Journal of Volcanology and Geothermal Research 197 (2010) 133–148

Contents lists available at ScienceDirect

Journal of Volcanology and Geothermal Research

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

Substrate deformation associated with the Jocotitlán edifice collapse and debris avalanche deposit, Central México

Anja Dufresne [a,*], Sergio Salinas [b], Claus Siebe [b]

[a] Department of Geological Sciences, PB 4800, Canterbury University, Christchurch, New Zealand
[b] Departamento de Vulanología, Instituto de Geofísica, Universidad Nacional Autónoma de México, Mexico D.F., Mexico

ARTICLE INFO

Article history:
Received 14 January 2009
Accepted 28 February 2010
Available online 11 March 2010

Keywords:
debris avalanche
substrate deformation
Jocotitlán
volcano spreading

ABSTRACT

An impressive debris avalanche deposit is preserved at Jocotitlán volcano in Central Mexico. The northern flank of this edifice collapsed ~9690 years B.P. resulting in a 80 km^2-covering clast-supported deposit that lacks substantial matrix, fine, weak or hydrothermally altered materials. The deposit can be subdivided into three morphologically distinct areas which are each accompanied by specific, and often unique, deformation features in the underlying and adjacent volcaniclastic and lacustrine sediments. From these features, a complex history of pre- and syn-avalanche events was reconstructed beginning with edifice-spreading on the weak substrate material prior to and in preparation of part of the flank collapse event. The north-eastern flank in particular was strongly coupled with the deforming substrate material as is still evident in its extensional profile and the unique mode of failure during the catastrophic event resulting in the deposition of what resembles non-volcanic blockslide deposits rather than the typical hummocky volcanic debris avalanche morphology. This latter type of failure occurred at the north-western flank of Jocotitlán volcano where few signs of substrate interactions are preserved in a deposit dominated by large conical hummocks. In addition to substrate response, interaction with pre-avalanche topography in the eastern deposit area facilitated the emplacement of a lobe roughly perpendicular to the flank failure direction, at apparent high emplacement velocity, and with longitudinal ridges as its most striking surface expression.

1. Introduction

Volcanic sector collapse events are common characteristics of strato- and composite-volcanoes world-wide and have produced voluminous debris avalanche deposits altering the shape of the volcano edifice and their surrounding landscape. The deposits have volumes of up to tens of km^3; and in rare cases hundreds of km^3 have been reported. Areas devastated typically range from a few to 1000 km^2, with distances from source reaching 10 to 100 km; exceeding 100 km in the cases when avalanches transformed into more mobile debris flows. In Mexico, 48% of the edifice-forming volcanoes are currently known to have produced one or more large debris avalanche deposits (30 deposits recognized at 21 volcanoes; all data from Dufresne et al., 2008). Interaction of these debris avalanches with their runout path material is often reported, and substrate relation to avalanche and sector collapse dynamics is the focus of this study.

Jocotitlán volcano is an andesitic–dacitic composite volcano situated circa 60 km WNW of Mexico City. When part of the edifice collapsed to the NNE 9690 years B.P. (Siebe et al., 1992) it changed the local landscape from a broad volcaniclastic and lacustrine sediment- and lake-filled valley to today's hummocky topography of the clast-supported Jocotitlán debris avalanche deposit.

Deformation features within the sediments underneath and adjacent to debris avalanche deposits are used in the study of avalanche emplacement processes, and help to discern the exact timing of events, i.e. whether deformations occurred (1) before avalanche emplacement due to some local or regional process (e.g. seismic, tectonic, volcano spreading), (2) during avalanche emplacement as a direct consequence of interaction with the moving avalanche material, or whether (3) they are the result of post-emplacement loading by the avalanche mass or some other mechanism unrelated to avalanche emplacement (e.g. tectonic, seismic, etc.). Herein we report the sediment deformation features found in and around the Jocotitlán volcanic debris avalanche deposit and discuss their timing and relation to its emplacement.

2. Regional setting

The Jocotitlán volcanic edifice is located in the central part of the Trans Mexican Volcanic Belt (TMVB) within the northern Toluca Basin (Ixtapantongo Basin; Fig. 1). Its current summit reaches a height of 3950 m above sea level. To the north of Jocotitlán volcano lies the active Acambay Graben, a feature in NNW–SSE extension, roughly

* Corresponding author. Tel.: +64 3364 2987; fax: +64 3364 2769.
E-mail address: volcanja@web.de (A. Dufresne).

0377-0273/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.jvolgeores.2010.02.019

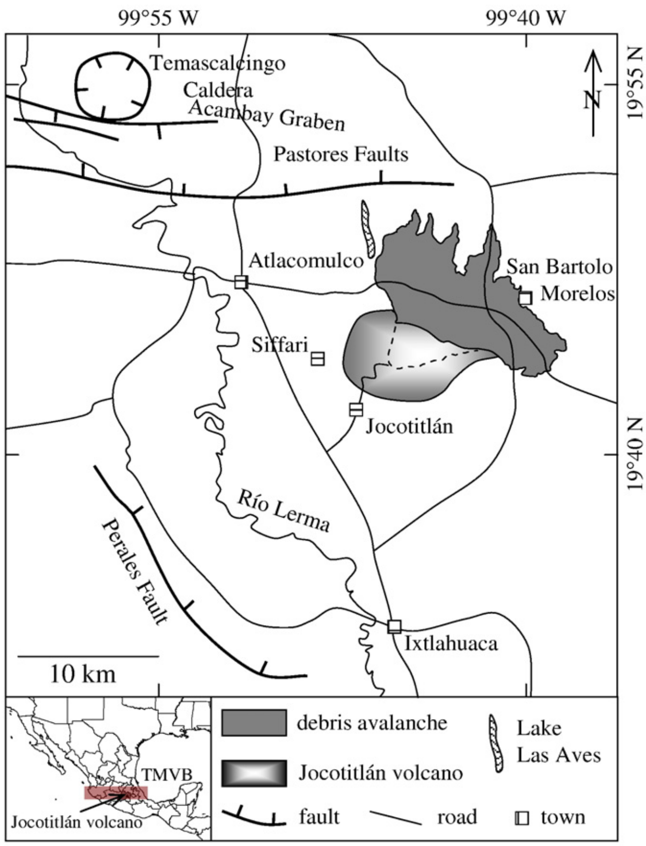

Fig. 1. Sketch map showing major tectonic features and relevant towns in the vicinity of Jocotitlán volcano.

perpendicular to the volcanic arc axis (Suter et al., 2001). Its extensional regime reflects the overall tectonic nature of the entire TMVB in recent geological time (Suter et al., 1991). South of Jocotitlán is the inactive Perales Fault, a normal fault trending roughly NW–SE, and which belongs to a NNW–SSE striking Basin and Range province normal fault system that predates the Acambay Graben system (Suter et al., 2001). A series of basaltic–andesitic scoria cones and few dacitic domes are scattered throughout the Toluca Basin. Jocotitlán last erupted 680 ± 80 years B.P. (Siebe et al., 1992) and is at present in a state of dormancy.

2.1. Paleoclimate

From a study at Almoloya Lake south of Jocotitlán, Ludlow-Wiechers et al. (2005) reconstructed the regional Late Pleistocene–Holocene paleoclimate of the central Mexican highlands. Between 11,500 and 8500 years B.P., the vegetation was very similar to today's moist to sub-humid climate. Cold temperatures before 10,800 years B.P. changed to temperate and warm–temperate conditions that led to pine forest growth around 10,000 years B.P. A considerable drop in lake level in Central Mexico is inferred from this and other sites to have occurred around 8400 years B.P. Hence at the time of sector collapse and debris avalanche emplacement, shallow lakes were widespread in the central highlands.

3. Edifice and debris avalanche morphology

Steep slopes mark the sides of the Jocotitlán edifice, and its current summit rises 1300 m above the surrounding landscape which is composed of lava flows, volcaniclastics, and lacustrine sediments. From west to east, morphologically distinct areas of the edifice and debris avalanche deposit can be distinguished (Fig. 2).

The northern and north-eastern sections of the edifice are scarred following the catastrophic collapse around 9690 years ago (Siebe et al., 1992). Previously, one single collapse scarp has been outlined by Siebe et al. (1992), within which two distinct source areas can be identified based on edifice morphology and relation to collapse debris distribution. A large, horseshoe-shaped scarp opening to the NNE and extending to the foot of the edifice characterizes the north-western section, whereas collapse of the north-eastern sector produced a long and steep failure surface (see below). Post-collapse volcanic activities in the form of dome extrusions and associated pyroclastic deposits as well as erosional overprinting obscure the original collapse geometry, particularly in the western area.

In its western part, the deposit features strikingly conical hummocks with individual heights of up to 125 m in the proximal zone. With distance from source these grade into smaller hummocks and hummock clusters. The hummocks form alignments radial to source pointing back to the now partially infilled horseshoe-shaped area of the collapse scarp. Debris from here spread over 90°. Near the western margin (Fig. 4a) the debris avalanche topography changes abruptly from the thick hummocky deposit to a lower-lying area with few smaller hummocks and ridges visible above the later lake infill. Currently, Lake Las Aves fills part of the north–south trending valley to the northwest of Santiago Acutzilapan; its extent at the time of debris avalanche emplacement remains subject to speculation, but it might have extended to this change in topography at the western margin, offering a potential explanation for its existence. A similar step in topography is seen near San Marcos Tlazalpan accompanied by a change to a flatter, lower-lying distal area with few small, isolated hummocks. Although lacking the topographic step, distal areas of scattered hummocks have also been observed at the Parinacota debris avalanche in Chile (Clavero et al., 2002). Overall, the major volume of the material in the western depositional area was emplaced directly to the north of the collapse scarp and current edifice summit, with less spreading to the north-west and north-east.

On the east side, the edifice is elongated in an E–W orientation and bears a ~3.5-km long, steep scarp which extends to the foot of the volcano. The edifice elongation direction and scarp strike coincide with the major fault orientations in the area; however no surface trace of an active fault extending beyond the volcano is recognized. Viewing this ridge from the north lends a step-like impression to its profile, stepping down and extending towards the east (Fig. 3a,b).

The long and steep collapse scarp is the source area of the middle and eastern part of the debris avalanche deposit. Boulders in excess of 4–5 m in diameter make up part the easternmost escarpment of this ridge; however, dense vegetation restricts access to this area. Large landslide ridges or blocks up to 200 m high and 3 km long, with an overall east to west orientation mark the middle part of the deposit. Like a jigsaw-puzzle these ridges can be visually retrofitted into one coherent piece of landscape which fits back into the failure scarp of the Jocotitlán ridge (see Siebe et al., 1992 and reconstruction in Fig. 3c).

The morphological resemblance of this deposit area to blockslides (e.g. Green Lake, New Zealand; Hancox and Perrin, 1994) is striking. Initial failure was directed to the NE , but a change in travel direction occurred almost immediately and is still documented in the rotation of the more distal blocks towards the ENE roughly around point 'x' in Fig. 3c. The blocks came to rest very close to their source; the toe of Loma Alta was translated roughly 2.3 km, whereas the rest of the initially coherent block disintegrated increasingly with distance travelled, resulting in smaller blocks or hummocks further from source similar to toreva block disintegration at the Socompa debris avalanche (van Wyk de Vries et al., 2001). Similar large blocks at