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Relationship between monogenetic magmatism and stratovolcanoes in western Mexico: The role of low-pressure magmatic processes

Chiara M. Petrone

Department of Earth Sciences, University of Cambridge, Downing Street, CB2 3EQ Cambridge, UK

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ABSTRACT

A large Quaternary monogenetic volcanic field is present in the western part of the Trans-Mexican Volcanic Belt. It is composed by mafic-intermediate scoria cones and silicic domes that are arranged in two NNW–SSE alignments. These mark the north and south borders (Northern Volcanic Chain and Southern Volcanic Chain, SVC) of the San Pedro–Ceboruco graben. The products of this monogenetic volcanic field span a large range of compositions (from basalt to rhyolite) and magma affinities (from sub-alkaline to Na-alkaline), defining different magmatic groups. Mafic and silicic monogenetic centres from the north alignment also coexist with two stratovolcanoes (Ceboruco and Tepetiltic) and sometimes punctuate their flanks.

Whole-rock analyses indicate the existence of 4 different types of primitive magmas (Na-alkaline, High-Ti, Low-Ti/SVC and sub-alkaline) which have evolved independently by low-P magmatic processes. Despite the relatively small size and simplicity of the monogenetic magmatism, open-system processes have modified the geochemical and isotope composition of erupted products. The negative correlation between Sr isotope ratios and MgO contents observed for Southern Volcanic Chain and High-Ti groups points to crustal interaction via AFC processes, involving upper granitic crust and mafic lower crust respectively. In contrast, the large variability in Nd-isotopic ratios, combined with low and less variable $^{87}Sr/^{86}Sr$, shown by the most mafic compositions of the High-Ti group is mostly due to mantle source heterogeneities. Low-Ti and Na-alkaline compositions are only slightly modified by crustal contamination processes and their whole-rock geochemistry reflects the complex nature of the western Mexico sub-arc mantle. It is therefore apparent that a combination of mantle source processes plus crustal assimilation has generated complex geochemical and isotopic characteristics in the western part of the Trans-Mexican Volcanic belt.

Despite the presence of monogenetic cones on the flanks of stratovolcanoes, limited magma interaction between monogenetic and polygenetic magmatism has been recognised only at Ceboruco, possibly producing the chemical variability of post-caldera lavas. Indeed, mafic magma feeding High-Ti monogenetic systems might represent the possible mafic end-member which triggered the Ceboruco caldera-forming event. This may have important implications for other explosive systems in which monogenetic magmatism is associated with stratovolcanoes.

A geographic/tectonic control is also suggested by the geochemical data. Na-alkaline compositions are only found in the northern part of the Northern Volcanic Chain. Parental magmas of both the High-Ti and Low-Ti monogenetic series, erupted between the Ceboruco and Tepetiltic stratovolcanoes, were modified by lower crust AFC processes possibly favoured by the stress regime. Indeed, the presence of a local left-hand step over along the northern main fault systems between the two stratovolcanoes might inhibit free uprising of monogenetic mafic magmas. The preferential alignment of stratovolcanoes and monogenetic volcanic vents parallel to the northern main fault systems and the possible mixing between High-Ti mafic monogenetic magmas and more evolved Ceboruco magmas suggests that, under the predominance of regional stress, the influence of central volcanic vents on monogenetic magmatism might be more complex than simple control of vent directions and might favours magma mixing processes.

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1. Introduction

It is well known that monogenetic volcanism can show large compositional variations despite the small volumes of magma and relatively short eruption durations (~1 day to ~15 years, Johnson et al., 2008). This is certainly true for domes but it has also been proved dramatically true for mafic or intermediate monogenetic volcanism (i.e., scoria cones or cinder cones). Strong chemical variation occurs within the products of single basaltic to andesitic scoria cones sometimes tapping two different and unrelated magma sources (e.g., Cascades, Strong and Wolff, 2003). Little is known about the development and

E-mail address: cmp57@cam.ac.uk.

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evolution of the possible plumbing systems. Recently, a two-stage crystallization process has been proposed to explain the compositional differences observed in high-Mg basaltic magmas from Volcán Jorullo in Mexico (Johnson et al., 2008). Nevertheless, even in the case of the long-lived (15 yr) Volcán Jorullo, magma composition spans a relatively narrow range from basalt to basaltic andesite. In the case of more complex monogenetic volcanic fields (i.e., Cascades, Mercer and Johnston, 2008) bimodal magmatism seems to be present, but the complete series from basalt to dacite/rhyolite has not been recognised. In addition, little attention has been paid to the correlation between mafic and silicic magmas from different monogenetic centres.

A large Quaternary monogenetic volcanic field is present in the western part of the Trans-Mexican Volcanic Belt. It is composed of mafic-intermediate scoria cones and silicic domes arranged in two NNW–SSE alignments which mark the north and south borders (Northern Volcanic Chain and Southern Volcanic Chain, SVC, respectively) of the San Pedro–Ceboruco graben (Fig. 1). Magma compositions range from basalt to rhyolite with a variety of magma affinities (from sub-alkaline to Na-alkaline, Petrone et al., 2003). Mafic and silicic monogenetic centres from the Northern Volcanic Chain, also coexist with two stratovolcanoes (Ceboruco and Tepetiltic, Fig. 1) sometimes punctuating their flanks.

The coexistence of monogenetic and polygenetic volcanism is usually very common in volcanic arcs and it seems to be linked to variations in magma supply rate as well as differential stress (Takada, 1999). Monogenetic mafic centres (i.e., scoria cones) associated with polygenetic stratovolcanoes are usually considered as ephemeral flank activity, often taking place during paucity of central-vent eruption. Domes usually occur within the craters or on the flanks of large composite volcanoes and are often associated with the later phase of eruptions. Scoria cones and domes associated with stratovolcanoes are usually related to the same plumbing system. Nevertheless, this scenario does not apply to the Northern Volcanic Chain where monogenetic centres, located on the flanks of both Ceboruco and Tepetiltic stratovolcanoes, erupted magmas belonging to at least two different and unrelated magmatic series (Petrone et al., 2003). Indeed, this suggests a more complex mechanism and not a simple relationship between polygenetic and monogenetic volcanism.

Despite the relatively small size and limited evolutionary processes of monogenetic magmatism, an increasing number of studies testify to its variety and complexity (i.e., Johnson et al., 2008; Mercer and Johnston, 2008). The development and evolution of each plumbing systems and the relationships between them, and between monogenetic magmatism and stratovolcanoes are crucial to our understanding of monogenetic systems. The aim of this study is to investigate the low-pressure processes that acted in the monogenetic volcanic centres from the Northern and Southern Volcanic Chains and which caused differences in their magmatic evolution. Interaction between monogenetic systems and stratovolcanoes is also considered and a petrologic/tectonic model is proposed for the western part of the Trans-Mexican Volcanic Belt.

2. Geologic setting

The active Trans-Mexican Volcanic Belt developed as a result of the subduction of the Rivera and Cocos plates beneath the North America plate (Pardo and Suarez, 1995). Despite the predominance of subduction-related magmatism, the coexistence of calc-alkaline and alkaline magmatism is widespread in the western as well as in the eastern part of the arc (Ferrari et al., 2001; Petrone et al., 2003; Orozco-Esquivel et al., 2007). In particular, in the western part it is associated with monogenetic centres that are widespread between the Ceboruco and Sanganguey volcanoes (Petrone et al., 2003) (Fig. 1). Recently, Petrone and Ferrari (2008) have also highlighted the presence of adakitic rocks and Nb-enriched basalts in this part of the Mexican arc particularly in the San Pedro–Ceboruco graben.

The following four different volcanic systems have been recognised in the San Pedro–Ceboruco graben (Ferrari et al., 2003) (Fig. 1): (i) two polygenetic stratovolcanoes (Ceboruco and Tepetiltic); (ii) a volcanic complex (San Pedro–Cerro Grande Volcanic Complex) made up of several domes with adakitic composition and a mafic shield volcano (Amado Nervo) constituted by Nb-enriched basalt (Petrone et al., 2006; Petrone and Ferrari, 2008); (iii) alignment of monogenetic volcanic centres represented by scoria cones and domes located along the northern border of the San Pedro–Ceboruco graben (Northern Volcanic Chain); (iv) alignment of monogenetic volcanic centres represented by scoria cones and domes located along the southern border of the San Pedro–Ceboruco graben (Southern Volcanic Chain).

The two monogenetic alignments have developed along NNW–SSE trending lines parallel to the regional structural trend (Ferrari et al., 2003). The Northern Volcanic Chain represents the main alignment and runs for almost 25 km in a NNW–SSE direction along the northern border of the graben, from the village of Ixtlan del Rio to the northern flank of Tepetiltic (Fig. 1). A few cones are slightly displaced relative to the main trend. This alignment is composed of around 30 monogenetic volcanic centres that consist mainly of scoria cones, sometimes associated with lava flows, and secondarily by domes. Some of these volcanic centres punctuated the flanks of both Ceboruco and Tepetiltic volcanoes and have been considered linked to their volcanic activity (i.e., Sieron and Siebe, 2008). Scoria cones with associated lava flows and a few domes constitute the Southern Volcanic Chain. It developed along the undefined southern border of the San Pedro–Ceboruco graben. The southern alignment is composed of around 10 volcanic centres along a 20 km long NNW–SSE line starting from west of the Marquezado village and ending west of Compostela (Fig. 1).

The age of magmatism in the San Pedro–Ceboruco area has been constrained by several published ages (Petrone et al., 2001; Frey et al., 2004; Sieron and Siebe, 2008) which are reported in Fig. 1. Numerous ages are available for the Northern Volcanic Chain but it is still quite difficult to precisely constraint the age of the magmatism. Indeed, despite the good agreement between the K–Ar ages of Petrone et al. (2001) and the Ar–Ar ages of Frey et al. (2004), recent radiocarbon ages by Sieron and Siebe (2008) indicate that the magmatism could be younger than previously thought. Whilst a discussion of the age dating is far beyond the scope of this work, it is evident that some of the monogenetic magmatism of the Northern Volcanic Chain is quite young (11–4 ka according to Sieron and Siebe, 2008). It cannot be ruled out that the magmatism might have started around 50 ka (Petrone et al., 2001) roughly overlapping the volcanism of Tepetiltic (>48 ka, Petrone et al., 2001) and the pre-caldera activity of Ceboruco (>45 ka, Frey et al., 2004). Unfortunately, there is only one age for the Southern Volcanic Chain which indicates that monogenetic magmatism along the southern border of the graben may be significantly older (2.52 Ma, Petrone et al., 2001).

Most of the scoria cones have a rounded shape with a diameter ranging from less than 1 km to a few km. In the northern alignment, most scoria cones have been quarried for road material and the visible internal structure consists of bedded ash, lapilli and bombs. The juvenile products are either black or red scoria, ranging from less than 1 cm up to 30–40 cm in diameter. Almost all the scoria cones are associated with lava flows of variable thickness and extension. Coalescent scoria cones are located on the northern flank of Ceboruco.

3. Samples and analytical procedures

The Northern and Southern Volcanic Chains were sampled in detail and over 60 samples of lava flows and scoria were collected from all of the cones and domes (Fig. 2, Table 1 in Supplementary data set). In some cases, more than one sample was collected from the same scoria cone in order to investigate the possible compositional variability of products outpoured by a single volcanic centre. In

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