ARCHAEOLOGY

Sea-Floor Dust Shows Drought Felled Akkadian Empire

SAN FRANCISCO—When civilizations collapse, the blame is often laid on the culture itself—leaders who overreached, armies that faltered, farmers who degraded the land. Such were the conventional explanations for the end of the world's first empire, forged by the Akkadians by 2300 B.C. Their reign stretched 1300 kilometers from the Persian Gulf in present-day Iraq to the headwaters of the Euphrates River in Turkey. They were the first to subsume independent societies into a single state, but the Akkadian empire splintered a century later, not to be reunited in such grandeur for 1000 years.

In 1993, however, archaeologist Harvey Weiss of Yale University proposed that the Akkadians were not to blame for their fate. Instead, he argued that they were brought low by a wide-ranging, centuries-long drought (*Science*, 20 August 1993, p. 985) that toppled other civilizations too, including those of early Greece, the pyramid builders in Egypt, and the Indus Valley in Pakistan. Many archaeologists were skeptical because the timing of these collapses was imprecise, and purely social and political explanations seemed to suffice. But now Weiss's theory, at least as applied to the Akkadians, is getting new support from a completely independent source: an accurately dated, continuous climate record from the Gulf of Oman, 1800 kilometers from the heart of the Akkadian empire.

At the annual fall meeting last month of the American Geophysical Union here, paleoceanographers Heidi Cullen and Peter deMenocal of Lamont-Doherty Earth Observatory in Palisades, New York, and their colleagues reported that a sediment core retrieved from the bottom of the gulf matches Weiss's version of events: The worst dry spell of the past 10,000 years began just as the Akkadians' northern stronghold of Tell Leilan was being abandoned, and the drought lasted a devastating 300 years. The new results illustrate, says Weiss, that climate change "is emerging as a new and powerful causal agent" in the evolution of civilization.

Some archaeologists aren't willing to accept that the same drought changed history across the Old World, however. That argument "just doesn't float," says archaeologist Carl Lamberg-Karlovsky of Harvard University. But he and others agree that the new marine record lends support to the climate-culture connection that Weiss identified at the ruined city of Tell Leilan in the northern part of Mesopotamia, a region that includes parts of present-day Syria, Iraq, and Turkey (see map). Weiss began excavations there, on the Habur Plains of northeast Syria, in 1978.

Tell Leilan was a major city covering 200 acres by the middle of the third millennium B.C., and its people thrived on the harvests of the plains' fertile fields. But, unlike the farmers of Sumer in southern Mesopotamia, who used irrigation from the Euphrates and Tigris rivers to ensure bountiful harvests, the farmers of Tell Leilan depended on plentiful rainfall to water their fields. Less than a century after the people of Akkad in central Mesopotamia extended their reach into the north, those rains began to fail, says Weiss.

H. WEISS/YALE UNIVERSITY

Left in the dust. Clues such as grain storage vessels *(above)* and dust from a core show that drought did in the Akkadians in 2200 B.C.

When Weiss and Marie-Agnès Courty, a soil scientist and archaeologist at the National Center for Scientific Research in Paris, dug through the accumulated debris of Tell Leilan, they encountered an interval devoid of signs of human activity, containing only the clay of deteriorating bricks. The abandonment began about 2200 B.C., as determined by carbon-14 dating of cereal grains. Soil samples from that time showed abundant fine, windblown dust and few signs of earthworm activity or the once-abundant rainfall. All this suggested that the people of Tell Leilan, and, presumably, its environs, retreated in the face of a suddenly dry and windy environment, triggering the collapse of the Akkadian empire's northern provinces. Only after the signs of dryness abated, about 300 years later, was Tell Leilan reoccupied.

Weiss went further, however, proposing that refugees from the drought went south, where irrigation helped protect crops. Droves of immigrants would have further strained a sociopolitical system already stressed by the same drought, he says, until the whole system collapsed under the strain. And he noted that the pyramid-building Old Kingdom of Egypt, the towns of Palestine, and the cities of the Indus Valley went into precipitous declines at about the same time and apparently also suffered unstable climates.

It's a neat story, but critics questioned whether the drying really was catastrophic enough to bring down all of Mesopotamian civilization, where irrigation would have helped farmers cope with the drought. And they were even more skeptical that such a drought could have felled other cultures across the Old World. To test these ideas, deMenocal and Cullen decided to see just how big and bad the drought really was. They analyzed sediment from the Gulf of Oman, reasoning that if all of Mesopotamia had become a dust bowl, the hot northwest summer wind called the Shamal would have blown that dust down the Tigris and Euphrates valley, over the Persian Gulf, and finally into the Gulf of Oman, 2200 kilometers from Tell Leilan.

Cullen and deMenocal looked for this far-traveled dust in a 2-meter sediment core spanning the past 14,000 years, which was retrieved from the Gulf of Oman by paleoceanographer Frank Sirocko of the University of Kiel in Germany. In samples taken every 2 centimeters along the core, they measured the amounts of dolomite, quartz, and calcite—minerals that today dominate the dust blown from Mesopotamia by the Shamal. They found that wind-blown dust levels in the Gulf of Oman were high during the last ice age until about 11,000 years ago, then settled down to levels more typical of today. But in the sample from 2000 B.C. plus or minus 100 years, as dated by carbon-14, the abundance of dust minerals jumped to two to six times above background, reaching levels not found at any other time in the past 10,000 years.

The extreme dustiness—which suggests a wide-ranging area of dryness—persisted through the next sample 140 years later but faded away by the third sample, indicating a duration of a few hundred years. The team also tracked isotopes of strontium and neodymium, which occur in different ratios in dust from different regions. They confirmed that during the dust pulse, the proportion of minerals with a composition similar to that of the soils of Mesopotamia and Arabia increased.

Given the uncertainties of carbon dating, the marine dust pulse and the abandonment of Tell Leilan could still have been several centuries apart. But Cullen and deMenocal found in the core another time marker that makes a somewhat tighter connection. Less than about 140 years before the dust pulse is a layer containing volcanic ash. And Weiss had already reported that a centimeter-thick ash layer lies just beneath the onset of aridity and abandonment at Tell Leilan. The strikingly similar elemental compositions of the two ashes imply that they stem from the same volcanic event. If so, then Tell Leilan was abandoned just after the start of a climatic change of considerable magnitude, geographical extent, and duration. "There's something going on, a shift of atmospheric circulation patterns over a fairly large region," says Cullen.

Some archaeologists agree that this climate shift did change history outside northern Mesopotamia. "Most people who work in this range of time don't pay much attention to climate," says archaeologist Frank Hole of Yale; "rather, it's political and social events [that matter]. ... But I think the evidence is overwhelming that we've got something going on here."

While conceding that climate and culture interact, a number of archaeologists still think that Weiss is pushing the connection too far. Drought may well have driven people from farmland dependent on rainfall, like that around Tell Leilan, says Lamberg-Karlovsky, but Weiss "generalizes from his northern Mesopotamia scenario to a global problem. That's utterly wrong. ... Archaeologists fall in love with their archaeological sites, and they generalize [unjustifiably] to a larger perspective."

Even in Mesopotamia, "you do not have by any means a universal collapse of cultural complexity," says Lamberg-Karlovsky. For example, at 2100 B.C., in the midst of the drying, the highly literate Ur III culture centered in far southern Mesopotamia was at its peak, he says, as was the Indus River civilization to the east, which thrived for another 200 years. Weiss counters that cuneiform records show that Ur III did in fact collapse 50 years later, apparently under the weight of a swelling immigrant population and crop failures. That timing still fails to impress Lamberg-Karlovsky, who concludes that Weiss is "getting little support for the global aspect of it."

Such support may yet come from climate records being retrieved from around the world. In an enticing look at the postglacial climate of North America, Walter Dean of the U.S. Geological Survey in Denver found three sharp peaks in the amount of dust that settled to the bottom of Elk Lake in Minnesota. Dust peaked at about 5800, 3800, and 2100 B.C., plus or minus 200 years, according to the counting of annual layers in the lake sediment. During the 2100 B.C. dust pulse, which lasted about a century, the lake received three times more dust each year than it did during the infamous Dust Bowl period in the U.S. in the 1930s. But the archaeological record doesn't reveal how this drought affected early North Americans, who at that time maintained no major population centers.

In another sign that the Mesopotamian drought was global, Lonnie G. Thompson of Ohio State University and his colleagues found a dust spike preserved in a Peruvian mountain glacier that marks "a major drought" in the Amazon Basin about 2200 B.C., give or take 200 years. It is by far the largest such event of the past 17,000 years. But it doesn't seem to have had entirely negative effects; indeed, it roughly coincides with a shift in population centers from coastal areas of Peru, where the ocean provided subsistence, to higher regions, where agriculture became important. As more such records accumulate in the rapidly accelerating study of recent climate, archaeologists will have a better idea of just how much history can be laid at the feet of climate change.

–Richard A. Kerr

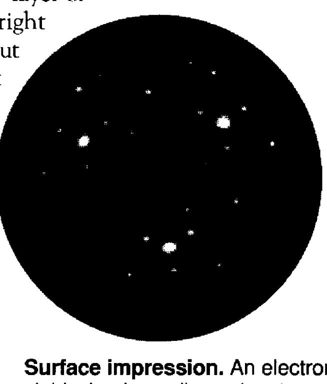
MATERIALS SCIENCE

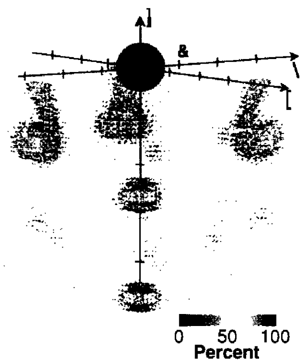
Getting a 3D View of Surfaces

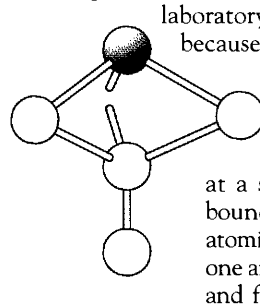
The true character of a material is often just skin deep. The arrangement of the first two or three layers of atoms can be enough to determine key properties such as friction, hardness, and chemical reactivity. Learning how those atoms are organized has been notoriously difficult, however. Scanning tunneling microscopes look at only the top layer of atoms, while x-rays pass right through to deeper layers. But imaging surfaces is about to get considerably easier and faster.

For years, researchers solved the atomic structure of a surface by sending in a beam of low-energy electrons, collecting the diffraction pattern generated when the electrons scatter off the surface, and comparing that to model calculations. But without an approximate picture of the surface structure to start with, low-energy electron diffraction, or LEED, was little help. Now, a team of surface physicists from the University of Erlangen-Nürnberg in Erlangen, Germany, has found a way to turn LEED data directly into three-dimensional images of the atomic arrangements.

"When we deal with complex materials, and we want to know more about the surface structure, or we want to tailor-make some structures for certain applications, then this will help us do it," says Ulrich Starke, a member of the Erlangen-Nürnberg team, which describes its work in the 15 December 1997 *Physical Review Letters* (*PRL*). "Anything for which a fundamental understanding of surface crystallography is important should benefit from this technology," adds Dilano Saldin, a solid-state theorist at the University of Wisconsin, Milwaukee.







Surface impression. An electron diffraction pattern *(left)* from a silicon carbide surface yields the three-dimensional arrangement of atoms, which matches a model *(right)*.

REUTER *ET AL.*, *PRL*

The LEED technique dates back to the 1920s, although it wasn't until the late 1960s that researchers developed the algorithms needed to determine the atomic structure of a surface from the data. Since then, LEED has spread to virtually every surface-science laboratory in the world, in part because it is so simple and inexpensive. An electron gun, like a cathode ray tube in your television set, is aimed at a surface; the electrons bounce off the first few atomic layers, interfere with one another like light waves, and form a diffraction pattern on a luminescent screen. From the intensities and positions of the spots in the pattern, an algorithm recreates the arrangement of the surface atoms.

But it can only do so by iteration, starting with an approximate model of the surface in question. "You give this model to the computer and make the computer calculate the