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Volcanic ash in ancient Maya ceramics of the limestone lowlands: implications for prehistoric volcanic activity in the Guatemala highlands

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Abstract

In the spirit of collaborative research, Glicken and Ford embarked on the problem of identifying the source of volcanic ash used as temper in prehistoric Maya ceramics. Verification of the presence of glass shards and associated volcanic mineralogy in thin sections of Maya ceramics was straightforward and pointed to the Guatemala Highland volcanic chain. Considering seasonal wind rose patterns, target volcanoes include those from the area west of and including Guatemala City. Joint field research conducted in 1983 by Glicken and Ford in the limestone lowlands of Belize and neighboring Guatemala, 300 km north of the volcanic zone and 150 km from the nearest identified ash deposits, was unsuccessful in discovering local volcanic ash deposits. The abundance of the ash in common Maya ceramic vessels coupled with the difficulties of long-distance procurement without draft animals lead Glicken to suggest that ashfall into the lowlands would most parsimoniously explain prehistoric procurement; it literally dropped into their hands. A major archaeological problem with this explanation is that the use of volcanic ash occurring over several centuries of the Late Classic Period (ca. 600–900 AD). To accept the ashfall hypothesis for ancient Maya volcanic ash procurement, one would have to demonstrate a long span of consistent volcanic activity in the Guatemala Highlands for the last half of the first millennium AD. Should this be documented through careful petrographic, microprobe and tephrachronological studies, a number of related archaeological phenomena would be explained. In addition, the proposed model of volcanic activity has implications for understanding volcanism and potential volcanic hazards in Central America over a significantly longer time span than the historic period. These avenues are explored and a call for further collaborative research of this interdisciplinary problem is extended in this paper.

1. Introduction

Volcanoes have presented major hazards and important advantages to human populations who have lived in their vicinities (cf. Sheets, 1983; Sheets and Grayson, 1979; Mooser et al., 1958; Boserup, 1981). Obvious hazards relate to the short-term repercussions of violent eruptions on local inhabitants and have been studied with respect to particular archaeological sites [Ceren, El Salvador ca. 260 AD (Sheets, 1983); Pompeii, Italy 79 AD (Jashemski, 1979); Sunset Crater, Arizona 1064 AD (Pilles, 1979); Thera, Greece ca. 1625 (Kuniholm, 1990)] and modern populations [Nevado del Ruiz, Columbia (Voight, 1990); Paricutin, Mexico (Nolan, 1979)]. Advantages include the long-term effects related to improved soil fertility (Williams and McBirney, 1979), and the access to volcanic products, such as volcanic ash and obsidian for use by prehistoric and modern societies. Indeed, manufactured goods from archaeological sites in the

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vicinities of volcanoes traditionally use the products of eruptions: volcanic ash in ceramics (Arnold, 1985, p. 59; Shepard, 1956, pp. 164, 378–381), obsidian for cutting implements (Gaxiola and Clark, 1989) and as a semi-precious stone in jewelry, and other extrusive rocks for building materials, stone implements and abrasives.

In terms of volcanic hazard studies, archaeology offers vital information that can contribute to the extension of time series data for activity patterns in volcanic regions and understanding the effects of volcanic activity on populations for which no historic record is available. In Central America, there has been human occupation for several millennia, but historic documents start with the Spanish conquest in the mid 1500s. Volcanologists are conscious of changes in activity patterns of volcanoes — cyclic, monotonic and sequential — that operate in time scales much longer than the 500 years of "history" represented in Central America. To accurately interpret the activity record of a particular volcano and the various hazards it may present to nearby inhabitants, long-term time records are essential. Archaeology offers the potential to illuminate the prehistoric chronological record. Archaeological investigations of sites buried by volcanic deposits can help date specific volcanic activity by association with local eruptions. When volcanic ash, obsidian, or other volcanic products are recovered from archaeological sites remote from volcanoes, questions of source and procurement become important. Collaboration between volcanologists and archaeologists has considerable potential for resolving such issues. Some avenues are pursued in the problematic case of the use of volcanic ash in ancient Maya ceramics (cf. Ford and Glicken, 1987).

The abundance of volcanic ash in common everyday utilitarian ceramic vessels used throughout the Central Maya Lowlands (Fig. 1) in the Late Classic Period (600–900 AD), coupled with the problem of ash transport from at least 150 air km (nearest ash beds) without draft animals, leads one to search for alternative explanations for procurement (cf. Arnold, 1985, pp. 32–57). Glicken (pers. commun., 1983, 1984) proposed that an ashfall into the lowlands would best explain the procurement issue. But such an explanation is not without problems. In this paper, we present a general picture of the archaeology of highland and lowland Maya regions, the specific problems of the Late Classic Period in the Maya Lowlands, and a preliminary model of volcanism in the Guatemala Highlands that can account for most of the archaeological data. We conclude with a call for further collaborative efforts to confirm or reject the model for highland volcanic activity in the latter half of the first millennium AD.

1.1. The archaeology of the Maya area

While the earliest occupants of the Maya area date back into the Archaic Period before 2000 BC, it is the development of sedentary agricultural groups of the region that is pertinent to the questions at hand. Early villages in Highland Guatemala, around the active volcano vents, and on the Pacific slope to the south appeared during the second millennium BC and grew in size over time. The Maya Lowlands, situated on a Cretaceous to Eocene limestone shelf to the north of the highlands, were only sparsely settled at that time by pioneering agriculturalists.

By 1000 BC agricultural settlements had been established throughout the region, including the highlands and lowlands. Ceramics, used commonly by households, become an important part of archaeological assemblages of these sedentary agriculturalists. Emergent complex and hierarchical societies appeared throughout Mesoamerica during this era and by the beginning of the first millennium AD, the civilization centered at Teotihuacan in the Basin of Mexico was exerting its power over all of Mesoamerica. In Highland Guatemala, complex societies were consolidating in the Valley of Guatemala at Kaminaljuyu. This was also the time of expanded settlement into the Maya Lowlands and the establishment of lowland centers, such as Tikal.

The Early Classic Period (250–600 AD) marks the establishment of dynastic hierarchies in the highlands and the lowlands. Major centers and surrounding settlements are recorded at Kaminaljuyu in the highlands and Tikal in the lowlands. These independent societies evolved in sophisticated organizations in the region, recognizable by the large public architectural feats of temples, palaces and plazas that characterize their major central communities.

The Late Classic Period (600–900 AD) marks a significant change and contrast between the highlands and lowlands. Where a long developmental period of

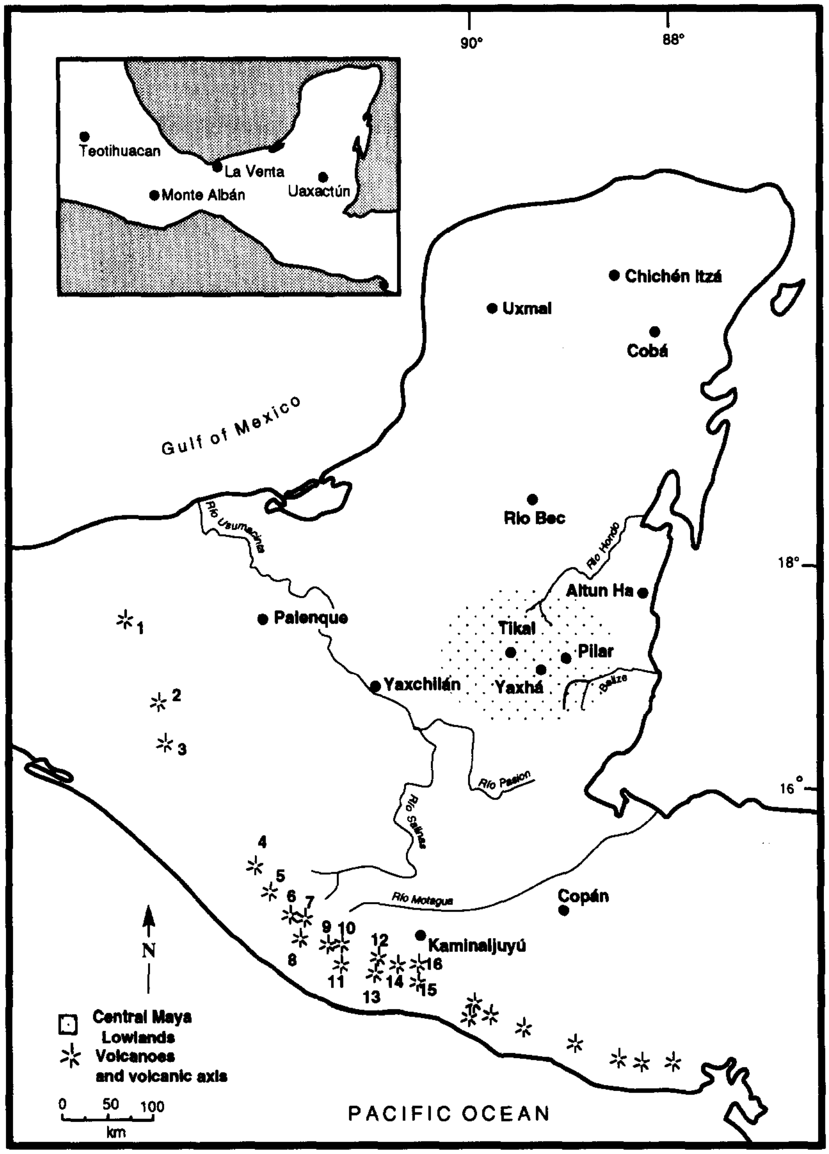

Fig. 1. The Maya area with the volcanic highlands, ancient Maya lowlands, and archaeological sites indicated. The inset shows the general Mesoamerican area (embracing modern Mexico, Guatemala and Belize) and archaeological sites of the region. The numbered volcanoes are those included in Table 2.

growth was characteristic of both regions up through the Early Classic, this growth is arrested in the highlands and accelerates in the lowlands. Highland centers disintegrate, settlements atomize, and there appears to be little growth or expansion of centers. At the same time, the lowlands experience intense growth with residential settlement densities more than doubling to 200 structures/km^2. Centers of the lowlands witness significant growth in public monumental architecture. The largest center of this period, Tikal, covered over 1 km^2 and included more than 85 major public plazas. Tikal was twice the size of the next largest center and four times the size of its nearest neighbors (Adams and Jones, 1981).

Coincident with the dramatic lowland growth is the widespread use of volcanic ash as a temper, or aggregate, in the fine ceramic wares in the region (Ford and Glicken, 1987; Jones, 1986; Shepard, 1939, 1942). The use of volcanic ash is prevalent not just in the few, limited, and highly decorated elite ceramic vessels (e.g., vases), but also in general household utility vessels (cooking, storing and serving pots). In fact, 30–40% of Late Classic ceramics are volcanic ash tempered (Ford and Glicken, 1987; Jones, 1986; Shepard, 1939 Shepard, 1942). Thus, for approximately 300 years during the Late Classic, volcanic ash was dependably available in sufficient quantities to use regularly in the production of specific ceramic vessels used generally by both commoners and the elite of ancient Maya society. The availability of volcanic ash is significant as a tempering agent for ceramics. Local limestone carbonates are unstable when temperatures exceed 850°C, which is difficult to control in traditional open-air firing conditions employed by the ancient Maya, where volcanic ash is highly stable under the same conditions (see Shepard, 1956, pp. 29, 158; Ford and Lucero, in prep.).

The close of the Late Classic Period in the lowlands is marked by the Classic Maya collapse e.g., Culbert, 1973. This event is documented most dramatically at the center of Tikal where all monumental building ceased and settlements were abandoned over a 100 year period. The beginning of the Postclassic is documented by relic settlements and the scarcity of volcanic ash tempered ceramics in the lowlands (e.g., Rice, 1987, pp. 56, 107, 118). This same period witnesses growth of settlements in Highland Guatemala and competition among highland centers. Highland centers of the Postclassic Period are generally imposing and defendable. In the lowlands, populations are low, growth is limited, and the settlements do not recover their earlier grandeur before the Spanish conquest of the New World (Turner, 1990).

The significant aspect of this gloss of highland and lowland Maya prehistory focuses on the general data related to the Late Classic Period: (1) the atomization of settlements in the volcanic highlands; (2) the growth of settlements in the limestone lowlands; and (3) the problematic use of volcanic ash in ceramics of the lowlands. When one seeks an explanation for the problem of lowland volcanic ash procurement in this context, the hypothesis of volcanic ashfall gains credibility.

1.2. A model of volcanic highland hazards and limestone lowland benefits

Starting, as Glicken and Ford did, with the problem of volcanic ash procurement for ceramic production by the ancient Maya in the limestone lowlands during the Late Classic Period, it is obvious that ash was readily available based on the hundreds of ceramic pieces examined (see examples in Table 1 and Fig. 2). Given the evidence for volcanic ash availability, there should be a reasonable explanation as to its presence. While the estimated overall amount of ash used in the lowlands during the 300 year Late Classic Period could be accounted for by an eruption volume of less than.007 km^3 (7×10^6 m^3), not a large figure by geological standards, but phenomenal by archaeological standards. The estimated use of volcanic ash in ancient Maya ceramics is no less than 1400 m^3/y (based on Ford and Glicken, 1987, pp. 491–492, 497). This, in fact, is quite a large volume to regularly transport over long distances from the nearest source of volcanic ash, approximately 150 air km away, especially without draft animals. Other exotics of volcanic origin imported to the area, such as obsidian, occur in very small quantities and limited access (Ford, 1991; Rice, 1984; Sidrys, 1976). Thus, the large quantities and wide distribution of the volcanic ash stands in contrast and must be explained.

Given the constraints of distance and transportation, an explanation that included ashfall into the lowlands is attractive. But again, while the overall volumes of ash are small in comparison to a major volcanic eruption, it is very unlikely that a single ashfall into the limestone lowlands could account for the consistent use of volcanic ash over a 300 year period. Human societies focus on short term planning, as modern occupation near active volcanoes demonstrates. Storage and con-

Fig. 2. Photomicrograph of pottery fragment (a: 386A, b: 300A, c: 213A) from the Tikal–Yaxha Intersite area. This is a typical texture for Maya ceramics tempered with volcanic ash. Notable is the large volume percentage of fine particles easily identifiable as pyroclasts. All ash particles are angular, unweathered and clearly preserved, suggesting they were collected as fresh ash for ceramic temper. The phenocryst minerals are also easily identifiable and large enough for microprobe analysis.

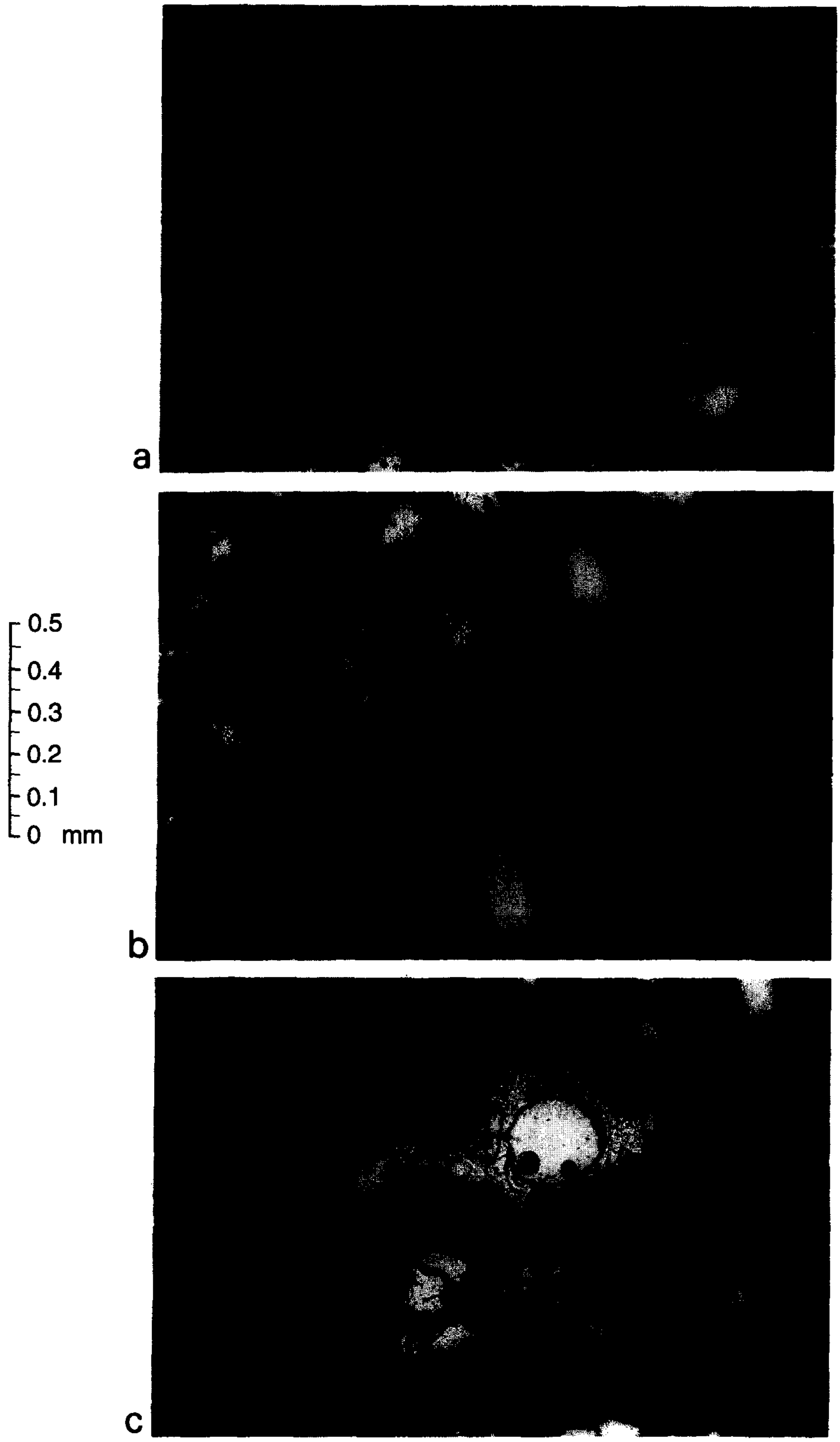
a
b
c
0.5
0.4
0.3
0.2
0.1
0 mm

Table 1
A general description of volcanic ash temper in thin sections of ceramics from the Tikal–Yaxha intersite area[a]

Catalog number	Grain size crystals (estimated median)		Lithic?	Excavation area	Time period
370A* fine bowl	0.20 mm	b, hb	absent	5E	Late Late Classic
280F* fine vase	0.25 mm	b, hb	absent	3A	Late Late Classic
213D* fine bowl	0.15 mm	b, hb	absent	2A	Late Classic
300A[X] fine bowl	0.20 mm	b, hb, z	tuff? or cluster of ash	3A	Late Classic
237A* fine bowl/jar	0.20 mm	b, hb	present	44C	Prob. Late Classic
939B~ fine bowl/kar	0.08 mm	b	tuff? or cluster of ash	44C	Prob. Late Classic
386A[X] fine jar	0.10 mm	b hb	present	8A	Early Classic
410 A* fine jar	0.40 mm	b,hb	absent	8A	Early Classic
193D[X] fine lg. bowl	0.15 mm	b	tuff? or cluster of ash	2A	Late Preclassic
326A~ bowl (orange)	0.07 mm	hy	present, also tuff?	63D	Middle Preclassic
355D~ bowl (orange)	0.07 mm	hy	absent	41E	Middle Preclassic

~: fine grained, hornblende absent, biotite rare, hypersthene common, median grain size ca. 0.07 mm.
*: coarse grained, hornblende and biotite common, hypersthene absent, median grain size ca. 0.15–0.40 mm.
[X]: similar to the above (*) but may be different.
Mineral key: b = biotite, hb = hornblende, hy = hypersthene z = zircon. [a]Ceramic collections for this table are derived from the research of and Ford and Glicken (1987).

servation of goods rarely exceeds several years, even with critical products such as food stuffs. Therefore, it is difficult to imagine there would be volcanic ash stock-piling for ceramic production planned for centuries to come. This stockpiling would need to cover a time frame of at least twelve generations, far beyond any long-range planning of modern societies. To accept the ashfall hypothesis for procurement — a hypothesis that argues no long-distance movement of materials, but rather the raw material arrives at your doorstep — one would have to propose the regular, cyclical influx of volcanic ash into the lowland region. Thus, the hypothesis we propose, argues that the long-distance movement of volcanic ash from highlands sources to the lowlands occurred naturally and frequently over a 300 year period.

Because we know that significant ashfalls occurred in the Maya Lowlands following the 1982 El Chichon eruption (Rose et al., 1984, p. 163), we think that eruptions of similar size (about 0.5 km^3) from either El Chichon or other neighboring volcanoes could, especially if they occurred repeatedly, account for the extensive availability of volcanic ash for use in prehistoric Maya ceramics. The current patterns of high level winds have been compiled from radiosonde records collected by meteorologists in Guatemala (Fig. 3). These data are consistent with patterns shown for historic ash fallout blankets in Guatemala and demonstrate ash fallout mainly in a westerly direction for eruptions in the wet season months of May to November, and in a northeasterly to easterly direction in the dry season months of December to April. These ash distribution patterns would only be expected to carry ash erupted from southern Mexico or western Guatemala to the Maya Lowlands between December and April.

The hypothesis of regular ashfalls into the limestone lowlands has implications for highland volcanic activity (see Williams, 1960). The proposal of a model of

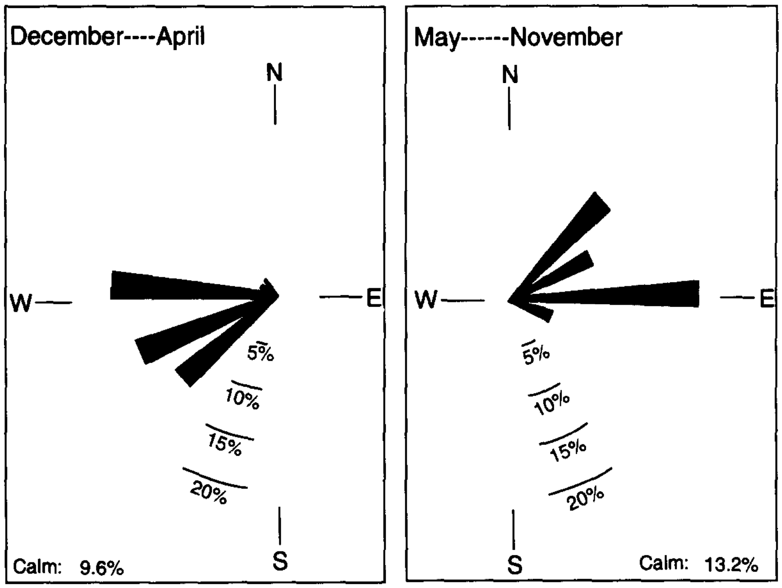

Fig. 3. Wind rose diagram showing predominant winds aloft at altitudes between 10,000 and 50,000 feet at Guatemala City. This figure is a graphic representation of a ten-year statistical summary of balloon (radiosonde) measurements (two times a day) showing seasonal patterns. The length of black lines are proportional to their frequency and they are elongated in the direction from which the winds come. Data are from the Instituto Nacional de Sismologia, Vulcanologia, Meteorologia, e Hidrologia, Guatemala.

volcanic activity in the highlands has a number of implications both geologically and archaeologically. If there was a long period of consistent, regular volcanic activity, with minimal periods of repose in the volcanic highland, this could help resolve the question of volcanic ash procurement in the Maya Lowlands and settlement decrease in the highlands. The period of volcanic activity could begin with a relatively major event with a significant eruptive volume of dispersed tephra. If there were successive eruptions with short periods of repose, the eruptive volume would be significantly less, particularly if the time span of the eruptions embraced centuries.

Observations of volcanological systems characterized by the eruption of magma of intermediate to silica composition provide a basis for understanding considerations of eruptive volume (V) and repose time (t_R). Evidence suggests a general power-law relationship between volume and repose time (Smith, 1979; Spera and Crisp, 1981; Trial and Spera, 1990). In particular, the data suggest a relation of the form $V = k \times t_R^b$ with $b \approx 0.8 \pm 0.1$ and $k \approx 3 \times 10^{-3}$ km^3 a^{-b}. For systems of tectonic setting and composition similar to those of Highland Guatemala, the scaling suggests eruptive volumes of 0.02 km^3 and 0.07 km^3 for repose times of 10 and 50 years, respectively. The actual average extrusion rates of active Guatemalan and Salvadoran volcanoes are estimated from field data and known dates. Fuego has a rate of about 0.015 km^3/y (Martin and Rose, 1981), Santiaguito's rate varies between 0.01 and 0.07 km^3/y (Rose, 1987a, b) and Izalco has a rate of about 0.009 km^3/y (Woodruff et al., 1979). A period of several hundred years of local volcanic activity in Highland Guatemala would create a hazardous environment in the vicinities of the active volcanoes, but could promote benefits in terms of access to ash as an additive for temper in ceramics and for enriching soils for agricultural production in distant locations, such as the limestone Maya Lowlands.

In order to support the ashfall hypothesis, three major avenues of evidence need to be pursued: (1) a petrographic analysis of Maya ceramics; (2) microprobe analysis of glass shards in the ceramics; and (3) tephra- and geochronological studies in the highlands. The first stage of verification is the petrographic characterization of volcanic ash in the ancient Maya ceramics of the lowlands. The characterization of the major, minor and trace elements composition of the volcanic ash together with the phenocryst assemblage could enable one to determine the general volcanic source of the ash. To a large extent, this has been accomplished (Ford and Glicken, 1987, pp. 485, 494–495). After a review of thousands of ceramic pieces and hundreds of thin section examples of Maya ceramics from major lowland sites, we identified the types of ceramics that had volcanic ash tempering added to the clay paste and determined that volcanic ash made up more than 20% of the ceramic paste matrix of the ash tempered ceramic collections (see examples in Table 1 and Fig. 2). The ash and mineral assemblage (biotite, hornblende, hypersthene and zircon) all are consistent with Guatemala Highland tephra (cf. Drexler et al., 1980; Rose et al., 1981). The petrographic analysis suggests the procurement of finely sorted vitric volcanic ash (see Shepard, 1956, pp. 29–38), with grain sizes under 0.25 mm (see Table 1), well below the range of fine ash (Fisher, 1961, p. 1411; see also Kittleman, 1979, pp. 63–70). This size range is indicative of windborne (volcanic loess) particles distributed distal from the source vent(s), where particle size is inverse to the distance from the source (Kittleman, 1979, pp. 55–57).

Both Mexican and Guatemalan volcanoes could potentially erupt ashes that would repeatedly fall out in the Maya Lowlands. The high level wind patterns suggest that volcanoes in either the highlands of Guatemala or the Chiapecan belt are positioned favorably for this (Figs. 1 and 3). A list of volcanoes in Mexico and Guatemala that are possible sources are presented in Table 2. We compared the mineralogical information of the potential volcanoes (see Table 2) with the phases observed in the ancient Maya ceramics (see Table 1). Biotite is the mineral most frequently cited in ceramics. Biotite is not found in most of the potential volcanoes and, when present, is typically only a minor feature. The difference between the ceramic mineralogy and the potential source volcanoes may be explained by atmospheric dispersion of the ash, which would be expected to cause biotite flakes, with high surface area/mass and attendant high drag coefficients, to be preferentially carried farther than other, more equidimensional minerals. Thus, the conspicuous presence of biotite, along with the vitric nature of the ash in the ancient Maya ceramics (Shepard, 1939; Shepard, 1942), suggests that the ash included in the ceramics had undergone an air winnowing process. Given the mineralogy of the potential source volcanoes (Table 2) and focusing specifically on biotite, a number of potential sources are suggested for the ceramic tephra.

Table 2
Petrographic data on Mexican and Guatemalan volcanoes which might have produced tephra fallout in the central Maya Lowlands

Volcano	Phenocryst phases (approximate order of abundance)	Reference
1. El Chichon	pl, hb, cpx, mag, an, b, ap, sph	Luhr et al., 1984
2. *Tzomtehuitz**	*pl, hb, cpx, mag, sp, ap, z*	Capaul, 1987
3. *Nicolas Ruiz**	*pl, hb, cpx, mag, sp, ap, qtz, z*	Capaul, 1987
4. Tacana	pl, cpx, opx, ol, hb, mag, qtz	Mercado and Rose, 1992
5. Tajumulco	pl, hb, opx, cpx, b, mag, ol	Rose, unpublished
6. *Chicabal**	*pl, opx, cpx, hb, mag*	Gierzycki, 1976
7. Cerro Quemado	pl, hb, mag, cpx, opx, b, ol, qtz	Conway et al., 1992
8. Santa Maria	pl, hb, cpx, opx, ol, mag	Rose, 1987a, b
9. San Pedro	pl, cpx, hb, opx, mag, ol, qtz	Halsor and Rose, 1991
10. Toliman	pl, cpx, opx, mag, ol, hb, qtz	Halsor and Rose, 1991
11. Atitlan	pl, cpx, opx, ol, mag	Halsor and Rose, 1991
12. Acatenango	pl, cpx, opx, mag, ol, hb, b	Rose, unpublished
13. Fuego	pl, ol, cpx, mag, hb, opx	Chesner and Rose, 1984
14. Agua	pl, cpx, opx, mag, hb, ol	Rose, unpublished
15. Pacaya	pl, ol, cpx, mag, opx	Eggers, 1971
16. Amatitlan	pl, qtz, hb, b, mag, opx, z, ap	Wunderman and Rose, 1984

Mineral key: pl = plagioclase, ol = olivine, b = biotite, cpx = clinopyroxene, hb = hornblende, mag = magnetite, opx = orthopyroxene, qtz = quartz, z = zircon, ap = apatite.
* Unlikely to have been active in the 600–900 AD period based on current descriptive data.

The best candidate volcanoes include El Chichon, Tajumulco, Cerro Quemado, Acatenango and Amatitlan (see Table 2).

The second line of verification should include microprobe examination of ancient Maya ceramics representative of the full time range and regional lowland distribution. The microprobe examination should focus on the volcanic ash shards and the biotite as well. By determining the major elemental composition of the glass shards, microprobe analysis would verify the number of potential volcanic ash sources involved and would provide a baseline for the identification of eruption frequency. Ion microprobe, still in the experimental stages, could prove invaluable in the measure of trace elements in biotite, as trace elements in phases are more specific than glass. While the petrographic analysis points generally to the Guatemala Highlands, microprobe data would address the specific variety of sources involved.

The final avenue of verification involves careful tephrachronological and geochronological studies of highland eruptions focused specifically on the latter half of the first millennium AD (cf. Self and Sparks, 1979; Miller, 1985). The microstratigraphic data from the tephra sequences would address the eruption histories of the highlands by focusing on the deposition and frequency of eruptions and linking the sequence with the archaeological data from that region. The results of the geochronological work covering the relevant time period would represent the most critical piece of evidence to account for the archaeological presence of volcanic ash in the limestone Maya Lowlands.

Among the biotite-bearing volcanoes in Table 2, several are known to have been active in the period of 600 to 900 AD. El Chichon has dated eruptions in the age range of about 100 until about 700 AD, and may have been active repeatedly in this interval (Rose et al., 1984; Tilling et al., 1984). Tajumulco has no historic eruptions and no known dated deposits in the period of interest. However, detailed field work has not been conducted, so Tajumulco cannot be exclude as a possibility. Cerro Quemado is known to have been quite active at about 800 AD (Conway et al., 1992) and the area has a complex tephra stratigraphy which suggests that this activity could have continued for some time. Acatenango is known to have had a significant eruption involving dacitic tephra at about 1300–1400 AD, based on the discovery of pottery remains in the Alotenango area (southeast of the volcano) immediately underlying the tephra. There is a stratigraphy of mixed dacite/basaltic andesite ash layers that mantles the northern flanks of the volcano, indicating repeated activity. Although these layers are undated it is possible that they reflect activity in the 600–900 AD period. The Amatitlan caldera has had an eruptive history of several hundred thousand years, and has produced large amounts of biotite-bearing tephra (Wunderman and Rose, 1984). Most of its eruptions are much older than the 600–900 AD period, but there are young undated mixed tephra south of Lake Amatitlan that could have been erupted in the critical period, and the dome complex south of the lake could have been active with attendant ash eruptions at that time. In summary, existing data are inadequate to resolve the specific source volcano or volcanoes possibly responsible for the volcanic ashes of the Maya Lowland ceramics. All five volcanoes which carry biotite must be considered as possible candidates. Of the existing chronological data on eruptions, we know that both El Chichon and Cerro Quemado were quite active in the Classic Period. Also, El Chichon's ash shows a good mineralogical match with the ceramic data. Further, the 1982 eruption of El Chichon reminds us that winds can be expected to carry El Chichon ash to the Maya Lowlands, as Fig. 3 demonstrates.

1.3. Implications of the model

Volcanic hazard research is typically based on the careful study of volcanic deposits to determine the style of activity and to establish the chronology and frequency of activity. In many parts of the world geological field studies are limited, which means that hazard studies are strongly influenced by records and descriptions of historical activity. In Central America, the historical record begins in 1541, and it is important to recognize that 550 years of history is not long enough to reflect the entire range of activity that volcanoes may exhibit. If ashfalls of biotite-rich ashes regularly blanketed the Maya Lowlands in the years 600–900 AD, this represents a style of activity not experienced in the historic record. In the absence of volcanic hazard studies based on the geologic record, the historic record governs the public awareness of hazard. This is critical because historic settlement in Central America is strongly localized along the volcanic axis. If significant fallouts were documented for the distant Maya Lowlands, the effects associated with the same eruptions near the volcano were clearly more severe. Should regular explosive activity recur, such as that proposed here, it is likely that large populations of the Guatemala Highlands would be displaced. In this case, the archaeological record may be able to reveal important aspects of volcanic hazards that have implications for the present and the future.

Volcanoes are most prominently known for their hazardous impacts on populations, especially those within the region of accumulation (e.g., Sheets, 1983; Rees, 1979; Rosi et al., 1981; Voight, 1990; Warrick, 1979). At the same time, enhanced soil fertility is a well-recognized benefit of volcanic eruptions (Williams and McBirney, 1979, p. 363). Recently, hazard planning in regions of volcanic activity has become routine even though periods of eruption may be outside human memory. In times past, such long-range planning was unknown. Hazard avoidance in terms of volcanic eruption was only on an emergency basis. The ancient Olmec abandonment of the Mexican Gulf Coast in the Preclassic and the destruction of Pompeii in Italy are examples.

Evacuation and abandonment of areas in the vicinity of active volcanoes are related to the experience of devastating eruptions and the reinforcement of that experience through periodic observation of similar eruptions. Severe impacts are predictable in areas immediately surrounding the active volcanoes (< 30 km radius). Generalized impacts are not uncommon to surrounding regions within 500 km (Thorarinsson, 1979, p. 126). Data from Iceland suggest that fresh tephra and ash falls of 30–50 cm caused complete abandonment of permanent settlements while deposits of 15–20 cm caused short-term (up to 5 years) abandonments (Thorarinsson, 1979, p. 139). The impacts, no matter how extreme, will be short-term unless the periods of repose are brief. Extended periods of repose would encourage resettlement, as observed in modern Michoacan after a decade long period of activity of Paricutin, Mexico (Nolan, 1979), in Iceland (Thorarinsson, 1979), in the archaeological cases of Thera (Greece) and at Mt. Vesuvius (Italy) (Santacroce, 1987). On the other hand, risks of reoccupation of areas surrounding active volcanoes will be high where periods of repose are brief. Thus, tephra falls resulting in a 30-cm thick deposit (or thicker), with regular rates of accumulation as the result of frequent, periodic volcanism would render areas in the vicinity of active volcanoes inhospitable for settlement.

Settlements in the volcanically active Guatemala Highlands have always been at some risk due to local volcanism. Prehistoric, historic and modern groups were faced with the same risk. In certain regions, archaeologists have demonstrated abandonment as a result of volcanism (Sheets, 1983; Sheets, 1992). Thus, the marked change and reduction in highland settlements in the Late Classic could be accounted for by reference to local occupation risks due to volcanism.

While volcanic hazards are easily appreciated in the immediate and short-term sense, benefits of soil enrichments with volcanic ash would be only recognized over the long term, implying periodic, accumulative ashfalls that would offset soil depletion and maintain productivity, especially in regions where agricultural practices were widespread. Thus, for the lowland Maya subsistence system to be affected by volcanic ash fertilization, it would have to have regularly accumulated and replenished the limestone lowland soils through periodic ashfalls occurring frequently at least within ten year periods (see Williams and McBirney, 1979). Within the proposed period of heightened volcanic activity in the Guatemala Highlands, lowland soil enrichment could be an outcome, especially if the frequent ashfalls spanned several centuries.

Local environmental conditions of the tropical Maya Lowlands have erased any potential evidence of volcanic ash deposits that could account for ash procurement and soil enrichment in prehistory. The Central Maya Lowlands are typically divided into wet and dry seasons, with 2000 mm of rain per annum falling mainly between June and January. Weathering conditions are relatively rapid in the tropics, and high rainfall, high temperatures, and seasonal dehydration exacerbate and accelerate the desalination and weathering processes (Lowe, 1986, pp. 275–79). The rapid weathering process decreases only when rates of tephra accumulation occur regularly (Lowe, 1986). Without the regular addition of volcanic ash, the lowland environmental conditions would degrade any ashfall quickly, as Glicken and Ford witnessed in the region over a period less than twelve months after the 1982 El Chichon eruption that blanketed the region (Carey and Sigurdsson, 1982). Soil studies in the region have characterized the pedology as locally derived and principally composed of mollisols and vertisols of in situ origin (Cowgill et al., 1966; Cowgill and Hutchinson, 1963; Olson, 1969; Simmons et al., 1959; Wright et al., 1959).

Analyses of lake core sediments from the lowlands indicate no distinct ash layers (e.g., Deveey et al., 1979). Glicken and Ford's field work in spring 1983[1]

[1] Field soil collected and analyzed in spring 1983 were focused on (1) archaeological survey zones of the Belize River Archaeological Settlement Survey (Ford and Fedick 1992); (2) natural sinks and ponds within the upper Belize River valley; and (3) stream and river drainages of the New River, Belize River and Sibun River systems in Belize.

consisted of an examination of river, stream and pond deposits, as well as alluvial and general soils in the vicinities of the archaeological surveys in the Belize River area (Ford and Fedick, 1992). Conducted within one year of the 1982 El Chichon eruption, Glicken's laboratory analysis did not identify any evidence that volcanic glass or crystals representative of El Chichon or other highland volcanoes were present in any catchments or deposits of the Maya Lowlands. Soil studies from the specific Belize River area document local soil development and composition that substantiate Glicken and Ford's initial conclusions (Fedick, 1988, 1989; Jenkin et al., 1976). The lowland Maya soils are very different from those adjacent to volcanoes, such as those described for Thera (e.g., Betancourt et al., 1990).

If the volcanic ash was collected as fallout in the Maya Lowlands and used as a tempering agent in ceramics soon after the fallout, as we are suggesting, there is potential to gain remarkable information concerning ash dispersion and deposition. Data on distal ashes are rarely preserved in any context and its description is vital for accurate volume assessments of explosive eruptions. The study of ash material in archaeologically dated pottery from the Maya Lowlands can provide information about distal fallout from deposits that are no longer preserved (Carey and Sigurdsson, 1982). Thin sections of ancient Maya ceramics can yield data on particle size and shapes (see Fig. 2), of particular interest to those investigating atmospheric fallout processes (Rose and Chesner, 1987). In addition, petrographic studies allow for a robust quantitative description of the mineralogy of the ashes for comparisons. Identification of source volcano(es) is possible by microprobe analysis of the glass and phenocrysts in the ancient ceramics. These data could be, then, associated with similar data from proximal volcanic deposits of potential source volcanoes. Given the archaeological ceramic chronology, the analyzed data from the Maya ceramics will help volcanologists to reconstruct prehistoric activity of certain volcanoes, thus, expanding the knowledge of volcanic activity in Central America. We conclude that petrographic and microprobe studies of the large number of available ceramic materials from lowland Maya excavations have the potential of providing information on eruption histories, atmospheric fallout processes, and volcanic hazards, and at the same time address the procurement problem for the use of volcanic ash by the ancient Maya.

2. Conclusion

We have outlined a tentative model of volcanism suggesting a centuries-long period of volcanism during the latter half of the first millennium AD. This concept was originally proposed in collaborative discussions between Glicken and Ford. Glicken could not accept that long-distance trade accounted for the quantity or use of volcanic ash in the lowlands. He felt an ashfall could best explain the use of ash in ancient Maya ceramics. From the anthropological point of view, this proposition would only be tenable if there had been a dependable lowland source of volcanic ash during the entire time span of use, as the volcanic ash tempered ceramics that were made and used by the ancient Maya throughout the Late Classic Period (ca. 600–900 AD). To accept the direct ashfall hypothesis for the Maya Lowlands, it is necessary to adopt a model of long-period volcanic activity in the Guatemala Highlands. Such a scenario would feature regular and periodic tephra eruptions and ashfalls into the lowlands. The volume repose characteristics of such a system appear consistent with volcanological observations at other volcanic areas of the world.

The proposition of regular ashfalls into the limestone lowlands has implications for highland volcanic activity. There are at least two volcanoes — El Chichon and Cerro Quemado — which are known to have been active in the Late Classic Period and could have produced ashfalls into the lowlands. There are also several other volcanoes which are candidates, based on the mineralogy of their erupted products and their location, but these volcanoes lack field descriptions and geochronological descriptions of their prehistoric deposits. Microprobe studies of phenocrysts in the ceramics and ash deposits of candidate volcanoes is needed to test correlations between the ash in the ancient Maya ceramics and specific Guatemala volcanoes. Stratigraphic/age date studies of the tephra at candidate volcanoes is also needed to test for several other viable source volcanoes. These potential volcanoes include Acatenango, Tajumulco and recent Amatitlan tephras.

If the geological research could document a three century period of consistent, regular volcanic activity in the Guatemala Highlands, this could account for a number of archaeologically recognized occurrences: (1) The presence of volcanic ash in Late Classic Period ceramics of the limestone lowlands, (2) the increased settlement in the lowlands due to enhanced fertility associated with ash enrichment of soils, (3) the reduction of settlements in the volcanic highlands, and (4) the Classic Maya collapse as a consequence of the cessation of volcanic activity. This hypothesis is both sweeping and parsimonious. Harry Glicken began this collaborative venture with archaeology. We now need other volcanologists that can advance this challenging project.

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