CENTRAL AMERICA AND MESOAMERICA

ARMAGEDDON TO THE GARDEN OF EDEN: EXPLOSIVE VOLCANIC ERUPTIONS AND SOCIETAL RESILIENCE IN ANCIENT MIDDLE AMERICA

Payson Sheets

Technology is a blessing to be sure, but every blessing has its price.
The price of increased complexity is increased vulnerability.
Garret Hardin (1993: 101)

Large explosive volcanic eruptions can be disastrous or even apocalyptic for people, as well as for flora and fauna, and they may well have seemed like Armageddon (Rev 16:16) to many people in preindustrial societies. On the other hand, periods of quiescence can generate very fertile, volcanically derived soils, providing for a veritable Garden of Eden. Comparative analyses of eruptions and their effects on ancient Middle American societies have shown that peoples varied dramatically in their vulnerabilities to explosive eruptions. Although I have considered only a very small sample, simpler egalitarian societies apparently were more resistant to sudden massive stress than were more complex societies. The greater resilience of egalitarian societies apparently involved lower population densities, smaller social units, less reliance on the "built" environment, greater access to refuge areas, less hostility among neighbors, and greater reliance on a wide range of wild and domesticated foods. But this comparative study has found that other factors, beyond complexity, can render societies highly vulnerable to even small sudden stresses, and it is suggested here that the concept of "scaled vulnerability" can help explain patterns and variations in societies' susceptibility to collapse in the face of explosive volcanism.

The frequent eruptions of Arenal volcano in Costa Rica (fig. 1) provide cases where sudden ashfalls necessitated emigration by egalitarian sedentary societies, and those simpler societies are striking for how resilient they were to sudden massive stresses. In contrast, the eruption of Baru volcano in nearby Panama, which affected the Barriles chiefdoms, shows the importance of

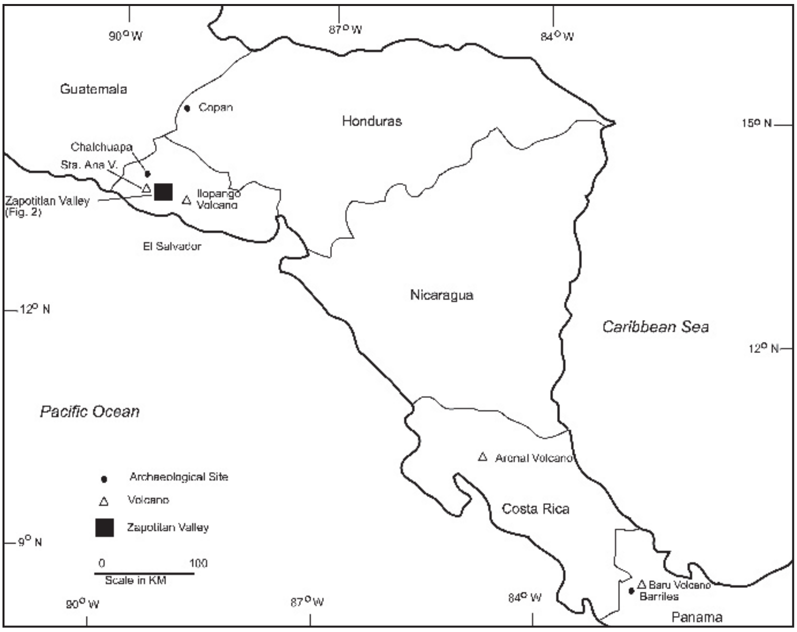

FIG. 1 Map of ancient Central America with archaeological sites and volcanoes indicated.

political factors in understanding human-environmental interactions. Baru's relatively small eruption had great repercussions, evidently because of the institutionalized hostility among chiefdoms.

In Mesoamerica volcanoes often erupted explosively, from the small eruption of Loma Caldera that buried the Cerèn site in El Salvador (fig. 1) to the massive eruptions of Ilopango and Popocatepetl that had widespread and long-lasting effects. In some cases full cultural recovery was achieved relatively rapidly, and in other cases not at all.

Volcanic eruptions can have disastrous effects on people, their societies, and their environments, and there is much written on the topic. However, disasters can have positive or creative effects, as people learn from them and change their adaptations, their "built" environments, their loci of settlement, and their belief systems to deal with uncertainty and fear. Scholars from the technologically sophisticated, secular Western world can easily underestimate the importance of religious belief and ritual for indigenous people as they deal with sudden massive stresses. Disasters, or hazards as disasters waiting in the wings, certainly can figure heavily in human interactions with the supernatural world. This chapter explores the interplay of natural, cultural, and supernatural elements in response to explosive volcanic eruptions.

Burton, Kates, and White (1978) provide a useful framework for comparing human reactions to sudden massive stresses. The minimal adjustment is Loss Absorption, which occurs after the first threshold of Awareness is crossed. People simply accept the losses and get on with their lives. When the stress is greater and the Direct Action threshold is crossed, then Loss Reduction is the result. Still greater stress crosses the Intolerance threshold, and people must take Radical Action. An example of Radical Action would be a forced migration to an area far from the disaster and different from the homeland, thus necessitating significant changes in the society, culture, and/or adaptation.

This chapter examines the relationships among a wide range of factors including explosive volcanism, different organizations of human societies, environments, flora and fauna affected by eruptions, and how people deal with volcanic hazards using natural-cultural-supernatural means. The pertinent variables thus cover a great range, including the pre-eruption environment, climate, society, culture, demography, the nature of the eruption, surrounding societies, the political landscape, and natural as well as cultural recoveries. It is not reasonable to expect compelling conclusions about robust patterns among so many variables with only thirty-six eruptions considered. The cases vary greatly in how thoroughly they document natural and cultural variables before and after each eruption. Precision in dating eruptions also varies. All radiocarbon dates used in this chapter are calibrated. Thus, this study should be considered exploratory. Another thing to consider is that an explosive eruption will have varying effects on nature and people depending on distance from the source, wind direction, and other factors. Often there are zones of total devastation surrounded by zones of lesser impact that are, in turn, surrounded by a zone that has experienced some beneficial effects.

This chapter uses research results from as wide a range of disciplines as possible. There is a surprising number of disciplines doing disaster research—a total of thirty, according to Alexander (1997), ranging from the social sciences to the physical sciences and engineering. Alexander (1995) tabulated the research funding for disaster studies, and found that 95% went to the physical and technological sciences, and only 5% went to the social sciences. Although disaster research was initiated by Gilbert White (e.g., 1945), a cultural geographer who started working in the first half of the twentieth century, it is now dominated by the physical sciences and engineering.

The principal variables included in this study are societial complexity, adaptation, architecture, economics, politics, ideology, demography, environment, and the nature of eruptions. Most of the disciplines Alexander (1997) discusses deal with the immediacy of an eruption; in contrast, archaeology studies phenomena over centuries or millennia.

THE CASES

The following cases of explosive eruptions affecting Pre-Columbian societies in Middle America, extending from Panama to Mexico, are organized from simpler to more complex societies, because organizational complexity apparently was an important factor in resilience. Other key factors, such as the political landscape, are highlighted when they are relevant. Because the more complex societies developed in the northwestern end of the area covered here, the cases begin in Lower Central America and then move to Mesoamerica.

FIG. 2 Six of the ten white volcanic-ash layers from the major eruptions of Arenal volcano. The dark layer under the lowest white-ash layer is the clay-laden soil prior to Arenal beginning to erupt. The dark layers on top of the white-ash layers are soils that sustained vegetation and some cultivation. The small lens of whitish ash at the man's chest level is the remains of the 1968 eruption.

Arenal, Costa Rica

The Arenal project found a virtually continuous record of human habitation in northwest Costa Rica for the past ten millennia (Sheets 1994). That record began with PaleoIndian occupation (est. 10,000–7000 BC),[1] as evidenced by the Clovis-style projectile point recovered from the south shore of Lake Arenal, which proves that PaleoIndians had adapted to moist tropical rainforest environments.

The very low PaleoIndian population densities were followed by higher densities during the Archaic Period (est. 7000–3000 BC). Settled, sedentary villages with at least a small fraction of the diet from maize emerged near the end of this Archaic Period, perhaps as early as the fourth millennium BC (calibrated ^{14}C date TX-5275 from Tronadora Vieja site G-163 is 3780 [3765] 3539 BC). Arford (n.d.) reports the earliest maize pollen at about 1900 BC in the lake sediment cores from Lake Cote, only 3 km north of Lake Arenal's north shore. That date is consistent with the archaeological record of the Lake Arenal area (Sheets 1994).

The succeeding Tronadora phase may begin as early as the mid-fourth millennium BC, but we conservatively place its beginning at 2000 BC. The villages were small, with circular houses around 5 m in diameter that presumably were roofed with thatch; the dead were buried beside the houses. Houses were provisioned with metates and manos for food grinding, ceramics, cooking stones, and a basic core-flake lithic technology, all of which showed remarkable perseverance up to the Spanish Conquest, a span of three and a

1 Dates and ranges for all periods and sites are expressed as calendar years BC/AD based on calibrated radiocarbon dates (Stuiver and Reimer 1986; Stuiver and Becker 1993).

FIG. 3 Arenal volcano erupting. Part of the eruptive column collapsed into a pyroclastic flow, seen racing down the slope into tropical rainforest. The rainforest was vaporized.

half millennia. Melson (1994) dated Arenal's first big explosive eruption to about 1800 BC, but that may have been Cerro Chato's final eruption (Soto et al. 1996), and the Arenal and Chato eruptive sequence before 1000 BC may be more complex than we thought. Soto et al. found evidence of eight eruptions from about 5000 to 1000 BC, for an average of one every 550 years, but we have little or no direct documentation of sites interdigitated with most of those tephras.

Although the source of the ca. 1800 BC tephra is in doubt, what is more pertinent for this study is that ten large explosive eruptions affected people in the Arenal area over the course of the last four millennia (fig. 2), for an average periodicity of four hundred years, a span of time well within human societies' abilities to maintain knowledge within an oral-history tradition. The ancient inhabitants of the Arenal area may have been less surprised by explosive eruptions than were the recent residents when it erupted in 1968 and killed almost a hundred people (fig. 3).

The paleolimnological and tephrostratigraphic work at Lake Cote has detected a major climatic change at about 500 BC (Arford n.d.). Arford found that the climate from 2000 to 500 (or 400) BC was dryer than it is at present, indicated by the relatively high concentrations of grass pollen and charcoal in sediments from that time span. He notes the decline of grass pollen and charcoal in post-400 BC layers and interprets that as a shift to wetter conditions. That climatic change correlates with the cultural change from the Tronadora to the Arenal phase (Sheets 1994), which is evident in ceramics and in many other aspects of culture. In addition, cemeteries were located at a moderate to considerable distance from the villages and village size increased, as did regional population density. Ceremonial feasting after the dead were interred began in a major way.

In fact, at least in this area of Costa Rica, postinterment ceremonialism peaked during the Arenal phase. Because all these changes are consonant with cultural changes that were underway throughout lower Central America, it is not clear whether any of these changes had anything to do with the climatic change. Alternatively, the climatic change detected at Lake Cote could have been more widespread than is currently understood. At most, the increase in site size and density could have been facilitated by the increase in moisture, but that is only speculation at this point. However, the eastern end of the research area is now so humid that maize agriculture is not feasible, because soils are saturated eleven months of the year and seeds rot rather than germinating, discouraging even the most determined cultivator. While the increase in moisture may have discouraged seed-based agriculture, it must have increased the biomass and probably the diversity of wild flora and fauna.

Recounting each eruption and looking at each case for possible cultural effects is not necessary here. That information is available elsewhere (Melson 1994; Sheets 1994, 1999). Because we have yet to find an Arenal eruption that coincided with, and may therefore have led to, significant culture changes, we can deal with them in the composite here. Population densities from the Archaic to the Spanish Conquest varied significantly, reaching a peak during the Arenal phase (500 BC–AD 600), but populations never reached the densities of Mesoamerica or the Andes during the same long time span. Societal complexity remained low, with egalitarianism the rule from the PaleoIndian period up to the Spanish conquest. The only time local societies probably were pushing that boundary, and thus perhaps could be considered "trans-egalitarian," was during the Arenal and Silencio phases. During both of those phases slight variations were noted in the upper and lower areas of cemeteries. The upper areas of cemeteries in both phases received slightly more elaborate treatment of the dead during burial and with subsequent feasting, than did the lower areas. Skeletal preservation is insufficient, especially during the Arenal phase, to explore the possibility that gender was a factor in this differential treatment.

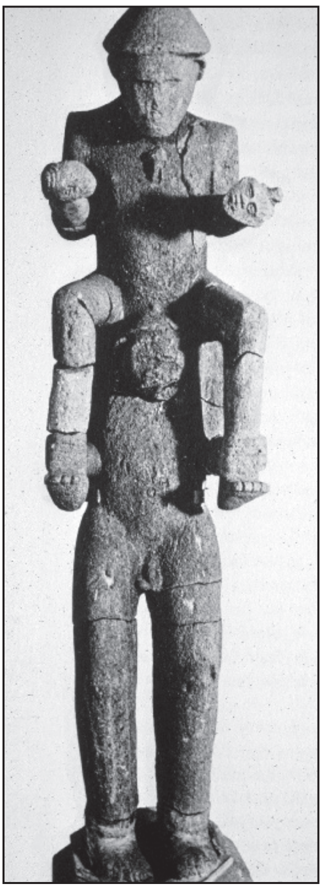

FIG. 4 Life-sized sculpture of a commoner in the Barriles society, nude, holding an elite or chief on his shoulders. The top individual wears a peaked cap and a pendant as symbols of high status and holds an axe and a severed human head in his hands.

Barriles, Panama

Compared to the Arenal-area societies, the Barriles societies (Linares and Ranere 1980), which I evaluate as ranked societies or chiefdoms, were more complex, having clearly crossed the threshold from egalitarian (fig. 4). But they were

FIG. 5 Barriles site (BU-24) test pit, with the thin tephra layer from the Baru volcano eruption, indicated by the T on the wall. The soil developed from that has largely incorporated the tephra, and a few more centuries of weathering and soil formation will eliminate it as a visible layer. The thick fertile soil that sustained the Barriles society is visible below the T and the tephra from which it was derived is visible at the bottom of the pit.

not markedly more complex than at Arenal, especially when compared to the state-level societies of Mesoamerica, and both area societies lived in similar environments. The population density along river courses was greater at Barriles than at Arenal, but certainly did not reach the densities of Mesoamerica. Thus, if we were conjecturing solely in terms of complexity, we would expect the Barriles chiefdoms to be moderately more sensitive to sudden explosive volcanism than were Arenal societies. The Baru volcano erupted, probably in the seventh century AD, and buried the nearby Barriles chiefdoms in the upper reaches of the Chiriqui Viejo River under a relatively thin blanket of volcanic ash (fig. 5). The ash depth, probably in the 10–20 cm range, is comparable to the ash blankets that affected Arenal-area societies at the west end of the lake. Those societies recovered completely; we are unable to detect any culture change that coincides with any eruption and thus may have been forced by that eruption.

Based upon the above factors of adaptation, population density and distribution, climate, complexity of society, and magnitude of the eruption, we would predict that the Baru volcano eruption would have caused some short-term dislocations, probably crossing the Direct Action threshold but not beyond. Thus, the same societies would have reestablished their settlements and culture within a few decades. But that expectation is strikingly different from what actually happened. For reasons that initially were unclear, the Barriles chiefdoms in the upper reaches of the Chiriqui Viejo River resorted to Radical Action, permanently abandoned their settlements, and moved over the divide and down to the Caribbean coast (Linares and Ranere 1980: 244–245). They had to change their architecture and fundamentally change their subsistence adaptation to the much wetter environment, and they never returned to the Pacific drainage.

Politics rendered the Barriles chiefdoms more vulnerable than did ecology, eruption, adaptation, or demography (Sheets 1999). The Barriles chiefdoms engaged in chronic warfare, often capturing victims from adjacent polities and decapitating them. Although they shared the same culture, presumably spoke the same language, and shared the same adaptation, peoples' allegiances were intra-chiefdom, and the political landscape was one of hostility. Therefore, when a relatively small volcanic eruption deposited 10–20 cm of volcanic ash in their terrain, no refuge area was available to them, and they had to emigrate and change much of their culture. Thus, the factor of interpolity hostility generated a high vulnerability, even though all factors except politics would indicate a relatively low composite vulnerability. Politics alone evidently increased Barriles chiefdom vulnerability. Vulnerabilities are therefore a composite of complexities and other key factors such as institutionalized hostility.

El Salvador, Focusing on the Zapotitan Valley

The first estimates of the dating of the Coatepeque eruption (Williams and Meyer-Abich 1955) to perhaps 10,000 years ago indicated that it might have affected human populations (Sheets 1984). However, recent volcanological research has dated its big eruptions from about 77,000 to 57,000 years ago (Rose et al. 1999; Pullinger n.d.).

People have occupied what is now El Salvador for at least the past 10,000 years (Sheets 1983a, 1983b, 1984), and they often have interacted with volcanoes (Sheets 1980) (fig. 6). By the first centuries AD, the "Miraflores" cultural

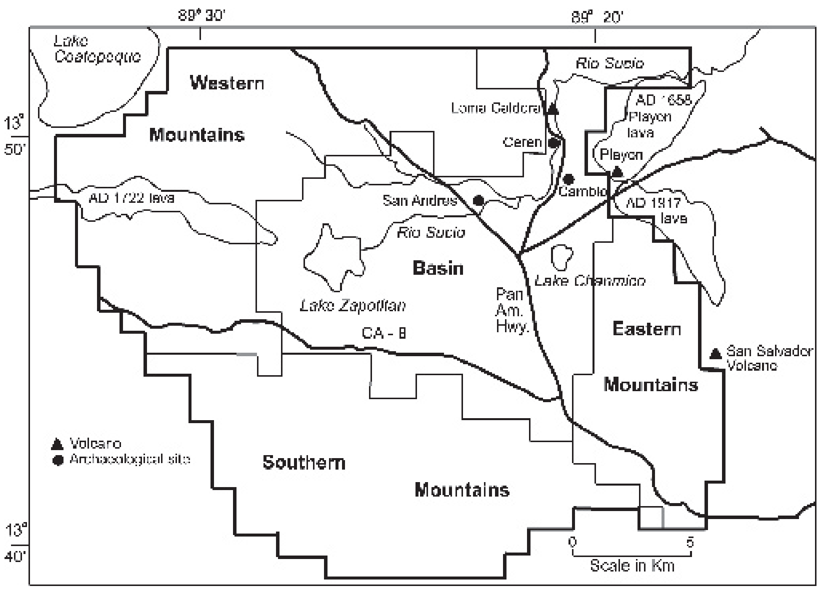

FIG. 6 Map of the Zapotitan Valley, including sites, volcanoes, and lava flows

sphere had developed, extending from El Salvador well into the Guatemalan highlands (Dull et al. 2001). This precocious cultural florescence included large chiefdoms or small states with hierarchical settlement and economic systems in the intermontane valleys (Sharer 1974). Monumental construction was made of adobe brick or rammed earth, while domestic vernacular architecture was the highly earthquake-resistant wattle-and-daub (Sheets 1992). Stelae commemorating rulership were carved, and included hieroglyphics and calendrics (Sharer 1974). This cultural florescence was forever truncated by the huge eruption of Ilopango volcano, initially dated to calibrated one sigma AD 260±114 (Sheets 1983a), but recently redated to AD 408 (429) 536 calibrated two-sigma range (Dull et al. 2001). The plinian and phreatomagmatic eruption was one of the greatest in Central America during the Holocene, and at least 1000 km² were rendered uninhabitable for people as well as fauna and flora (fig. 7). The estimated minimal population density of 30/km² allows for an estimated death toll of some 30,000 people. The surrounding 10,000 km² received tephra depths greater than .5 m, creating stresses greater than traditional agriculturalists could handle. This disaster crossed the Intolerance threshold, necessitating Radical Action in the form of emigration by an estimated 300,000 people, though we have no idea how many asphyxiated or how many survived to emigrate. Many could have avoided asphyxiation by breathing through fine-weave cotton cloth. Areas farther from the source received thinner tephra blankets, resulting in less disruption. Areas receiving only a few centimeters could have benefited from the mulch effect as well as increasing soil porosity and suffocation of some insect pests.

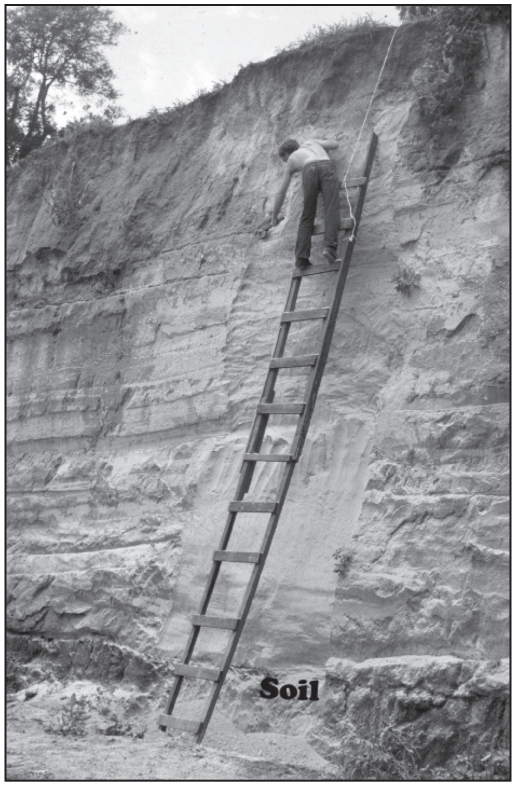

FIG. 7 Payson Sheets cleaning a profile of tephra from the Ilopango eruption overlying the pre-eruption soil (labeled "Soil" on the photo) and a small archaeological site. The volcanic ash is 6.7 m deep, and soil formation after almost two millennia of weathering is not as thorough as with the pre-eruption soil. This locality is 11 km from the source.

Lothrop (1927) was the first to suggest that the reoccupation of the area devastated by Ilopango (Porter 1955) was from the north, by Maya-affiliated people, and that identification has stood the test of time. Thus, cultural recovery by descendants of the original inhabitants of the Miraflores cultural sphere never occurred. One of the earliest settlements yet found representing the reoccupation of the devastated area is Cerén, where polychrome ceramics and architecture show close relationships with the Classic Maya site of Copán and environs (Beaudry-Corbett 2002; Sheets 2000, 2002; Webster et al. 1997). We estimate Cerén was established about a century after the Ilopango eruption, and it functioned for about another century. Early- to mid-seventh century, the Loma Caldera volcanic vent opened nearby and buried the village under 5 m of tephra (Miller 2002, n.d.). I doubt we will ever know the year in which it erupted, but we do know the month and time of day, an irony of archaeological dating. The eruption occurred in August, the middle of the rainy season, based on maturation of annuals and sensitive perennials. As evidenced by multiple artifact patterns, the eruption occurred in the early evening, after dinner was served but before the dishes were washed, that is, around 6:00 to 7:00 pm, if Cerénians were following eating patterns similar to those of traditional Central American households today. The eruption devastated only a few km^2 of the valley.

Recovery from the Loma Caldera eruption is best documented at the Cambio site (fig. 6), 2 km south of Cerén (Chandler 1983). All of the artifact categories are identical before and after that eruption, with only one minor exception. After the eruption the people reoccupying the area had a new kind of polychrome pottery called Arambala, but all other types and wares continued unchanged (Beaudry-Corbett 2002).

Life went on in the Zapotitan Valley for about two centuries without a significant explosive eruption that we have detected, but toward the end of the Classic Period San Salvador volcano erupted a fine-grained wet pasty tephra that severely affected the eastern half of the valley. Hart (1983) named it the "San Andres Talpetate Tuff" and argued that it was phreatomagmatic, being erupted through a lake that occupied the large crater called "Boqueron." It devastated some 300 km^2, thus placing it midway between Loma Caldera and Ilopango in magnitude. Estimated population sizes range from 21,000 to 54,000 people, who would have had to migrate to arable areas. Cambio again best documents the recovery from the Boqueron eruption (Chandler 1983), a recovery that was complete by the end of the Classic Period at about AD 900. The moderately complex large chiefdoms or small states were sufficiently resilient to withstand these two eruptions—small and medium in scale, respectively—recovering thoroughly within a few decades.

Extensive documentation is available for the numerous historic eruptions in the Zapotitan Valley (fig. 6), beginning with the Playon eruption in 1658, and including large lava flows in 1722 and 1917, and the growth of the Izalco volcano from 1770 until 1966. Browning (1971) provides a fascinating account of native Pipiles having to emigrate from the area devastated by Playon, and their decades of struggle before they finally gained access to some land for subsistence. These eruptions further emphasize how volcanically active the Zapotitan Valley landscape has been, but they are beyond the Pre-Columbian focus of this chapter.

Mexico: Tuxtla Mountains

The Tuxtla Mountains, on Mexico's southern gulf coast (fig. 8), were volcanically active in the Holocene (Reinhardt n.d.) and have often affected populations. The Tuxtlas average four explosive eruptions per thousand years, a periodicity comparable to the Zapotitan Valley, and about twice that of Arenal. Santley (1994) has investigated the archaeological site of Matacapan. The earliest eruption that must have affected people dates to 3000–2000 BC, but few direct data are available. The second eruption that affected people dates to about 1250 BC, and is known as the CMB tephra. The affected society was egalitarian and sedentary. I measure the tephra depth from Reinhardt's (n.d.: 97) profiles at about 60 cm, and Santley (1994) notes that the area was abandoned for nine centuries. The CMB tephra may have had a seriously deleterious effect on local settlement, but until regional research is done we will not know how large an area was affected. The radiocarbon dates on these Tuxtla Mountain eruptions were calibrated using the computer program CALIB (Stuiver and Reimer 1986).

The third eruption deposited the CN tephra in about AD 150, which I measure from Reinhardt's section (n.d.: 86) at about 40 cm. Based upon the dating, one would expect societies after the decline of Olmec civilization but before the Classic-Period florescence, and thus most settlements probably were egalitarian farming villages with some ranked societies, perhaps midway between Arenal and Barriles in complexity. Santley reports that the area was abandoned but recovery was relatively rapid. The next two eruptions (CP and LN tephras) occurred in such rapid succession that no soil development occurred on the earlier, so for purposes here they are considered together. I measure their combined thickness at about 20–30 cm on Reinhardt's (n.d.: 100) section, and Santley notes that people continued to live at the site. Apparently this tephra depth was within the domain of Loss Acceptance, that is, within the abilities of agriculturalists to continue to farm their lands. The societies affected may have been slightly more complex than the earlier ones, perhaps ranked societies.

The final Classic-Period eruption occurred about AD 600, and I measure the LC tephra at about 45 cm in thickness on Reinhardt's (n.d.: 97) section. Santley (1994) found a ridged maize field below the tephra. Societal complexity was at a peak at the time, but then began a steady decline. I suspect the consistent, direct correlation between tephra depth and societal impact in these Tuxtla cases is more than coincidence, because the greater depths caused greater dislocations. However, Santley and Arnold (n.d.) do not agree with my interpretation here: they argue that the more complex societies can harness more energy and labor than less complex societies, and are thus able to better withstand volcanically induced stresses.

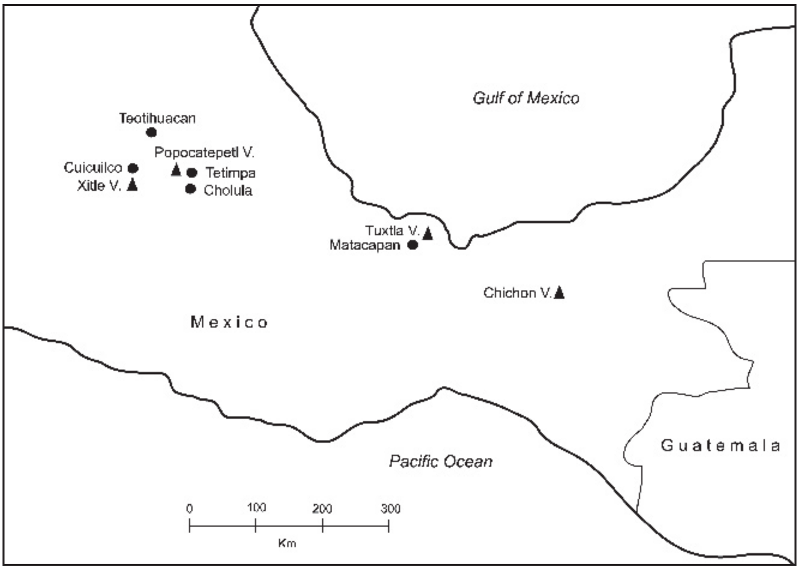

FIG. 8 Map of Mexico with volcanoes and archaeological sites indicated

El Chichon

El Chichon volcano (fig. 8), some 200 km ESE of the Tuxtlas, has erupted often during the past few thousand years (Espindola et al. 2000), and each time must have affected human populations. Espindola et al. (2000) document eruptions at 5750 BC, 1750 BC, 1150 BC, 550 BC, 50 BC, AD 50, AD 350, AD 450, AD 700, AD 1050, and AD 1400. All dates are calibrated using Stuiver and Reimer (1986). The eruptions of AD 700 and AD 1400 deposited significant plinian pumice falls. And, of course, Chichon erupted a couple of decades ago, in AD 1982, blasting fine ash into the stratosphere over 20 km in height. Espindola et al. (2000) found ceramic artifacts between some of the tephra deposits and reasonably infer that the eruptions must have affected people. Here is an excellent opportunity for interdisciplinary research by archaeologists and geologists to study the eleven Pre-Columbian eruptions, effects on societies, resilience, and recoveries. The archaeology of the area has barely begun.

Central Highland Mexico

The Basin of Mexico and nearby Puebla (fig. 8) were affected by explosive volcanism at various Pre-Columbian times, and Popocatepetl continues to erupt tephra and gasses today. Plunket and Uruñuela (1998) document a fascinating persistence of ritual activity during the past two millennia by people trying to persuade Popocatepetl not to erupt. Plunket and Uruñuela have broached a topic that, in my opinion, is woefully underdeveloped by archaeologists: people turning to the supernatural to help them with their anxieties. Miller and Taube (1993: 119–121) summarize the deliberate symbolism of pyramids as constructed sacred mountains in Mesoamerica, and the Maya referring to pyramids as mountains with their word *witz*. One can easily see how the doorway into the temple symbolizes the mouth of the volcano, and the copal incense smoke billowing forth symbolizes the gasses emitted. Miller and Taube (1993: 120–121) note how the twin pyramids with temples in the Aztec capital of Tenochtitlan symbolized the twin volcanoes of Popocatepetl and Iztaccihuatl, and how intricately rituals, feasting, and sacrifice were integrated into volcano and deity worship. It appears that Popocatepetl has been a major volcanic presence in northern Mesoamerica farther back than the Postclassic Period.

Sedentary human communities settled along the resource-rich shores of Lake Texcoco in the Basin of Mexico as early as the sixth millennium BC (Niederberger 1979). The descendants of those communities in the southern part of the basin were devastated by a series of tephra deposits at about 3000 BC, especially pyroclastic flows. These date to about the same time as Siebe et al. (1996) have documented a large eruption from Popocatepetl, so the tephra that devastated those egalitarian communities could be the northwestern component of that same eruption. Adams (1991: 38) was convinced by Niederberger's interpretations, and he noted that it took about five centuries for people to move back into the area.

Siebe et al. (1996) document three large eruptions of Popocatepetl in the past five millennia: the first is the above-mentioned one, dated to between 3195 and 2830 BC, the second to between 800 and 215 BC, and the third to between AD 675 and 1095. All three large eruptions began with small ashfalls and ashflows, but soared to massive Plinian eruptions with extensive ash and pumice falls and pyroclastic flows, and ended with extensive mudflows.

Siebe (2000: 61) revised the dating of the second large "cataclysmic" eruption to 250–50 BC and evaluated the magnitude at a Volcanic Explosivity Index or VEI=6. He notes the devastation was particularly extensive toward the east of Popocatapetl, including the site of Tetimpa and throughout much of the Puebla Valley (fig. 8), due to airfall tephra and pyroclastic flows. He notes that the devastation would also include the northwestern slopes that extend down into the Basin of Mexico, particularly the Amecameca-Chalco regions.

Plunket and Uruñuela (n.d.) summarize the most recent archaeological research pertaining to the second of these big eruptions. Their excavations (1998) at the site of Tetimpa have been well documented, and paint a fascinating picture of farmers visiting the site only as long as necessary to keep their fields functioning, and then retiring to what they must have perceived as a safer location. The farmers maintained volcano-effigy shrines in their households to use supernatural intervention to decrease risk. Plunket and Uruñuela (n.d.) suggest that the populations displaced after the big eruption could have been very useful to the elite of Cholula (fig. 9), to be used in great public-works projects such as building the massive central pyramid. The idea that a volcanic disaster can serve as a slave-delivery system is a new concept in archaeo-volcanology.

Plunket and Uruñuela (n.d.) turn their attention to the archaeology of the northwestern flank of Popocatepetl, the area Siebe (2000) documented as devastated. As they note, this area has long been known as the most fertile, moist, and arable of the Basin of Mexico, and Sanders et al. (1979) had documented a long occupation leading to quite dense populations up to about 100

FIG. 9 Cholula site, in Puebla, Mexico. Talud-tablero architecture was buried by a lahar from Popocatepetl volcano.

BC, while the more arid northern part of the basin remained very sparsely populated. Sanders et al. stated that the dramatic population decline in this southern area included at least ten large regional centers along with some hundred other settlements. The reason or reasons why the most arable and densely populated area of the Basin of Mexico was suddenly depopulated has puzzled archaeologists for many decades. As Sanders et al. (1979: 107) state, "we know of no other situation in the historical or archaeological record in which so large a sedentary regional population was involved in such a drastic relocation." Plunket and Uruñuela use Sanders's population figures to estimate that about 70,000 people were affected by this eruption in the basin, and for the first time one can see a possible explanation for both the sudden diminution in the population of the southern basin and the sudden rise in Teotihuacan's population, as both were forced by the eruption. The sudden arrival of tens of thousands of refugees would have strained the newly emerging political, economic, and adaptive systems. Those systems survived the test, and Teotihuacan emerged as Mesoamerica's first urban-based expansionistic empire. Thus, I think Plunket and Uruñuela have gone far to solve two of the Basin of Mexico's longest-lasting Pre-Columbian puzzles.

The most controversial eruption in Mesoamerica surely is that of Xitle (fig. 8), approximately two millennia ago, in the southern Basin of Mexico. It has aroused controversy in its dating, its direct effects on societies, and its possible indirect effects on the rise of Teotihuacan, Mesoamerica's first megacity and aggressively expansionistic civilization. As Cordova et al. (1994) have noted, some scholars dated the eruption to as early as 400 BC, while other investigators dated it as late as AD 400. They side with the later date. If they are correct, they would reverse the common interpretation that Xitle's

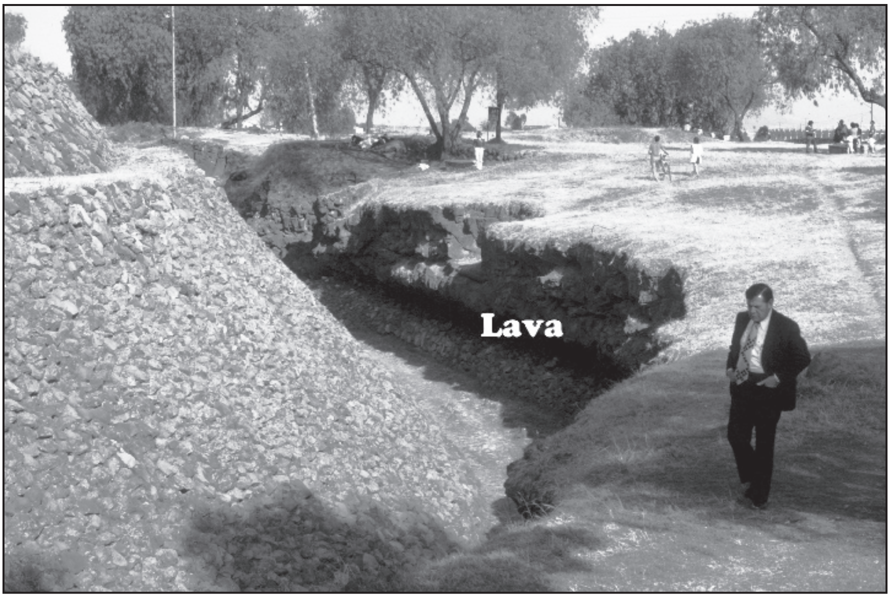

FIG. 10 Cuicuilco, Mexico. The principal pyramid, circular in plan, was partially buried by the lava flow from Xitle volcano.

eruption forced Cuicuilco (fig. 10) residents northward, thus contributing to the growth of Teotihuacan as well as the demise of competition. If they are correct, it is more likely that Teotihuacan outcompeted and absorbed Cuicuilco, and that the demise of Cuicuilco was for cultural reasons, not because of a volcanically induced disaster. More recent research (Urrutia-Fucugauchi 1996), however, places the eruption squarely in the center of that time range, at about the time of Christ, approximately contemporary with the cataclysmic Popocatepetl eruption. The most recent geological dating of the Xitle eruption is somewhat later, 1670 ±35, or AD 245–315, calibrated using Stuiver and Becker (1993), based on charcoal below the lava (Siebe 2000). Archaeologists do not agree on whether Cuicuilco was a thriving community at the time of the eruption, in decline, or even abandoned.

SUMMARY AND ISSUES

Of the thirty-six cases of explosive eruptions in ancient Middle America considered here, about a third are so minimally documented that they contribute little to our knowledge. The other cases vary dramatically in the magnitude of the eruption, the environment and ecosystem affected, the nature of the society impacted, and recovery. Vulnerabilities and recoveries vary significantly, but perhaps an inkling of a pattern can be detected. The egalitarian and minimally agricultural societies in the Arenal area of Costa Rica were remarkably resilient, in part because they were not deeply invested in the "built environment" of major architecture and intensive agriculture, occupational specialization, political hierarchy, and a redistributive economy. The Barriles societies of neighboring Panama were somewhat more complex but were very vulnerable to even a relatively minor stress from the eruption of the Baru volcano, and had to migrate to a different environment and change many aspects of their adaptation. The political landscape of institutionalized hostility among polities is proposed as the reason for their enhanced vulnerability. The most complex societies considered in this paper, the Pre-Columbian states of Mesoamerica, apparently were the most vulnerable to a sudden massive stress and often did not recover their lands after weathering and soils were adequate to sustain reoccupation.

An important cross-cultural study found that unpredictable sudden stresses were much more difficult for non-Western societies to handle than were the more predictable long-term stresses such as sustained droughts (Ember and Ember 1992). Unpredictable stresses or disasters led to warfare to obtain resources from other societies or settlements more often than chronic stresses and more predictable disasters. The simple unilinear causality reasoning that treats people mechanistically and solely as passive victims of disasters is woefully oversimplified. If disasters were like mutations that affected their targets randomly and unpredictably, then that simple unilinear causality mode of reasoning, exemplified by "disaster strikes people," would be warranted. However, people are not uniformly distributed across landscapes, stresses such as disasters rarely affect all people equally, all components of societies are not equally vulnerable, and human societies are not uniform in their natures and distributions. The actual diversity and array of societies on our planet places some cultures and some segments of societies at greater risk than others. Often the politically disenfranchised urban poor in many of the world's cities today are crowded into floodplains, gulleys, or steep slopes, and thus suffer more greatly from floods, lahars, and landslides than do wealthier and more politically active segments of the same societies.

Donald Kennedy (2002), in an editorial in the journal *Science,* described the similarities between disasters and terrorist attacks on societies, how societies perceive each of those risks, and how societies can plan to diffuse the effects of both. He suggests that changing our society to better cope with both types of sudden massive stress would include "retrofitting society to create a more diffuse and distributed infrastructure." The more diffuse and distributed infrastructure of Arenal-area societies apparently aided their reaction to, and recovery from, explosive volcanic eruptions. The state-level societies of Mesoamerica were the antithesis of diffuse and distributed, and they suffered greatly when faced with big explosive eruptions (Sheets 1999). Kennedy (2002) concluded that "[b]ecause our social and economic arrangements have made us vulnerable to both [terrorist attacks and disasters], we can gain from working on them together with a program that involves the social sciences as deeply and as actively as the physical sciences." Because 95% of the research funding for disasters goes to the physical sciences and engineering (Alexander 1995), I am not optimistic that a balance will be soon achieved.

Most disaster research emphasizes the scientific, the measurable, and the empirical aspects of extreme geophysical events. Anthropologists can contribute other important perspectives, as exemplified by the Plunket and

Uruñuela (1998) study of religious appeasement of Popocatepetl volcano over the past two millennia. Our Western societies perceive hazards and disasters very differently from many non-Western preindustrial societies. We study the secular disaster agent from many angles such as frequency, intensity, duration, and impact. We document the effects on societies and trace the recovery process in detail, at least initially. In contrast, non-Western societies often invoke supernatural sources and meanings/causes for disasters. Disasters are often explained by claims (sometimes self-serving, by leaders) that people failed in their portion of the sacred covenant; therefore deities generate extreme natural events as warnings and disasters as punishments. Ritual, sacrifice, feasting, procession, and other supernatural contacts and activities are used to decrease risks.

Not all aspects of the human responses to disasters are negative, particularly in the long run. Tropical biologists and botanists have long wondered why tropical wet environments have such high species diversity. Recently, tropical botanists have been developing new ideas that are taking form in what is called the "intermediate disturbance hypothesis," which postulates that intermediate scales of disturbance upset equilibrium conditions and promote species diversity (Molino and Sabatier 2001). Intermediate scales of disturbance are of the magnitude of the volcanic eruptions considered here, greater than local disasters but smaller than the truly huge disasters that occasionally have occurred in Earth's history. Here I propose an analogue with cultures, that medium-scale disasters can have creative aspects, in addition to the obvious destructive aspects that have received the bulk of attention. People can learn from disasters, they can maintain oral histories and traditions that assist in coping with the next disaster, they can create elaborate religious systems to provide explanation and assurance, and they can modify their loci of residence and the nature of their adaptations.

Archaeologists are particularly well posed to explore the destructive and creative aspects of disasters, and do so in a multidisciplinary and even interdisciplinary manner. Archaeology can leave the immediacy of the disaster, the personal tales of bravery and suffering, along with the deaths, injuries, and destruction, to other disciplines and the media. Archaeology's contribution is rightly in the long term, documenting the processes of recovery of the natural environment along with people, studying empirical and supernatural means of coping with the unknown, and exploring scaled vulnerabilities and cultural recoveries or the lack thereof.

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