The Effects of Explosive Volcanism on Simple-to-Complex Societies in Ancient Middle America

Payson Sheets, Anthropology, University of Colorado, Boulder CO 80309-0233

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"Just as the progress of a disease shows a doctor the secret life of a body, so to the historian the progress of a great calamity yields valuable information about the nature of the society so stricken."

Marc Bloch

ABSTRACT

The ancient societies of Middle America were not equally vulnerable to the sudden stresses of explosive volcanic eruptions. Although the sample size of known cases is small, the simple egalitarian societies apparently were more resilient to sudden massive stress, in the long run, than were the more complex chiefdoms or states. The simpler societies often repeatedly reoccupied the recovering landscapes, taking advantage of the short-term benefits of the volcanically active environments, with little or no detectable culture change that can be traced to the volcanic impacts. The more complex societies in this sample had greater difficulties in coping with sudden massive stresses, apparently because of their greater reliance on the built environment, staple cultigens, long range trade networks, greater population density, competitive-to-hostile political landscapes, redistributive economies, and other centralized institutions. An unanticipated result of this study is the realization of the importance of the political context of a society prior to a sudden stress.

Introduction

The objective of this manuscript is to compare the effects of explosive volcanic eruptions on the ancient societies of Middle America (Mexico and Central America), to explore the role of social complexity in determining the vulnerability of societies to sudden massive stresses. It is clear that some societies were resilient to explosive eruptions, re-establishing their society, adaptation, and material culture in the devastated area after natural processes of recovery allowed human resettlement. In other cases, societies were more vulnerable to massive environmental change from explosive eruptions, as they were not able to cope with the changed circumstances. The more complex societies in this small sample were more vulnerable to these stresses, particularly when they were quite competitive or hostile with nearby societies.

Ancient egalitarian societies can be distinguished from complex societies readily with archaeological evidence. Egalitarian societies, whether based on hunting and gathering, marine resources, or agriculture, are characterized by household posessions that are essentially the same throughout the society. What differences that show up in households or burials are due to age or sex differences within the household rather than differential wealth or authority among households. Complex societies exhibit centralized authority in a number of domains, including politics, religion, and economics. An important source of evidence of societal complexity detectable in ancient societies is the degree of centralization of wealth or authority. Differential wealth usually manifests itself in burials, with richly stocked tombs of the elite contrasting with the more plain commoner's burials. Differential wealth also is recorded in architecture and artifacts. Differential resource access within a society can be seen in the archaeological record in storehouses attached to palaces, and the size, construction, and decoration of the palaces themselves as contrasted to the housing of the majority of the population. The elites control aspects of production and distribution systems and thus accumulate wealth, they live in more

permanent and elaborate dwellings, they bury their dead with more luxurious grave goods, they commonly are "closer to the deities" and thus have greater religious power, their social prestige is superior to the commoners, and they concentrate power in their hands. In the cases considered in this paper there is sufficient archaeological evidence to characterize a society as egalitarian or complex, and in many cases finer distinctions can be made. Centralization of authority can be detected in control of labor, power in military or police functions, or in religious authority and control.

This paper does not focus on the deaths, injuries, or devastation of the built and utilized environment caused directly by the eruptions. The archaeological and geological records are weak in this regard. Gathering systematic regional data on these topics would require immense research efforts. Rather, the record is more suitable for studying human behavior in the environment in the long-term, over the centuries following an eruption, to see recovery or the lack of recovery of the society, culture, and/or adaptation.

Of course, volcanic activity in general terms can be beneficial or detrimental to human adaptation to an environment, in different ways at different times. The tapestry of human-volcanic interactions is a rich and varied one, into which this paper can only begin to explore. The cliché of Juan Valdez, of Colombian Coffee fame, cultivating his rich volcanic soils can be true, but only after weathering has formed that soil. A volcanic ash fall that formed a fertile soil after decades of soil genesis can have a chemically similar coeval lava flow beside it that required centuries to form an equally fertile soil. Volcanically active areas often provide key resources such as obsidian that can be fashioned into sharp cutting and scraping tools, basalt and andesite for grinding implements, and hematite and other pigments. Further, volcanically active areas are seismically active as well, and indigenous societies generally developed earthquake-resistant vernacular architecture. Within the range of benign-to-devastating volcanic phenomena this paper focuses on sudden explosive eruptions and how ancient societies coped with them, or

failed to cope with them. There are other highly destructive volcanic phenomena such as mudflows that are beyond the scope of this paper. They are not included here largely because the prehistoric cases rarely have been documented from both natural and social science perspectives.

Because of the thousands of years of human occupation in Middle America (Mexico and Central America), and the frequency of volcanic eruptions, the number of times that Precolumbian societies were affected by explosive volcanism must have been great. The number of cases that have been researched and adequately documented is small, but at least sufficient to begin establishing a comparative framework, and those cases are presented below. Ideally, one would wish to have a sample size sufficient to explore a single variable such as societal complexity, to see the degree to which the internal organization of societies was a factor in their reaction to sudden explosive volcanic stress. But, the range of significant variables in volcanological-human societal interactions is considerable, and it is often difficult to determine the relative importance of factors such as the nature and magnitude of the eruption, vulnerability of flora and fauna to stress from tephra (volcanic ash, cinders, etc. that moved through the air), duration and dating of eruptions, chemical and grain size variation, climate, weathering rates and recovery processes, in addition to political, economic, demographic, and social factors of the affected and the surrounding societies. Thus, anything approaching a statistical analysis is not possible with the present state of knowledge, and this study is best seen as exploratory.

The significant variables to be considered in comparing and contrasting cases where explosive eruptions affected societies range from natural to social and cultural factors. They include the nature of the tephra (depth, chemical and physical properties, area and nature of emplacement), the climate, and the particular edaphic requirements of cultigens. Sociocultural factors include the regional cultural system including possible competition for resources and warfare, the adaptation and the economy of the society affected, the political system, residential

mobility or sedentism, the density and distribution of population, reliance on fixed facilities and the internal complexity of the society affected, and the religious system.

The most useful cases for this study are those in which investigators have dated the eruption well, have done regional analysis of the extent of the tephra blanket, have conducted regional survey and excavations to document pre-eruption population density and distribution, and the timing and nature of the recovery, including soils, flora, fauna, and humans. Societies living beyond the extent of the ashfall should also be known and can be examined for possible indirect effects including the housing of refugees or taking advantage of the suddenly changed circumstances in the region such as re-routing trading systems or eliminating competitors. Regional studies determine the pattern of diminishing ash thickness with distance from the source, distinguishing the zone of devastation from the zone of less deleterious effects from the zone where a slight dusting of ash was beneficial shortly after deposition. A recent example of the latter was the crop improvement in eastern Washington state by a thin dusting of Mt. St. Helens ash from the 1980 eruption, as the tephra acted as a mulch that improved water retention and the fine grains asphyxiated many insect pests. Soil recovery and plant succession generally are more rapid on the peripheries of a tephra blanket, allowing for earlier human reoccupation. The chemical and physical characteristics of the tephra have been studied in the ideal case, noting how finer grained and more mafic (basic) tephras weather more rapidly and thus allow for more rapid recovery. The more useful cases here have documented the pre-eruption subsistence system, including the degree to which it was reliant upon wild or domesticated species, swidden or intensive agriculture, a staple crop or a wide variety of foods. Beyond subsistence, the regional economy is understood, whether it was regionally-integrated and hierarchically organized or characterized by societial, settlement, or household self-sufficiency. Similarly, the political and religious systems in the ideal cases are well understood so their roles in the impact of the sudden stress as well as the coping and recovery can be studied.

CASES

Two important variables for comparison of these cases of volcanic impacts (Fig. 1) are the depth of burial of sites and the subsistence sustaining areas of those sites. Burial by explosive volcanism is essentially instantaneous, and the depth of burial is proportional to the deleterious impact. Ideally we would wish to compare cases of volcanic impacts on regional scales but many cases are weak in this regard because they focus on a single site. In conducting regional volcanological-ecological-archaeological research in El Salvador, Panama, and Costa Rica, I and my project members have been more successful in searching for, finding, and investigating sites buried by between 1/2 to 2 meters of tephra. Sites buried by less than 1/2 meter of tephra are generally poorly preserved because of plowing, bioturbation, erosion, and other post-impact factors. The more deeply buried sites are increasingly difficult to find and excavate. Thus, an aspect of practicality inadvertently assists this study for purposes of comparability, as many of the sites under consideration in this paper had approximately similar depths of burial with approximately similar tephra impacts on the environment and roughly comparable effects upon those sites and their sustaining areas. Some more deeply buried sites, such as Cuicuilco and Ceren, are also considered here, but in less detail.

Arenal, Costa Rica

People occupied the Arenal area of northwestern Costa Rica for at least the last 10,000 years, most of which was prior to the earliest eruption of Arenal volcano about 2000 BC (Sheets 1994). Arenal volcano erupted ten times in 4 millenia with major explosive eruptions (Melson 1994), including the 1968 eruption, an average of one per 400 years. These eruptions provide cases of sudden stresses on egalitarian social groups with diversified subsistence economies and relatively low population densities. The eruptions that are relatively well dated and understood are here presented (Table 1) within the context of the regional culture history as discovered by the Arenal Research Project (Sheets 1994). All of Arenal's precolumbian eruptions affected

egalitarian societies (ibid.). Thus, the Arenal area provides a contrast to most of the other cases in Middle America where explosive volcanism affected more complex societies with quite different adaptations and political and economic systems, and greater population densities. Therefore the Arenal eruptions and affected societies are examined more closely than most other cases in this chapter.

The hilly research area spans the continental divide, with elevations on both Atlantic and Pacific drainages ranging from 400 to 1000 meters. Mean precipitation varies considerably, with averages as low as 1300 mm at low elevation western stations to averages over 6000 mm at stations in the east close to Arenal volcano. That moisture gradient correlates with a vegetational spectrum from a tropical dry-seasonal forest to a non-seasonal dense rainforest. The erosional potential of some very moist areas is so great that it is against federal law to cut trees.

PaleoIndian peoples (est. 10,000-7000 BC) lived in the area in apparently very low population densities, as evidenced by the recovery of only one datable artifact to that time. However, population increased significantly during the Archaic (est. 7000-3000 BC), as detected by datable sites and artifacts. The Arenal area is unusual in Middle America in that regional population density did not continuously rise after plant domestication occurred, but remained relatively constant. The utilization of domesticated foods certainly began by 2000 BC, and perhaps by 3500 BC, but the dating is not precise. Maize was cultivated by that 2000-3500 BC time horizon, but beans and squash are not confirmed in the record until later. Sedentary villages, with heavy (therefore not portable) metates and manos presumably to grind maize, accompanied the addition of mazize. In contrast to most areas of Middle America, domesticated plants supplied only a small fraction of the diet, evidently no more than 12%, as a greater reliance was placed on wild flora and fauna even up to the Spanish Conquest. Other aspects of Arenal area culture that showed no change from the Archaic to the Conquest are the basic core-flake lithic technology and the use of heated stones for cooking in villages and cemeteries. We

were not able to detect any changes in the circular houses with activity areas and (presumably) thatch roofs from early Formative times to the Conquest. Other aspects of culture did change, and the key question considered here is whether any of the changes can be attributed to stresses caused by the biggest explosive eruptions of Arenal volcano.

Eruption	**Date (est.)**	**Cultural Phase**	**Immediate Effects**	**Long-term Effects Detected**
Unit 10	AD 1968	Historic	Initial Abandonment	Too early to know
Unit 20	AD 1450	Tilaran	Abandonment	None
Units 41 & 40	AD 800	Silencio	Abandonment	Population concentration in Rio Piedra
Units 53 & 52	AD 1	Arenal	Abandonment	None
Unit 55	800 BC	Tronadora	Abandonment	None
Unit 61	1800 BC	Tronadora	Abandonment	None

Table 1. Principal Explosive Eruptions of Arenal Volcano, Costa Rica. Moderate to small eruptions, or poorly dated eruptions, are not included. "Units" are volcanic ash layers that are numbered sequentially, with the earliest eruption unit having the largest number.

Arenal volcano first erupted at about 1800 BC (Melson 1994), thus causing the first of ten massive stresses for people and beginning the detailed human-volcanological interaction record. That explosive eruption, which deposited a thick tephra layer we call Unit 61, resulted in the devastation of many km^2 of rainforest and gardens, and certainly eliminated human habitation for a large area surrounding the volcano, particularly on the western (downwind) side. However, survivors on the periphery of the devastated zone, a few generations later, reoccupied the area

after soil and vegetation recovery had occurred. The Tronadora phase, conservatively dated from 2000 to 500 BC, is characterized by numerous small villages scattered across the landscape. People lived in circular houses and buried their dead just outside those structures in small rectangular pits with occasional ceramic vessel offerings. The small pit sizes probably indicates the burials were secondary (disarticulated). Maize was cultivated and processed with manos and metates, but probably was a minor part of the diet, as numerous wild species were utilized. The ceramics were surprisingly sophisticated in technology and decoration and show relationships with those in southern Mesoamerica (Hoopes 1987). The phase had been underway for at least two centuries, and perhaps as much as 1700 years, when Arenal volcano first erupted.

Toward the end of the Tronadora phase at about 800 BC, Arenal's second huge explosive eruption occurred. It deposited Unit 55 throughout the area, resulting in a similar devastation of flora, fauna, and human populations. As we compare pre- and post-eruption conditions of both of these eruptions, we are not able to detect any culture changes that can be attributed to the disaster. People certainly had to abandon the area for a few generations, but the reoccupants were culturally indistinguishable from the pre-eruption occupants. That resilience to volcanic disaster continued to characterize Arenal area society for 3500 years.

It was during the Arenal phase (500 BC - AD 600) that population density reached its peak in the area. Although never approaching the high densities of Mesoamerica during these same centuries, there were more and larger sites than at any other time in the Precolumbian period in the Arenal area and much of the rest of Costa Rica. Domestic housing remained unchanged. Human burial was in discrete cemeteries on ridges above and a few hundred meters away from the villages. They shifted from secondary burials of the Tronadora phase to elaborate primary burials with plots demarcated by outlines of upright stones. Then, a layer of round cobbles was laid between the upright stones, and dozens of whole vessels and decorated metates were smashed on the rocks and left in place. Two volcanic ash layers (Units 53 and 52) fell

about the middle of the phase, at about the time of Christ, with very little time separating them. Although individually thinner than the other major tephra blankets considered here, the combined deposits are about as thick as the other big eruptions and therefore probably had ecologic and demographic impacts similar to the earlier big eruptions. The eruptions do correlate with a sub-phase cultural boundary, the shift from the early to the late facet, identified by subtle changes in ceramic decoration. These changes apparently were a local manifestation of regional culture change in the Greater Nicoya cultural area rather than an effect of the volcanic disaster. I believe the important point is that they occurred in spite of the eruption, rather than because of it.

A mild population decline occurred at the beginning of and during the Silencio phase (AD 600-1300), as both large and small sites declined in number, a change that also occurred in most of lower Central America for unknown reasons. That process clearly was not caused by volcanism, but at most it could have been accelerated locally by volcanic activity during the 9th century. Chipped stone and ground stone industries show little change, and ceramics indicate considerable continuity, but with the addition of polychrome painting. Cemeteries are located at still greater distances from villages, as exemplified by the Silencio cemetery located on the continental divide many kilometers from the villages that utilized it. Burial practices remain elaborate, and have adopted the stone box technique: using flat-fracturing andesite slabs to create a stone coffin along the two sides and on top.

At about AD 800 or 900 two large eruptions (Units 41 and 40) occurred in rapid succession during the Silencio phase. They must have had ecologic and demographic effects as drastic as the earlier big eruptions, as their magnitudes are comparable. As with the earlier recoveries, the culture that re-established itself is indistinguishable from that prior to emplacement. It is possible that the increase in population in the western end of the study area during the latter part of the phase was a result of the eruptions (Mueller 1994: 63). That area

received less volcanic ash from the two eruptions than the rest of the study area and could have served as a refuge area. If this interpretation is correct, it is the sole example of our being able to detect a human change attributable to volcanic pressures in the Arenal area at any time. That demographic shift is detectable for perhaps three centuries.

With the disappearance of the last larger sites as well as a decline in the number of smaller sites, the population decline of the Silencio phase continued through the Tilaran phase (AD 1300 - 1500). The quality of ceramic manufacture and firing as well as elaborateness of painted decoration also decline dramatically in this period. The primary cultural affiliation of Arenal area peoples during all previous phases had been to the west with Greater Nicoya and ultimately with Mesoamerica, but that reversed itself as the primary affiliation shifted eastward toward the Atlantic watershed and the Meseta Central. The reasons for that change are not clear, but it does not coincide with any volcanic activity and thus it apparently had nothing to do with volcanism. Toward the end of the phase, at about AD 1450, Arenal emitted one of its largest eruptions of all times, depositing the thick Unit 20 across the landscape. It appears that the combination of this eruption and the Spanish Conquest, with the attendant diseases, was too much stress for local native societies, and they disappeared from the area.

In summary, the resilience of Arenal area society to the sudden environmental stresses of explosive volcanism is extraordinary, particularly in contrast to the cases below. Only once can we find a significant change in human occupation, beyond the immediacy of the disaster, that persisted and perhaps was caused by volcanism. Thus, what is striking about Arenal area societies is their resilience to explosive volcanism that occurred on the average of every four centuries. That resilience probably is based on a number of factors, each of which is explored and contrasted to the other more complex societies considered in the rest of this chapter. One is the high degree of Arenal village self sufficiency, as most food, building materials, clay, and stone for chipped and ground stone implements were available locally. Only the material for

stone axes was obtained from a distance, and that was not a very great distance, only a day's walk away. Domesticated foods were a small portion of the diet, so the elimination of gardens removed only a fraction of the diet. Relocating survivors could increase their exploitation of wild flora and fauna to compensate for lost cultivated foods in areas beyond the devastated zones. I suspect another major reason Arenal societies were so resilient is that even during the millennia of sedentism following 2000 BC they still maintained a reasonably high degree of residential mobility, and the technology that supported it. The archaeological record for the Silencio phase, for instance, clearly indicates that households would establish temporary residence at cemeteries at considerable distances from their village and use boiling stones instead of heavy ceramic cooking vessels, and presumably collect wild flora and fauna as food sources. Finding some maize pollen at cemeteries, with no villages for many kilometers, indicates they even cultivated crops at those distant localities to provide a source of food for people involved in the elaborate feastings and ancestor worship. A periodicity of a few hundred years is well within the capibility of traditional societies to maintain an oral history of volcanism and their adjustments, and that may have aided Arenal area societies in dealing with those massive stresses.

Panama

Research in western Panama (Linares, et al. 1975, Linares 1977, Linares & Ranere 1980) discovered an example of volcanism affecting a society intermediate in complexity between Arenal and the Mesoamerican cases. The Barriles chiefdom developed in the upper reaches of the Rio Chiriqui Viejo from about 200 BC until the seventh century AD. Although they are called a chiefdom, they actually were a series of chiefdoms along watercourses in western Panama and eastern Costa Rica sharing the same culture and presumably language. In spite of the shared characteristics they fiercely defended their own individual chiefdoms (polities), and in so doing they developed an iconography clearly depicting aggression, capture, and human

sacrifice by decapitation. The eruption of Volcan Baru during the seventh century AD deposited a layer of tephra comparable in thickness to those deposited by Arenal on sites mentioned in the previous section. That explosive eruption evidently caused a permanent abandonment of the Barriles-Cerro Punta area by Barriles peoples, as they or their descendants never reoccupied the area. The other chiefdoms farther downriver were not as heavily impacted and weathered the stress in situ. Linares and Ranere (1980:244-45) believe some of the Barriles residents migrated northward over the Continental Divide and founded sites on the Atlantic drainage such as those in the Bocas del Toro area. In contrast to the facility of recovery of Arenal peoples, the Baru tephra had a much greater effect on local populations, and centuries later when Precolumbian people finally did reoccupy the valley, they were not the descendants of the societies that lived there before the eruption, as evidenced by the dramatic and fundamental differences in artifacts and decorations.

I suspect the reason Baru's cultural impact was greater than Arenal's was because the Barriles chiefdoms were relying on maize as a staple, with a more intense adaptation, more fixed facilities, and a more complex or rigid political, economic, and social system. Even more importantly, the Barriles chiefdoms were functioning within a more demographically dense and fully utilized landscape with competitive aggressiveness marking inter-polity relationships indicates a lack of land into which migrants could settle. Related to that ecologic scarcity there probably was a lack of desire and incentive for a relatively intact polity (beyond the zone of negative volcanic impact) to assist the survivors of a suddenly stressed polity that was an adversary. In fact, the degree of competitive aggressiveness between polities is greater than in any other of the cases presented in this paper, and probably is the reason why that eruption had a more dramatic societal impact than would be predicted by ecological factors alone. Survivors in the two uppermost Barriles chiefdoms could expect hostility if they tried to move farther downriver into other chiefdom’s territories, and thus had to migrate over the continental divide

into the very moist non-seasonal tropical rainforest to the north, near the Atlantic shoreline. As this was the only known eruption to have affected western Panamanian societies in the two millenia prior to the conquest, it may have caught them without any oral history of such phenomena, and thus less prepared than their Arenal neighbors.

El Salvador

El Salvador provides a few cases of eruptions and their effects on Precolumbian societies, ranging from the immense eruptions of Coatepeque and Ilopango to the small and highly localized Loma Caldera eruption (Table 2). The huge Coatepeque eruption, dated to between 10,000 and 40,000 years ago, may predate human occupation in Central America. The societies affected by the post-Coatepeque eruptions were more complex than those affected by eruptions in Costa Rica and Panama. Of course the magnitude of the eruption is correlated with the magnitude of ecologic and societal disruption, but it is a major point of this paper that it is not the only primary variable. It appears that the more complex Salvadoran societies were more vulnerable to explosive volcanic stresses than were Costa Rican societies. Holocene eruptions in El Salvador, of which these considered here are only a few, were sufficiently frequent that we can reasonably expect Precolumbian Salvadoran societies to have maintained oral histories of them and how to deal with them.

Eruption (source)	**Date**	**Km^2 Covered**	**Regional Effects**
El Playon	AD 1658-1659	30	Slight
El Boqueron (San Salvador Volcano)	est. AD 900-1100	300 (deeper than 7 cm.)	Moderate

Loma Caldera (Ceren tephra)	AD 590 ± 90	less than 5	Insignificant
Ilopango (Tierra Blanca Joven)	AD 260 ± 114 or summer AD 175 (by ice cores)	10,000 (deeper than 50 cm)	Massive and long lasting

Table 2. Four Explosive Eruptions affecting Societies in Central El Salvador during the past 2 Millennia.

The white volcanic ash layer that buried ancient artifacts in central and western El Salvador has been the subject of intermittent interest by archaeologists and geologists for much of the 20th century, beginning with Jorge Larde in 1917 (Larde 1926, Lothrop 1927, Vaillant 1934, Porter 1955, Boggs 1966, Schmidt-Thome 1975, Sharer 1978, Sheets 1979, Hart and Steen-McIntyre 1983. Called the "tierra blanca joven" or "TBJ," it was erupted from a volcanic vent under the west end of Lake Ilopango. It is radiocarbon dated to AD 260 ± 114 (calibrated, with a one sigma range from AD 146 to 374), but a more precise dating may be provided by comparison to ash layers found in Greenland ice cores. A volcanic ash began falling in the summer of AD 175 in Greenland which might be Ilopango has a relatively high silica content of 69%. The Ilopango ash is 69% silica (Hart and Steen-McIntyre 1983). Where it is well preserved at Chalchuapa, 77 km from the source, it is over 1/2 m thick, indicating a regional disaster of major proportions.

The Ilopango eruption occurred in three phases. First, a great explosion deposited a thin, relatively coarse pumice across the countryside, to a radius of about 30 km. This was followed by two colossal pyroclastic flows that headed north to the Rio Lempa and west into the Zapotitan valley. These were unusually massive and long, stretching for more than 45 km. The one that headed west had sufficient impetus to flow up and over the Santa Tecla (Nueva San Salvador)

pass at 1000 m elevation and then down into the Zapotitan valley, even though the vent elevation is only 500 m above sea level. Both of these first stages were devastating to flora, fauna, and people in their paths, but the third phase was even more damaging regionally. That was an immense blast of very fine grained volcanic ash that fell over all of central and western El Salvador, and must have been significant in adjoining southern Guatemala and southwestern Honduras. The eruption must have blasted tephra well into the troposphere, so finding Ilopango ash in Greenland ice cores should not be surprising.

Some 8000 km^2 may have been rendered uninhabitable by the Ilopango eruption. Segerstrom (1950) found that 10 to 25 cm of volcanic ash was too much for traditional agriculturalists to cope with in Mexico after Paricutin erupted, and natural processes of tephra erosion, weathering, soil formation, and plant succession were necessary before the affected area could be reoccupied by cultivators. Depending on the tephra and the environment, those processes can take decades or centuries. Given a conservative estimated regional population density in central El Salvador of forty people/km^2, one can very roughly estimate that some 320,000 people could have been killed or displaced by the eruption (Sheets 1979). The fact that the TBJ tephra was highly acidic (sialic) rendered the impact more drastic and the recovery delayed, as more mafic materials weather more rapidly. The dozens of sites in the Zapotitan valley buried by some 1-2 m of Ilopango tephra are comparable in tephra depth to many of the sites in the Arenal area. The contrast is how different the pre- and post-eruption societies were in El Salvador, and how similar the pre- and post-eruption societies were in Costa Rica. To some degree that contrast is due to more rapid culture change in Mesoamerica compared to the Intermediate area, and to the greater area devastated by Ilopango, and to some degree it is due to greater resilience to perturbation by Arenal societies for a number of inherent reasons.

Many areas of central and western El Salvador were abandoned for a century or two (Sheets 1979, 1980). Many archaeologists have noted the striking population decline along

Guatemala's Pacific coastal plain at about this time (e.g. Shook 1965, Bove 1989), which probably was a result of the environmental damage caused by the Ilopango ashfall.

Flooding is a common aftermath following a volcanic ash deposit in a river's headwaters, as protective vegetation is killed or suppressed. The flooding reported at so many sites in western Honduras at the Formative-Classic boundary likely was caused by the Ilopango tephra and resultant heavy runoff and redeposition (Sheets 1987). This includes sites such as Copan, Playa de los Muertos, Pimienta, and Los Naranjos. Even some sites as far away as Barton Ramie in Belize witnessed flooding at about this time, but that is at a considerable distance from Ilopango, and it may have occurred there for quite different reasons. In Middle American areas where only a few mm to cm of Ilopango tephra were deposited, the deleterious affects probably were minimal and the light dusting could have been beneficial in the first year after emplacement.

Central El Salvador was affected at least three more times by explosive volcanism after the Ilopango eruption (Sheets 1983, 1992a). The Loma Caldera volcanic vent opened up underneath the Rio Sucio and initiated a series of 14 alternating lateral blasts and airfall volcanic ash and lava bomb units that buried a few square kilometers of the Zapotitan Valley, including the Ceren site. From the evidence of artifact placement and plant maturation, the eruption occurred in the evening, during the month of August, c. AD 590, with sufficient warning that the inhabitants could literally "head south," but without enough warning to remove their possessions. Although it had devastating consequences for the inhabitants of the Ceren village, this eruption was so small as to have had no detectable effects on the course of societal change in southern Mesoamerica. The Loma Caldera eruption was followed a few centuries later by a moderately large eruption of San Salvador volcano (Boqueron eruption) at about AD 900 or 1000 that did negatively affect some 200 to 300 km^2. The Boqueron eruption interfered with cultivation for a

few decades, and must have had a negative impact on San Andres and surrounding settlements for quite some time, but unfortunately the research at that key site remains unpublished.

Playon was the most recent explosive eruption to affect the Zapotitan valley, beginning late in 1658, and burying 30 km^2 under lava and a larger area under tephra. Although soils on the Playon lava have barely begun to recover from their pre-eruption state, and support only a scrub vegetation, soil recovery on the tephra is now sufficient to support intensive agriculture. All three of these post-Ilopango eruptions caused severe problems for villages and households near the sources, but they cannot be seen as having had long lasting societal repercussions and certainly were not massive regional natural disasters. Of the post-Ilopango eruptions, only Boqueron probably had significant negative societal effects lasting perhaps for a few decades.

MEXICAN CASES OF VOLCANISM AND ANCIENT SOCIETIES

Matacapan & the Tuxtla Volcanic Field

Matacapan, in the Tuxtla Mountains in the Mexican Gulf, has been investigated by Santley (1994) and Reinhardt (1991). The Formative occupation was interrupted by almost a millenium by a large eruption (Table 3), but population and society recovered and grew to maximum size by the middle of the Classic period, in spite of some smaller eruptions.

Volcanism in the Tuxtla Volcanic Field (TVF), located some 150 km SE of Veracruz, Mexico, has been studied by Reinhardt (1991). The younger (last 50,000 years) volcanic sequence covers some 400 km^2, with an average frequency of eruptions of at least four per 1000 years, an activity rate almost twice that of Arenal during the past 4000 years and comparable to central El Salvador in the past 2000 years. The most recent eruptions that are preserved in the stratigraphy at the Matacapan archaeological site date to the Late Archaic to the Middle Classic Periods. The earliest of these occurred about 3000 to 2000 BC and its effects on surrounding populations are unknown. Societies at that time would have been egalitarian and probably at least semisedentary, with a mixed domesticated and non-domesticated subsistence base. It is

likely that village life was emerging in the area at that time, but regional population density would have been quite low, compared to Formative and Classic times. The eruption left a relatively thin deposit, some 15 cm, at Matacapan.

The second TVF eruption dates to the Early Formative, about 1250 BC, and deposited the Cerro Mono Blanco (CMB) tephra. Matacapan was occupied at the time by egalitarian agriculturalists and tephra buried the maize ridges of an agricultural field. The society affected was relatively simple, as small villages dotted the landscape. The deposit, as measured from Reinhardt's drawn sections, is moderately thick, over 60 cm. The area was abandoned for some 9 centuries, but was reoccupied during the Late Formative. Thus, the second eruption appears to have been much bigger than the first, at least from the Matacapan perspective, and it had exceptionally long-lasting deleterious effects on settlement.

The third TVF eruption, at about AD 150, buried Late Formative remains in the Matacapan area under the Cerro Nixtamalapan (CN) tephra. It is about 40 cm thick on Reinhart's section (1991:86). Given that the decline of Olmec civilization was largely complete by this time, and the local Classic period societal resurgence had yet to occur, I would presume the volcanism affected relatively simple societies, probably egalitarian villages. As with the second eruption, the area was abandoned, clearly indicating significant initial impact of a substantial eruption. However, the abandonment lasted only for a short while.

At about AD 400, during the Early Classic, two closely spaced eruptions (no evidence of soil developed between the layers) deposited the Cerro Puntiagudo (CP) and the Laguna Nixtamalapan (LN) tephras. These evidently had less of an impact than the other TVF tephra emplacements, as the site apparently was not abandoned. I estimate their thickness from Reinhart's sections at only about 20 to 30 cm. The society affected would have been moderately complex, perhaps a chiefdom, but this is uncertain. It appears the stress caused by this relatively thin deposit was within the resilience of the agroeconomic adaptation, and it is possible that for

the cultingens that have roots sufficiently deep to tap into the pre-eruption soil, the tephra could have been beneficial as a mulch layer. The tephra thickness is barely withing what Segerstrom (1950) found to be within the resilience of traditional agriculture in Mexico.

The final eruption occurred in the middle of the Classic period, about AD 600, and the tephra measures some 40 to 45 cm in thickness in the sections. It sealed an agricultural field with maize ridges under it. Compared to the above Matacapan examples, this is a moderately large eruption, and societal complexity as well as population density were at a peak at this time. Coincident with the ashfall is the reversal in Matacapan's fortune. Matacapan's population began to decline during the 600's, a part of which I suspect may have been caused by the ecologic stress of volcanic ash deposition. It should be noted that Santley and Arnold (n.d.) came to the opposite conclusion, as they note that volcanism in the Formative caused abandonments and major population resettlements, while volcanism in the Classic did not have the same results. Their suggested explanation is the ability of the state to harness energy and labor on a larger scale and thus cope better with these sudden massive natural stresses.

Period	**Tephra**	**Date (approx.)**	**Thickness (est. from sections)**	**Effect on habitation**
Middle Classic	Laguna Cocodrilos	AD 600	40-45 cm.	moderate impact on complex society, gradual but consistent decline
Early Classic	Laguna Nixtamalapan & Cerro Puntiagudo	AD 400	20-30 cm	none detected, occupation continues.

Late Formative	Cerro Nixtamalapan	AD 150	40 cm	significant impact, abandonment, rapid recovery
Early Formative	Cerro Mono Blanco	1250 BC	60 cm	900 yr. long abandonment, major impact on simple society
Late Archaic	n. a.	3000-2000 BC	n. a.	unknown

Table 3. Volcanism and Human Settlement in the Matacapan Area, Tuxtla Mts, Mexico. ("n.a." means not available.)

The relative ecologic-agrarian-societal stresses caused by various volcanic eruptions can only be researched if their magnitudes and distributions are understood and can be compared. Because such information is not yet available for the TVF, and lacking other indications, the relative magnitudes can only be approximated very roughly by comparing tephra depths from measured sections. I believe it is significant that the thickness of tephra correlates directly with the societal impacts of the eruptions at Matacapan, as the thinnest of ash layers (CP and LN at c. 20 cm) did not cause abandonment, but the thicker layers did cause abandonment proportional to their thickness (CMB at about 60 cm and CN at 40 to 45 cm). The LC tephra, about 40 cm thick, correlates with demographic and societal declines, and the site never recovered. However, viewing societal impacts from only a single site can be very misleading, and regional research is needed to understand Tuxtla impacts and recoveries. What is needed in the TVF (as well as in other Middle American cases) is isopach (depth and distribution) mapping of each unit, with estimates of the magnitude, volume, and distribution of each tephra, and documentation of soil recovery as well as human reoccupation, within a well-dated natural and cultural framework.

Chase (1981) argued that an eruption of San Martin volcano at some time around 600 BC in the Tuxtlas caused sufficient damage to the utilized landscape in the Tres Zapotes area to have rendered it uninhabitable, and migrations of tens of thousands of people resulted. He relied on stratigraphic information from Drucker's research at Tres Zapotes. Unfortunately, the dating of the eruption is rather speculative, as it is not based on extensive data, and the sourcing of the tephra is weak. This tephra might be from the same eruption as the CMB or CN tephra at Matacapan, or it may be unrelated.

Popocatepetl volcano and Cholula, Puebla, Mexico

For the past couple decades a number of separate discoveries of volcanic ash burying cultural features have been made in Puebla, generally to the northeast, east, or southeast of Popocatepetl volcano. Seele (1973) reported well-preserved maize ridges under white airfall tephra at San Buenaventura Nealtican, and others have reported other maize ridges or artifacts buried by primary or secondary volcanic deposits in the general area. Fortunately, Siebe et al. (1996) are working to synthesize these isolated discoveries into a regional interpretive framework. They have found evidence of three major eruptions of Popocatepetl at about 3000 BC, between 800 and 200 BC, and probably at AD 822. The earliest eruption was characterized by a series of large phreatomagmatic (magma in contact with water resulting in steam explosions) eruptions resulting in multiple surge deposits followed by a thick pumice deposit and ending with a number of ash flows that extended over 50 km from their sources. The effects on late Archaic populations are unknown, but must have been devastating. The recovery of soils, vegetation, and human societies resulted in reasonably dense occupation by the first millennium BC, buried by the “Lower Ceramic Plinian” eruption. This eruption consisted primarily of a thick widespread andesitic pumice deposit followed by ash flows and lahars (mud flows) radiating from Popocatepetl. These primary and secondary deposits buried agricultural fields (e.g. Seele 1973), artifacts, and other cultural features. Even household groups with talud-tablero

(sloping panel with overhanging vertical panel) architecture are buried, dating to a few centuries prior to that architectural style's appearance in Teotihuacan. The migrations forced by this eruption may have brought talud-tablero architecture to the northern Basin of Mexico. The eruption's effects on habitation on or near the slopes of Popocatepetl were obviously devastating, but its effects on Cholula and the Puebla Valley, or the southern Basin of Mexico, are not clear.

The third eruption, called the Upper Ceramic Plinian, is primarily composed of surge deposits from phreatomagmatic explosions followed by pumice falls and extensive lahars. The age of AD 822 is from a Greenland ice core (Seibe et al. 1996), but the detailed geochemistry to confirm that association has yet to occur. Massive lahars filled the Puebla basin and Atlixco valley after the eruption, having apparently devastating effects on settlement. Lahar deposits a few meters thick buried architecture at Cholula, and are clearly visible to the visitor today. They must have devastated agriculture for many square kilometers around Cholula for many decades. I suspect that the weakened Cholulan society was unable to resist the intrusion of Putun Maya, resulting in settlements such as Cacaxtla.

The cultural, economic, political, and demographic effects of these large eruptions, as well as smaller ones reported by Siebe et al (1996), remain unknown. Archaeologists have reported cultural and architectural declines and florescences (e.g. Weaver 1993), and two of the declines Weaver reports do approximately correlate with the later two large eruptions, especially in the Late Classic. Correlations are intriguing, but establishing probable causalities will require regional interdisciplinary research. Here is a regional integrated archaeological-volcanological project crying to happen, with the high probability of significant results. Such a project could go far to understand the beneficial and detrimental aspects of living in volcanically active areas, and to explain demographic and societal declines and surges in this area. The Puebla area is one of the most culturally important areas of ancient Mesoamerica, yet it remains one of the most poorly studied on an integrated regional basis.

The Basin of Mexico: Cuicuilco and Xitle Volcano

In the Basin of Mexico, Niederberger (1979) documented the emergence of sedentary human communities in the resource-rich lacustrine environments of the Chalco and Xochimilco basins by the sixth millennium B.C. In the southern part of the Basin of Mexico these communities were devastated by a series of volcanic deposits at about 3000 B.C. Because that is the same time as the earliest Popocatepetl eruption documented by Siebe et al (1996) I suggest this may be the northwestern component of the same eruption. Niederberger (1979) refers to the deposits as a series of nuees ardentes ("glowing clouds" or pyroclastic flows of hot volcanic ejecta and gasses that flow rapidly downhill) leaving thick white pumice layers. They are thick enough to have caused ecologic and human societal devastation, and because of their sialic composition and the high elevation I would expect slow weathering rates and thus slow environmental recovery, on the scale of a few centuries. Adams (1991:38) finds Niederberger's interpretation convincing and states that it took some five centuries for human reoccupation of the area.

The case of the Xitle eruption in the southern Basin of Mexico some 1500 to 2000 years ago remains controversial, and probably will remain so until a regional multidisciplinary project is conducted to resolve a number of issues. To date, many individual archaeologists and geologists have conducted small and localized investigations, and the interpretations vary widely. Many scholars have noted that the demise of Cuicuilco, the site that had been the dominant polity of the Late Formative in the Basin of Mexico, the rise of Teotihuacan, and the eruption of Xitle may have been causally interrelated. Parsons (1974, 1976) suggests Xitle devastated Cuicuilco in the first century AD and thus facilitated the rise of Teotihuacan. Similarly, Diehl (1976) notes the political ascendancy of Teotihuacan and suggests it was in part because Xitle's elimination of Cuicuilco as a competitor. Adams (1991:109) dates the volcanic destruction of Cuicuilco to about 150 B.C., correlating with its decline.

A major problem in exploring human-volcanic interaction in the Cuicuilco area is dating of the eruption of Xitle. Cordova, Martin del Pozzo, and Camacho (1994) reviewed the attempts to date the eruption. They note that the early research efforts dated it to around 400 BC, while more recent efforts dated it to the third century AD to as late as AD 400. They conclude that the most accurate radiocarbon date is 1536 $\pm$ 65 BP, or about AD 400. They also feel that Cuicuilco had been abandoned well before the eruption. If these conclusions are correct, the demise of Cuicuilco certainly was not caused by the Xitle eruption, and its abandonment may have been caused by the expansion of, and competition from, Teotihuacan, thus neatly reversing the causality and plucking it from the volcanological domain and placing it in the cultural domain. Heizer and Bennyhoff (1958) noted the deterioration of Cuicuilco architecture prior to burial by the Xitle lava, indicating abandonment prior to the eruption. If this later dating of the eruption is substantiated, a study still needs to be done to explore the demographic-ecologic-societal implications of burying some 75 km^2 of the most fertile land in the Basin of Mexico under basaltic lava during the early Classic period. Recent research indicates the most accurate dating of the Xitle eruption is about the time of Christ (Urrutia-Fucugauchi (1996), and Claus Siebe personal communication 1997), thus putting it at about the same time as the large eruption of Popocatepetl that devastated such a large area of Puebla. If these more recent datings are more accurate, then the demise of Cuicuilco and the devastation of the southern basin and Puebla could have facilitated the rise of Teotihuacan.

During a survey conducted shortly after World War II Gifford (1950:185)) found a deep pumice deposit over early (Late Formative) artifact-bearing layers in the Ixtlan del Rio area of southeast Nayarit. Many sites were under 3-4 meters of tephra, and Gifford attributed the eruption to Ceboruco Volcano, but that was not convincingly demonstrated. Certainly the eruption was of sufficient magnitude to be the reason for a decline in cultural complexity in the area, but so little research has been conducted there that the topic remains speculative.

Summary and Conclusions

Although the sample of reasonably well researched cases where Precolumbian Middle American societies were affected by explosive volcanism is small, at least some patterns are presented here in a preliminary fashion. The trends or patterns are presented as five factors, each of which is explored for the range of variation seen in the data, and each is examined for the ways in which it affects the resilience or vulnerability of societies. The factors are demography, experience, adaptation, economy, and politics.

Demography, in terms of the distribution and density of population, played an important role in how Precolumbian societies reacted to sudden massive stresses of explosive eruptions. At the low end of the spectrum were the Arenal societies of Costa Rica, with very low regional population densities that mainfested themselves as small villages scattered along river courses and lake shores. The fact that the Costa Rican societies maintained remnants of residential mobility by living for significant periods of time in graveyards probably assisted their sudden need for mobility in the face of an eruption from Arenal volcano. And, the low regional populations afforded opportunities for refugees without threatening surrounding populations. In contrast, the city of Cholula and the densely populated region around it was highly vulnerable to the large eruptions of Popocatepetl volcano. Part of that vulnerability is the fact that surrounding arable lands for many hundreds of km were similarly densely occupied, making migration difficult. Cuicuilco and El Salvador some 2000 years ago were similar to Cholula, but with less population, and those two cultures did not recover.

The factor of experience, and the decision making that results from it, is difficult to reserch archaeologically in non-literate societies. However, non-literate societies commonly retain accurate oral histories for many generations, often for centuries, and thus some possibilites should be considered here. Given the high frequencies of eruptions in the Tuxtlas, highland

central Mexico, El Salvador, and Costa Rica, it is likely that societies in these areas did maintain oral histories of eruptions. It is much less likely that the Barriles chiefdoms in western Panama had similar oral histories because of the rarity of known eruptions in that area. Similarly, Workman (1979) found that the high frequency of eruptions in southwestern Alaska and the Aleut's oral traditions assisted recovery. That contrasted to the rarity of eruptions in the inland Yukon and the non-recovery of northern Athabascans from the Mt. St. Elias eruption. According to Boehm (1996) it would be erroneous to assume that simpler societies are less capable of efficient decision making in the face of crisis than are more complex societies.

The factor of adaptation is very important, ranging from the extensive adaptation of the Arenal societies to the intensive adaptations of Mesoamerican states. The Arenal villages relied on wild (non-domesticated) sources for most of their foods, so when their gardens with the domesticated maize, beans, and squash were devastated, they had only to rely more heavily on already-exploited wild sources of food, often in refuge areas outside the zone affected by deep tephra deposits. The Mesoamerican states, as exemplified by Cholula, Cuicuilco, and Late Preclassic El Salvador, relied on maize as their staple crop, supplemented by beans, squash, and chiles. The states relied on intensive agriculture, harvesting and storing of foods during the dry season, and food redistribution as controlled by the elite. Their reliance on intensive production, fixed facilites, and vertical controls on redistribution rendered them vulnerable to massive eruptions.

The cases examined here vary widely in the factor of economics. Anchoring one end of the spectrum are the Arenal area societies where village self-sufficiency in resources is striking. Each village obtained their food, materials for artifacts, and housing construction materials from nearby or contiguous territory, and only needed a day's walk to obtain materials for their stone axes. The re-establishment of village self sufficiency as refugees from devastated zones could be achieved without too much trouble. That contrasts with the centralized economies of the

Mesoamerican states such as Cholula, where elites and their attached specialists provided ceramics, obsidian tools, and other items in exchange for commoner-produced foods and other items. Many of the elite-controlled items were dependent on trade routes that stretched for hundreds of kilometers. The centralization of economic authority in the elite in a specialized and redistributive economy is vulnerable to sudden massive stresses, as seen in the Mesoamerican cases.

Political factors also played a role in varying degrees of vulnerability. The lack of conflict among the egalitarian Arenal villages assisted in relocation following the large eruptions. The warring Barriles chiefdoms are the most striking example of the other end of the spectrum. The relatively small Baru eruption caused sufficient stress on the uppermost two chiefdoms that they had to migrate over the continental divide and change their adaptation to the non-seasonal tropical lowlands. Cholula is another example, as following the late Classic Popocatepetl eruption the aggressive and competitive Putun Maya established a fortified center overlooking the ruins of Cholula.

In general, the Precolumbian Middle American societies that shared certain characteristics found recovery from explosive volcanic eruptions more difficult. Those characteristics include sedentary large populations relying on intensive agriculture that focused on a domesticated staple, a high degree of "built environment" of fixed facilities, a vertical organization of decision making with centralized authority concentrated in the elite. That centralized authority encompassed the realms of economics, politics, and religion. The most resilient were those that maintained self sufficiency at the village level, low regional populations, continuation of some residential mobility, maintanance of a broad-spectrum adaptation, and perhaps an oral tradition of dealing with volcanic eruptions.

Figure Caption: Figure 1. Map of Middle America. Volcanoes and the Precolumbian societies affected by them that are the cases explored in this chapter are indicated. The dashed line in Honduras separates Mesoamerica to the west from the Intermediate Area (lower Central America).

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References

Adams, R. E. W. 1991 Prehistoric Mesoamerica (Revised Edition). Norman: Univ. of Oklahoma.

Boehm, C. 1996 "Emergency Decisions, Cultural-selection Mechanics, and Group Selection." Current Anthropology 37:5: 763-93.

Boggs, S. 1966 "Pottery Jars from the Loma del Tacuazin, El Salvador" Middle American Research Records 3:5. Tulane University, New Orleans.

Bove, F. 1989 Settlement Classification Procedures in Formative Escuintla, Guatemala. In F. Bove and F. Heller (Eds.) New Frontiers in the Archaeology of the Pacific Coast of Southern Mesoamerica. Anthropological Research Papers, Arizona State University, No. 39. Pp. 65-102.

Chase, J. 1981 "The Sky is Falling: The San Martin Tuxtla Volcanic Eruption and its Effects on the Olmec at Tres Zapotes, Veracruz." Vinculos 7:2: 53-69.

Cordova, C., A. L. Martin del Pozzo, and J. Lopez Camacho 1994 "Palaeolandforms and Volcanic Impact on the Environment of Prehistoric Cuicuilco, Southern Mexico City. Journal of Archaeological Science 21:585-596.

Diehl, R. 1976 "Pre-Hispanic Relationships between the Basin of Mexico and North and West Mexico." In E. Wolf (Ed.) The Valley of Mexico: Studies in Pre-Hispanic Ecology and Society. Albuquerque: University of New Mexico Press. Pp. 249-286.

Ferrero Acosta, L. 1981 "Ethnohistory and Ethnography in the Central Highlands - Atlantic Watershed and Diquis. In Between Continents/Between seas: Precolumbian Art of Costa Rica, Ed. by Elizabeth Benson. Pp. 93-103. Abrams, N.Y.

Gifford, Edward 1950 Surface archaeology of Ixtlan del Rio, Nayarit. University of California Publications in American Archaeology and Ethnography 43:2. Los Angeles.

Harris, D. 1973 "The Prehistory of Tropical Agriculture: An Ethnoecological Model." In The Explanation of Culture Change, Ed. by C. Renfrew. Pp. 391-417. Duckworth, London.

Hart, W., and V. Steen-McIntyre 1983 "Tierra Blanca Joven Tephra from the AD 260 Eruption of Ilopango Volcano" In Sheets (Ed.) Archaeology and Volcanism in Central America: The Zapotitan Valley of El Salvador. Austin: University of Texas Press. Pp. 14-34.

Heizer, R. and J. Bennyhoff 1958 "Archaeological Investigations of Cuicuilco, Valley of Mexico, 1956." Science 127:232-233.

Hoopes, J. 1987 Early Ceramics and the Origins of Village Life in Lower Central America. Ph.D. dissertation, Anthropology, Harvard University.

Larde, J. 1926 "Arqueologia Cuzcatleca: Vestigos de una Poblacion Pre-Mayica en el Valle de San Salvador, C. A., Sepultados Bajo una Potente Capa de Productos Volcanicos." Revista de Etnologia, Arqueologia, y Linguistica 1:3 and 4. San Salvador.

Linares, O. 1977 Ecology and the Arts in Ancient Panama. Dumbarton Oaks Studies in Pre-Columbian Art and Archaeology, No. 17. Washington, DC.

Linares, O. and A. Ranere (Eds.) 1980 Adaptive Radiations in Prehistoric Panama. Peabody Museum, Harvard University.

Linares, O., P. Sheets, and E. Rosenthal 1975 “Prehistoric Agriculture in Tropical Highlands,” Science 187:137-145.

Lothrop, S. 1927 "Pottery Types and Their Sequence in El Salvador. Indian Notes and Monographs 1:4:165-220. Museum of the American Indian, Heye Foundation, New York.

Melson, W. 1994 "The Eruption of 1968 and Tephra Stratigraphy of Arenal Volcano." In P.Sheets and B. McKee (Eds.) Archaeology, Volcanism, and Remote Sensing in the Arenal Area, Costa Rica. Austin: Univ. of Texas Press. Pp. 24-47.

Mueller, M. 1994 "Archaeological Survey in the Arenal Basin." In P. Sheets and B. McKee (Eds.) Archaeology, Volcanism, and Remote Sensing in the Arenal Area, Costa Rica. Austin: Univ. of Texas Press. Pp. 48-72.

Niederberger, C. 1979 “Early Sedentary Economy in the Basin of Mexico.” Science 203:4376:131- 142.

Parsons, J. 1974 "The Development of A Prehistoric Complex Society: A Regional Perspective from the valley of Mexico. Journal of Field Archaeology 1:81-108.

Parsons, J. 1976 "Settlement and Population History of the Basin of Mexico." In E. Wolf (Ed.) The Valley of Mexico: Studies in Pre-Hispanic Ecology and Society. Albuquerque: University of New Mexico Press. Pp. 69-100.

Porter, M. 1955 "Material Preclasico de San Salvador." Communicaciones del Instituto Tropical de Investigaciones Cientificas 3/4:105-112. San Salvador.

Reinhardt, B. 1991 "Volcanology of the younger volcanic sequence and volcanic hazards study of the Tuxtla Volcanic Field, Veracruz, Mexico. M.A. Thesis, Tulane University.

Santley, R. 1994 "The Economy of Ancient Matacapan" Ancient Mesoamerica 5:243-266.

Santley, R., and P. Arnold III n.d. "Prehispanic Settlement Patterns in the Tuxtla Mountains, Southern Veracruz, Mexico. MS in possession of the authors.

Schmidt-Thome, M. 1975 "The Geology in the San Salvador Area: A Basis for City Development and Planning." Geol. Jb. 813, S, 207-228.

Seele, E. 1973 "Restos de milpas y poblaciones prehispanicas cerca de San Buenaventura Nealtican, Puebla. Puebla, Fundacion Alemana para la Ciencia, Communicaciones, 7: 77-86.

Segerstrom, K. 1950 Erosion Studies at Paricutin. US Geological Survey Bulletin 965A. Washington, D.C.

Sharer, R. (Ed.) 1978 The Prehistory of Chalchuapa, El Salvador. 3 Volumes. Philadelphia: University of Pennsylvania Press.

Sheets, P. 1979 "Environmental and Cultural Effects of the Ilopango Eruption in Central America. In P. Sheets and D. Grayson (Eds.) Volcanic Activity and Human Ecology, 525-564. Academic Press, New York.

Sheets, P. 1980 "Archaeological Studies of Disaster: Their Range and Value." Natural Hazards Research Working Papers #38. University of Colorado, Boulder. 35pp.

Sheets, P. (Ed.) 1983 Archeology and Volcanism in Central America: The Zapotitan Valley of El Salvador. Univ of Texas Press, Austin.

Sheets, P. 1987 "Possible Repercussions in Western Honduras of the Third-Century Eruption of Ilopango Volcano." In G. Pahl (Ed.) The Periphery of the Southeastern Classic Maya Realm. UCLA Latin American Center, Los Angeles, CA. Pp. 41-52.

Sheets, P. 1992a The Ceren Site: A Prehistoric Village Buried by Volcanic Ash in Central America. Ft. Worth: Harcourt Brace.

Sheets, P. 1992b "The Pervasive Pejorative in Intermediate Area Studies." In F. Lange (Ed.) Wealth and Hierarchy in the Intermediate Area. Dumbarton Oaks, Washington, DC.

Sheets, P. 1994 Summary and Conclusions. In Sheets, P. and B. McKee (Eds.) Archaeology, Volcanism, and Remote Sensing in the Arenal Region, Costa Rica. Austin: Univ. of Texas Press. Pp 312-326.

Shook, E. 1965 Archaeological Survey of the Pacific Coast of Guatemala. Handbook of Middle American Indians, Vol. 2, part 1. Pp 180-194. Austin: Univ. of Texas Press.

Siebe, C., M. Abrama, J. Macias, and J. Obenholzner 1996 "Repeated volcanic disasters in Prehispanic time at Popocatepetl, central Mexico: Past key to the future?" Geology 24:5:399-402.

Urrutia-Fucugauchi, J. 1996 "Palaeomagnetic study of the Xitle-Pedregal de San Angel lava flow, southern Basin of Mexico. Physics of the Earth and Planetary Interiors 97:177- 196.

Vaillant, G. 1934 "The Archaeological Setting of the Playa de los Muertos Culture." Maya Research 1:2:87-100.

Weaver, M. 1993 The Aztecs, Maya, and their Predecessors. San Diego: Academic Press.

Workman, W. 1979 "The Significance of Volcanism in the Prehistory of Subarctic Northwest North America." In P. Sheets and D. Grayson (Eds.) Volcanic Activity and Human Ecology. NY: Academic Press. Pp. 339-372.