Quaternary Science Reviews 191 (2018) 378–392

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Late Holocene volcanic activity and environmental change in Highland Guatemala

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ARTICLE INFO

Article history:
Received 21 April 2018
Received in revised form
10 May 2018
Accepted 10 May 2018

Keywords:
Central America
Guatemala highlands
Lake Amatitlan
Volcanism
Environmental change
Tephrochronology

ABSTRACT

We present a record of late Holocene volcanic eruptions with elemental data for a sequence of sampled tephras from Lake Amatitlan in Highland Guatemala. Our tephrochronology is anchored by a Bayesian P_Sequence age-depth model based on multiple AMS radiocarbon dates. We compare our record against a previously published study from the same area to understand the record of volcanism and environmental changes. This work has implications for understanding the effects of climate and other environmental changes that may be related to the emission of volcanic aerosols at local, regional and global scales.

1. Introduction

In recent years there has been a growing emphasis in Mesoamerican archaeology on correlating cultural and environmental records, specifically those pertaining to climate change (Brenner et al., 2002, 2003; Curtis et al., 1996, 1998; Gill, 2000; Hodell et al., 1995, 2001; 2005; Kennett et al., 2012; Kennett and Voorhies, 1995; Lachniet et al., 2012; Neff et al., 2006b; Rosenmeier et al., 2002; Voorhies and Metcalfe, 2007; Yaeger and Hodell, 2008). This reflects increased understanding of how climate change influenced pre-Columbian cultural and political systems (Iannone, 2014). Additionally, multi-disciplinary investigations continue to contextualize both coastal and inland adaptations, such as intensive wetland agricultural production, in relation to sea level changes that were linked to climate change (Beach et al., 2009, 2013; Luzzadder-Beach and Beach, 2009; Neff et al., 2006a; Pohl et al., 1996; Voorhies, 2004). Cultural responses to environmental changes like these varied widely, including shifting settlement choices, adopting new farming strategies in response to fluctuations in water tables or encroaching shorelines, and reorganizing political networks.

Volcanism, as an environmental factor that affected pre-Columbian culture in Mesoamerica (Cooper and Sheets, 2012; Dull et al., 2001; Gill and Keating, 2002; Mehringer et al., 2005; Plunket and Uruñuela, 1998, 2006; Siebe, 2000; Sheets, 1983, 2005, 2008), has received less attention. Volcanically active areas like Central Mexico and the Central American Volcanic Arc (CAVA), running from the Guatemala Highlands south through El Salvador, are commonly associated with explosive eruptions that decimated large surrounding areas, buried villages like Cerén in El Salvador and Tetimpa in Puebla, and caused widespread abandonment. Such

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https://doi.org/10.1016/j.quascirev.2018.05.014

documented responses, however, may not represent the total capacity for human societies to successfully adapt and prosper in volcanically active regions. Cultural responses came not only in the context of the expulsion of ash and lava across the landscape, but must also have contended with how volcanic activity directly and indirectly influences local, regional and even global environments. For example, sulfur-laden aerosols (e.g., SO_2) from volcanic activity force global climate change by absorbing upper-level atmospheric solar radiation, which disrupts solar-driven atmospheric and oceanic circulation cells that convey both heat and moisture between regions (Mayewski et al., 1994; Zielinski, 2000). Recent work has helped to link specific volcanic events with punctuated, historically recorded periods of global climate change, specifically cold, dry periods (Larsen et al., 2008; Lavigne et al., 2013; Miller et al., 2012; Sigl et al., 2015). We anticipate that, as linkages between volcanic SO_2 aerosol emissions and climate change become better understood (Crowley et al., 2008; Gao et al., 2008; Ridley et al., 2015; Sigl et al., 2013; Zielinski, 2000), the effects of volcanism on ancient Mesoamerican populations, in terms of sudden catastrophic events, general landscape instability, and the gradual or cumulative effects of aerosol loading on regional climates, will also receive increasing attention.

An important component of this research is the enhanced temporal precision of paleoenvironmental records, achieved through various methods. This has made it possible to define punctuated events more accurately and better understand the role of these events in local and regional political processes (e.g., Siebe, 2000). In some cases, such as reconstructions of climate patterns from $\delta^{18}O$ records in speleothems (Bernal et al., 2011; Kennett et al., 2012; Lachniet et al., 2012; Medina-Elizalde et al., 2016), chronometric resolution is achieved by fine-interval U-Th dating. Although such resolution is not possible in alluvial, marine, or lacustrine sediment contexts that rely on radiocarbon dates, very high-resolution sedimentation rates and sequences are occasionally encountered, as in the marine Cariaco Basin off Venezuela (Haug et al., 2001) or the distal beach plain at the mouth of the Usumacinta-Grijalva river system in Tabasco, Mexico (Noreen et al., 2017), that allow for precise dating of environmental events. Better chronometric precision is important in studies of environmental and climate change, as they relate to human cultures, because it enables researchers to better contextualize specific natural events in terms of past human social experiences that occurred within a generation or less.

Here, we present results from analyses of a sediment core from Lake Amatitlán, located approximately 25 km south of present-day Guatemala City (Fig. 1). This highland lake is uniquely suited for paleoenvironmental study in a region characterized by complex and dynamic cultural developments that began in the Terminal Pleistocene (Love, 2007; Love and Kaplan, 2011). Unlike the lowlands to the north, comparatively little environmental information is available from highland zones. Consequently, archaeologists lack context for understanding the societal effects of terminal Late Formative drought (Dahlin, 1983; Neff et al., 2006b; Popenoe de Hatch et al., 2002), which may have contributed to widespread regional decline (Love, 2007:299). And indeed, little is known of environmental conditions in the highland region for many other periods. Lake Amatitlán was cored previously (Tsukada and Deevey, 1967; Velez et al., 2011) and several lines of evidence were explored to infer the history of environmental change in relation to cultural developments in the nearby Valley of Guatemala. Our work builds on these earlier studies, but with a focus on the late Holocene record of regional volcanism. We used a Bayesian age-depth model (Bronk Ramsey, 2008) that integrates AMS radiocarbon ages and depth information to refine the sediment chronology and better understand the temporal environmental history of this region.

2. Regional geology and climate

The Guatemalan Highlands are a dynamic landscape where orogenic structure has a significant effect on local and regional environments, extending downslope to both the Pacific and Caribbean coastlines. This mountain chain was formed by a convergent boundary between the Cocos and Caribbean continental plates. Subduction of the Cocos plate some 150 km offshore uplifts the Caribbean plate to form the southeast-to-northwest trending CAVA, which covers Guatemala, El Salvador, Nicaragua, and Costa Rica (Kutterolf et al., 2008, Fig. 2). This subduction zone does not extend northward, where the coastal area of Chiapas, Mexico, called the Soconusco, is less tectonically active. Archaic people focused on estuarine resources and maize cultivation by about 6500 years cal B.P. and have been documented in the Soconusco (Kennett et al., 2010; Voorhies, 2004; Voorhies et al., 2002). We anticipate that such ancient activities will be documented in our area by future research (Morgan, 2011; Neff et al., 2006a).

Lake Amatitlán is surrounded by active volcanoes that include Pacaya (Kitamura and Matías, 1995) and the Fuego-Meseta complex, which includes the Fuego, Meseta, and Pico Major (also called Acatenango) vents that were active in pre-Columbian times, as well as the non-active Yepocapa and Acatenango Antiguo vents (Eggers, 1971; Vallance et al., 2001, Fig. 3). This complex is one of four documented "paired volcanoes" in northern Central America (Haslor and Rose, 1988). In such pairs, the seaward vent has commonly been more active in recent times, and is also associated with more mafic magmas and higher Na_2O/K_2O than the landward vent. Although these trends may help distinguish eruptions within paired vents to some degree, differences among tephras from a single vent can exceed differences between two vents (see below). The presently inactive Agua volcano is also located nearby.

The Fuego complex, along with Pacaya, is among the most volcanically active in Guatemala and numerous eruptions from both are recorded in historic documents. Not only are both complexes active, but they are also quite young geologically; this fact has important implications for archaeological study of the region. Studies of lava deposits from Meseta suggest that the entire present-day edifice of Fuego may have been constructed in about 8500 years and that this impressive cone may be less than 30,000 years old (Vallance et al., 2001). Based on qualitative geomorphic evidence, Eggers (1971) suggested that the entire present-day cone structure of Pacaya is of Holocene age. Conway et al. (1992) corroborated this conclusion using paleomagnetic data from sequenced lava flows.

In addition to eruption events, other hazards associated with volcanism in this area include catastrophic edifice collapses that resulted in downhill debris-avalanches. Some time between about 30,000 and 8500 years ago, a massive edifice collapse at Meseta resulted in a debris avalanche with an estimated volume of about 9 km^3 that covered approximately 300 km^2 of the Pacific Coastal Plain south of Escuintla (Vallance et al., 1995). Eggers (1971) documented a similar debris avalanche associated with the collapse of the Pacaya edifice, and Vallance et al. (1995:341) inferred an age for that event of between 2000 and 400 years ago, based in part on soil development above this deposit and recovery of Late Preclassic pottery below it (Hunter, 1976, cited in Vallance et al., 1995). They estimated this debris-avalanche may have covered more than 55 km^2 along the Rio Metapa Valley, east of Escuintla, which is located about 30 km southwest of Amatitlán (Vallance et al., 1995). Clearly, active volcanism has important implications, not only for regional occupation histories but also for archaeological reconstruction of those histories.

Long-term study of the eruptive histories of Pacaya and Fuego