

Pollen evidence of the earliest maize agriculture in Costa Rica

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The domestication of maize and its spread throughout the Americas has long generated interest. Four symposia on maize at the March–April 2004 meeting of the Society of American Archaeologists in Montreal¹ helped to push research (and debates) forward. While there is at present widespread acceptance that one of the teosintes (likely *Zea mays* subsp. *parviglumis*) is the ancestor of domesticated maize (*Zea mays* subsp. *mays*), many questions remain about where, when, and how domestication took place, and about the subsequent spread of cultivated maize throughout the Americas (Society for American Archaeology 2004a, b; Smalley and Blake, 2003).

Botanical evidence for the presence of maize at different sites and times is key to the debate. This evidence consists of maize macrofossils (usually cobs, kernels, or fragments) and maize microfossils (pollen grains and phytoliths) for which ages can be determined using radiocarbon analysis. Until recently, almost all radiocarbon ages for maize macrofossils or microfossils were based on standard radiocarbon assays of associated charcoal or other organic remains in the soils or sediments from which the maize fossils were recovered. The development of accelerator mass spectrometry (AMS) radiocarbon dating, which requires a much smaller mass of sample, has made it possible to date individual maize kernels or cob fragments, and has led to the application of more exacting standards to botanical evidence of the history of maize and other New World crops (Smith, 1994–95; Fritz, 1994). Under these new standards, the primary class of botanical evidence consists of seeds or other plant parts that show morphologies indicative of deliberate planting and harvesting² and that are directly dated by AMS methods (Smith, 1994–95). Cultigen pollen and phytoliths that are not directly dated constitute less desirable, secondary classes of evidence, as do macrofossils that are not directly dated. Reinterpretation of the history of maize based only on primary botanical evidence, including direct AMS dates on maize cobs from rockshelters in the Tehuacán Valley of Mexico that had previously been dated only indirectly (Long *et al.*, 1989), led Fritz (1994) to question the standard 5000 BC date for maize domestication. The earliest primary botanical evidence she found was for a directly dated cob from the San Marcos (Tehuacán) cave that yielded an AMS date of 4700 ± 110 ¹⁴C years BP, a radiocarbon age that corresponds to a calendar age of between 3700 and 3100 BC when corrected for known variations in atmospheric ¹⁴C (see Table 1 for calibration methods and for calibrated age ranges for all dates for maize subsequently presented here). More recently, Piperno and Flannery (2001: 2102) dated two “primitive-looking maize cobs” from Guilá Naquitz cave in Oaxaca, Mexico, to 5420 ± 60 ¹⁴C years BP and 5410 ± 40 ¹⁴C years BP. Based on an analysis by Beadle and Ford, the dated cobs are thought to represent either “maize-teosinte hybrids

Site and material	Reference	Maize dates ¹⁴ C years BP	2-sigma calibrated BC age ranges ^a
Guila Naquitz cave, Oaxaca, Mexico primitive maize cob	Piperno and Flannery (2001)	5420 ± 60	4360–4050 BC
Guila Naquitz cave, Oaxaca, Mexico primitive maize cob	Piperno and Flannery (2001)	5410 ± 40	4340–4050 BC
San Marcos cave, Tehuacán Valley, Mexico maize cob	Fritz (1994) [from Long <i>et al.</i> 1989]	4700 ± 110	3700–3100 BC
Laguna Martínez, Costa Rica charcoal in interval of earliest maize pollen	This paper	4760 ± 40	3640–3380 BC
Arenal Prehistory Project, Costa Rica charcoal associated with excavated maize macrofossil	Bradley, 1994; Mahaney <i>et al.</i> , 1994	4450 ± 70	3340–2920 BC
Laguna Martínez, Costa Rica charcoal in maize interval 5 cm above earliest maize interval	This paper	4410 ± 40	3330–2910 BC.
Lago Cote, Costa Rica charcoal in sediment interval directly below maize interval	Arford (2001)	3630 ± 70	2200–1770 BC

Table 1. Radiocarbon dates relevant to the history of maize in Mexico and Costa Rica.

^aDetermined using CALIB 4.4.1 (Stuiver and Reimer, 1993) and the dataset of Stuiver *et al.* (1998). The probability that the true calendar age falls within the 2-sigma range is 95.4%.

or a primitive maize that demonstrated strong teosinte influence” (Piperno and Flannery, 2001: 2102).

But what about the record of maize microfossils, in Mesoamerica and beyond? Large grass pollen grains identified as *Zea mays* are routinely found in prehistoric sediments of lakes and swamps in Mexico and Central and South America. In northern Central America and Mexico the reconstruction of ancient maize cultivation from pollen is complicated by the difficulty of distinguishing the pollen of cultivated maize from that of teosinte, for which wild populations have been documented as far south as the Gulf of Fonseca region in the northern Pacific lowlands of Nicaragua (Iltis and Benz, 2000). But in southern Central America and South America, where wild populations of teosinte are unknown, the large *Zea* pollen grains should be strong evidence for the presence of cultivated maize, and we and other pollen analysts have interpreted them as such. Phytolith experts are similarly confident in their ability to document the past presence of maize in

southern Central and South America from phytoliths. (e.g., Pearsall *et al.* 2003; Piperno 2003).

An interesting, if sometimes troubling, pattern emerges when one compares the earliest dates on maize macrofossils and microfossils at many sites in this region. Microfossils of maize recovered from sediment cores or archaeological excavations frequently predate by one to many thousands of years maize macrofossils from archaeological sites (Smalley and Blake, 2003). Examples include maize phytoliths and pollen from the Cueva de los Ladrones archaeological site in central Panama that are associated with preceramic deposits dated to ~7000 ¹⁴C years BP (Piperno *et al.*, 1985); maize pollen and phytoliths in ~5300-yr-old sediments from Lake Ayauch¹, Ecuador (Bush *et al.*, 1989); and maize phytoliths in archaeological profiles from Las Vegas and Real Alto, Ecuador, that date to ~7000 ¹⁴C years BP (Pearsall and Piperno, 1990; Pearsall, 2002).

While some maize macrofossils are directly dated and thus constitute primary evidence in Smith's (1994–95) system, microfossils are almost always indirectly dated via the dating of associated charcoal or other plant macrofossils in the sediment core or archaeological profile. Is the pattern of microfossil dates predating macrofossil dates evidence that the former are suspect, or are other factors at play here?

Our view is that all early dates for maize microfossils (our own included) demand careful scrutiny, but that pollen and phytoliths in lacustrine sediment sequences that have been carefully dated (ideally by AMS dates on charcoal fragments or other terrestrial organic macrofossils) should not be excluded from consideration just because the microfossils are not themselves directly dated. We believe that the age discrepancy between maize microfossils and macrofossils in some areas of southern Central America and South America may be a consequence of different degrees of research effort and/or possibilities for preservation. The considerable interest that exists in unraveling the history of tropical plant communities using analyses of pollen and other proxy indicators in sediment cores has led to the recovery of cores from a large number of lowland lakes and swamps, many of which occupy watersheds that were likely farmed during prehistory, but in which archaeological excavations have yet to be carried out. Maize pollen does not disperse far from its source, but should pollen of nearshore maize plants be deposited in lake sediments, conditions for preservation are often excellent – perhaps far better than conditions for preserving maize macrofossils onshore. In our view, the presence of maize pollen in well-dated lacustrine sediment intervals predating local archaeological evidence is not a challenge to the veracity of pollen data, but instead evidence that future archaeological work at the site might be worthwhile.

Iltis (2000: 36) recently proposed a novel idea that may provide an additional explanation for the discrepancy between macrofossil and microfossil ages for maize in southern Central America and South America. Iltis suggested that maize was “originally domesticated not for its grain but for its sugary pith or other edible parts.” Smalley and Blake (2003: 675) elaborated on this idea by proposing that “during *Zea's* initial period of domestication the stalk provided a key source of sugar for many purposes, including the making of alcoholic beverages,” and that “the social importance of alcohol production was a precipitating factor in *Zea's* early and rapid spread.” If corn stalks, not kernels, were the focus of early maize production at sites in southern Central America and South America, cobs and kernels would be less likely to have been carbonized and preserved with hearth remains. Therefore, we might expect maize kernels and cobs to appear later than pollen even at sites with exceptional preservation of archaeological materials and where detailed excavations have been carried out in the watersheds of sediment coring sites. We look forward to new evaluations of both primary and secondary classes of evidence of maize at sites throughout the Americas that can build upon the ideas of Iltis (2000) and Smalley

and Blake (2003), and to new field research in archaeology, paleoecology, and cultural ecology that these ideas may stimulate. It appears to us that Latin Americanist geographers have a potential role to play in assessing the merits of the 'sugar stalk' hypothesis and the more general idea that alternate uses of maize were important in the early spread of the cultigen, and in assembling some of the datasets that can provide context (or tests) for these ideas.

Our recent field work and subsequent laboratory analyses have provided new data on the history of maize in northwestern Costa Rica that we share here with the objective of providing context for the reevaluation of the history of the spread of maize through southern Central America and into South America. Our new evidence consists of maize pollen grains that are significantly older than those found previously in Costa Rican sediments, and as old or slightly older than the maize macrofossil that until recently constituted the oldest botanical evidence of maize in the country (Blanco and Mora, 1994). In this case, the maize macrofossil as well as our microfossils are both indirectly dated, but the dates are compatible with direct AMS dates on maize macrofossils from Mexico and we believe them to be correct.

Our new maize data from northwestern Costa Rica derive from detailed investigation of multiple proxies in sediment records from six lakes on the lower Pacific slope of Volcán Miravalles in the NW-SE trending Cordillera de Guanacaste. These lakes formed just over 8000 years ago following pyroclastic flows from Miravalles volcano (Alvarado, 2000). The lakes range in elevation from 340 to 560 m.a.s.l., and in size from 0.5 to 4.5 ha. The climate in this area is warm (mean annual temperature of 22.5–25.0° C), and seasonally dry (annual rainfall of 1500–2000 mm occurring from May to November) (Bergoing, 1998; Coen, 1983). Modern vegetation is primarily pasture grasses with remnant patches of semi-deciduous forest. No archaeological excavations have been conducted near the lakes, but surveys in the general area suggest occupation dating to 4000 BP or earlier.

Sediment coring was conducted in four field seasons from 1999 to 2003, with laboratory analysis ongoing. We have dated all cores through AMS analyses of charcoal and leaf fragments, and have carried out detailed analyses of pollen and microscopic charcoal to document changes in vegetation and fire history resulting from climate change and human activity in the lake watersheds. We have found maize pollen in our standard (percentage) pollen counts of samples from all of the lakes, and have supplemented these counts by preparing multiple additional microscope slides and scanning them completely for maize at low-power magnification at additional levels below the lowest occurrences of maize in our standard counts. The large size of maize pollen in comparison to other pollen types makes this type of presence/absence analysis practical.

Maize pollen is present in the late Holocene sections of the cores from all six lakes, with the earliest occurrence at Laguna Martínez (10.642 N, 85.197 W, 340 m elevation). Laguna Martínez has a surface area of 1.5 ha, and a water depth of at least 3.6 m during the dry season. Our core from Laguna Martínez is approximately 5 m long and has a basal date of 7610 ± 50 ¹⁴C yr BP. Six AMS radiocarbon dates on charcoal fragments and dicotyledon leaves indicate rapid initial sedimentation followed by much slower sedimentation (or possibly a hiatus) that we associated with dry conditions around 6060 ± 40 ¹⁴C yr BP. Maize pollen first appears in the record shortly after this dry period ends, associated with a trend of decreasing percentages of tree pollen, and increased abundance of grass pollen and microscopic charcoal. Pollen grains of *Zea mays* subsp. *mays* in the Laguna Martínez sediments range in size from 62.5 to 92.5 μm with pore annuli diameters of 12.5 to 17.5 μm. These values are within the expected size range for maize pollen from Central America and Mexico (Ludlow-Wiechers *et al.*, 1983), and are similar to the sizes of preColumbian maize grains found at other sites in Costa Rica (Horn *et al.*, 2004). The

lowest occurrence of maize, at 141 cm, dates to 4760 ± 40 ^{14}C BP based on AMS dating of tiny charcoal fragments picked from the maize-containing interval. As a check on this date we obtained another radiocarbon date five centimeters upcore, also on charcoal fragments from an interval with maize pollen. That sample yielded a date of 4410 ± 40 ^{14}C yr. BP. The association of these early maize grains with declining tree pollen percentages and with abundant microscopic and macroscopic charcoal is strong evidence of local forest clearance and maize cultivation, likely on the very shores of the lake. In the Laguna Martínez sediment core, almost all samples above this initial interval of prehistoric agriculture contain maize pollen, until the uppermost section of the core corresponding to the last few hundred years, in which maize pollen is only sporadically present.

Previously, the earliest evidence of prehistoric maize in both northwestern Costa Rica and the country as a whole consisted of a carbonized maize kernel excavated during the Arenal Prehistory Project conducted at the present site of the Arenal reservoir (formerly a natural wetland) approximately 35 km east of the Miravalles lakes (Sheets and McKee, 1994). The maize kernel was not directly dated, but a date of 4450 ± 70 ^{14}C BP was obtained on carbonized wood found in association with the kernel (Bradley, 1994; Sheets, 1994; Mahaney *et al.*, 1994). Earlier dates were obtained for hearth fires in the Arenal excavations, but no evidence older than the above was found for maize cultivation. Until we began working at the Miravalles lakes, the oldest pollen evidence of maize agriculture came from near the base of a sediment core from Lago Cote, located a few km north of the area investigated in the Arenal Prehistory Project. That maize pollen was found just above a sediment interval which yielded an AMS date on macroscopic charcoal of 3630 ± 70 ^{14}C yr BP (Arford, 2001). Our new data from Laguna Martínez indicates that maize farmers at Lago Cote and Lago Arenal had company. Maize cultivation was occurring at these times and slightly earlier on the lower Pacific slope of Volcán Miravalles.

The dates at hand for both the Arenal maize kernel and the Laguna Martínez maize pollen indicate that the earliest maize now known from Costa Rica overlaps in time with the earliest maize cob from San Marcos (Fritz, 1994) but is ~ 700 – 1000 radiocarbon years younger than the primitive cobs from Guilá Naquitz (Piperno and Flannery, 2001) (see table). In our view, the Costa Rican maize dates do not conflict with the history of maize as interpreted from primary botanical evidence alone. We do not need to invoke the ‘sugar-stalk’ hypothesis to explain the Costa Rican dates, and of themselves the dates do not provide a test for the hypothesis. However, the reported occurrence in Panama and South America of maize pollen and phytoliths that predate the Costa Rican evidence as well as the oldest cobs from Guilá Naquitz may be evidence that the spread of maize southward from Mexico was influenced by alternate uses of the plant (Smalley and Blake, 2003). If people to the south were first using maize for its sugary pith or other plant parts, they may also have been doing so in Costa Rica.

Is earlier maize likely to be found in Costa Rica? SPH and collaborators are working at several dozen lakes and swamps in Costa Rica to develop multiproxy records of environmental history that include evidence of the history of maize, but most sedimentary basins at low- to mid-elevation are younger than the earliest maize from Martínez and Arenal. Cores from some of these sites document maize cultivation earlier than as yet documented by local or regional archaeological evidence (e.g., Clement and Horn, 2001; Horn and Kennedy, 2001), but cannot reveal the initial arrival of maize as the sediment records begin a millennia or more after maize arrived in Costa Rica. However, some of the sites we are presently investigating in Costa Rica may yield older records that are appropriate for determining the timing of initial maize introduction and spread in Costa Rica. Our ongoing analyses of stable carbon isotope signatures of lake and swamp sediments are providing new proxy data for maize agriculture (Lane *et al.*, in press) that could

predate the first microfossil evidence at some of our sediment coring sites. On the archaeological front, the study of starch grains on stone tools may provide additional data points on early maize in Costa Rica (as they do in Ecuador; Piperno and Holst, 1998). Archaeological research carried out in tandem with multi-proxy paleoecological research may offer the best opportunities for refining the ‘maize story’ in Costa Rica, and for perhaps ultimately determining whether early maize agriculturalists were motivated by maize kernels alone or also (or instead) by fermentable stalks.

Notes:

¹ The symposia were organized by Michael Blake, John Staller, John Hart, and Robert Thompson. Presenters and paper titles are listed under sessions 86, 111, 136, and 161 in SAA (2004a) and abstracts are in SAA (2004b). A book is planned, edited by John Staller, Robert Tykot, and Bruce Benz.

² With domestication, morphological changes are seen that allow differentiation of domesticated plants from their wild forms. For seed crops, for example, such changes include “greater seed size, thinner seed coats, and loss of natural seed dispersal mechanisms such as non-brittle rachis.” (Smith 1994–95: 176).

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