

## EARLY PREHISTORIC MAIZE IN NORTHERN HIGHLAND ECUADOR

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*The discovery of the fully developed Formative sites of Cotocallao (ca. 3750–2350 cal. B.P.) in the Quito Basin and La Chimba (ca. 2650–1700 cal. B.P.) in the northern highlands of Ecuador has raised questions about their cultural antecedents, which have not been resolved despite decades of archaeological work in the region. Paleoenvironmental coring investigations were conducted at Lake San Pablo in northern highland Ecuador to determine the date for the onset of prehistoric maize farming in the temperate highland valleys of this region. The investigations included analysis of lake sediments for pollen, phytoliths, diatoms, and tephra. Maize pollen was identified as early as 4900 cal. B.P., while maize phytoliths dated even earlier, to 6200 or 6600 cal. B.P. These results demonstrate a long history of maize farming in valleys around Lake San Pablo, but in the context of a punctuated record of major and minor volcanic eruptions. It is concluded that early horticultural sites predating Cotocallao and La Chimba must exist, but to find such sites, archaeologists will have to locate and study deeply buried A-horizon soils.*

*El descubrimiento en la sierra del Ecuador de sitios completamente desarrollados del periodo Formativo como Cotocallao (aproximadamente 3750 a 2350 cal. a.P.) y La Chimba (aproximadamente 2650 a 1700 cal. a.P.) en el valle de Quito y en la sierra norte, respectivamente, ha generado preguntas acerca de sus antecedentes culturales. Estas no han sido sin resueltas, aun con décadas de trabajos arqueológicos efectuados en la región. Se realizaron, por lo tanto, investigaciones paleoambientales en el Lago San Pablo de la sierra norte del Ecuador, mediante la extracción de núcleos de sedimentos, para determinar en qué fechas se inició el cultivo prehistórico del maíz en los templados valles de esta región. Las investigaciones de sedimentos incluyeron el análisis de polen, de fitolitos, de diatomeas y de tefra. Se pudo identificar polen antiguo de maíz en contextos fechados en 4900 cal. a.P., mientras que los fitolitos de la misma planta se ubican en fechas más antiguas cercanas al 6200 o 6600 cal. a.P. Estos resultados demuestran una larga historia del cultivo de maíz en los valles que rodean al Lago San Pablo, aunque en el contexto de un registro esporádico de erupciones volcánicas de mayor y menor escala. Se concluye que deben existir sitios hortícolas que preceden a Cotocallao y a La Chimba. Para hallar tales sitios, los arqueólogos tendrán que buscar e investigar horizontes A profundamente enterrados.*

The primary goal of the Lake San Pablo coring study was to determine when agriculture, in particular maize (*Zea mays* L.) cultivation, began in the inter-Andean valleys of northern highland Ecuador (Figure 1). Ethnohistoric studies have shown that maize was the sub-

sistence base of indigenous societies in northwestern South America, including the temperate highland regions (Reichel-Dolmatoff 1961; Salomon 1986). In the northern highlands of Ecuador, the importance of maize during late prehistoric times has also been demonstrated through

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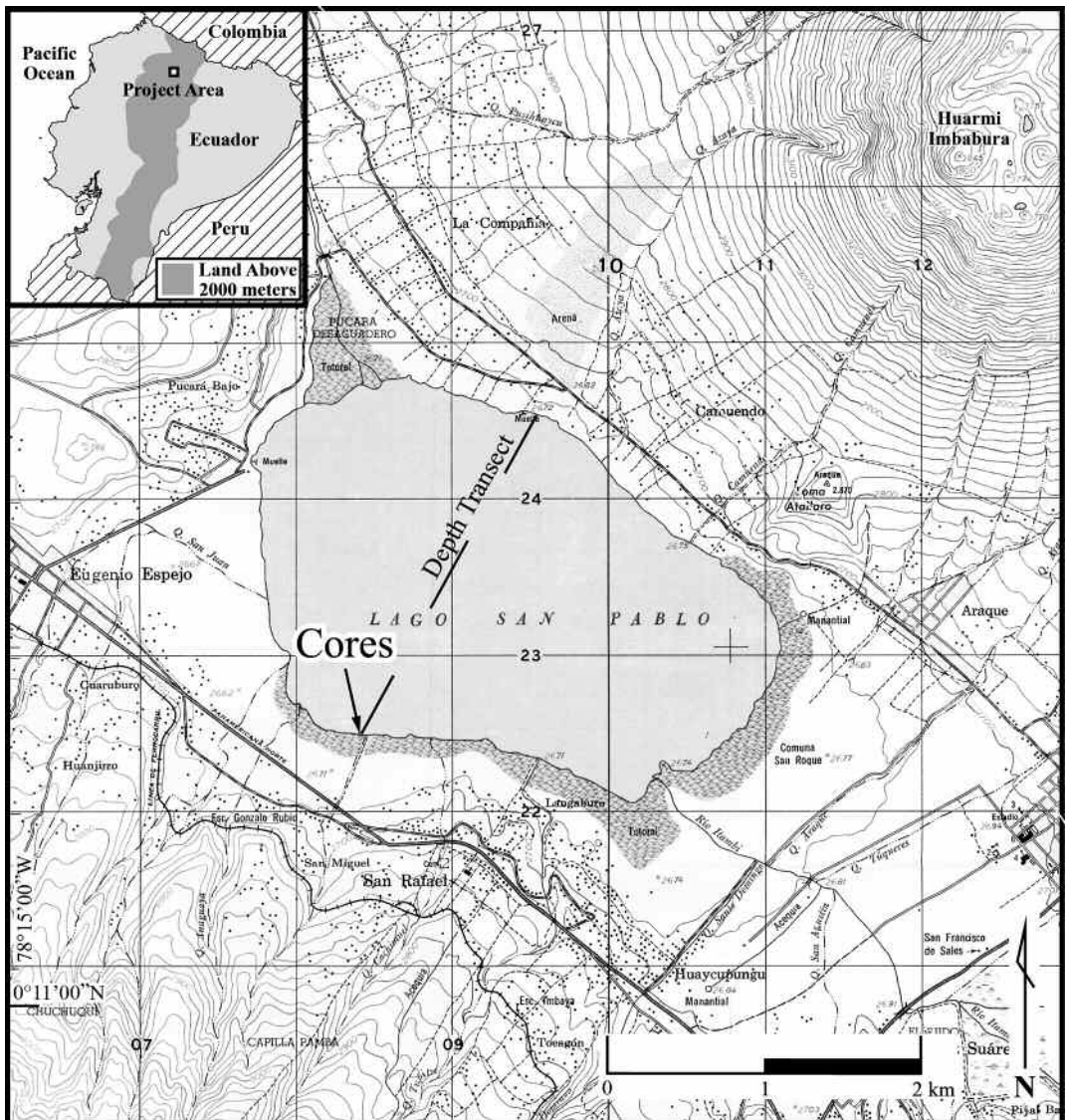


Figure 1. Lake San Pablo, showing location of cores. Note extensive *Scirpus totora* wetland around southern and western margins of the lake. The city of Otavalo is about 3 km northwest of the lake. Portion of 1979 topographic map, Instituto Geográfico Militar, 1:25,000.

stable isotope studies of human bones from archaeological sites (Tykot et al. 2006:193–194; Ubelaker et al. 1995), as well as the abundance of charred maize remains in archaeological middens. Understanding the history of this cultigen, therefore, can potentially provide fundamental insight into northern Andean cultures, including the trajectory of population growth and culture change. Also of interest are the environmental and climatic contexts for early horticulture, especially the frequency and intensity of volcanic

eruptions and their effect on human settlement and horticulture.

Recent genetic, molecular, and morphological data demonstrate that maize was domesticated from the wild grass Balsas teosinte (*Zea mays* ssp. *parviglumis*; Doebley 2004; Matsuoka et al. 2002; van Heerwaarden et al. 2011), which has a narrow distribution in southwestern Mexico centering on the Balsas River Valley. Molecular dating indicates that the transformation (i.e., domestication) of teosinte into *Zea mays* L. occurred

about 9,000 years ago (Doebley 2004:41; Matsuoka et al. 2002:6083). The determination that maize derived from Balsas teosinte poses the difficult question as to why a seemingly unproductive plant with impenetrable seed cases that non-synchronously ripen and shed themselves from a minute ear, would have been subjected to human selective pressure. The details of the domestication process are fascinating, although not yet completely understood (see especially Iltis 2006; Piperno et al. 2009; Piperno et al. 2015).

Archaeological remains, along with starch grain and phytolith microfossil evidence, indicate that domesticated maize was present in the Balsas River Valley by 8990–8610 cal. B.P. (Piperno et al. 2009:5021; Ranere et al. 2009:5017). Following domestication, maize spread from Mexico to Panama by about 7800–7900 cal. B.P., and to coastal Ecuador by about 8000 cal. B.P. (details of dating summarized in Piperno 2011:S458–S459). Maize also reached the Colombian Andes by the eighth millennium (Piperno 2011:S458–S459). Even though the productivity of early maize would have been quite low, it was clearly an important resource for hunter-gatherers transitioning to horticulture. Maize eventually became a dietary staple, or at least an important food resource, for prehistoric peoples inhabiting a variety of environments throughout the New World. Indeed, maize has been called “the grain that civilized the New World” (Culotta 1991:1792).

Much progress has been made during the past several decades in tracing the early geographical spread of *Zea mays* along with the investigation of related issues (Staller et al. 2006). In the same vein, the present study aims to determine the chronology for the onset of maize cultivation in the fertile inter-Andean valleys of northern highland Ecuador, using paleoenvironmental coring at Lake San Pablo in northern highland Ecuador (Figure 1). Located 3 km southeast of the small city of Otavalo at an elevation of 2,670 m asl, this 6.2 km<sup>2</sup> lake has a catchment area of roughly 145 km<sup>2</sup>. Most of this catchment lies below the elevation limit for agriculture (roughly 3,400 m asl) and is used for indigenous fixed-plot horticulture on small land holdings with maize as the dominant crop. The lake reaches a maximum depth of 32 m as determined by a bottom depth transect across the lake (Athens et al. 2015:25).

This region receives an average of 950 mm of rainfall each year, most of it falling between October and April, which is the planting-growing season. As a result of the location of Lake San Pablo only 23 km north of the equator, there is little variation in mean monthly temperatures throughout the year, which range between a low of 13.2°C in June and July and a high of 14.3°C in May (Wernstedt 1961). Frost and freezes during the rainy season are infrequent except at higher elevations (Knapp 1988). Considering these characteristics, Lake San Pablo provided an ideal opportunity to investigate the history of horticulture in this highland area.

### An Archaeological Conundrum

One of the underlying motivations for this study was the disconnect between the horticultural histories of the Ecuadorian coastal lowlands and the western Amazon region, on the one hand, and the highlands, on the other hand. For coastal Ecuador, especially as represented by the Las Vegas sites (Piperno and Pearsall 1998:183–199), the beginning of agriculture dates back to the end of the Pleistocene with domesticated squash (*Cucurbita ecuadorensis*) dating to 11,750–10,220 cal. B.P., gourd and leren (*Lagenaria siceraria* and *Calathea allouia*) appearing between 11,060 and 10,220 cal. B.P., and maize by 8015–7945 cal. B.P. (Piperno 2011:S458; Piperno and Pearsall 1998:186, 197). Maize is also associated with the earliest phase of the subsequent Valdivia culture between about 6500 and 4000 cal. B.P., which is the earliest Early Formative cultural manifestation showing clear evidence for settled village life, a primarily agricultural subsistence base, and the use of pottery. As Pearsall (2002:51) observes, “maize is documented from the beginning of the Valdivia period . . . and with root crop cultivation, supported the florescence and expansion of Valdivia culture” (see also Piperno and Pearsall 1998:244–256; Zarrillo et al. 2008)<sup>1</sup>.

The evidence for maize in the above-cited studies is based on the identification of maize microfossils, including phytoliths, starch grains, and pollen, in well-dated deposits. Although some investigators have been reluctant to accept microfossil data, advances in microfossil identification procedures leave no doubt about the effi-

cacy of such an approach (Holst et al. 2007; Pearsall 2000; Pearsall et al. 2003; Piperno et al. 2007; Piperno et al. 2009:5019–5022). The recent discovery of a 3.1-cm maize husk with partially charred shank dating to 6775–6504 cal. B.P. from the Paredones site of northern coastal Peru now dispels any doubt about the very early presence of maize in northwestern South America (Grobman et al. 2012:1756).

Besides records from the coast, there is also evidence for early farming from the Lake Ayauch<sup>1</sup> core in the Amazon lowlands of eastern Ecuador. Phytoliths indicate that maize was present “minimally” as early as about 6000 cal. B.P. (Piperno 1990:672–673). Because sediments were not available for analysis for 29 cm below the deepest analyzed core samples that produced maize phytoliths, maize may date even earlier.

In contrast to lowland evidence for early agriculture in Ecuador, the earliest archaeological site in the northern highlands is La Chimba, which dates to 2783–2517 (md = median 2650) cal. B.P.,  $2\sigma$ , in its basal deposit (Zarrillo 2012:250; recalibrated with CALIB 7.0.4 and SHCal13 data set). At 3,180 m asl, La Chimba contained abundant evidence of agriculture (Athens 1990, 1995; Pearsall 2003:234). Mention should also be made of limited early archaeological remains at the Im-11 site in Otavalo. Here a small number of obsidian flakes with scattered pieces of charcoal were found in a deeply buried A-horizon soil beneath a thick volcanic ash deposit. The charcoal-dated to 3826–3410 cal. B.P.,  $2\sigma$ , (CALIB 7.0.4 and SHCal13 data set); There was no evidence for agriculture or pottery (Athens 1999:180–183). Although not part of what is generally referred to as the northern highlands, it is of interest that farther south in the Quito basin, substantial Formative-period village deposits and features were documented at the Cotocollao site between about 3750 and 2350 cal. B.P. Like La Chimba, it included a suite of cultivars, such as maize and root crops (Zarrillo 2012:294–295, 310), attesting to horticultural village life by this time in the central highlands.

Given the absence of archaeological evidence to the contrary, it appears that the central and northern highlands were largely ignored by agriculturalists for some 3,000 years or more, despite a flourishing Early Formative culture on the

Ecuadorian coast, and slightly later evidence for horticulture in the western Amazon region. Given the highly fertile inter-Andean valleys in this area, and to some extent an abundance of wild game as indicated by the La Chimba site (Stahl and Athens 2001), this apparent oversight by early horticulturalists is puzzling. Could environmental or adaptive factors have delayed the adoption of agriculture in the central and northern highlands?

Concerning the environment, Hall and Mothes (1999:30, 2008:353–354; also Sauer 1965:269–274) note the presence of hardened *cangagua* deposits throughout the highlands, which formed from volcanic ash during the dry, windy conditions of the Late Pleistocene. The nutrient-poor *cangagua* would have prevented the adoption of agriculture until A-horizon soils, a product of the gradual revegetation of the area, could form sometime after the onset of wetter and warmer conditions of the Holocene. These earliest A-horizon soils would have been repeatedly buried by periodic volcanic ash falls during the Holocene (Hall and Mothes 1994, 2008).

This raises the question: Do buried A-horizon soils exist in the northern Andes of Ecuador that predate present archaeological evidence for agriculture? The previously noted finding of early archaeological remains at the Im-11 site indicates the affirmative, and certainly there are other buried A-horizon soils (Hall and Mothes 1994). It is a question, however, that archaeologists have not explored in this area (but see examples discussed by Isaacson and Zeidler 1999 for the *montaña* region to the west). Given the amount of Holocene volcanism in the central and northern highlands, and the often massive accumulations of sediments in the valleys due to repeated tephra falls and hill-slope erosion, most early sites, if they exist, would be deeply buried.

As to the botanical issue of whether it took time for tropical maize to become adapted to the cooler highland conditions before it could be grown productively, it may be noted that early domesticated maize was documented in a mid-elevation zone (964 m asl) in the Balsas River valley of Mexico (Piperno et al. 2009; Ranere et al. 2009:5015, 5017). Also, maize cobs dating to 6250 cal. B.P. were recovered from Guilá Naquitz Cave in Oaxaca, Mexico, at 1,926 m asl (Piperno and Flannery 2001). Thus, maize was capable of

growing in highland areas from an early time. The temperate inter-Andean valleys of northern highland Ecuador should not have posed any climatic challenge to its cultivation.

### Lake San Pablo Core

Two relatively short cores (Cores 1 and 2) were recovered from a near-shore location at Lake San Pablo in 1989, and two additional cores (Cores 3 and 4) were recovered in 1994 (Figure 1). The earlier cores were limited to depths of 4.99 and 6.15 m below the lake bottom due to the restricted penetrating capability of the Livingston corer that was used. In 1994, a GeoCore was employed (Colinvaux et al. 1999), permitting 11.49 m of penetration below the lake bottom for the later two cores. Deeper penetration, despite vigorous hammering, was not possible due to an abrupt blockage of an undetermined nature. The blockage was perhaps caused by deposits of dome breccias from Huarmi Imbabura on the northeast side of the lake as a result of an eruption about 9250–8420 cal. B.P.,  $2\sigma$  (Le Pennec et al. 2011:126, 131). This event ejected more than 2.8 km<sup>3</sup> of volcanic material, which presumably would have provided enough volume to cover the bottom of the lake.<sup>2</sup>

The upper ca. 1 m of all of the cores consisted of soft, unconsolidated lake muck. Below the muck were lightly banded dark brown humic silt and silt loam sediments interspersed with tephra deposits. The tephra, which are labeled in the Core 4 profile (Figure 2), have a combined thickness of 2.55 m. Two archaeologically important tephra deposits were identified. These are the Pululahua tephra (Tephra C), which is 47 cm thick, and the Cuicocha tephra (Tephra G), which is 15 cm thick.

### Age of the Lake San Pablo Core

Fifteen radiocarbon determinations provide the basis for dating the core sequence (Table 1). Based on these determinations, both linear regression and linear interpolation models were used to determine the ages of all sampling intervals.<sup>3</sup> Error ranges at two standard deviations were also calculated for each regression age sample interval using clam software (Blaauw 2010)

with the SHCal04 (southern hemisphere) calibration curve. A depth-age graph shows the close correspondence between the regression and interpolation models, which is supported by a coefficient of determination of  $r^2 = .9816$ ,  $p < .001$  (Figure 3). The greatest divergence between the models is at the base of the core, with the regression model suggesting a date of 6392–6138 (md 6266) cal. B.P.,  $2\sigma$ , while the interpolation model indicates a date of 6772 cal. B.P. Although it is important to eventually resolve the discrepancy between the two models, especially at the base of the core, it is of minor concern for present purposes.

To check the validity of the core date sequence, the ages of the Pululahua and Cuicocha tephra in the cores (Tephra C and G, respectively, in Figure 2) were compared with ages of these same tephra deposits obtained from geological exposures and archaeological sites. The core dates for the Pululahua tephra are 2290–2196 (md 2244),  $2\sigma$ , and 2299 cal. B.P. (regression and interpolation models, respectively). This compares to a geological date of  $2305 \pm 65$  B.P. (Hall and Mothes 1994:51–53), which calibrates to 2432–2090 (md 2261) cal. B.P.,  $2\sigma$  (CALIB 7.0.4 with SHCal13 data set). Based on a consideration of evidence from several studies, Isaacson and Zeidler (1999:50) accept this as the most reliable of several dates for the Pululahua eruption. Both San Pablo dating models fit this independent dating result well.

As for the Cuicocha tephra, the core dates are 3527–3386 (md 3457),  $2\sigma$ , and 3345 cal. B.P. (regression and interpolation models, respectively), while the independently determined geological dates for this tephra deposit are 3819–2209, 3583–2856, and 3981–3411 cal. B.P.,  $2\sigma$  (CALIB 7.0.4 with SHCal13 data set), which have median ranges of 3014, 3220, and 3696 years, respectively (Athens 1999:178; Hall and Mothes 1994:48–50). In addition, the previously noted buried A-horizon at the Im-11 site, which directly underlies a .75 to 1.0 m thick layer of Cuicocha tephra, produced a date of 3826–3410 (md 3618) cal. B.P.,  $2\sigma$ . This date suggests that the early part of the 3981–3411 cal. B.P. range of the geological date can be discounted. While the median ranges of the two other geological dates appear reasonable for dating the Cuicocha ash, the 3819–2209 (md 3014) cal. B.P.

### Lake San Pablo - Core 4

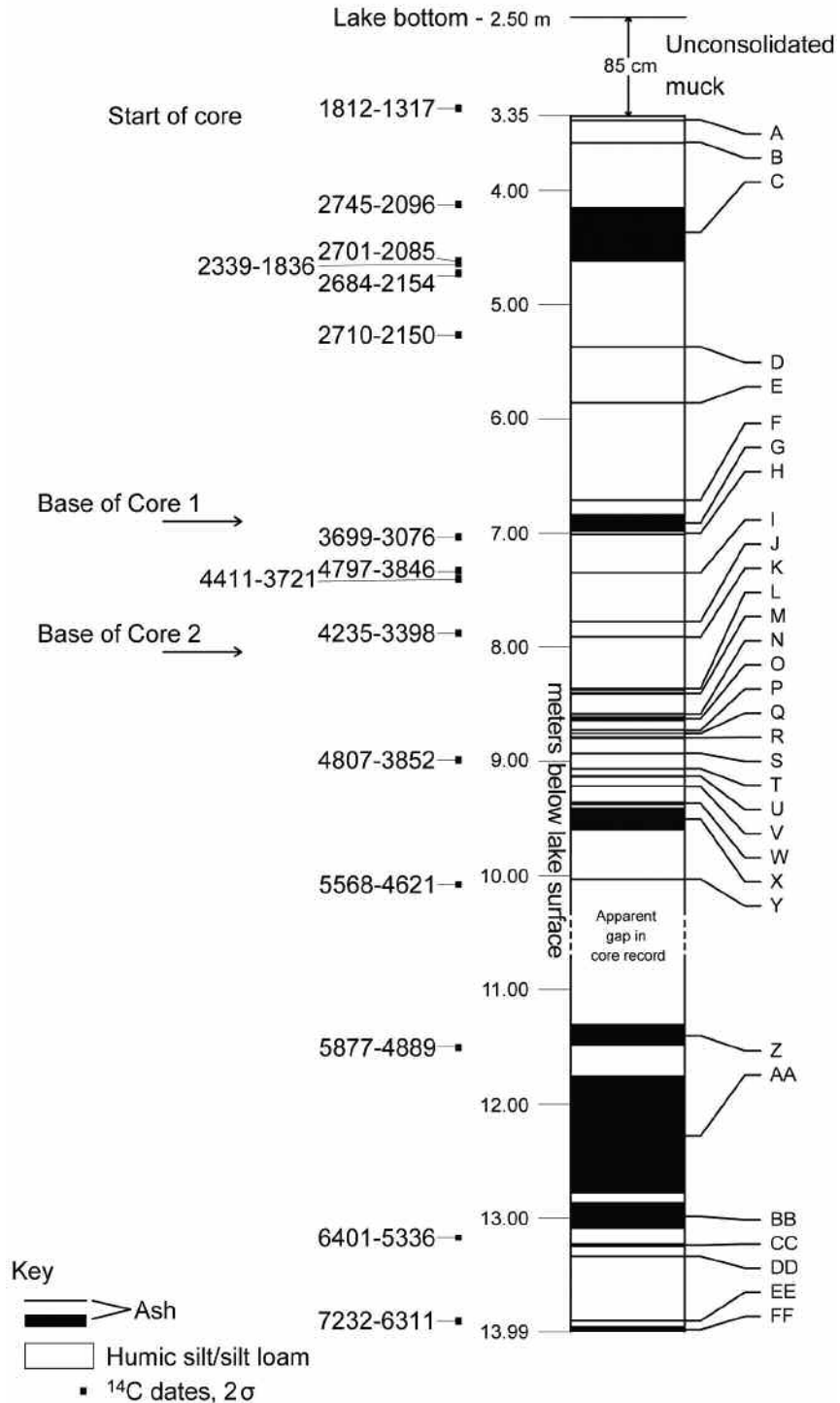


Figure 2. Profile of Core 4, Lake San Pablo. Radiocarbon determinations from Cores 1 and 2 are shown at their respective locations in Core 4. Tephra C and G have been identified as the Pululahua (C) and Cuicocha (G) tephras.

Table 1. Radiocarbon Dating Results, Lake San Pablo, Cores 1, 2, and 4.

Lab. No.	Provenience	Depth minus ash; Cores 1 & 2 corrected to Core 4, cm bs	Weight, Material, g <sup>c</sup>	$\delta^{13}\text{C}$ ‰	Conventional Age B.P.	Calibrated Age B.P., 2 $\sigma^a$	Md 2 $\sigma$ range
Beta-34806 <sup>b</sup>	Core 1, 255-260 cm bs; top Ash C	412	71.8, hs/o	-24.8	2400 ± 130	2745-2096	2421
Beta-36973 <sup>b</sup>	Core 2, 605-609 cm bs	726.3	54.3, hs/o	-25.3	3740 ± 120	4411-3721	4066
Beta-37518 <sup>b</sup>	Core 2, 375-380 cm bs	502.3	70.3, hs/o	-26.5	2370 ± 90	2710-2150	2430
Beta-37519 <sup>b</sup>	Core 2, 520-525 cm bs; below Ash G	641.3	80.0, hs/o	-26.4	3240 ± 120	3699-3076	3388
Beta-37520 <sup>b</sup>	Core 2, 590-595 cm bs	707.1	74.7, hs/o	-24.6	3890 ± 140	4797-3846	4322
Beta-45749 <sup>b</sup>	Core 2, 175-180 cm bs	330.5	75.5, hs/o	-25.5	1690 ± 110	1812-1317	1565
Beta-45750 <sup>b</sup>	Core 2, 290-295 cm bs; base Ash C	416.5	60.1, hs/o	-24.9	2140 ± 110	2339-1836	2088
Beta-69783 <sup>b</sup>	Core 1, 280-285 cm bs; base Ash C	414	49.0, hs/o	-22.9	2340 ± 90	2701-2085	2393
Beta-69784	Core 2, 315-320 cm bs	442.8	87.4, hs/o	-22.8	2360 ± 60	2684-2154	2419
Wk-3959	Core 4, 785-790 cm bs	721.5	53.12, hs/o.	-22.6 ± 2	3550 ± 160	4235-3398	3817
Wk-3960	Core 4, 897-902 cm bs	817.2	50.60, hs/o.	-25.1 ± 2	3900 ± 150	4807-3852-	4330
Wk-3961	Core 4, 1005-1010 cm bs	904	51.23, hs/o	-26.1 ± 2	4470 ± 150	5568-4621	5095
Wk-3962	Core 4, 1148-1153 cm bs	1027	45.52, hs/o.	-22.3 ± 2	4760 ± 170	5877-4889	5383
Wk-3963	Core 4, 1315-1319 cm bs	1069.5	33.05, hs/o	-24.9 ± 2	5200 ± 220	6401-5336	5869
Wk-3964	Core 4, 1387-1392 cm bs	1139.7	41.17, hs/o.	-26.7 ± 2	5950 ± 190	7232-6311	6772
Beta-46746	bottom dredge sediment: 1,000 m east of Puerto Lago, depth of 27 m	--	152.4, hs/o	-27.8	820 ± 60	800-567-	684

<sup>a</sup>Calibrations from CALIB 7.0.4 (Stuiver and Reimer 1993). All calibrations based on SHCal13 data set (Hogg et al. 2013).

<sup>b</sup>Small sample size; carbon weights after pretreatment of samples are as follows: B-34806 = 0.27 g, B-36973 = 0.32 g, B-37518 = 0.43 g, B-37519 = 0.37 g, B-37520 = 0.27 g, B-45749 = 0.32 g, B-45750 = 0.32 g, and B-69783 = 0.5 g; quadruple-normal counting time for all small samples to reduce statistical error.

<sup>c</sup>hs/o = humic silt/silt foam/organics.

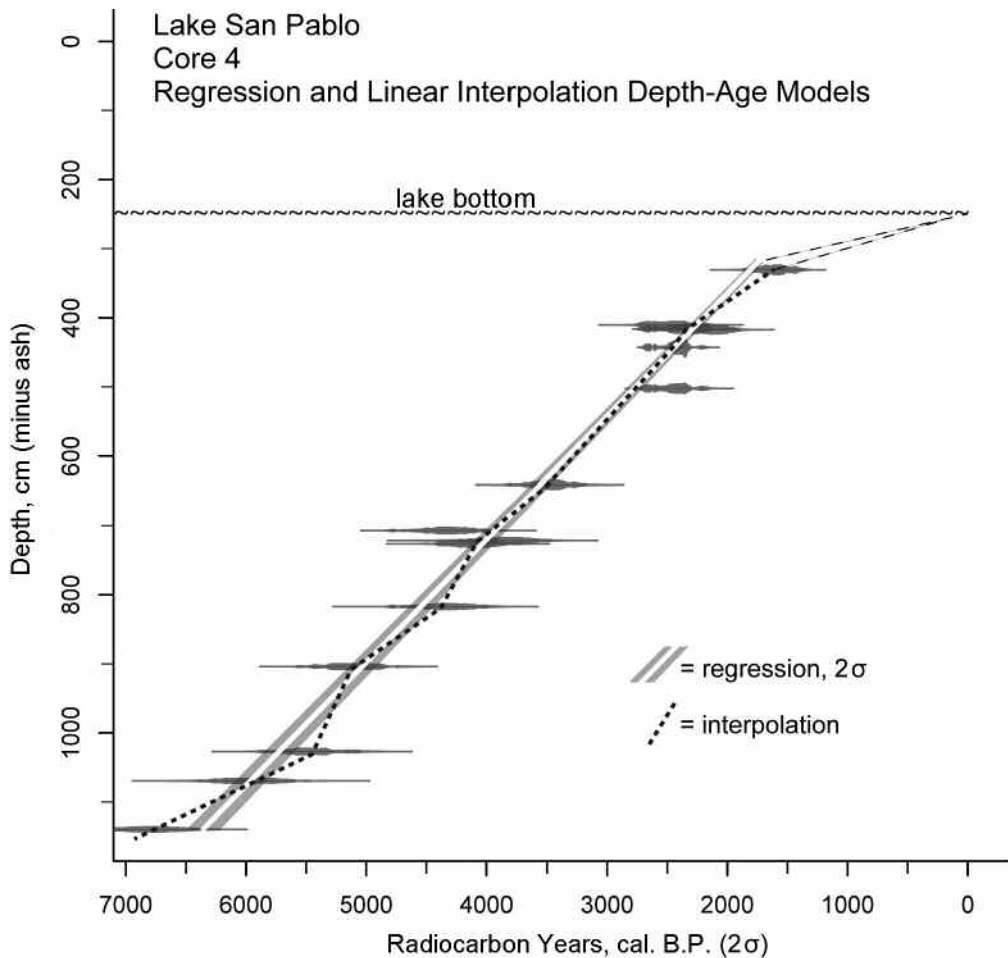


Figure 3. Depth-age graph showing the radiocarbon dating results ( $2\sigma$  calibrated ranges) for Core 4 with dates added from Cores 1 and 2 at the corresponding depths. The diagonal line shows the linear regression model, which begins and ends with the most recent and the oldest dates, respectively. The heavy dashed line overlaying the regression model is the linear interpolation model (see Note 3 for procedure). The thin dashed line at the top of the graphs connects both models with the surface of the bottom of the lake, which has a presumed modern age.

determination should be discounted due to its excessively broad probability range. This leaves the 3583–2856 (md 3220) and 3981–3411 (md 3696) dates as the most reasonable geological estimates for the Cuicocha ash, but with the early part of the 3981–3411 date range discounted, the median for this date drops to about 3600 cal B.P. In sum, the San Pablo Cuicocha dates align fairly well with the geological and archaeological dates, and could well be more accurate. The independent dating of both tephra deposits indicates that the San Pablo core chronology can be used with confidence.<sup>4</sup>

### Diatom Analysis

Fifty-four diatom taxa were identified in the 32 samples analyzed throughout Core 4. The diatom assemblage indicates the presence of fresh and nutrient-rich waters in Lake Pablo until more recent times, with moderate to high alkaline conditions throughout most of the history of the lake (complete documentation of diatom study in Athens et al. 2015). The two dominant diatom taxa in the core, *Cocconeis placentula* and *Nitzschia amphibia*, frequently occur on submerged vegetation (epiphytic) or sediment (epipellic) in modern



aquatic environments (Patrick and Reimer 1966). Furthermore, the relatively high frequencies of *Epithemia adnata*, *E. argus*, *Cocconeis pediculus*, and *Rhopalodia gibba* throughout the core also suggest the presence of submerged aquatic macrophytes in a highly alkaline environment. In sum, given that nearly 90 percent of the diatom taxa throughout the core included attached forms (epiphyton/epipelon), there would have been an extensive aquatic macrophyte stand in the shallow areas of the lake throughout the core record.

Another pattern noted in the diatom assemblage concerns the variable abundances of *C. placentula* and *N. amphibia* through time, which suggest changes in water levels, perhaps due to fluctuating rainfall regimes. They further imply a deeper water column in the lake starting around 1900 or 1700 cal. B.P. (regression or interpolation models, respectively) since proportions of both of these diatom taxa significantly declined after that time. This change also coincides with the replacement of *Aulacoseira granulata* by *A. ambigua*, further supporting the notion of an increase in water depth after about 1900 or 1700 cal. B.P. Also, *A. ambigua* predominates in more transparent (i.e., high-light) lake systems with reduced nutrients (Bradbury and Dieterich-Rurup 1993). The substantial drop in diatom density after about 1900 or 1700 cal. B.P. also reflects both a deeper water column and reduced nutrients.

### Pollen Analysis

Thirty-one pollen samples were processed from Core 4 from the surface to the deepest sampled interval at 1374–1380 cm bs (6067–6319 [md 6194] cal. B.P. regression; 6609 cal. B.P. interpolation). Of these, 23 samples involved full pollen analysis, while 11 were sieved to enhance *Zea* recovery (3 were both sieved and fully analyzed). Pollen recovery was modest for all intervals, possibly limiting the identification of rarer types. Full details of the pollen analysis are provided in Athens et al. (2015).

Pollen zones were delimited using CONISS, a program for stratigraphically constrained cluster analysis (Grimm 1987). While five zones were identified, the documented changes were relatively minor throughout the sequence. The biggest change was in the uppermost SP-1 zone, which

was based on only two samples, one at the top, dating to the present, and another at the bottom, dating to about 1883–1804 (md 1845) or 1665 cal. B.P. (regression and interpolation models, respectively). Pollen data from this zone reflect an expansion of the wetlands around the lake with *Alnus*, *Cyperus*, and *Scirpus* increasing at the base of this zone. The tree, *Alnus*, and the two sedge genera thrive in constantly damp or water-saturated soils.

Pollen zones below SP-1 (SP-2 through SP-5) do not provide evidence for significant changes to the vegetation within the Lake San Pablo watershed; instead, there are only minor shifts in taxa frequencies. The overall picture is one of a disturbed landscape. Grass is the dominant pollen type, although there are other significant disturbance indicators, including two Asteraceae types, three Caryophyllaceae types, the Chenopodium type, and *Plantago*. Interestingly, the occurrence of grass (Poaceae) pollen is highest in the earliest part of the core, after which it begins a gradual and somewhat punctuated decline. Its high value (both absolute counts and percentages within sampling intervals) at the base of the core could reflect the time lag in the formation of Holocene soils on top of a *cangagua* cap after the Pleistocene (Hall and Mothes 1999:30), or, alternatively, recovery of the landscape from the Huarmi Imbabura eruption. Curiously, *Alnus* pollen is the dominant tree pollen in the basal pollen interval and also in SP-1 at the top of the core; otherwise tree and shrub types are rather minor contributors to the pollen assemblage (though *Hedyosmum* and Urticaceae do have a solid secondary presence throughout the core).

Of particular interest is the record of maize (*Zea mays* L.) in the pollen samples of Core 4 (Table 2; Figure 4). The San Pablo pollen study confirmed *Zea mays* pollen to a depth of 987–995 cm, dating to 4974–4776 (md 4875) or 4963 cal. B.P. (regression and interpolation models, respectively). Maize pollen also was found in all intervals above this zone, increasing significantly in frequency in the middle and upper portions of the core.<sup>5</sup>

The size of the Lake San Pablo maize pollen is of interest, and measurement data are provided in Table 3. A statistical analysis of size measurements of maize pollen grains using the Kruskal-Wallis

Table 2. Recovery of *Zea mays* Pollen and Phytoliths, Core 4, Lake San Pablo.

Core, depth interval, cm	<i>Zea</i> pollen <sup>a</sup> grains, no.	<i>Zea</i> phytoliths; <sup>a, b</sup> P = present	Regression date, cal. B.P., 2s (median)	Interpolated date cal. B.P., median
SP-4,surface	1	NA	-	0
SP-4,338-346	2	NA	1804-1883 (1845)	1665
SP-4,388-396	18	NA	2071-2160 (2116)	1771
SP-4,490-498	13	NA	2370-2471 (2421)	2435
SP-4,550-558	25	NA	2691-2804 (2748)	2721
SP-4,590-598	14	NA	2903-3024 (2964)	2911
SP-4,641-649	24	NA	3180-3313 (3246)	3159
SP-4,700-711	30	NA	3430-3572 (3501)	3388
SP-4,746-753	19	NA	3663-3815 (3740)	3733
SP-4,792-796	NA	P (df, 2c, 6b, 1V1)	3902-4064 (3983)	4071
SP-4,796-805	19	NA	3940-4103 (4022)	4093
SP-4,811-815	NA	P (1b)	4005-4171 (4089)	4126
SP-4,819-825	7	NA	4059-4228 (4144)	4155
SP-4,823-825	NA	P (df, 2c, 1b, 4V1)	4065-4233 (4149)	4158
SP-4,835-837	3	NA	4135-4307 (4221)	4196
SP-4,846-848	NA	P (df, 1V1)	4168-4341 (4255)	4213
SP-4,848-853.5	10	NA	4173-4346 (4260)	4218
SP-4,862.5-867	6	NA	4227-4403 (4316)	4247
SP-4,867-869	NA	P (df)	4260-4437 (4349)	4263
SP-4,886-890	NA	P (df)	4352-4533 (4443)	4312
SP-4,890-895	2	NA	4363-4544 (4454)	4319
SP-4,961-965	NA	P (1b, 3V1)	4635-4827 (4731)	4734
SP-4,965-971	2	NA	4651-4844 (4748)	4760
SP-4,973-977	2	NA	4689-4883 (4787)	4822
SP-4,987-995	1	NA	4776-4974 (4875)	4963
SP-4,1102-1104	NA	P (1V1)	5394-5618 (5507)	5327
SP-4,1311-1315	NA	P (2c, 1V1)	5752-5991 (5872)	5863
SP-4,1331-1332	NA	P (1b, 2V1)	5844-6087 (5967)	6075
SP-4,1348-1350	NA	P (2c, 2b)	5937-6183 (6061)	6300
SP-4,1362-1366	NA	P (df, 1V1)	6018-6268 (6144)	6493
SP-4,1372-1374	NA	P (df, 1V1)	6067-6319 (6194)	6609

<sup>a</sup>NA = not analyzed (each interval was analyzed for either pollen or phytoliths, but not both). Twelve pollen samples were analyzed below the 987-995 cm interval, but no maize pollen was found.

<sup>b</sup>Basis of maize phytolith identification: df, discriminant function; c, cob bodies; b, large bilobates; V1, large or extra-large Variant 1 crosses. Counts given for c, b, V1.

rank-sum test with a Wilcoxon rank-sum test for pairwise comparisons demonstrates a significant increase in grain sizes after about 2471–2370 (md 2421) or 2435 cal. B.P. (regression and interpolation models, respectively), the date of the 490–498 cm core interval (Table 4; Figure 5). Before that time, pollen grain sizes on average were rather small, but by about 2400 cal. B.P. they began to reach the lower range of modern and late historic pollen sizes (comparative information from Holst et al. 2007:17608). Although speculative, this shift in pollen grain size at Lake San Pablo may be related to the development or introduction of new and possibly more productive races of maize. For example, in the northern Andes this could represent a shift from a mostly small-cobbed race of maize

to a mostly large-kernelled maize, as attested by carbonized maize kernels found in archaeological sites (Pearsall and Piperno 1990:334). It is therefore notable that a small-cobbed variety of maize, probably a popcorn, was common at the La Chimba site, dating between about 2650 and 1700 cal. B.P. (Athens 1990, 1995; Pearsall 2003; Zarrillo 2012:250). The larger-kernelled maize may represent the introduction of flour corn to the northern highlands, which is suggested by the common presence of *manos* and *metates* in later archaeological sites in the Lake San Pablo area (Athens, personal observations). This interpretation can be tested by comparing pollen grain sizes of popcorns still grown in the Lake San Pablo area today with flour maize varieties.



Figure 4. *Zea mays* pollen, from Lake San Pablo Core 2, 5.25–5.30 m, 14 cm below the Cuicocha ash. Pollen grain is 90  $\mu\text{m}$  at widest point. Photomicrograph by Roger Byrne, 1992.

### Phytolith Analysis

Twenty-three phytolith samples were analyzed from depths of 792 to 1,382 cm below the lake surface (3983 to 6238 cal. B.P., regression; 4071 to 6712 cal. B.P., interpolation) in Core 4. Although pollen analysis was undertaken for the full San Pablo sequence, only the lower part of the core was analyzed for phytoliths. The presence of maize was already well established for the upper part of the core based on pollen analyses, making the secure determination of its presence in the lower core a priority.

*Zea mays* phytoliths were present in 13 of the analyzed core intervals, with absences tending to be more common in the middle intervals (Table 2; Figures 6 and 7). The identification of *Zea mays* was based on a combination of four analytical approaches, providing multiple lines of evidence in support of the correct identification of maize phytoliths. First, discriminant function (DF) formulae were applied to predict whether maize or wild panicoid grasses contributed the cross body assemblages observed in the strata. Variables include: mean size Variant 1 crosses, mean size Variant 5/6 crosses, and proportion Variant 1 crosses of all crosses present (Pearsall 2000).

Maize is predicted when the value of the maize prediction formula is greater than that of the wild prediction formula. The DF was used for several cases for which single Variant 1 or Variant 5/6 crosses were present (i.e., mean value could not be calculated). Second, selected strata of the core were reexamined for the presence of ruffle top rondels or elongate rondels. These two maize cob types do not overlap with festucoid rondel assemblages (Logan 2006; Logan et al. 2012). Third, during reexamination of the selected strata, a number of large bilobates were observed. While no formal maize identification method has been developed based on these forms, large bilobates are not produced in festucoid grasses and are common in some varieties of maize. Finally, presence of large (16  $\mu\text{m}$  or larger) or extra-large (> 20  $\mu\text{m}$ ) Variant 1 crosses was noted. Large Variant 1 crosses are much more common in maize than in wild grasses, and extra-large Variant 1 crosses occur only in maize. This approach allowed for the evaluation of strata that lacked Variant 5/6 crosses (i.e., DF analysis could not be applied).

The earliest occurrence of maize phytoliths was observed in the 1,372–1,374 cm interval (the second deepest sample), dating to 6319–6067 (md 6194) or 6609 cal. B.P. (regression and interpola-



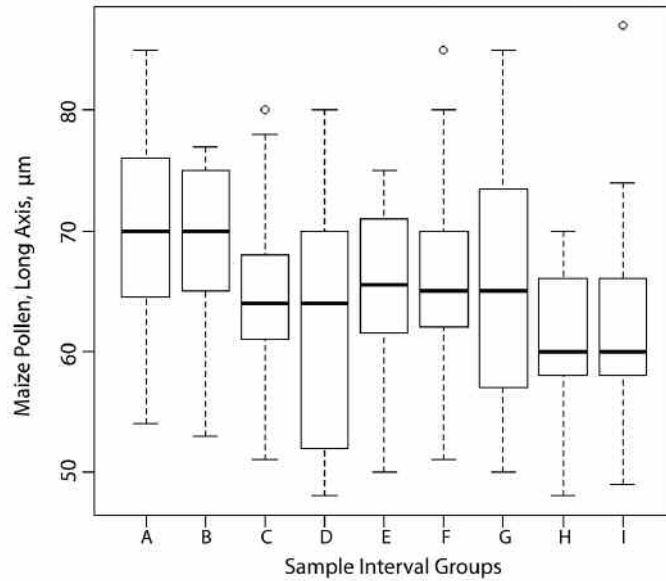


Figure 5. Maize pollen size boxplots organized by sample depth. Note that intervals with small counts of maize pollen measurements have been aggregated into larger sample interval groups to minimize possible small sample size biases (see Table 4 heading for intervals). Outlier measurements (any value outside 1.5 times the interquartile range) are represented by small circles.

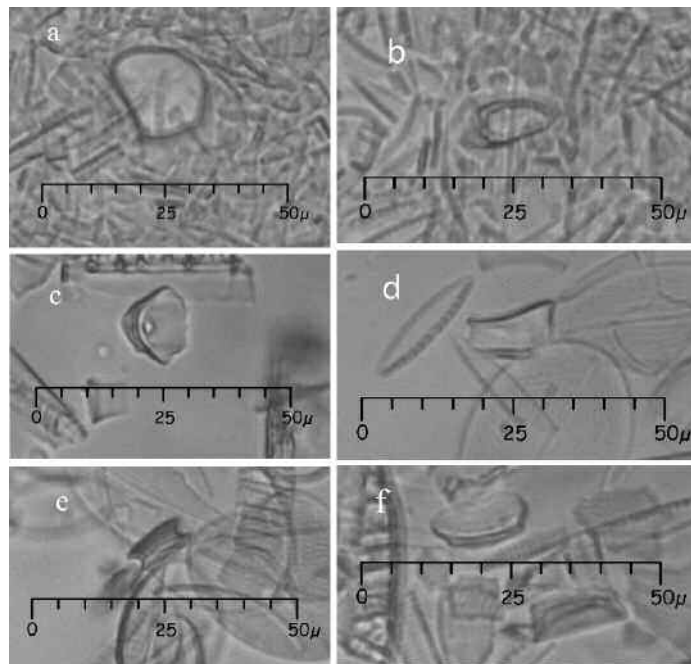


Figure 6. Phytoliths of *Zea mays* cob bodies from Core 4, Lake San Pablo. Z: Zeiss microscope image number; ps: phyto soil number (i.e., MU processing number). (a) Z4073, ps1491, 1348-1350 cm bs, ruffle top rondel; (b) Z4076, ps1491, 1348-1350 cm bs, ruffle top rondel; (c) Z4179, ps1477, 823-825 cm bs, ruffle top rondel; (d) Z4090, ps1489, 1311-1315 cm bs, elongate rondel; (e) Z4091, ps1489, 1311-1315 cm bs, elongate rondel; (f) Z4137, ps1220, 792-796 cm bs, elongate rondels (2).

Table 4. Wilcoxon Rank-Sum Test for Multiple Comparisons of Pollen Grain Measurements.

Core 4 sample intervals (cm)	338-346, 388-396	490-498	550-558	590-598	641-649	700-711	746-753	796-805, 819-825	835-837 to 987-995 (7 intervals)
	A	B	C	D	E	F	G	H	I
B	1.000								
C	0.888	1.000							
D	1.000	1.000	1.000						
E	1.000	1.000	1.000	1.000					
F	1.000	1.000	1.000	1.000	1.000				
G	1.000	1.000	1.000	1.000	1.000	1.000			
H	0.018*	0.095*	1.000	1.000	0.858	0.805	1.000		
I	0.105	0.386	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Note: Values indicate statistical probability that the samples are the same. \* = Significantly different samples at the 90% confidence level.

tion models, respectively). The phytolith findings suggest a significantly earlier occurrence of maize than obtained from the pollen data, extending its chronology back ca. 1,300 or 1,650 years.

The differing times for the initial appearance of maize as documented by pollen and phytoliths (~4900 cal. BP for pollen, and ~6200 or ~6600 cal. BP for phytoliths) may be due to the lower frequency of occurrence of maize pollen in the deeper core intervals. This could reflect limited horticultural use of the land near the lakeshore during the earlier part of the sequence. Also, the restricted range of maize pollen dispersal is well documented (Lane et al. 2010; Paterniani and Stout 1974; Pleasants et al. 2001; Raynor et al. 1972), resulting in underrepresentation of maize pollen even from fields located next to lakes. The wetland vegetation along the south margin of Lake San Pablo, which pollen findings indicate was significant beginning with the earliest intervals (but not as extensive as during the latest intervals), would have further restricted maize pollen dispersal (Lane et al. 2010). Less information is available concerning maize phytolith dispersal, but it is presumed that its much smaller size, coupled with a predominantly fluvial mode of deposition, probably accounts for somewhat better representation in the lake, although recovery of maize phytoliths was still quite sparse in the San Pablo core.

The phytolith assemblage did not disclose the presence of other economic plants.

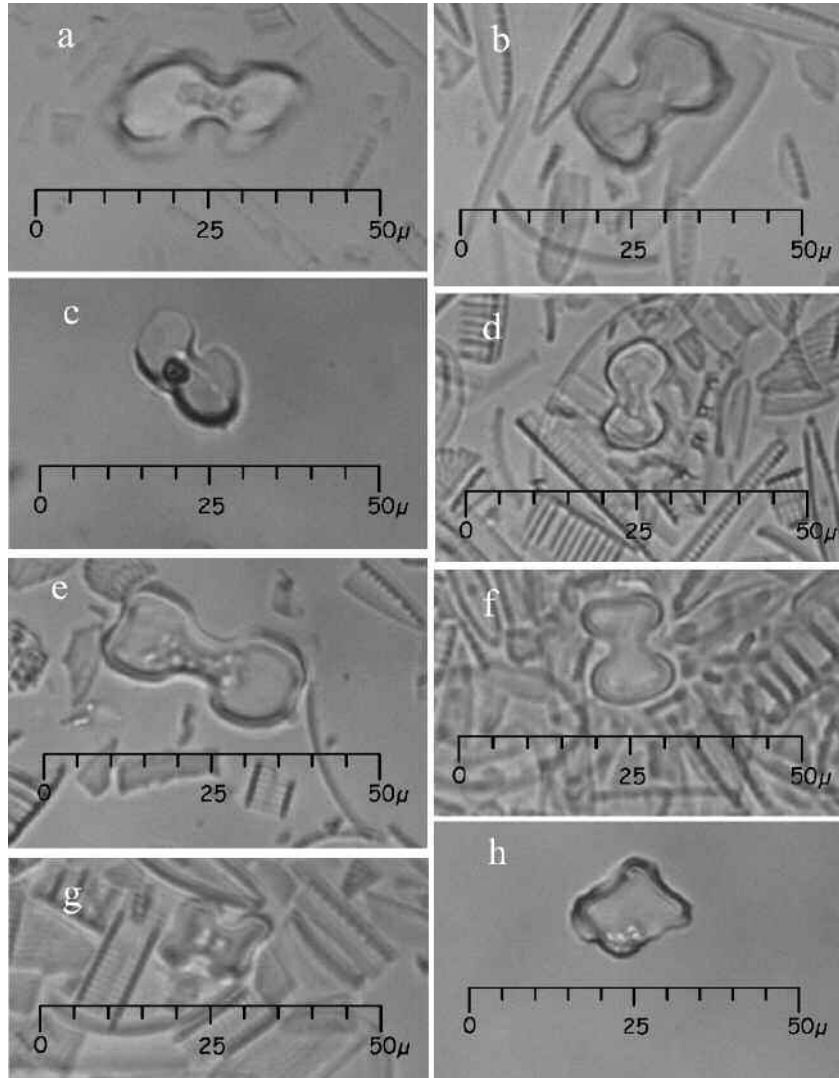
Phytoliths of wetland plants are well represented in most core intervals, including *Scirpus*, *Cyperus*, and *Carex*. This result supports the

pollen evidence, besides confirming the relatively shallow depth of the lake at the location of the core, including even the deeper sample intervals.

In terms of the overall vegetation pattern in the Lake San Pablo watershed, the phytolith assemblage suggests a slight change over time in the relative proportion of arboreal types to disturbance indicators, with the latter becoming somewhat more prevalent in later times. Although the change is minor, it appears that cultivated lands were gradually expanding or that cultivation intensified.

## Conclusion

The Lake San Pablo core record demonstrates maize cultivation in the northern highlands of Ecuador taking place since about 6200 or 6600 cal. BP, confirming that the northern Ecuadorian highlands (south of the Chota-Mira River) very much took part in the early Holocene transition to a farming way of life. A similar pattern is also found in the mid-elevation zones of the Colombian highlands (Dickau et al. 2015; Piperno 2011; Santos et al. 2015), although more complete documentation for the early maize sites would be desirable. While the findings from Ecuador and Colombia are based on microfossil evidence, including pollen, phytoliths, and starches, there are now well-dated macro-remains of maize dating as early as 6775–6504 cal. B.P. from the north coast of Peru (Grobman et al. 2012). Other investigations in north coastal Peru suggest that maize cultivation had become widespread after about 5000 cal. B.P. (Haas et al. 2013) in keeping with a similar but earlier pattern observed for the



**Figure 7.** Phytoliths of *Zea mays* leaf bodies from Core 4, Lake San Pablo. Z: Zeiss microscope image number; ps: phyto soil number (i.e., MU processing number). (a) Z4109, ps1491, 1348-1350 cm bs, bilobate short cell; (b) Z4113, ps1491, 1348-1350 cm bs, bilobate short cell; (c) Z4128, ps1214, 961-965 cm bs, bilobate short cell; (d) Z4153, ps1220, 792-796 cm bs, bilobate short cell; (e) Z4136, ps1220, 792-796 cm bs, bilobate short cell; (f) Z4168, ps1476, 811-815 cm bs, bilobate short cell; (g) Z4157, ps1220, 792-796 cm bs, cross short cell; (h) Z4170, ps1476, 811-815 cm bs, cross short cell.

Early Formative coastal sites in Ecuador. With these early coastal dates, located roughly 3,300 to 4,000 km from the place of origin of maize in Mexico, there can be little question about the compelling nature of maize even at an early point in time when it was not nearly as productive as later varieties.

The absence of archaeological sites in the northern highland valleys dating to the middle and early Holocene can be attributed to their deep

burial by tephra deposits as a result of frequent volcanic eruptions that occurred throughout the Holocene. The San Pablo record abundantly demonstrates the frequency and intensity of regional volcanism, and geologists have extended this record into the Late Pleistocene. Burial of sites in the fertile valleys by tephra deposits was no doubt aided by the ongoing process of slope erosion, which would have been exacerbated during the rainy season each winter.

Considering the San Pablo findings, it is clear that archaeologists must look for the corresponding archaeological remains of these early farmers in deeply buried A-horizon soils. It no longer can be assumed that sites are not present, or that La Chimba-age or Cotocollao-age sites suddenly appeared out of nowhere in Imbabura and Pichincha Provinces at ca. 2650 cal. B.P. (La Chimba) or 3750 cal. B.P. (Cotocollao) to begin a well-developed agrarian way of life as the first people to make use of the highly fertile volcanic soils of these regions.

The San Pablo results suggest some degree of dependence on horticulture, including maize, in the northern highlands during the middle Holocene. It should not be concluded, however, that archaeological sites of this time would have necessarily incorporated the most diagnostic cultural attribute of the Early Formative Valdivia and Machalilla cultures of coastal Ecuador, which is that of abundant and finely made pottery (Lathrap et al. 1975). Numerous archaeological studies in the upland Middle Cauca region of Colombia show that pottery does not appear until about 3600 B.P. (Dickau et al. 2015:44; specific dates are not provided). Nevertheless, as Dickau et al. (2015:52) note, “By 7080 ± 50 B.P. [7966–7739 cal. B.P., 2σ, CALIB 7.0.4, SHCal13 data set], people were clearly engaged in cultivation practices, growing maize (*Z. mays*), along with manioc, yams, and beans (Aceituno and Lalinde 2011; Aceituno and Loaiza 2014).” It may well turn out that middle Holocene archaeological sites in the northern Ecuadorian highlands were preceramic until a similarly late time frame.

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### Notes

1. While this paper was in press, Pagán-Jiménez et al. (2015) published on findings of maize starches on stone tools dating to 8078–7959 cal. B.P. ( $2\sigma$ ) in the Cubilán area of Ecuador at 3,170 m asl. These investigations establish the apparent contemporaneous use of maize in the southern highlands with the coastal lowlands.

2. Le Pennec et al. (2011:126–127) also document the dome collapse of Huarmi Imbabura on its southwest flank at 31,190–34,450 cal. B.P.,  $2\sigma$ , which produced a debris avalanche and blast breccias that can be traced over a broad area (at least 100 km<sup>2</sup>), extending to the lower slopes of Mt. Mojanda southwest of Lake San Pablo. Undoubtedly these pyroclastic breccias underlie Lake San Pablo. It would be of paleoenvironmental interest to determine whether lake deposits are preserved between this older debris flow and the 9250–8420 cal. B.P.,  $2\sigma$ , debris flow that presumably prevented deeper penetration of the cores.

3. Median points of date ranges as used in linear interpolation depth-age models of cores can provide misleading age approximations (Telford et al. 2004). This potential problem can be circumvented by using *clam* software (Blaauw 2010), which calculates uncertainties associated with depth intervals of interest. Various types of models can be generated by *clam*, depending on the particular characteristics of the core and date distribution. For the San Pablo dates, the linear regression model seemed most suitable given the obvious close linear alignment of the dates when graphed. The advantage of such a modeling procedure is that it is fully transparent, provides error estimates for each sampling interval, and is completely objective. While it can mask changes in the depth-age relationship if there happen to be small changes in the rate of sedimentation, this possibility is a minor concern given the broad error ranges of the San Pablo radiocarbon dates. Notably, no assumptions had to be made as to which dates might be in error.

For the linear interpolation model, it was necessary to make several assumptions because of dating inconsistencies. One of these concerned the date for the Pululahua tephra. There were three radiocarbon determinations immediately above and below the ash (Beta-34806, -45750, and -69783). Two had similar but older ranges, but one was significantly younger. A decision was made to use an average of these dates (2299 cal. B.P.). Also, two determinations, one seemingly too young (Beta-37518) and the other seemingly too old (Beta-37520), were eliminated from the linear interpolation model to avoid chronological inversions.

While both models are statistically highly correlated, the regression model has the advantage of defining error ranges

for each sampling interval. Nevertheless, it appears that the linear interpolation model could possibly be a better estimator of age for the bottom 70 cm of the core.

4. There has been a concern with radiocarbon dating lake sediments in either limestone or volcanically active regions due to the possible presence of <sup>14</sup>C-depleted carbon entering the lake, and then being metabolized by lake organisms, especially algae, which then becomes part of the organic remains in the sediment (Byrne and Horn 1989:185–186; Deevey et al. 1954; Rieth and Athens 2013:17–18; Sheppard et al. 1979). The result is that the radiocarbon determinations will be significantly older than their true ages. To evaluate this possibility at Lake San Pablo, a LaMotte bottom dredge sediment sample, which should date to a modern or recent historic time frame, was recovered from the middle of the lake and 27 m below the water's surface. While the sample would have incorporated sediment to a depth of about 5 cm (Lane et al. 2010:179), making an unknown fraction of the sample somewhat older than the expected modern time frame, the resulting date of 800–567 (md 684) cal. B.P.,  $2\sigma$  (Table 1), does point to a possible problem with <sup>14</sup>C-depleted carbon in the lake. The agreement of the independently dated tephtras, Pululahua and Cuicocha, with the core dates for these same tephtras might seem to contradict this finding. But the dated core samples, consisting of organic-rich humic silt and silt loam, and often having a fine peaty and somewhat fibrous texture, almost certainly were substantially composed of the remains of emergent aquatic plant debris consisting mainly of *Scirpus totora* and *Cyperus* sp, which currently form a dense floating mat along the southern shore of the lake (Figure 1). As noted by MacDonald et al. (1991:1153), these plants “obtain their photosynthetic CO<sub>2</sub> from the atmosphere and have provided reliable radiocarbon dates.” Both the pollen and phytolith records confirm the significance of emergent aquatics throughout the core record (including *Carex*, a type of sedge, in the phytolith findings), and the diatom study attests to a shallow water column, although variable at times. For this reason, if there is any effect from <sup>14</sup>C-depleted carbon on the Lake San Pablo radiocarbon record, it is almost certainly small and of minor consequence. Had the core been taken in deeper water where emergent aquatics do not grow, it is possible that <sup>14</sup>C-depleted carbon would have been more of an issue.

5. A special effort was made to identify and confirm the presence of the earlier maize pollen because the grain size of putative maize pollen in the Lake San Pablo core in the earlier intervals tended to be smaller than modern or later prehistoric maize pollen. It was also necessary to be certain that it was not present in the deeper analyzed intervals. In this respect, the assistance of Enrique Moreno, a palynologist at the Smithsonian Tropical Research Institute, is particularly appreciated due to his research experience with maize pollen identification. Although he has no responsibility for this presentation, the results herein conform to his observations that maize pollen is absent below 987–995 cm interval in Core 4.