Phytolith Evidence for a Grass-Dominated Prairie Landscape at Quiroste Valley on the Central Coast of California

Rand R. Evett
Division of Ecosystem Science, Department of Environmental Science, Policy, and Management, University of California, Berkeley, CA 94720 (revett@sonic.net)

Rob Q. Cuthrell
Department of Anthropology, University of California, Berkeley, CA 94720 (rcuthrell@berkeley.edu)

Abstract Phytoliths are microscopic particles of silica formed in many plant taxa, particularly grasses. To better understand the extent of grass-dominated vegetation and the utilization of grasses by indigenous peoples in Quiroste Valley on the central coast of California, we used phytolith analysis of soil columns collected on the valley floor and columns collected within late Holocene archaeological site CA-SMA-113, located within the valley. Surface soil phytolith content in all soil columns is greater than 0.75 percent, much higher than normal for grassland in California. High phytolith content indicates extensive grass cover in the valley for several hundred to thousands of years, and cannot be explained by historical land use practices. The phytolith content–depth relationship of non-midden columns within the archaeological site mirrors the pattern observed for off-site soils; midden columns exhibit high variability at very small scales and consistently greater phytolith content below 35 cm than soils. Phytolith content of excavated ash features was highly variable; several features exhibited very high grass phytolith content. Phytolith evidence suggests there was considerable indigenous management of vegetation in Quiroste Valley; frequent burning was likely required to maintain grass-dominated grassland. Phytolith analysis is a useful tool to routinely include in archaeological investigations in California.

Resumen Los fitolitos son partículas microscópicas de sílice formadas en muchos taxones de plantas, particularmente en las gramínea. Para entender

California Archaeology, Volume 5, Number 2, December 2013, pp. 319–335.
Copyright © 2013 Society for California Archaeology. All rights reserved

mejor el alcance de la vegetación dominada por los pastos y la utilización de estas plantas por los pueblos indígenas en el valle Quiroste de la costa central de California, utilizamos el análisis de fitolitos de columnas de suelo recogidas desde el piso del valle y muestras de columna recogidas dentro del sitio arqueológico del Holoceno Tardío CA-SMA-113 que está ubicada en el valle. El contenido de fitolitos del suelo muestreado desde la superficie en todas las columnas de suelo es mayor de 0.75%, mucho más que lo normal para los prados en California. Alto contenido de fitolitos indica que una capa de hierba extensa existió en el valle por varios cientos hasta miles de años, y es inexplicable por las prácticas históricas de utilización de la tierra. La relación entre contenido de fitolitos y profundidad de columnas que no fueron recogidas desde los basureros dentro del sitio arqueológico refleja el patrón observado en suelos fuera de sitio; columnas de basurero exhiben gran variabilidad a pequeña escala y consistentemente mayor contenido de fitolitos debajo de 35 cm que los suelos. El contenido de fitolitos de los rasgos de ceniza excavados fue muy variable; varios rasgos exhibieron alto contenido de fitolitos gramínea. La evidencia de fitolitos sugiere que hubo gestión considerable de la vegetación en el valle Quiroste, la quema frecuente fue más probable necesario para mantener las praderas dominadas por los pastos. Análisis de fitolitos es una herramienta útil para incluir en una manera rutinaria en las investigaciones arqueológicas en California.

There has been considerable debate regarding the extent of hunter-gatherer management of local environments in California during late Holocene and historic times. Recent research, centered on the 89-ha Quiroste Valley State Cultural Preserve in Año Nuevo State Park on the central coast of California, has focused on examining management practices, particularly anthropogenic burning, that indigenous populations may have used to enhance the productivity of non-domesticated plants (Lightfoot et al. 2013). Within the multidisciplinary framework of the eco-archaeological approach guiding these investigations, various types of ecological and archaeological data have been collected from both on- and off-site contexts (Cuthrell et al. 2012). Phytolith analysis, a microbotanical technique extensively utilized in archaeology and paleoecology, has been an important component of this effort.

Phytoliths are microscopic particles of amorphous silica that are formed in and between plant cells and are deposited in the soil when the plant dies (Piperno 2006). All grasses produce large quantities of phytoliths, typically comprising 2 to 5 percent and sometimes up to 15 percent of plant dry weight (Epstein 1999). Many trees and a few herbaceous forb taxa also produce

phytoliths, but quantities are generally much less than in grasses (Piperno 2006). Phytoliths are useful in paleoecology and archaeology because they are highly resistant to weathering and can remain in the soil for hundreds or thousands of years (Piperno 2006; Wilding 1967). Soil phytolith weight data and counts of distinctive phytolith morphotypes can be used to reconstruct long-term vegetation composition at a location and provide insight into vegetation that was utilized at an archaeological site.

Soil phytolith content under long-term grassland in North America is commonly 1 to 5 percent soil dry weight, an order of magnitude higher than long-term forest soil phytolith content, which is usually less than 0.4 percent dry weight (see Evett et al. 2006:358). Additionally, phytolith assemblages in soils with long-term grass dominance have high absolute counts and phytolith assemblage proportions of short cells, distinctive phytolith morphotypes formed only within specialized silica concentrating cells (including rondels, bilobates, and crenates) found only in grasses (Evett and Bartolome 2013; Evett et al. 2013). After examining soil phytoliths at 153 locations in California, Evett and Bartolome (2013) classified soils with greater than 0.30 percent soil phytolith content and greater than 200,000 grass rondels per gram of soil as areas with a long-term history of grass-dominated vegetation.

However, not all pre-colonization grasslands in California can be identified using phytolith analysis alone. The grassland physiognomic type, characterized by short herbaceous plants including grasses, sedges, and forbs, is not necessarily dominated by grasses. Californian grassland is currently dominated by exotic annual grasses that invaded California after European colonization. Recent phytolith evidence, combined with historical accounts, suggests that much of the modern grassland landscape seen today in California was indeed grassland prior to European settlement, but was dominated by forbs rather than native grasses (Evett and Bartolome 2013; Minnich 2008), although locations near the coast probably had substantial grass cover. Because most forbs produce few phytoliths, pre-colonization forb-dominated grassland in California had very low soil phytolith content, in contrast to most grassland in North America. Soil phytolith analysis can be used to reliably identify pre-colonization grass-dominated grassland in California, but not forb-dominated grassland.

Background and Methods

The location and setting of Quiroste Valley is described in detail by Cuthrell et al. (this issue). To investigate phytolith content and morphotype assemblages in

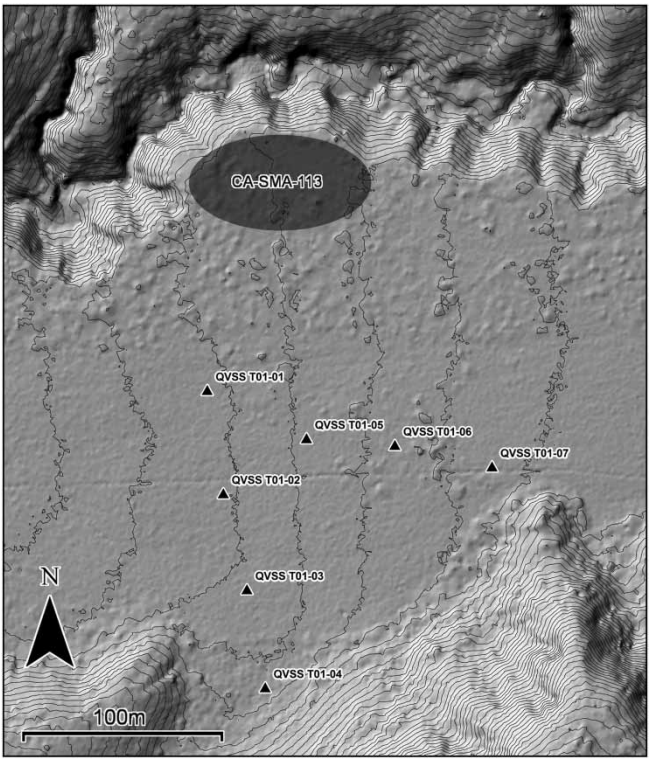

Figure 1. Locations of QVSS Transect 1 soil phytolith sampling columns (TSCT 01/01-07) and CA-SMA-113 on the southern floor of Quiroste Valley. Elevational contours are at 1-m intervals.

Quiroste Valley soils, we collected seven column samples (Quiroste Valley Soil Samples [QVSS] Transect 1, Columns 1–7; referred to as TSCT 01/01-07) from an area of the valley floor beginning ca. 100 m from archaeological site CA-SMA-113 (Figure 1). Four column samples (TSCT 01/01-04) representing a cross-section of the valley floor were collected at 50-m intervals from the toe of the southern hillside slope to the center of the valley, and three column samples (TSCT 01/05-07) were collected longitudinally along the steeper east–west elevation gradient of the valley floor. In each column sample, ca. 50 g of soil was collected at 10-cm vertical intervals, beginning 5 cm below the soil surface and continuing to 105–125 cm depth.

Archaeological deposit samples for phytolith analysis were also collected from CA-SMA-113. Column samples of archaeological deposits were collected

from profiles after excavation in 1-m^2 units was completed (i.e., culturally sterile levels were reached). Seven column samples were collected from units in the central portion of the site, which contained a 40–50 cm layer of midden material, and two columns were collected from units which contained sporadic artifacts but no midden deposits. Discrete archaeological deposits uncovered during the excavation, including ash deposits and silt lenses, were also sampled.

Phytoliths were extracted using a modified microwave digestion and heavy liquid flotation method (see Parr 2002). Briefly, 10 g of dried soil or sediment (<0.5 mm portion) was deflocculated with sodium bicarbonate. Clay was removed through repeated centrifugation and samples were microwave digested in a solution of nitric acid, hydrochloric acid, and hydrogen peroxide. Phytoliths were isolated by flotation using a 2.3 g/ml solution of sodium polytungstate. A second clay removal was performed on the light fraction and samples were gravity fractionated to isolate particles less than ca. 75–100 μm in size. Samples were exposed to a saturated solution of crystal violet and methylene blue stains, which stained most non-phytolith particles in the samples. Samples were mounted in immersion oil and analyzed at 200–400× magnification. A computer-assisted digital image analysis technique was used to quantify the proportion of phytoliths on each slide, and these values were used to calculate the percentage of silica phytoliths in soils. A detailed description of phytolith sample collection, processing, and analysis techniques for determining phytolith content in soils is provided in the supplementary online materials for this article.

In order to obtain absolute counts of phytolith morphotypes per gram of soil, phytoliths were counted for each slide following the protocol used by Evett et al. (2013). Morphotype classes counted were based largely on the generic grass morphotype classification of Twiss et al. (1969) because little basic research to identify diagnostic morphotypes has been done for Californian plant species. Rondel, bilobate, and crenate phytoliths are short cells morphotypes found only in grasses. Elongates and appendages are forms common in grasses, but are also found in many non-grass phytolith-producing species.

At least 200 phytoliths were counted on each slide in systematic transects spanning the entire slide. Each phytolith was rotated so that three dimensional characteristics could be observed. Only phytoliths with clearly recognizable morphotypes were counted. Highly weathered or broken phytoliths were not tallied. Diatoms, indicators of perennially moist soil or surface water that were extracted with soil phytoliths, were also counted.

Results

Phytoliths in Non-Archaeological Quiroste Valley Soils

Phytolith content in near-surface samples from soil columns collected from the floor of Quiroste Valley was consistently high, ranging from ca. 0.75 to 1.75 percent soil dry weight in the upper 25 cm of sampling columns (Figure 2; Supplementary Table 1), well within the range for grasslands in North America and substantially above the 0.30 percent grassland threshold proposed for California (Evett and Bartolome 2013). These data clearly indicate that all transect

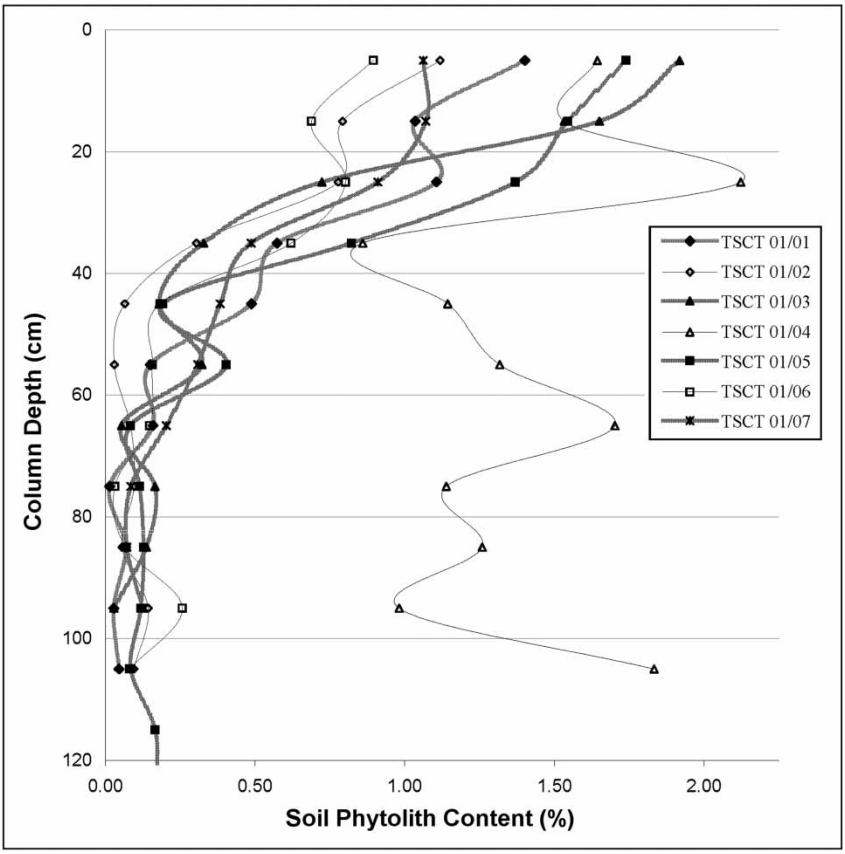

Figure 2. Phytolith content (percent dry weight) at 10-cm soil depth intervals in non-archaeological soil columns (TSCT 01/01-07) on the floor of Quiroste Valley.

locations have been dominated by grasses over the long term. Phytolith morphotype counts strongly support this conclusion. Near-surface grass rondel counts are >200,000/g soil at all locations (Supplementary Table 1), far above the grass-dominated grassland threshold of >90,000/g soil proposed by Evett et al. (2013), while total short cells are >500,000/g soil, dwarfing the >200,000/g threshold proposed by Evett and Bartolome (2013). Furthermore, phytolith content is exceptionally high compared to contemporary grasslands elsewhere in California. Because forbs likely dominated vegetation cover of most Californian grasslands, only two of 153 grassland locations examined in a statewide study (Evett and Bartolome 2013) had phytolith content greater than 0.75 percent, and none were above 1.11 percent.

The bilobate/total phytolith ratio is very low at all locations (Supplementary Table 1), indicating that native grasses producing bilobate phytoliths (probably *Stipa* or *Danthonia* species) were present throughout the valley but not dominant in the past. The rondel:elongate ratio is <1.0 at most locations, generally lower than values for long-term grasslands at Pepperwood Preserve, 150 km north of Quiroste Valley in the Coast Ranges (Evett et al. 2013). This probably reflects differences in the proportions of short cell morphotypes produced by distinct suites of native grasses. Crenate short cell counts were much higher at Quiroste Valley compared to Pepperwood. Adding rondel, crenate, and bilobate counts to create a total short cell:elongate ratio may be a more robust measure of grass-dominated grassland, indicated at Quiroste Valley by values >0.8 (Supplementary Table 1).

Six of the seven columns show a similar pattern of both decreasing phytolith content and morphotype numbers at increased depths (Figure 2; Supplementary Table 1), dropping to <0.25 percent by 55 cm depth and remaining near this percentage or below at greater depths, consistent with expectations for coastal California soils that have been long-term stable (White et al. 2012). Not all soil columns exhibit a pattern of monotonic decay in phytolith content at depths below 55 cm. However, most of these anomalies are not confirmed by increasing phytolith morphotype counts (Supplementary Table 1), suggesting they are not indications of buried soil surfaces. Increased weight percentages at these depths may be due to subsurface formation of non-phytolith amorphous mineral silica (White et al. 2012).

Column TSCT 01/04 exhibits several exceptional phytolith characteristics compared to the other soil column locations (Figure 2; Supplementary Table 1). There is high overall phytolith content and high variation in phytolith content between depths, ranging from 0.86 percent at 35 cm to 2.12 percent at 25 cm (the highest value at this depth recorded for any column location),

contrary to the typical grassland pattern of decreasing phytolith content with increasing depth. This pattern is probably the result of accumulative sedimentation characteristic of wetland environments, an interpretation strengthened by the presence of diatoms throughout the column. If so, this location may contain a stratigraphic microfossil record (phytoliths and pollen) of long-term vegetation change on the valley floor, a hypothesis to be tested by radiocarbon dating samples from various depths in the column. Furthermore, the very high grass short cell:elongate ratio at all depths but 5 cm (up to an order of magnitude higher than other locations) suggests extreme dominance by grasses for substantial periods of time, perhaps because this moist location favored grasses to the exclusion of forb species. The high bilobate:total phytolith ratio at 45 and 55 cm indicates a period of *Stipa* and/or *Danthonia* dominance.

An important question is whether the current soil phytolith pool could have been produced by land clearance, ranching, and agricultural activities during the past ca. 150 years or whether the phytolith content of the soil reflects indigenous landscape use prior to European colonization. The minimum time required for soil to accumulate the observed weight of phytoliths has been calculated at two near-coastal grassland locations in California having lower soil phytolith weight than Quiroste Valley soils. Using the total soil profile phytolith weight, phytolith production rates in grasses, proportion of phytoliths in plant biomass, and bulk density of soils, minimum time estimates at the coastal Santa Cruz terraces—a location 30 km from Quiroste Valley with similar vegetation and climate—ranged from 330 to 900 years (White et al. 2012).

At Pepperwood Preserve near Santa Rosa, California, soil phytolith pool production times were estimated at ca. 450 years (Evett et al. 2013). Because much of the annual phytolith input is poorly silicified and rapidly dissolved (Alexandre et al. 1997; Blecker et al. 2006), and soil phytolith weight at Quiroste Valley is higher than at the Santa Cruz terraces, the time required to build the phytolith pool to the observed weight is likely much longer than the minimum 330 years indicated by these studies. Although we have not discovered records of grain cultivation in the valley, because grains are grasses, annual phytolith input from grain crops would likely have been similar to grass-dominated vegetation, but only for a maximum of ca. 60 to 80 years based on historical records of land use (Mowry 2004). Quiroste Valley's high soil phytolith content probably indicates extensive grass cover during at least the past 1,000 years. While these estimates are variable because more research is needed at a local scale to refine the dynamics of phytolith production, deposition, and dissolution,

it is clear that only a small fraction of the phytolith content in Quiroste Valley soils can be explained by inputs from historical land use practices such as agriculture.

The very high soil phytolith content observed in Quiroste Valley is unlikely due to changes in climate during the late Holocene. Pollen evidence from Skylark Pond, upstream from the valley, does not show dramatic vegetation changes during the past ca. 3,200 years, indicating that the climate was relatively stable during this period (Cowart and Byrne, this issue). Additionally, nearby Santa Cruz terrace grassland sites, subjected to the same minor variations in regional climate as Quiroste Valley, have considerably less soil phytolith content (White et al. 2012). High soil phytolith content does not appear to be related to unusual soil characteristics in Quiroste Valley. Soils on the valley floor are mostly vertisols, while those on and near the toe-slopes of the valley are mollisols. Mollisols (typically formed under grassland vegetation) and vertisols were extensively sampled in the statewide soil phytolith study by Evett and Bartolome (2013), including the nearby Santa Cruz terraces, but phytolith content never exceeded 0.86 percent.

Another possible explanation for high phytolith content in Quiroste Valley soils, that there was a higher water table in the past that may have favored higher grass production, is also unlikely. Because diatoms respond to moist soil conditions, soil diatom content can be used as a rough indicator of soil moisture. Column TSCT 01/04 has high phytolith and diatom content throughout the profile (Supplementary Table 1), indicative of long-term moist conditions, while Columns TSCT 01/01 and TSCT 01/02 have high diatom and phytolith content only in the upper horizons, suggesting that these sites have become more, rather than less, moist over time. The remaining four sites have limited diatom content and little correlation between soil diatom and phytolith content, thus these data do not indicate that valley soils are drier now than they were in the past.

The most likely explanation for the anomalously high phytolith content observed in Quiroste Valley soils is that there were pre-colonization indigenous management practices that favored high grass cover. Because numerous historical accounts of early explorers described extensive burning by indigenous peoples near the coast (Minnich 2008), it is likely regular burning was commonly practiced in Quiroste Valley. The phytolith evidence suggests that not only was there cultural management of vegetation through regular burning to favor grassland over the likely coniferous forest climax vegetation in Quiroste Valley, but possibly also additional management factors, such as precisely timed seasonal burning, that strongly favored grasses over forbs.

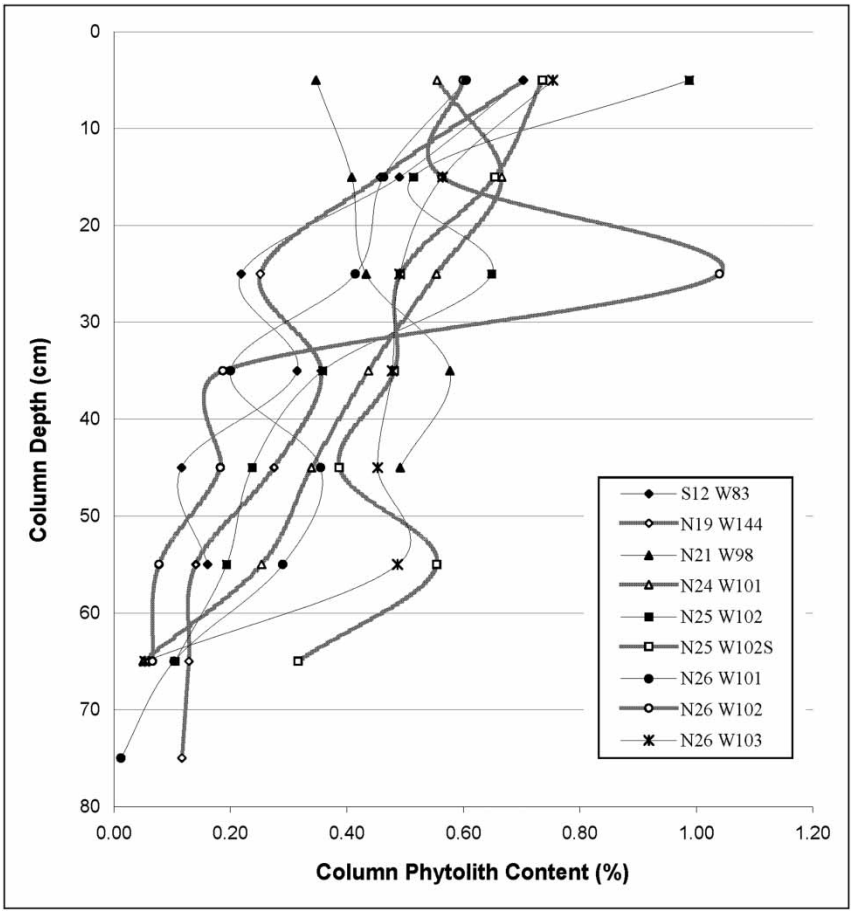

Figure 3. Phytolith content (percent dry weight) at 10-cm depth intervals in columns sampled at CA-SMA-113 in Quiroste Valley. Columns from Units S12 W83 and N19 W144 are non-midden locations within the site; remaining columns are from midden-containing deposits.

Phytoliths in CA-SMA-113 Sampling Columns (Non-Discrete Deposits)

Although the two non-midden sampling columns (N19 W144 and S12 W83) at CA-SMA-113 were located 70 m apart, their patterns of phytolith content and morphotype counts are very similar, with high phytolith densities near the surface, gradually decreasing to <0.2 percent at ca. 45 cm depth, mirroring the overall pattern of non-archaeological soil sampling columns (Supplementary Table 2; Figure 3). This suggests that the course of soil development at these

locations has been largely the same as the rest of the valley floor. However, unlike non-archaeological soil columns, both non-midden archaeological deposit columns display increased phytolith counts at ca. 35 cm depth, although only S12 W83 shows increased morphotype counts at this depth. Interestingly, both sites show very high bilobate:total phytolith ratios at or near this depth. This could indicate that vegetation cover in the area near CA-SMA-113 at some point in the past was distinct from the portion of the valley floor sampled by the non-archaeological soil column transect.

Phytolith content between columns collected within the CA-SMA-113 midden is highly variable (Figure 3; Supplementary Table 2). Phytolith content of near-surface samples is comparable to non-archaeological soil columns, but phytolith content at depths greater than ca. 35 cm is higher than in offsite columns. Because six of the seven midden columns (all except N21 W98) were collected from a single block of excavation units, the high variation in phytolith content and morphotype counts indicates a high degree of variability at very small scales within the archaeological midden deposit. Excluding the 5 cm level of Unit N25 W102, variability in phytolith content between these columns is lower near the soil surface than at greater depths, perhaps due to historical disc plowing of near surface soils during the twentieth century, which, along with rodent bioturbation, may have homogenized phytolith content in the upper soil horizons throughout the valley.

Because the phytolith sampling column in Unit N26 W102 intersected Feature 1 (a linear, compacted silt/clay lens at ca. 25 cm depth and ca. 3–5 cm thick running diagonally through several excavation units in this block), the pattern of phytolith content in this column differs from the others (Figure 3; Supplementary Table 2). Interpretation of Feature 1 is problematic. Although there are no associated historic artifacts, its location near the soil surface suggests it could be a nineteenth- or twentieth-century compacted trail, pathway, or vehicle track. The sediment sample collected at 25 cm depth, representing fill from Feature 1, has nearly twice the phytolith content compared to other samples collected at this depth. However, the phytolith morphotype counts are much less than expected for a sample with elevated phytolith content (Supplementary Table 2). Closer examination of the slide revealed aggregations of very small particles of non-phytolith amorphous silica that is probably of mineral origin, so it is unlikely this feature represents vegetation change, but could possibly be a vehicle track. This observation underscores the fact that for accurate interpretation of phytolith data, phytolith content should be examined in conjunction with absolute morphotype counts (Evett

and Bartolome 2013). Samples with a large discrepancy between these two parameters require closer scrutiny.

The contrasting pattern of phytolith content and morphotype counts in midden columns compared to non-midden archaeological columns suggests that the majority of phytoliths deposited at these levels result from the practices of the CA-SMA-113 site inhabitants. For example, at 55 cm depth (a level with dense midden deposits in all units in this excavation block), phytolith content in midden columns is up to five times higher than in non-midden columns (Figure 3; Supplementary Table 2).

The pattern of phytolith content in column N21 W98 is different from other columns in the excavation block, increasing from atypically low 0.35 percent at 5 cm depth to 0.58 percent at 35 cm depth (Figure 3; Supplementary Table 2). In this case, there are no distinctive characteristics of the column to suggest a cause for the pattern, and interpretation of this unexpected data remains problematic.

Phytoliths in CA-SMA-113 Discrete Deposits

Fifteen of the 18 samples from discrete deposits within the midden have substantial phytolith content (Figure 4; Supplementary Table 2). Most samples are from ash deposits with distinct natural stratigraphic boundaries. In the absence of rapid phytolith dissolution, phytolith content in ash deposits should reflect the amount of phytolith-producing vegetation burned (e.g., grasses and sedges). Ash deposits have highly variable phytolith content, with a range of nearly two orders of magnitude between samples QVSS 009 (0.05 percent) and QVSS 020 (4.22 percent). Although total sample size is small,

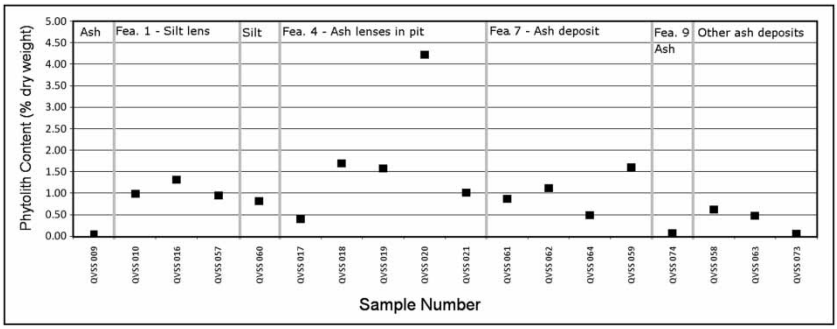

Figure 4. Phytolith content (percent dry weight) of samples from discrete archaeological contexts at CA-SMA-113.

ash deposits can be divided into four categories based on phytolith content and morphotype counts (Supplementary Table 2):

(1) samples with low phytolith content (<0.4 percent and total phytolith morphotypes <500,000/g soil; QVSS 009, 017, 073, 074)

(2) samples with moderate to high phytolith content (0.4–1.7 percent and total phytolith morphotypes >500,000/g soil; QVSS 010, 016, 017, 018, 057, 058, 060)

(3) samples with very high phytolith content >4.0 percent (QVSS 020)

(4) samples with moderate to high phytolith content but low morphotype counts, either because many phytoliths are highly corroded and non-identifiable, perhaps due to high burning temperature, or because there is considerable content of amorphous mineral silica (content >0.4 percent and total counts <400,000/g soil: QVSS 019, 021, 059, 061, 062, 063, 064).

Samples in the first category may represent fires in which very little phytolith-producing vegetation was burned, while those in the third category may represent intentional burning of large quantities of grass related to food preparation or disposal.

To compare phytolith content variability at very small scales within discrete deposits, four ash samples were collected and processed from Feature 7, an ash lens 50 cm diameter and 3 to 6 cm thick located 32 to 38 cm below the soil surface in Units N21 W90 and N22 W90. Phytolith content within this deposit was characterized by high heterogeneity at very small scales. Sample QVSS 059 has nearly three times the phytolith content of sample QVSS 064 (0.49 percent vs. 1.61 percent), and there is a 0.6 percent difference in phytolith content between QVSS 059 and QVSS 061, which were located only 10 cm apart (Supplementary Table 2). However, very low phytolith morphotype counts for these samples suggest that their phytolith contents may not be accurate because there are few identifiable phytoliths. The bulk of the unidentifiable silica may be corroded by burning or of non-biogenic, mineral origin. If we assume that most of the silica content is corroded phytoliths, the high heterogeneity in phytolith content could indicate this is an in situ deposit, since transporting the ash and dumping it would tend to homogenize phytolith content.

Soil samples collected from the units containing Feature 7 were not processed for phytolith analysis. However, based on the phytolith content values in other midden units, it is probable that phytolith content in Feature 7 is much higher than in the surrounding midden deposit. At 35 cm depth, all

other midden samples have phytolith content between ca. 0.2 and 0.6 percent soil dry mass, compared to 1.0 percent for Feature 7. If the high phytolith content in Feature 7 is due to phytolith deposition at the time the feature was created rather than mineral contamination, the results indicate that: (a) phytolith deposition within Feature 7 was spatially heterogeneous at a very small scale, and (b) Feature 7 included burning of phytolith-bearing vegetation, significantly enriching the deposit with phytoliths compared to the surrounding midden deposit.

Sample QVSS 020, collected from an ash lens in Feature 4 (a shallow pit), has much higher phytolith content than any other discrete deposit sample analyzed, 4.2 percent of deposit dry weight. Unlike other samples from discrete deposits, the fraction of large micro-particles (>100 microns diameter, isolated through gravity fractionation) in this sample contains a large proportion of aggregated sheets of silicified bodies composed of dozens to hundreds of cells. The contribution of these silicified sheets to sample phytolith weight was not quantified during phytolith analysis because few samples contain significant content in this size fraction, but they would undoubtedly increase overall phytolith content, probably to more than 5 percent soil dry weight. Several of the large silicified bodies in this sample appear to be awn structures from grass inflorescences. The extremely high phytolith content and presence of inflorescence phytoliths suggests that this deposit probably resulted from intentional burning of grass chaff for disposal, perhaps after seed winnowing. The amount of grass biomass represented by phytoliths in this small ash deposit is between 0.5 and 1.5 kg, roughly equivalent to burning the entire grass cover of two to ten square meters of grass-dominated vegetation.

Conclusion

Although there are significant uncertainties in the dynamics of phytolith pools in soils, the phytolith content of Quiroste Valley soils is too high to be the result of historical land use practices. Even without accounting for phytolith dissolution, the soil phytolith content in Quiroste Valley suggests that grass has dominated the vegetation cover for hundreds to more than a thousand years. Under a non-anthropogenic, lightning-caused fire regime, we expect fire return intervals would be on the order of 50 to 100 years (see Cuthrell, this issue), allowing woody north coast scrub and mixed conifer forest vegetation to dominate the landscape except during the first one to three decades following a fire. In these conditions, phytolith input to soils over the long term would be minimal.

Outside of highly unlikely scenarios that lightning-ignited fires were much more frequent in the past, or past climatic conditions were not favorable for woody vegetation, anthropogenic burning was required to maintain grass-dominated grassland vegetation for the length of time necessary to produce the observed phytolith content in soils on the valley floor. In addition, because surface soil phytolith content is much higher than elsewhere in California, Quiroste Valley grasslands likely had much higher grass cover than most other Californian grasslands, which were likely dominated by forbs. This suggests that either the anthropogenic burning regime (seasonality and frequency) was fine-tuned to favor grasses, or there were unknown species interactions and/or management practices that enhanced the proportion of grasses in coastal grasslands.

Data from column samples at CA-SMA-113 suggest that phytolith content, spatially and temporally heterogeneous at small scales compared to offsite samples, is at least partly the result of indigenous human activities such as food preparation, crafting, and construction-related practices. The variable phytolith content in discrete ash deposits at CA-SMA-113 reflects differences in the amount of grasses and/or sedges burned in fires. In one deposit, the presence of large, multicellular phytolith sheets originating from grass inflorescences suggests that grass chaff may have been burned as waste material from seed winnowing, supporting macrobotanical evidence for intensive use of wild grains in the foodways of site inhabitants (Cuthrell, this issue).

Using comparative materials from all plant species growing in or near Quiroste Valley, in future phytolith research we will employ computer-assisted quantitative morphotype analysis to identify diagnostic phytolith morphotypes that will permit identification of paleovegetation species composition. Combining this knowledge with radiocarbon dating of the soil column at site TSCT 01/04 and other accumulative wetland sites will allow description of long-term vegetation dynamics in the valley. Additionally, the extent of the pre-colonization grass-dominated grassland will be estimated by analysis of phytoliths extracted from surface soil samples collected along more extensive transects within and outside the valley.

Phytolith analysis has been applied successfully at numerous archaeological sites worldwide for more than 40 years (Piperno 2006). We believe this area of research has much unrealized potential in the context of California archaeology. By providing examples of productive phytolith research applications, we anticipate the success of this study and others in California (e.g., Lawlor 1995; Linda Scott Cummings, personal communication 2013; extensive unpublished work) will foster widespread use of phytolith research by California archaeologists in the future.

Acknowledgments

This project was financially supported by the California Department of Parks and Recreation, the National Science Foundation (BCS-0912162), and the Gordon and Betty Moore Foundation through the Berkeley Initiative in Global Change Biology. We thank the Amah Mutsun Tribal Band for their continued support and collaboration in our team's archaeological and environmental research in the Quiroste Valley Cultural Preserve. We also thank California Department of Parks and Recreation staff who have facilitated access and collections, including District Archaeologist Mark Hylkema, District Ecologist Tim Hyland, and Año Nuevo State Parks head rangers Gary Strachan and Terry Kiser. Thanks as well to the UC Berkeley Archaeological Research Facility for providing access to laboratory space and equipment, and to Dr. Christine Hastorf and Dr. Alexandre Chevalier for guidance in phytolith analysis. We would like to thank two anonymous reviewers for their helpful comments on an earlier version of this article.

Reference Cited

Alexandre, Anne, Jean-Dominique Meunier, Fabrice Colin, and Jean-Mathias Koud
1997 Plant Impact on the Biogeochemical Cycle of Silicon and Related Weathering Processes. *Geochimica et Cosmochimica Acta* 61:671–682.

Blecker, Steve W., Rebecca L. McCulley, Oliver A. Chadwick, and Eugene F. Kelly
2006 Biologic Cycling of Silica across a Grassland Bioclimosequence. *Global Biogeochemical Cycles* 20:GB3023.

Cuthrell, Rob Q., Chuck Striplen, Mark G. Hylkema, and Kent G. Lightfoot
2012 A Land of Fire: Anthropogenic Burning on the Central Coast of California. In *Contemporary Issues in California Archaeology,* edited by Terry L. Jones, and Jennifer E. Perry, pp. 153–172. Left Coast Press, Walnut Creek, California.

Epstein, Emanuel
1999 Silicon. *Annual Review of Plant Physiology and Plant Molecular Biology* 50:641–664.

Evett, Rand R., and James W. Bartolome
2013 Phytolith Evidence for the Extent and Nature of Prehistoric Californian Grasslands. *The Holocene* 23(11):1642–1647.

Evett, Rand R., Roy A. Woodward, Wayne Harrison, James Suero, Patricia Raggio, and James W. Bartolome
2006 Phytolith Evidence for the Lack of a Grass Understory in a *Sequoiadendron giganteum* (Taxodiaceae) Stand in the Central Sierra Nevada, California. *Madroño* 53:351–363.

Evett, Rand R., Arthur Dawson, and James W. Bartolome
2013 Estimating Vegetation Reference Conditions by Combining Historical Source Analysis and Soil Phytolith Analysis at Pepperwood Preserve, Northern California Coast Ranges, USA. *Restoration Ecology* 21:464–473.

Lawlor, Elizabeth J.
1995 Archaeological Site-formation Processes Affecting Plant Remains in the Mojave Desert. Ph.D. dissertation, Department of Anthropology, University of California, Riverside.

Lightfoot, Kent G., Rob Q. Cuthrell, Chuck Striplen, and Mark G. Hylkema
2013 Rethinking the Study of Landscape Management Practices among Hunter-Gatherers in North America. *American Antiquity* 78:285–301.

Minnich, Richard A.
2008 *California's Fading Wildflowers: Lost Legacy and Biological Invasions*. University of California Press, Berkeley, California.

Mowry, Harvey H.
2004 *Echoes from Gazos Creek Country: San Mateo County's South Coastal Region,* edited by Mary Guzman. Mother Lode Printing, Jackson, California.

Parr, Jeffrey F.
2002 A Comparison of Heavy Liquid Flotation and Microwave Digestion for the Extraction of Fossil Phytoliths from Sediments. *Review of Palaeobotany and Palynology* 120:315–336.

Piperno, Dolores R.
2006 *Phytoliths: A Comprehensive Guide for Archaeologists and Paleoecologists*. Altamira Press, Lanham, Maryland.

Twiss, Paige C., Erwin Suess, and Robert M. Smith
1969 Morphological Classification of Grass Phytoliths. *Soil Science Society of America Proceedings* 33:109–115.

White, Art F., Davison V. Vivit, Marjorie S. Schulz, Tom D. Bullen, Rand R. Evett, and Jugdeep Aagarwal
2012 Biogenic and Pedogenic Controls on Si Distributions and Cycling in Grasslands of the Santa Cruz Soil Chronosequence, California. *Geochimica et Cosmochimica Acta* 94:72–94.

Wilding, Larry P.
1967 Radiocarbon Dating of Biogenic Opal. *Science* 156:66–67.