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Facies architecture of an isolated long-lived, nested polygenetic silicic tuff ring erupted in a braided river system: The Los Loros volcano, Mendoza, Argentina

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ABSTRACT

Los Loros is a small, well-preserved ~1 million year old volcanic depression. The circular ~50 m deep and ~1 km broad crater is inferred to be a complex small-volume volcano; with multiple eruptive phases produced by magmatic and minor phreatomagmatic explosive eruptions in two distinct eruptive episodes and consequently produced two tuff rings separated by fluvial deposits and/or paleosols. Geochemical data, alongside a new age determination, underlies the fact that the volcano is far older than had been expected from its morphology, and its composition represents a bimodal nature with eruptive products belonging to a typical intraplate basalt to phonolite and a crustal influenced intra-continental rhyolitic lineage. Tuff ring 1 erupted into a braided river system that has already accumulated channelised volcaniclastic conglomerates from distal sources. Tuff ring 2 formed in the same place as Tuff ring 1 and produced welded pyroclastic density current deposits, a capping lava flow and a single intermediate block-and-ash flow deposit which all prevented the edifice from erosion. Los Loros is a small-volume volcano, similar to mafic tuff rings, however, its magma compositions, eruption styles, and inter-eruptive breaks suggest, that it closely resembles a volcanic architecture commonly associated with large, composite volcanoes.

1. Introduction

Tuff rings are small constructional volcanic landforms, that consist of a broad crater and relatively thin tephra rim that is dominated by pyroclastic deposits accumulated from pyroclastic density currents and fall events (Chough and Sohn, 1990; Sohn, 1996). They mainly form by explosive interaction of rising magma and surface (or shallow subsurface) water (Heiken, 1971; Lorenz, 1986; White, 1991; Vespermann and Schmincke, 2000). Tuff ring formation generally involves mafic magma such as basalt (Vespermann and Schmincke, 2000). However, an increasing number of tuff rings have been identified that were formed by the eruption of more silicic magma and are commonly associated with lava dome formation (Brooker, 1988; Brooker et al., 1993; De Rosa and Dellino, 1999; Riggs and Carrasco-Nunez, 2004; Cano-Cruz and Carrasco-Nunez, 2008; Zimmer et al., 2010). Such tuff rings show similar morphological features to those of mafic monogenetic volcanic fields in intracontinental settings (Brooker et al., 1993; Zimmer et al., 2010). Silicic tuff rings are known in association with composite volcanoes as proximal pumice cones in summit vents that are commonly associated with long-lasting eruptive episodes from a central vent (Riedel et al., 2003). Silicic tuff rings are commonly the source of silicic lava flows, coules and/or domes, that are typically confined at the low rim of the tuff ring (for example, the Acigöl Rhyolitic Complex in Anatolia (Druitt et al., 1995)). Commonly such felsic lava dominated tuff rings form isolated volcanic complexes such as at Cerro Pizzaro in Mexico (Riggs and Carrasco-Nunez, 2004). Felsic tuff rings are also known to be associated with erosion resistant enigmatic welded lava spatter fed cones such as the Corral de Coquena rhyolitic spatter ring in northern Chile (Self et al., 2008).

Mafic tuff ring tephra rims are typically dominated by pyroclastic deposits that are laterally restricted, thin and commonly show textural features characteristic of magma/water explosive interaction in shallow subsurface environments (Brand and Clarke, 2009); deposits are characteristically dominated by glassy pyroclasts and accidental lithic fragments are relatively minor (Dellino, 2000; Buttner et al., 2002). Pyroclastic deposits are cross-bedded, stratified to well bedded, fine grained and moderately sorted, characteristics that are typical of deposition from laterally moving pyroclastic density currents (Sohn, 1996). Generally the eruptive products of tuff rings are laterally restricted but there are exceptions that represent eruptive phases capable of producing sub-Plinian to Plinian styles that form laterally extensive and thick pyroclastic fall and flow deposits (Van der Bogaard and Schmincke, 1984; Schumacher and Schmincke, 1990;

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Mastrolorenzo, 1994). Such eruptions are commonly associated with magma from complex sources (Woerner and Schmincke, 1984; Woerner and Wright, 1984) and their eruption can result in significant environmental effects similar to those from long-lived, composite volcanoes (Schmincke et al., 1999).

The influence of mafic tuff rings on the evolution of a sedimentary basin is relatively small, and their eruptive product preservation potential is minimal in comparison with long-lived composite volcanoes (White, 1990; White, 1991; Manville et al., 2009). Mafic tuff rings commonly show advance erosional features along their rim shortly after their formation (Németh and Cronin, 2007). A similar record is expected from silicic tuff rings, unless the eruptive sequence of such volcanoes includes welded ignimbrite units, capping lava spatter deposits and/or the volcano erupted in an arid environment where erosion processes act in a slower fashion than in humid climate. However, the influence of lava dome-dominated volcanism on background sedimentation can be characteristic as recorded from a mid-Tertiary lava dome field in Arizona (Riggs et al., 1997).

In this paper we describe a small-volume silicic tuff ring that is erupted away (over 10 km) from other volcanic complexes and forms a well-preserved isolated volcanic landform. Los Loros is a tuff ring that is typical in its geometrical parameters to other tuff rings and erupted over a volcaniclastic succession that had accumulated in an intra-continental basin influenced by composite silicic arc-type magma. Here we describe the sedimentary facies architecture of the Los Loros volcano and its interplay with the background braided river sedimentation, and infer its eruption history.

2. Geological setting

Los Loros is located in the Colorado River valley between Neuquén and Mendoza Province in western Argentina (Fig. 1). It is part of the intraplate volcanic system that has developed behind the active volcanic arc in the Andean cordillera, a few hundred kilometres to the east of the currently active volcanic front. The area around Los Loros is characterised by two well distinguished morphotectonic elements, 1) the Neuquén Basin and 2) Tertiary to Holocene volcanic centres (Fig. 1).

2.1. Neuquén Basin and the pre-volcanic rocks of the Neuquén Group

Sedimentation in the Neuquén Basin began in the Jurassic and was active through the Cenozoic. The basin formed gradually and its evolution stopped with the development of the Andean magmatic arc (Franzese and Spalletti, 2001). The accumulated thick and complex sedimentary succession of the basin has been intercalated with eruptive products of the Upper Cenozoic volcanism augmenting an accumulation of more than 3500 m of sediments. The Los Loros eruptive products described here are accumulated discordantly as one of the upper sedimentary unit of the Neuquen Group.

The Neuquén Group was initially described in the early 20th century (Doering, 1882; Ameghino, 1906). Its stratigraphic units and the geological key to their identification developed shortly after (Roll, 1939; Groeber, 1946; Herrero Ducloux, 1946) together with its lateral extension (Cazau and Uliana, 1973; Legarreta and Gulisano, 1989; Legarreta et al., 1993). The Neuquén Group has been divided into the Río Limay, Río Neuquén and Río Colorado Subgroups, characterised by alternating sequences of sandstones, mudstones and conglomerates accumulated from continental alluvial processes (Cazau and Uliana, 1973; Legarreta and Gulisano, 1989; Condat et al., 1990; Cruz, 1993). These deposits define cycles of ephemeral river systems, draining a disconnected endorheic basin from the Pacific Ocean (Legarreta and Uliana, 1999). The beginning of deposition in the basin coincides with the age of the "*Intercretácica*" unconformity (97 ± 3 Ma, Early Cenomanian), while the upper limit of the Group is determined by the "*Huantráiquica*" unconformity (74 ± 3 Ma).

2.2. Miocene to Recent volcanism and volcanic centres in the region

The Southern Volcanic Zone of the Andes has a voluminous Quaternary basaltic province along the retroarc (a type of back-arc basin which is floored by continental crust). The main sediments are fluvial, deltaic, or marine, derived from the uplifted area behind the arc. The Payenia Volcanic Province (Fig. 1) covers an area larger than 40,000 km^2 between 33°30′ and 38° South latitudes, with an estimated erupted magma volume of about 8387 km^3 producing more than 800 volcanic centres in the last ~2 Ma (Ramos and Folguera, 2011; Llambías et al., 2010). This mainly basaltic province is subdivided into three segments: 1) the northern segment has isolated minor monogenetic fields; 2) the central segment presents large volcanic fields with extensive lava flows characterised by Cerro Nevado, Llancanelo and Payún Matru volcanic fields (Fig. 1); and 3) the southern segment shows some large volcanoes with less extensive lava flows characterised by the Tromen and Auca Mahuida volcanic fields (Fig. 1) (Ramos and Folguera, 2011).

3. Volcanic framework of Los Loros tuff ring

Los Loros is located about 20 km south of a major back-arc volcanic complex, the Chachahuén Volcanic Complex (Fig. 1) (500 km east of the modern trench) a nested caldera complex belonging to the Payenia Volcanic Complex of (Ramos and Folguera, 2011) located in the intersection of a NW–SE and a NE–SW-trending fault system (Kay et al., 2006a). The Chachahuén Volcanic Complex is the only Late Miocene volcanic centre in the central part of the Neuquén Basin. The evolution from ca.7.6 Ma to 4.8 Ma of the Chachahuén Volcanic Complex (Kay et al., 2006b) involved orthopyroxene-bearing andesitic to rhyodacitic magmas with an intraplate to arc-like chemical affinity as well as basaltic andesite to hornblende-bearing dacite magmas with an arc-like chemistry (Kay et al., 2006a,b).

The Payún Matrú caldera is located a few tens of kilometres to the north of Chachahuén Complex (Fig. 1). K–Ar radiometric dating shows that Payún Matru has been built since latest Pleistocene; ages range from 280 ± 5 ka to 7 ± 1 ka (Germa et al., 2010). The main edifice is a Hawaiian shield-like volcano that formed in a small number of explosive dome collapse eruptions. The original edifice of Payún Matru was partially destroyed by an explosion which formed a 8 × 6.5 km wide caldera, dated at around 168 ± 4 ka (Germa et al., 2010), and is related to the eruption of the widespread andesitic to trachyandesitic welded ignimbrite covering an area more than 2200 km^2 and reaching a distance of 60 km from the vent (Llambías, 1966).

Just 62 km to the south of Los Loros volcano a large basaltic shield volcano, the Auca Mahuida volcano (Fig. 1) stands about 100 km east of the orogenic front with a well-preserved central caldera (1500 m in diameter) and an andesitic plug with coulees (Llambías et al., 2010). To the west of Los Loros the Tromen volcanic plateau (Fig. 1) was recently mapped in detail (Kay et al., 2006a; Galland et al., 2007; Folguera et al., 2008) (Fig. 1). Geochemical studies have shown that most of the sequence that forms the Tromen volcanic plateau comes from typical intraplate magmas, with no or very limited influence of subducting slab. The Tromen volcanic field developed an extensive basaltic lava plateau with ages ranging from 1.8 to 1.6 Ma that support monogenetic volcanoes and the younger Tromen volcano (elevation of 3969 m asl). The intraplate lavas of the Tromen stratovolcano range in age from 2.27 ± 0.1 Ma to 0.04 ± 0.04 Ma (Ar–Ar) showing a long lasting volcanic activity.

4. Los Loros tuff ring

The Los Loros tuff ring belongs to the youngest volcanoes of the Payenia Volcanic Province (Fig. 1) but it is characteristically different from other volcanoes of the Payenia Volcanic Province such as the voluminous volcanic edifice of Auca Mahuida Volcanic Shield (Fig. 1)