

Ancient slag offers insight into the uneven pace of technological advances

Enlarge / Copper production waste at Khirbat en-Nahas, Jordan, was piled 6m (18 ft) deep.

T. Levy 2019

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Sometimes, clues about ancient technology are hidden in the most mundane things. In this case, Tel-Aviv University archaeologist Erez Ben-Yosef and his colleagues went rummaging through heaps of slag, the glassy waste discarded after smelters separate copper from its ore. Their goal? To hunt for clues about industry and innovation in the ancient Edomite Kingdom.

Less copper mixed with the slag suggests more-efficient smelting, so by tracking changes in the slag, Ben-Yosef and his colleagues could track the progress of a technology that powered the ancient world.

The archaeologists found mostly small, gradual improvements over the course of five centuries, punctuated by a sudden, drastic increase in efficiency around 925 BCE in the wake of an Egyptian invasion of the area. That suggests that a model for the evolution of new species may also apply to human technology and that we may need a little instability to break out of equilibrium and trigger bursts of innovation. It also

reveals how one society in particular benefitted from the Bronze Age Collapse and later took advantage of the disruption of a foreign invasion to make a leap forward in technology.

Ancient industry

The Wadi Arabah spans the modern border of the Timna area of Israel and the Faynan area of Jordan. For centuries, people there smelted copper in furnaces that used sack bellows to supply extra air to the fuel, boosting combustion and producing more heat. The bellows furnace technology probably originated somewhere in Egypt's Sinai Peninsula or in western Saudi Arabia, and it made its way into the Levant when Egypt claimed Timna as a province. But from 1300 BCE until 925 BCE, the people of Wadi Arabah ran the furnaces and made their own small improvements to the process along the way.

Under the pharaohs of the New Kingdom, large copper-smelting centers dotted the landscape of Timna, supported by networks of small mining camps. Today, over 110,000 tons of slag lies on the surface in ancient mounds. Ben-Yosef and his colleagues studied 154 slag samples from those old smelting centers and made a timeline through radiocarbon dating based on the charcoal mixed in.

They used X-ray fluorescence and mass spectrometry to measure how much copper each sample contained. Across the region, the amount of copper left behind in the slag varied widely from site to site, which suggested that although the basic technology was the same, the techniques people were using weren't very standardized—some smelting centers seemed to be much more efficient than others.

Bronze Age Collapse

Around 1140 BCE, the Egyptians pulled out of Wadi Arabah and the nearby province of Canaan due to political and economic

instability at home. Egypt had fallen into the Late Bronze Age Collapse, when civilizations around the Eastern Mediterranean faced political and economic upheaval, and in many cases collapse or decline. But in the slag heaps of Wadi Arabah, Ben-Yosef and his colleagues noticed a subtle clue that indicated the chaos swirling around them didn't keep the locals—known in Hebrew texts as the Edomites—from thriving.

Work at the smelting centers hadn't been very standardized before, but around 1140 BCE, the copper content of slag heaps from Timna and from sites in Faynan, 105km (65 miles) away, suddenly got a lot more consistent. That suggests that after the Egyptians left, the semi-nomadic tribes of the region (who had been operating the copper industry all along) banded together and established more centralized control over the industry.

“The collapse of empires left a vacuum that was taken advantage of by local societies such as the Edomites, the ancient Israelites, and others; in the absence of the empires' yoke, they rose and created kingdoms,” Ben-Yosef told Ars. “The Edomite society benefited from the collapse; production increased, and the local tribes united to operate together the mines of the entire Arabah Valley. They became centralized and strong rather fast.”

Even then, however, the basic technology of Edomite copper smelting didn't change much: the techniques got more standardized, but the overall efficiency of the process didn't improve drastically, and people were still using the same technology they'd been using for centuries. That wouldn't change until a drastic leap 200 years later.

- The 10th century BCE copper production site at “Slaves' Hill” in Timna.
- E. Ben-Yosef and the Central Timna Valley Project
- Archaeologists excavate an ancient copper mine in the

Wadi Arabah.

E. Ben-Yosef and the Central Timna Valley Project

- Archaeologists analyzed the chemical composition of pulverized slag samples with pXRF.

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- Copper production waste at Khirbat en-Nahas, Jordan, was piled 6m (18 ft) deep.

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- Archaeologists radiocarbon dated each layer of slag to create a high-resolution record of change over time.

E. Ben-Yosef

Punctuated equilibrium

A sudden, dramatic increase in the efficiency of Edomite smelting around 925 BCE suggests that human innovation proceeds in fits and starts, with long periods of stability in between. The idea, called punctuated equilibrium, was originally developed by paleontologists to explain patterns in the emergence and diversification of new species, which sometimes seems to happen in sudden bursts of activity after eons of stability.

Archaeologists first noticed a similar pattern in Paleolithic stone tool assemblages, where the types of tools and the way they were made seemed to stay essentially the same for thousands of years until a sudden spate of new knapping techniques or new tool types.

But looking back into the Pleistocene, it's hard to identify specific social or cultural factors that may have spurred those bursts of invention. By studying technological change in more recent periods, like the end of the Bronze Age, archaeologists have a chance to link bursts of innovation to social, political, or economic events. "Technology can function as a proxy for otherwise indiscernible social processes," wrote Ben-Yosef and his colleagues.

Bigger nozzles, better production

Of course, ancient Edomite smelters were probably constantly looking for ways to get more copper out of their ore. But copper production was a complex process, and nearly every element of the process from mining the ore to selling the finished copper depended on other technologies or materials. For example, specific mixtures of ore dictate specific smelting methods. That kind of interdependence can hold back innovation.

For innovation to happen, something had to come along and shake up those systems, and that something turned out to be an Egyptian invasion. According to Hebrew and Egyptian texts and inscriptions, Pharaoh Shoshenq I marched his troops east into Edom and Israel in 925 CE to deal with a series of incidents along the border. "Some sites in the Levant were probably destroyed by him; Jerusalem, according to the Bible, was plundered," Ben-Yosef told *Ars*. "In the Arabah the results were different, because of the great importance of copper to Egypt."

And around the time of the invasion, Ben-Yosef and his colleagues saw that smelting got more efficient, leaving less copper behind in the slag. The slag itself even looked different from what furnaces were churning out before the Egyptian invasion. Archaeological excavations at the smelting centers revealed the source of the increased efficiency and the changes in slag: larger blast furnaces, equipped with much larger nozzles for delivering air to the furnace.

According to Ben-Yosef and his colleagues, the Egyptian invaders brought knowledge of the newer, more efficient furnaces when they marched into Edom. The Edomite smelters, after centuries of producing copper and trying to improve the process with existing technology, were happy to take advantage of the new toolkit. (Hence the origin of the old saying: when

life gives you lemons, smelt more copper.)

In the wake of that burst of innovation, the Edomite Kingdom kept producing copper with larger-nozzled furnaces for another century. Equilibrium had returned, in other words. Ben-Yosef and his colleagues say that while the Edomite Kingdom and its copper industry are a good illustration of the model, archaeologists need to study detailed records of long-term technological change from other times and places.

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