VOLCANISM, ECOLOGY AND CULTURE: A REASSESSMENT OF THE VOLCÁN ILOPANGO TBJ ERUPTION IN THE SOUTHERN MAYA REALM

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The Tierra Blanca Joven *(TBJ) eruption of the Ilopango caldera in central El Salvador was one of the largest Holocene volcanic events in Central America, and its ecological and cultural impacts were felt throughout El Salvador and adjoining areas of Guatemala and Honduras. Early radiocarbon measurements established a ca. A.D. 260 ± 114 calendar date for the eruption. However, a reevaluation of the original* ^{14}*C dates, in addition to new AMS* ^{14}*C assays, shows that the TBJ eruption occurred at least a century and a half later than originally estimated. The revised* ^{14}*C composite supports an Early Classic Period calendar date for the eruption: 1 sigma = A.D. 421(429)526; 2 sigma = A.D. 408(429)536. A review of archaeological settlement, ceramic, and radiocarbon evidence from sites throughout the area of greatest devastation reveals a large-scale demographic collapse following the event. We believe that the population crash was caused both by the biophysical effects of the eruption and by the resulting disarticulation of the "Miraflores" cultural-economic sphere. The affected areas of El Salvador and southeastern Guatemala did not completely recover until the seventh century A.D.*

La erupción del Tierra Blanca Joven (TBJ) de la caldera de Ilopando en la porción central de El Salvador, fue uno de los eventos volcánicos más grandes del Holoceno en Centroamérica. El Salvador y zonas limítrofes de Guatemala y Honduras resintieron el impacto ecológico y cultural de este evento. Con base en los fechamientos de radiocarbono con que se contaba previamente la erupción se datό hacia 260 + 114 d.C. Sin embargo, una reevaluación de esas fechas además de otras recientemente procesadas, muestran que la erupción del TBJ ocurrió cuando menos siglo y medio después de lo que se había calculado originalmente. De esta manera, se fundamenta la adscripción temporal de la erupción en el periodo Clásico Temprano: 1 sigma = 421 (429) 526 d.C.; 2 sigma = 408 (429) 536 d.C. Una revisión de los asentamientos arqueológicos, la cerámica y las fechas de radiocarbono de varios sitios en el área que sufrió la mayor devastación, en el occidente de El Salvador y el sureste de Guatemala, evidencian un colapso demográfico a gran escala después del evento. La mayoría de las personas que habitaban en un área de 1000 km2 al occidente de la caldera del Ilopango –incluyendo el valle de San Salvador y partes del valle de Zapotitán- deben haber perecido instantáneamente a causa del impacto de materiales piroclásticos; quienes vivían más al occidente, en la cuenca del Río Paz y en la costa suroeste de El Salvador, probablemente abandonaron los pueblos a causa del colapso agrícola, el hambre y las enfermedades. En el sureste de Guatemala, donde los efectos biofísicos de la erupción no fueron tan severos, al parecer el decremento poblacional se debió a la desarticulación resultante de la esfera económico-cultural Miraflores. Los desplazados por el desastre que migraron hacia el norte, posiblemente contribuyeron al crecimiento de la población rural del valle de Guatemala y del centro urbano de Copán, Honduras. Las áreas que resultaron afectadas por el evento volcánico en El Salvador y el sureste de Guatemala lograron recuperarse hasta el siglo VII d.C.

The Neovolcanic axis of Central America traverses El Salvador along its entire length, and the country has experienced numerous volcanic eruptions in historic times and throughout the late Quaternary (Rose et al. 1999; Sapper 1925; Simkin and Siebert 1994). Young volcanic soils have supported tremendous agricultural productivity in El Salvador (Stevens 1964), and correspondingly the population density during most of the late Holocene has been the greatest of any mainland country in the Americas (Daugherty 1969; Denevan 1992; Lovell and Lutz 1995; Wilkie and Ortega 1997). Unfortunately, the corollary to this agricultural success is that innumerable human inhabitants of El Salvador have been either killed or displaced by the direct impacts of volcanic eruptions throughout the Holocene (Feldman 1993; Lardé y Larin 1957; Sheets 1971, 1979, 1983a).

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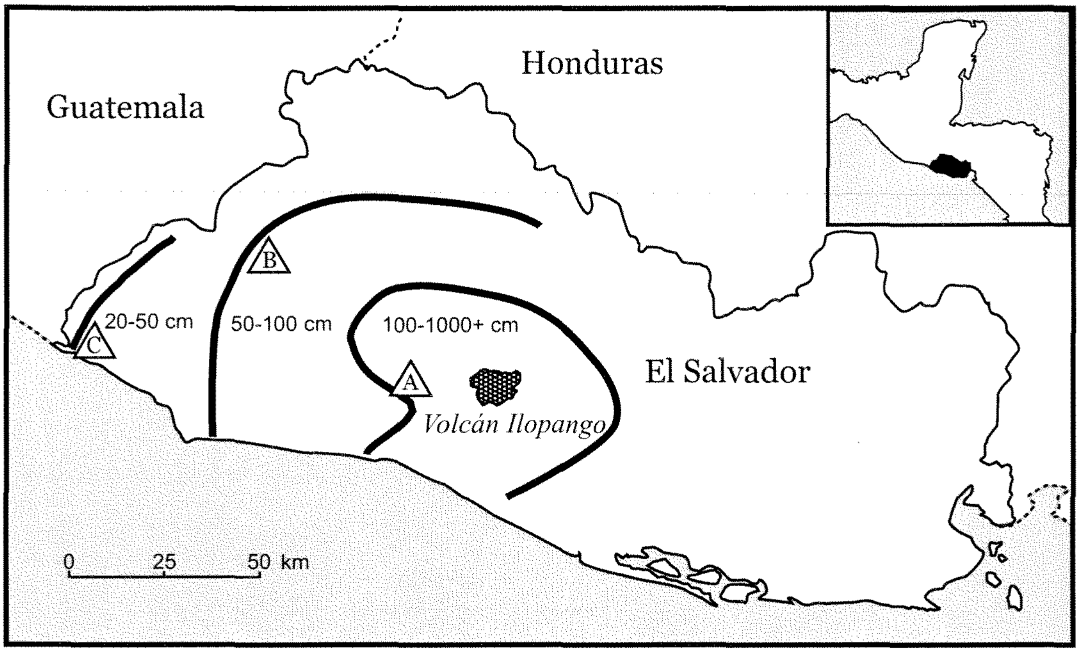

Figure 1. TBJ tephra isopachs in central and western El Salvador (adapted from Hart and Steen-McIntyre 1983).

The greatest known Holocene eruption in El Salvador, and one of the largest late Quaternary events in all of Central America, was the Tierra Blanca Joven (TBJ) event. This Plinian eruption was roughly the size of the 1991 Mt. Pinatubo eruption, ejecting a total volume of ~18 km^3 DRE (dense rock equivalent), and blanketing an area of at least 10,000 km^2 under more than 50 cm of tephra (Hart and Steen-McIntyre 1983; Rose et al. 1999; Simkin and Siebert 1994). The large volume of tephra emitted by TBJ eruption covered virtually the entire area from the Valley of San Salvador west to the international border with Guatemala (Figure 1).[1]

The importance of the TBJ tephra as a correlative stratigraphic marker in archaeology was recognized in the early twentieth century by the Salvadoran historian Jorge Lardé, who in 1917 discovered the "remains of an archaic civilization, much older than the Maya civilization" [translation by author] buried below the *tierra blanca*, or "white earth" (Lardé 1926:154). Recognizing that the *tierra blanca* tephra was distributed in a radial pattern around Lago Ilopango, both Lardé and his American colleague Samuel Lothrop deduced that this tephra must have come from Volcán Ilopango (Lardé 1926; Lothrop 1927).

Since the initial reporting of the *tierra blanca* tephra by Lardé and Lothrop, numerous archaeological sites buried by this distinctive pumiceous tephra deposit have been discovered throughout central and western El Salvador (Amaroli and Dull 1999; Sheets 1979). A comprehensive study of the TBJ eruption was initiated in the mid 1970s (Sheets 1983a), including analyses of pre-TBJ soils and archaeological sites, as well as tephra distribution, petrography, and geochemistry. The *Tierra Blanca Joven* eruption was defined in this study as "the deposit resulting from the youngest major eruption of the Ilopango vent complex" (Hart and Steen-McIntyre 1983).

The TBJ eruption had a major impact on the cultural development of central and western El Salvador (Sharer 1974; Sheets 1971, 1979, 1984). During the Early and Middle Formative periods, sedentary villages supported by maize-based agriculture appeared throughout the alluvial valleys and coastal plain of central and western El Salvador (Amaroli and Dull 1999; Demarest 1988; Sharer 1974; Sheets 1983a). By the close of the Formative period and during the "Protoclassic,"[2] western El Salvador was a densely populated region with strong cultural and economic ties to the Southern Maya Highlands and the Pacific coast of Guatemala (Brady et al. 1998; Demarest and Sharer 1986; Neff et al. 1999; Sharer 1974; Sheets 1984).

The TBJ eruption abruptly terminated the Late Formative/ "Protoclassic" cultural florescence in western El Salvador (Demarest 1988; Sharer 1978b; Sheets 1984). It is doubtful that anything (or anyone) living in the ~1000 km^2 zone of devastation survived. This area was subjected to pyroclastic flows that uprooted, engulfed, and carbonized forest trees, even at distances of ~25 km west of the vent. Although sites in eastern El Salvador such as Quelepa emerged from the TBJ disaster relatively unscathed (Andrews 1986:241), survivors in western El Salvador (e.g., the Rio Paz drainage basin) were left with a sterile, denuded landscape. This ash-choked region could not support any significant agricultural production for some decades after the eruption (Dull 1998; Sheets 1979, 1981, 1983a).

There is unequivocal evidence that the TBJ eruption had a significant effect on the cultural trajectory of central and western El Salvador; more challenging is gaining a clear understanding of its role in the social, political, and economic evolution of the greater Maya area (Demarest 1988; Henderson 1997; Schortman and Urban 1991; Sharer and Gifford 1970; Sheets 1981, 1987). Toward this end, more precise dating of the eruption is critical (Earnest 1999).

The original suite of nine radiocarbon dates yielded a composite ^{14}C age of 1708 ± 114 years (A.D. 260 ± 114 cal yr B.P.) for the TBJ eruption (Sheets 1983b). However, closer inspection of these nine ^{14}C dates reveals a bimodal distribution, with dates clustered respectively around 1950 and 1600 ^{14}C yr. B.P. (Figure 2). In the research reported here we reject the earlier cluster of dates in favor of the latter, and three new AMS dates obtained from plant material directly associated with the TBJ eruption support this analysis. We conclude that the eruption occurred between A.D. 410 and 535 (2 sigma calibrated date), during the Early Classic period.[3] Furthermore, we suggest that the TBJ eruption caused a large-scale demographic and economic collapse that was felt throughout the southern Maya Realm.

Methods

Samples of organic material from two field sites in El Salvador were collected for AMS ^{14}C dating in April 1998. The material sampled was chosen because we believe these plants were living at or very shortly before the time of the TBJ eruption and that their ^{14}C content reflected that of the contemporary atmosphere.

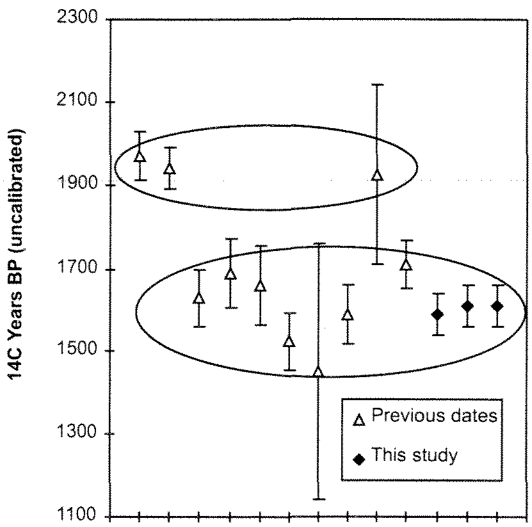

Figure 2. Uncalibrated TBJ radiocarbon dates listed in Table 1 with one sigma errors. The two ellipses highlight the bimodal distribution of the dates. See text for discussion of accepted vs. rejected dates.

One sampling locality (Figure 1: Site A) is located 2 km NNW of Santa Tecla on the highway between San Salvador and Santa Ana. At this locale, charred plant remains are incorporated into a ~6 m high pumiceous pyroclastic flow, erupted from the Ilopango vent during the TBJ eruption. A total of eight intact samples of carbonized wood material (tree trunks, branches, twigs, etc.) were collected from four fresh exposures in the field and wrapped in tin foil for transportation.

These carbonized samples retained the overall shapes of the original plant forms and also showed clear microscopic wood-grain structures, but had cracked into hard, apparently well-preserved, charcoal blocks. They seemed at first sight to be ideal for radiocarbon dating, but we found that in all cases the material was completely base-soluble (which we speculate was somehow due to charring in the unusual chemical environment of a pyroclastic flow). Thus, in some sense the samples were not true charcoal; more importantly, they could not be subjected to a standard acid-base-acid pretreatment to remove soil humics. Therefore, to minimize possible contamination, we dated only the largest of these samples (a complete section of a fully carbonized 35 cm diameter tree trunk).

We took a 2 cm^3 block from 1 cm below the cambium of the trunk, scraped off the outer few mm from all sides of the block, and treated it with 1N

HCl at 80°C, followed by a five-minute base treatment with 1N NaOH at 80°C, which dissolved about half the material. Two different fractions—(1) the reacidified undissolved residue and (2) a fraction reprecipitated from the base wash with 6N HCl—were independently washed, dried, combusted, converted to graphite and assayed for ^{14}C using standard AMS techniques (CAMS 46574 and 46575).

The second sampling locale is a small lake ~1 km north of the town of Chalchuapa, some 75 km west of the Ilopango caldera (Figure 1: Site B). This site—Laguneta El Trapiche—was cored from an anchored platform with a 3 cm–diameter modified Livingstone square rod piston coring device (Wright et al. 1984). Sediment cores were extruded into plastic lining and wrapped in tin foil and PVC pipe for transportation.

In the laboratory, the core containing the TBJ tephra was split and a .5 cm sample of partially carbonized sedge (Cyperaceae) peat was extracted from immediately below the TBJ tephra for AMS dating (CAMS 60527). Monocot leaf material from the peat was subjected to a standard acid-base-acid treatment and then assayed for ^{14}C. $\delta^{13}C$ was -27.2, indicative of terrestrial or emergent aquatic plants that receive their carbon directly from the atmosphere, rather than subaquatic vegetation that might produce biased dates through photosynthesis of geologically derived bicarbonate in "hard" water.

Results and Discussion

Radiocarbon Ages

The two fractions of the Santa Tecla tree-trunk sample yielded uncalibrated ^{14}C dates of 1590 ± 50 and 1610 ± 50 B.P., which we combine for a best ^{14}C age for the sample of 1600 ± 35 B.P. Because the dated "charcoal" could not be subjected to a full chemical pretreatment, we cannot completely rule out the possibility that it contained some residual contaminating humics. However, we believe any age bias is insignificant because the tree was located beneath three meters of sorbent ash; the tree itself clearly provided the great majority of the base-soluble material; and the two fractions dated gave virtually identical results. The Laguneta El Trapiche peat macrofossils yielded a date of 1610 ± 50 B.P., which concurs precisely with the Santa Tecla result.

Previous dates for the TBJ eruption were measured on acid-base-acid treated charcoal, or in one case on soil humics (Table 1; Figure 2). A widely quoted calendar date (A.D. 260 ± 114) for the eruption was obtained from the unweighted mean of 9 conventional radiocarbon dates using the 1979 MASCA radiocarbon calibration (Michael and Klein 1979; Sheets 1983b). In assessing these 9 previously reported dates for the TBJ event, we chose to discard Hv5001 and 5004 (1450 ± 310 and 1925 ± 215 B.P.), which had very large uncertainties due to the small size of the samples dated (M. Geyh, Hanover ^{14}C laboratory, personal communication 2000), not because they were in any sense "wrong" but simply due to the lack of precision. We also rejected the soil carbon date (Tx2324: 1940 ± 50 BP), because soil humics typically have built-in reservoir ages of several hundred years (Harrison et al. 1993; Vogel et al. 1990).

Sharer (1978a) also reports a single date on charcoal from the TBJ stratum at Laguna Cuzcachapa, Chalchuapa (Lawn 1974). This date (P-1803, 1709 ± 62 B.P.) is well within 2 sigma of our new determinations (Figures 2, 3), but we consider it unreliable, since it is from a feature that is specifically described as "deposition and *redeposition* of cultural debris, *outwash* and volcanic ash" (Sharer 1978a:51, emphasis added).

Five of the 6 remaining TBJ dates cluster around 1600 ^{14}C yr B.P., but one is clearly older (Table 1, Figure 3). Tx3114 (1940 ± 50 BP) was measured on charcoal taken from a small carbonized tree in a TBJ pyroclastic flow 3 km NNW of Santa Tecla, very near the sampling locality of CAMS 46574 and 46575. It appears to be an ideal sample from short-lived material well associated with the TBJ tephra, and we have no explanation why the date is so old. Nevertheless, since it is so discrepant from the other five results (which have a weighted mean of 1610 ± 30 B.P. in excellent agreement with our new data), we reject it as an outlier[4] ($\chi^2 / \upsilon = 6.5$, $\upsilon = 5$, $P < .001$).

Calibrated Age

The weighted mean of the remaining five concordant results and the dates for our two new samples yield a ^{14}C age of 1605 ± 20 B.P. for the TBJ event (Figure 2). Figure 3 shows calibrated age ranges obtained using the INTCAL98 tree ring ^{14}C calibration (Stuiver et al. 1998). We use the two sigma age range of A.D. 408(429)536 as our estimate for the TBJ calendar age (Figure 3; Stuiver et al. 1998: method A), while noting that the probability distribution for the calibrated date is weighted toward the early part of

Table 1. List of TBJ Radiocarbon Dates Used in this Study.

Lab #	Site	Material	$\delta^{13}C$	^{14}C Age (yr B.P.)	(± 1σ)
Tx2324	Laguana Seca, Chalchuapa	soil humics	—	1970	60
Tx3114	Santa Tecla, Rio Los Chorrospyroclastic flow	carbonized tree trunk	—	1940	50
Tx3122	Santa Tecla, Rio Los Chorrospyroclastic flow	carbonized tree trunk	—	1630	70
Hv264	Santa Tecla, Rio Los Chorrospyroclastic flow	charcoal	—	1690	85
Hv2534	Santa Tecla, Rio Los Chorrospyroclastic flow	charcoal	—	1660	95
Hv2535	San Salvador	charcoal	—	1525	70
Hv5001	Santa Tecla	charcoal	—	1450	310
Hv5002	4 km N of Huizucar, S of San Salvador	charcoal	—	1590	70
Hv5004	4 km N of Huizucar, S of San Salvador	charcoal	—	1925	215
P-1803	Laguna Cuzcachapa, Chalchuapa	charcoal	—	1710	60
This Study:					
CAMS 46574	Santa Tecla, Rio Los Chorrospyroclastic flow	carbonized tree trunk	−24.0	1590	50
CAMS 46575	Santa Tecla, Rio Los Chorrospyroclastic flow	carbonized tree trunk	−24.0[a]	1610	50
CAMS 60527	Laguneta El Trapiche, Chalchuapa	sedge peat macrofossil	−27.2	1610	50

Note: Only the CAMS dates are AMS determinations; all others are conventional radiocarbon dates. Tx = the University of Texas, Austin Radiocarbon Laboratory; Hv = Hanover Radiocarbon Laboratory, Germany; P = University of Pennsylvania Radiocarbon Laboratory; CAMS = Center for AMS, Lawrence Livermore National Laboratory, California.

[a] As CAMS 46574 and 46575 are two fractions of the same sample, $\delta^{13}C$ was inferred for CAMS 46575 from the measured value on CAMS 46574.

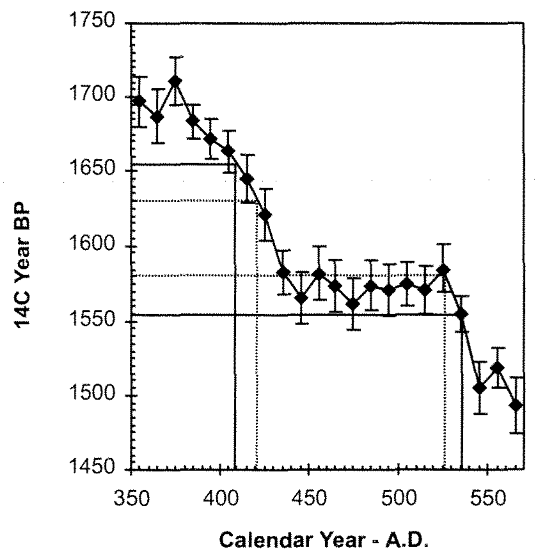

Figure 3. The INTCAL98 (Stuiver et al. 1998) calibration of the accepted composite ^{14}C date for the TBJ eruption, 1605 ± 20 yr. BP. Stippled lines = 1 sigma, solid lines = 2 sigma. Note that the calibration also reflects the one sigma error of the calibration curve itself (~15 years).

this range (Stuiver et al. 1998: method B): A.D. 415–476 ($p = .58$), A.D. 477–530 ($p = .42$).

Refining the Calendar Age

Several lines of related evidence may help to further constrain the date of the TBJ eruption: ceramic evidence, ice core records of prehistoric volcanism, and tree-ring temperature records.

A compelling argument for an early fifth-century TBJ eruption has recently been put forth on the basis of a study comparing central and western Salvadoran ceramic sequences to major regional sequences elsewhere in the southeastern Maya area (Earnest 1999).[5] Earnest notes that although much of the Copán and Chalchuapa ceramic-assemblage sequences can be roughly matched, the correspondence breaks down during Copán's Brujo facet of the Acbi phase at ca. A.D. 400. Earnest interprets the lack of early Acbi- and Esperanza-phase (Kaminaljuyú) equivalents at Chalchuapa as evidence for an occupation hiatus. He estimates that the time period characterized by a lack of ceramic production at Chalchuapa after the eruption lasted for roughly 100–150 years (1999:288).

The archive of prehistoric volcanism recorded in the GISP2 ice cores from Greenland provides a high-resolution temporal record of large explosive north-

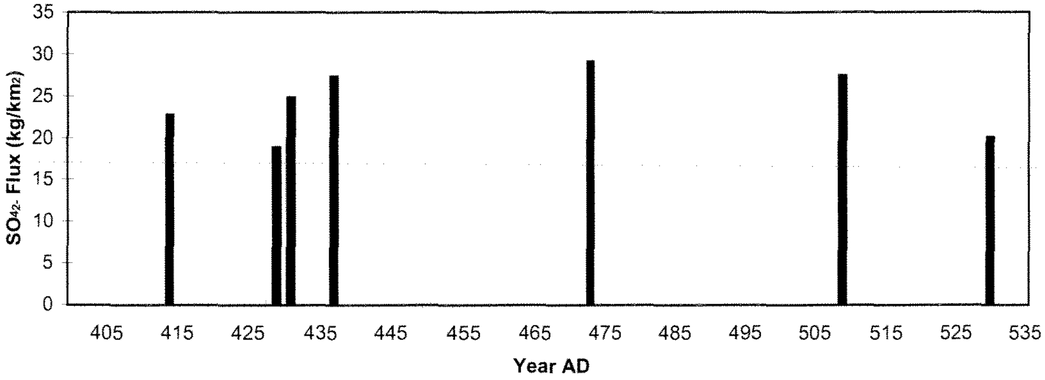

Figure 4. SO_4-2 volcanic acidity record for the 2 sigma TBJ age range as recorded in the GISP2 Greenland ice core (courtesy of Greg Zielinski).

ern hemisphere eruptions (Zielinski 2000). Based on the original A.D. 260 TBJ date, Zielinski and colleagues (Zielinski 1995; Zielinski et al. 1994) identified two prominent third-century A.D. sulfate concentration peaks as candidates for the TBJ acidity signal, but subsequent detailed chemical analyses of tephra from these strata indicated that they did not originate from Ilopango (G. Zielinski, personal communication 2000). Our dating evidence suggests that the most likely candidate for the TBJ tephra in the GISP2 record is one of the seven volcanic events recorded between A.D. 410 and A.D. 535 (Figure 4). Four of these events occurred during the 25-year period A.D. 415–440, in the interval during which the eruption is most likely to have occurred. The conclusive attribution of one of these acidity spikes to Ilopango awaits future microprobe analyses of the composition of the tephra glass shards in the GISP2 core for comparison with the TBJ tephra.

A potential global impact of a large explosive volcanic eruption such as the TBJ is climate forcing (Bryson and Goodman 1980; Zielinski 2000). Aerosols (most notably H_2SO_4) formed by SO_2 injected into the stratosphere by volcanic eruptions can effectively increase stratospheric absorption and reflection of incoming solar radiation. The result is increasing temperatures in the stratosphere and decreasing temperatures in the troposphere. Global temperature depressions resulting from large explosive eruptions have been recorded in both instrumental (Angell and Korshover 1985) and tree-ring records (Briffa 2000). Dendroclimatological proxies of paleo-temperature show that most large eruptions, Volcanic Explosivity Index (VEI) >5 (Simkin and Siebert 1994), especially those at low latitudes, result in planetary cooling for periods of 1–3 years (Briffa 2000; Zielinski 2000).

The 1835 Coseguina eruption in Nicaragua (Williams 1952) provides some idea of the climate-forcing potential of Neotropical eruptions. Although of a lesser magnitude than the TBJ event, the Coseguina eruption (VEI = 5) was followed by significant summer cooling in the northern hemisphere from 1835–1837 (D'Arrigo and Jacoby 1999; Jones et al. 1995). No such volcanically induced cooling periods have yet been linked to Ilopango (VEI = 6), but at least two northern hemisphere dendroclimatological records show pronounced cooling within the early part of the fifth century. Marked temperature depressions—as evidenced by ring width and wood density minima—are recorded in the Sierra Nevada, California between ca. A.D. 420 and 428 (Scuderi 1990:76), and in a composite record from three high-latitude northern hemisphere sites[6] at A.D. 421, 426, and 436 (Briffa 2000:89).

Although ice-core volcanic acidity peaks and tree-ring temperature records are consistent with a climatically effective ca. A.D. 420–435 volcanic eruption, there is no "smoking gun" linking these events to Volcán Ilopango. Given the new TBJ ^{14}C results reported here, we propose that the TBJ eruption is a likely candidate, but these assessments are clearly speculative pending further research.

Disaster and Recovery: The TBJ in Ecological Context

The devastated area probably remained biologically impoverished and geologically unstable for decades posed by thick tephra deposits. These adjustments include deep tap roots deployed to reach the underlying pre-eruption soil and wide networks of adventitious roots developed to overcome nutrient and water deficiencies in porous tephra (Thornton 2000:1060). Cultivated annuals, such as maize, squash, and beans do not exhibit the same adaptability (Scarth 1999). The pollen record from Chalchuapa (Dull 1998) shows that forest recovery preceded agricultural recovery in the Rio Paz basin, and this is probably what happened throughout central and western El Salvador.

The most densely populated areas of Precolumbian El Salvador were the interior valleys (Sheets 1983a), and it is these areas that would have experienced the slowest recovery (Eggler 1963: 50–51; Rees 1979; Thorarinsson 1979:139). The valleys of San Salvador, Zapotitán, Rio Lempa (including the Paraiso Valley) and Rio Paz (Figure 6) were affected most severely. Tephra eroded from upland areas would have added to total tephra depths in these valleys. Primary streams and their tributaries would have been overwhelmed by transient bedload material, aggrading and depositing reworked tephra well outside the former stream channels. Areas that were once relatively flat, valley agricultural lands would have become hummocky and gullied, as the unconsolidated tephra was continually shifted and reworked by fluvial and aeolian processes (Rees 1979).

Incipient soil development in the valley bottomlands may have commenced within the first two decades (Jenny 1941:36–37). However, the porosity of the tephra-derived soils (andosols) probably contributed to leaching, and subsequently to deficiencies in basic cations (Ugolini and Zasoski 1979:112). Some combination of the following would likely have impeded the reestablishment of agriculture in these valleys for decades, if not a century or more: acidity, low water holding capacity, low organic content, and deficiencies of phosphorous, nitrogen, potassium, calcium, magnesium, cobalt, selenium and copper (Antos and Zobel 1987:251; Fisher et al. 1997:243; Thornton 2000; Ugolini and Zasoski 1979). Even relatively thin tephra deposits from Volcán Parícutin, Mexico thwarted repeated attempts to reintroduce cultivation in that region[8]: "Where the ash lay 15 cm or more deep, the land was virtually useless for over a decade for crops such as maize or beans" (Scarth 1999:208). Much of the former farmland surrounding Parícutin that was covered in 50 cm. of tephra was still uncultivable 35 years after the eruption (Rees 1979:283).

Previous studies of the Ilopango TBJ eruption allowed for some two centuries of weathering of its highly silicic tephra, vegetation succession, animal recolonization, and formation of an A-horizon sufficient to support maize-based agriculture . Here we revise the estimate slightly downward, but maintain that agricultural recovery within the area represented by the 50 cm TBJ tephra isopach (Figure 1) probably took a century or more.

Reevaluating the Archaeological Record: The TBJ Tephra in Cultural Context

The human populations most directly affected by the TBJ eruption were those living in the territory extending 100 km directly west of the Ilopango caldera. However, the indirect effects on social, economic, and political systems affected a much wider area of Mesoamerica. The Ilopango TBJ eruption permanently severed the previously close cultural and economic relationships that had existed from the Middle Preclassic to the Early Classic periods among peoples living in the southern Maya area extending from Kaminaljuyú to Chalchuapa and beyond.

The decimation of human populations in central El Salvador has been clearly documented (Sheets 1971, 1979, 1981, 1983a). It is not likely that anyone survived in the San Salvador or Zapotitán valleys (Figure 6), as both of these basins were either deeply buried (2 m+) by airfall tephra or overrun by pyroclastic surges (Hart and Steen-McIntyre 1983; Figure 1). The pyroclastic flows emanating from Ilopango's flanks would have been deadly to humans, as we know from the 1902 eruptions of Mt. Pelée on the Caribbean island of Martinique, where some 27,000 people perished (Scarth 1999:157–190). Such explosive lateral blasts of pyroclastic material (up to 1000°C+) would have completely annihilated all biota in their paths (Smith 1992:139). Temperatures exceeding 500°C have been measured within pumice deposits several weeks after a pyroclastic flow (Thornton 1996:94) and 105°C a year later (Williams and McBirney 1979:156–157). The carbonized plant material found in this study at sampling site A (Figure 1) attests to the heat of the TBJ pyroclastic flows, even at a distance of 25 km from the source vent.

Other volcanic hazards that could have affected

Figure 5. Photograph of a Guatemalan landscape near Volcán Santa Maria following the 1902 eruption. The photograph was taken by F.M.Cardenas and originally published by Sapper (1927).

following the eruption. Volcanic debris would have choked major waterways and the summer rains would have reactivated deep tephra deposits, causing massive post-eruption lahars (mudflows), such as those following the 1991 eruption of Mt. Pinatubo (Fisher et al. 1997:123–132; Scarth 1999:268–271). Although it is possible that some trees might have survived burial by >2 m of tephra (Antos and Zobel 1987:250; Thornton 2000), primary succession would have ensued in most areas covered to this depth (Blong 1984:319; Eggler 1948); no plants would have survived in the areas overrun by pyroclastic flows (Thornton 1996). Slowly the region would have been colonized, first by algae and mosses, then by pteridophytes (ferns and fern allies), monocots (grasses and sedges), and ruderal dicot herbs (Eggler 1963; Thornton 1996). Finally, perennial shrubs and arboreal species would have appeared, although initially only on steep slopes and along riparian zones where the thick ash deposits were first removed by gravity and fluvial processes (Thornton 1996).

The ecological recovery of areas with deep (100+ cm) tephra deposits following the TBJ eruption can probably be best understood when considered in light of historic-period analogs. For example, the VEI 6 eruption of Volcán Santa Maria, Guatemala can give us some idea of what the post-TBJ landscape looked like (Figure 5).[7] Perhaps the best-studied post-eruption tropical ecosystem is that of Krakatau, Indonesia (Thornton 1996), a VEI 6 eruption (Simkin and Siebert 1994). Although a debate continues as to whether all life on the island was eradicated by the eruption, it is certain that deep tephra deposits prevented forest recovery until roughly 50 years after the 1883 eruption (Thornton 1996:75). Similarly, 25 years after the eruption of Coseguina, Nicaragua blanketed that volcano with deep tephra deposits, Squier (1860:536) reports, "The appearance of this mountain is now desolate beyond description. Not a trace of life appears upon its parched sides." Another reconnaissance of Coseguina made by Karl Sapper in 1897, 62 years after the eruption, found that forest vegetation had recovered up to an elevation of 750 m (Sapper 1925:74–75).

Forest recovery, however, does not equate to agricultural recovery (Ugolini and Zasoski 1979:110). Many tree and shrub species are well equipped to deal with periodic tephra deposition, and can adjust to overcome water deficiency and nutrient barriers

Figure 6. Map of archaeological sites mentioned in the text in relationship to the Miraflores-Providencia sphere (Demarest 1986) and the area depopulated as a result of the TBJ eruption.

people in the immediate vicinity of the vent during the eruption include: lahars, earthquakes, acid burns, carbon dioxide, carbon monoxide and flourine poisoning, and coastal tsunamis along the Pacific coast (Blong 1984; Scarth 1999; Thorarinsson 1979).[9]

Although there is little doubt that central El Salvador was completely devastated by the TBJ eruption and void of human life immediately following it, the post-TBJ demography of western El Salvador has been the subject of some debate; one side arguing for the virtually complete and prolonged depopulation of the upper Rio Paz drainage basin (Sharer 1974, 1978b; Sheets 1984), and the other for demographic and cultural continuity—suggesting only temporary local displacement of human populations following the TBJ event (Demarest 1986, 1988). Demarest (1986:179–180) speculates that the denizens of Chalchuapa must have remained in western El Salvador, moving "up out of ash-buried basins," or that they retreated west to the nearby highlands and coastal plain of southeastern Guatemala. As of yet, however, there is no archaeological verification of either suggested movement. Indeed it appears that most of southeastern Guatemala was also abandoned in the 5th century A.D. immediately following the TBJ eruption (Estrada Belli personal communication 2000; Shook 1965; Wauchope and Bond 1989). It might be that the western Salvadoran and southeastern Guatemalan sites receiving the immigrants have not yet been found, or it could be that most of the Early Classic residents of Chalchuapa emigrated to areas further afield; we believe the latter interpretation is more likely.

The crippling of Chalchuapa had a profound

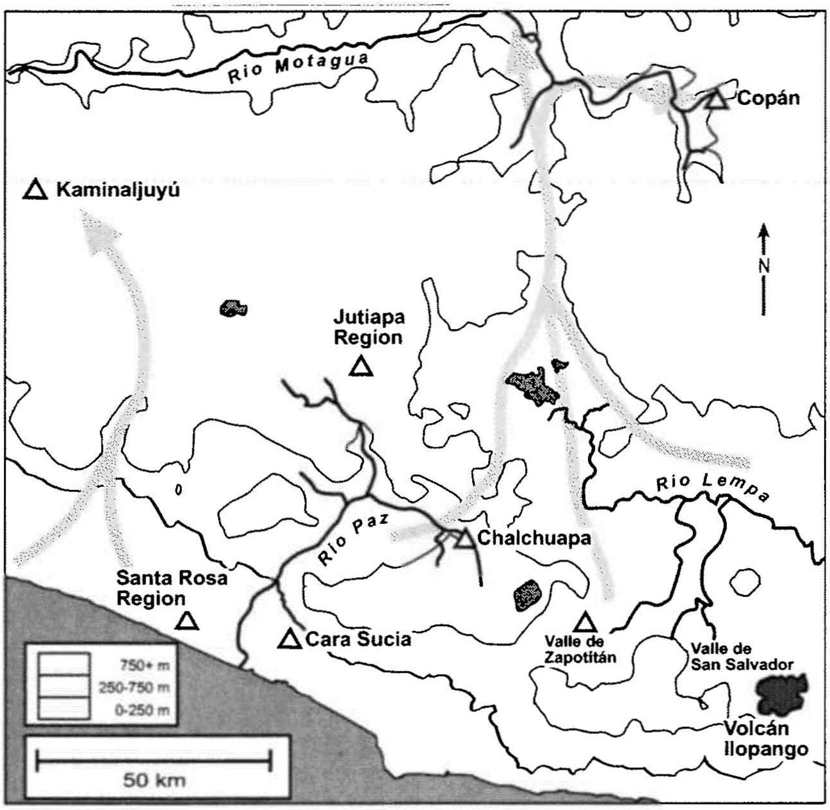

Figure 7. Zone of greatest impact from the TBJ eruption, including posited evacuation routes.

effect on the interregional economy of the southeastern Maya area. Chalchuapa was one of the two largest regional centers in the southeastern highlands at the time of the TBJ eruption, controlling the production and exportation of many important trade items during the Formative and Early Classic Periods (Demarest 1986; Schortman and Urban 1991; Sharer 1974, 1978a). This area produced prodigious amounts of Usulután ceramics that were circulated throughout the highlands and Pacific lowlands of Guatemala, and even exported to sites in the Maya Lowlands such as El Mirador and Cuello (Neff et al. 1999; Sharer 1974). Other items that may have been traded through Chalchuapa include Ixtepeque obsidian (Demarest and Sharer 1986), Motagua jade (Sheets 1979), and Pacific slope commodities such as cacao (Bergmann 1969; Bove 1993a; Young 1994), cotton (Arroyo 1993; Sheets 1979), and salt (Andrews 1991). Because of Chalchuapa's central position in this interregional trading network, the eruption of Ilopango not only caused the collapse and abandonment of the city but also "signaled the end of the southeast periphery interaction system focused on it" (Schortman and Urban 1991:137).

West of Chalchuapa, in the Jutiapa region of Guatemala (Figure 6), a population decline is also noted at this time (Wauchope and Bond 1989:102, 111). The eight sites surveyed in this study record a cultural hiatus from the end of the Preclassic until ca. A.D. 600. Wauchope and Bond indicate that the TBJ eruption might be responsible for the hiatus, but no firm conclusions are reached.

The deleterious effects of the TBJ eruption also extended into the Pacific coastal plain and piedmont zone of southern Guatemala and El Salvador (Sheets 1987). Tephra deposits exceed 30 cm. at Laguna Gamboa, 105 km from Ilopango (Figure 1-Site C). Located two kilometers east of Laguna Gamboa, the archaeological site of Cara Sucia (Figures 6, 7) also contains as much as 50 cm of TBJ tephra (Amaroli 1987:IX-1). These tephra units are the eroded, weathered, and reworked remnants of the original airfall ash deposits, which presumably were much greater at the time of deposition. Immediately following the eruption Cara Sucia was abandoned for more than 200 years10 (Amaroli 1987:IV-10).

Cara Sucia was not the only Pacific slope site deserted following the TBJ eruption. Indeed, much of the southeastern Pacific coast and piedmont zone of Guatemala seems to have been abandoned from ca. A.D. 400/450 to 600 (Bove 1993b; Estrada Belli 1998, personal communication 2000; Shook 1965).

The area of southern Guatemala hardest hit directly by the TBJ eruption was the Department of Santa Rosa in southeastern corner, just west of the Rio Paz (Figure 6). Although not initially attributed to the TBJ eruption of Ilopango,[11] tephra deposits of 5–10 cm. within the Classic Period stratum have been measured in test units at several sites in this zone (Estrada Belli, personal communication 2000). Based on ceramic cross-dating, Estrada Belli originally assigned the cultural hiatus to ca. A.D. 200–450 (Estrada Belli 1997),[12] and raised the possibility that it could have been caused by the TBJ eruption (1998:190). However, given the new dating of the TBJ, and considering the ceramic sequences found in the region, Estrada Belli now believes that the cultural hiatus may well have occurred 200–250 years later than he had originally estimated (personal communication 2000).

Slightly to the west of Santa Rosa, in the Escuintla region (Figure 6), the Balberta project also found widespread abandonment between A.D. 400/450 and 600, but apparently no tephra (Bove 1993b). Bove (1993b:191) gives no material explanation for the Early Classic population collapse, but remarks that, "It is difficult to believe in a population abandonment for several centuries of such a rich environmental zone." More recently Bove has argued that the abandonment of the Balberta nuclear zone should be attributed to an "explosive and militaristic aggressive intrusion of Teotihuacan colonists" (personal communication 2000).

The depopulation of southern Guatemala west of Escuintla (Figure 6) may have been significant following the TBJ eruption, if not as dramatic as the southeastern coastal areas. Bilbao is inland and farther from Ilopango (~215 km., Figure 6), and it suffered a marked decline in the Early Classic, but not an abandonment (Parsons 1967). Even more distant sites in the Ocos area (~340 km) apparently were at least largely abandoned in the Early Classic, and reoccupied in the Late Classic (Coe and Flannery 1967). Ocos might have been more vulnerable to even a light (<5 cm) dusting of tephra because people there relied more heavily on aquatic protein resources (Coe and Flannery 1967) that would have been greatly damaged by the fine volcanic ash (Sheets 1987).

The abandonment of Cara Sucia can probably be explained by the direct effects of the deep airfall tephra deposition. However, environmental difficulties in this area would likely have been overcome within two or three decades, not centuries. Pacific coastal and piedmont sites to the west of Cara Sucia would not have been hindered by long-lasting environmental problems; to the contrary, tephra deposits of < 20 cm may even have been beneficial to agricultural production in southeastern Guatemala within a decade following the eruption (Blong 1984; Ugolini and Zasoski 1979). Why then, was this region largely abandoned for nearly two centuries immediately following the TBJ eruption? We agree with Schortman and Urban (1991) that the demise of Chalchuapa—and numerous smaller sites in central and western El Salvador such as Cara Sucia—also signaled the downfall of a powerful interdependent southeastern periphery economic sphere (Providencia-Miraflores), one with a long history spanning much of the Formative period (Demarest and Sharer 1986). The TBJ event, therefore, should not be viewed exclusively in terms of its environmental impacts; the more potent blow to the entire southern Maya realm probably came in the form of a collapsing regional economy and, as a result, the political destabilization and decentralization of a number of fledgling mercantile polities.

Tephra fallout from the TBJ eruption was most severe to the west of the Ilopango caldera (Hart and Steen-McIntyre 1983; Figure 1). Accordingly, the debilitating effects of the TBJ eruption, felt so strongly in western El Salvador and parts of southeastern Guatemala, did not extend too far north into western Honduras. Situated 40 km north of Ilopango, the Paraíso Basin—a sub-basin of the upper Rio Lempa Basin (Figures 6, 7)—did receive ~60 cm of tephra (Earnest 1999:41; Fowler and Earnest 1985), and although there is some evidence for a small remnant population following the eruption, the agricultural lowlands of the valley were "virtually uninhabitable for several centuries" following the TBJ eruption (Fowler and Earnest 1985:24).

There is no evidence of tephra deposition 130 km north of Ilopango at Copán. In fact, Copán thrived immediately following the TBJ eruption (Fash 1986; Sharer et al. 1999), perhaps filling the void in the interregional economy left by the collapse of Chalchuapa. We are not suggesting that the impressive rise of Copán during the Classic Period was precipitated solely by the collapse of Chalchuapa. The TBJ eruption was just one of many factors that together allowed the remarkable ascent of the burgeoning polity beginning in the fifth century A.D. Apparently another reason for Copán's emergence at this time was its increasing association with a much larger cultural and economic sphere of influence, one controlled by Teotihuacan.

The expansionist mercantile Teotihuacan civilization evidently affiliated with one of the power blocks in the Early Classic period emerging in the Peten: Tikal (Moholy-Nagy 1999; Schele and Freidel 1990; Sharer 1994). By the Middle Classic period, the Tikal-Teotihuacan association expanded south to Kaminaljuyú and subsequently into Copán, possibly to facilitate access to the two major Maya highland obsidian sources (El Chayal and Ixtepeque), and probably the jade source along the middle Motagua River.

The Teotihuacan presence at Kaminaljuyú began slowly, perhaps with indirect exchange relationships (Henderson 1997:135) dating to the early 300s A.D. or perhaps earlier (Sanders and Michaels 1977; Sharer 1994:676). That presence increased dramatically in the second half of the fifth century, and continued strong until the second half of the sixth century, when it began a decline and cessation.

We suggest here the possibility that highland Maya society in the Kaminaljuyú area was weakened from the Ilopango disaster and by the abrupt cessation of economic ties with the larger Miraflores sphere (especially Chalchuapa), thereby facilitating the Teotihuacan strengthening of demographic, political, and economic influence there in the mid to late 400s. The weakening of Kaminaljuyú is confirmed by Michels (1979:30), who reports that "the stability that largely characterized the Early Classic is terminated dramatically with the onset of the Middle Classic phase." Several notable demographic changes occur during this time at Kaminaljuyú: a significant drop in Rank I (Paramount Elite) households from 39 percent in the Early Classic (A.D. 200–400) to 14 percent in the Middle Classic (A.D. 400–600); a 33 percent reduction in total urban population; and a 12.8 percent increase in the "sustaining" rural population (Michels 1979:194–197).

The trends in the urban data at Kaminaljuyú (declines in population, household wealth) are consistent with the socioeconomic disruption presumably caused by the TBJ eruption. The increase in rural populations might be explained by some combination of out-migration from the economically depressed Kaminaljuyú and immigration of subsistence farmers from the ash-mantled Pacific slope region; indeed, post-TBJ ceramic linkages affirm a Pacific coast–Guatemalan highland association (Neff et al. 1994, 1999). There is evidence to suggest that other highland sites in Guatemala may also have been affected by the TBJ eruption and collapse of the southern Maya economic sphere. Semetabaj, for example—located on the north rim of Lago Atitlan (Figure 6)—was completely abandoned around A.D. 400 (Shook et al. 1979:16).

Similar Teotihuacan political-economic objectives may have, at least in part, underlain the founding of the Copán royal dynasty in A.D. 426 (Sharer et al. 1999:20). The Teotihuacan elements are clear in the early talud-tablero architecture, the depictions of the earliest king Yax K'uk Mo in later art, and in artifacts. The Maya colonization of the area included movement into the Ixtepeque obsidian source and founding of Papalhuapa (Graham and Heizer 1968), a Maya "factory town" for processing that obsidian into macrocores for export back into the Maya lowlands.

The dramatic population increase in the Copán Valley during the Middle Classic (Fash 1986:79–82) may not only be explained by the immigration of colonists from the Maya lowlands; the arrival of refugees from Chalchuapa and neighboring sites in western El Salvador left uninhabitable by the TBJ eruption may also have played a part.[13] Residents of Chalchuapa fleeing the Rio Paz basin would have found a similar physical environment (elevation, precipitation, temperature) in Copán to the one they left behind in Chalchuapa (Portig 1965; Sharer 1994). This notion is bolstered by evidence linking Copán to western El Salvador ceramic traditions after the TBJ eruption (Neff et al. 1999).

Beyond the southeastern region of the Maya realm, there is no clear evidence for economic or political disruption precipitated by the physical effects of the TBJ eruption. However, the event may have had a great psychological effect on human populations over an area much larger than the devastated zone. Comparisons to other large Plinian eruptions suggest that earthquakes, heavy rain, lightening storms, and daytime darkness probably accompanied the TBJ eruption (Sheets 1987:45; Thorarinsson 1979:139; Williams 1952).

The 1835 Coseguina eruption, for example, caused numerous earthquakes felt strongly in Leon, Nicaragua (88 km away) and San Miguel, El Salvador (90 km), dry season torrential rains in Tegucigalpa, Honduras (130 km), and several days of near complete darkness stretching at least 550 km from Guatemala City southeast to Rivas, Nicaragua (Williams 1952:32–33). Residents of Leon, Nicaragua attributed the earthquake, darkness, and violent electrical storms to divine anger, and flocked to the temples imploring the mercy of heaven (Scarth 1999:130). The Coseguina eruption was heard as far away as Bogotá, Colombia (1,750 km) in the south and Oaxaca, Mexico (1,100 km) in the north, and tephra deposition was reported as far away as southern Mexico (700 km) and Jamaica (1,280 km) (Sapper 1925; Scarth 1999; Squier 1860; Williams 1952).

Effects similar to those caused by Coseguina would have also been generated by the much larger TBJ eruption. To the prehistoric Maya, the accompanying wind, lightening, darkness, and earthquakes would have held great religious significance, and would likely have been attributed to supernatural forces (Marcus 1978; Thompson 1970). As a result, we can speculate that the psychological trauma induced by the TBJ eruption might have contributed to temporary social disruptions over an area of Mesoamerica much wider than the zones of demographic and economic collapse (Figures 1, 6, 7).

Depopulation and Demographic Recovery

The area of demographic collapse following the TBJ eruption is still not clearly demarcated, but it stretched west at least to the Escuintla region and north to Asunción Mitla/Jutiapa, overlapping much of the Providencia-Miraflores economic sphere (Figure 6). It may be that the western and northern fringes of this area were not completely deserted, but it seems at a minimum that centralized political systems were abandoned and monumental construction was halted.

Not everyone necessarily fled the area outlined in Figure 6 immediately following the eruption. However, any survivors in the area of deep (> 50 cm) tephra airfall would have encountered many tephra-related hardships, most notably in the areas of food procurement and disease outbreaks. Although post-eruption starvation and disease have caused only 4 percent of the volcano-related deaths worldwide since 1900, this percentage swells dramatically to 49 percent for the pre-industrial period from 1600 to 1899 (Tilling 1989:5). More people died from disease (~3000) following the 1902 eruption of Volcán Santa Maria in Guatemala (Figure 5) than from the direct effects of the eruption itself (Blong 1984:126). One account of the Santa Maria disaster is particularly revealing in this respect: "One of our greatest troubles was that of sickness, owing to the balance of Nature having been upset by the eruption, which, having killed all the birds for some hundreds of miles, enabled the flies, mosquitoes, and rats to multiply to such an extent that life to man became nearly unbearable" (Anderson 1908, cited in Blong 1984:126). Thus, malnutrition, starvation, and pestilence following the TBJ eruption might have been partly responsible for progressive demographic collapse throughout the abandonment zone.

Those who did evacuate the zone outlined in Figure 6 probably fled north and northwestward toward Copán and Kaminaljuyú respectively (Figure 7). Ceramic evidence implies an economic realignment following demographic recovery in central and western El Salvador and southeastern Guatemala. Where formerly the Miraflores economic sphere united virtually the entire area (Demarest and Sharer 1986), the post-TBJ ceramic associations show two distinct north-south trending economic spheres, one uniting western El Salvador and Copán, and another linking Kaminaljuyú to the Pacific slope region of Guatemala (Neff et al. 1999).

Although we now have a much more precise understanding of when the TBJ eruption happened, the geography and chronology of reoccupation in the depopulated zones is limited by a dearth of published radiocarbon data, and by inaccurate ceramic cross-dating. Furthermore, the post-TBJ radiocarbon dates that are available are generally not taken from the earliest reoccupation archaeological contexts. If we adopt the working hypothesis that the eruption occurred at ca. A.D. 425,[14] we can begin to standardize reports of an Early Classic population contraction throughout central and western El Salvador and southeastern Guatemala. Table 2 shows what we consider to be the "best"[15] radiocarbon dates for the post-TBJ reoccupation of several sites in central and western El Salvador, including: Cerén, Chalchuapa and Cara Sucia. Table 3 contains sites from south-

Table 2. Radiocarbon Dates for Latest Post-TBJ Reoccupation in Central and Western El Salvador.

Lab #	Material	Site	Sampling Context	Measured Age (^{14}C yr B.P.)	Calibrated Age –1σ (calendar yr A.D.)	Calibrated Age –2σ (calendar yr A.D.)	Source
Tx3113a	*T. plumosus*[a] charcoal	Cerén	Thatch roofing, structure 1, south room	1330 ± 70			Sheets 1983b:7
Tx3119a	wood charcoal	Cerén	Roof beam, structure 1, center room	1420 ± 50			Sheets 1983b:7
Tx6600	*T. plumosusa* charcoal	Cerén	Thatch roofing, structure 3	1520 ± 70			authors
Tx6601	*T. plumosus*[a] charcoal	Cerén	Thatch roofing, structure 2	1350 ± 90			authors
E1S40	*T. plumosus*[a] charcoal	Cerén	Thatch roofing, structure 1	1440 ± 135			Sheets 1983b:7
A-10743	*T. plumosus*[a] charcoal	Cerén	Thatch roofing	1360 ± 50[b]			McKee personal communication 2000
		Cerén Composite	(weighted mean)	1390 ± 30	642(656)662	605(656)684	
Y-682	charcoal	Tazumal/ Chalchuapa	Pot 1, Grave 16, structure 1	1480 ± 120			Stuiver and Deevey 1961:131
Y-685	charcoal	Tazumal/ Chalchuapa	Pot 8, Grave 13, structure 1	1520 ± 120			Stuiver and Deevey 1961:131
		TazumalComposite	(weighted mean)	1500 ± 85	434(562,592,596)644	395(562,592,596)678	
A-1949b	carbonized maize cob	Cara Sucia	Tamasha Phase basurero	1380 ± 180	533(658)859	260(658)1018	Amaroli 1987: IV-4

Note: All dates are calibrated using the INTCAL 98 calibration (Stuiver et al., 1998). Tx = the University of Texas, Austin Radiocarbon Laboratory; EIS = Universidad Nacional, Physics Department Radiocarbon Laboratory, El Salvador; A-10743 = University of Arizona Radiocarbon Laboratory; Y = Yale University Radiocarbon Laboratory; A-1949b = University of Miami Radiocarbon Laboratory.

[a] Trachypogon plumosus

[b] δ^{13}C = –11.9. This is the only Cerén ^{14}C date that has been δ^{13}C corrected.

Table 3. Post-TBJ Reoccupation in Southeastern Guatemala.

Region	Evidence	Approximate Date for Reoccupation	Citation
Jutiapa	Stratigraphic hiatus, Ceramic seriation	ca. A.D. 600	Wauchope and Bond 1989:102
Santa Rosa	Stratigraphic hiatus, Ceramic seriation	ca. A.D. 625[a]	Estrada Belli 1998:189, 261
Escuintla	Stratigraphic hiatus, Ceramic seriation	ca. A.D. 600	Bove 1993a: 191

Note: These dates should be considered tentative at present, as the cultural sequences of southeastern Guatemala have yet to be well-dated by radiocarbon. Future radiocarbon work focused on the reoccupation period should help refine our understanding of the geography and chronology of the post-TBJ hiatus in this region.

[a] The Santa Rosa region reoccupation date is based on an A.D. 425 TBJ eruption (this study) and Estrada Belli's estimate of a 200-year hiatus during the Early Oscuro phase, immediately following the TBJ eruption (Estrada Belli 1998: 261).

eastern Guatemala discussed in the text and their reported reoccupation times. We conclude from these data that the depopulated area outlined in Figure 6 represents a cultural hiatus of roughly 100–150 years. It is clear that much of the area abandoned after the eruption was resettled by the end of the sixth century A.D.

The TBJ Tephra as a Time-Stratigraphic Marker

Understanding the impacts of the TBJ eruption on the cultural history of Mesoamerica has provided the impetus for much of the work done on this spectacular geologic event to date. Its utility as an interpretive scientific tool, however, goes far beyond studies of Maya demography and socioeconomic change.

The TBJ tephra as a tephrochronological marker is important to archaeologists and paleoecologists alike. In archaeological contexts, the very presence of the TBJ tephra layer provides a low cost, highly reliable minimum date for cultural remains that lie below it (Amaroli and Dull 1999; Earnest 1999; Fowler and Earnest 1985). Similarly, the presence of the TBJ tephra in marine, estuarine, and lacustrine sediments allows for regional correlation of stratigraphic records of environmental change (Dull 1998). Moreover, a well-dated, widely distributed tephra such as the TBJ can help circumvent problems associated with the lack of suitable samples for radiocarbon dating—for example, the "hardwater effect" that often confounds efforts to use radiocarbon to date stratigraphic lacustrine sequences in karstic areas like the Maya lowlands (Leyden 1987).

Conclusion

New dating evidence indicates that the TBJ eruption of Volcán Ilopango, El Salvador occurred not at the close of the Formative Period, but at least 150 years later, during the Early Classic Period. Three new AMS determinations support a reanalysis of the previous radiocarbon dates reported for the event. The composite calibrated radiocarbon date for the event is now A.D. 408(429)536 (two sigma range), but the bulk of the probability distribution for the calibrated radiocarbon date is concentrated near the older end of this range, before A.D. 476. Ceramic, ice-core, and dendroclimatological data are all consistent with an early-to-middle fifth-century A.D. eruption, but so far none of this evidence can definitely be linked to Ilopango.

The trajectory of deposition for the majority of volcanic ejecta emitted by the TBJ event trends to the west of the Ilopango vent. Pyroclastic flows and deep (2 m +) airfall tephra deposits had the greatest impact on people living near to or directly west of Ilopango in the San Salvador basin and on the eastern fringes of the Zapotitán basin. Most inhabitants of this region probably perished as a result of their proximity to deadly volcanic hazards: pyroclastic flows, lahars, emissions of noxious gasses, or deep tephra deposits.

Outside of the zone of devastation, there is a much larger area of prolonged depopulation (~100–150 years) following the TBJ eruption. The demographic collapse in this area—encompassing most of western El Salvador and southeastern Guatemala—was probably progressive and can be attributed to a combination of three factors: immediate evacuation due to volcanic hazards, post-eruption starvation and disease, and regional economic collapse.

Residents of Chalchuapa, located 77 km west of the vent, were probably far enough away that most of them survived, but they would not have been able to remain in the ash-laden Rio Paz basin following the eruption. The initial airfall deposits would have gradually been augmented by tephra eroded from the upland areas during the first few rainy seasons following the eruption. Comparative studies show that it would have taken decades before subsistence agriculture could have been resumed in the valley floor. The radiocarbon data from Tazumal support this finding, showing that Chalchuapa was not significantly reoccupied until the sixth century A.D.

An Early Classic period depopulation is also posited for the Pacific slope of western El Salvador and southeastern Guatemala. However, the population collapse in this region cannot be explained merely in terms of physical and biological effects/constraints. We believe that the TBJ eruption had a profound effect on the economic viability of this region via its dependence on trading partners who were more heavily impacted directly by the eruption (e.g., Chalchuapa). So although much of southwestern El Salvador and southeastern Guatemala was covered with a measurable layer of ash (~5–50+ cm) following the eruption, the environmental damage only partially explains the Early Classic hiatus in the region. The disruption of the "Miraflores" southern highland-Pacific coast cultural/economic sphere was likely more damaging to the inhabitants of the Pacific slope over the long term than the environmental effects of the TBJ.

The southern highlands of Guatemala may also have been strongly affected by the TBJ eruption. At Kaminaljuyú, the 200-year period following the TBJ event is characterized by marked declines in the wealthiest households and overall urban populations, and a modest increase in rural populations. We attribute the declines in urban dwellers and wealthy households to the economic disruption of the southern Maya area caused by the TBJ eruption. Furthermore, we believe that the instability created by the physical and economic effects of the eruption facilitated the penetration of Teotihuacan cultural, political, and economic influence. The increase in rural populations surrounding Kaminaljuyú might have resulted from out-migration from Kaminaljuyú or from rural farmers fleeing the ash-covered Pacific slope of southern Guatemalan and El Salvador.

Another possible recipient of the TBJ refugees is Copán, which experienced a pronounced increase in population beginning in the fifth century A.D. Copán was apparently spared the severe environmental impacts of the TBJ that were so crushing in areas directly west and northwest of the Ilopango caldera, and this is precisely why Copán was probably so attractive to the fleeing urbanites of Chalchuapa. In Copán, the former inhabitants of Chalchuapa would have found a growing, vibrant urban center geographically situated along a mid-elevation river valley, a very similar environment to the one they left behind in the Rio Paz basin. During this period of rapid demographic, cultural, and economic change at Copán—partly spurred by the TBJ event—the dominant preexisting political infrastructure was apparently weakened, facilitating the ascendance of the lowland Maya-Teotihuacan alliance.

Finally, it is our hope that this paper will highlight the general need in Mesoamerican archaeology for a more critical reading of radiocarbon results and more intense scrutiny of the radiocarbon dates that support ceramic seriations. Our understanding of incipient food production in Mesoamerica has changed radically in recent years due to the reanalysis (using AMS techniques) of long-established archaeological chronologies (Fritz 1994; Long et al. 1989), and this is certainly not the end of the road. The re-dating of the TBJ eruption is just one step in a long process of critically reevaluating the chronology of cultural evolution and Holocene environmental change throughout Mesoamerica.

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Notes

1. The two innermost isopachs (100+ cm and 50–100 cm) are based on the field measurements by Hart and Steen-McIntyre (1983:22, Figure 2–10). The outermost partial isopach (20–50 cm) is based on field measurements by Robert Dull in lake sediments from Laguna Llano (20 cm+) and Laguna

Gamboa (30 cm+), both in the department of Ahuachapan, and measurements by Paul Amaroli in archaeological test units at Cara Sucia (Amaroli 1987). Amaroli found TBJ deposits as thick as 50 cm. in his Cara Sucia excavations (1987: IX–1)

2. In using the term "Protoclassic," we follow the interpretation of Brady et al. (1998), who suggest that the Protoclassic ceramic stage spans the period from ca. A.D. 75 to 420, overlapping both the Late Formative and Early Classic periods.

3. We define the Early Classic as the period from A.D. 250 to 600 (Henderson 1997).

4. This date (1940 ± 50^{14}C yr B.P) is also apparently too old in comparison to 2 pre-TBJ dates from the Chalchuapa area. One of these dates, 1840 ± 40 ^{14}C yr B.P. (P-1547), is from charcoal within a Caynac complex (Sharer 1978a) vessel from El Trapiche (Lawn 1974). The other date, 1830 ± 40 ^{14}C yr B.P. (CAMS 60524), comes from a dicot leaf macrofossil sample over a meter below the TBJ tephra in a Laguna Cuzcachapa lake sediment core.

5. We only discovered that Earnest was working on the TBJ chronology problem in March 2000 as we were completing the first draft of this manuscript. The ceramic cross-dating issue is one that we had not confronted, and Earnest does an excellent job of piecing together that complicated puzzle. Note that he also reevaluates the radiocarbon evidence for the timing of the TBJ eruption, and though he offers no new data, his conclusions based on a detailed reassessment of the original suite of TBJ dates are very similar to our own.

6. These records include: Tornetrask, Sweden (68°N, 20°E), Yamal, Russia (67.5°N, 70°E) and Taimyr, Russia (72°N, 102°E).

7. Although the post-Santa Maria eruption landscape depicted here is probably an accurate analog for the TBJ eruption in terms of tephra volume—VEI 6 (Simkin and Siebert 1994), the landscape does not convey the violence associated with the TBJ pyroclastic flows. The fact that dead trees remain standing in this Santa Maria photograph indicates that lateral base surge pyroclastic flows, such as those that were so devastating in El Salvador during the TBJ eruption (Hart and Steen-McIntyre 1983), were not a component of the 1902 Santa Maria eruption. The photograph is reprinted from Sapper (1927:88, Tafel IV).

8. It should be stressed that the middle twentieth-century farmers of Parícutin possessed more advanced farming implements and technological knowledge than the ca. fifth-century farmers of the Rio Paz basin. Foremost among the advantages of the Parícutin farmers were metal tools (plows, hoes, shovels, etc.) and domesticated animals (e.g., oxen). Nonetheless, tephra deposits of only 15 cm posed an insurmountable hurdle to agricultural success for more than a decade after the eruption (Scarth 1999).

9. Historic examples of these hazards include: lahars such as those that in 1985 killed more than 23,000 people when the Nevado del Ruiz volcano erupted in Colombia; carbon dioxide poisoning such as that which in 1986 killed more than 1,700 residents of Cameroon; and coastal tsunamis such as those that in 1883 killed more than 32,000 people following the eruption of Krakatau in Indonesia (Scarth 1999; Tilling 1989).

10. The reported hiatus period of 300 years should be considered tentative considering the apparent lack of internal consistency in the reported radiocarbon data series (Amaroli 1987:chapter IV). Using the best of Amaroli's reoccupation dates (A-1949b, Tamasha Phase carbonized maize cob: 533(658)859 cal AD) , we interpret the Cara Sucia hiatus to be roughly 200 years (Table 2).

11. Estrada Belli has shown samples of this material to Sheets, who suggested that a TBJ identification could not be made without trace element verification.

12. The Pacific coast disruption was also assigned this Formative/Classic date by Neff et al. (1994:333), who conclude that, "some kind of dramatic historical discontinuity affected the lives of the Pacific-slope people around A.D. 200."

13. Given the proximity to the Motagua Valley, it is quite likely that Salvadoran TBJ refugees also made found their way into that region and perhaps to the Maya Lowlands beyond (Sharer and Gifford 1970; Sheets 1979).

14. A best guess considering the probability distribution of the composite radiocarbon data and supplementary ice core, tree ring, and ceramic data discussed earlier.

15. We decided to consider only those dates from identifiable short-lived samples (plant macrofossils) and charcoal from controlled proveniences. It should be noted that many samples unsuitable for radiocarbon data are reported in the literature, and caution must be used in interpreting these results. The dates that are reported should be considered as latest possible dates for reoccupation. The Cerén dates actually date houses buried by the Loma Caldera eruption; clearly some years must have passed after the time people reoccupied the Zapotitán basin, before the Loma Caldera eruption. Similarly the dates from Tazumal record a period of resumed monumental architecture construction in the Chalchuapa area at some time following the initial re-occupation.

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