The petrogenesis of 30–20 Ma basic and intermediate volcanics from the Mogollon-Datil Volcanic Field, New Mexico, USA

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Abstract. In the western USA calcalkaline magmas were generated hundreds of kilometres from the nearest destructive plate margin, and in some areas during regional extension several Ma after the cessation of subduction. The Mogollon-Datil Volcanic Field (MDVF) in southern New Mexico was a centre of active magmatism in the mid- to late-Tertiary, and a detailed field, petrographic and geochemical study has been undertaken to evaluate the relations between extensional tectonics and calcalkaline magmatism in the period 30–20 Ma. The rocks comprise alkalic to high-K calcalkaline lavas, ranging from basalt to high silica andesite. Most of the basaltic rocks have relatively low HFSE abundances, elevated $^{87}$Sr/$^{86}$Sr and low $^{143}$Nd/$^{144}$Nd, similar to many Tertiary basalts across the western USA, and they are inferred to have been derived from the continental mantle lithosphere. Two differentiation trends are recognised, with the older magmas having evolved to more calcalkaline compositions by magma mixing between alkalic basaltic andesites and silicic crustal melts, and the younger rocks having undergone 30–40% fractional crystallisation to more alkalic derivatives. The younger basalts also exhibit a shift to relatively higher HSFE abundances, with lower $^{87}$Sr/$^{86}$Sr and higher $^{143}$Nd/$^{144}$Nd, and these have been modelled as mixtures between an average post-5 Ma Basin and Range basalt and the older MDVF lithosphere-derived basalts. It is argued that the presence of subduction-related geochemical signatures and the development of calcalkaline andesites in the 30–20 Ma lavas from the MDVF are not related to the magmatic effects of Tertiary subduction. Rather, basic magmas were generated by partial melting of the lithospheric mantle which had been modified during a previous subduction event. Since these basalts were generated at the time of maximum extension in the upper crust it is inferred that magma generation was in response to lithospheric extension. The association of the 30–20 Ma calcalkaline andesites with the apparently ‘anorogenic’ tectonism of late mid-Tertiary extension, is the result of crustal contamination, in that fractionated, mildly alkaline, basaltic andesite magmas were mixed with silicic crustal melts, generating hybrid andesite lavas with calcalkaline affinities.

Introduction

Early interpretations of Tertiary magmatism in the western United States (Christiansen and Lipman 1972; Lipman et al. 1972) related the mid-Tertiary calcalkaline andesite-rhyolite volcanic association to contemporaneous subduction and the late Tertiary basalt-rhyolite association to within-plate continental extension. However, subsequent workers have established that in many areas extension pre-dated the cessation of subduction (Gans 1981; Zoback et al. 1981; Chamberlin 1983) and that the volcanism associated with this extension was of a high-K calcalkaline nature (Elston 1984). Thus, the initial simple relationships between magmatism and tectonism have been questioned. Gans et al. (1989), for example, argued that Tertiary magmatism in the western United States is atypical of destructive plate margins, and focused attention on how calcalkaline rocks were generated in such an environment.

In southwestern New Mexico, mid-Tertiary volcanism was centred upon the Mogollon-Datil volcanic field (MDVF), where it has been shown that the basic and intermediate volcanics can be usefully separated into two temporally and geochemically distinct groups: pre 30 Ma and 30–20 Ma (Davis 1991; Davis et al. in press). The former was initially contemporaneous with subduction, albeit more than 500 km inland, whereas the volcanic rocks of the 30–20 Ma group, although high-K calcalkaline in character, were active during a period of ductile extension (Elston 1984) which reached its peak locally at ~ 28.5 Ma (Gans et al. 1989). This contribution presents the results of an integrated field, petrological, and geochemical study on the 30–20 Ma rocks of the MDVF to investigate the genesis of calcalkaline magmas.

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Background geology and petrology

In the Mogollon-Datil volcanic field (MDVF) mid-Tertiary volcanism is divided stratigraphically into three periods of broadly 'andesitic' lavas separated by two periods of extensive ignimbrite activity. The three andesitic sequences are known respectively as T2, T3a and T4a (Clemons et al. 1982; Elston 1989) and the chemically distinctive 30-20 Ma group contains the T4a, and upper part of the T3a sequences (Davis 1991; Davis et al. in press; and see also Figs. 4 and 6). The regional geology of the MDVF and the distribution of the 30-20 Ma lavas is shown in Fig. 1. Samples for this study were collected in the North-Central MDVF and the Mimbres Valley in the southern MDVF. A more detailed geological map of these areas and a composite stratigraphic column for the 30-20 Ma rocks are presented in Fig. 2.

The upper T3a lavas lie directly below the regionally extensive high silica ignimbrites of the T4r group, Ar-Ar dated at 28.9 - 27.3 Ma (McIntosh 1989). This gives the T3a lavas a minimum age of ~29 Ma. In the south of the field, good upper T3a exposures are found in the Mimbres Valley and southern Black Range, where they are known locally as the Bear Springs Formation (Elston 1957) and the Middle Mountain Member of the Alum Mountain Group (Krier 1980). In the north, at Luera Peak, Fodor (1975) identified upper T3a lavas separated from petrologically similar T4a lavas by the Bloodgood Canyon Tuff, dated at 28.0 ± 0.3 Ma (McIntosh 1989). Upper T3a lavas range from quartz-normative high silica ignimbrites of the T4r group, Ar-Ar dated at 28.3 ± 0.5 Ma (Marvin et al. 1987) to glassy, two-pyroxene andesites, and they generally occur as 5 - 10 m thick flows within tens to hundreds of metres of lavas. In the southern Mimbres Valley, the Bear Springs Formation has an estimated thickness of 300 m (Elston et al. 1976). Identifiable volcanic centres are largely unknown, although in the northern Mimbres Valley, T3a activity is thought to have centred around Middle Mountain (Krier 1980). Another centre was in the northern part of the Dwyer quadrangle, on the west side of the Mimbres River between the villages of Dwyer and San Juan. Sampling of the upper T3a group for this study was confined to the Bear Springs Formation and the Middle Mountain Member of the Alum Mountain Group, in the Mimbres Valley of the southern MDVF.

The T4a lavas are the more volumetrically significant sequence in the 30-20 Ma group. Most of these lavas were erupted from small shield/stratovolcanoes 1-10 km³ in size (Futa and Ratté 1989), that are still identifiable today. These volcanic centres are distributed throughout the central and northern MDVF (Fig. 2), and form the peaks of the Mogollon, Tularosa and Mangas Mountains. The alignment of some of these centres; Elk Mountain (E), O-Bar-O Mountain (OO), Pelona Mountain (P) and Luera Peak (LP), along the southern flank of the San Augustin Plains graben has been interpreted as being controlled by an old lithospheric suture, the Morenci lineament (Ratté 1989). A similar alignment of Eagle Peak (EP), John Kerr Peak (JK) and Mangas Mountain (M), sub-parallel another ancient suture, the Morenci-Reserve fault zone (Fig. 2). However, there are exceptions, in particular Black Mountain (BM) and Bearwallow Mountain (BW), for which the available K-Ar dates are in the range 27 - 23 Ma (Marvin et al. 1987), significantly older than the late Tertiary block faulting responsible for the present day horst and graben appearance of these two pre-Tertiary suture.

The rocks associated with the T4a centres are predominantly basaltic andesites and andesites. There are several late plug domes of more silica-rich compositions, for example, the John Kerr Peak Quartz Latite (Smith 1976) but these are thought to be more suitably associated with the late-Tertiary, T5r group (Davis 1991). The stratocone-related T4a basaltic andesites and andesites are known collectively as the Bearwallow Mountain Formation after Elston et al. (1976) although, more recently Marvin et al. (1987) re-defined them as the Bearwallow Mountain Andesite. In this study Elston's former definition is preferred, because the T4a lavas are not solely andesitic in composition. Indeed, early work on the T4a Bearwallow Mountain Formation (Fodor 1975, 1976; Bornhorst 1980; Stinnett 1980) has shown that individual centres exhibit variable degrees of differentiation. Thus Black Mountain is entirely andesitic, whereas Bearwallow Mountain has a compositional range from basaltic andesite through to andesite. In order to understand both the processes of differentiation, and the geochemical nature of parental magmas, a range of lava compositions was collected from a number of different centres. As well as sampling Black Mountain and Bearwallow Mountain, more mafic basaltic andesites were collected from John Kerr Peak and Luera Peak. Samples were also collected from Mangas Mountain, located north of the San Augustin Plains. This allowed constraints to be placed on chemical variations that might result from its closer proximity to the Colorado Plateau.

The other type of T4a rocks occur as localised, mainly basaltic, lava piles between 10 and 100 m thick, but their association with any of the T4a stratocones is uncertain. The age of these units is poorly constrained, although their position above the T4r ignimbrites clearly distinguishes them stratigraphically from the basalts of the upper T3a group. At Lake Roberts a high level T4a basaltic flow has been dated at 20.6 ± 0.5 Ma (Elston et al. 1973), and similar T4a lavas are found along Black Canyon in the East Gila Wilderness area, and along New Mexico Highway 78 just north of Beaverhead. Samples for this study were collected only from Black Canyon and Lake Roberts (Fig. 2). The flows around Lake Roberts interfinger with the basal sedimentary rocks of the Gila Group. These are interpreted as lakebeds in Basin and Range – age basins and