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Secular variations in magmatism during a continental arc to post-arc transition: Plio-Pleistocene volcanism in the Lake Tahoe/Truckee area, Northern Sierra Nevada, California

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ABSTRACT

In the Lake Tahoe–Truckee River area of northeastern California, a suite of latest Pliocene to Pleistocene volcanic rocks, termed the Tahoe–Truckee volcanic field (TTVF), overlies Miocene to Pliocene volcanic rocks of the Ancestral Cascades arc. The lavas post-date the passage of the south edge of the subducting Juan de Fuca plate, and represent a secular transition from continental arc to post-arc volcanism associated with a slab window. Compared to the older arc volcanic rocks, TTVF lavas are small in volume, non-porphyritic, and mildly alkaline. TTVF lavas have a subduction signature in primitive mantle-normalized plots but, compared to the older arc rocks, are enriched in the light rare earth elements, Nb, and Ta, and depleted in the large ion lithophile elements. Isotopically, TTVF rocks overlap with Ancestral Cascade arc lavas, although most TTVF rocks fall at the high $^{87}Sr/^{86}Sr$–low $^{143}Nd/^{144}Nd$ end of the range of Ancestral Cascade compositions. Pb and oxygen isotope ratios overlap completely. Although the incompatible element systematics are consistent with increased importance of a within-plate mantle source component in the TTVF, the more radiogenic Sr and less radiogenic Nd isotopic compositions are not and require a source that is old. We propose that, like the Ancestral Cascades arc in this region, the post-arc lavas are primarily tapping a lithospheric mantle source, but for the TTVF, melting is triggered by asthenospheric upwelling around the south edge of the Juan de Fuca slab. TTVF lavas include a much lower proportion of melts from the (now, ex-) mantle wedge, since slab fluids are no longer supplied to the mantle beneath this region. The lithospheric mantle source in the TTVF may be similar chemically and mineralogically to that of the Big Pine volcanic field and Long Valley caldera in the Western Great Basin. This example of slab window volcanism is unusual in that the lavas are not melts of a mantle source that is more depleted in incompatible elements than the arc source.

1. Introduction

The Sierra Nevada mountains in the region of northern and central California are capped by highly eroded remnants of Tertiary volcanic complexes (Lindgren, 1897; Thompson and White, 1964; Saucedo and Wagner, 1992; Saucedo, 2005). Recent studies of the geochronology, petrology, and geochemistry of these rocks demonstrate that they are related to subduction of the Juan de Fuca plate, and constitute the Miocene to Pliocene southern Ancestral Cascades volcanic arc (Fig. 1) (Cousens et al., 2008; Busby et al., 2008b; Du Bray et al., 2009). The northward migration of the southern, trailing edge of the Juan de Fuca plate has resulted in northward migration of the Pacific–Juan de Fuca–North American triple junction and shutdown of the Ancestral Cascade arc, such that the southernmost expression of arc volcanism currently is located at the Lassen Volcanic Region (Clynne, 1990; Dickinson, 1997; Atwater and Stock, 1998). In the Lake Tahoe region, the geographic focus of this study, arc volcanism is proposed to have ceased approximately 6–4 Ma, based on reconstructions of the position of the triple junction (Fig. 1) (Atwater and Stock, 1998) and the geochronology of composite arc volcanic centers in the region (Saucedo and Wagner, 1992; Cousens et al., 2008).

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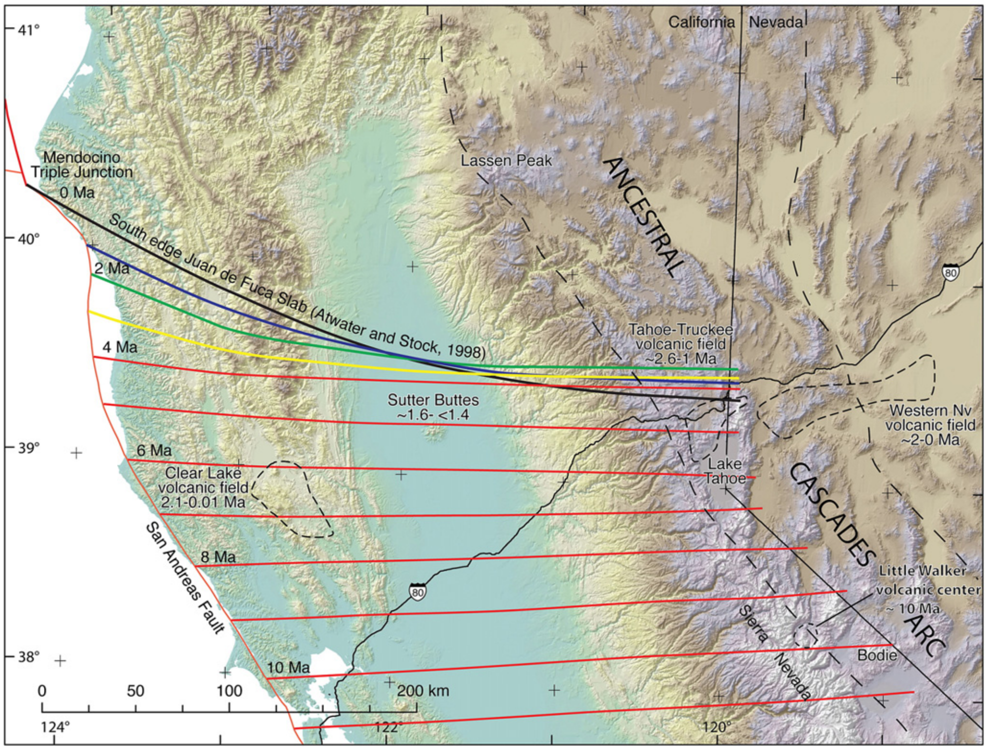

Fig. 1. Digital topography of northern California and western Nevada, showing the location of the Tahoe–Truckee volcanic field relative in the Sierra Nevada. Also shown are the locations of the Quaternary Clear Lakes, Sutter Buttes, and Western Nevada volcanic fields, plus the Miocene Little Walker volcanic center. Subhorizontal lines show the location of the southern edge of the Juan de Fuca plate (Atwater and Stock, 1998) from 12 Ma to the present.

Subsequent to the termination of arc activity in the Lake Tahoe region, a post-3 Ma suite of mafic to intermediate flows and flow complexes was emplaced on the northwest side of Lake Tahoe and along the course of the Truckee River between Lake Tahoe and the northern Carson Range (Fig. 2) (Lindgren, 1897; Birkeland, 1963; Thompson and White, 1964; Latham, 1985; Saucedo, 2005). We refer to this suite as the Tahoe–Truckee Volcanic Field (TTVF; Figs. 1 and 2). Unlike the older arc volcanic rocks, the post-3 Ma suite includes only small-volume volcanic centers that lack the highly plagioclase-porphyritic rocks that dominate the arc volcanic centers (Cousens et al., 2008). Mapping of these latest Pliocene and Pleistocene flows at the University of California Santa Barbara (Sylvester et al., 2007) is summarized in Saucedo (2005), along with a summary of available geochronology for the flows. Further mapping and dating of the young volcanic centers along the west side of Lake Tahoe is underway (Kortemeier and Schweickert, 2007; Kortemeier et al., 2009).

In this paper, we present new geochemical and geochronological analyses of lavas from the Pliocene–Pleistocene TTVF that demonstrate a secular change in geology and geochemistry from earlier continental arc volcanism. Although there is little discernable break in age between the end of Ancestral Cascade arc volcanism and initial activity in the TTVF, the morphology of the volcanic centers, petrographic distinctions, and subtle but consistent differences in geochemistry indicate that the TTVF represents post-arc volcanic activity. This post-arc volcanism may be driven by passage and stagnation of the trailing edge of the Juan de Fuca Plate, allowing upwelling of hot mantle around the edge of the slab (exemplified by Zandt and Humphreys, 2008) to maintain conditions necessary for melting beneath the Lake Tahoe region. Upwelling around the slab edge may be the cause of Pliocene through Pleistocene volcanism in a east–west belt that includes Sutter Buttes (Hausback et al., 1990), the TTVF, mafic and felsic igneous rocks in the Reno-Carson City–Virginia City area (Thompson and White, 1964), and intrusions and maars around Fallon, NV. (Fig. 1) (Cousens et al., 2009).

2. Geologic setting

In the northern Sierra Nevada, Miocene–Pliocene Ancestral Cascades arc rocks were extensively glaciated, and only remnants of the composite volcanoes remain. Volcanic edifices are composed of lava flows, dome collapse breccias and debris flows, erupted upon granitoids and metamorphic rocks of the Mesozoic Sierra Nevada batholith. K–Ar and ^{40}Ar–^{39}Ar geochronology indicates that volcanic complexes in this area range in age from 20 Ma to 3.5 Ma (summarized in Cousens et al., 2008). The lavas are primarily highly porphyritic andesites to dacites, dominated by plagioclase phenocrysts accompanied by either pyroxene or hornblende with rare biotite. Less-phyric, olivine- and clinopyroxene-bearing basalts and basaltic andesites are volumetrically minor.

Volcanism continued in the Lake Tahoe/Truckee area between 2.6 and 0.92 Ma (this work, plus compilation in Saucedo and Wagner, 1992; Kortemeier et al., 2009). Plio-Pleistocene volcanism was focused in the Alder Hill, Bald Mountain, and Dry Lake areas (Fig. 2), the latter two of which lie in low areas that may be fault-bounded basins between high ridges of Mio-Pliocene volcanic rocks. None of these centers approach the estimated volume (10 to 100 + km^3) of Ancestral Cascades arc volcanic complexes (Cousens et al., 2008). Isolated lava flows were also emplaced along the northwest shore of Lake Tahoe, between Kings Beach and Tahoe City, and along the course of the Truckee River from Truckee to Boca Ridge and the northern Carson Range. Individual flows range from 70 to 130 m thick and are commonly columnar jointed. Palagonitized pillow lavas are exposed along Highway 89 just north of Tahoe City, indicating that they were erupted at a time when Lake Tahoe water levels were much higher than those today (further elaborated by Kortemeier et al., 2009). Cinder cones are found atop the Bald Mountain and Alder Hill complexes, at the northwestern edge of a large flow northwest of Tahoe City, and at two localities along the Truckee River, indicating that the volatile content of these magmas was high enough to cause