Journal of Volcanology and Geothermal Research 250 (2013) 1–8

Contents lists available at SciVerse ScienceDirect

Journal of Volcanology and Geothermal Research

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

Emplacement of pyroclastic dykes in Riedel shear fractures: An example from the Sierra de San Miguelito, central Mexico

S.-S. Xu *, A.F. Nieto-Samaniego, S.A. Alaniz-Álvarez

Universidad Nacional Autónoma de México, Centro de Geociencias, Boulevard Juriquilla No. 3001, Querétaro, Qro., 76230, Mexico

ARTICLE INFO

Article history:
Received 5 March 2012
Accepted 15 October 2012
Available online 23 October 2012

Keywords:
Domino faults
Simple shear
Riedel fractures
Pyroclastic dykes
Mexico

ABSTRACT

Although magmatic dykes are considered to be emplaced at depth, there are very few studies about the emplacement of pyroclastic dykes. There are two commonly accepted mechanisms for dike emplacements; namely, formation of a hydraulic (tension) fracture and filling of pre-existing fractures. In the Sierra de San Miguelito, central Mexico, there is a dike swarm with orientations that do not concur with any of the above two cases. Instead, the dikes have orientations resembling some type of secondary fractures within the fault-bounded blocks.

Within a fault-bounded block, the reverse drag of the normal faults can be explained by simple shear. Based on the simple shear mechanism, we establish a series of equations to calculate the extension and the direction of the simple shear within a fault-bounded block. As an application of our methodology, the value of β, which is the angle measured from the vertical to the direction of the simple shear, is calculated from the domino faults in the Sierra de San Miguelito, Mesa Central, Mexico. The results demonstrate that the absolute values of β for the inclined shear are smaller than 34°. The inclined shear can be antithetic ($\beta>0$), synthetic ($\beta<0$) or vertical ($\beta\approx0$). The pyroclastic dykes in the study area have most of the strikes between 300° and 330° and are sub-parallel to the major faults. The preferred dips of the pyroclastic dykes vary from 80° to 90°. The distribution of the pyroclastic dykes in the study area indicates that the dikes were primarily emplaced along the *R* fractures due to simple shear. These results are different from the traditional understanding, which assumes that the dykes were mainly emplaced within the tension fractures.

1. Introduction

Different mechanisms of emplacement of dykes have been proposed and are mainly dependent on the relationship between a tectonic stress field and fluid pressure. Tension fracture is the most common mechanism and consists of the formation of type I fractures by hydraulic stress (e.g., Anderson, 1951; Takada, 1994). Another such mechanism is the emplacement of magma in a pre-existing fracture and it depends on the difference between the normal stress on the fracture walls and the fluid pressure of the magma (e.g., Delaney et al., 1986). A less well known mechanism is the injection of magma during the movement of a fault. This mechanism can be inferred from the asymmetric structures within a dyke. These structures record the relative movement between the walls and the magma flow. Existing studies involve magmatic dykes emplaced at depths where the velocities of the flow of the magma are approximately 1 m/s (Correa-Gomes et al., 2001). In contrast, there are very few studies about the emplacement of pyroclastic dykes that are formed in an episodic manner in very shallow environments, with injection velocities faster than the magmatic dykes and most likely comparable to velocities encountered in pyroclastic column models that range from 100 to 300 m/s (e.g., Woods, 1998).

The Sierra de San Miguelito, in central Mexico, presents an ideal example to study the emplacement of pyroclastic dykes. The rhyolitic ignimbrites and the pyroclastic rocks of the Sierra de San Miguelito are crosscut by the San Luis–Tepehuanes fault system. No calderas have been identified in the Sierra de San Miguelito as potential sources for the deposits. A possible eruption of the ignimbrites through fissures has been proposed by some authors based on the presence of numerous pyroclastic dykes that are parallel to the main faults (Labarthe-Hernández et al., 1982; Tristán-González, 1986; Labarthe-Hernández and Jiménez-López, 1994; Orozco-Esquivel et al., 2002; Torres-Hernández et al., 2006). A detailed study of the composition and internal structure of the pyroclastic dykes of Sierra de San Miguelito was performed by Torres-Hernández et al. (2006). The authors proposed that the dykes were either emplaced through the formation of new fractures or by the injection of magma into pre-existing fractures. They observed that the dykes were located in the hanging wall of the major faults, but they did not discuss the type of structure that would correspond to the orientation of the dykes in the fault system.

There are three main aspects of this paper. First, we present new structural data of the pyroclastic dykes and the normal faults in the Sierra de San Miguelito, Mesa Central of México. From these data, the relationship between the normal faults and the dykes is inferred. Second, assuming that vertical shear was the mechanism that deformed the fault-bounded blocks (Xu et al., 2004), we obtained the

* Corresponding author.
E-mail address: sxu@dragon.geociencias.unam.mx (S.-S. Xu).

0377-0273/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jvolgeores.2012.10.010

equations for the extension and simple shear direction of the hanging wall of the major fault. Third, using these equations, the type of fracture orientations that would concur with the pyroclastic dyke orientations was determined.

2. Geology of the Sierra de San Miguelito, México

The Sierra de San Miguelito is located in the physiographic province of Mesa Central, in central México (Fig. 1a) (Nieto-Samaniego et al., 2007; Tristán–González et al., 2009). The Mesa Central (MC) represents an intense acid volcanism episode comprising a large volume of lava and domes that were emplaced over an area of ca. 10,000 km^2. The pyroclastic deposits are located in the upper part of the stratigraphic column. The study area mainly consists of lava and pyroclastic rocks and comprises seven Oligocene units (Fig. 1b) (Labarthe-Hernández and Jiménez-López, 1994). From the bottom to top, the units are as follows: Portezuelo Rhyodacite, San Miguelito Rhyolite, Cantera Ignimbrite, Zapote Rhyolite, Lower Panalillo Ignimbrite, La Placa Basalt and Upper Panalillo Ignimbrite. Additionally, there are two units that unconformably overlay the Oligocene volcanic rocks, namely, the Halcones conglomerate and the alluvial deposits of Quaternary age. The Lower Cantera Ignimbrite and the Lower Panalillo Ignimbrite have better stratification than the other units (Fig. 1c). Therefore, the two ignimbrites were used as markers to measure the bedding length, bed dip and fault displacement.

In the Sierra de San Miguelito, a system of normal faults (Fig. 1a) developed coevally with the Oligocene volcanic field. The normal faults show domino style that produces the tilting of blocks in a direction opposite to that of the dip direction of the faults (Figs. 1 and 2). The dips of the beds vary from a few degrees to 30°. The variation in the dips occurs both along the fault strikes and in cross-sections, which depends on the fault dips, displacements and distance away from the fault planes. The tilting of these beds was interpreted by Xu et al. (2004) to be produced by a vertical shear. Furthermore, there are numerous small normal faults in the area that also show domino style (Fig. 2a, b). We measured some parameters of the normal faults of different sizes. The results indicate that most of the faults have strikes between 290° and 340° (Fig. 3a). Comparing the dips of all the faults (Fig. 3b) with the dips of only the major faults (Fig. 3c), it is evident that the dips of the numerous small normal faults are greater than those of the large normal faults.

In contrast, the dominant pitch of the slickenlines on the faults is in the range 80°–90° (Fig. 3d). The faults with small pitches were most likely either formed during a different set of tectonic events for the Mesa Central as proposed by Nieto-Samaniego et al. (2005) or were a result of fault interaction during a single tectonic event (Xu et al., in press).

3. Pyroclastic dykes in the study area

Many pyroclastic dykes emplaced along the NW–SE faults have sub-vertical dips (Torres-Hernández et al., 2006). The dykes consist of pumice and rhyolite fragments, and broken crystals of quartz, sanidine and biotite. Some dykes show banded structure (Fig. 4a, b). The bands have different fragments, color and size. Some bands consist of symmetric structures, with the axis located near the center and parallel to the contact of the dyke with the wall rocks (Fig. 4b). This feature indicates that the dykes with the bands were formed by multiple intrusions. A comprehensive description of these dykes can be found in Torres-Hernández et al. (2006). On the walls of some of the dykes, slickenlines with a high angle of pitch (Fig. 4c) were observed. We measured the size of the pyroclastic dykes. In general, the dyke length varies from a few meters to hundreds of meters and their thickness varies from 1 cm to 80 cm. The thickness of the pyroclastic dykes ranges largely

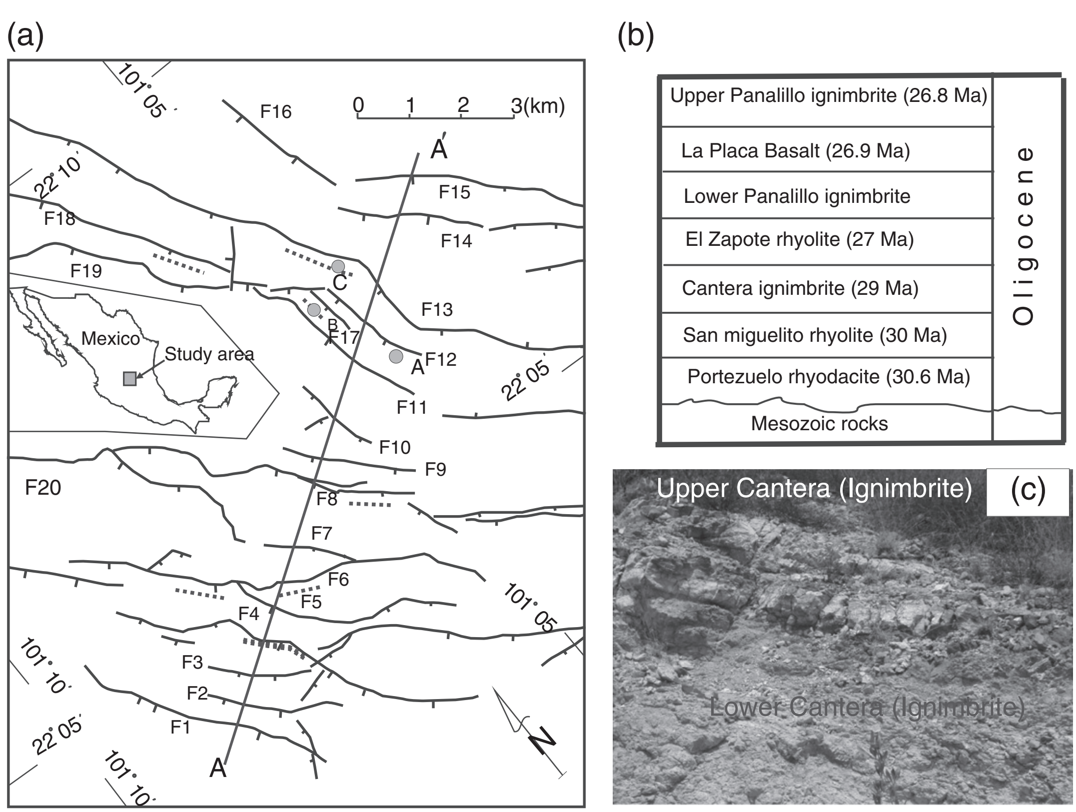

Fig. 1. (a) Normal faults in the San Miguelito, Mesa Central, Mexico, display a domino style. The insert shows the location of the study area. AA′ line is the measured cross-section. Dotted lines are the outcrops of the pyroclastic dykes. Gray circles are points of detailed observation of the pyroclastic dykes. (b) Simplified column of the stratigraphic sequence. (c) Photograph of the Cantera Ignimbrite showing good stratification.