Late Cenozoic Deformation in the Coso Range, Eastern California, and Relation to the Coso Geothermal and Magmatic Systems

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ABSTRACT

Fluid circulation in the Coso geothermal system is governed by active movements in the dextral Airport Lake—Owens Valley (ALOV) fault zone. Two new observations lead to reexamination of the hypothesis that a right step-over in a still-developing fault zone localizes the geothermal system: (1) the ALOV fault zone proves to be a long-lived crustal boundary that accommodated 65 km of dextral slip since Late Cretaceous time, and (2) the Cretaceous Coso dike swarm may continue largely undisrupted across the location of the proposed step-over. Alternative models that may account for Coso Range faulting include block rotation, partitioning of dip- and strike-slip faulting, and faulting driven by magmatic intrusion. Plio-Pleistocene magmatic intrusion may have been the cause, rather than the result, of the structural complexity of the Coso Range segment of the ALOV fault zone.

Introduction

Heat introduced by Quaternary magmas drives the Coso geothermal system (e.g., Duffield et al., 1980), but active tectonic deformation governs patterns of hydrothermal circulation. The geothermal system is located in a complex portion of the Airport Lake—Owens Valley (ALOV) fault zone (Figure 1), and it is likely that there is a close genetic link between the fault zone and the Coso geothermal-magmatic system. The internal structure and displacement patterns of the fault zone therefore are important to understanding and optimal development of the geothermal resource.

Regional Tectonic Setting

The ALOV fault zone is part of the boundary between the stable Sierra Nevada microplate to the west and the transtensional Walker Lane Belt to the east (Figure 1). Geologic (Lee et al., 2001) and geodetic (Dixon et al., 2003) estimates of the long-term dextral slip rate across the Owens Valley fault zone roughly converge at about 2-3 mm/yr. Whitmarsh et al. (1996), Walker and Whitmarsh (1998), and Unruh et al. (2002) inferred diffuse transfer of this dextral shear through the Coso Range to the Airport Lake fault zone based on field observations (Figure 2, overleaf) and on seismicity. The Coso magmatic-geothermal system appears to be localized in a right (extensional) step-over in the ALOV fault zone (Bacon, 1982;

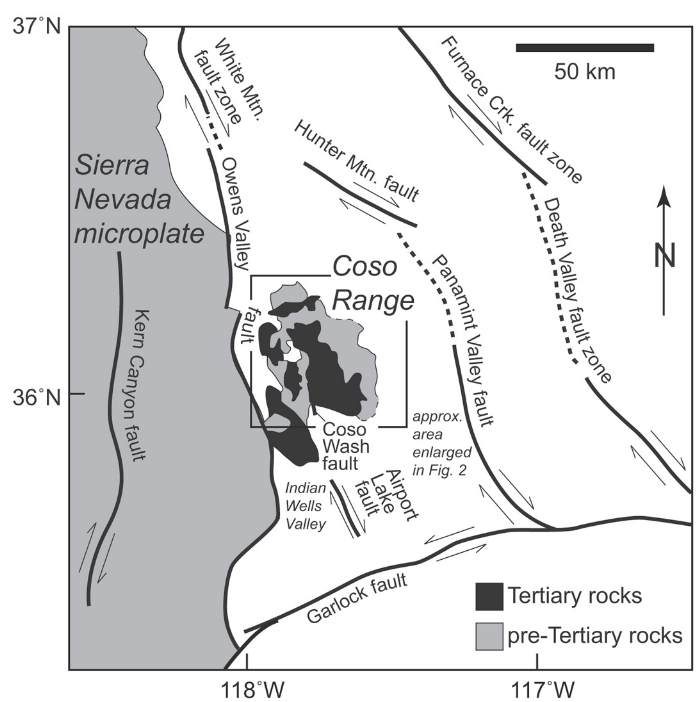

Figure 1. Major fault zones of the southern Walker Lane belt. Simplified geology of only Coso Range and Sierra Nevada microplate are shown for clarity. The focus of this paper is how dextral slip across the Airport Lake fault is linked through the Coso Range to Owens Valley. The area enlarged in Figure 2 is indicated.

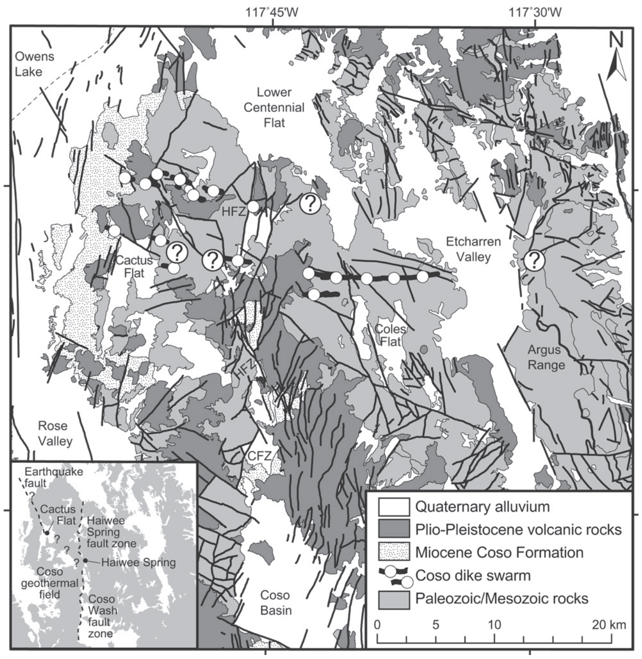

Figure 2. Simplified geologic map of the Coso Range and surrounding area. Queries (?) on the main figure indicate where Coso dike swarm appears to continue but has not been mapped in detail. CFZ—Coso Wash fault zone; HFZ—Haiwee Spring fault zone (HFZ). Inset shows relations between the Coso geothermal area, CFZ, HFZ, and the southern end of the 1872 earthquake rupture in Owens Valley.

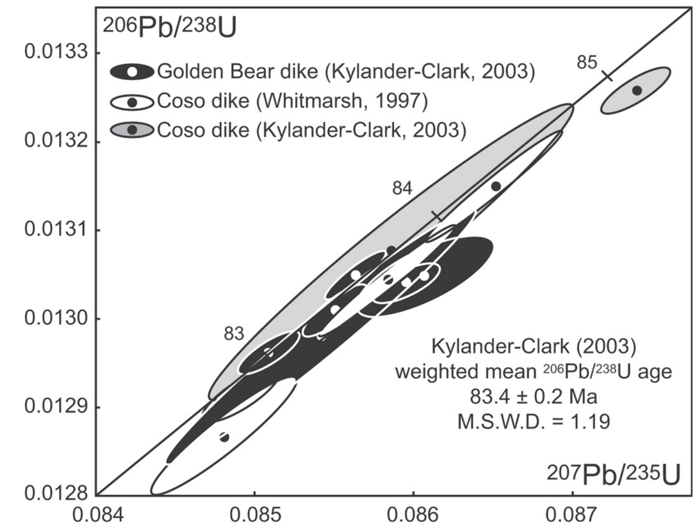

Figure 3. U-Pb zircon geochronologic data fom the Golden Bear and Coso dikes. Several discordant fractions plot outside the area of the diagram and are interpreted to reflect significant Pb-loss, inheritance, or both. Data come from five different samples (2 Golden Bear, 3 Coso) and indicate that the dikes all are the same age. The weighted mean $^{206}Pb/^{238}U$ age for the western Golden Bear dike sample (83.4 ± 0.2 Ma) is the preferred age because it yielded zircon least affected by inheritance and Pb-loss (Kylander-Clark, 2003).

Dooley et al., 2003). The north-striking Coso Wash normal fault is the most prominent single fault in the transfer system (Figure 2).

Until recently, net dextral slip across the ALOV fault zone was thought to be only a few kilometers (e.g., Ross, 1962), consistent with the modern slip rate and with geologic evidence for Pliocene initiation (e.g., Monastero et al., 2002). Recent initiation and small net slip also are consistent with a lack of evidence for active surface-rupturing faults that fully bridge the step-over (Unruh et al., 2002), and thus the fault system has been interpreted still to be developing (Dooley et al., 2003).

However, recent field studies indicate 65 km of net dextral slip across Owens Valley since Late Cretaceous time. Some of this slip probably did not accumulate in the modern tectonic regime (Bartley et al., 2003) but, regardless of its precise age, this magnitude of net displacement likely means that the ALOV fault zone was a through-going structure long before the Pliocene onset of Coso Range magmatism. Such boundaries commonly are major crustal weaknesses that govern later structural development. We therefore consider alternative models for faulting in the Coso Range and for the relationship between faulting and magmatism.

Coso Dike Swarm

The Late Cretaceous Coso dike swarm is a key structural marker in deducing Late Cretaceous to Cenozoic displacements in the region. Duffield et al. (1980) described east striking, steeply dipping, conspicuously K-feldspar-phyric granitic dikes up to 10 m thick in the northern Coso Range (Figure 2). Whitmarsh (1998) named these the Coso dike swarm, mapped several dikes, and obtained a U-Pb zircon date of ~ 84 Ma from a thick dike on the northern side of swarm. Kylander-Clark (2003) obtained U-Pb zircon data from two other Coso dikes that also favor an age of 83-84 Ma (Figure 3).

The strikingly similar Golden Bear dike is exposed on the eastern flank of the Sierra Nevada (Moore, 1963), ~60 km northwest of the Coso Range. Kylander-Clark (2003) obtained U/Pb isotopic data from two Golden Bear dike samples that indicate an age of 83.4 Ma (Figure 3). The Coso and Golden Bear dikes intrude very similar wall rocks, including 102 Ma leucogranite plutons not found elsewhere along either side of Owens Valley. Consequently, Kylander Clark (2003) correlated the Golden Bear and Coso dike sets and inferred 60-65 km of dextral offset across ALOV fault zone. Similar offsets also have been proposed for the 148 Ma Independence dike swarm (Glazner et al., 2003), distinctive Paleozoic rocks (Stevens and Stone, 2002), and the $^{87}Sr/^{86}Sr$ isopleth in Mesozoic plutons (Kistler, 1993).

Within the Coso Range, Whitmarsh et al. (1996) noted 5 km of dextral offset between exposures of ~10 m thick Coso dikes on either side of Upper Centennial Flat, and attributed the offset to slip across the north-striking Haiwee Spring fault zone (Figure 2). The Haiwee Spring fault thus was interpreted to be a significant component of the inferred right step-over of the ALOV fault zone. However, one of these dike segments lies directly on strike across the Haiwee Spring fault zone from another 10 m thick Coso dike (Figure 2; Kylander-Clark, 2003; authors' reconnaissance), suggesting that there may be little dextral slip across the Haiwee Spring fault zone. Based on this observation, on other mapping by Whitmarsh (1998), and on the presence of Coso-type dikes in the Argus Range (J. D. Walker, unpublished), there may be little post-83 Ma dextral shear anywhere in the northern Coso Range or Argus Range (Figure 2). Combined with the lack of active surface-rupturing faults in the northern Coso Range (Unruh et al. 2002), this unexpected result makes it important to consider other interpretations of Coso Range deformation besides a right step-over between the Airport Lake and Owens Valley fault zones.

Alternative Kinematic Models

At least three other mechanisms, which are not exclusive either of each other or of the right step-over mechanism, may account for faulting in the Coso geothermal area.

Block Rotation

Displacement transfer away from the Coso Wash fault as it dies out northward may be accomplished by clockwise rotation of its footwall block, which includes the active geothermal area. Block rotation would transfer displacement westward to the Rose Valley area rather than northward as predicted by the right step-over model. If the pivot point were located near the northern tip of the Coso Wash fault, then contractional deformation is predicted between Haiwee Spring and Cactus Flat. Several ENE-striking high-angle faults cut Pliocene volcanic rocks in this area (Figure 2) that have been inferred to accommodate sinistral slip (Unruh et al., 2002). However, similarly oriented faults in the Mojave Desert prove to accommodate significant reverse slip (Bartley et al., 1990; Schermer et al., 1996). Independent evidence for active horizontal contraction in this vicinity comes from inversion of seismic and geodetic displacements (J. Unruh, personal communication).

Kinematic Partitioning

The large net slip across the ALOV fault zone suggests that it is a well established, through-going crustal boundary similar to the nearby Garlock fault. Such major structures commonly are mechanically weak and decouple the blocks that they bound. The distribution of offset markers such as the Golden Bear-Coso dikes and the Independence dike swarm indicates that the main through-going ALOV fault is located between the Sierra Nevada and the Coso Range. The Panamint Valley fault zone may bound the eastern side of the Coso Range-Argus Range structural block. Major dextral shear may be accommodated largely at the block boundaries, and deformation within the block represents extension partitioned away from the bounding faults (cf. Bacon, 1982). Partitioning of strike-slip and dip-slip faulting is well known from other areas of transpressional and transtensional tectonic deformation. If this model applies to the Coso Range, then extension across Coso Wash should be relayed to extensional faults farther north. This might not conflict with a lack of mapped offset of the Coso dike swarm because vertical dikes are not offset by vertical fault slip. However, this alternative may be difficult to reconcile with an absence of young surface-breaking faults in the northern Coso Range (Unruh et al., 2002; J. Unruh, personal communication).

Magmatic Inflation

Normal faulting in Coso Wash may be caused by magmatic intrusion. A laccolith forming under the geothermal field could lift its roof by forming surface-breaking normal faults. The northern and southern limits of Quaternary volcanism and of significant dip slip across the Coso Wash fault broadly match, forming a pattern consistent with vertical surface displacement caused mainly by laccolith inflation.

Relation Between Magmatism And Faulting

Regardless of the correct model for internal deformation of the Coso Range, the evidence for 65 km of net dextral slip across the ALOV fault zone renders it difficult to attribute the lack of through-going faults to incomplete development of the fault zone. The ALOV fault zone must have been well established long before the Pliocene onset of Coso Range magmatism. We thus propose that, rather than magmatism being localized at a stepover in the developing ALOV fault zone, the onset of magmatism changed the geometry and kinematics of a pre-existing fault zone. A right step-over could form along a previously relatively straight fault if magmatic thermal weakening caused displacement to be dispersed through the crust adjacent to the fault zone. Block rotation also fits well within this framework. Shallow intrusion of magma adjacent to the ALOV fault would mechanically decouple overlying upper crust and allow it to rotate in response to dextral shear. If the Coso Wash fault mainly accommodates lifting the roof of a laccolith in its footwall, then the resulting crustal weaknesses could serve to disperse displacement away from the main ALOV fault zone and into the Coso Range.

Conclusions

Two new lines of tectonic evidence prompt us to reexamine the hypothesis that the Coso magmatic-geothermal system is localized in a right step-over in an incipient dextral fault zone: the ALOV fault zone is a long-lived crustal boundary that has accommodated 65 km of dextral slip, and the Coso dike swarm may continue undisrupted across the area of the proposed step-over. Alternative models for Coso Range faulting include one or more rotating blocks, partitioning of extensional and dextral faulting, and faulting driven by magmatic intrusion. Regardless of the specific deformation process, the ALOV fault zone probably was well developed prior to Coso Range magmatism and, therefore, the magmatism may be better considered as a cause, rather than a consequence, of the current structural complexity of the Coso Range segment of the ALOV fault zone.

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