EARLY MESOZOIC VOLCANICLASTIC ROCKS OF AGNEW MEADOWS, EAST-CENTRAL SIERRA NEVADA, CALIFORNIA

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1. Abstract

In the Ritter Range pendant of the east-central Sierra Nevada, volcaniclastic strata of the Koip sequence in Agnew Meadows have a northwest strike and dip steeply to the northeast, allowing a transect through early Mesozoic volcanic arc stratigraphy. Strata exposed around Agnew Meadows include ≈220 Ma rhyolitic tuff and tuff breccia. The tuff contains broken phenocrysts (< 2 mm) and fiamme (< 2 cm) and is likely a pyroclastic density current deposit. Predominantly matrix-supported pumice clasts (< 1.5 m) constitute the tuff breccia, which may be floating-to-water-logged pumice and ash erupted from a subaqueous volcano. These rhyolitic deposits are deformed and altered; however, we look past those secondary processes to characterize the original volcanic facies and magmatic products.

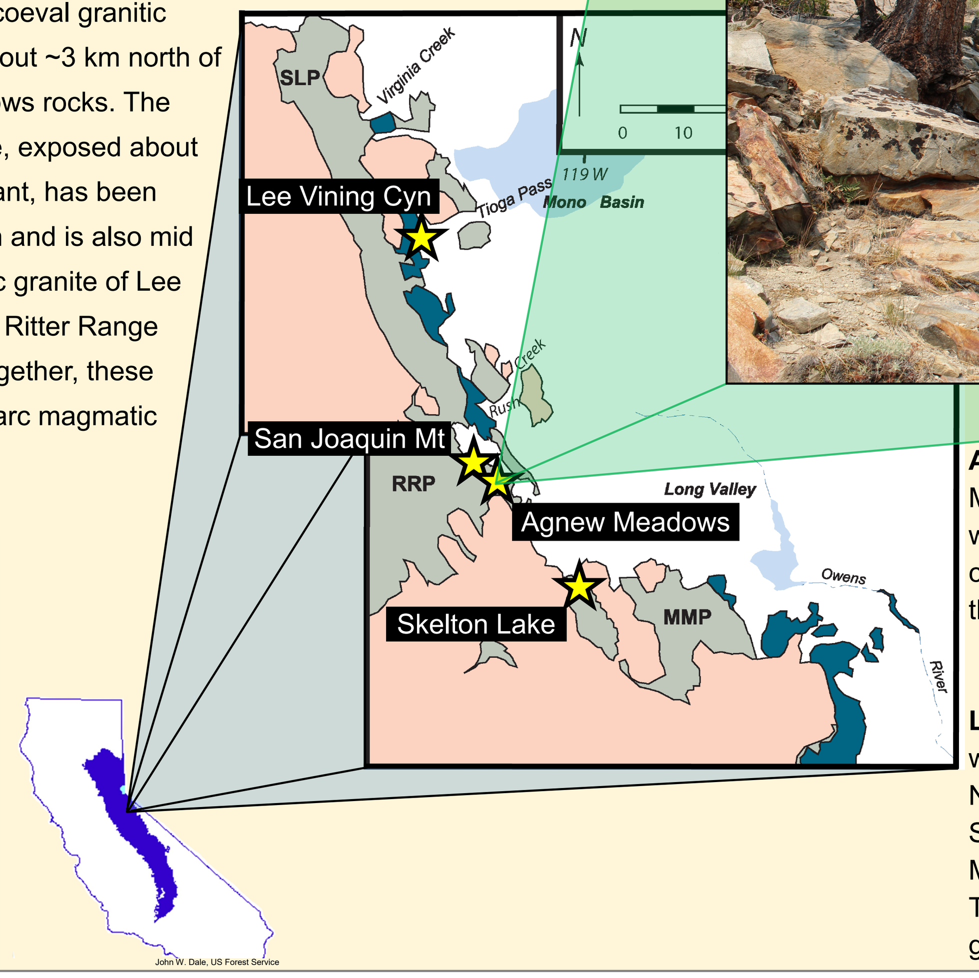
The tuff and tuff breccia clasts are crystal-poor and porphyritic with an average of 11% ß-quartz and plagioclase phenocrysts. The ß-quartz phenocrysts are mostly fragmented with few subhedral to euhedral grains < 2.6 mm, and ≈30% of the intact crystals are embayed. The plagioclase grains are approximately equally fragmented and subhedral to euhedral grains (< 1.8 mm). Harker diagrams show whole-rock compositions are similar while the breccia clasts are relatively more silica-rich: the tuff samples average 72.4% SiO_2 by weight while the breccia clasts average 76.7%. Negative covariation between silica and fluid-immobile elements (Al_2O_3, TiO_2, Zr) indicate the breccia clasts are more fractionated than the tuff. Chondrite-normalized REE patterns are light REE-enriched with small negative europium anomalies and slight depletion in the middle to heavy REE.

Similar physical and chemical characteristics are noted in other Triassic tuffs in the eastern Ritter Range and Mount Morrison pendants as well as in the granite of Lee Vining Canyon, a pluton of the late Triassic Scheelite Intrusive Suite. Observations of the physical, chemical, temporal, and spatial homogeneities between various Sierran intrusive and extrusive rocks suggests that volcaniclastic rocks and plutons were coeval and probably cogenetic. If early Sierran arc plutons and volcanic deposits had similar origins, then at least some of the plutons must be fossil magma chambers.

2. Introduction & Geological Setting

The Sierra Nevada in eastern California exposes Mesozoic granitic plutons, locally separated by pendants composed in part of broadly coeval volcanic deposits (Fiske and Tobisch, 1978). These deposits record volcanism associated with the development of the Sierra Nevada batholith (Barth et al., 2011). In this study, we examined the depositional setting and geochemical relationships between units in a section of marine ash flow tuff and tuff breccia in Agnew Meadows, along the eastern side of the volcanic section in the Ritter Range pendant. The tuff and tuff breccia of Agnew Meadows are ≈220 Ma (U-Pb zircon; Barth et al., 2018), placing volcanic activity very early in the history of batholith construction in the mid-Triassic. The eastern Ritter Range pendant deposits have been faulted and rotated to very steep dips, allowing us to transect this marine volcanic section. However, deformation and greenschist to epidote amphibolite facies metamorphism has obscured some primary features of the volcanic rocks, which presents a challenge in analysis of their magmatic and depositional history.

In order to place the Agnew Meadows rocks in regional context and develop a more complete mid-Triassic magmatic history, we compared them to nearby coeval tuffs of the eastern Ritter Range and Mount Morrison pendants and to a coeval granitic pluton. The tuff of San Joaquin Mountain crops out ~3 km north of and stratigraphically beneath the Agnew Meadows rocks. The thick and laterally-extensive tuff of Skelton Lake, exposed about 18 km to the south in the Mount Morrison pendant, has been correlated with the eastern Ritter Range section and is also mid-Triassic in age (Barth et al., 2018). The Triassic granite of Lee Vining Canyon intrudes the eastern edge of the Ritter Range pendant north and east of Agnew Meadows. Together, these volcanic and intrusive rocks make up the early arc magmatic record in the eastern Sierra Nevada.



Above: An outcrop of tuff breccia (**tb1**) in Agnew Meadows (20 x 25 cm composition notebook for scale) with nearly vertical planar fabric and obloid-shaped clasts, and outcrop of tuff (**t1**) in Agnew Meadows with the tuff breccia in the background for spatial reference.

Left: A geologic map of the east-central Sierra Nevada where the areas of interest are marked by yellow stars. North to south, the pendants shown in green are Saddlebag Lake (SLP), Ritter Range (RRP), and Mount Morrison (MMP). The areas in blue represent the Triassic Scheelite Intrusive Suite, which includes the granite of Lee Vining Canyon.

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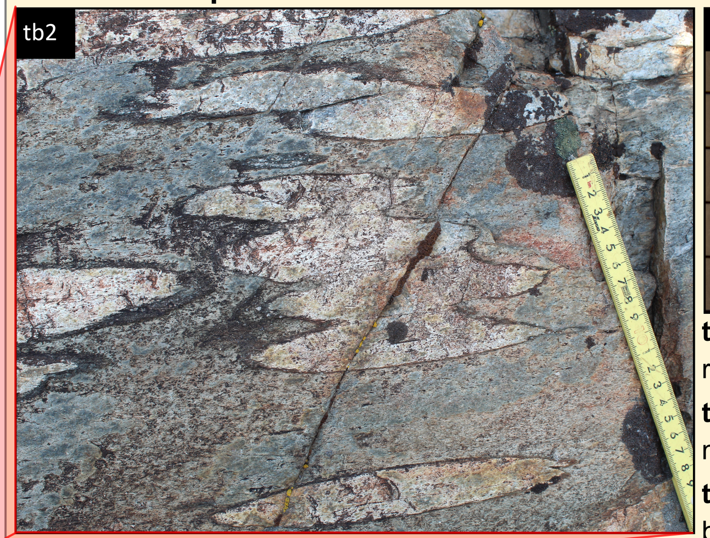
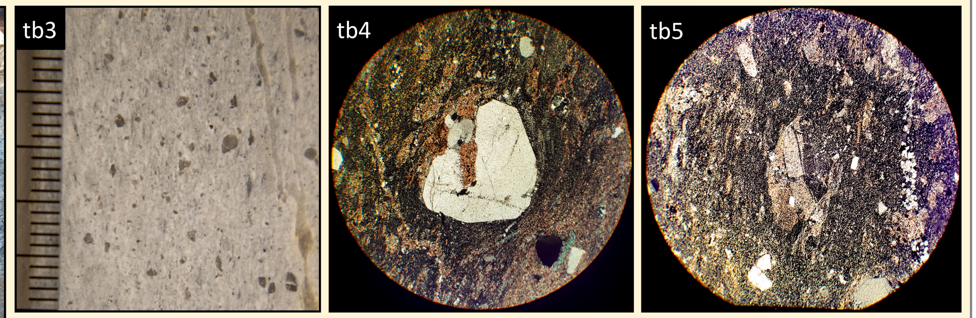
3. Mineralogy & Point Counting

Agnew Meadows and neighboring coeval tuffs:
- porphyritic texture
- ß-quartz and plagioclase phenocrysts
- low xl to matrix ratio

Granite of Lee Vining Canyon:
- ß-quartz and plagioclase crystals

A closer inspection of the tuff breccia



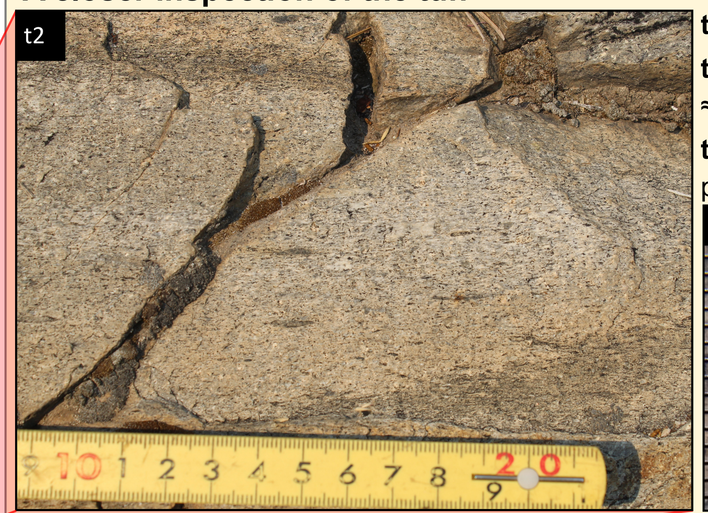


tb2: Agglomerated clasts in a predominantly matrix-supported breccia—clast range = 0.1-1.5 m and average ≈ 0.4 m (long axis).

tb3: Porphyritic breccia clast—phenocrysts of quartz (r = 0.5-2.5 mm; avg ≈ 1 mm) and plagioclase (r = 0.5-2 mm; avg ≈ 0.5 mm).

tb4 & **tb5**: XPL photomicrographs of embayed, subhedral ß-quartz and broken plagioclase, respectively (40x mag; FOV = 4.4 mm). The quartz embayment records a temperature rise immediately preceding eruption.

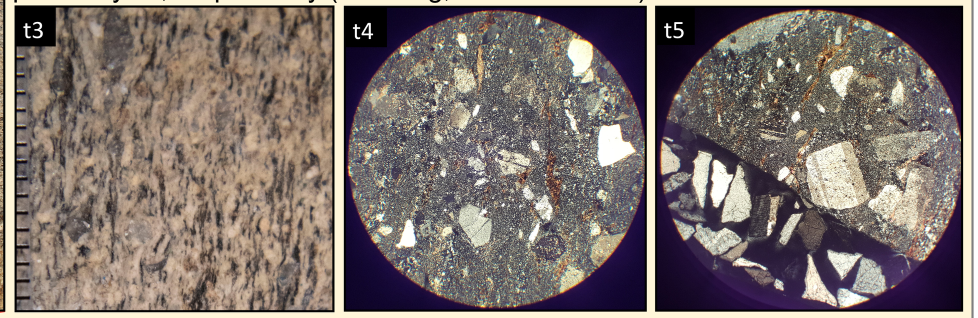
A closer inspection of the tuff

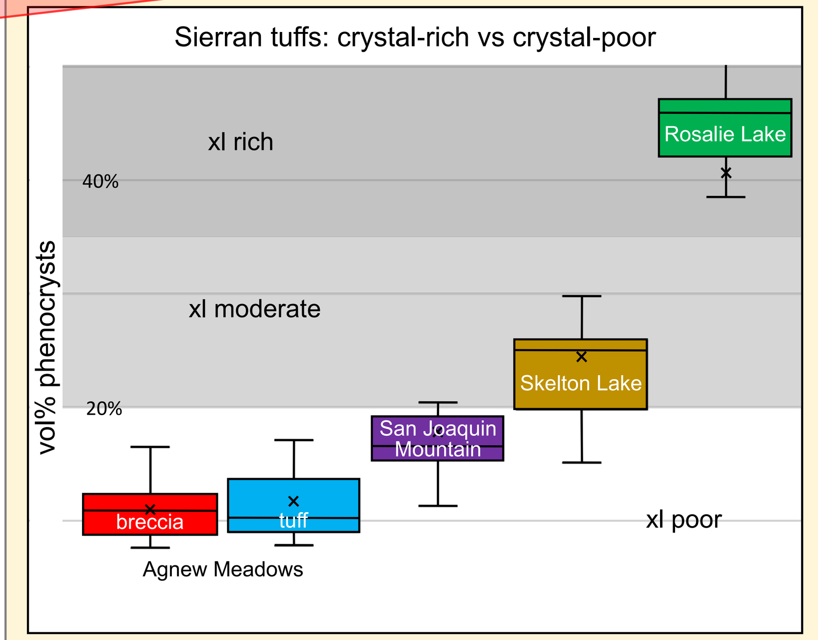


t2: Fiamme in the tuff (range = 0.5-2 cm; average ≈ 1 cm).

t3: Porphyritic tuff hand sample—phenocrysts of quartz (r = 0.5-2.5 mm; avg ≈ 1 mm) and plagioclase (r = 0.5-2 mm; avg ≈ 0.5 mm).

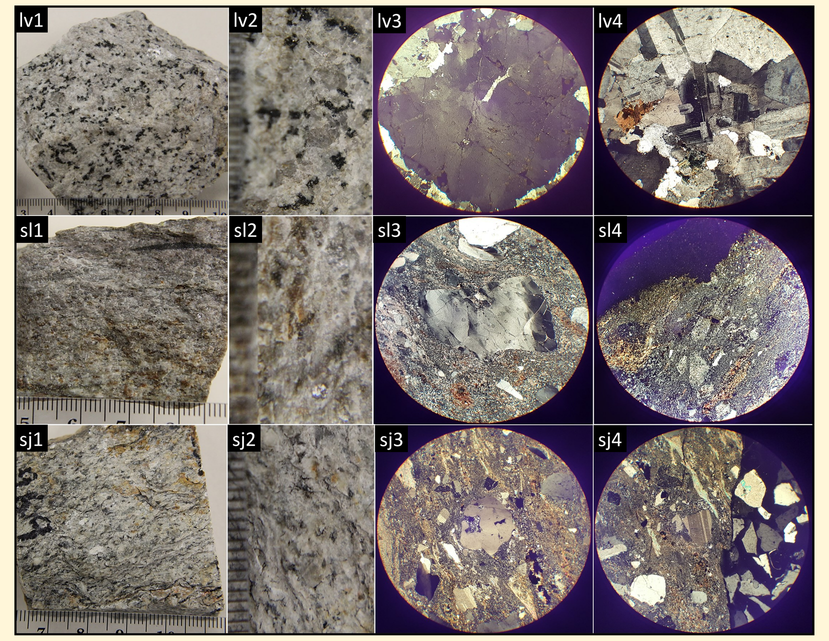
t4 & **t5**: XPL microphotographs of shattered ß-quartz and plagioclase phenocrysts, respectively (40x mag; FOV = 4.4 mm).





Crystallinity of Sierran tuffs compared to Basin and Range tuffs (Bachmann and Bergantz, 2008; Huber et al., 2012). Black lines = median, x = mean, and outliers are removed. The breccia and tuff of Agnew Meadows are xl poor while San Joaquin Mt. is more xl rich. Skelton Lake ranks as xl moderate (Wright, sect. 96 #33), and the nearby Jurassic tuff of Rosalie Lake is plotted as an xl-rich example (Middleton, sect. 116 #310).

Neighboring tuffs and granite (all ≈ 220 Ma)



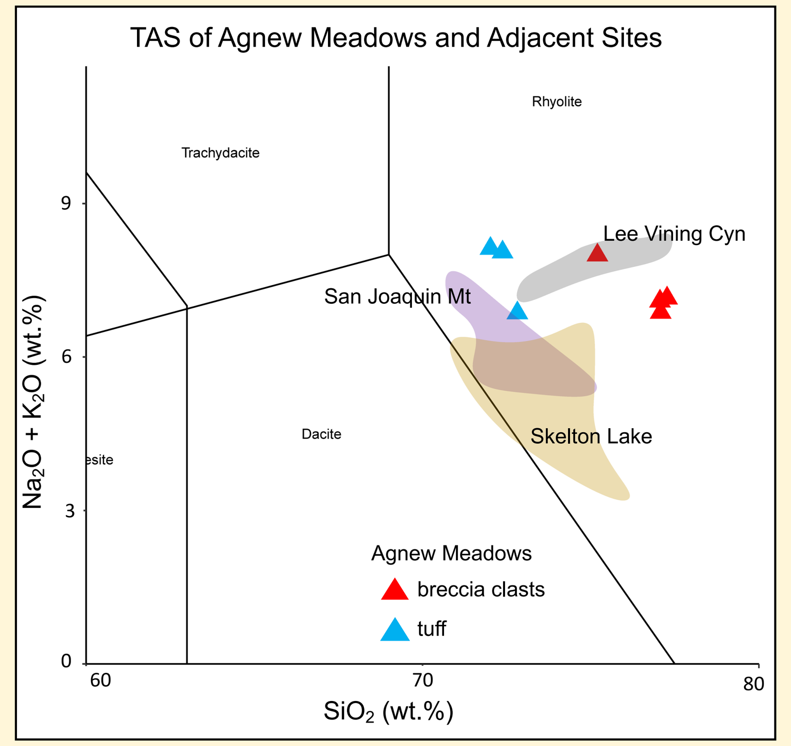
Top to bottom: granite of Lee Vining Canyon (**lv**) and tuffs of Skelton Lake (**sl**) and San Joaquin Mountain (**sj**). Left to right: hand sample (**1&2**) and phenocrysts of ß-quartz (**3**) and plagioclase (**4**). The mineralogy of all samples is similar to the tuff and tuff breccia of Agnew Meadows. All samples contain ß-quartz and plagioclase, and all the tuffs have quartz embayments, recording a temperature rise preceding complete crystallization.

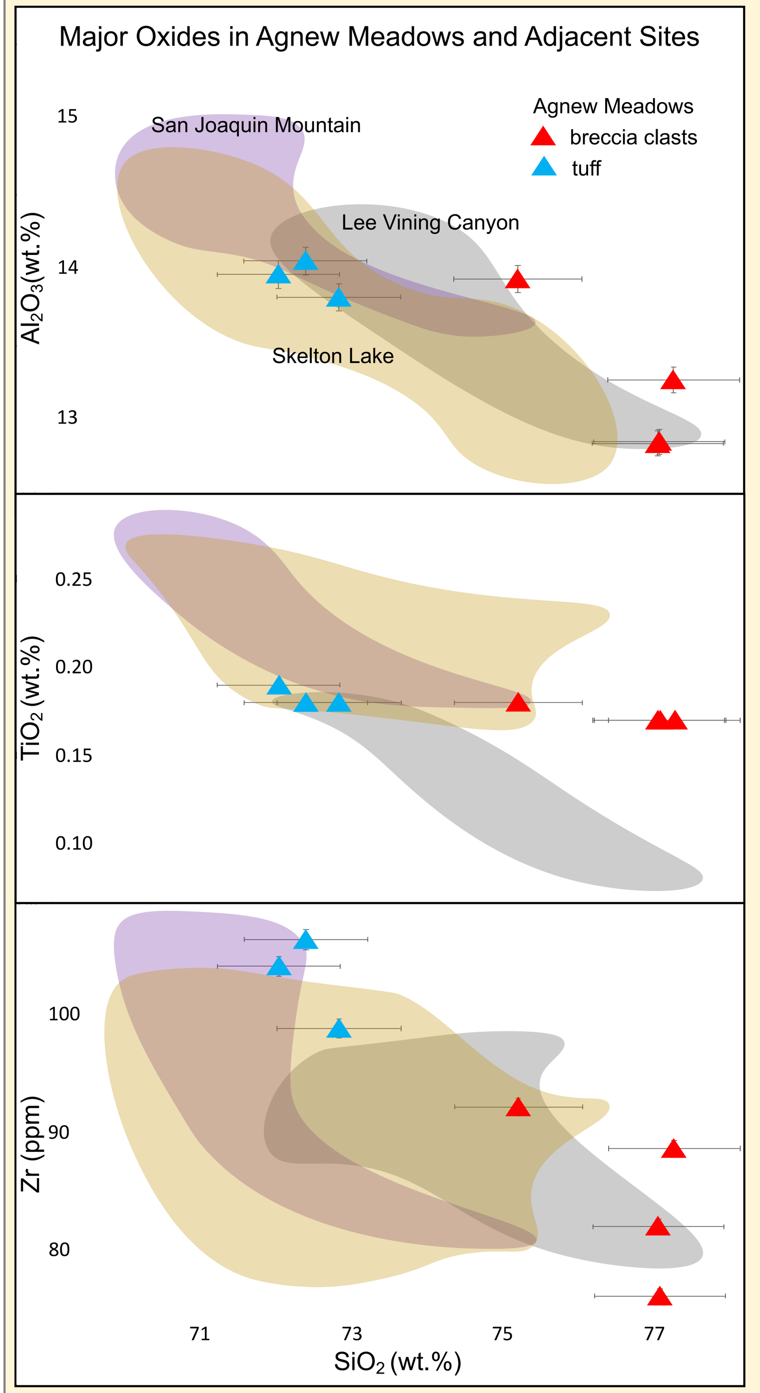
4. Chemical Analysis

Agnew Meadows and neighboring coeval tuffs:
- silica-rich rhyolites
- products of fractionation
- chemically similar

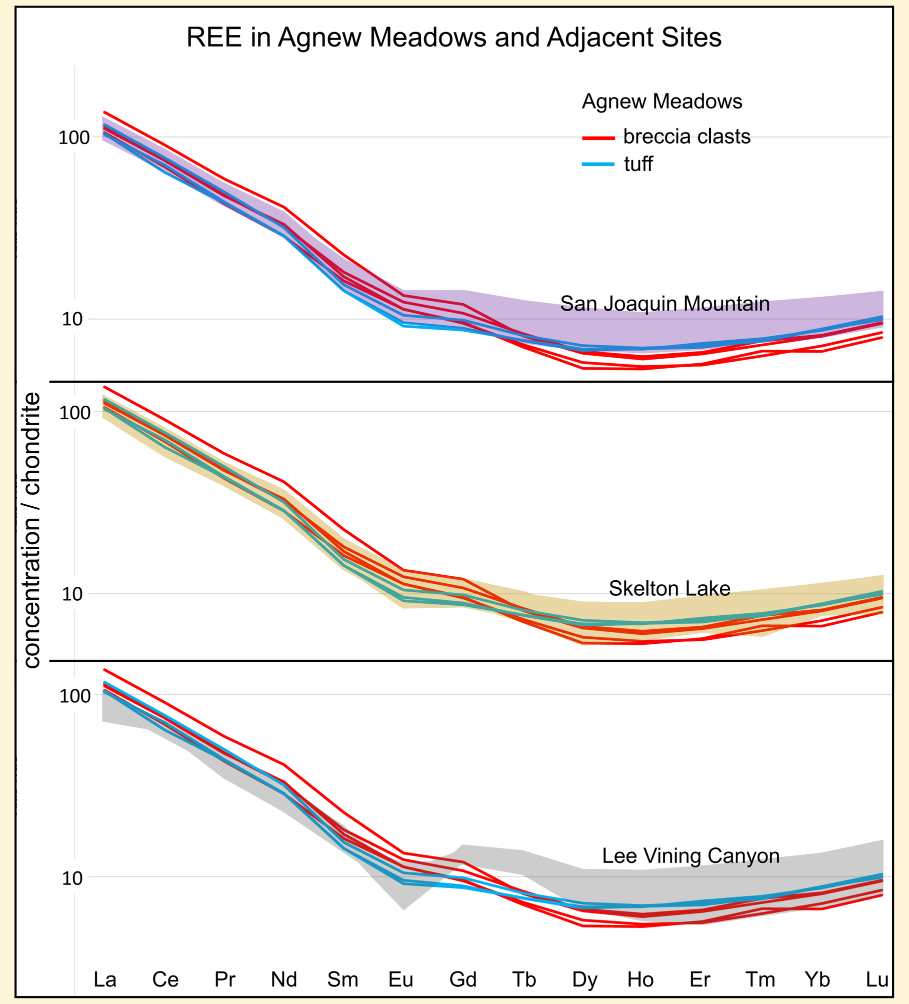
Granite of Lee Vining:
- silica-rich rhyolite when plotted as extrusive
- product of fractionation
- chemically similar to adjacent tuffs

Right: The tuff and tuff breccia of Agnew Meadows are classified as rhyolites, and the comparison sites, including the granite of Lee Vining Canyon, have similar compositions. However, hydrothermal alteration has likely affected the alkali content. Note the high SiO_2 -content of the breccia clasts which also have the lowest phenocryst count.





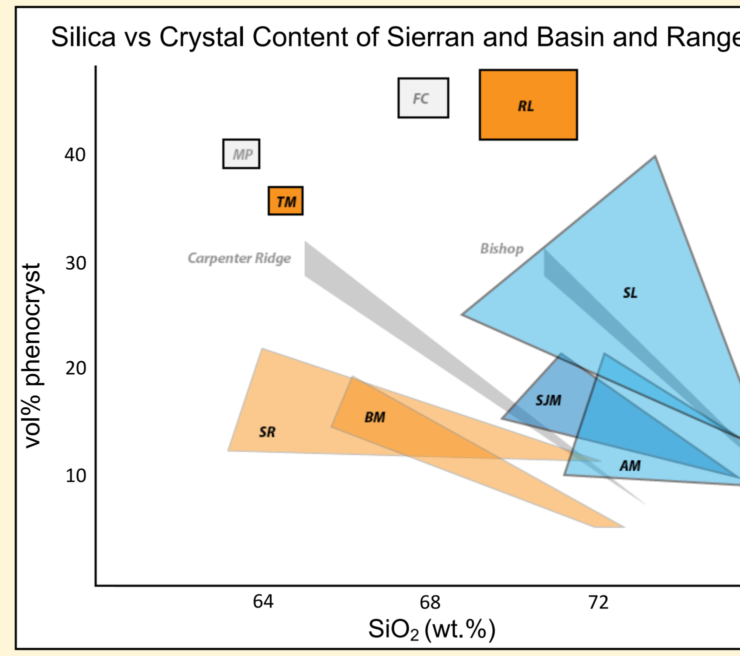
Harker diagrams of fluid immobile major elements in Agnew Meadows and comparison sites. Generally, Agnew Meadows is similar to Skelton Lake, and all sites indicate fractionation: as Zr, Ti, and Al decrease in abundance, Si increases. All the breccia clasts are more fractionated than the tuff of Agnew Meadows.



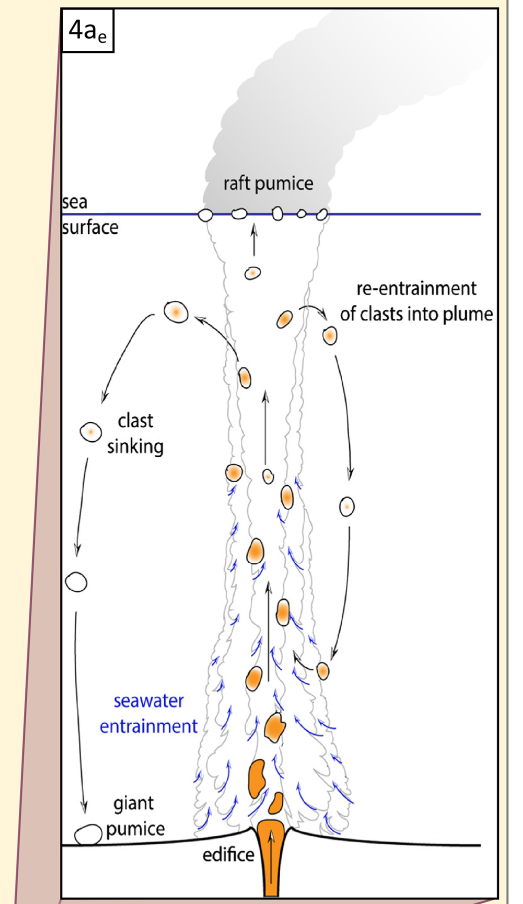
Spider diagrams of normalized REE. Agnew Meadows, like San Joaquin Mountain and Skelton Lake, is light REE-enriched, a characteristic of volcanic arcs, and has minimal Eu anomalies suggesting oxidizing conditions in the magma chamber. The granite of Lee Vining Canyon has a slightly more pronounced Eu anomaly suggesting a more reducing environment during crystallization. The granite's heavy REE are also slightly higher than Agnew Meadows, but Lee Vining's negative trend in light REE suggests it is also a product of arc volcanism.

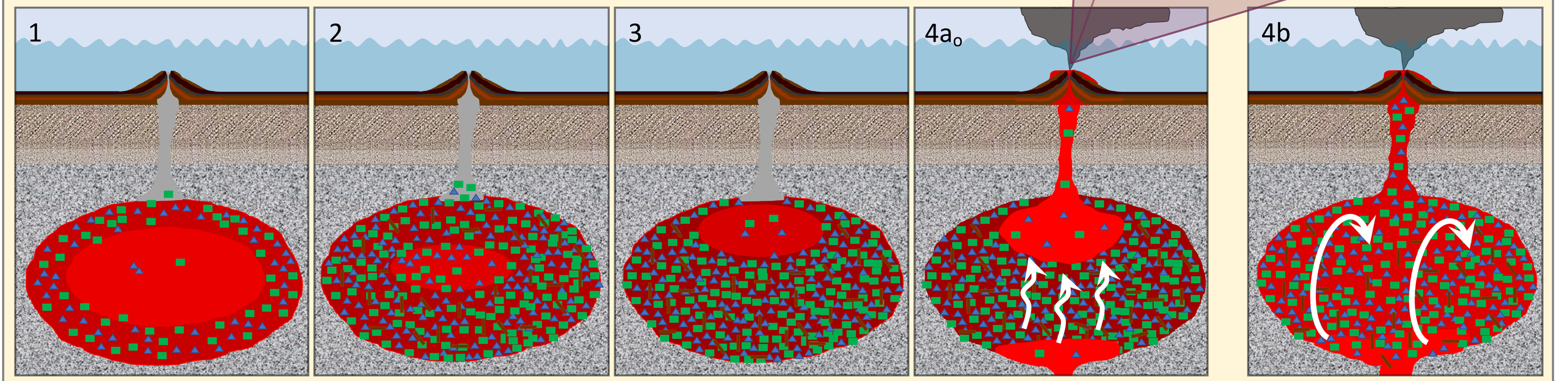
5. Magma Chamber Model

Agnew Meadows and neighboring coeval tuffs:
- crystal fractionation
- negative correlation between SiO_2 and phenocryst abundance
- similar characteristics to Bishop Tuff
- Bachmann and Bergantz (2008) magma chamber model and Mitchell et al. (2018) physical eruption model



Above: A plot of silica versus phenocryst abundances for Sierran tuffs. Triassic tuffs (blue): Agnew Meadows (AM), San Joaquin Mountain (SJM), and Skelton Lake (SL); Jurassic tuffs (orange): Black Mountain (BM), Stoddard Ridge (SR), Turtle Mountain (TM), and Rosalie Lake (RL); Basin and Range tuffs: Fish Canyon (FC), Masonic Park (MP), Carpenter Ridge, and Bishop. Note the two groups: 1) the crystal-rich, silica poor tuffs and 2) the crystal-poor, silica rich. All of the Triassic tuff samples from east-central Sierra Nevada fit the latter description.





1: Magma accumulates in country rock and begins to crystalize. According to Piwinski (1968), the first mineral to saturate the melt is plagioclase, then ß-quartz.

2: Crystals interlock as the accumulate, creating a matrix with a greater density than surrounding melt.

3: The crystal matrix collapses, segregating the fractionated melt. At 45-65% crystals, interstitial melt efficiently migrates to segregated lens of melt. If this igneous body continues to cool with no further influx of heat, it will become a pluton. This is the likely scenario for the granite of Lee Vining Canyon. However, if new, hot melt is introduced to the system, a volcanic eruption could be triggered.

$4a_o$: New, hot melt is injected. Gas percolation efficiently transfers heat and volatiles to the fractionated silica-rich lens of segregated melt, causing an eruption that produces crystal-poor, high-silica tuff. This scenario is plausible for the tuff and tuff breccia of Agnew Meadows, San Joaquin Mountain, and Skelton Lake.

$4a_e$: In a subaqueous eruption, the production and deposition of floating-to-water-logged pumice and ash could produce matrix-supported pumice breccia.

4b: New, hot melt is injected and heats the entire body of mush, unlocking it as convection mixes the magma chamber before erupting a crystal-rich homogenous tuff. This scenario is plausible for the tuff of Rosalie Lake and Fish Canyon.

Acknowledgements

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