Profile of Dolores R. Piperno

Plants decay so quickly in the steamy warmth of the tropics that it is often fruitless for botanical archaeologists to search the soils there for the fossilized remains of the seeds and roots traditionally used in their work. Dolores R. Piperno, elected to the National Academy of Sciences in 2005, solved that dilemma by pioneering the use of different kinds of plant fossils. Her work with phytoliths and other microscopic remains shows that even plants in the tropics leave behind telltale signs of their presence thousands of years later.

Phytoliths, tiny inclusions of solid silica formed within plant cells that help to protect plants from herbivores, offer a window into agricultural and environmental history in the tropics and elsewhere (1–4). In her Inaugural Article in this issue of PNAS (5), Piperno, a scientist at the Smithsonian Tropical Research Institute (Panama) and the National Museum of Natural History (Washington, DC), uses phytoliths, pollen, and charcoal evidence retrieved from lakes to reconstruct the environmental and agricultural history of Mexico's Central Balsas Valley. The region is known as the possible origin of maize domestication approximately 9,000 years ago.

Dolores R. Piperno (center) with Silvestre Taboada (left) and Enrique Moreno (right), project palynologist, coring at Laguna Tuxpan, in Southern Mexico.

Combining Two Fields in the Field

Piperno's work connects two passions she has had since childhood. "I've always liked the life sciences, and I've always been interested in prehistory," she says. "What I do now combines both." Born in 1949, Piperno spent 13 years in Philadelphia before her family moved across the river to Pennsauken, NJ. The middle child of three, Piperno enjoyed reading science and history books and playing sports, such as golf, tennis, and softball. She entered Rutgers University (Camden, NJ) in 1967 and graduated with a B.S. in medical technology in 1971.

"The Med Tech curriculum was essentially a biology major with the senior year being spent in the clinical laboratory of a hospital rotating through the various sections such as microbiology, chemistry, and hematology," she explains. "I received good training in different kinds of laboratory techniques."

After graduation, she went to work as a research technician for Dr. Scott Murphy at the Hematology Research Center of Presbyterian Hospital in Philadelphia. "Patients with serious blood disorders came in and were treated by Scott and others, who were among the top practitioners in their field," she says. "We carried out tests and research on the patients' blood in order to closely study the efficacy of current treatments and develop new ones. I learned some valuable lessons and skills during that 5-year period, including the importance of good microscopy work."

By 1976, Piperno wanted to expand her horizons and responsibilities. She decided to return to her interest in prehistory and biology by pursuing graduate studies in anthropology at Temple University in Philadelphia. There, she joined the laboratory of Anthony Ranere, a tropical forest archaeologist who had worked extensively in Panama.

"I went to Panama for the first time in 1979 on a student grant from the Smithsonian Tropical Research Institute (STRI)," which is based there, she explains. "I was part of a field crew that reexcavated an ancient shell mound called Cerro Mangote. By that point I knew that I was interested in focusing on archaeobotany, and that summer in Panama I got hooked on the tropics."

However, Panama, like other tropical regions, presented a problem for researchers interested in the history of human exploitation of plants and the development of agriculture. Plant remains that are visible to the naked eye simply do not survive long in tropical soils, where the warmth and humidity cause rapid decay. Therefore, although tropical forests contain the richest diversity of useful plants and many major American crops like manioc and sweet potato were obviously tropical, anthropologists did not generally consider tropical forests as a place where ancient agriculture originated.

"It was clear that different methods were needed to study these problems," Piperno recalls. For her master's thesis, she decided to look for something that would fit the bill. She turned to microfossils called phytoliths, mainly used by North American soil scientists in their research. Phytoliths are tiny, intricately shaped pieces of silica that many species of plants produce and that, because of their mineralized nature, could survive

This is a Profile of a recently elected member of the National Academy of Sciences to accompany the member's Inaugural Article on page 11874.

intact in many kinds of sedimentary environments over long periods of time. Piperno wanted to see if she could use phytoliths to discover the kinds of plants people ate in central Panama at the Aguadulce Rock Shelter, which Ranere excavated.

"There wasn't much known about which plants produced phytoliths," says Piperno, "and it was thought that they had limited taxonomic value."

For her dissertation research, Piperno explored in detail the potential of using phytolith analysis in tropical archaeobotany by examining Panamanian archaeological sites of different ages that had been excavated by Ranere and STRI scientist Richard Cooke. Her simultaneous studies of phytoliths in a wide range of modern tropical plants allowed her to assess the characteristics and utility of phytolith formation. In her doctoral thesis, Piperno showed that phytoliths commonly occurred in diagnostic shapes in many kinds of plants, including important tree and herbaceous flora, and that they were present in high numbers in archaeological sediments.

When Piperno received her Ph.D. in 1983, she knew that phytoliths could be an important archaeological tool and that they also had promise in paleoecological research as a counterpart to pollen studies, and she developed the technique further in Panama through a postdoctoral fellowship with STRI (6–9).

"My phytolith data were met with considerable skepticism at first," Piperno recalls. "A number of different plants and crops were being documented in ancient tropical sediments for the first time, and there was resistance."

Based in part on a lack of empirical evidence for agriculture in tropical environments, "there was a belief in a part of the scholarly community that tropical forests were unfavorable environments for cultural advances, including the development of agricultural systems," says Piperno.

Nevertheless, the phytolith evidence that contradicted these ingrained views grew, and it appeared that important crops like maize had been dispersed to, and grown in, Panama during the Preceramic era 7,000 years ago (6–8).

Another Use for Phytoliths

For her second postdoctoral fellowship, funded by the National Science Foundation Program in Environmental Biology, Piperno began to carry out more detailed studies of phytoliths in lakes and other kinds of paleoecological contexts. She compared and contrasted phytolith data with pollen and other records from the sites. During this time, she worked with paleoecologists Mark Bush and Paul Colinvaux, then of Ohio State University (Columbus, OH), analyzing lake cores from the Ecuadorian Amazon. To their surprise, they found 6,000-year-old phytoliths and pollen from maize along with evidence of significant forest disturbance by humans.

This finding provided independent evidence of a significant pre-Columbian human presence in a place where no archaeological research had been carried out and that now looked like pristine forest (10, 11). Piperno also found that using pollen, phytolith, and charcoal data in tandem generated more robust environmental histories. "There are weaknesses in any single technique or data set," says Piperno. "That's what makes multidisciplinary research so useful." For example, plants that do not produce much pollen may contain high numbers of diagnostic phytoliths or vice versa. "Being able to recognize more plants in paleoecological records and increase the resolution of the reconstructions is particularly important where species diversity is high," Piperno says.

In 1988, Piperno published the first book on using phytolith analysis for research in archaeology and environmental history (12). That same year, STRI offered Piperno a permanent position as staff scientist. She would spend the next 16 years in Panama, enjoying the "great scholarly and interpersonal atmosphere" at STRI and the "gifted leadership" of Director Ira Rubinoff. Now Acting Undersecretary for Science at the Smithsonian Institution, Rubinoff encouraged his scientists to take risks and push the envelope, recalls Piperno.

In the late 1980s and early 1990s, Piperno continued her collaboration with Bush and Colinvaux with more work on sediment cores from lakes. Laguna La Yeguada, strategically located near the archaeological sites that formed the basis of her phytolith work, provided a fruitful place to look for evidence of past climate change and human impacts on the vegetation. The lake turned out to be 14,000 years old, which was old enough to also study ice-age climate and vegetation and the environmental changes that marked the end of the Pleistocene and transition to the Holocene in the lowland tropics (13–15).

In the core sediments, Piperno and her colleagues found phytolith and pollen evidence of significant forest modification from humans practicing slash-and-burn cultivation starting 7,000 years ago. This date coincided with the first appearance of maize phytoliths and pollen in the nearby archaeological sites. Because maize did not originate in Panama, but in Mexico, the data indicated that an even earlier domestication of maize occurred.

"We realized that, in contrast to the then-popular 'Noble Savage' view of prehistoric human–environmental interactions, systematic human interference with and sometimes destruction of the natural vegetation had occurred in the tropical forest thousands of years ago," says Piperno. The data indicated that the human population density there was higher than previously assumed and was supported by earlier and more sophisticated systems of agriculture than had been imagined.

In 2006, the Republic of Panama gave Piperno the Orden de Vasco Nuñez de Balboa, the highest award given to a civilian, for her contributions toward understanding the prehistory of Panama.

In the early 1990s, Piperno further expanded the geographic and taxonomic scope of phytolith investigations. With another phytolith researcher, Deborah Pearsall from the University of Missouri (Columbia, MO), Piperno set out to explore for the first time the wild ancestors of crops like maize and major plants from the Old World, such as rice, so that the plants could be studied in their areas of origin (16).

"We were continuing to firm up existing analysis and push it further," she says. They quickly realized that significant phytolith data could be obtained from "almost anywhere."

In 1998, Piperno and Pearsall published *The Origins of Agriculture in the Lowland Neotropics* (17), in which they summarized the evidence collected over the last two decades for plant domestication and past natural and human impacts on tropical forest. The book included data from molecular biologists who in the 1990s had become involved in issues surrounding plant domestication and were studying the genetic differences between wild plants and domesticated crops to identify the crops' ancestors.

Thus, Piperno explains, even where there was not yet archaeological evidence of the early stages of domestication and crop dispersals, as with major root crops like manioc, the ecological and molecular evidence gave considerable insight into where these processes occurred. Piperno and Pearsall (17) tied all of the research lines together and made the case that lowland tropical forests were major and independent centers of domestication. Piperno is proud of the work. "Someday, we'll probably do another edition [of the book]," she says. "There is a lot more evidence now from all the contributing disciplines."

Another Surprising Tool

By the late 1990s, Piperno felt that she had a grip on the early cultivation and dispersals of maize and other seed crops, such as squashes, in Panama and northern

South America. But she had no data on the major root crops that were native to the tropical forest, such as manioc and yams. These plants did not produce identifiable phytoliths and could not easily be traced through their pollen. To fill this gap, Piperno explored a new direction in tropical research called starch grain analysis. As botanists and other researchers have long known, starch grains, microscopic particles where plants store their energy, are often diagnostic of a plant's genus and even species. The big question was whether the grains could survive in tropical environments.

"Investigators were beginning to show that in the southeast Asian tropics, starch grains were well preserved on stone tools used to process plants that were recovered from ancient archaeological contexts, so I decided to try [starch grain analysis]," she says.

She and STRI's Irene Holst analyzed 5,000- to 7,000-year-old stone tools from the Aguadulce Shelter and found starch grains that appeared to be from manioc, maize, yams, and arrowroot (18). "We were really pleased that perhaps we finally had a method to document the root crops plus another source of data for identifying maize," she says. "But we needed to do more to firm up these findings."

Piperno and Ranere went back to the Aguadulce Rock Shelter in 1997 and re-excavated it, recovering more stone tools and retrieving sediments that were closely associated with the tools that could serve as control samples. They also examined modern starch grains from a much larger set of economic plants so that they could be more sure of the archaeological starch grain identifictions. The results verified the first set of starch data, providing evidence for an early use of manioc and yams, and corroborated previous phytolith data for maize (19).

Since then, Piperno and her colleagues have continued to develop starch grain analysis. She recently isolated wild barley starch grains from a 20,000-year-old stone-grinding tool from Israel (20). "It's a fast-growing field in archaeology," she says. "Already a diverse array of important plants in addition to root crops that we couldn't study effectively before, like chili peppers, are being documented in ancient records."

Investigating the Cradle of Maize

For the past 7 years, Piperno and her team have tackled the long-debated question of where and when maize was domesticated. In the 1990s, John Doebley and his team from the University of Wisconsin (Madison, WI) produced molecular evidence showing that the tropical Central Balsas watershed of Mexico, a not arid, high elevation region, was probably the cradle of maize domestication (21). Few researchers, however, had undertaken archaeological or paleoecological work there, says Piperno.

To remedy that, Piperno and her colleagues have been studying lakes and archaeological sites in the region (5). Core samples they have taken from three lakes and a large swamp showed that the oldest of these sites is approximately 14,000 years old. Combining studies of climate, vegetation, and land-use history with archaeological work, Piperno and her colleagues have developed a picture of human occupation together with the agricultural and environmental history of the region. Their analyses of phytoliths and pollen from the lake cores found the same kinds of environmental shifts as in other regions of the lowland tropics, with a rapid and marked transition to the present warmer, wetter climate taking place at the end of the Ice Age approximately 10,000 years ago (5).

The evidence also shows that the lakes became foci of early human activity and that farmers were clearing the forests in the lakes' watersheds more than 6,000 years ago. Piperno sampled sediments from the lake edges specifically because she thought that people would have used these fertile areas. Indeed, they found phytoliths from maize and a domesticated species of squash in these areas that are probably at least 8,000 years old (5). Her Inaugural Article (5) focuses on the microfossil evidence from the lakes. She will present archaeological evidence on early agriculture from sites near the lakes in a forthcoming paper.

In the next 10 years, Piperno would like to extend the utility of phytoliths, she says. Specifically, because the microfossils entrap the contents of cells when they form, she is hoping to find ancient DNA inside them. Meanwhile, she published a new edition of her phytolith book last year, in which she reviewed the present state of knowledge about the discipline and the growth of the field since 1988 (3). Piperno says she has enjoyed watching as phytoliths are applied in archaeology and paleobotany around the world.

She also plans to work more with starch grain analysis, continuing to develop it by investigating the microfossils in a variety of plants and ancient sites and determining more precisely what processes or conditions preserve or destroy the grains, because some have even been found in residues from ceramics used for cooking. In addition, Piperno plans another long-term collaboration with Mark Bush to study paleoecological records from the Amazon Basin and to determine past human impacts on biodiversity and forest structure there.

Although Piperno moved to Washington, DC, in 2004 to join the curatorial staff of the Smithsonian National Museum of Natural History (NMNH), she continues her work at STRI and has not slowed her fieldwork. She spends much of her free time with her 15-year-old daughter, Jenny, who, Piperno says, is proud of her mom's success. Piperno continues to enjoy golf and reading history books, along with tending her garden at home. "When I was younger, I couldn't have imagined the interesting life and wonderful career I would have," she says. "It's great to go to work every day and not feel that you're at work."

Tinsley H. Davis, *Freelance Science Writer*

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