Social and Physical science approaches to volcanism, people, and cultures in the Zapotitan Valley, El Salvador

Payson Sheets, Anthropology, Univ. of Colorado, Boulder CO 80309-0233

ABSTRACT

Ancient and historic human societies living in Middle America apparently varied considerably in their long-term reactions to the sudden massive stresses caused by explosive volcanic eruptions. The focus of this chapter is on ancient and historic complex societies and volcanic eruptions in the Zapotitan valley of what is now El Salvador during the past two millennia. Each eruption certainly was disastrous for the communities living near the volcanic vents that were buried under meters of volcanic ash or lava, but the focus here is on resilience and the long-term effects, or the lack thereof. In all but one case, societies recovered quite readily and negligible long-term effects of the eruptions were detectable. In some cases a volcanic eruption could have had creative long-term effects, as societies reacted to stresses.

Comparing eruptions and their societal effects indicates that there was a threshold of magnitude of these eruptions beyond which the society affected did not recover, and if reoccupation occurred, it was by a different ethnic or cultural group. An example is the TBJ (Tierra Blanca Joven) eruption of Ilopango where the descendents of the original inhabitants never reoccupied the area. In contrast, the smaller Boqueron eruption devastated the eastern half of the Zapotitan valley, but recovery was achieved by the indigenous society. Volcanic magnitude is one of many key variables, and other "scalar

vulnerabilities" need to be considered in comparing societal responses to eruptions. These scalar vulnerabilities include physical factors such as the magnitude of eruptions, speed of onset (explosive versus effusive eruptions) and the natural and modified environments. Cultural scalar vulnerabilities include organizational complexity, adaptation, demography, and institutionalized hostility. Simpler egalitarian societies in Middle America were more resilient to sudden massive stresses than were the more complex societies. Simpler societies relied less on intensive agriculture, staple crops, fixed facilities, redistributive economies, and hierarchical institutions. Cultural factors such as chronic political hostilities can greatly increase the vulnerability of societies at any point on the simple-to-complex range. It is argued here that assessing a society's vulnerability must include the magnitude of stress, the complexity of the society (including the related factors of adaptation, demography, and the "built environment"), and the political landscape.

INTRODUCTION

It is suggested here that multiple physical and social science aspects should be considered in exploring the impact and repercussions of explosive volcanic eruptions on Precolumbian societies, and societal reactions. These include phenomena in the natural sciences such as the magnitude of the eruption, speed of onset, geochemical and physical aspects of the ejecta, the flora and fauna, climate, and soils in the area of impact. The pertinent aspects also include cultural and social phenomena such as demography, societal complexity, adaptation, the built environment, and the political landscape

(Sheets, 1980). Variation along any of these scales can affect the resistance or vulnerability of a society attempting to cope with sudden massive stress.

What would be an adequate sample size of well documented cases to study interacting natural-social science components to explore patterning and variation? Probably many hundreds of cases would be necessary, because of the great range of pertinent variables, but reaching that number is many years in the future for any culture area, so what follows should be considered preliminary and exploratory. I have documented twenty five cases from Mexico through Central America (Sheets 1999) but they vary considerably in the thoroughness of documentation of physical and social science aspects. The data base is very lean.

The Zapotitan valley of El Salvador has been affected by numerous explosive and effusive (e.g. lava flows) volcanic eruptions during the past two millennia, and the emphasis here is the interplay among the factors of the volcanic impact, effects on flora, fauna, soils, and human societies, as well as the societal recoveries or lack of recoveries as they are documented in the archaeological, historic, and geological records.

A DYNAMIC THEORETICAL FRAMEWORK FOR EXPLORING THE HUMAN RESPONSES TO VOLCANIC ERUPTIONS

Torrence and Grattan (2002) have noted the difficulties archaeologists have faced in dealing with natural disasters in the ancient past. In many cases archaeologists have emphasized the dramatic apocalyptic aspects, and at worst archaeologist have treated all volcanic eruptions as natural disasters. They wisely advocate a careful examination of individual cases, with a healthy dose of skepticism about long-term disasters caused by extreme geophysical events. And an important component here is scale. Eruptions vary immensely in scale, from a highly localized eruption to huge eruptions, usefully arranged on the Volcanic Explosivity Index (VEI) of Newhall and Self (1982). And, turning to the scale of human society affected, an eruption can be disastrous for that isolated human household living too close to the volcanic vent, but the societal effects of an eruption can be negligible in either the short or especially the long run.

But how can archaeologists explore the record for variation in impacts of different eruptions, as we carefully examine individual cases and make at least initial attempts to discern patterns? I suggest a useful way to examine coping strategies to volcanic eruptions is to utilize the human behavioral adjustments that people commonly use when faced with extreme geophysical events, as developed by Burton et al. (1978). Burton and his colleagues developed a set of adjustments and thresholds based on their extensive documentation of many cases from a wide range of natural disasters. The minimal adjustment is **Loss Absorption**, defined as making incidental adjustments with no need for a conscious, overt program of changes. Evidence of this is not likely to preserve in the archaeological record. However when the scale or intensity of impact increases, and the first threshold of *Awareness* is crossed, the second level of adjustment is **Loss Acceptance**. Loss Acceptance involves conscious awareness of the problem, and the losses of the victims are often borne by a larger group of people. However, if the stress is greater and the second threshold, *Direct Action*, is crossed, then **Loss Reduction** is the result. The material correlates of Loss Reduction would have a better chance of being preserved in the archaeological record. If the stress is yet greater, then the third threshold, *Intolerance*, is crossed with the result being **Radical Action**. Radical Action can involve in-situ significant to fundamental adaptive changes, or more drastic adjustments such as migration, and these have the greatest chance of being detectable by archaeologists. An example of Radical Action is migration to a location far from the disaster, such as that done by the uppermost polities near Volcan Baru in Panama, that also involved significant changes in their adaptation. That case is discussed briefly, after the Zapotitan valley section.

Burton et al. (1978) focus on the negative societal impacts of natural disasters on people and societies that survived. For our purposes here I want to expand their framework one step in both directions. We need to consider the cases where people did not survive, and study the geographic and demographic scales of those cases. At the other end of the scale, there were beneficial effects of volcanic eruptions where thin tephra layers could contribute aeration and nutriments to soils as well as asphyxiate some insect pests. And, the stresses of eruptions can have creative effects, as people react with various degrees of action. The challenges and societal changes can be in the built environment, in the cognized environment, in oral history, religion, and ritual.

Beneficial and creative Effects of Natural Disasters

Loss Absorption

Awareness threshold

Loss Acceptance

Direct Action threshold

Loss Reduction

Intolerance threshold

Radical Action

Devastation, no human survival

Table 1. Range of Impacts and Human/Cultural Responses

Disasters can have creative effects on cultures, as people adjust to their changed circumstances by making modifications in their settlements, adaptations, oral histories, and religious belief and practice. This is somewhat analogous to some new thinking in biology, as scholars explore the ways in which natural disturbances can help maintain biodiversity and productivity (Lindenmayer et al. 2004). Natural disasters can recreate structural complexity as well as landscape heterogeneity within biologic communities.

VOLCANIC ACTIVITY, HUMAN IMPACTS, AND RESPONSES IN THE ZAPOTITAN VALLEY

Although the natural and cultural records of the interplays among volcanic eruptions, societies, and people in El Salvador's Zapotitan valley (Figure 2) are far from complete, at least the outlines of some of these interactions can be traced over the past couple thousand years. There are a few islands of knowledge, but unfortunately they are surrounded by seas of ignorance that need sustained research.

Coatepeque eruptions

The Coatepeque eruptions during the late Quaternary, that emanated from the Santa Ana volcanic complex, have been studied for a good half century, beginning with Williams and Meyer-Abich (1955) describing them as a caldera collapse and/or explosion of an earlier edifice. Estimates of the age ranged from 10,000 to 40,000 years, and the possibility that PaleoIndian sites might be buried under Coatepeque tephra deposits, which could date to the more recent end of that range, was raised (Sheets 1984). However, more recent volcanological research has dated the Coatepeque eruptions farther back in time, thus dramatically diminishing the possibility that people were affected by any of them. The chances are slight that people were living in what is now El Salvador before 15,000 to 20,000 years ago.

The three big eruptions of Coatepeque, including the caldera formation, have been identified and radiometrically dated by Pullinger (1998). Rose et al. (1999) and Pullinger (1998) date the Bellavista eruption to 77,000 +/- 2000 years ago. The greater Arce eruption followed shortly thereafter, at 72,000 +/- 3000 years ago, and probably included the caldera formation. The Arce event involved the greatest volume, at about 40 km^3 (Pullinger, 1998:37). The final eruption, called the "Congo event," is dated to 56,900 +2,800 –2,100 years ago. Each of these Coatepeque eruptions could be considered a true natural disaster in the physical sense, as each drastically affected the local flora and fauna, but not people. The eruptions considered below will not be described only as "natural disasters" because they are complex networks of natural and cultural factors. People and their societies were deeply involved, prior to each disaster, during its impact, and in the aftermath and recovery, or lack of recovery. Thus, these disasters are explored in multiple dimensions, including natural, cultural, economic, and political domains, at least insofar as the available documentation will allow. Often only one or two domains are well published in particular cases, thus limiting understandings.

Southeastern Mesoamerican society prior to the Ilopango TBJ (Tierra Blanca Joven) eruption

The pre-TBJ eruption southern Mesoamerican society was complex, with advanced chiefdoms or small city states dominating the broad intermontane valleys in the few centuries before and after Christ. What is now western El Salvador played a major role in the late Preclassic “Miraflores” cultural sphere that extended well into the Guatemalan highlands (Sharer 1974, Dull et al. 2001). This cultural florescence was characterized by elite-dominated primary sites in the midst of landscapes dotted by secondary sites, towns, and villages, as documented by Black (1983) in the Zapotitan valley. Sophisticated earthen architecture included adobe brick construction as well as rammed earth and bajareque (wattle-and-daub) construction. The latter is remarkably earthquake resistant and was favored for commoner housing before and after that eruption (Sheets 1992). Stelae were carved with calendrical and textual hieroglyphics at Chalchuapa (Sharer 1974). Large carved stone jaguar faces were placed at the bases of stairways surmounting earthen-fill pyramids. Ceramic innovations were notable, with technically sophisticated Usulutan resist decoration being made in this cultural sphere, particularly at Chalchuapa (Sharer 1974) and imitated by ceramicists elsewhere in southern Mesoamerica. Lithic specialists, attached to the elites at primary and secondary centers, were producing prismatic blades, macroblades, tanged macroblades, and scrapers for use in households at all levels of society (Sheets 1983b). Commoners could obtain their obsidian implements and the other elite-controlled materials such as jade for axes, hematite and cinnabar pigments, shell, and other items at marketplaces in the primary or secondary centers in the valley (Sheets 2002). Commoners thus had some choice in where they would get their elite-provided goods, and how, so elites would have had to compete for clients, and thus did not have total power and authority. This presents a different view than that "from the top of the pyramid." Commoners could negotiate their way through the social/economic landscape, instead of being the automatons of basic production.

The Ilopango TBJ eruption

The Coatepeque and Ilopango eruptions were physically similar massive plinian eruptions of acidic tephra that certainly were devastating to the tropical flora and fauna of central and western El Salvador. They also are similar in that each source had multiple eruptions. Rose et al. (1999:107, 109) describe four eruptions from Ilopango, from earliest to the most recent, called the TB4, TB3, TB2, and the TBJ. The TB4 probably occurred prior to human habitation of the area, but the TB3 and TB2 eruptions may have affected people. Loci where the TB 3 and 2 tephra units bury paleosols that contain artifacts should be sought and studied. Ceramic analyses are capable of identifying time blocks on the order of a century or two, and thus could assist in dating these two poorly known tephra units.

Porter (1955) excavated some 3000 potsherds, 47 obsidian artifacts, two metates, and charcoal in a paleosol buried by a thick deposit of white volcanic ash at Barranco

Tovar in San Salvador. She noted that ash layer to be 10 to 20 m thick around San Salvador, which sounds like the Ilopango TBJ tephra with the associated pyroclastic flows. She obtained one C14 date, run in the early 1950s when radiocarbon dating was early in its infancy: 1040 +/-360 BC. There are two obvious possibilities, (1) the site is buried by the TBJ and the date is considerably too early, or (2) the date may be reasonable and thus the site is earlier and buried by tephra from the TB2 or 3 eruption. The site is no longer accessible because a large apartment building occupies that location, but other parts of the site may extend beyond the building's foundations. Most volcanological and archaeological research on Ilopango has focused on the latest large explosive eruption, the TBJ, and that is the focus of the rest of this section.

Almost a century ago the Salvadoran scholar Jorge Larde (1926) discovered various exposures in the San Salvador region where white volcanic ash buried ceramic and lithic artifacts. He reasoned an ancient eruption had buried archaeological sites. He showed the deposits and artifacts in what he called the "C horizon" to Sam Lothrop, who described the ash and artifact exposures in considerable detail (Lothrop 1927). Lothrop focused on the Cerro Zapote site, in southeastern San Salvador. He recognized the early character of the ceramics, dating to what is now called the Preclassic period. Lothrop also identified the artifacts stratigraphically superior to the volcanic ash layer as Maya in character, in what he called the "A horizon," thus indicating the cultural affiliation of the group that reoccupied the area. He identified the major stratigraphic layers by arbitrary letters that are not related to how soil horizons are designated today. He speculated that Ilopango could be the source of the volcanic ash. Later research has confirmed Lothrop's suspicion of source, as it is now known that the archaeological sites were buried by tephra from Ilopango, called the TBJ (*tierra blanca joven*, i.e. young white earth) tephra (summarized in Sheets, 1983b). Curiosity about the possibility that the numerous other exposures with visually similar tephra and artifacts that were recorded by various scholars in the middle decades of the 20th century (Sheets, 1983b) could have been affected by the same massive eruption led to regional research by Sheets, Steen-McIntyre, Hart, and others. Later research demonstrated that most tephra deposits mentioned in these studies were from the same massive eruption, the TBJ tephra from Ilopango (Hart and Steen-McIntyre, 1983).

The Ilopango TBJ eruption was dated to AD 260 +/- 114 by multiple radiocarbon analyses (calibrated 1-sigma composite) conducted in the 1970s (Sheets, 1983a). That date may be too early, based on recent efforts to obtain more precise radiocarbon dates by careful sampling and AMS (accelerator mass spectrometry) dating. The results indicate that eruption may have occurred a century and a half later at AD 421 (429) 526 calibrated one sigma, or AD 408 (429) 536 calibrated two sigma (Dull et al. 2001). A problem is the eruption occurred at a section of the radiocarbon calibration curve that is particularly difficult, and I suspect that significant improvements in dating will not occur until the signature of the eruption is detected and confirmed in the Greenland ice cores.

The TBJ eruption was one of the greatest Holocene eruptions in Central America, and its ecological and societal impacts were felt throughout El Salvador and adjoining Guatemala and Honduras. The plinian and phreatomagmatic eruption resulted in the elimination of flora and fauna over tens of thousands of square kilometers. Although population density prior to the eruption has not been established, a conservative estimate is at least 30 people per square kilometer on a general regional basis (based on Black

1983). The eruption ejected a total volume of approximately 18 km^3 of dense rock equivalent (DRE) into the air, creating a zone of total devastation in an area of some 1000 km^2 surrounding Ilopango (Dull et al. 2001) where no people, animals, or plants would have survived. The area was devastated by huge pyroclastic flows that uprooted and carbonized trees even at distances of 25 km from the vent. The death toll in this area is estimated at 30,000 people (Dull et al. 2001). This is the area of Devastation (Table 1).

Beyond the area of total devastation was a zone of at least 10,000 km^2 where the ash blanket was more than 50 cm thick (Dull et al. 2001). This has been mildly called the zone of depopulation by Dull et al. (2001). Based on tephra-induced roof collapses at Ceren (see below), all roofs were collapsed in this zone. An estimated 300,000 people lived in this zone, and some of them could have survived by taking protective measures such as breathing through cotton cloth to filter out the fine tephra, but many must have perished from asphyxiation. Certainly, no survivors could continue living in the area with contaminated freshwater and agricultural fields deeply buried by the sterile white ash. Segerstrom (1950) found that volcanic ash depths greater than 10-25 cm from the recent eruption of Paricutin exceeded the coping abilities of traditional Mesoamerican maize agriculturalists. Survivors would have had to migrate to arable land outside the zone, thus crossing the Intolerance threshold and adopting the Radical Action response mode (Burton et al. 1978).

Dull (2004) recently published the results of a regional research program investigating the paleoecological records of lake sediments in western El Salvador. He found evidence of intensive agriculture in the centuries before the eruption, and ecologic devastation by the massive eruption. He saw no chance of human survival in the 100 to

200 km2 area near the source, i.e. the San Salvador area and eastern portion of the Zapotitan valley. Farther, people could have survived but had to emigrate. People did not come back into the region until the end of the sixth century. Significantly, people reoccupied lowland areas near rivercourses, but not the highlands, as shown by the core from Laguna Verde in the mountains of Apaneca (Dull 2004:241).   As he summarizes, "It appears that the TBJ eruption was not merely a temporary setback or inconvenience for the people of western El Salvador. The bulk of the evidence (e.g., settlement patterns, ceramic affinities, paleoecological records) suggests that the TBJ eruption forced a wholesale social and economic reconfiguration of western El Salvador and southeastern Guatemala"(Dull 2004:242).   The Sierra de Apaneca had been occupied and farmed for three millennia, from 2500 BC until the TBJ eruption, but the lake core indicates no occupation and agriculture in the succeeding centuries of the Precolumbian era. As he suggests, the population pressures of the Preclassic period that led to occupation in highland mountainous areas probably did not occur in the late Classic and Postclassic periods. I think another significant factor is the slower weathering rates of tephra at higher elevations and the slower vegetative recolonization rates and thus slower vegetative and soil recoveries in the higher mountains.

The favored loci for settlement in the Preclassic through the Postclassic periods were low-lying valleys, alluvial floodplains, and basins (Black 1983, Sheets 1984), because of the access to freshwater, higher water table for natural vegetation and cultigens, and the most arable soils for agriculture. These were the zones most deleteriously impacted by the pyroclastic flows and lahars during the Ilopango TBJ eruption. Thus, in intensively exploiting the prime loci for settlement and adaptation, people in the centuries prior to the TBJ eruption were inadvertently concentrating themselves where the eruption would have the greatest impacts. Generations of people had benefited from living in the favored areas, but their descendents paid the price when Ilopango erupted. The long-run benefits were truncated by the apocalyptic eruption.

Areas beyond the zone of disruption would have dealt with the thinner ash levels by Loss Acceptance, as yields diminished under the tephra-induced stress but maize and other cultigens could survive, and people could still plant through the ash blanket. And, with weathering and incorporation of the tephra, soils could have improved within a few years of the eruption. Still farther from the eruption, in areas like the western Maya highlands, northern Honduras, and the Southern Maya Lowlands, the thin dusting of TBJ tephra could have improved agricultural productivity in the first year of emplacement by providing a mulch layer and increasing soil porosity, adding nutrients, and perhaps suffocating some insect pests. As tephra weathered in the years following the eruption, and became incorporated into soils by human and bioturbation, the zone of beneficial effects of the eruption moved steadily toward the source.

The Ilopango TBJ eruption was about the same scale as the 1st century AD eruption of Popocatepetl in highland central Mexico, also rated a VEI (volcanic explosivity index) of 6 (Plunket and Uruñuela 2002). Large areas of the northeastern flanks of Popocatepetl had to be abandoned, and Plunket and Uruñuela think Cholula benefited from the arrival of refugees who may have been coerced into the massive construction programs. The northwestern flanks also were devastated, and Pluknet and Uruñuela suggest a solution to two longstanding archaeological problems. Archaeologists have long wondered why the most fertile and moist area of the Basin of

Mexico was abandoned at the same time some 50,000 people arrived at Teotihuacan (Plunket and Uruñuela, 2002), and the volcanic impact on the slopes of Popocatepetl is suggested as the likely push factor (Plunket and Uruñuela 2002). Archaeologists also have long wondered why so many people moved into Teotihuacan almost 2000 years ago. Their suggestion of the use of refugee labor at Cholula could also apply to Teotihuacan. It appears the huge eruption drastically affected populations on both sides of the volcano, as immigrants affected the social dynamics of the two largest settlements in central highland Mexico.

Human recovery from the Ilopango TBJ eruption

As a general rule, recoveries from tephra-induced stresses occurred earlier at greater distances from Ilopango, as areas with only a few mm or cm of tephra would have recovered rapidly and benefited from the dusting. But some areas such as the Apaneca mountains (Dull 2004) never recovered during Precolumbian times, probably because of elevation, topography, and perhaps lower population pressures after the eruption than before. The general source of the reoccupants is clear. As Lothrop suggested (1927) for central El Salvador, the reoccupation of the Zapotitan valley emanated from the north, judging from the close similarities in architecture and ceramics of the 6th century immigrants with those from the general Copan area of Honduras. The close cultural and economic relationships of western Salvador and highland Guatemala that existed prior to the eruption were permanently severed by the eruption, and they never were re-established. And as Dull (2004) showed, some upland areas never were repopulated in Precolumbian times. Demographic recovery from the Ilopango eruption occurred within about a century, but cultural recovery in the sense of resilience and re-establishment of the same pre-eruption cultural tradition never occurred. The Preclassic, and barely into the Classic, indigenous cultural florescence of the "Miraflores" cultural tradition in central and western El Salvador was permanently truncated (Dull et al. 2001). While the western component of the "Miraflores" tradition continued in the Guatemalan highlands, the eastern component was devastated and never recovered in El Salvador.

One of the earliest villages yet found representing the human recovery from the Ilopango eruptions is Ceren (Figure 3), in the northern end of the Zapotitan valley (Sheets 1992). We estimate about a century elapsed between Ilopango devastation and the founding of the Ceren village, and it thrived for about another century before it was entombed by the tephra from the Loma Caldera eruption.

The Ceren site

The Ceren site, called the "Joya de Ceren" in El Salvador, was a thriving agricultural village on the left bank of the Rio Sucio (Sheets 1992). All domestic architecture and even the ridges in the agricultural fields run parallel to or perpendicular to the bank of the river that runs 30 degrees east of north. This regular alignment of public and household architecture as well as agriculture had been a puzzle until its correspondence with the riverbank was noted recently, from a suggestion by Cynthia Robin (personal communication 2002). Only the religious buildings diverge from this orientation, in what appears to be a deliberate exception, presumably for supernatural objectives.

The Ceren site provides detailed information on the timing and the nature of recovery from the Ilopango eruption. If the central numbers from the calibrated AMS radiocarbon dates, AD 429 and AD 656, are used to estimate roughly the elapsed time between the eruptions of Ilopango and Loma Caldera, they appear to have been separated by about two centuries. The Ilopango tephra in the Ceren area was measured at the Cambio site, only 2 km south of Ceren, at 1.2 meters (Hart and Steen-McIntyre 1983:23). Erosion and compaction decreased that thickness, so its original thickness was somewhat greater. That would place the Ceren area, and most of the Zapotitan valley, within the zone of complete devastation from the Ilopango eruption. The eruption would have changed a tropical gallery forest environment interspersed with swidden and intense agriculture and dense human populations into a white sterile desert overnight. The acidic (sialic) nature of the Ilopango TBJ tephra would have slowed soil formation and vegetation recolonization. Floral, faunal, and soils recovery would have preceded maize-based human agricultural recovery. Maize is very demanding of nitrogen, and a juvenile soil on a sialic tephra would be nitrogen-deficient. Perhaps a century of time between the eruptions was needed for the natural processes of weathering, soil formation, vegetation recovery, and faunal reoccupations, a time estimate consistent with what has been found at Ceren. The next century, the 6th century AD, witnessed the human aspects of recovery from the Ilopango eruption, with the immigrants founding Ceren and other communities in the Zapotitan valley.

The conservation ethic at Ceren, a World Heritage site (administered by the United Nations), prohibits excavations into structures, so our only evidence of the earliest buildings at Ceren comes from examining the bulldozer cut that sliced into the northern end of Structure 1 in Household 1. That cut divulged several stages in remodeling and replastering that probably extended over a few generations. Another indicator of the duration of occupation is provided by the midden in Operation 2 (McKee 2002), where the amount of trash accumulation indicates at least many years of occupation, and probably a few generations, but not centuries of household discard activities. It therefore appears that Ceren was occupied for perhaps a century before its burial by tephra from the Loma Caldera volcanic vent.

Because Ceren is the earliest known community established in the Zapotitan valley after the Ilopango eruption, it is pertinent to this paper to note the internal nature of the Ceren community, as it provides insight into the nature of social recovery from Ilopango. Ceren was a village of commoners, with perhaps 100 to 150 inhabitants and no elite or attached occupational specialists (Sheets 2002). To date a total of four households has been excavated, and only one of them in its entirety, so the sample is very small. In addition to the households, a civic core of the village has been found, consisting of a formal plaza surrounded at least on its south and west sides by solid earthen-walled public buildings. A religious core of two special structures has also been found at the easternmost edge of the site, at the highest elevation within the site, on the bank overlooking the Rio Sucio. The two buildings were constructed to be different from household and public buildings in that their orientation was different from the abovementioned 30^{o} east of north. In addition, both contrasted with all other buildings at the site with their white painted walls with red hematite decoration, their unique construction of earthen columns, and the multiple floor levels from outside to the most elevated back room.

The ethnicity of the Ceren immigrants and thus their home territory are probably best explored by examining two categories of material culture, architecture and artifacts. Each Ceren household built at least three functionally differentiated buildings, including a domicile, a storehouse, and a kitchen (Sheets 2002). This kind of household structure differentiation and use of built space is a Maya characteristic that existed in the Copan valley at the time of Ceren (Webster et al. 1997). The Chorti Indians of the same area near Copan continued to construct functionally differentiated household structures in the last century (Wisdom 1940). Because people had wide ranges of choices in constructing their housing, from the Maya style of multiple buildings to the Lenca style of a single building subdivided internally, I believe architecture is a more reliable indicator of ethnicity than are portable artifacts. The artifacts with the highest ethnic sensitivity are the polychrome food and drink serving vessels that make up about 22% of each household's fired clay vessel inventory (Beaudry-Corbett 2002). The majority of polychrome vessels are of the Copador type, evidently made in one or more localities in the Copan area and imported into the Zapotitan valley. The Copador polychromes were made available to the commoners by local elites, for exchange by barter, presumably in the marketplace in primary or secondary centers. The locally made utilitarian ceramics, for cooking and storage, are very different from those at Copan and Quirigua. Because no hieroglyphic texts have been found (or are likely to be found) it is not known what language was spoken in Ceren. However, both the architecture and decorated pottery of Ceren are so close to those of the Maya of Copan, that I believe it is justified to state that the Ceren residents were closely Maya related. This puts an ethnic, cultural, and perhaps a linguistic distance between the pre-TBJ eruption peoples and those that recolonized the

Zapotitan valley and surrounding areas. The vibrancy of the pre-Ilopango "Miraflores cultural sphere" was never re-established in El Salvador, because direct cultural recovery never occurred locally. Demographic recovery of prime habitable areas in the valley and most of central and western El Salvador was complete within three centuries after the eruption, while other areas never recovered demographically in Precolumbian times.

Loma Caldera eruption

Loma Caldera was not a volcanic edifice before the eruption, and now is only a small, highly dissected cinder cone. The Loma Caldera vent, only 600 meters north of the Ceren village, opened under the Rio Sucio and began erupting early one evening in August. The dating to time of day is by artifact patterns related to activites, and to time of year by vegetation maturity (Sheets 1992).   Vegetation, including annuals such as maize, and seasonally sensitive trees such as guayaba, indicate the middle of the rainy season, most likely the month of August. Artifacts indicate a meal was just served before the eruption, but the dishes were not yet washed, as evidenced by the finger swipes of food left in hemispherical serving bowls. In tropical climates dishes generally are washed soon after a meal is completed in order to avoid attracting noxious insects, so I believe the eruption occurred very soon after the meal was served. Because dried and stored maize was placed in soaking vessels to soften overnight, agricultural tools were back from the fields, and pots were removed from the three-stone hearths, it evidently was the evening meal. That would mean the Loma Caldera eruption began about 6-7 pm, if Cerenians ate dinner about when traditional Salvadoran campesinos do now. Ironically, the dating by year is more challenging than dating to month and time of day, and the calibrated radiocarbon dates, when averaged, yielded a composite 2-sigma calibrated range from AD 610 to 671 (McKee 2002).

Volcanologically the eruption from the nearby Loma Caldera vent was miniscule in comparison to the Ilopango TBJ eruption, as it devastated only a few km^2 (Miller 1992). People beyond that devastated zone, between 10 to 20 km^2 in area, would have crossed the intolerance threshold and abandoned their homes and take up farming elsewhere. The estimated 165-440 people per km^2 in this very fertile basin province (Black 1983) would indicate some 1500 to 9000 displaced people. When compared to the Ilopango eruption, natural recovery from the Loma Caldera eruption was faster, because the tephra was more mafic and therefore weathered more rapidly. Also, the source areas for recolonizing flora and fauna were no farther than a few kilometers from any point on the tephra blanket. Human demographic and cultural recoveries were relatively quick in the area, probably requiring only a few decades.

The Cambio site: Recovery from the Loma Caldera eruption

Rarely can regional processes and phenomena be understood from a single site, and Ceren is not an exception. The Cambio site, two km south of Ceren, provides a more complete stratigraphic record of the physical and cultural processes following the Loma Caldera eruption (Chandler 1983). Cambio received a thin layer of the Loma Caldera tephra, measured by Miller (2002) at 10 cm. Weathering, compaction, and human disturbance likely had thinned it in the decades after its emplacement. Human reoccupation of Cambio occurred soon after the Loma Caldera eruption, after a juvenile “A” horizon soil had formed, based on our inspection of the stratigraphy. That probably took a few decades at most, and perhaps only a few years. We closely examined all artifact categories to try to detect even the slightest cultural changes from Ceren to the reoccupation of the area at Cambio, and could detect none at all, with only one exception. Beaudry-Corbett (2002) found that the "before and after" ceramic assemblages were identical, except that a new kind of polychrome pottery called "Arambala" is present in small amounts after the Loma Caldera eruption at Cambio but was absent at Ceren. Arambala seems to be a local imitation of the imported Copador and Gualpopa polychrome pottery styles. Other than that small addition to the ceramic inventory, the material culture is indistinguishable from Ceren before Loma Caldera erupted. And, I would not argue that the change was caused by the volcanic eruption, but more probably is indicative of regional cultural changes that occurred while people were living away from the small depopulated zone. While the effects of the Ilopango TBJ eruption echo through the centuries, the Loma Caldera eruption affected only a small area for a short time.

Boqueron eruption: The San Andres talpetate tuff

San Salvador volcano, in a phreatomagmatic eruption, blasted a fine wet tephra through its large crater (Boqueron means "big mouth") that coated the Zapotitan valley during the Late Classic period. It hardened into a tough compact unit when it dried. The tephra is 6 m thick atop Boqueron (Hart, 1983), and the nature of tephra deposits convinced Hart that the eruption was through a crater lake. Hart (1983) named the tephra the "San Andres Talpetate Tuff" after the San Andres site where it had been noted by various archaeologists for many years, and finally described by Hart at that site and published. The tephra was thick enough on the eastern side of the valley to eliminate flora, fauna, and people, and it thinned rapidly on the western side. Because the tuff was over 30 cm thick at the San Andres site (Hart, 1983), it probably caused abandonment of that city for a few decades. The research at the San Andres site in the 1990s found evidence of a hiatus in occupation following the tephra emplacement (Chris Begley personal communication 1997).

Sofield (2004) presents the most recent information on this eruption, which created the current 1 km diameter crater. He found that the eruption began with a pyroclastic flow that extended some 3 km northwest of the crater. Then the main eruption began, which covered about 293 km^2 with 10 cm or more of indurated tephra. He calculated the total eruptive volume at almost a half of a cubic kilometer. He unfortunately published a date of the eruption at ~800 B.P. which he attributes to me, but that is not correct. The eruption has yet to be dated, so estimates based on artifacts above and below the deposit are our only means of estimating the date. The eruption probably occurred a few centuries earlier.

The tephra was over 20 cm thick at Cambio (Chandler 1983), and would have had almost as long a deleterious effect there. Hart estimated at least 300 km^2 were covered by the tuff with depths over 7 cm, but Sofield's data are more detailed. Because this tephra is so compact and hardened, it would have been more damaging to traditional agriculture than would a loose, dry airfall tephra. I think that some 10 cm of this hard tephra may be beyond the maximum with which traditional maize-based agriculturalists could cope, as I extrapolate from Segerstrom's finding (1950) that traditional maize agriculturalists could cope with unconsolidated tephra deposits of 10 to 25 cm in depth.

This would mean that this eruption caused agricultural difficulties that exceeded the intolerance threshold all over San Salvador volcano and including the eastern and much of the central part of the Zapotitan valley. If this is correct, San Salvador volcano and slightly more than half of the Zapotitan valley was abandoned for a few decades. Vegetation recolonization, soil formation, and faunal recoveries probably came gradually and steadily from the northwest, where the tephra blanket was thinner, as well as from other directions toward the thickest deposits.

We can generate a rough estimate of the number of people forced into Radical Action, as the intolerance threshold was crossed and outmigration became necessary. Black's (1983:82) Zapotitan valley survey estimated the overall regional population densities in the Late Classic to be between 70 and 180 people per square kilometer. Sofield's 293 km^2 estimate establishes a range of 20,510 to 52,740 people would have had to migrate. Thus, Boqueron caused a much greater disaster than that caused by the Loma Caldera eruption, but an order of magnitude smaller than the Ilopango TBJ-caused disaster. From a long-term perspective the cultural and demographic recoveries from Boqueron were complete throughout the lowlying areas of the Zapotitan valley within a few decades to perhaps a half century, but the dating of both eruption and recoveries is far from satisfactory.

Unfortunately, virtually all of the archaeological data recovered at San Andres remains unpublished and thus is of little help in dating the eruption, studying its immediate effects, and documenting recovery processes. The best dating is provided by the stratigraphy at the Cambio site, where the tuff is sandwiched between two Late Classic occupation layers that postdate Ceren and the Loma Caldera tephra (Chandler

1983). The eruption most likely dates to the 9th century AD or shortly thereafter, but this is not certain.

In terms of ecological and human impacts this eruption was between Ilopango TBJ and Loma Caldera, but closer to the Loma Caldera end of the scale. Cultural and demographic recoveries from the Boqueron eruption occurred relatively rapidly as shown by Cambio stratigraphy (Chandler 1983). There was no cultural disjuncture that has been detected, in contrast to the Ilopango aftermath. This suggests important lessons about physical scales of eruptions interacting with human scales of vulnerability. The repercussions of these three cases, in the same environment and with similar societal complexities, indicate a significant physical-cultural threshold. An eruption the scale of Ilopango creates disruptions on such a great regional scale that surviving refugee households or communities were not able to maintain cultural continuity and to reoccupy their native territory after sufficient ecologic recovery had occurred. Ilopango overwhelmed many political units. It also overwhelmed the regional economic system of subsistence as well as the elite economic interchange of exotic goods. The nodes of still functioning pre-Ilopango society, which could have provided recovery sources maintaining the pre-eruption culture, were nowhere to be found in the region. In contrast, the Boqueron eruption devastated over half of one intermontane valley, causing an estimated tens of thousands of deaths and migrating refugees, but within a few decades full demographic and cultural recovery occurred. The sources for recovery probably were surviving settlements in the western and northern parts of the valley and perhaps settlements outside the valley. Probably a key factor is that the cultures surrounding the Zapotitan valley in the Late Classic were virtually identical to that within the valley.

Playon eruption AD 1658-71

The fissure system that runs northwest from San Salvador volcano has been active often in the past few thousand years, and the Boqueron eruption as well as the seventh century eruption of Loma Caldera provide examples. Sofield (2004) provides the most recent overview of this activity. He has documented at least 42 volcanic events at San Salvador volcano and vent during the past 40,000 years. If this periodicity was roughly consistent throughout that time, people have lived in the area for about a third of that time, and thus could have been affected by some 15 volcanic events. Of those 15 we have archaeological or historical information on only three. Or, more specifically, Sofield notes that there have been 13 monogenetic magmatic eruptions on the northwestern flank of the volcano during the past 1800 years (2004:153), but very few of these have been investigated archaeologically. This is a humbling window on how much more work needs to be done to adequately document the dynamics of human-volcanic interactions of just one volcano in Mesoamerica.

A millennium after the Loma Caldera eruption, on 3 November 1658, the area was rocked by major earthquakes that killed many people and destroyed settlements including Quetzaltepeque and San Salvador. The Playon eruption began in earnest the next day as volcanic ash spewed from the vent and an andesitic lava began flowing downhill to the north (Meyer-Abich 1956). Both lava and tephra caused great destruction to agriculture, the local indigo industry, and livestock, according to colonial documents

(Gallardo 1997). The lava came within 2 km of the town of Quetzaltepeque and largely encircled and partially buried the town of Nexapa, clearly exceeding their intolerance threshold, forcing them to relocate their settlement to its present location at Nejapa. The lava covered at least 8 km^2 (Hart 1983). At its northernmost extent the lava blocked the Rio Sucio (formerly known as the Rio Nixapa, or "river of ash" in Nahuat) and formed a sizeable lake in the center of the Zapotitan valley. The lacustrine sorting and redeposition of Playon tephra are clearly seen in Gallardo's photographs (1997) of the devastated indigo processing plant at San Andres. The lake lasted for only a few weeks, until the river eroded the lava dam. The soils formed on Playon tephra presently support an exuberant vegetation and intensive agriculture, but the soils formed on the lava are patchy and thin, and the present vegetation is sparse and scrubby, consisting of scattered bushes and seasonal grasses.

Browning (1971:100-104) describes the struggles of the displaced Nexapa residents. Nexapa was a Pipil Indian community, occupying the bottom of the colonial social hierarchy, and their common lands unfortunately were largely buried under the lava. They moved eastward, to what is now Nejapa, and petitioned the colonial government for land owned by the Crown to be changed for use as their sustaining area. Browning documents the resistance mounted by local Spanish hacienda owners and indigo processors, and the frustrated struggles by Nejapa residents to be recognized as land owners rather than simply land occupiers. Those struggles continued for almost 80 years, until finally in 1736 Nejapa was awarded legal title to the land on which the town stood and a narrow strip of common land extending almost 30 km to the southwest up the slope of San Salvador volcano. Even at this early historic time land was not freely available, and struggles for clear land ownership were particularly difficult for disenfranchised disaster victims.

San Marcelino eruption AD 1722

Pullinger (1998:78) described the 1722 lava flow that emerged from the eastern side of the Santa Ana volcanic complex. The flow headed from two vents at 1325 meters eastward 11 km and destroyed the traditional village of San Juan Tecpan. The destruction of approximately 15 km^2 of prime agricultural land, for subsistence crops as well as cacao, was a major blow to local 18th century residents on the western side of the Zapotitan valley. The lava flow burial of residences and agricultural land, of course, exceeded the intolerance threshold and people were forced to evacuate. I have not been successful in finding more information about the repercussions of this eruption. I suspect that colonial documents contain information on impact, refugees, search for replacement land, and legal struggles, perhaps analogous to Nejapa residents after the Playon eruption. The soils and vegetation on top of this lava flow at present are patchy and sparse, similar to those on top of the Playon lava described above.   Centuries of weathering and plant succession are needed before this area regains its productivity.

Izalco eruptions AD 1779 – 1966

Izalco is El Salvador’s most famous volcano, as its almost continuous eruptions from the 18th into the 20th century were visible well into the Pacific Ocean, earning it the title “Lighthouse of the Pacific” for sailors. Meyer-Abich (1956) conducted the earliest serious geological study of Izalco, and Pullinger (1998: 79-81) recently surveyed current knowledge. The volcano started building itself from a vent at 1300m on the southern flank of Santa Ana volcano in 1779, and ceased eruptions in 1966 when the crater rim reached 1952m. Local lore claims that the president of the country ordered the air force to bomb the crater so it would continue erupting, in order that his dedication of a volcano observatory and tourist complex in 1966 would not be an embarrassment, but the air force was unsuccessful because the crater was only 400 m in diameter!

Many lava flows during Izalco's two centuries were in the 5-8-km long range, and many ashfalls affected people and vegetation within a few km of the volcano, on and just beyond the southeastern edge of the Zapotitan valley, exceeding many communities' intolerance thresholds. A pyroclastic flow buried the traditional village of Matazano in 1926, killing 56 people. The net decline in local agricultural production because of the volcano was, and continues to be, considerable. The large area occupied by the volcano had been a highly productive gentle lower southern slope of the Santa Ana complex, producing coffee, cacao, indigo, and sugar cane. Once again volcanism resulted in a dramatic decline in the life support capacity of a portion of this crowded nation for a few centuries.

San Salvador volcano Earthquake and lava flow 1917

The large crater of San Salvador volcano, or "Boqueron," contained a crater lake in the early 20th century. However, in June of 1917 the lake boiled away in the same week that an earthquake did considerable damage to cities on all sides of the volcano, and lava began to flow from the volcano's north side (Meyer-Abich 1956). Sofield (2004:152) estimates the earthquake at about 5.6 on the Richter scale, and he notes the lava emanated from three vents. The lava flows destroyed highly productive coffee farms. The black basaltic lava covered about 16 km^2 and is still devoid of vegetation other than some lichens and occasional grasses. The principal use of the flow today is to filter rainwater that is collected and pumped over the volcano to supply San Salvador's needs for water. A grim use of the area developed in the civil war from 1979 through 1992 as paramilitary squads used the lava flow as their favored place to dispose of bodies.

At first glance the record of volcanic eruptions affecting the environment and residents of the Zapotitan valley during the last 2000 years, presented in this chapter, might seem impressive. However, the record is very incomplete. Sofield (2004) mentioned many eruptions for which geological and archaeological documentation are lacking. Also, some sizeable lava flows are not included here for lack of documentation, such as that near Cerro Chino, which covers over 10 km^2. Miller (2002) noted a few eruptions in the past two to three thousand years that affected the northern Zapotitan valley that are not yet understood and thus not a part of the record that can be included here.

THE ISSUES OF CULTURAL COMPLEXITY AND WARFARE: TWO COMPARATIVE CASES

In order to pursue two elements of "scalar vulnerabilities," or cultural factors that affect vulnerability to sudden massive stresses, I wish to introduce two comparative cases. One is in Costa Rica, where I see impressive resiliency to explosive eruptions due to egalitarian societies, low population densities, reliance mainly on wild foods for subsistence, and a minimal built environment. The other case is in Panama, where a middle-range society evidently was rendered vulnerable due to the intensity of chronic hostility.

The Arenal case, Costa Rica

Human societies vary considerably in their vulnerability to disasters, including hazard perception, ability to cope with a sudden massive stress, make adjustments, and recover or attempt to recover. A study of ancient Mexican-Central American cases of explosive volcanism found that “simple” egalitarian villages were considerably more resilient to explosive volcanism than their more complex chiefdom and state neighbors (Sheets 1999). The striking resilience of egalitarian ancient Costa Rican societies to some 10 explosive eruptions (Melson 1994) of Arenal volcano is attributed to low population densities, availability of refuge areas, utilization of agriculture for a small percentage of the diet, reliance on a wide variety of wild food sources in the rich tropical rainforest for a majority of the diet, lack of hostility among groups, and minimal investment in the “built environment” of facilities constructed for living, storage, workshops, or agriculture. The elaborate post-interment feasting in cemeteries may have involved multiple communities, and if so, could have facilitated exchanges and alliances that could prove useful in times of emergencies when refuge areas were needed. Complex state-level societies in ancient Mesoamerica evidently were more vulnerable to sudden massive stress because of their greater reliance on the “built environment” as well as high population densities, scarcity of refuge areas, reliance on intensive agriculture and domesticated dietary staples. The utilization of a wide range of food sources, from seed crops such as maize and beans, through root crops such as manioc, to tree crops such as palm fruits, may provide resilience to sudden stresses. A significant tephra fall of 20 cm could be very damaging to young seed crops, mildly damaging to some root crops, and minimally deleterious to tree crops. The actual tephra depths in the research area range from only a few cm. to a meter or two per eruption. The thickness of each tephra layer thins from the eastern end, closer to the source, toward the western end.

The Barriles case, Panama

One case highlights the importance of understanding cultural factors in the complex blend of significant physical and social aspects of disasters (Sheets 1999). Volcan Baru (Figure 1) in western Panama erupted, probably in the seventh century AD, and deposited a relatively thin tephra layer, perhaps some 10-15 cm originally, on settlements in the Barriles area (Linares and Ranere, 1980). The social organization of Barilles, and Aguas Buenas culture generally, are controversial (Hoopes 1996). Hoopes suggests the ranking that is detectable in sites may be only local “big men” rather than being more centralized chiefdoms. However, the Barriles societies appear to me to be sufficiently centralized to qualify as chiefdoms. Barriles society consisted of a series of culturally similar but politically independent polities packed into the floodplain of the Rio Chiriqui Viejo. The tephra depth is comparable to Arenal tephra depths deposited on egalitarian villages toward the western end of Lake Arenal, where egalitarian communities recovered rapidly, probably within a few decades, with no detectable changes in their architecture, artifacts, adaptation, or any other measure that could be found. So, based solely on volcanological and ecological factors one could predict a reasonably short-term dislocation of Barriles peoples until soil and vegetation recovery had proceeded sufficiently to allow reoccupation. Or, if we focused on vulnerability related to social complexity, based upon Barriles society being mid-range between egalitarian and a state, one might expect mild short-term effects, and negligible to nonexistant long-term effects from a relatively small eruption.

In fact, the stress from the thin tephra blanket from Volcan Baru forced a drastic cultural adjustment. The Barriles chiefdoms in a highland tropical moist seasonal environment in the upper reaches of the river abandoned their territories, never to return, and thus cultural recovery never occurred. They migrated over the continental divide to an environment with much greater precipitation and had to change their architecture and agriculture to adapt to the changed conditions (Linares and Ranere 1980:244-245). Physical factors such as tephra thickness, chemistry, natural environment, flora, or fauna do not explain the dramatic differences in human reactions. Cultural factors are relevant and include the following. The Barriles societies relied on more intensive agriculture than did Arenal societies, based upon a maize staple, and they built more elaborate architecture, especially in the chief's villages. Full-size human sculptures (Haberland 1973) depicted the social order graphically, with nude males upholding "big men" or chiefs on their shoulders, although other interpretations are conceivable. The "big men" or chiefs wear the peaked caps and necklaces with pendant as symbols of superior status, and often hold ceremonial axes in one hand and a bowl or decapitated human head in the other. So, much higher population density, intensive agriculture, and greater built environment than at Arenal evidently put the Barriles societies at greater risk to sudden stresses, but one other factor should be considered. Although they shared a common culture, the polities were competitive and often at war with each other. The evidence of hostility is recorded in stone sculpture (Linares and Ranere 1980: 50) with severed heads, the abovementioned sculptures with severed heads, and the special axes made for decapitations. Thus, a hostile political landscape obviated tephra-stressed people taking refuge in nearby areas, in contrast to impacted Arenal societies, and a drastic solution of long-distance migration to a wet lowland non-seasonal tropical rainforest environment ensued. Thus, a tradition of competition and hostility between adjacent social groups can lay the groundwork for more drastic adjustments in times of emergency.

Archaeology and volcanology can provide examples of multidisciplinary research that can examine disasters and their effects on the environment as well as on human societies of all kinds. Archaeologists, in various parts of the world, have studied how humans have coped with volcanic eruptions, ranging from late Pliocene eruptions in east Africa to late Holocene eruptions throughout the world. The long time scales analyzed by both disciplines allow researchers to study long-range interactions as societies cope with sudden massive stresses with varying degrees of success. This contrasts with most disaster studies that focus on the immediacy of the impact, the deaths, injuries and destruction, and the early stages of people trying to adjust to the disaster. The most important contributions that archaeologists can make in studying disasters is the long-run, over decades or centuries, because this adds a dimension that is largely lacking in disaster research. The following section focuses on some cases of volcanic eruptions and human societies in a small area of Central America.

CONCLUSIONS, CONSIDERATIONS, AND IMPLICATIONS

An overarching model that could be used to compare eruptions and human responses is here called "scalar vulnerabilities." As the scales or magnitudes of eruptions are compared, along with the scales of societal complexities, dependence on facilities of the built environment, political hostilities, and intensities of agriculture, some tentative patterns begin to emerge. At the extremes of the greatest eruptions, VEI 6 or greater, no pre-industrial human societies survive unscathed in the long run. The Ilopango TBJ eruption had massive and long-lasting effects on complex societies in the Zapotitan valley and adjoining areas in southeastern Mesoamerica, comparable to the Late Preclassic eruption of Popocatepetl in highland Mexico. However, at considerably lesser order of magnitude, the eruptions such as Arenal and Boqueron had significant effects on local societies, necessitating Radical Action in terms of outmigration. Both the egalitarian and complex societies recovered thoroughly, as far as can be detected archaeologically. In striking contrast is the modest eruption of Volcan Baru in Panama, which drastically affected the adjacent Barriles chiefdoms necessitating Radical Action of outmigration with no recovery and reoccupation. The hostile political landscape among the polities is the apparent explanation of the consequences of the eruption being so much greater than the scale of the physical event or the nature of the societies would predict. Relatively small eruptions, such as Loma Caldera or various lava flows in the Zapotitan valley, had deleterious effects on the settlements directly affected but they did not have long lasting societal repercussions. In general, in the cases considered here egalitarian societies with low levels of "built environments" and minimal reliance on intensive agriculture and domesticated staples, and low population densities, exhibited the greatest resilience to sudden massive volcanic stresses. This contrasts with Torrence and Grattan (2002). Along the scale of societal complexity, the more complex societies were the most vulnerable to volcanically induced stresses. Apart from social complexity, the scale of political hostility can dramatically affect a society's vulnerability, as a small perturbation among societies with chronic warfare can require more extreme coping strategies than would be predicted by the other physical science and societal complexity scales.

The predictability or unpredictability of changes in a society's environment can have different implications. An important cross-cultural study found that unpredictable sudden stresses were much more difficult for nonwestern societies to cope with, than were long-term stresses such as sustained droughts (Ember and Ember, 1992). Unpredictable stresses or disasters led to warfare to obtain resources from others more often than chronic stresses and more predictable disasters. Viewed in this light, the Barriles chiefdoms had engineered a high level of predictable stress in the form of chronic hostility, which left them vulnerable to the relatively small but unpredictable stress: the eruption of volcan Baru.

The various components of volcanic eruptions affected human populations in quite different ways. Lava flows covering a few km^2 eliminated agriculture for many centuries and caused resettlements. Tephra deposits affected a few km^2 to thousands of km^2, but only the really great tephra deposits such as the Ilopango TBJ fundamentally altered the cultural trajectory of ancient societies. The medium to smaller size tephra aprons caused short-term difficulties but weathering, plant succession, and human recovery were relatively rapid and no long-term cultural effects resulted. A punctuated equilibria model could apply in a general fashion to the cases of the dynamic interactions among volcanic eruptions, people, cultures, and the organizations of societies in the past two millennia in the Zapotitan valley. Small and middle-scale eruptions temporarily interrupted the equilibria of complex societies but the nearby sources of flora, fauna, and people allowed for full recovery in the short to medium run of years to decades. The punctuated equilibrium model also applies with the great eruptions as analogous to extinction events. The biggest eruptions created stresses so vast, in all domains of ecology, economics, politics, and society that recoveries of the original social orders simply did not occur. The demographic and cultural reoccupations following the mega-disasters were by different societies.

In a general sense punctuated equilibria models seem to apply to many of the cases considered here. However, on closer examination equilibrium conditions are an idealization, because some variation in environmental conditions and social environments occurs with all societies through time. Even the most stable society mentioned in this chapter, Arenal in Costa Rica, exhibited changes in material culture through the centuries, especially in ceramic form and decoration. Because none of these changes correlate with the documented disasters, no relationships are suggested here.

Tropical botanists are considering the “intermediate disturbance hypothesis” which proposes that intermediate scales of disturbance promote maximum species diversity (Molino and Sabatier, 2001). Their test of the hypothesis in a South American rainforest was sustained. An analog with cultures could be proposed, that small to medium scale disasters can have creative aspects in addition to their much-heralded (and over-reported) destructive aspects. Some disasters are so immense that they overwhelm all cultures, but medium-scale disasters could promote cultural diversity, redundancy of social units, and societal resilience.

Volcanic/human disasters are not egalitarian, in that they do not affect all components of societies uniformly. People have some choices in the degree to which they wish to put themselves at risk from the hazards that they perceive in their environments. They can then make decisions regarding where they will live. And it is my personal observation that, in complex societies, the degree of freedom of choice is not uniform among social classes in complex societies. The upper class, the people with greater wealth and power, has greater freedom of choice in where to locate their residences and other facilities than do the poor or politically disenfranchised.

The population of what is now El Salvador has changed dramatically in ancient and historic-to-modern times (Sheets, 1992:125). The population in that area generally was between 250,000 and 750,000 people in Precolumbian times, with regional population densities ranging from 10 to 50 per km^2. After the decimation from imported Old World diseases in the 16th and 17th centuries, the population recovered back to its Precolumbian peak of 750,000 in 1900. The population of El Salvador has burgeoned at the end of the 20th century to more than 6,000,000 people, with a density of about 300 per square kilometer. And population is continuing to surge upward as church and state are reluctant to support family planning and thus some kind of population control. Therefore more people are forced to live and work in harm's way, where volcanic and other disasters will take progressively greater tolls of death and destruction. Many of the urban and rural poor are crowded into especially hazardous locations in El Salvador today, such as lowlying barrancas that are particularly vulnerable to floods, lahars, and pyroclastic flows.

Some of the best research into ancient natural disasters is multidisciplinary. On a broader scale, we can ask how well have social and physical sciences worked together in the way suggested by Kennedy (2002), with the objective of an integrated understanding of disasters? Alexander (1995, 1997) has answered this question in his two extensive surveys of hazards and disasters, including the full range of physical and social science and engineering disciplines. He tabulated a total of 30 academic disciplines conducting disaster research, which at first glance might indicate a robust thriving field of study. However, he found most studies were intradisciplinary. Further, he noted the assumptions and understandings of the relationships among people, societies, and nature varied markedly among the various disciplines. He also found a great imbalance in support, with 95% of disaster research funding going to the physical sciences and technology, and only 5% going to social science studies. Based on the above findings, it is little surprise that Alexander (1995:6) found hazard and disaster theory to be fragmented and poorly developed across the diversity of disciplines.

Ironically, disaster research began with the pioneering social science work of the geographer Gilbert White (1945). Since then many physical and social science disciplines have begun investigating aspects of hazards and disasters, but anthropology has been one of the slowest to join in. Perhaps one reason for that reluctance is the excess of environmental determinism in the early decades of anthropology's founding has made scholars leery of exploring the field.

Disaster research is clearly multidisciplinary today, but very few studies or projects are interdisciplinary. Because different disciplines vary considerably in their assumptions and theories about human-environmental interaction, and an individual discipline changes over the decades, comparative studies are often difficult. Not only do different disciplines view hazards and disasters in different ways, so to do different societies. Modern western societies, with extensive education in the physical sciences, view disasters with a heavy emphasis on the geophysical components of their initiations and impacts. However, most human societies have not studied the geophysical mechanics of disaster initiation. Rather, most human societies have explained disasters in religious terms, often explaining extreme events as caused by failures in the sacred covenant between people and deities, and when hazards are perceived they often turn to ritual and sacrifice to try to decrease risks.

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FIGURE CAPTIONS