Late Cenozoic Magmatic Sweeps in the Basin and Range and the Setting of the Coso Geothermal Field, California

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ABSTRACT

Animations of geochronologic data from the NAVDAT database of western U.S. magmatism reveal several well-defined patterns, few of which can be directly tied to plate-tectonic events. The most noticeable pattern swept southwestward out of Montana about 50 m.y. ago, into central Nevada and western Utah 30 m.y. ago, and into southern Nevada and eastern California about 15 m.y. ago. The Coso geothermal area lies near the southern limit of this sweep, and animations of a more detailed dataset from California and Nevada shows that the active geothermal area lies at the southern end of a late Miocene-Pleistocene sweep of magmatism. The geothermal area is developed around rhyolite domes in a Pleistocene basalt-rhyolite field. The northern part of the Pleistocene field, erupted through the Pliocene field, is almost entirely rhyolite; the southern part, erupted through pre-Cenozoic basement, is almost entirely basalt. These relationships, geochemical data, and the time-space patterns revealed by animation are consistent with the hypothesis that the Pleistocene rhyolite and associated geothermal field developed where Pleistocene basaltic magmas were trapped by still-warm Pliocene mafic and intermediate plutons, which melted to form the Pleistocene rhyolites.

Introduction

Space-time patterns of magmatism can give insight into the conditions needed to form and sustain a geothermal resource. Such patterns have long been used to decipher plate interactions along the west coast of North America (e.g., Lipman et al., 1971; Coney and Reynolds, 1977; Dickinson, 1997), although the interpretations are rarely unambiguous.

The NAVDAT project (navdat.geongrid.org) is compiling geochemical and geochronological data on Cenozoic magmatic rocks in western North America into a web-accessible and web-searchable database. One preliminary product of this effort is a number of animations of magmatic trends in western North America. Several animations are available at the NAVDAT web site, and these are updated as new data are added to the database. These animations provide a powerful new tool for analyzing the magmatic and tectonic settings of a given volcanic field.

Magmatic Sweeps in the Basin and Range

Several first-order patterns of magmatism are apparent in the NAVDAT animations (Figure 1), including: (1) A strong sweep starting in Montana ~50 Ma and moving rapidly southwestward into the Great Basin, reaching southern Nevada ~15 Ma. (2) A clockwise sweep around the Colorado Plateau, starting in southwestern New Mexico ~30 Ma and also end-

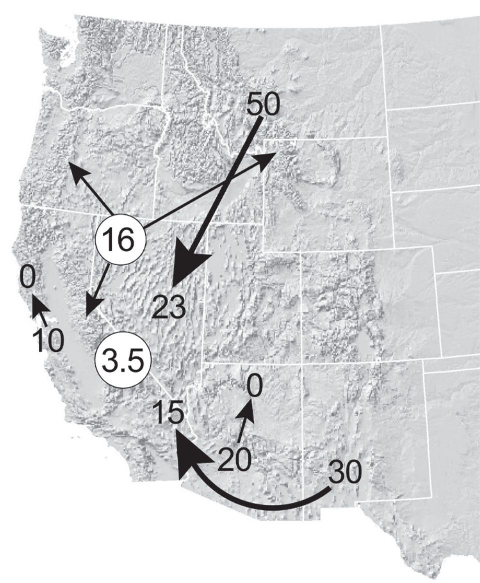

Figure 1. Notable sweeps of magmatism seen in animations of magmatism from the western U.S. Several animations are posted at the NAVDAT website, navdat.geongrid.org.

ing in southern Nevada ~15 Ma. (3) A burst of magmatism in northern Nevada ~15 Ma that spread outward to Yellowstone, the central Sierra Nevada, and central Oregon. (4) Waves that converged in the Quaternary on the High Cascades from the west (slowly) and east (rapidly). (5) A Pliocene outburst at 3.5 Ma in eastern California. (6) Several more local northward migrations, including late Cenozoic movements through the San Francisco Bay area and along the southern Wasatch Front, and Miocene-Recent movement through Phoenix to the San Francisco Peaks of Arizona.

The patterns displayed by these animations are clearly migratory at several scales, but it is difficult to tie them to simple models of plate interaction. Patterns that could be related to shallowing and steepening of the Farallon plate (Coney and Reynolds, 1977) or to developing slab windows (Dickinson, 1997; Atwater and Stock, 1998) are not obvious, although further work may yet isolate them. The “splash” of magmatism in the northern Great Basin is consistent with impingement of a Yellowstone plume head. The strongest pattern of all, the southwestward sweep of magmatism from Montana to Nevada, runs counter to relative plate motion between the North American and Farallon plates.

Coso in the Context of Basin and Range Magmatism

Magmatism in the Coso volcanic field (Figure 2) broadly fits into the southwestward-sweeping pattern of activity that crossed the Great Basin in the Tertiary. Volcanism in the Coso region occurred in two pulses, one Pliocene and one Pleistocene. Volcanism commenced in earnest ~4 Ma with eruption of basalts and a suite of intermediate lavas, and continued from ~0.5 Ma to present with eruption of a bimodal suite of basalts and high-silica rhyolites (Duffield et al., 1980). These authors noted that vents for the earlier Pliocene event are arranged in an arcuate pattern northeast of the younger Pleistocene vents (Figure 3).

The youngest volcanism in the Coso field lies at the southwestern end of a wave of volcanism that swept southward from the Darwin Plateau area through the northern Coso Range to Volcano Peak and surrounding volcanoes (Figures 2, 3), mimicking the pattern seen in the Great Basin. The southward jump into the Coso geothermal area can be viewed as the most recent increment of the Great Basin sweep. This wave, which was episodic, is well displayed on animations of eastern California volcanism. In the greater Coso region, volcanism began in earnest ~5.5 Ma in the Darwin Plateau and Hunter Mountain areas (these areas were contiguous at that time, as Saline Valley had not yet opened). This volcanism was dominantly basaltic and jumped southward to a widespread event, largely basaltic and andesitic, at ~3.5 Ma in the northern Coso Range. Volcanism then jumped south again at ~ 0.5 Ma to produce rhyolite volcanism at the geothermal area and basaltic volcanism at Volcano Peak and areas to the south of the geothermal area. Within the Coso Range, volcanism migrated in a general way from northeast to southwest, with the current

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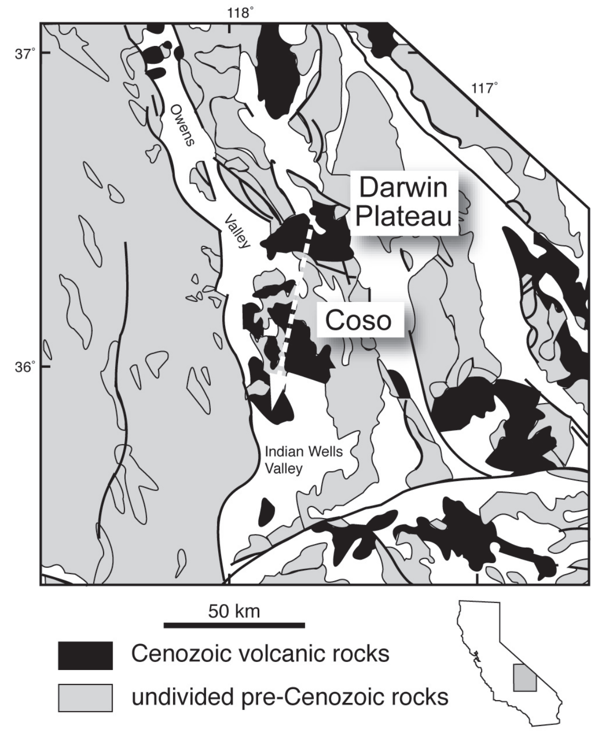

Figure 2. Eastern California showing the Coso and Darwin Plateau volcanic fields. As in the Basin and Range as a whole, volcanism jumped southward through this area (dashed line).

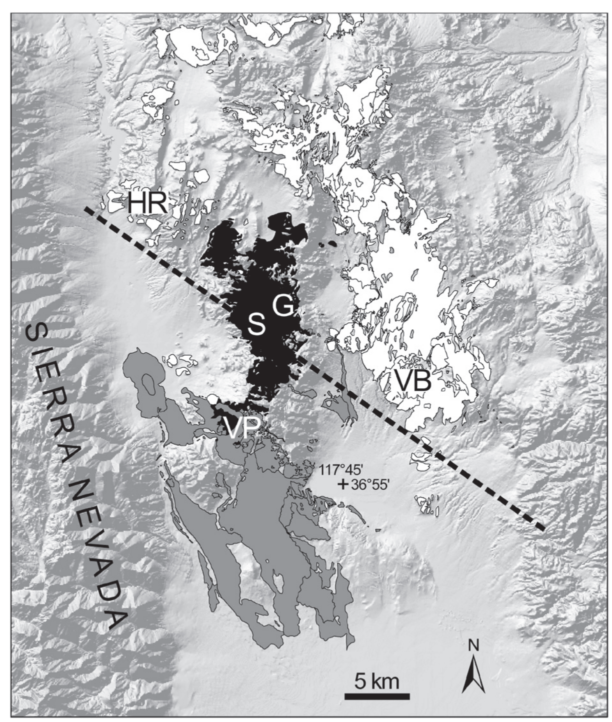

Figure 3. Close-up of the Coso volcanic field showing Pliocene rocks (white), Pleistocene basalts (gray), and Pleistocene rhyolites (black). The rhyolites mostly crop out within the limits of the Pliocene field (see text). Dashed line give topographic escarpment that bounds the southwestern side of the Pliocene field. G = geothermal area, HR = Haiwee Ridge, S = Sugarloaf, VB = Volcano Butte, VP = Volcano Peak.

cus centered around Volcano Peak and Sugarloaf (Figure 3.)

The widespread 3.5 Ma lavas, which produced the lava plateaus of Wildhorse Mesa, are bounded sharply on the southwest by a topographic escarpment that runs from near Volcano Butte northwest through Sugarloaf to the south end of Haiwee Ridge (Figure 3). Pliocene magmatism was almost entirely restricted to the region northeast of this line, and Pleistocene magmatism was largely restricted to the area southeast of the line. In the subsurface, Pliocene rocks occur southwest of the line (F. Monastero, pers. comm., 2004), but are not found as lavas on exposed basement rocks there.

The bimodal Pleistocene magmatic rocks around the geothermal area were erupted along a north-south line that cuts across the southwestern side of the Pliocene magmatic event. Where Pleistocene rocks erupted through the Pliocene field they are mostly rhyolite; where they came through the basement southwest of the Pliocene field they are mostly basalt. Isotope data (Miller et al., 1996; J. S. Miller and A. F. Glazner, unpublished) show that the Pleistocene rhyolites have unusually high Nd isotope ratios, similar to mafic Pliocene rocks (basalts and andesites) and unlike Pleistocene basalts. These data permit production of the Pleistocene rhyolites by melting of Pliocene mafic rocks and suggest that the rhyolites (and thus the geothermal field) formed where the Pleistocene basalts came into the crust and remelted still-warm mafic and intermediate Pliocene plutons. Preliminary thermal modeling indicates that mid-crustal temperatures can remain elevated 100°C or more above ambient temperatures even 2 million years after pluton assembly. Thus, injection of Pleistocene basalts into the warm Pliocene plutons could have led to remelting and production of rhyolite, thereby trapping basalts under the silicic mush (Bacon, 1980), keeping magmatic heat in the ground, and forming a geothermal resource.

Acknowledgments

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References

Atwater, T., and Stock, J., 1998, Pacific-North America plate tectonics of the Neogene southwestern United States: an update: International Geology Review, v. 40, p. 375-402.

Coney, P. J., and Reynolds, S. J., 1977, Cordilleran Benioff zones: Nature, v. 270, p. 403-406.

Dickinson, W. R., 1997, Overview: Tectonic implications of Cenozoic volcanism in coastal California: Geological Society of America Bulletin, v. 109, p. 936-954.

Duffield, W. A., Bacon, C. R., and Dalrymple, G. B., 1980, Late Cenozoic volcanism, geochronology, and structure of the Coso Range, Inyo County, California: Journal of Geophysical Research, v. 85, p. 2381-2404.

Lipman, P. W., Prostka, H. J., and Christiansen, R. L., 1971, Evolving subduction zones in the western United States, as interpreted from igneous rocks: Science, v. 174, p. 821-825.

Miller, J. S., Groves, K. R., and Whitmarsh, R. S., 1996, Sources of the Pleistocene Coso rhyolites; a Nd isotopic perspective: Eos, Transactions, American Geophysical Union, v. 77, p. 791.