Oregon Sunstones: Copper and Lithium Diffusion Analysis of Eastern Oregon Sunstones

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INTRODUCTION & GEOLOGIC BACKGROUND

- Sunstones are large plagioclase feldspar crystals (An65 to An67) that contain microscopic inclusions of native copper (Cu). Located approximately 150 km apart Sunstone-bearing lavas occur in two mining localities (Ponderosa and Plush), within the Columbia River Basalt Province.
- Sunstones exhibit a variety of colors, including pink, yellow, red, and green; and areas of dense color correspond to higher concentrations of Cu within the crystal
- Age data indicates that the basaltic lavas containing sunstones have a notable age discrepancy
- The two leading hypotheses for the sunstone source includes magmatic source due to proximity and uniqueness of the lavas. However, heavy weathering and oxidation present in the groundmass of the basalt flows hosting the sunstones suggests that hydrothermal activity played a role.

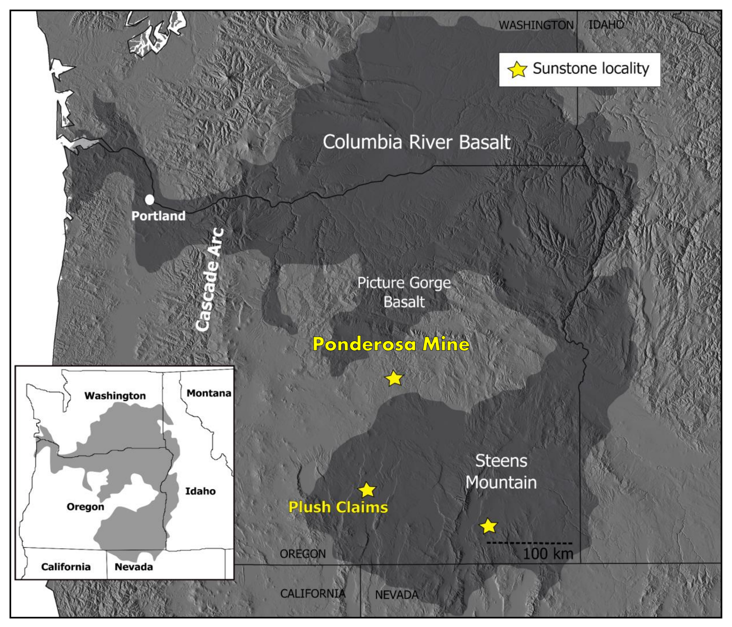


Figure 1. (Left) Map of geographic extent of Columbia River Basalt flow locations in dark gray. The yellow stars are placed at the locations of the sunstone mines. The northern star denotes Ponderosa and the southern stars near the Steens mountains represent the plush mines. Map provided by USGS.

Table 1. (Below) Represents the age discrepancies between the ground mass and plagioclase at each mine location.

Location	Groundmass Age (Ma)	Plagioclase Age (Ma)
Ponderosa	16.2	8.2
Plush	~9	10-17

OUSTANDING QUESTIONS & HYPOTHESES

This work is a part of a larger collaborative research project surrounding the source and processes involved in copper enrichment within Oregon's state gemstone. The occurrence of these copper-rich plagioclase is rare, and it is unlikely that the same anomaly would occur only 150 km apart and be unrelated in source.

The goals of this collaborative project are to confirm age discrepancies and characterize geochemical features of sunstones of different colors and source locations.

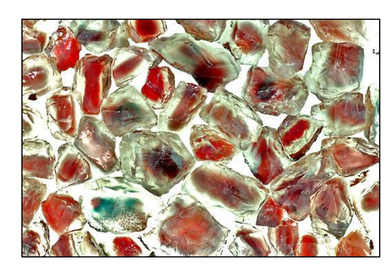
Potential Sources:

- Copper entered the lattice during plagioclase fractionation (magmatic)
- Copper entered the lattice post plagioclase fractionation at some depth (hydrothermal)

Motivation for this project:

- **Are sunstones zoned in major or trace elements? (This Work)**
- What is the age of the basaltic lavas that contain sunstones? (Kyle Nunley)
- Is there a systematic relationship between oxygen isotopes values of the sunstones and the hosting basalt? (Scott Toney)

Based on preliminary age and geochemical data I hypothesize that trace element diffusion profiles will differ slightly between the source locations, Ponderosa and Plush.



Figures 3 &4. (Right) Images demonstrate some of the color varieties possible within Oregon Sunstones. Samples were selected by color intensity and divided as blue-green, watermelon, shiller, and deep red. Note the gradual change from rim to core, this was the focus to determine potential elemental changes not only between mines, but within the stone as well.

METHODS

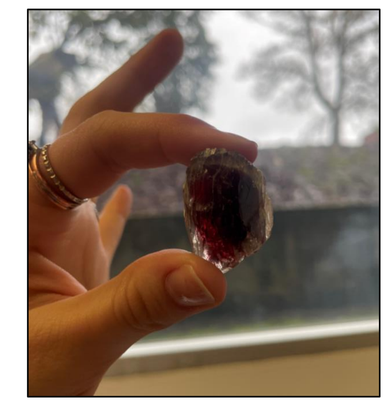
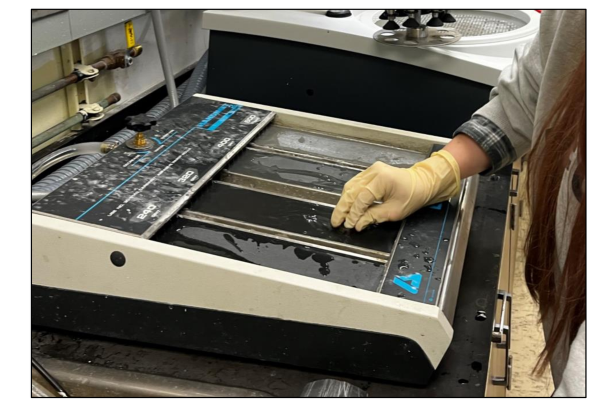


Figure 3: Deep Red sunstone that was utilized in each of the three research projects: element zoning, oxygen isotope values, and age analysis.



Figures 4: Polishing of pucks on varied sandpaper strips under running water.

Figure 5: Separates in epoxy after polishing ready for laser ablation.

Figure 6: Transect mapping of each sample for ablation work

Field Work

Samples were collected from sunstone mines located in eastern Oregon through multiple field seasons, including summer 2022, at the open pit mines: Plus, near Plush, OR and Ponderosa in the Ochoco National Forrest.

Sample Prep

Samples were chosen based on source location (i.e. different mines) and color intensity (red, shiller, blue-green, deep red). They were then crushed to into smaller fragments focused on the varied colors. Individual separates were then placed in epoxy and polished down to expose the areas of deepest color within the crystal.

Data Analysis

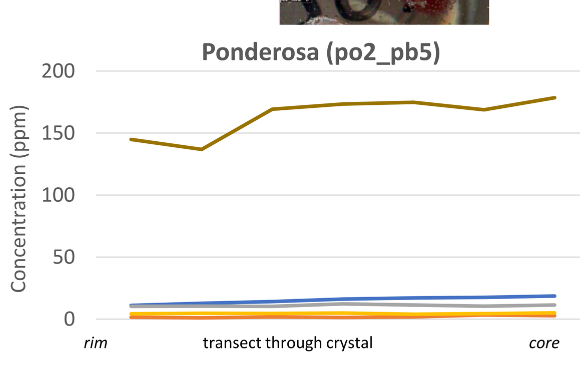
Data analysis was completed using , laser ablation inductively coupled plasma-mass spectrometry (LA-ICP-MS). Transects for laser ablation were created to allow measurements of both colorless outer rims and richer colored areas. Element Concentrations recorded include: Li, B, Mg, Si, Ca, Ti, Fe, Cu, Zn, Sr, Ba, La, Ce, Eu, Pb, Au, Sc, Y, and Zr.

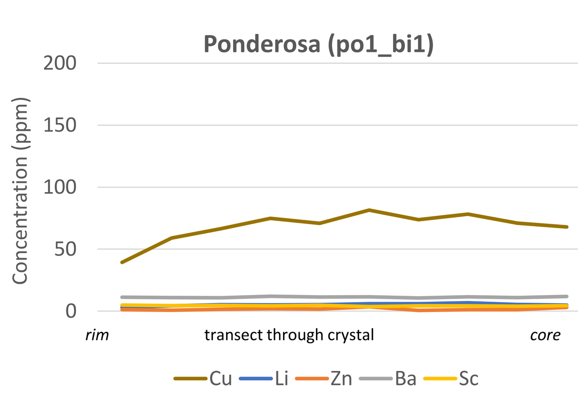
Data Reduction

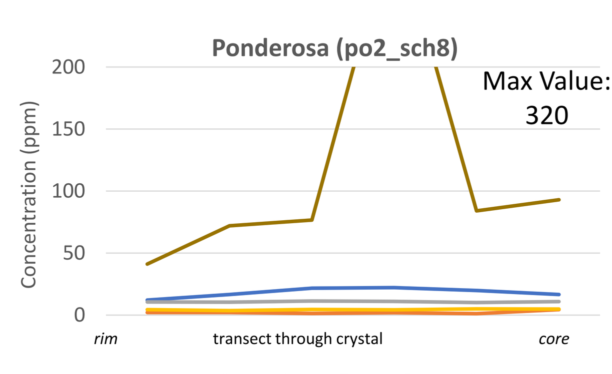
Data reduction will be completed using the Laser Time Resolved Analysis Module (LaserTRAM) and LaserCalc (programs built to calculate element compositions. Intervals from the time record of the laser analysis are selected in LaserTRAM to determine elemental ablation rates compared to predetermined standard ratios. LaserCalc then utilizes the outputs from the LaserTRAM to calculate the element concentrations.

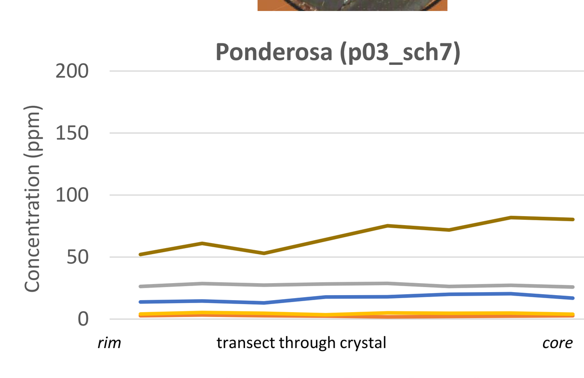
RESULTS

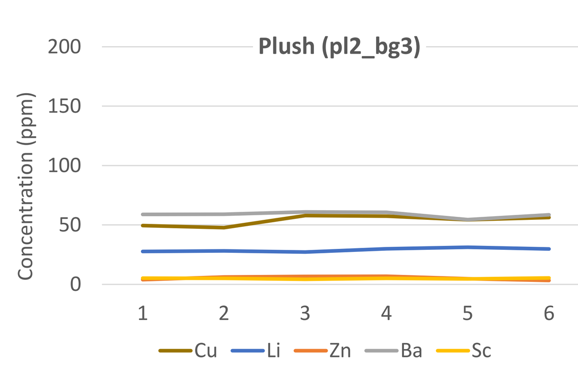
Element concentration of individual crystals from rim (colorless) to core (color dense)

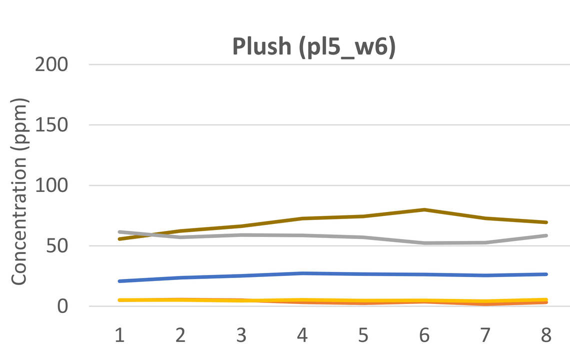


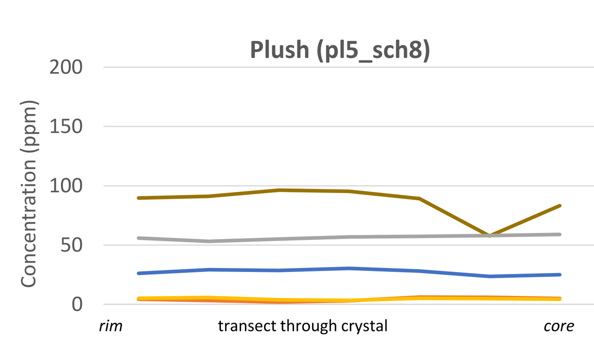


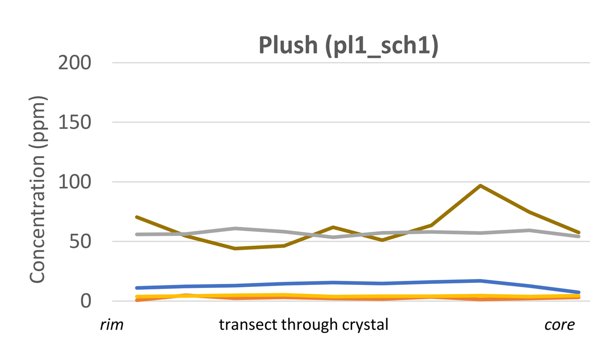


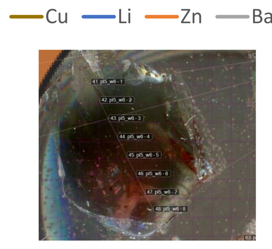


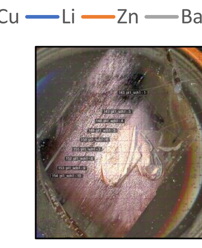




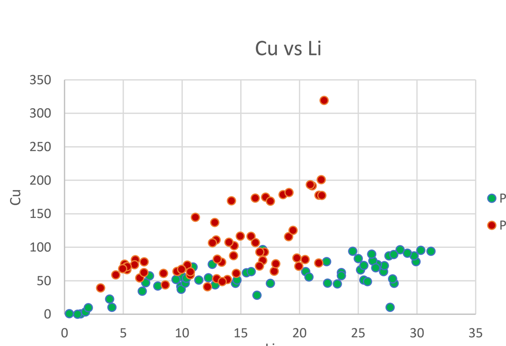


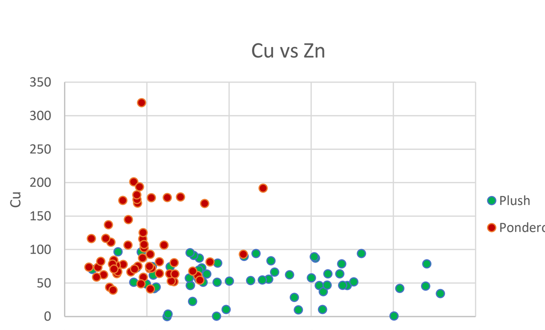


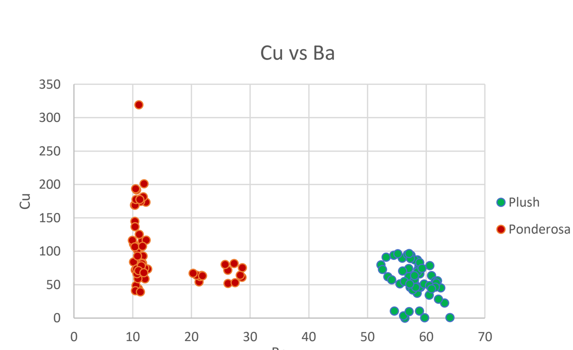


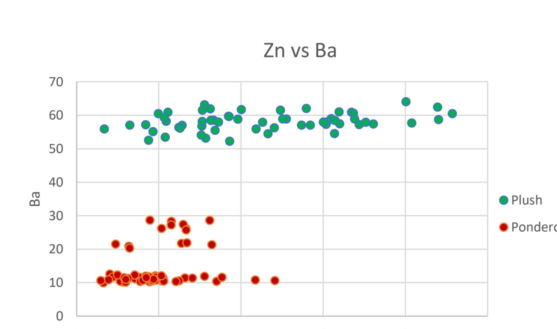


Element relations and correlations compared between the two source locations (Ponderosa and Plus)





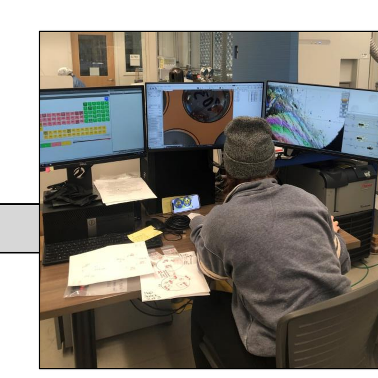


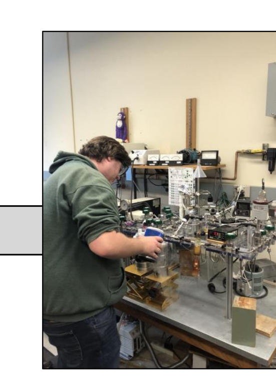


CONCLUSIONS

- Sunstones from the two source locations exhibit geochemical fingerprints (i.e. Ba is higher in Plush than Ponderosa)
- Cu variability through Plush crystals is independent decoupled with other elements of interests (i.e. Li, Zn, Ba, Sc)
- In some sunstones Cu and Ba appear anti-correlated (pl5_w6), however in other sunstone Cu seems to have a lot of variability that is not reflected in Ba concentration (po2_sch8)
- Relative to other colors, in schiller sunstones from both locations there is a significant increase in the variability in cu concentrations in sunstone that does not seem to be reflected in other colors of interest
- Cu and Li at both locations seem to be correlated, however there is possibility that sunstones originating from the Plush location sat at higher temperatures longer creating a more flatline correlation.
- Ponderosa element concentrations are more constrained with lower values than that of Plush

Given the geochemical fingerprints in the sunstones from both locations the trace element diffusion profiles do differ and can allow for distinction between sunstones originating from each source location.





The Sum of Three:

Scott Toney, Kyle Nunley and myself are all apart of a larger project to determine the source of the Oregon Sunstone. Through elemental zoning we can determine patterns and/or differences between the diffusion profiles of the Ponderosa and Plush mines. Oxygen isotope testing will provide insight to the potential of hydrothermal activity in the formation of the sunstones. Argon dating will clarify discrepancies within the age differences between groundmass and plagioclase found in the Ponderosa and Plush mines.

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