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GEOCHRONOLOGIC AND HAFNIUM ISOTOPIC CONSTRAINTS ON THE EVOLUTION OF THE SALINIAN MAGMATIC ARC

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INTRODUCTION

Magmatic arcs are crucial in the formation of continental crust. Due to the complex metamorphism found in continental margins where continental arcs form and rarity of exposed magmatic arcs very little is known about these bodies of rock and the processes that form them (Hildreth and Moorbath, 1988; Rudnick and Gao, 2003; Lackey et al. , 2005). The Salinian block along the central coast of California contains a large magmatic arc section, including deep (~25 km paleodepths) crustal magmatic roots (Mattinson, 1978, 1990; Ross, 1978; Kidder et al., 2003; Chapman et al. , 2014). Despite being an accessible exposure of a tilted continental arc section, the Salinian arc remains understudied.

The purpose of this study is to better understand the timing of pluton emplacement in the exposed continental arc through U-Pb isotope geochronology, particularly in the Coast Ridge Belt (CRB), the westernmost portion of the exposed plutonic assemblage, plutons of the Central block exposed east of the CRB, and plutons adjacent to the Sierra de Salinas schist (Figure 1). Hafnium isotopic data is used to better constrain the source(s) of Salinian arc magmas and the timing of separation of these magmas from the mantle. We hypothesize, based on trends in the Sierra Nevada batholith and existing work in the Salinian block (e. g. , Nadin and Saleeby, 2008; Kistler and Champion, 2001), that ages and hafnium isotope values will show plutons to the east are younger, uncoupled from the mantle later and to have a more crustal/felsic composition than plutons to the west.

GEOLOGIC BACKGROUND

The Salinian block is a composite terrane bounded by the San Andreas fault to the east, the Nacimiento fault to the west, and the Big Pine fault to the south (Kidder et al., 2003). On both sides the Salinian block is sandwiched by Mesozoic accretionary terranes of the Franciscan complex (Kistler and Champion, 2001). The Salinian terrane is part of a larger magmatic

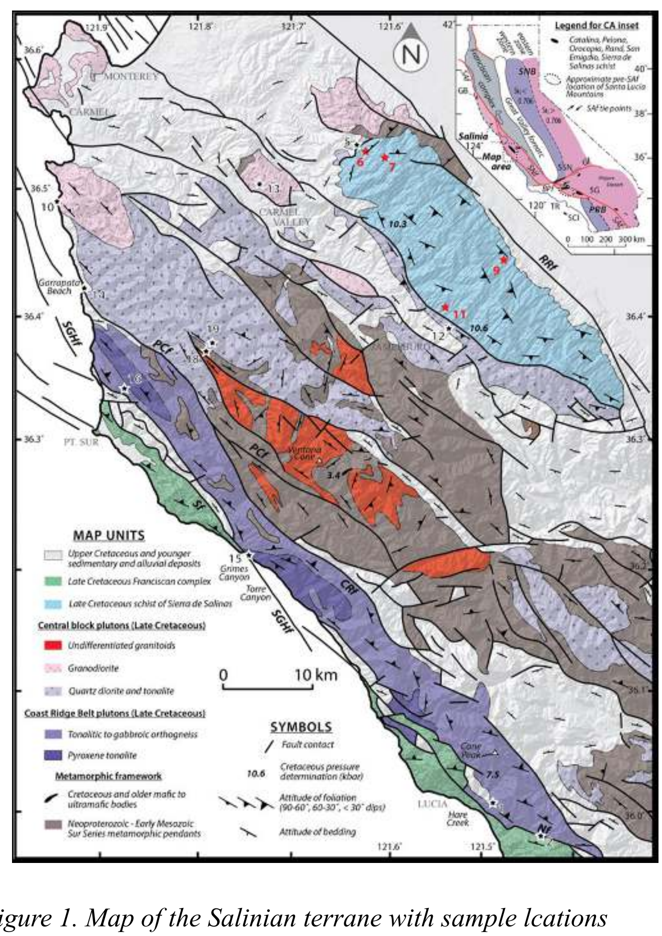

Figure 1. Map of the Salinian terrane with sample lcations marked. The Sierra de Salinas schist is in blue. The Coast Ridge Belt is in dark purple

complex stretching some 1500 km along the coast of California, the California arc. The Salinian block of the California arc is an allochthonous block originally emplaced in the southwest section of the Sierra Nevada batholith, a ~600 km long section of the California arc (Hall, 1991). The Salinian block was displaced ~300 km along the San Andreas fault after emplacement (Hall, 1991).

Plutonic masses of the Salinian arc include calc-alkaline tonalites gabbros, diorites, and, grandiorites (Ross, 1978, Chapman et al. 2014). Magmatism in the Salinian arc is constrained between 93 Ma and 79 Ma (Mattinson, 1978, 1990; Kidder et al. , 2003). Compositional variation and thermobarometric estimates in plutons indicate that the arc is tilted to the northeast, exposing plutons ranging from paleodepths of 10 km to 25 km (Ducea, 2003; Kidder et al., 2003; Chapman et al., 2012). Structural evidence shows transitions from a steep batholithic fabric to subhorizontal foliation around 25 km paleodepth (Ducea et al., 2003; Kidder et al., 2003). Additionally, petrographic analysis indicates a change from predominantly felsic material to more mafic material around 25 km paleodepth, consistent with the structural and thermobarometric data as well as implications for the natural buoyancy of mafic magmas (Ducea, 2003). In addition to structural tilting, the Salinian arc also appears to contain a SW-side-up structural break across the Coast Ridge-Palo Colorado fault, a NNW trending structure that separates amphibolite- to granulite-grade mafic rocks to the west from less metamorphosed rocks to the east (Ross, 1976; Chapman et al. 2012).

METHODS

U-Pb Geochronology

Zircon grains were extracted from plutonic samples using standard mineral separation techniques of crushing, sieving, magnetic separation, processing through heavy liquids, and hand picking. Separates were mounted in epoxy, then imaged using the JEOL 6610 LV scanning electron microscope at Macalester College. Zircon grains extracted from sampled plutons are generally euhedral and show oscillatory zoning in cathodoluminescence (CL) images (Figure 3). Geochronologic analyses were performed by laser ablation-multicollector-inductively coupled plasma-mass spectrometry (LA-MC-ICP-MS) at the Arizona Laserchron Center (ALC) using methods described by Gehrels et al. (2008). Laser ablation was conducted with a beam diameter of 20 microns and a pit depth of 12 microns. Data reduction was done using in-house ALC Microsoft Excel programs and ISOPLOT/Ex Version 3 (Ludwig, 2003).

Figure 2. Exposure of Grimes point charnockitic tonalite showing three distinct materials. Notice the gabbroic dike cross cutting both the leucosome and melanosome; gabbro not sampled.

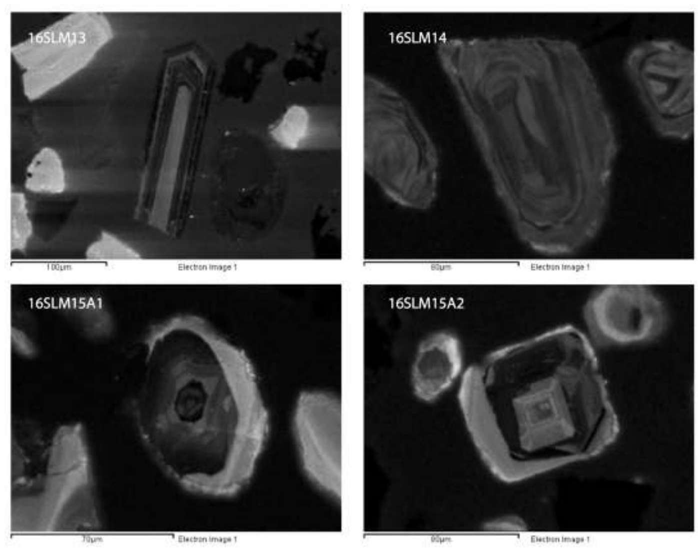

Figure 3. A sample of zircon grains that were analyzed. Many of the grains analyzed were similar to the grains above showing euhedral grains with oscillatory zoning.

Hafnium

Hf isotope measurements were gathered via ablation on top of the pre-existing U-Pb pits; In situ Hf isotope data were acquired using a 40 μm beam centered directly on top of the pit previously excavated for U-Pb analysis. Standard Hf analyses were performed by LA-MC-ICP-MS in the ALC using methods described by Cecil et al. (2011). An average of 10 zircon grains were analyzed from each sample using several accepted standards including MT, FC, SL, 91500, TEM, and PLES.

RESULTS

We present U-Pb zircon ages from 10 plutons and integrate our data with data from previously dated plutons spread across the Salinian terrane (Mattinson, 1978, 1990; Barth et al. , 2003; Kidder et al. , 2003). Sampled plutons show a trend of decreasing in age from SW to NE (Figure 2). The oldest sampled plutons are part of the Coast Ridge Belt (CRB). From south to north, samples of the CRB include:

16SLM1) A foliated CRB gabbro diorite containing zircon exhibiting faint oscillatory zoning. A weighted mean age of 94.4± 1.4 Ma was calculated from 34 grains with 3 rejected because of high uncertainty in the ages. Hf isotope values for 16SLM1 ranged from -9.6 to +9.4.

16SLM15A and 16SLM15B) Two samples of Compton's migmatitic charnockite tonalite (Compton, 1960) were collected at the same location. Sample 16SLM15A was collected from leucosome material and 16SLM15B from melanosome material. Both samples contain euhedral zircons with oscillatory zoning. Sample 16SLM15A yielded a weighted mean age of 100.1 ± 1.2 Ma from 35 grains with 2 rejected while 16SLM15B yielded a weighted mean age of 101.1 ± 1.5 Ma from 35 grains. Weighted mean zircon Hf isotope values were -3.3 and -3.2 respectively.

16SLM16) A tonalite gneiss that yielded a weighted mean of 99.9± .0 Ma from 35 grains and a weighted mean εHf isotope value of +1.3.

Samples collected from east of the Coast Ridge-Palo Colorado fault include:

16SLM19) A variable quartz monzonite possibly from part of the Sobranes quartz diorite (Kistler and Champion, 2001) containing oscillatory zoned zircon grains yielding a weighted mean age of 101.8 ± 3.0 Ma calculated from 16 grains and Hf isotope values of -7.1.

16SLM14) A hornblende quartz diorite from the Sobranes Point mass, contains zircon exhibiting oscillatory zoning and yielding a mean weighted age of 91.6 ± 0.7 Ma calculated from 35 grains and Hf isotope values of -6.9.

16SLM10) The Monterey grandiorite (Kistler and Champion, 2001) containing simple oscillatory zoned zircon grains. The weighted mean U-Pb zircon age and εHf values calculated from this sample are 86.6 ± 1.7 Ma (from 34 grains with 2 rejected) and -7.7, respectively.

Plutons farther to the northeast record younger U-Pb zircon dates than to the southwest:

16SLM12) A sample of Ross' (1978) hornblende-biotite-quartz diorite, yields a weighted mean average of 90.5 ± 0.7 Ma calculated from 35 grains (2 rejected) and εHf isotope values of -5.0.

16SLM13) A sample of the grandiorite of Cachagua (Ross, 1978) generally shows oscillatory zoning under CL but some grains have gradational growth or single bright rims around a anhedral core. The weighted mean average is 86.5 ± 1.0 Ma calculated from 34 grains (3 rejected). A Hf value of -9.2 was calculated from this sample.

16SLM5) The Corral De Tierra biotite quartz diorite from the upper plate of the schist of Sierra de Salinas contains zircon that show distinct core and rim regions. Rim domains are ~10 μm thick and hence too thin for LA-MC-ICP-MS analysis. The weighted mean age is 86.0 ± 0.9 Ma, calculated from 35 grains. Zircon Hf isotope values of -5.9 were calculated from this sample.

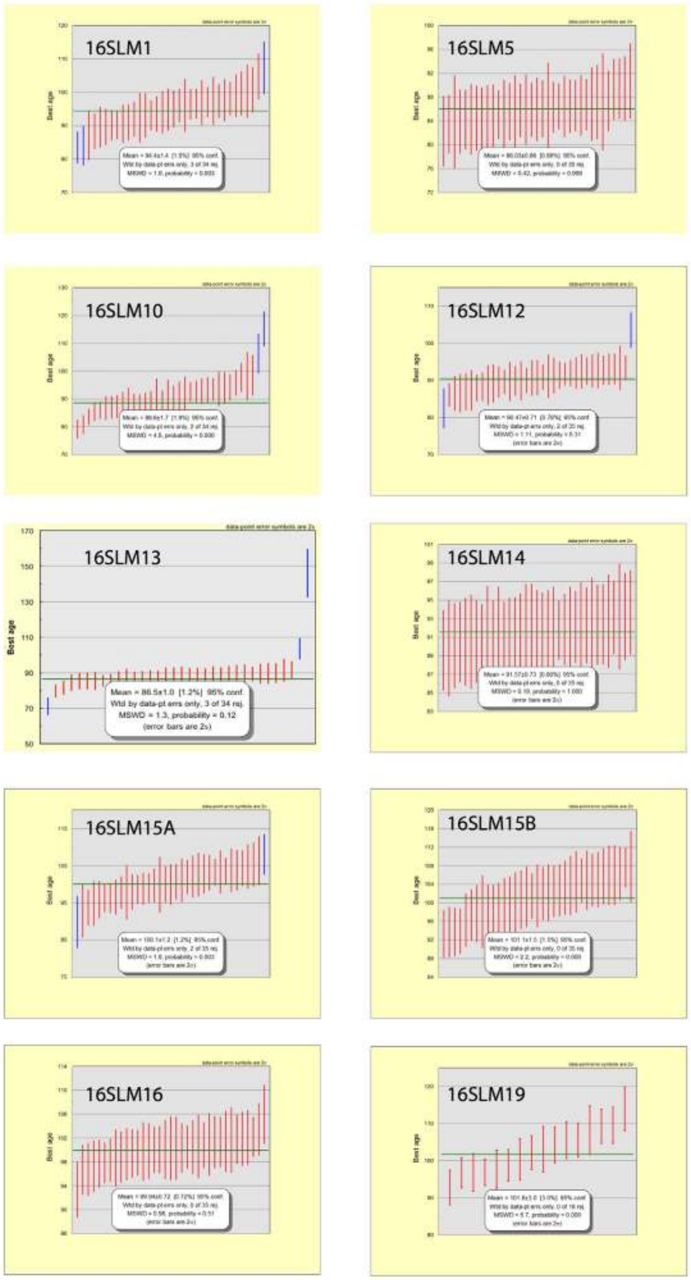

Figure 4. Weighted mean of photos analyzed.

DISCUSSION

Southwest-Northeast Trends

Our samples were collected along two transects. One close to the coast and another surrounding the Sierra de Salinas schist. The plutons we sampled follow a general trend of having younger ages farther to the northeast. The oldest plutons are roughly situated in the CRB (samples 16SLM1, 16SLM15A, 16SLM15B, and16SLM16) and slightly east of the CRB (16SLM 19). These samples show oscillatory zoned interiors, and are more mafic than the rest of the plutons. Sample 16SLM19 is oscillatory zoned but is part of the "variable quartz monzanite of Wiebe (1966). Ross (1978) describes these rocks as not well understood but they are interpreted as part of the Soberanes unit.

Samples to the NE of the CRB plutons show slightly younger ages and agree in age with published literature (Mattison, 1978; Barth et al., 2003; Kidder et al., 2003). The youngest plutons in the Salinian arc surround the schist of Sierra de Salinas. Most of these samples show igneous oscillatory zoning. Plutons east of the Coast Ridge-Palo Colorado fault young approximately 0.1 Myr per km NE of the CRB. (Fig. 5)

If magmatism was continuous within the Salinian arc, one may infer an arc migration rate of ~10 mm/yr from the observed SW-NE age differential in Salinian plutons. However, a general lack of pluton ages between ca. 100 and 90 Ma raise the possibility that magmatism was not continuous. Instead we suggest that magmatism within the Salinian arc occurred in two distinct pulses, a ca. 100 Ma pulse in the CRB and a ca. 90-85 Ma pulse inland (Kistler and Champion, 2001).

Pluton ages are younger to the east suggesting a migration of pluton emplacement eastward as the magmatic arc evolved. This is well documented in the literature and rate of magmatic arc migration have been estimated as high as 3-4mm/yr (Mattinson, 1990). Magmatic activity has been constrained to 104 Mya at the earliest (Mattinson, 1978), not far off our oldest recorded ages of 101 Mya in the CRB. Based on the plutons we sampled an eastward migration of the magmatic arc is higher, more on the scale of 10 mm/yr. This rate may be misleading as most of the magmatic activity in the Salinia block took place in a window between 93Mya and 86, matching our eastern most pluton ages (Kistler and Champion, 2001). Kidder et al. (2003) suggests that the crustal thickening from the period of increased magmatism could explain the eastward migration of pluton emplacement.

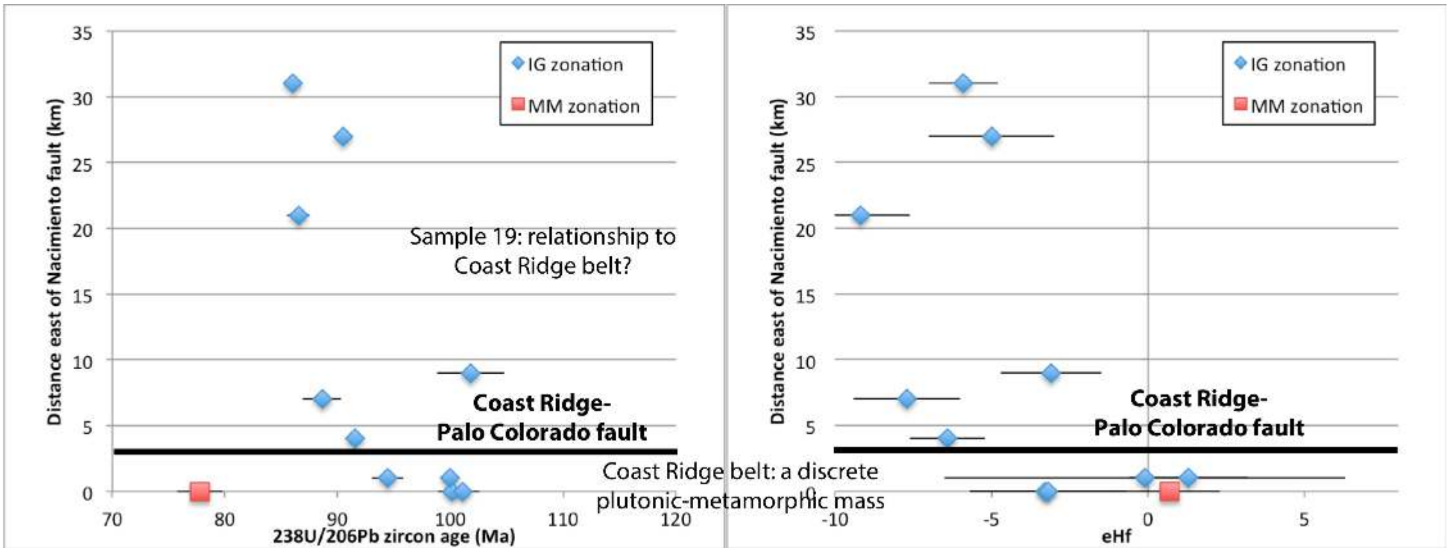

Figure 5. Plot showing distance from CR-PC plotted against 238/206 zircon ages and epsilon units from Hf isotopes.

Hafnium Isotopes

Hafnium isotope data follow a similar trend to that observed in U-Pb data. Near the Coast Ridge-Palo Colorado fault there is a ~5 epsilon unit break in Hf values, with the exception of sample 19. Hf values from west of the Coast Ridge-Palo Colorado fault zone range between -1.3 and 0.

East of the Coast Ridge-Palo Colorado fault, Hf isotope values are much more negative, suggesting an increasing crustal component. Within the eastern plutons negative εHf values between -8 to -9 may be a separate domain than the -5 to -6 from plutons closer to the schist of Sierra de Salinias. The differing Hf values for CRB plutons align with the interpretation of those plutons as being a distinct and deeper section of the arc.

CONCLUSION

The ~10 Myr age gap and ~5 εHf unit shift between CRB assemblages and plutons farther to the east coincides with a complex fault system that also shows a sharp break in metamorphic conditions (Kidder et al. 2003, Chapman et al. 2012). The grouping of ages from U-Pb isotope data correlates with similar grouping of Hf isotope values indicating that magmatic activity in the Salinia terrane probably happened in bursts. The Coast Ridge Belt is older, drier, and hotter than plutons to east and shows an Hf isotopic signature distinct from eastern plutons.

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