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Inverse steptoes in Las Bombas volcano, as an evidence of explosive volcanism in a solidified lava flow field. Southern Mendoza-Argentina

Corina Risso [a, *], Claudia Prezzi [b], María Julia Orgeira [b], Francisco Nullo [c], Liliana Margonari [a], Karoly Németh [d]

[a] Departamento de Geología-IGEBA-Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires – Intendente Güiraldes 2160 – Ciudad Universitaria, Pabellón II, Buenos Aires, C1428EG, Argentina
[b] Departamento de Geología-IGEBA-FCEN-UBA-CONICET, Argentina
[c] Newphoenix SRL., Argentina
[d] Massey University, CS-IAE, Volcanic Risk Solutions, New Zealand

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ABSTRACT

Here we describe the unusual genesis of steptoes in Las Bombas volcano- Llancanelo Volcanic Field (LVF) (Pliocene – Quaternary), Mendoza, Argentina. Typically, a steptoe forms when a lava flow envelops a hill, creating a well-defined stratigraphic relationship between the older hill and the younger lava flow.

In the Llancanelo Volcanic Field, we find steptoes formed with an apparent normal stratigraphic relationship but an inverse age-relationship. Eroded remnants of scoria cones occur in "circular depressions" in the lava field. To express the inverse age-relationship between flow fields and depression-filled cones here we define this landforms as *inverse steptoes*.

Magnetometric analysis supports this inverse age relationship, indicating reverse dipolar magnetic anomalies in the lava field and normal dipolar magnetization in the scoria cones (e.g. La Bombas). Negative Bouguer anomalies calculated for Las Bombas further support the interpretation that the scoria cones formed by secondary fracturing on already solidified basaltic lava flows.

Advanced erosion and mass movements in the inner edge of the depressions created a perfectly excavated circular depression enhancing the "crater-like" architecture of the preserved landforms.

Given the unusual genesis of the steptoes in LVF, we prefer the term *inverse steptoe* for these landforms. The term steptoe is a geomorphological name that has genetic implications, indicating an older hill and a younger lava flow. Here the relationship is reversed.

1. Introduction

Volcanism in the Andean region is attributed to the subduction of the oceanic Nazca plate below the South American plate (Isacks et al., 1982) (Fig. 1A).

The Nazca plate subducts to the east under the Southern Volcanic Zone with an angle of c. 30° and with seismicity at average depths of 90–100 km under the volcanic arc (Yañez et al., 2002). The volcanic arc along the Andes comprises closely-spaced volcanoes that are still active (e.g: Calbuco volcano 2015; Cordón Caulle volcano 2011–2012; Chaitén volcano 2008, etc.).

Behind the active Andean volcanic arc the volcanic development of the 60,000 km^2 Payenia back-arc province has been suggested to be linked to the differential movements of the subducting Nazca plate and the overriding South American plate (e.g. Muñoz et al., 1989; Kay et al., 2006; Mazzarini et al., 2008; Folguera et al., 2009; Ramos and Folguera, 2011; Gudnason et al., 2012).

The name Payenia volcanic province, given to the area by Polanski (1954), has been used in more recent papers (e.g. Germa et al., 2010; Ramos and Kay, 2006. Gudnason et al., 2012; Quidelleur et al., 2009; etc.) and it can be divided from south to north in Rio Colorado Volcanic Field, Payún Matrú Volcanic Field, Nevado Volcanic Field, Llancanelo Volcanic Field and Northern segment (Gudnason et al., 2012; Folguera et al., 2009) or Diamante Volcanic Field (Morales Volosín, 2015).

The activity in the area is represented by large composite volcanoes such as Payún Matrú, Payún Liso and Cerro Nevado that have produced evolved volcanic material including the large

* Corresponding author.
E-mail address: corina@gl.fcen.uba.ar (C. Risso).

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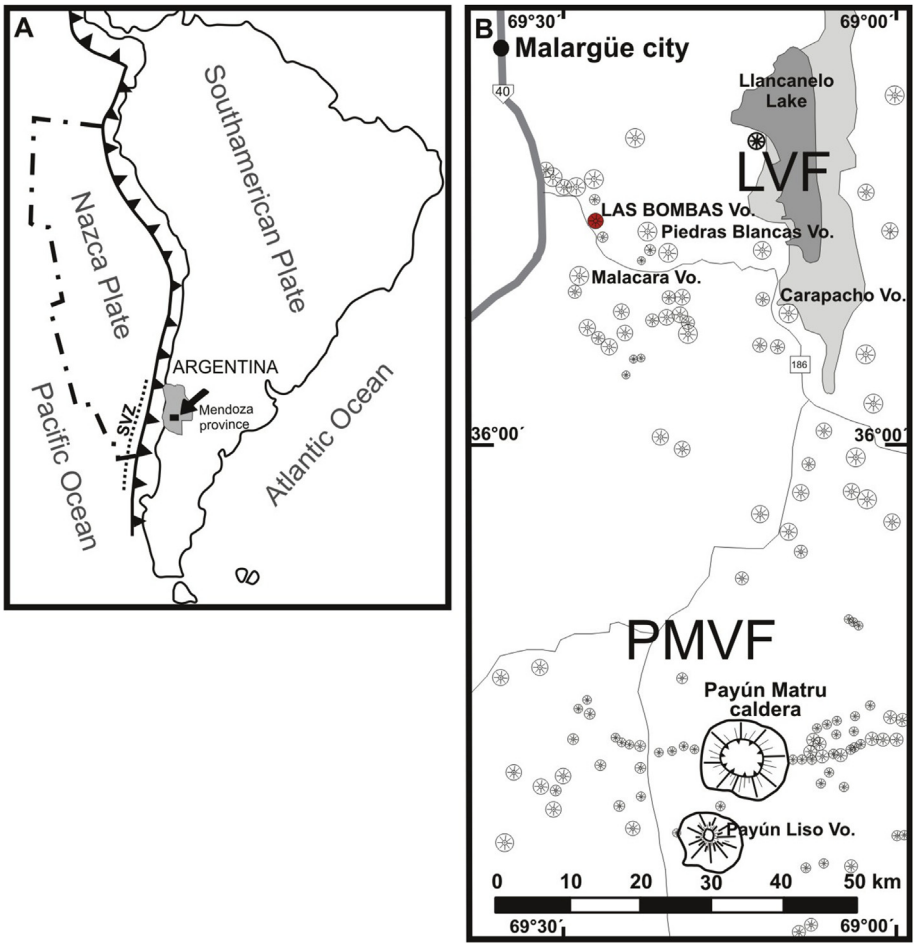

Fig. 1. A: Location map of South America and Argentina, highlighting the Southern Volcanic Zone (SVZ) and the subduction of the Nazca plate beneath the South American plate. B: Map of Llancanelo Volcanic Field (LVF) and Payún Matru Volcanic Field (PMVF) with location of Las Bombas Volcano.

caldera forming eruptions of Payún Matrú (Llambías, 1966; Bermúdez, 1988; Ramos and Kay, 2006; Folguera et al., 2009; Germa et al., 2010). Surrounding the larger volcanoes there are two volcanic fields represented by monogenetic scoria cones of almost exclusively basaltic composition often aligned and concentrated in small clusters: the Llancanelo and Payún Matrú Volcanic Fields (Fig. 1A and B).

Volcanism in Payenia encompasses activity from the Pliocene (Kay et al., 2006; Lambías et al., 2010; Gudnason et al., 2012) to the youngest activity within the Payún Matrú caldera (Escorial del Matrú), dated at 7 ± 1 ka (Germa et al., 2010).

The Llancanelo Volcanic Field (LVF), (Figs. 1B, 2A and 5E) covers an area of 10,700 km^2 in the south-eastern region of the province of Mendoza, Argentina, between latitudes 35° 39′ and 35° 50′ S and longitudes 69° and 69°30′ W, approximately 200 km east of the trench in the Southern Volcanic Zone (Fig. 1A).

In addition, south of the LVF, the Payún Matrú Volcanic Field (PMVF) surrounds the Payún Matrú shield volcano (Fig. 1B). The Payún Matrú shield is a complex volcano with an 8 × 6.5 km wide summit caldera, with trachybasalts (hawaiites) to trachytes lava flows, domes, coulees and extensive pyroclastic flow deposits (Hernando et al., 2014; Hernando et al., 2012; Llambías, 1966; González Díaz, 1972; Ramos and Key, 2006). $^{40}Ar/^{39}Ar$ radiometric dating shows that the Payún Matrú volcano has been active since at least 700.6 ± 10.6 ka (Hernando et al., 2014) and should be considered an active but dormant volcano. The youngest activity within the caldera has been dated at 7 ± 1 ka (Germa et al., 2010).

Volcanic activity in the LVF (Fig. 1B) was primarily of Hawaiian and Strombolian type, resulting in at least 150 scoria and/or lava spatter cones with edifice heights ranging from 50 to 150 m, crater diameters ranging between 150 and 200 m, and slope angles varying between 16 and 27° (Inbar and Risso, 2001). Preserved pyroclastic deposits of the scoria and spatter cones are typically coarse ash and lapilli that consist of red, scoriaceous pyroclasts with common meter-sized ballistic bombs and blocks of vesicular and degassed spindle-shaped pyroclasts. Both, large vesicular, spindle-shaped lava bombs and blocks as well as bread crusted bombs and blocks with a diameter up to 3.5 m, are common.

In well-drained areas with large volumes of near-surface and/or ground water, tuff rings and/or maar volcanoes form (Martin and Németh, 2004). The presence of subordinate phreatomagmatic volcanoes in a volcanic field could indicate variations in hydrogeology of the volcanic field, or variations of the water saturation state of the sub-surface sediments or rock units over time (Aranda-Gomez and Luhr, 1996; Gutman, 2002). Such variations are also noted to take place during the total life span of a volcanic field resulting age-clustered volcanoes dominated by eruption styles related more to dry versus wet external eruptive environments (Kereszturi et al., 2011; Kereszturi and Németh, 2012).

The Las Bombas (LB) volcano is located in the low-lying regions