animal remains from the same site. "Over time they change hunting techniques and strategies, but still continue to cook and eat plants."

Early humans probably ate a balanced diet, leaning on starchy plants for calories when game was scarce or hard to hunt. "And being able to find carbohydrates as they moved into new ecologies would have provided important staple foods," Larbey adds.

Evidence suggests that plants were popular among Neanderthals, too. In 2011, Amanda Henry, a palaeoanthropologist now at Leiden University in the Netherlands, published her findings from dental plaque picked from the teeth of Neanderthals who were buried in Iran and Belgium between 46,000 and 40,000 years ago. Plant microfossils trapped and preserved in the hardened plaque showed that they were cooking and eating starchy foods including tubers, grains and dates[7]. "Plants are ubiquitous in our environment," Henry says, "and it's no surprise we put them to use."

In May, Christina Warinner, a palaeogeneticist at Harvard University in Cambridge, Massachusetts, and her colleagues reported the extraction of bacterial DNA from the dental plaque of Neanderthals, including a 100,000-year-old individual from what is now Serbia. The species they found included some that specialized in breaking down starch into sugars, supporting the idea that Neanderthals had already adapted to a plant-rich diet[8]. Plaque on the teeth of early modern humans shared a similar bacterial profile, providing more evidence to suggest that they were eating starchy plants.

The finds push back against the idea that our ancestors spent their time sitting around campfires mostly chewing on mammoth steaks. It's an idea that has penetrated popular culture, with proponents of the palaeo diet arguing that grains, potatoes and other starchy foods have no place on our plates because our hunter-gatherer ancestors didn't evolve to eat them.

> **"The old-fashioned idea that hunter-gatherers didn't eat starch is nonsense."**

But it has become clear that early humans were cooking and eating carbs almost as soon as they could light fires. "The old-fashioned idea that hunter-gatherers didn't eat starch is nonsense," says Fuller.

Invisible cooks

The push to better understand how people were cooking in the past also means paying more attention to the cooks themselves. It's part of a larger trend in archaeology to look at household activities and daily lives. "Essentially, we're trying to figure out what kind of information you can find out about people who have never had histories written about them," says Sarah Graff, an archaeologist at Arizona State University in Tempe.

In the past, when researchers found plant remains at archaeological sites, they often considered them as accidental 'ecofacts' — natural objects, such as seeds, pollen and burnt wood, that offer evidence for what kind of plants grew in a region. But there has been a shift towards treating food remains as evidence of an activity that required craft, intent and skill. "Prepared food needs to be looked at as an artefact first and a species second," Fuller says. "Heated, fermented, soaked — making food is akin to making a ceramic vessel."

And, as researchers increasingly collaborate to compare ancient remains, they're finding remarkable similarities across time and cultures. At Neolithic sites in Austria dating back more than 5,000 years, for example, archaeologists found unusually shaped charred crusts. It was as though the contents of a large jar or pot had been heated until the liquid burned off, and the dried crust inside began to burn. The team's first guess was that the crusts were from grain storage jars destroyed in a fire. But under the scanning electron microscope, the cell walls of individual grains looked unusually thin — a sign, Heiss says, that something else was going on.

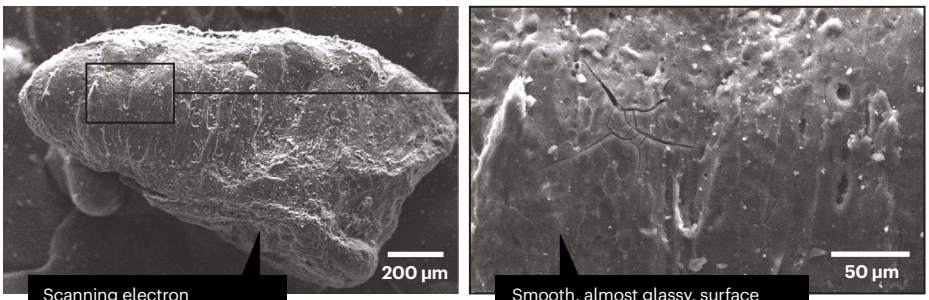
After comparing the Austrian finds to similar crusts found in Egyptian breweries from around the same time, Heiss and Valamoti concluded that the thin cell walls were the result of germination, or malting, a crucial step in the brewing process. These early Austrian farmers were brewing beer[9]. "We ended up

JOE ROE

Amaia Arranz-Otaegui (right) and colleagues found evidence of bread from 14,500 years ago.

FAST FOOD OF THE BRONZE AGE

Bulgur-like grain fragments found at a roughly 4,000-year-old site in northern Greece have microscopic features resembling those of modern samples that had been parboiled and charred in experiments. The ancient grain was apparently boiled then dried to speed up later cooking.



Scanning electron microscope reveals surface textures of grain fragment.

Smooth, almost glassy, surface indicates that the grain gelatinized, perhaps from parboiling.

SOULTANA MARIAVALAMOTI *ET AL. J. ARCHAEOL. SCI.*

with something completely different" from the earlier hypotheses, Heiss says. "Several lines of evidence really interlocked and fell into place."

Bread, it seems, goes even further back. Arranz-Otaegui was working at a 14,500-year-old site in Jordan when she found charred bits of 'probable food' in the hearths of long-ago hunter-gatherers. When she showed scanning electron microscope images of the stuff to Lara González Carretero, an archaeobotanist at the Museum of London Archaeology who works on evidence of bread baking at a Neolithic site in Turkey called Çatalhöyük, both researchers were shocked. The charred crusts from Jordan had tell-tale bubbles, showing they were burnt pieces of bread[10].

Most archaeologists have assumed that bread didn't appear on the menu until after grain had been domesticated — 5,000 years after the cooking accident in question. So it seems that the early bakers in Jordan used wild wheat.

The evidence provides crucial clues to the origins of the Neolithic revolution, when people began to settle down and domesticate grain and animals, which happened at different times in various parts of the world. Before farming began, a loaf of bread would have been a luxury product that required time-consuming and tedious work gathering the wild grain needed for baking. That hurdle could have helped to spur crucial changes.

Arranz-Otaegui's research suggests that — at least in the Near East — demand for bread might have been a factor in driving people to attempt to domesticate wheat, as they looked for ways to ensure a steady supply of baked goods. "What we are seeing in Jordan has implications for bigger processes. What drove the transition to agriculture is one of the fundamental questions in archaeology," Arranz-Otaegui says. "This shows hunter-gatherers were using cereals."

The next frontier for archaeobotanists is prehistoric salad bars. Researchers are working on ways to look for the remains of food that wasn't cooked, such as leafy greens, another overlooked part of the ancient diet. Because raw greens and vegetables are even harder to find in the archaeological record than cooked seeds and grains, Kubiak-Martens calls them the "missing link" in knowledge about ancient diets. "There's no way to prove green leaves were eaten from charred remains," Kubiak-Martens says. "But you would be surprised at how much green vegetables are in human coprolites", or preserved faeces. Kubiak-Martens got a grant in 2019 to look at 6,300-year-old palaeofaeces preserved at wetland sites in the Netherlands, which she hopes will reveal everything prehistoric farmers there had on their dinner tables.

Recreating ancient meals

The quest to understand ancient diets has led some researchers to take extreme measures. That's the case with Göbekli Tepe, which has yielded very few organic remains that could provide clues to the prehistoric plant-based meals there. So Dietrich has tried innovative thinking — and a lot of elbow grease. Her approach has been to recreate the tools people used to make food, not the dishes themselves.

In her airy lab on a tree-lined street in Berlin, Dietrich explains her time-consuming and physically demanding process. Starting with a replica grindstone — a block of black basalt the size of a bread roll that fits neatly in the palm of her hand — she photographs it from 144 different angles.

After spending eight hours grinding four kilograms of heirloom einkorn wheat kernels, Dietrich photographs the stone again. A software program then produces 3D models from the two sets of pictures. Her experiments have shown that grinding fine flour for baking bread leaves a different finish on the stones from producing coarsely ground grain that is ideal for boiling as porridge or brewing beer.

And after handling thousands of grindstones, she is often able to identify what they were used for by touch. "I touch the stones to feel for flattening," she says. "Fingers can feel changes at the nano level." By comparing the wear patterns on her modern replicas to the stones piled in Göbekli Tepe's rock garden, Dietrich could show that fine-ground bread flour was the exception. In a 2020 study[11], she argues people there were mostly grinding grain coarsely, just enough to break up its tough outer layer of bran and make it easy to boil and eat as porridge or ferment into beer.

To test the theory, Dietrich commissioned a stonemason to carve a replica of a 30-litre stone vat from Göbekli Tepe. In 2019, she and her team successfully cooked porridge using heated stones, carefully recording and timing each step of the process. They also brewed a Neolithic beer from hand-ground germinated grain, or malt, in the open vessel. The results were "a bit bitter, but drinkable", Dietrich says. "If you're thirsty in the Neolithic."

From the grind stones and other plant-processing tools at Göbekli Tepe, a picture is now emerging for what was going on there 12,000 years ago. Rather than just starting to experiment with wild grains, the monument builders were apparently proto-farmers, already familiar with the cooking possibilities grain offered despite having no domesticated crops. "These are the best grinding tools ever, and I've seen a lot of grindstones," Dietrich says. "People at Göbekli Tepe knew what they were doing, and what could be done with cereals. They're beyond the experimentation phase."

Her experiments are shifting the way archaeologists understand the site — and the period when it was built. Their initial interpretations made the site sound a bit like a US college fraternity house: lots of male hunters on a hilltop, washing down barbecued antelope with vats of lukewarm beer at occasional celebrations. "Nobody really thought of the possibility of plant consumption" on a large scale, Dietrich says.

In a study late last year[12], Dietrich argues the 'barbecue and beer' interpretation is way off. The sheer number of grain-processing tools at Göbekli Tepe suggest that even before farming took hold, cereals were a daily staple, not just part of an occasional fermented treat.

Andrew Curry is a science journalist in Berlin.

1. Dietrich, L. *et al. PLoS ONE* **14**, e0215214 (2019).
2. Heun, M. *et al. Science* **278**, 1312–1314 (1997).
3. Valamoti, S. M. *Veget. Hist. Archaeobot.* **11**, 17–22 (2002).
4. Valamoti, S. M. *et. al. J. Archaeol. Sci.* **128**, 105347 (2021).
5. Inchley, C. E. *et al. Sci. Rep.* **6**, 37198 (2016).
6. Larbey, C., Mentzer, S. M., Ligouis, B., Wurz, S. & Jones, M. K. *J. Hum. Evol.* **131**, 210–227 (2019).
7. Henry, A. G., Brooks, A. S. & Piperno, D. R. *Proc. Natl Acad. Sci. USA* **108**, 486–491 (2011).
8. Fellows Yates, J. A. *et al. Proc. Natl Acad. Sci. USA* **118**, e2021655118 (2021).
9. Heiss, A. G. *et al. PLoS ONE* **15**, e0231696 (2020).
10. Arranz-Otaegui, A., Gonzalez Carretero, L., Ramsey, M. N., Fuller, D. Q. & Richter, T. *Proc. Natl Acad. Sci. USA* **115**, 7925–7930 (2018).
11. Dietrich, L. & Haibt, M. *J. Archaeol. Sci. Rep.* **33**, 102525 (2020).
12. Dietrich, L. *et al. J. Archaeol. Sci. Rep.* **34**, 102618 (2020).