A STABLE ISOTOPE STUDY OF FLUID-ROCK INTERACTIONS IN THE SADDLEBAG LAKE ROOF PENDANT, SIERRA NEVADA, CALIFORNIA

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Introduction

A reconnaissance stable isotope study of the Saddlebag Lake Pendant (SLP) documents a complex fluid history involving magmatic, metamorphic, and meteoric-hydrothermal fluids. The SLP is an ~5 km-wide zone of Ordovician-Cretaceous metasedimentary and metavolcanic rocks just east of the 95-85 Ma Tuolumne Intrusive Complex (TIC) in the Sierra Nevada (Memeti et al., 2014). This pendant contains, from east to west: (1) Ordovician-Devonian metasedimentary rocks of the Palmetto Sequence that are intruded by Upper Triassic diorite bodies (i.e., Saddlebag Lake pluton; Paterson et al., 2014), (2) Permian-Triassic metasedimentary rocks of the Diablo and Candelaria Formations, (3) Triassic metavolcanic and metasedimentary rocks of the Koip Sequence (KS) comprising conglomerate of Cooney Lake and overlying rhyolite tuffs, andesite, and minor basalt, (4) a strongly-deformed and thinly-bedded sequence of early Jurassic greenschists, phyllites, metasandstone, metaconglomerate and calc-silicates of the Sawmill Canyon Sequence (SCS), and (5) a thin zone of Cretaceous metavolcanic rocks (Schweickert & Lahren 2006; Paterson et al. 2014).

The dextral transpressive Steelhead Lake Shear Zone (SLSZ) is a >2 km wide shear zone with rock fabrics and veins that indicate both ductile and brittle deformation (Paterson et al., 2014). These features include: (a) ductilely sheared and folded TIC dikes that are truncated at a major brittle fault, (b) quartz-tourmaline and quartz-epidote veins that contain both brittle and ductile deformation, (c) leach zones with low-temperature calc-silicate minerals, and (d) meter-scale quartz veins with crack-seal textures (Hartman et al. 2014). Higher temperature metamorphism is found in host rocks adjacent to the TIC contact, but most of the pendant is metamorphosed to greenschist facies.

Stable isotope studies of other roof pendants in the Eastern Sierra Nevada documented a diversity of fluid systems that include seawater-dominated systems that affected Jurassic volcanic rocks (Hanson et al. 1993), Cretaceous events that involved magmatic fluids (Lackey et al. 2008), metamorphic fluids (Ferry et al. 2001; Lackey and Valley 2004) and meteoric-hydrothermal fluids (Hanson et al. 1993; D'Errico et al. 2012). The SLP provides an excellent opportunity to investigate the role of fluid systems on deformational style as the transpressional SLSZ evolved from ductile to brittle conditions during the cooling of the TB and exhumation of the system during the Late Cretaceous. The objective of this study is to identify the complex fluid evolution of the pendant through this history.

Methodology

All stable isotope values were determined using the ThermoFinnigan DeltaPlus-XP isotope ratio mass spectrometer at the Institute for Integrated Research in Materials, Environments and Societies at California State University, Long Beach. The thermo-reduction method of Sharp et al. (2001) and laser fluorination method (Sharp, 1990) were employed for the acquisition of δD and $\delta^{18}O$ values, respectively. Calibration, accuracy, and analytical precision of isotope data (δD = ±2‰; $\delta^{18}O$ = ±0.2‰) were determined using NBS-30 biotite (δD = –65.7) and Caltech Rose Quartz ($\delta^{18}O$ = +8.45) standards. Mineral separates for isotopic analyses were prepared by crushing, followed by hand picking and magnetic, density, or centrifuge separation, if needed. Primary and alteration mineralogy were determined by thin section petrography, PIMA spectroscopy, and powder XRD.

Results

The samples, collected in a ~50 km^2 study area in the Sawmill Canyon area, have a wide range of isotopic values (Figure 1). Epidote from the Palmetto Formation has $\delta^{18}O$ and δD values of +8.1 and –112. The Candelaria Formation contains epidote and tourmaline δD values that range between –99 and –77. Quartz ($\delta^{18}O$ = +9.6) and tourmaline ($\delta^{18}O$ = +7.1) from the Saddlebag Lake Pluton are typical for Sierran intrusive rocks (Lackey et al., 2008), but tourmaline (–121) and hornblende (–94) δD values are lower than those produced by magmatic fluids (see Figure 1). The high quartz and biotite $\delta^{18}O$ and δD values (+15.8 and +14.7, –75) from the Cooney Lake Conglomerate suggest the preservation of isotopic values set during diagenesis. Quartz and feldspar $\delta^{18}O$ values (+11.3 and +8.1 to +9.8) in the KS metavolcanics appear to be in isotopic equilibrium, but a wide range of hydrous mineral $\delta^{18}O$ and δD values (+5.9 to +9.7, –140 to –97) suggests exchange with small amounts of meteoric-hydrothermal water. Epidote (+1.3 to +9.9) and plagioclase (+2.7 to +10.0) $\delta^{18}O$ values from the SCS are variable and pairs are nearly equal in their $\delta^{18}O$ values, suggesting hydrothermal alteration involving fluids of variable composition; this is supported by a wide range of δD values (–113 to –67). A plagioclase-epidote vein ($\delta^{18}O_{plagioclase}$ = +9.4, $\delta^{18}O_{epidote}$ = +8.8, $\delta D_{epidote}$ = –89) and host rock ($\delta^{18}O_{plagioclase}$ = +9.8, $\delta^{18}O_{biotite}$ = +4.8, $\delta D_{biotite}$ = –94) pair from the TIC suggests that early veins formed from fluids of a magmatic source.

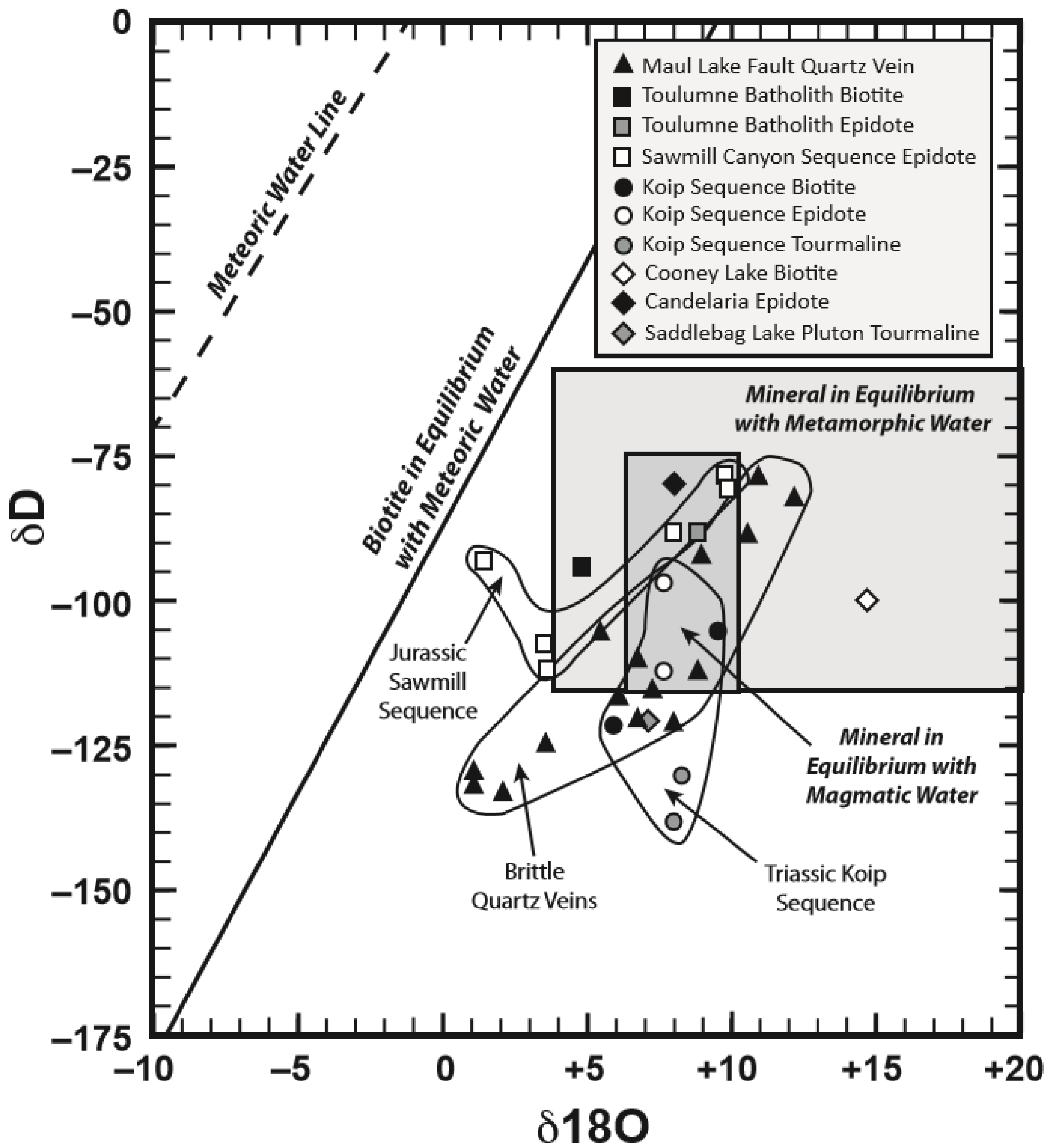

Figure 1. Plot of δ18O and δD values of minerals from the Saddlebag Lake Pendant. Fields for magmatic and metamorphic water are approximate for δ18O and δD values of minerals in equilibrium with such fluids at 400°C.

Apparent $^{18}O/^{16}O$ equilibrium temperatures were estimated using mineral pairs and the fractionation factors of Bottinga and Javoy (1975), Zheng (1993), and Kotzer et al. (1993). One quartz-biotite pair from the Cooney Lake Conglomerate produced an unreasonable temperature. A quartz-tourmaline pair from the Saddlebag Lake Pluton indicated T ~ 480℃, a value typical for a slow-cooled plutonic rock (e.g., Taylor, 1997). Apparent temperatures inferred from quartz-tourmaline, albite-epidote, and albite-biotite mineral pairs in the KS ranged from 250-500℃. Geothermometry from the SCS is inconclusive due to the very small $^{18}O/^{16}O$ fractionations between anorthite and epidote, but one quartz-epidote pair suggests T ~ 530℃.

Assuming equilibrium, the stable isotopic compositions of waters were estimated using the above temperatures and published mineral-H_2O fractionation factors (Bottinga and Javoy, 1973; Chacko et al., 1999; Suzouki and Epstein, 1976; Jibao and Yaqian, 1997; and Zheng, 1993). Waters related to the two plutonic units are magmatic in origin. The KS fluids have $\delta^{18}O$ and δD values that ranged from +5 to +9 and –100 to –42, respectively. Water from the SCS had $\delta^{18}O$ values that ranged from +3 to +11 and narrow range of δD values (–65 to –30). These ranges of fluid compositions indicate a complex, but poorly understood, hydrothermal history involving magmatic, metamorphic and meteoric-hydrothermal fluids.

Discussion

The mineral stable isotopic values from this reconnaissance study do not indicate any strong correlation with lithology or location, but our data from most units do display deviation from the expected values of their protoliths, suggesting the involvement of external fluids. The δD and $\delta^{18}O$ values from epidote alteration in the SCS are too low to have been the product of seawater alteration such as that observed in the Ritter Range Pendant along strike to the south (Hanson et al., 1993). These relatively low isotopic compositions are most likely due to exchange with evolved meteoric-hydrothermal water.

This preliminary set of isotopic data has not produced a strong spatial or temporal pattern, leaving many questions open about the SLP's fluid history. However, an identifiable facet to consider is mixing between magmatic TIC fluids and meteoric-hydrothermal fluids. This is evidenced at a >10 meter-wide fault-hosted late-stage brittle quartz vein that preserves crack-seal textures near Maul Lake (Figure 1, Hartman et al. 2014). This mixing trend is defined by a linear pattern of quartz $\delta^{18}O$ values from +11.2 to +0.7 and fluid inclusion δD values from –79 to –134, with values that decrease from the edges of the vein toward its center. Our preliminary epidote $\delta^{18}O$ and δD values from the SCS plot parallel to the Maul Lake vein trend (Figure 1), suggesting that this fluid mixing event may have occurred in the Jurassic section during the late-stage brittle faulting, as many brittle structures are hosted by the SCS (Figure 1). The lowering of δD values, especially for tourmaline, accompanied by likely protolith $\delta^{18}O$ values in the KS suggests that very small amounts of meteoric-hydrothermal fluid infiltrated other units less affected by Cretaceous transpressive brittle deformation.

The proximity of the SLP to the TIC (Paterson et al., 2008) suggests that magmatic fluids coming from the pluton may have been involved in deformation along the SLSZ. The lone sample from a TIC plagioclase-tourmaline dike does indicate the presence of magmatic fluid, but the evidence for such fluids from other units in the SLP is inconclusive and more studies are needed to delineate the extent of such fluids. However, the SLP does contain some minor epithermal W, Mo, and Ag deposits, abundant greisen alteration, and highly oxidized host rocks, suggesting fluid mixing between saline crustal fluids and meteoric fluids (e.g., Taylor, 1997; Wagner et al., 2009).

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