Temporal, Spatial, and Compositional Constraints on Extension-Related Volcanism in Central Death Valley, California

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Neogene volcanism in central Death Valley (12–0.7 Ma) was accompanied by large-scale regional extension accommodated in part by regional low-angle faulting, extensive footwall uplift, and significant displacement along northwest-trending strike-slip faults. In excess of 700 km^3 of lava flows, domes, and pyroclastic deposits were emplaced from numerous centers mainly in the upper plate of a northwestward-migrating detachment system. We defined four stages of volcanism based on whole-rock K-Ar geochronology, geologic mapping, petrology, and geochemistry. Stage I eruptions (12–8.5 Ma), associated with the onset of extension, include minor basaltic andesite lava flows but are dominated by calc-alkalic dacite to rhyolite lavas erupted from presently unrecognized centers. This sequence includes the Rhodes Tuff (9.6 Ma), the only regional rhyolite ash-flow sheet in the volcanic field. The deposits were highly attenuated along both low-angle and high-angle faults and, in places, intruded by late Miocene silicic, hypabyssal plutons, stocks and dikes. Stage II eruptions (8.5–7.5 Ma) are coincident with and in places postdate a period of rapid unroofing of the Black Mountains. This sequence includes basaltic lavas (>8 wt.% MgO; <50 wt.% SiO$_2$) but consists largely of dacite to rhyolite lava flows and minor pyroclastic deposits erupted in the south-central and southeastern part of the field. The third stage of volcanism (7.0–5.5 Ma) postdated major tectonic denudation, was restricted to the central part of the field, and consisted of basaltic to rhyolitic lava flows and small-volume, weakly welded ash-flow tuffs and associated ash-fall deposits. Volcanism between 5.0 and 0.7 Ma (Stage IV) was wholly basaltic to andesitic; deposits are little deformed and restricted to the northern part of the volcanic field with the exception of low-volume eruptions from Quaternary centers on the floor of southern Death Valley. Pre-Quaternary eruptive activity migrated northwestward, paralleling the dominant regional extension direction.

Basaltic lavas are dated at approximately 9.4, 8.5, 8.3, 7.7, 7.5, 7.0, 5.8, 5.0, 4.0, 1.6, and 0.7 Ma, increasing in volumetric proportion with decreasing age. Early basaltic lavas (>8 Ma) in part record contributions from ocean island basalt (OIB)-type mantle, reflected in low LREE to HFSE ratios (La/Ta=12; La/Nb=1), low light- to middle-REE ratios (La(n)/Sm(n)<3) and high epsilon Nd values (ε_{Nd}=+7). Basalts younger than 4 Ma exhibit high LREE to HFSE ratios (La/Ta >50) and low light- to middle-REE ratios (La/Nb >3 and La(n)/Sm(n) >4), giving rise to characteristic Ta and Nb troughs on chondrite-normalized element plots. These depletions are accompanied by low epsilon Nd values (ε_{Nd}= -7), and thus the sources apparently derive from subduction-modified lithospheric mantle. Coincident eruption of basalts that exhibit trace-element and isotopic characteristics of multiple mantle sources reflects melting of heterogeneous subcontinental mantle during large-scale crustal extension. Major- and trace-element compositions of primitive lavas (<8 Ma) rule out contamination of melts derived from OIB-type mantle solely by assimilation and fractional crystallization processes involving continental crust.

Basaltic rocks exhibit a wide range of isotopic compositions with ε_{Nd}=+7 to –11, I_{Sr}= 0.7045 to 0.7085 and ^{206}Pb/^{204}Pb=18.0 to 19.0. Primitive compositions [low Th (2 ppm), Rb (11 to 16 ppm) and SiO_2 (<48 wt.%) and high Cr (150 to 260 ppm) and MgO (>7.5 wt.%)] are believed to be derived from three distinct mantle sources: (1) Mantle A, interpreted as ancient LREE-enriched lithospheric mantle, with ε_{Nd}= -6, I_{Sr}=0.7065 and ^{206}Pb/^{204}Pb=19.0; (2) Mantle C, interpreted as depleted asthenospheric mantle with ε_{Nd}=+7, I_{Sr}=0.7045, and ^{206}Pb/^{204}Pb=19.0; and (3) Mantle B, possibly a mixture of Mantle A and Mantle C with ε_{Nd}=+2, I_{Sr}=0.7050, and ^{206}Pb/^{204}Pb =19.0.

Trends of decreasing ^{206}Pb/^{204}Pb ratios with decreasing ε_{Nd} values and increasing I_{Sr} ratios and Th, Rb, and SiO_2 concentrations indicate interaction of primitive melts with an ancient U-depleted crustal component. Samples from chemically defined suites of lavas either increase or decrease in ^{208}Pb/^{204}Pb with increasing I_{Sr} and decreasing ε_{Nd}. This suggests that individual suites interacted with one of two types of crust: (1) lower crust with an ancient U and Th depletion similar to Proterozoic granulite basement exposed in the region; or (2) crust with an ancient U-depletion only.

Trends of ε_{Nd} versus time suggest that there was no simple progression in magmatic source regions from lithospheric mantle- to asthenospheric mantle-dominated melts as the magnitude of extension increased, as has been suggested by other studies in the Basin and Range province. Early magmatic input to the crust (12–10 Ma) was dominated by Mantle B, followed in time by input (8.5–5 Ma) from three components: Mantle A, Mantle B, and a reasonable estimate of asthenospheric-type mantle component represented by Mantle C. This later period of magmatic activity coincides with a peak in eruptive volume, partly coincident with latter stages of extension and unroofing of the Black Mountain crustal block (Holm and others, 1992; Holm and Dokka, 1993; Wright and others, 1991; Serpa and Pavlis, 1996).

Combined Pb isotope data (this study and the Nova basalts of the northern Panamint Mountains (Coleman and Walker, 1991) suggest that the lithospheric mantle beneath the Death Valley region has highly variable ^{206}Pb/^{204}Pb, ^{207}Pb/^{204}Pb, and ^{208}Pb/^{204}Pb. The geographic distribution of these rocks suggests that a major structural and (or) geochemical boundary separates the subcontinental mantle beneath the eastern and western extremes of the region.

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