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Eruption of the dacite to andesite zoned Mateare Tephra, and associated tsunamis in Lake Managua, Nicaragua

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Abstract

The dacite to andesite zoned Mateare Tephra is the fallout of a predominantly plinian eruption from Chiltepe peninsula at the western shore of Lake Managua that occurred 3000–6000 years ago. It comprises four units: Unit A of high-silica dacite is stratified, ash-rich lapilli fallout generated by unsteady subplinian eruption pulses affected by minor water access to the conduit and conduit blocking by degassed magma. Unit B of less silicic dacite is well sorted, massive pumice lapilli fallout from the main, steady plinian phase of the eruption. Unit C is andesitic fallout that is continuous from unit B except for the rapid change in chemical composition, which had little influence on the ongoing eruption except for a minor transient reduction of the discharge rate and access of water to the conduit. After this, discharge rate re-established to a strong plinian eruption that emplaced the main part of unit C. This was again followed by water access to the conduit which increased through upper unit C. The lithic-rich lapilli to wet ash fallout of unit D is the product of the fully phreatomagmatic terminal phase of the eruption. A massive well-sorted sand layer, the Mateare Sand, replaces laterally variable parts of unit A and lowermost part of unit B in outcrops up to 32 m above present lake level. The corresponding interval missing in the primary fallout can be identified by comparing the composition of pumice entrained in the sand, and pumice from the local base of unit B on top of the sand, with the compositional gradient in undisturbed fallout. The amount of fallout entrained in the sand decreases with distance to the lake. The Mateare Sand occurs at elevations well above beach levels and its widespread continuous distribution defies a fluviatile origin. Instead, it was produced by lake tsunamis triggered by eruption pulses during the initial unsteady phase of activity. Such tsunamis could threaten areas not affected by fallout, and represent a hazard of particular importance in Nicaragua where two large lakes host several explosive volcanoes.
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Keywords: plinian eruption; compositional zonation; tsunami; volcanic hazards

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1. Introduction

1.1. Volcanogenic tsunamis

Tsunamis are long waves triggered by the sudden displacement of water by mass movement at the seafloor. Tsunamigenic mass movements can be seismic events that offset the seafloor or submarine landslides (e.g., Harbitz, 1992; Bourgeois et al., 1999; von Huene et al., 2003) but also subaerial landslides and pyroclastic flows that enter the sea (Keating and McGuire, 2000; Self et al., 1984; Sigurdsson and Carey, 1989; Waythomas and Neal, 1998; McCoy and Heiken, 2000; Carey et al., 2001; De Lange et al., 2001; Freundt, 2003, in press). Tsunamis on the open sea have long wavelengths, low amplitudes, and travel at great speed depending on water depth. When these waves slow down in shallowing coastal waters their amplitude grows dramatically with a devastating effect on flooded coastal areas. Reported maximum tsunami runup heights include 326 m asl on Lanai (Moore and Moore, 1984), >400 m asl at Kohala on Hawaii (McMurtry et al., 2004), and 500 m asl at Lituya Bay, Alaska (Miller, 1960). Tsunamis of volcanic origin may be formed by earthquakes accompanying eruption, caldera subsidence, submarine explosions, and pyroclastic flows, landslides, avalanches and lahars entering the sea or moving under water (Latter, 1981), and several such processes may act simultaneously.

Most documented tsunamis occurred in the ocean and few reports exist on volcanogenic tsunamis in lakes. Voight et al. (1981) describe water runup to 260 m above Spirit Lake upon impact of the avalanche from the collapse of Mt. St. Helens' north flank at the beginning of the May 18, 1980, eruption. Belousov et al. (2000) report 2–30 m runup heights of tsunamis generated by subaquatic explosions during surtseyan eruptions in Lake Karymskoye, Kamchatka, in 1996. They also describe minor waves coupled to radially expanding surges.

The risk from volcanogenic lake tsunamis is particularly high in Nicaragua, where the most densely populated areas lie along the shores of Lake Managua and Lake Nicaragua, which together cover 10% of the country's area. These lakes lie within the active subduction-related volcanic arc. Although there have been speculations about lake tsunamis possibly formed by volcano-flank collapse at Mombacho volcano (Vallance et al., 2001) or pyroclastic flows from Apoyo caldera (Sussman, 1985), we here present the first documented case of an eruption-generated tsunami in Lake Managua.

1.2. Central Nicaraguan succession of widespread tephras

We have recently revised and extended the stratigraphy and ^{14}C dating of deposits of highly explosive eruptions from arc volcanoes in west-central Nicaragua, building on earlier work by Bice (1985) and references therein. The stratigraphic succession at the western shore of Lake Managua (Fig. 1) comprises the Chiltepe Formation (CF), including six tephras younger than 15 ka from plinian and phreatomagmatic eruptions on Chiltepe peninsula, and the newly identified Mateare Formation (MF) underneath a major regional unconformity, which is composed of numerous basaltic to dacitic lapilli-fallout and tuff deposits (Fig. 2). Chiltepe peninsula is a volcanic complex hosting the Apoyeque stratocone, the Xiloa maar, mafic cinder cones and tuff rings, and at least two other vent sites that are no longer visible. Highly explosive eruptions occurred at a relatively high and steady frequency during the recent past and will most probably continue at the Chiltepe volcanic complex. This emphasizes the need to understand its eruptive history and mechanisms to assess future volcanic hazards. In this contribution we focus on the eruption of the Mateare Tephra and its associated tsunami.

The Mateare Tephra is underlain by the phreatomagmatic dacitic Xiloa Tephra, which consists of two white pyroclastic-surge ash deposits (Xiloa A and C) bracketing a central ash-rich, normally graded pumice fallout layer (Xiloa B). Carbonized wood contained in the Xiloa Tephra yields a ^{14}C age of 6105 ± 30 a B.P. (Fig. 2). The dacitic plinian Chiltepe Tephra was produced by the youngest plinian eruption from the Chiltepe volcanic complex. In the area west of Managua City, the distal Chiltepe Tephra overlies the Masaya Triple Layer, a basaltic plinian fallout from Masaya caldera (Williams, 1983; Perez and Freundt, in press). Plant remains within the Masaya Triple Layer yield a radiocarbon age of 2120 ± 120 a B.P. These dates constrain the age of the Mateare Tephra to between 3000 to 6000 years ago.

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