

RAIN, RIVERS, AND THE FATE OF CIVILIZATIONS

by Cherie Winner



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The Harappans of ancient India created fine art such as the Dancing Girl (left) and big cities such as Mohenjo-Daro (above) about 4,500 years ago.

The Harappans may be the most advanced ancient civilization that most Westerners have never heard of. They flourished in the Indus River basin on the Indian subcontinent around the same time the Egyptians were building the pyramids along the Nile and the Mesopotamians were digging irrigation channels fed by the Tigris and the Euphrates.

The Harappans farmed the soil of the plains, soaked annually when the Indus and its tributaries flooded with rainwater and snowmelt. Their cities had fine architecture, massive water storage tanks, and sophisticated sewer systems. They traded by land and by sea, made jewelry and art, and were one of the first cultures in the world to develop a symbolic written language. They were probably the most egalitarian of ancient societies.

Then around 3,800 years ago, the Harappan civilization began to crumble. Eight centuries later, it was gone. Archaeologists have turned up no evidence of a war, epidemic, earthquake, or catastrophic flood. Reasons for the collapse have remained a mystery.

Now a team of scientists led by geologists from Woods Hole Oceanographic Institution (WHOI) has extracted subtle clues to reconstruct ancient environmental conditions. They suggest that a weakening of the monsoons doomed the Harappans.

“This shows that people can be vulnerable to a slowly changing climate, whether it is natural or human-induced,” said Liviu

Giosan, the WHOI geologist who spearheaded the studies.

Yet not all peoples living in the region suffered the same fate. As the climate changed and the Harappan civilization in the northwest started to decline, small groups of hunter-gatherers living in central and southern India began to thrive.

What spelled the difference? What lessons can we draw from their experience as we face climate change today?

Rain-bearing monsoons

The Indian subcontinent lies at the same latitude as the great desert regions to its west, yet India is not a desert, thanks to the yearly monsoons—seasonal winds that carry moisture from the ocean to land and bring life-giving rain. “The monsoon is the lifesaver,” said Giosan. “If you wouldn’t have monsoons here, this would be Sahara.”

Still, much of the Indian peninsula is semi-arid because coastal mountains catch most of the rain carried by the monsoons. The Indus River basin, in the region that is now northwest India and southeast Pakistan, is especially dry due to hot winds from the Middle East that often block the monsoons. The river itself has abundant water, though; in addition to some monsoon rain, it also

receives meltwater from the Himalayas in early summer.

Giosan became fascinated with the region, the Harappans, and their fate when he and WHOI colleague Peter Clift, now at Louisiana State University, led an expedition studying the geology of the Indus River delta in 2002. Over the next several years, he delved into the prehistory of India to understand what archaeologists had discovered about its cultures. He also began to think about how he could address long-standing questions about the region and its early peoples with new techniques from geology.

Getting the story right

By 2008, Giosan and an international team including Camilo Ponton, an MIT/WHOI Joint Program graduate student, were gathering geologic clues to reconstruct the ancient environment.

“In geology, we are storytellers,” Giosan said. “But you can tell a story only as good as the data you are gathering.”

He and Ponton suspected that existing information on Indian monsoons in ancient times didn’t tell the complete story. It showed that the monsoons have weakened during the past few thousand years, bringing less rain to the region than they did before.

That work relied on data from cores extracted from the deep seafloor off the coast of India. The cores are long cylinders of sediment, much of which was delivered to the ocean by rivers and wind. It piled up on the ocean bottom and preserved a record of past conditions on land.

But the cores used by previous monsoon researchers came from areas where so little sediment was deposited that a core 4 to 5 feet long included about 10,000 years of accumulation. Each sample of the cores with enough material to analyze represented 100 years or more. Ponton and Giosan thought that this sediment record might not capture significant events that happened on shorter time scales. So they delved into a core that offered more detail.

Core matters

Giosan helped collect the core on a cruise on the drillship *JOIDES Resolution* in 2006. It came from near the mouth of the Godavari River on the southeast coast of India. This was the perfect location for what the geologists wanted to do, because it is so close to the mouth of the river that sediments accumulate very fast there. In this core, 10,000 years is represented by about 26 feet of sediment. That meant the scientists would be able to examine samples laid down during periods as short as 25 years.

The location had other advantages. The Godavari drains a vast region of central India and reflects average conditions throughout the entire Indian peninsula. The area had also been home to hunter-gatherers who were contemporaries of the Harappans and may have roamed far beyond the river basin in search of seasonal foods.

Ponton said another key feature is that the Godavari receives no snow or glacial melt from mountains. All the water in the river comes from rainfall, and so it accurately reflects the amount of rain that fell in its catchment area.

Finally, fluctuations in the salinity of the Bay of Bengal provide a handy way to show how much water was carried by the river. Like all rivers that flow into the sea, the Godavari brings fresh water into a saltwater environment. That lowers the salinity of the sea, especially near the surface, because fresh water is not as dense as salty water and tends to float above it.

After the monsoon season ends, the river delivers much less



Tom Kleindinst, WHOI



Photo courtesy of Peter Clift

At left, WHOI geologist Liviu Giosan (red shirt) takes a sediment core from the Indus Valley to trace the history of flooding in the region. Above, Giosan and graduate student Camilo Ponton (left) use seafloor sediment cores to reconstruct environmental conditions in ancient India. A core from the Bay of Bengal yielded information about rainfall and vegetation.

water to the sea, and the bay’s salinity rises. As a result, the Bay of Bengal has some of the biggest changes in salinity in the world’s oceans. Those changes are incorporated into the calcium carbonate shells of foraminifera, tiny planktonic organisms that live in the bay.

“This species lives near the surface, where the change in salinity is highest,” Ponton said. “There is oxygen in their shells, in the form of carbonate. They take that oxygen from the water they are living in, so the chemical composition of the shells is related to the chemical composition of the water at that time.”

When the foraminifera die, their shells sink to the seafloor, preserving in the sediments a record of seawater salinity changes. After cutting slices from the core, Ponton isolated the fossilized shells that were embedded in the sediment. He then used a mass spectrometer to determine the ratio of various isotopes of oxygen in the shells. That ratio told him the salinity of the water when the foraminifera were alive—which indicates how much fresh water the Godavari was putting into the sea at the time.

Ponton and his colleagues found a striking pattern. From about 4,700 years ago to the present, the Bay of Bengal’s average salinity has risen slightly, indicating that monsoon rains have declined slightly. That was consistent with previous studies. But Ponton’s data show three distinct periods when conditions differed. From 4,700 to 4,000 years ago, salinity was essentially stable, with small

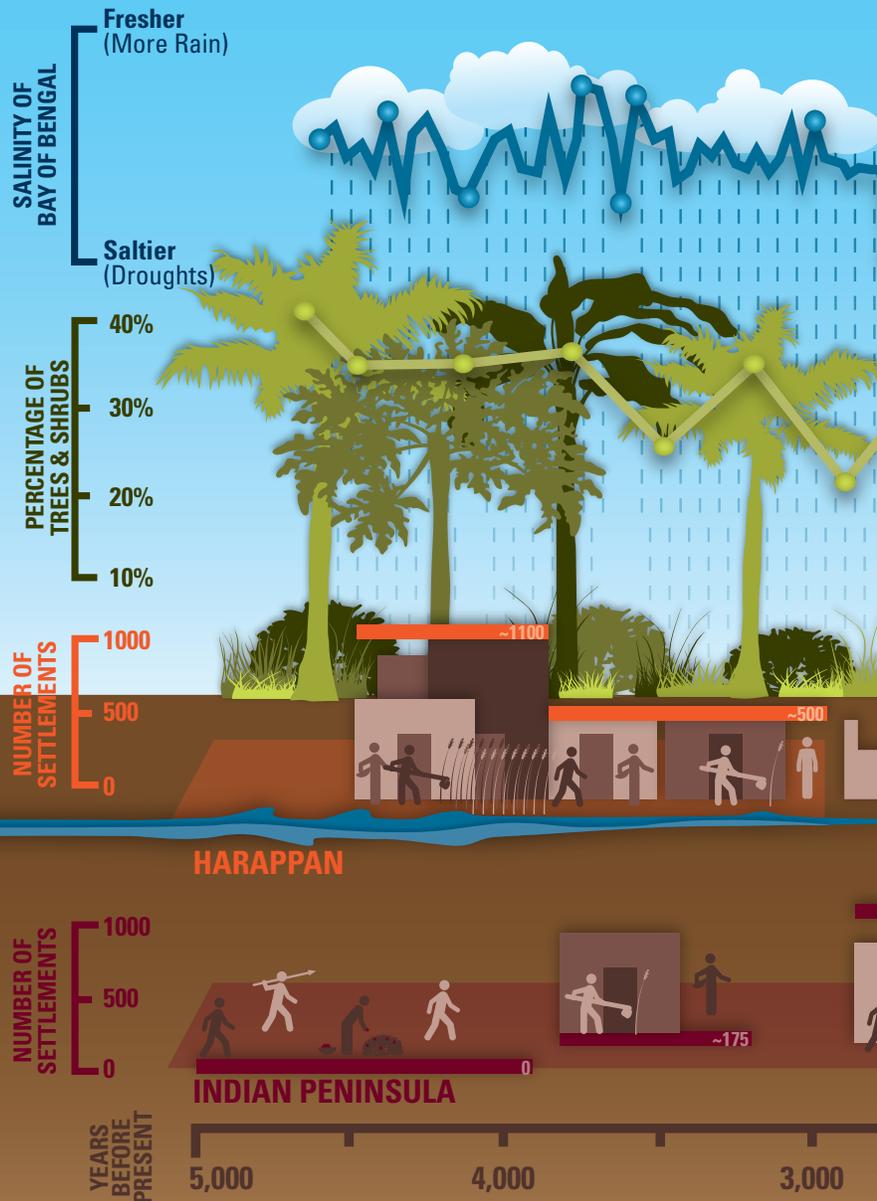
HOW CLIMATE CHANGE SPURRED THE RISE AND FALL OF ANC

Saltiness of seawater in the Bay of Bengal changes depending on how much fresh water flows into the bay from rivers like the Godavari. High salinity results from drought conditions on the Indian peninsula. About 4,000 years ago, the monsoons began to weaken and extended droughts became more frequent. Salinity was determined by analyzing oxygen isotopes in ancient plankton shells preserved in seafloor sediments cored near the river mouth.

As the region became drier, the percentage of shrubs and trees declined and grasses became more abundant. Plant waxes flushed out to sea and preserved in seafloor sediments show that before the monsoons weakened, nearly half of the region's plants were shrubs and trees and the rest were grasses.

4,500 years ago the Harappans farmed along the Indus and other rivers whose yearly floods irrigated the soil. When the monsoons weakened, the rivers no longer flooded enough to support farming. Harappan settlements diminished, and around 3,000 years ago the culture disappeared.

While the Harappans farmed, people living on the lush Indian peninsula survived as hunter-gatherers. When the monsoons began to weaken 4,000 years ago, the peninsula became more arid. The people turned to agriculture to get enough food and began to build settlements. Around 1,600 years ago, they started using tank irrigation to water their fields.



deviations representing minor droughts or wet periods. Between 4,000 and 1,800 years ago, average salinity rose slightly, and the region suffered a few severe droughts lasting a decade or longer. Starting about 1,700 years ago and continuing to the 19th century, severe droughts lasting decades occurred much more frequently.

That was exactly the kind of result that could not be seen in earlier studies. Using cores with slower-accumulating sediment, Ponton said, “you might miss these spikes in salinity.”

The work was published in February 2012 in *Geophysical Research Letters*.

When drought hits

But what difference did the droughts make, if average rainfall declined only slightly over the centuries?

“If you have extreme droughts for a decade or even a few consecutive years, the plants in the region must be able to withstand long periods without rain,” said Giosan. More consistent

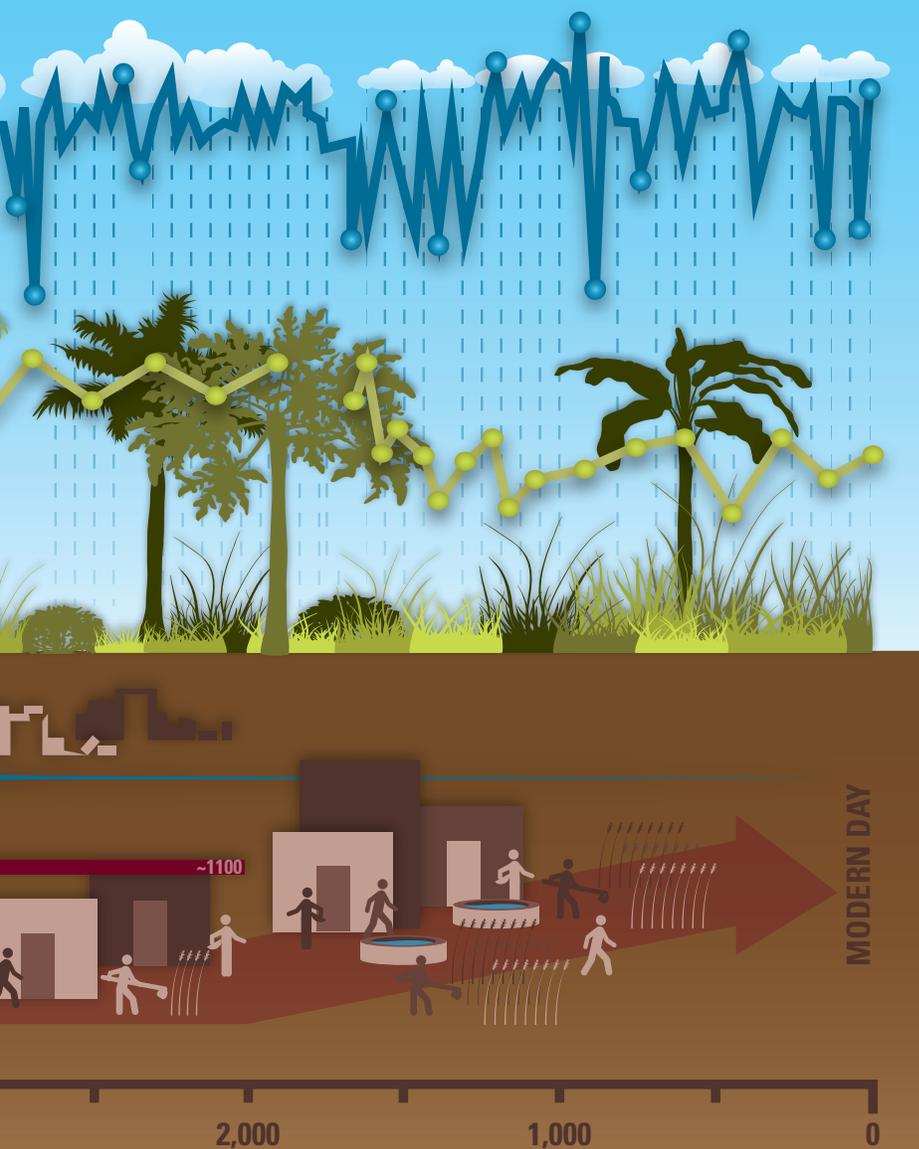
monsoons, on the other hand, put less stress on vegetation, even if the amount of rainfall declines over time.

Ponton returned to the Godavari sediment core and enlisted the help of organic geochemist Timothy Eglinton of ETH Zürich to find out whether vegetation in the region became more drought-resistant when the monsoons changed. Embedded in the sediment are waxes that plants made that got washed into soils and the river and ultimately into the sea. Once in the ocean, the waxes stuck to particles of sediment and settled onto the seafloor.

“The plant waxes are very stable molecules,” Ponton said. “They’re resistant to degradation, and they preserve well.”

They also carry a signature of the general type of plant that produced them. Grasses, which are better adapted to arid conditions, aren’t too picky about which carbon isotope they take up from the atmosphere. Shrubs and trees, which tend to be very sensitive to drought, have a stronger preference for one isotope. By extracting plant waxes from the sediment core and analyzing

SCIENT CIVILIZATIONS



"I call the Harappans the 'Goldilocks civilization.' They were probably the most egalitarian, and definitely among the most advanced societies of their time. And they depended completely on one resource—floods from the Indus River. They appeared as a civilization because the floods of the Indus River became less angry, less strong, and they exited history because the floods of the Indus became less frequent. So they hit that sweet spot when the floods were just right for them to make agriculture along the Indus.

What does that tell us that is valid today? Well, we hit a similar sweet spot using oil to create all these amazing things—but the span of time before that resource runs out is shorter than the Harappans had."

—Liviu Giosan

their carbon isotopes, Ponton could estimate the relative proportion of grasses versus shrubs and trees in the river's catchment area.

The researchers found that between 5,000 and 4,000 years ago, before the extended periods of drought began, vegetation in the river basin was 60 to 65 percent grasses. After that the proportion of grasses began to rise. By about 1,700 years ago it had reached 70 to 75 percent, and by 1,500 years ago grasses accounted for 80 to 85 percent of the vegetation in the region.

"There has been a significant change in the vegetation—grasses became more widespread than shrubs and trees," said Ponton.

Coming of agriculture

Giosan then wondered if the increasing aridification had affected the people in the Godavari River basin. Archaeologists had found that while the Harappans were tilling fields and living in sizable towns, these people lived in small groups that hunted, gathered wild fruits, and sometimes engaged in "casual"

agriculture that involved clearing a patch of forest, planting seeds, and then returning some months later to harvest the crop. They didn't develop a more settled lifestyle until much later.

Giosan called on Dorian Fuller, an archaeologist from University College London who specializes in the prehistory of south Asia, to see if Ponton's reconstruction provided a clue to explain why. They compared archaeological records of the number of settlements in the region with the timeline of changes in the monsoons. Between 5,000 and 4,000 years ago, before aridification, the region's forests were dense and productive and the number of settlements in the region was essentially zero. The people didn't live in villages that left discoverable traces. "There has to be some motivation to do all the work involved in settled agriculture," said Giosan. "They didn't do agriculture because they didn't need to."

But around 4,000 years ago, when conditions became drier and shrubs and trees began to struggle, wild food was not so easy to

Illustration by Amy Caracappa-Qubeck, WHOI

come by. Casual crops no longer survived on monsoon rain alone. The people in the region responded by adopting sedentary agriculture, which required them to tend their plots throughout the growing season. About 100 settlements have been found dating from 4,000 to 3,200 years ago.

By 2,800 years ago, the number had swelled to more than 1,000. Around 1,700 years ago, when severe droughts came even more frequently, the people began irrigating their fields with water they stored in cisterns.

Driven by the drying of the monsoons, the hunter-gatherers had settled down and become farmers.

Looking westward

Giosan knew that the drying revealed by the Godavari sediment core also must have affected the Indus region and its people. But the western side of India did not offer the same kind of sediment core he and Ponton benefited from in the east. He would have to find other ways of probing the geological record.

He tapped a vast resource provided by NASA, the U.S. space agency. During the Shuttle Radar Topography Mission in 2000, NASA personnel had used radar to compile detailed topographic data about almost the entire planet. Giosan and his colleagues used those data to develop detailed topographic maps of the Indus, its tributaries, and their basins, revealing details difficult or impossible to observe at ground level. They detected the ancient boundaries of riverbeds and compared them with hundreds of settlement sites identified by archaeologists. Their work was published in May

2012 in *Proceedings of the National Academy of Sciences*.

“This was a breakthrough,” said Giosan. “Archaeologists now have a new tool to decide where to go and dig. It gives a coherent framework to pick and choose which sites to invest their money in to understand the most about how these people lived.”

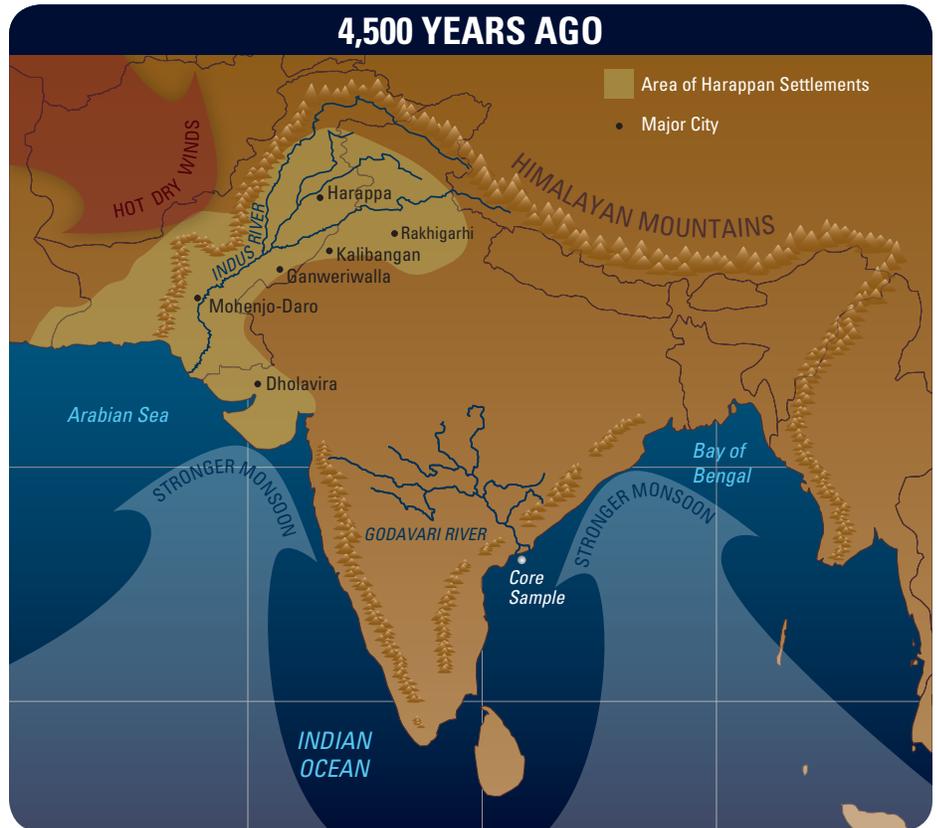
Guided by the topographical data, Giosan, Clift, Mark Macklin of Aberystwyth University in Wales, and their team took land cores at choice locations along the rivers and determined the age

of the sediments. They found that material near the surface of the floodplain is 2,000 to 3,000 years old, which indicated that the Indus has been relatively calm over that time, only rarely jumping its banks to carve a new channel—or to provide nourishing waters to the fields.

The scientists also gathered information on all Harappan sites that had been identified by archaeologists, both in the lower Indus valley and in the upper reaches of its tributaries. They compiled the most complete list to date of Harappan settlements and their ages and sizes. Then they compared the story told by those sites with the story revealed by their geological work.

Culture and climate

Before 5,000 years ago, the Indus and its tributaries were fed by strong monsoon rains and meltwater flowing out of the Himalayas. The rivers underwent raging



CRYSTAL CLEAR DATES FOR ANCIENT RIVER FLOODING

WHOI geologist Liviu Giosan (far right in blue shirt) and Florin Filip of the University of Bucharest collect sediment from trenches in the Indus River floodplain. Their work showed that annual floods of the Indus and its tributaries became sporadic and unpredictable, leading to collapse of the Harappan civilization, which depended on the floods for irrigation.

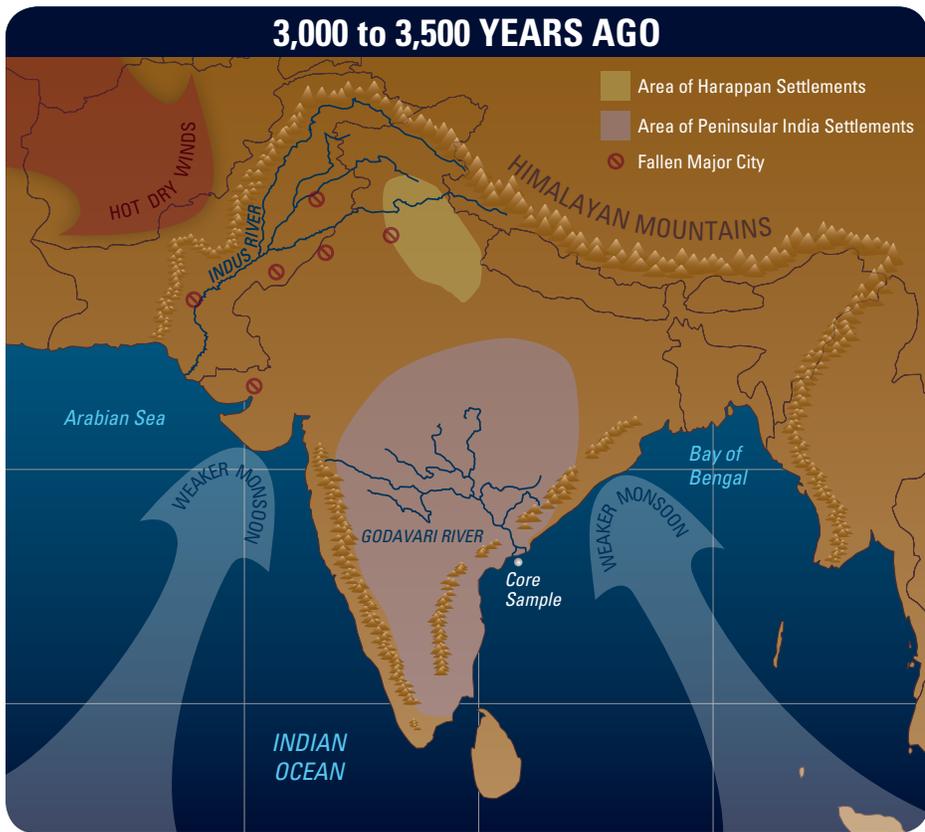
Giosan and his colleagues found the age of river sediments by radiocarbon dating and by optically stimulated luminescence using quartz from the sediment. Quartz crystals (below) emit light when they are exposed to light. The longer a crystal has been buried, the more light it emits, revealing when the crystal was last on the surface.



Public Domain



Photo courtesy of Peter Clift



Illustrations by Amy Caracappa-Qubeck, WHOI

floods every year that rendered their basins unsuitable for agriculture or permanent settlements. The ancestors of the Harappans lived in foothills west of the Indus plain where abundant monsoonal rainfall enabled them to do rain agriculture.

By about 4,500 years ago, the weakening of the monsoons reduced the fury of the floods. The Harappans settled in the river valleys and took up inundation agriculture, relying on the benign floods that soaked the soil and recharged the groundwater. Despite a lack of rain late in the growing season, irrigation systems were not needed.

More than 1,000 Harappan settlements have been dated to that period. They occurred along hundreds of miles of the Indus and its five major tributaries. Many of the sites were impressive cities with populations of about 20,000, very large for their time.

But then came the more intensive monsoon weakening and aridification, which Ponton had traced in his sediment core work and Giosan had seen in the changing behavior of the Indus. Inundation agriculture became difficult and then impossible. There was probably enough river flow from snowmelt to support crops if the Harappans had developed more sophisticated irrigation technologies, but they did not do that.

“They were living in a region that was already dry, and then when floods subsided and became irregular, they couldn’t sustain their numbers,” said Giosan. Around 3,800 years ago, at the same time the people in the Godavari basin were beginning to experiment with agriculture, the Harappan culture began to fall apart.

The people gradually migrated toward the foothills of the Himalayas, where the peaks stripped the last vestiges of moisture from the weakened monsoons. New, small settlements sprang up, but many more disappeared. Within a few hundred years, the

About 4,500 years ago (far left), river flooding allowed the Harappans to farm Indus Valley floodplains and build large cities. People living farther south on the Indian peninsula survived as hunter-gatherers. When the monsoons weakened (left), Indus valley agriculture failed and the Harappans left their cities. The peninsula became more arid, prompting the people there to settle in towns and become farmers.

number of Harappan settlements in the Indus basin dropped by half. None of the great cities survived.

Neither did the technological and artistic skills that had characterized the culture. When the Harappan people dispersed to smaller settlements, they left behind their architectural prowess. They no longer traded with distant lands or made sophisticated art. They stopped writing.

By 3,000 years ago, they had disappeared as a distinct culture.

Adapting to climate change

Although the changes in the monsoons occurred quickly on the geological time scale, they occurred much more slowly than present-day climate change. The cultures of the Indian subcontinent had hundreds of years to try to adapt to the drier conditions. The people of the lower Indian peninsula developed new technologies and new ways of living, and they survived. The Harappans in the west, despite all their previous accomplishments, did not.

The two cultures “were affected in different ways by the regional patterns of the same climatic phenomenon,” said Giosan. He thinks what happened to the Harappans should be viewed in the context of societies that came before—and after.

“In Mesopotamia, when aridity struck, they made a technological advance: They started to use irrigation. In Egypt, the same,” he said. “The Harappan people, instead, had a choice. They had a place to migrate toward keeping their way of life.” But they did not, probably could not, anticipate that their way of life would not survive that migration.

And what are *our* options, as we begin to grapple with the consequences of climate change and the need to provide food and water for a burgeoning human population?

“What I see as the most important reflection coming from this study is the problem of time,” said Giosan. “We expect events in climate to be intelligible to us on the scale of our lifetimes, or our children’s lifetimes. They are not. The changes could be slow enough, even now, that they transcend generations. And we have to prepare a long time for them.”

This research was funded by the National Science Foundation, Woods Hole Oceanographic Institution, the Leverhulme Trust, the University of Aberdeen, and Louisiana State University. It was conducted by teams of scientists from India, Pakistan, Romania, Switzerland, the United Kingdom, and the United States.