1999 In: The Angry Earth
Oliver-Smith & Hoffman (eds)

2

THE EFFECTS OF EXPLOSIVE VOLCANISM ON ANCIENT EGALITARIAN, RANKED, AND STRATIFIED SOCIETIES IN MIDDLE AMERICA

PAYSON D. SHEETS
University of Colorado

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

INTRODUCTION

GIVEN THE THOUSANDS OF YEARS OF HUMAN OCCUPATION IN MIDDLE AMERICA and Mexico, the number of times that pre-Columbian societies were affected by volcanism must have been relatively great. The objective of this chapter is to compare the effects that explosive volcanic eruptions had on the ancient societies of Mexico and Central America, to see if any patterns can be detected. The particular focus is to try to answer the question: Did societal complexity play a role in the vulnerability or the resilience of societies affected by those sudden massive stresses? Some societies were resilient to an explosive eruption, reestablishing their social organization, 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 an explosive eruption, as they were unable to cope with the changed circumstances.

In broad terms, volcanic activity can be both beneficial and detrimental to human adaptation to an environment. The cliché that volcanic soils can be quite rich is accurate, but only after the volcanic detritus has weathered to

form that soil. A volcanic ashfall that forms a fertile soil in a few decades can have a lava flow associated with it that requires centuries to form an equally fertile soil. Volcanically active areas often provide obsidian that can be fashioned into sharp cutting and scraping tools, basalt and andesite for grinding implements, and hematite and other pigments for painting pottery and other items that are of value to human occupation. On the other hand, volcanically active areas are seismically active as well, and indigenous societies often developed well-reinforced vernacular architecture for protection. Of the various sorts of phenomena, ranging from benign to devastating, this chapter focuses on the extreme of sudden explosive eruptions and how ancient societies coped or failed to cope with them. There are other highly destructive volcanic events that are beyond the scope of this chapter, including mudflows and hot debris flows. They are not included here largely because they have rarely been researched from both natural and social science perspectives.

It is important in this study to determine the approximate place each ancient society under consideration occupies along the continuum from the least complex egalitarian society to the highly complex state and empire. The evidence of societal complexity that archaeologists seek in the record of ancient societies is centralization of wealth or authority in the hands of a few. Differential wealth generally manifests itself in burials, with richly stocked tombs of the elite contrasting with the more plain commoners' burials. It is also recorded in architecture and artifacts. Differential resource abundance within a society can be seen in the archaeological record in storehouses attached to palaces, and in the palaces themselves as contrasted to the housing of the majority of the population. Centralization of authority can be detected in control of labor, power in military or police functions, or even in religious authority and control—all of which are revealed in quality and use of architecture, distribution of space, and kinds of artifacts. In some cases the record is clear, but in other cases the nature or degree of centralization is ambiguous, and statements must be carefully qualified.

The number of cases of pre-Columbian societies that endured volcanic eruptions that have been researched and adequately documented is small, but it is at least sufficient to begin establishing a comparative framework. 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 very great, 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 tephra (volcanic ash) stress, duration and dating of eruptions, chemical and grain size variation of the eruption, climatic

variation, weathering rates and recovery processes, in addition to political, economic, demographic, and social factors of affected societies. Thus, anything approaching a statistical analysis is not possible with the present state of knowledge. Although not many cases where explosive eruptions affected pre-Columbian societies have been extensively researched, there are sufficient cases to at least begin to compare and contrast them in this study.

The ideal cases for this archaeological-volcanological study are those in which investigators have dated the eruption well, have done regional analysis of the extent of the tephra blanket, and 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 are also known in the ideal case and can be examined for possible indirect effects, including housing refugees or taking advantage of the suddenly changed circumstances in the region such as rerouting trading systems. 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 and from the zone where a slight dusting of ash was beneficial shortly after deposition. An example of the latter are the crops improved by a thin dusting of Mount St. Helens ash from the 1980 eruption, as the ash acted as a mulch and also killed many insects. Soil recovery and plant succession are more rapid on the peripheries of the ash 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 ideal case has documented the pre-eruption subsistence system, whether it was reliant upon wild or domesticated species, swidden or intensive agriculture, a primary staple or a wide variety of foods. Beyond subsistence, the regional economy is understood, whether it was regionally integrated and hierarchically organized or characterized by settlement self-sufficiency. Similarly, the political and religious systems in the ideal cases are well understood, so the impact of the sudden stress as well as the coping and recovery can be studied.

CENTRAL AMERICAN CASES OF VOLCANISM AND ANCIENT SOCIETIES

An important variable in the consideration of cases of volcanic impact (Figure 1) is the depth of burial of sites and their subsistence sustaining areas. With explosive volcanism, burial is essentially instantaneous, and the depth of burial is proportional to the deleterious impact. In conducting regional volcanological-ecological-archaeological research in El Salvador, Panama, and

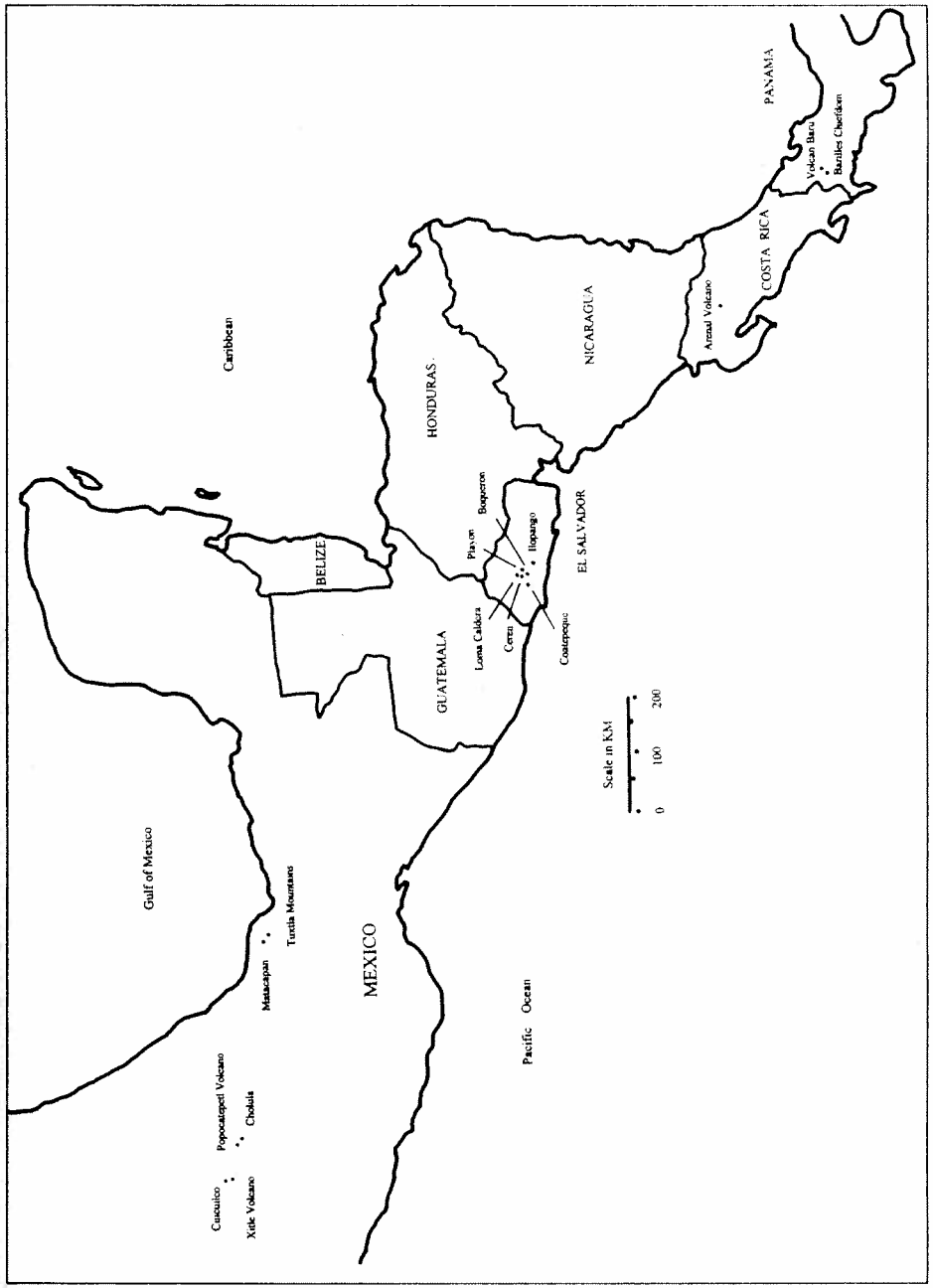

FIGURE 1. *Map of Southern Mexico and Central America. Volcanoes and the pre-Columbian societies affected by them that are the cases explored in this chapter are indicated.*

Costa Rica, I and my project members have found it more practical to search for, find, and investigate sites that are buried by about one half to two meters of tephra. Sites buried by less than that are generally not well preserved by the tephra, and sites buried more deeply are difficult to find and to excavate. Thus, an aspect of practicality ends up assisting 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 on societies. More deeply buried sites, such as Cuicuilco and Ceren, are also considered here, but in less detail.

The significant variables to be considered in comparing and contrasting cases where explosive eruptions affected pre-Columbian Middle American societies include the nature of the tephra (chemical and physical properties, area and nature of emplacement), the climate, the adaptation and the economy of the society affected, the political system, residential mobility, the density and distribution of population, reliance on fixed facilities, the particular edaphic (soil composition) requirements of cultigens, the regional cultural system including possible competition for resources and warfare, and the internal complexity of the society affected.

Arenal, Costa Rica

People have occupied the Arenal area of northwestern Costa Rica for at least ten thousand years (Sheets 1994). Since its birth almost four millennia ago, Arenal volcano has erupted nine times in a major way, not counting numerous small eruptions (Melson 1994), thus providing the opportunity to study the impacts 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 within the context of the culture history of the region, as discovered by the Arenal Research Project (Sheets 1994). All of Arenal's eruptions apparently affected egalitarian societies throughout prehistory, as there is no convincing evidence that more complex societies emerged in the area. Thus, the Arenal area provides a contrast with other areas of Middle America where explosive volcanism affected more complex societies with quite different adaptations and political and economic systems and greater population densities.

The hilly research area spans the Continental Divide, with elevations on both Atlantic and Pacific drainages ranging from four hundred to one thousand meters. Mean precipitation varies considerably, with averages as low as thirteen hundred millimeters at low elevation western stations to averages over six thousand millimeters at stations in the east close to Arenal volcano. The wetter areas give new meaning to the term "mean" precipitation. That moisture gradient correlates with a vegetational spectrum from a tropical dry-seasonal forest to a nonseasonal dense rainforest.

Paleo-Indian and Archaic peoples lived in the area in apparently very low population densities. The utilization of domesticated food sources certainly began by 2000 B.C., and probably before 3000 B.C., but the dating of that beginning is not very precise. Maize was cultivated by that 2000–3000 B.C. time horizon, but beans and squash are not confirmed until considerably later. Sedentary villages, with heavy metates and manos, presumably to grind maize, accompanied that subsistence addition. In contrast to many areas of Middle America, domesticated plants supplied only a small fraction of the diet, evidently no more than 12 percent, as 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 time up until the Conquest are the basic core-flake lithic technology and the use of heated stones in cooking. Project members were unable to detect any changes in the circular houses with activity areas and (presumably) thatch roofs from early Formative times to the Conquest. However, other aspects of culture did change, and the key question considered here is which of the changes can be attributed to the major societal stresses caused by the large explosive eruptions of Arenal volcano.

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

TABLE 1. *Principal explosive eruptions of Arenal volcano, Costa Rica. Moderate to small eruptions are not included. "Units" are volcanic ash layers that are numbered sequentially, with the earliest eruption unit having the largest number.*

The Tronadora phase, conservatively dated from 2000 to 500 B.C., is characterized by numerous small villages scattered across the landscape. People lived in circular houses, presumably with thatch roofs, and buried their dead near the houses in small rectangular pits with occasional ceramic vessel offerings. The small pit sizes probably indicate that the burials were secondary (disarticulated). Maize was cultivated and processed with manos and metates, but was probably a minor part of the diet, as numerous wild species

were utilized. The ceramics were surprisingly sophisticated in technology and decoration (Hoopes 1987). The phase had been underway for at least two centuries, and perhaps as much as seventeen hundred years, when Arenal volcano was born. That explosive eruption, which deposited the thick tephra layer referred to as Unit 61 (Melson 1994) at about 1800 B.C., resulted in the devastation of many square kilometers 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 reoccupied the area a few generations later after soil and vegetation recovery had occurred. Toward the end of the phase, at about 800 B.C., 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 the project team compared pre- and post-eruption conditions of both of these eruptions, we are unable to detect any long-range culture change that can be attributed to the disaster. People certainly had to abandon the area for a few generations, but the reoccupants are culturally indistinguishable from the pre-eruption occupants. That resilience to volcanic disaster continued to characterize Arenal-area society for thirty-five hundred years.

It was during the Arenal phase (500 B.C.–A.D. 600) that population density reached its peak in the area. Although never approaching the high densities of northern Central America during these same centuries, there were more and larger sites than at any other time in the pre-Columbian period. Domestic housing remained unchanged. Human burial was in discrete cemeteries on ridges adjacent to and above the villages. Interment shifted from secondary burials of the Tronadora phase to elaborate primary burials with plots demarcated with outlines of upright stones. 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 midway during 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, these deposits together probably had ecologic and demographic impacts approximately as significant as the earlier great eruptions. They do correlate with a subphase cultural boundary, the shift from the early to the late facet, defined by subtle changes in ceramic decoration. These changes were apparently a local manifestation of regional culture change in Greater Nicoya, rather than an effect of the volcanic disaster. In fact, I believe the important point is that the changes occurred in spite of the eruption, as local displaced populations maintained sufficient contact with regional societies to reflect overall culture change occurring in what is now northwestern Costa Rica and western Nicaragua.

A significant but not drastic population decline occurred at the beginning of and during the Silencio phase (A.D. 600–1300), as both large and small sites declined in number, a change noted in most of lower Central America with unknown causes. That process clearly was not occasioned by volcanism, although it could have been accelerated somewhat by volcanic activity during the ninth 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 long sides and on top. Remote sensing, with excavations for field verification, divulged the footpaths leading from the cemetery to a nearby spring, to stone sources, and to the villages that used them. During the phase at about A.D. 800 or 900, two large eruptions (Units 41 and 40) occurred in rapid succession and must have had ecologic and demographic effects as drastic as the earlier large eruptions,[1] but as with them, the culture that reestablished itself is indistinguishable from that prior to emplacement. It is possible that the increase in occupation of the Rio Piedra valley during the latter part of the Silencio phase was a result of the eruptions (Mueller 1994: 63). That western end of the Arenal drainage received considerably less volcanic ash from the two eruptions and could have served as a refuge area. If this is correct, it is one of the very few examples of our being able to detect a culture change at Arenal attributable to volcanic pressures. The 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 (A.D. 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, but that reversed as the primary affiliation shifted eastward toward the Atlantic watershed and the Meseta Central. The reasons for the change are not clear, but it apparently had nothing to do with volcanism. Toward the end of the phase, at about A.D. 1450, Arenal emitted one of its largest eruptions, 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. It is unknown if the societies could have recovered from the effects of the eruption had the Spanish not appeared shortly following it, but given their record of previous recoveries, I suspect they could have. This is an example of convergent disasters, as discussed by Moseley in chapter 3 of this volume.

In summary, the resilience of Arenal-area society to the sudden environmental stresses of explosive volcanism is notable. Only once can we find a significant change in human occupation, beyond the immediacy of the disaster, that persisted and is attributable with a reasonable degree of certainty to volcanism. That one occurrence was the sustained population relocation in the Rio Piedra region that lasted some three centuries. Thus, what is striking about Arenal-area societies is their resilience to explosive volcanism occurring on the average of every four hundred years. The resilience is probably based on a number of factors, each of which is in contrast to the other, more complex societies considered in the rest of this chapter. One is the high degree of village self-sufficiency, as most food, building materials, clay, and stone for chipped and ground stone implements were available locally. Only the material for celts (chisels or ax heads) was obtained from a distance, and that was from not a great distance, only a day's walk away. It probably also greatly aided households and villages in coping with thick ashfalls that domesticated foods were a small portion of the diet. People could increase their exploitation of wild flora and fauna to make up for lost cultivated foods in areas beyond the devastated zones. I suspect another major reason Arenal societies were so resilient to volcanic eruption is that even during the millennia of sedentism following 2000 B.C., they still maintained a reasonably high degree of residential mobility and the technology to support it. The archaeological record for the Silencio phase, for instance, demonstrates that households would "camp out" at cemeteries at considerable distances from their residences, use stone boiling instead of heavy ceramic cooking vessels, and presumably rely heavily on wild flora and fauna as food sources. Finding some maize pollen at cemeteries indicates that people cultivated crops at those distant localities to provide a source of food for inhabitants involved in the elaborate feastings and ancestor worship.

Panama

Archaeological research in western Panama (Linares, Sheets, and Rosenthal 1975; Linares 1977; Linares and Ranere 1980) encountered a case of volcanism affecting a more complex society than in Costa Rica but less complex than in Mesoamerica. The case involves the Barriles chiefdom that developed in the upper reaches of the Rio Chiriqui Viejo from about 200 B.C. until the seventh century A.D. Actually, the Barriles site consists of a series of chiefdoms along watercourses in western Panama and eastern Costa Rica sharing the same culture and, presumably, language but each fiercely defending its own individual polities. Among them there developed an iconography representing aggression, capture, and human sacrifice by decapitation as the society became more complex and competitive. The eruption of Volcan Baru during the seventh century A.D. 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 an abandonment of the area by Barriles peoples, and they or their descendants never reoccupied the area. Linares (Linares and Ranere 1980: 244–45) believes some of the Barriles residents who were forced to migrate headed 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 people finally did reoccupy the valley, they were not the descendants of the societies that lived there before the eruption. I suspect Baru's impact on its surrounding populations was greater than Arenal's 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. That the inhabitants were in a more demographically filled-in landscape with competitive aggressiveness marking intersocietal relationships indicates a lack of land into which migrants could settle. Beyond that ecologic scarcity there was probably a lack of desire and incentive for a relatively intact polity (beyond the zone of negative volcanic impact) to assist the survivors of a stressed polity. In fact, the degree of competitive aggressiveness between polities is greater than in any other of the cases presented in this paper and is apparently a part of the reason why a relatively small eruption had such a dramatic societal impact. Survivors in the two uppermost Barriles chiefdoms could expect hostility if they tried to move farther downriver into other chiefdoms' territories, and thus had to migrate over the Continental Divide into the very moist nonseasonal tropical rainforest to the north, near the Atlantic shoreline. It is possible the surviving chiefdoms were appreciative of the disaster that wiped out their upstream competitors.

El Salvador

El Salvador provides a few cases of eruptions and their effects on pre-Columbian societies, ranging from the immense eruptions of Coatepeque and Ilopango to the highly localized Loma Caldera eruption. The huge Coatepeque eruption, dated to between ten thousand and forty thousand years ago, may predate human occupation in Central America, but if people were in Central America at that time and there are Paleo-Indian sites buried by the Coatepeque tephra, those sites could yield considerable insight into lifeways and adaptations. The societies affected by the post-Coatepeque eruptions were more complex than those affected by eruptions in Costa Rica and Panama. The magnitude of the various eruptions correlates with the magnitude of ecological and societal disruption, but it is a major point of this chapter that the size of the eruption is not the primary variable. It appears rather that the more complex Salvadoran societies were more vulnerable to explosive volcanic disasters than were Costa Rican societies.

Eruption (source)	Date	Km² Covered	Regional Effects
El Playon	A.D. 1658–1659	30	Slight
El Boqueron (San Salvador Volcano)	est. A.D. 900–1100	300 (deeper than 7 cm.)	Moderate
Loma Caldera (Ceren tephra)	A.D. 590 + 90	less than 5	Insignificant
Ilopango (Tierra Blanca Joven)	A.D. 260 + 114 or summer A.D. 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 two 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 during much of this 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 1984.) 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 A.D. 260 ± 114 (calibrated; one sigma range: A.D. 146 to 374), but a more precise dating may be provided by analyses of Greenland ice cores. A volcanic ash began falling in the summer of A.D. 175 in Greenland which might have been caused by Ilopango; both share the same high silica content of 69 percent. Where it is well preserved at Chalchuapa, seventy-seven kilometers from the source, it is over one half meter thick, indicating a regional disaster of major proportions.

The Ilopango eruption occurred in three phases. First, a great explosion deposited a relatively coarse pumice across the countryside, to a radius of about thirty kilometers. That was followed by two colossal ash flows that headed north to the Rio Lempa and west into the Zapotitan valley. These were unusually massive and long, stretching for more than forty-five kilometers. The one that headed west had sufficient impetus to flow up and over the Santa Tecla (Nueva San Salvador) pass at one thousand meters elevation and then down into the Zapotitan valley, even though the vent elevation is only five hundred meters. Both of these first stages were devastating to flora, fauna, and people in their paths, but the third phase was even more damaging regionally. It 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 ash into the troposphere, so finding Ilopango ash in Greenland ice cores should not be surprising.

Some eight thousand square kilometers might have been rendered uninhabitable. Segerstrom (1950) found that ten to twenty-five centimeters of volcanic ash is too much for traditional agriculturalists to cope with, and natural processes of tephra erosion, weathering, soil formation, and plant succession are necessary before the affected area can be reoccupied by cultivators. Depending on the tephra and the environment, those processes can take decades or centuries. Given an estimated regional population density in central El Salvador of forty people to every square kilometer, 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. The dozens of sites in the Zapotitan valley buried by some one to two meters 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 (between Mesoamerica and the Andes), and to some degree it is due to greater resilience to perturbation by Arenal societies.

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 was probably a result of the ecologic suppression 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 (see Table 3) was likely caused by the Ilopango tephra and resultant heavy runoff and redepositions (Sheets 1987). Included are 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 Barton Ramie is a considerable distance from Ilopango, and the flooding might have occurred for quite different reasons. In Middle American areas, where only a few centimeters or millimeters of Ilopango tephra were deposited, the deleterious affects of the eruption were probably minimal and the light dusting could have been beneficial immediately.

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 fourteen 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, circa A.D. 590, with sufficient warning that the inhabitants could lit-

Period	Tephra	Date (approx.)	Thickness (est. from sections)	Effect on Habitation
Middle Classic	Laguna Cocodrilos	A.D. 600	40–45 cm.	Moderate impact on complex society, gradual but consistent decline
Early Classic	Laguna Nixtamalapan & Cerro Puntiagudo	A.D. 400	20–30 cm	None detected, occupation continues
Late Formative	Cerro Nixtamalapan	A.D. 150	40 cm	Significant impact, abandonment, rapid recovery
Early Formative	Cerro Mono Blanco	1250 b.c.	60 cm	900-yr.-long abandonment, major impact on simple society
Late Archaic	n.a.	3000–2000 B.C.	n.a.	Unknown

TABLE 3. *Volcanism and human settlement in the Matacapan area, Tuxtla Mountains, Mexico. ("n.a." means not available.)*

erally "head south," but without enough warning time to remove their possessions. Although it had devastating consequences for the inhabitants of the Ceren village and its environs, this eruption was so small as to have had no detectable effects on the course of societal change in southern Mesoamerica. It was followed a few centuries later by a moderately large eruption of San Salvador volcano (Boqueron eruption) at about A.D. 900 or 1000 that did negatively affect some two to three hundred square kilometers. 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 site remains unpublished. This eruption is an important research topic that, it is hoped, will be explored in the near future. Playon was the most recent eruption to affect the area, beginning late in 1658 and burying thirty square kilometers under lava and a larger area under tephra. Although soils on the Playon lava have barely begun to recover to their pre-eruption state, 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 and the Tuxtla Volcanic Field

Volcanism in the Tuxtla Volcanic Field (TVF), located some one hundred fifty kilometers southeast of Veracruz, Mexico, has been studied recently by Reinhardt (1991), and the following descriptions are taken from his master's thesis. The younger (last fifty thousand years) volcanic sequence covers some four hundred square kilometers, with an average frequency of eruptions of at least four per one thousand years, an activity rate approximately twice that of Arenal during the past four thousand years and comparable to central El Salvador in the past two thousand years. Matacapan, in the Tuxtla Mountains in the Mexican Gulf, has been investigated by Robert Santley (1994). The site zone was occupied twice during the Formative period, but grew to maximum size during the middle of the Classic period.

The most recent eruptions of the Tuxtla volcanos are preserved in the stratigraphy at the Matacapan archaeological site and date to the Late Archaic to the Middle Classic Periods. The earliest of these eruptions occurred about 3000 to 2000 B.C., 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 wild 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 fifteen centimeters, at Matacapan.

The second TVF eruption dates to the Early Formative, about 1250 B.C., and deposited the Cerro Mono Blanco (CMB) tephra. Matacapan was occupied at the time by agriculturalists, and tephra buried the maize ridges of an agricultural field and a dog. The society affected was relatively simple, as egalitarian villages dotted the landscape. The deposit, as I measured it from Reinhardt's drawn sections, is moderately thick, over sixty centimeters. The area was abandoned for some nine 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 A.D. 150, buried Late Formative remains in the Matacapan area under the Cerro Nixtamalapan (CN) tephra. It is about forty centimeters 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 for only a short while.

At about A.D. 400, during the Early Classic, two closely spaced eruptions (no soil between them) deposited the Cerro Puntiagudo (CP) and then the Laguna Nixtamalapan (LN) tephras. These evidently had less of an impact than the above tephra emplacements, as the site apparently was not abandoned. I measure their thickness from Reinhart's sections at only about twenty to thirty centimeters. 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 resiliency 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 final Classic period eruption occurred in the middle of that time span, about A.D. 600, and the tephra measures some forty to forty-five centimeters in thickness according to the sections. It sealed an agricultural field with maize ridges under it. Compared to the above examples, this is a moderately large eruption as viewed from Matacapan, 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 600s, a part of which I suspect might have been caused by the ecologic stress of volcanic ash deposition. It should be noted that Santley and Arnold (n.d.) came to quite an 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.

The relative ecological-agrarian-societal stresses caused by various volcanic eruptions can be researched only 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 be approximated only 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 about twenty centimeters) did not cause abandonment, but the thicker layers did cause abandonment proportional to their thickness (CMB at about sixty centimeters and CN at forty to forty-five centimeters). The LC tephra, about forty centimeters thick, correlates with a reversal of the demographic and societal trajectories, and the site never recovered. The societal impacts do not correlate, negatively or positively, with societal complexity when viewed from Matacapan. However, viewing societal impacts from only a single site can be very misleading, and regional work is needed for the Tuxtlas to shed light on impacts and recoveries. What is needed to research seriously the interaction of natural and human processes 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, 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 B.C. 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 from the time of World War II. Unfortunately, the dating of the eruption is rather speculative, as it is not based on extensive data, and sourcing of the tephra is weak. It is conceivable that this tephra might be from the same eruption as the CMB or CN tephra at Matacapan.

Popocatepetl Volcano and Cholula, Puebla, Mexico

For the past few 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. For instance, 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 B.C., between 800 and 200 B.C. (Lower Ceramic Plinian), and probably at A.D. 822 (Upper Ceramic Plinian). The earliest eruption was characterized by a series of 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 carried over fifty kilometers 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 habitation by the first millennium B.C., which was then buried by the second, or "Lower Ceramic Plinian," eruption. This eruption consists primarily of a thick widespread andesitic pumice deposit followed by ash flows and lahars (mud flows) radiating from the volcano. 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,

dating to a few centuries prior to that architectural style's appearance in Teotihuacan, are buried. The eruption's effects on habitation on or near the slopes of Popocatepetl were obviously devastating, but its effects upon Cholula and the Puebla Valley, or upon the 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 likely dating to A.D. 822 is from a Greenland ice core, 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.

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. Correlations are intriguing, but establishing probable causalities will require regional interdisciplinary research. Here is a regional integrated archaeological-volcanological project crying out to happen, with the high probability of significant results. Such a project could go far toward understanding the beneficial and detrimental aspects of living in volcanically active areas and explaining 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) has documented the emergence of sedentary human communities in the resource-rich lacustrine (lake) 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 the time is the same as the earliest Popocatepetl eruption documented by Siebe et al. (1996), I suggest this may be the northwestern component of the same eruption. She refers to the deposits as a series of *nubes ardientes* ("glowing clouds" of hot volcanic ejecta and gasses that flow rapidly downhill) leaving thick white pumice layers. They are thick enough to have caused ecological and human societal devastation, and because of their chemistry 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 notes 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 fifteen

hundred to two thousand years ago remains controversial and will probably 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 (one could say "wildly"). Many scholars have noted that the demise of Cuicuilco—apparently the dominant polity of the Late Formative in the Basin of Mexico—the rise of Teotihuacan, and the eruption of Xitle might have been causally interrelated. Parsons (1974, 1976) suggests Xitle devastated Cuicuilco in the first century A.D. and thus facilitated the rise of Teotihuacan. Similarly, Diehl (1976) notes the political ascendancy of Teotihuacan and suggests it was in part because of Xitle's elimination of Cuicuilco as a competitor. Adams (1991: 109) dates the volcanic destruction of Cuicuilco to about 150 B.C.

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), surveying the attempts to date the eruption, note that the early research efforts date it at around 400 B.C., while more recent efforts date it at the third century A.D. and to as late as A.D. 400. They conclude that the most accurate radiocarbon date is 1536 ± 65 B.P., or about A.D. 400. They also feel that Cuicuilco had been abandoned well before the eruption. If these conclusions are correct, the demise of Cuicuilco was certainly not caused by Xitle, and its abandonment might have been caused by the expansion of, and competition from, Teotihuacan, which neatly reverses the causality, plucks it from the volcanological domain, and places 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 seventy-five square kilometers of the most fertile land in the Basin of Mexico under basaltic lava during the early part of the Classic period. Recent research indicates the most accurate dating of the Xitle eruption is about the time of Christ (Claus Siebe, personal communication, 1997), thus putting it at about the same period as the large eruption of Popocatepetl that devastated such a large area of Puebla. Urrutia-Fucugauchi (1996) also dates it to the same time, two thousand years ago.

CONCLUSIONS

Although the sample size is very small, there does seem to be a pattern that more complex pre-Columbian societies were more vulnerable to the sudden massive stresses of explosive volcanism than were the simpler societies in Middle America. Ilopango overwhelmed Late Formative societies in southeastern Mesoamerica, Matacapan was inundated by a Tuxtla eruption, and Popocate-

petl inundated Cholula (and perhaps Xitle devastated Cuicuilco). These are cases where those complex cultures did not recover, competitors often took control and prospered, and later cultures were significantly different.

At the other extreme, the simple egalitarian societies living in the Arenal area of Costa Rica showed remarkable resilience to the repeated explosive eruptions of Arenal volcano over almost four millenia. This might seem counterintuitive, as most people living in Western state-level societies today would presume that complex societies with their centralized decision-making, police and military forces, warehouses, and advanced means of transportation and communication would be more prepared for massive emergencies than simple societies. That may be true where rescue and recovery efforts can involve people and institutions hundreds or even thousands of miles away, but it does not seem to pertain to pre-Columbian Middle America.

What might be the characteristics of simple egalitarian societies that would confer resilience against sudden massive stress by explosive volcanism? Based on the Costa Rican examples, I believe that low population densities within and beyond the zone of devastation are important, providing refuge areas without conflict. The Arenal-area societies avoided a single staple food, in contrast to most areas of Middle America, and when their agricultural fields were devastated they could readily replace the domesticated fraction of their diet by intensifying the collection of wild food sources. The Arenal villages were much more self-sufficient than settlements in Mesoamerica, as the latter relied on long-distance trade routes for essential commodities such as salt, obsidian, pigments, jade for axes, and other items. Housing in the Arenal villages was less substantial than in most areas of Middle America, and could be rebuilt in refuge areas more readily. Thus, the built environment was simpler and easier to replace. There is no evidence of warfare in the Arenal area at any time, and thus refugees presumably could have moved into refuge areas without hostility. The low population densities in a highly productive tropical rainforest environment with its abundance of wild food sources must have meant less competition for land and resources than in Mesoamerica.

An unanticipated consequence of this study comparing eruptions, environments and adaptations, and complexities of societies in Middle America is the realization of the importance of the political landscape into which a tephra falls. By ecological, volcanic, and societial expectations the eruption of Panama's Volcan Baru should have had only short-term negative effects on the Barriles chiefdoms. However, the chiefdoms were hotly competitive, as they were in a perpetual state of skirmishing and sacrificing captives from adjoining territories. Thus, when the tephra struck, a relatively minor stress caused abandonment and migration over the Continental Divide. That forced an adaptive change from maize-based agriculture in a highland valley to a much wetter tropical lowland environment where seed crop agriculture was selected against.

The factors which make the more complex Mesoamerican societies more vulnerable to sudden stress include demography, adaptation, ecology, politics, society, and economics. As all settlement units are integrated into a regional economy, with long-distance trade routes supplying essential commodities, the lack of self-sufficiency increases vulnerability to changes beyond their sphere of influence or knowledge. Complex societies with redistributive economies rely on central warehouses, markets, attached specialists, and, thus, are vulnerable when those are suddenly stressed or eliminated. A political landscape of hostility with adjoining or nearby societies can transform a moderate stress into an overwhelming stress, particularly where there is competition for arable land and resources. A packed demographic landscape in areas outside the zone of devastation makes relocation to a nearby refuge area difficult or impossible. Reliance on a staple crop, particularly where the agricultural infrastructure is intensive, may be difficult to cope with when massive agricultural failure occurs on a regional basis.

Thus, the larger explosive eruptions that deleteriously affected complex societies in pre-Columbian Mesoamerica may be similar to some eruptions and their effects in the Old World. Probably the most notable is the eruption of Thera and its devastating effects on Minoan civilization (see Hoffman, this volume, chapter 15), allowing for its competitor Mycenean civilization to prosper and expand.

NOTE

1. Archaeologists and volcanologists investigating the fall of volcanic ash blankets in tropical environments rarely observe the direct effects on the flora, fauna, and human populations in the same way that a modern observer can observe the trees dying and the animals asphyxiating. However, the effects can be inferred with a high degree of probability based on the observed effects of similar ashfalls on comparable contemporary environments. Therefore, phrases like "must have occurred" are used here to indicate a highly probable interpretation that is not a documented fact.

BIBLIOGRAPHY

Adams, R. 1991. *Prehistoric Mesoamerica* (Revised Edition). Norman: University of Oklahoma.

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

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 39: 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. 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,* pp. 249–286. Albuquerque: University of New Mexico Press.

Ferrero Acosta, L. 1981. "Ethnohistory and Ethnography," in E. Benson (ed.), *Between Continents/Between Seas: Pre-Columbian Art of Costa Rica*, pp. 93–103. New York: Abrams.

Harris, D. 1973. "The Prehistory of Tropical Agriculture: An Ethnoecological Model," in C. Renfrew (ed.), *The Explanation of Culture Change,* pp. 391–417. London: Duckworth.

Hart, W., and V. Steen-McIntyre. 1984. "Tierra Blanca Joven Tephra from the A.D. 260 Eruption of Ilopango Volcano," in P. Sheets (ed.), *Archaeology and Volcanism in Central America: The Zapotitan Valley of El Salvador,* pp. 14–34. Austin: University of Texas Press.

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.* Unpublished Ph.D. dissertation. Cambridge: 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.

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.* Cambridge: Peabody Museum, Harvard University.

Linares, O., P. D. Sheets, and E. J. 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. New York: Museum of the American Indian, Heye Foundation.

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*, pp. 24–47. Austin: University of Texas Press.

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, pp. 48–72. Austin: University of Texas Press.

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.

———. 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,* pp. 69–100. Albuquerque: University of New Mexico Press.

Porter, M. 1955. "Material Preclasico de San Salvador." *Communicaciones del InstitutoTropical de Investigaciones Cientificas,* 105–112. San Salvador.

Reinhardt, B. 1991. *Volcanology of the Younger Volcanic Sequence and Volcanic Hazards Study of the Tuxtla Volcanic Field, Veracruz, Mexico.* Unpublished M.A. thesis. New Orleans: 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." *Geologische Jahresbuch* 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, *Comunicaciones* 7: 7–86.

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

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*, pp. 525–564. New York: Academic Press.

———. 1980. "Archaeological Studies of Disaster: Their Range and Value." *Natural Hazards Research Working Papers* #38. Boulder: University of Colorado.

———. ed. 1983. *Archaeology and Volcanism in Central America: The Zapotitan Valley of El Salvador.* Austin: University of Texas Press.

———. 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,* pp. 41–52. Los Angeles, CA: University of California at Los Angeles Latin American Center.

———. 1992a. *The Ceren Site: A Prehistoric Village Buried by Volcanic Ash in Central America.* Fort Worth: Harcourt Brace.

———. 1992b. "The Pervasive Pejorative in Intermediate Area Studies," in F. Lange (ed.), *Wealth and Hierarchy in the Intermediate Area.* Dunbarton Oaks, Washington, DC.

———. 1994. "Summary and Conclusions," in P. Sheets and B. McKee (eds.), *Archael-*

ogy, *Volcanism, and Remote Sensing in the Arenal Region, Costa Rica*, pp. 312–326. Austin: University of Texas Press.

Shook, E. 1965. "Archaeological Survey of the Pacific Coast of Guatemala." *Handbook of Middle American Indians* 2, 1: 180–194. Austin: University 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*, pp. 339–372. New York: Academic Press.

3

CONVERGENT CATASTROPHE: PAST PATTERNS AND FUTURE IMPLICATIONS OF COLLATERAL NATURAL DISASTERS IN THE ANDES

MICHAEL E. MOSELEY
University of Florida

WHEN TWO OR MORE NATURAL DISASTERS TRANSPIRE IN CLOSE SUCCESSION IN the same region, as they have in certain Andean cases, the collateral crises produce what can be termed a "convergent catastrophe." Convergent catastrophe is best characterized by means of an analogy with disease. Suffered individually, a natural illness or a natural disaster is generally survived by a healthy population. However, when people are first struck by one malady and then are afflicted by still other disorders, recovery becomes tenuous and the likelihood of demise increases. The potency of collateral natural disasters lies in the compound stress they exert upon biotic communities. Convergent catastrophes are implicated contributors to past cases of economic collapse, fall of government, as well as change in ideology, demography, and health. The nature, intensity, and duration of composite stress varies because convergent catastrophes are generated by variable agencies of hazardous change.

The identification of convergent catastrophes is new to geoarchaeology. Therefore, this essay first reviews the forces that generate collateral hazards in the Andean Cordillera as well as potential symptoms of disastrous processes. It then summarizes several modern and ancient cases of collateral crises. It concludes with a consideration of how present policies can lead to future crises, as my intent is to convey recent research results which identify forms of hazardous stress that contemporary populations and their national planners are neither aware of nor immune to.