Petrological Constraints on Causes of Colorado Plateau Uplift

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Photo: Snap Point, western Grand Canyon, looking west towards the Grand Wash Cliffs and Lake Mead

Abstract

The dynamics that caused ~1.9 km of uplift of the Colorado Plateau since the Late Cretaceous are enigmatic, but created potentially observable effects in terms of volcanic products of melting events as well as in elevation changes. Recent advances in constraining the timing of Colorado Plateau uplift have suggested that unroofing occurred in the southwest Plateau margin in the Late Cretaceous to Early Tertiary, followed by a southwest to northeast unroofing of the Plateau interior in the mid- to Late Tertiary [1], and furthermore, that approximately 1000 m of uplift of the Plateau interior may postdate 6 Ma [2]. To complement these results, we are compiling a database of geochemical analyses from the literature, from basalts and related volcanic rocks erupted across Arizona in the last 20 Myr, both on the Colorado Plateau and in the adjacent Transition Zone and Arizona Basin and Range to the south. Volcanic products in this region range from widely scattered discrete, small-volume, monogenetic flows, to larger eruptive centers, but the cumulate volume of the group as a whole is large and represents a significant magmatic outpouring during uplift of the Plateau. Southwest to northeast temporal migrations in volcanism have previously been recognized for the western Grand Canyon sub-region [3] and the San Francisco Volcanic Field [4]. Preliminary results from our database show that this temporal migration persists over the entire study region, and furthermore is accompanied by distinct compositional trends. The strongest trace element trend is a decreasing Nb depletion in basalts representing a decreasing arc-like signature-- e.g., from 20 Ma to 1 Ma and from southwest to northeast, Nb/La increases from ~0.2 to ~1-2. There is also a trend of increasing average FeO* among basalts from 20 to 1 Ma, accompanied by decrease in average SiO_2 but no change in average MgO or Na_2O, that suggests a generally increasing depth of melting.

A second aspect of this project is field sampling of basalts and measurement of oxygen isotopes in olivines, to add to the geochemical dataset for the study region. Olivine is the earliest-crystallized mineral phase in these lavas and the most likely to preserve geochemical characteristics of the primitive melts, before any potential contamination by continental crust during magma ascent or storage in the crust. The oxygen isotope composition of these olivines should therefore point towards the oxygen isotope composition of the mantle source material. Ultimately we plan to compare geochemical trends of erupted lavas in space and time to geological constraints on the timing of unroofing and uplift described above, which will allow us to infer changes in parameters such as mantle source lithology and state of hydration, extent of melting, and depth of melting, associated with specific episodes of Plateau uplift. This should allow us to discriminate between the major models historically proposed for causes of uplift of the Plateau and acquisition of buoyancy.

COMPILING A DATABASE:

950 analyses from the literature
location, age, composition

How does magmatism relate to Colorado Plateau uplift?

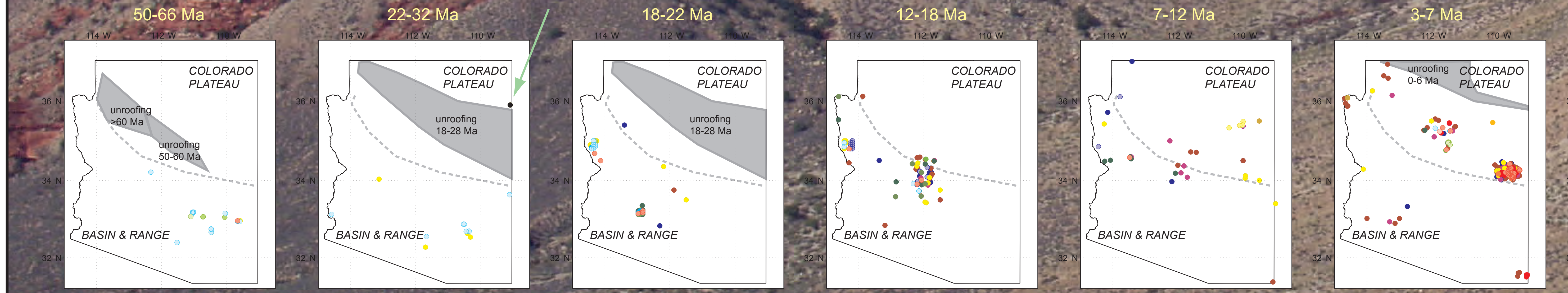
Summary of proposed mechanisms for uplift [8]:

1.) Sevier/Laramide deformation 60 Ma: thicken crust, thin upper mantle, or rarify upper mantle by adding volatiles?
Flux melting of mantle wedge above subduction zone-- arc magmas?
2.) Demise of Laramide flat slab mid-Tertiary (35 Ma): extract melt from upper mantle?
Decompression melting of upwelling asthenosphere?
3.) Late Tertiary regional extensional tectonics: convective removal of lithosphere, or heating from below?

Does Magmatism Follow Unroofing?

Regions of unroofing: (U-Th)/He apatite thermochronometry; from Flowers et al. (in press)

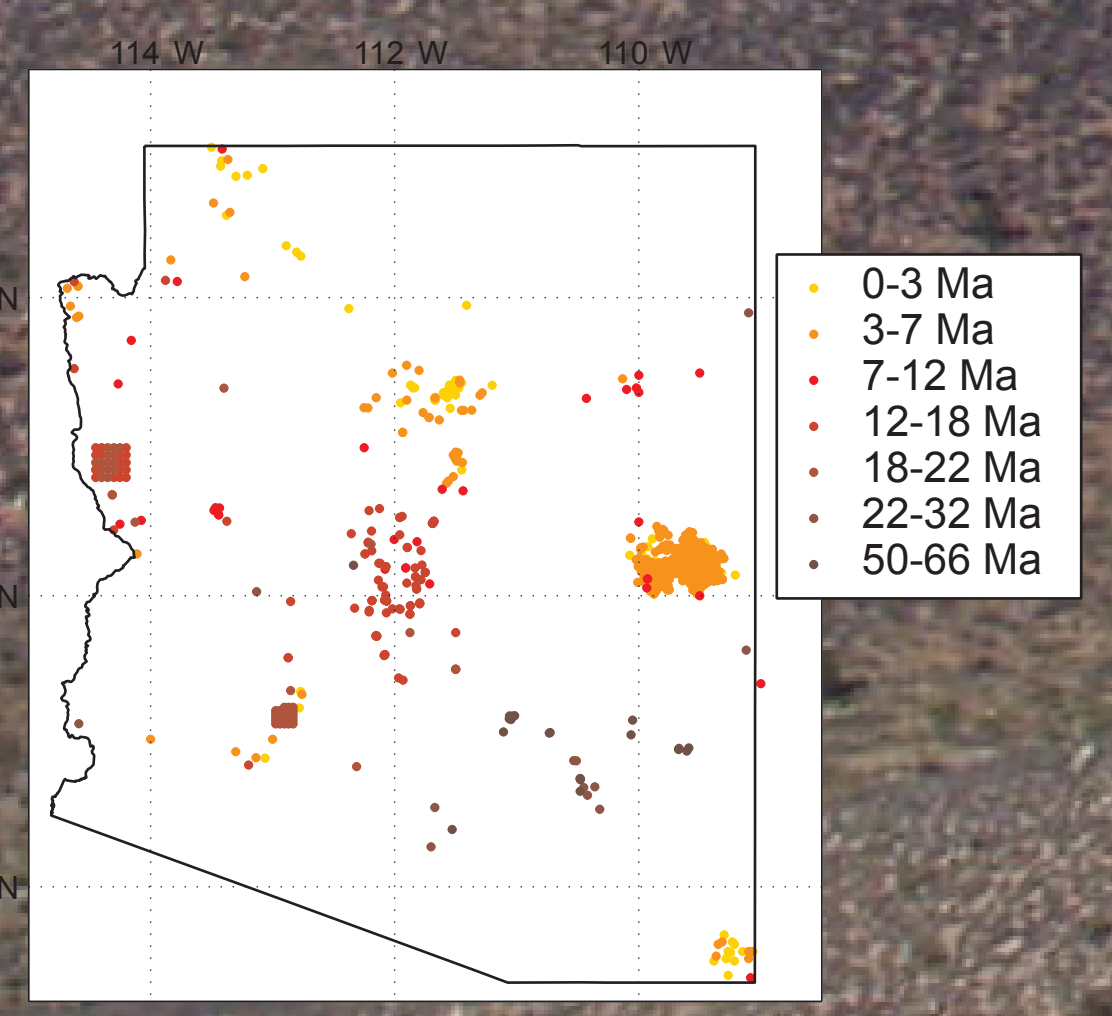
HSFE-rich oxide inclusions in garnet xenocrysts, in Navajo Buttes eruption 25-32 Ma [5]



- Tholeiite
- Alkali olivine basalt
- Calc-alkaline basalt
- Transitional basalt
- High-K calc-alkaline basalt
- High-K alkaline basalt
- Minette
- Icelandite
- Basaltic andesite
- Andesite
- High-K andesite
- Dacite
- Latite
- Rhyolite
- Hawaiite
- Mugearite
- Trachyandesite
- Trachyte
- Basanite
- Leucite basanite
- Lamproite
- Monchiquite
- Out of range

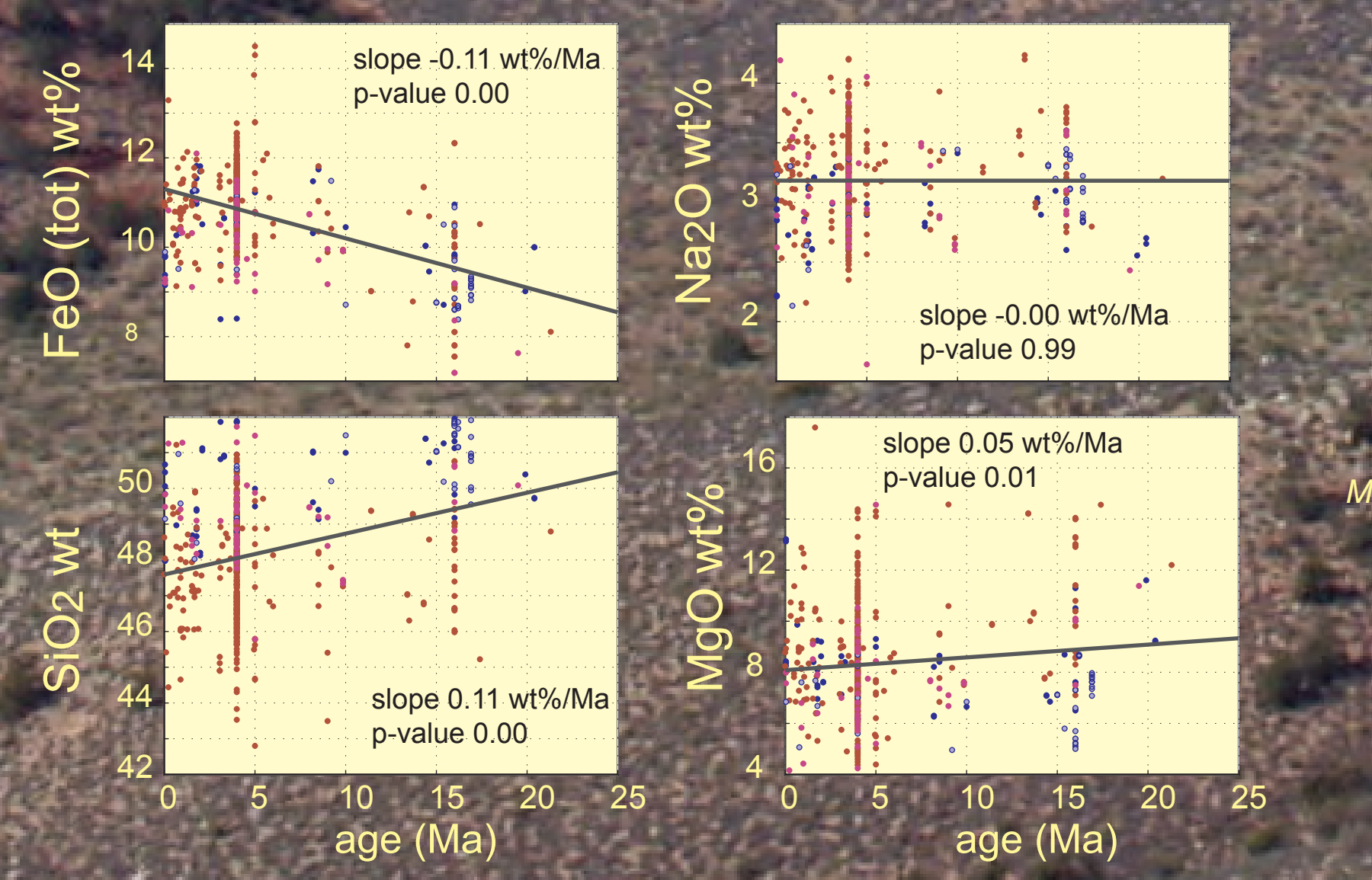
Note the compositional diversity present

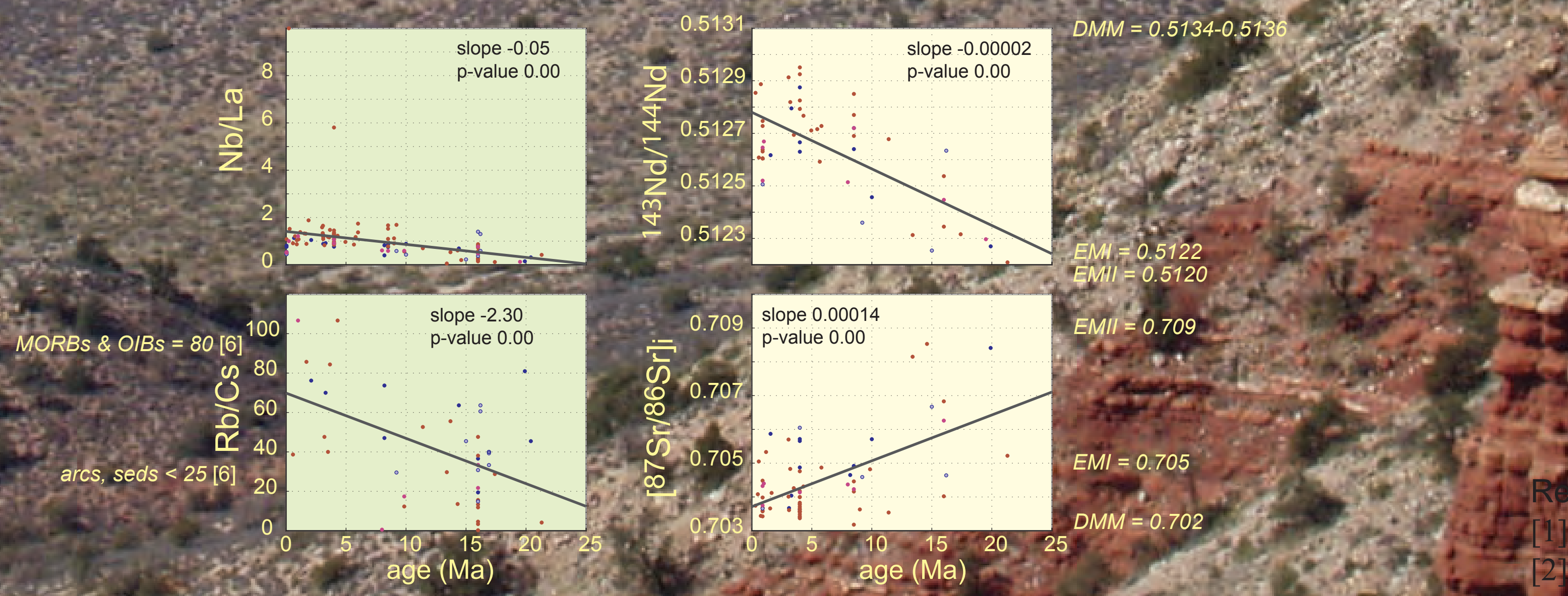
Temporal Migration of Magmatism



General Compositional Trends with Time: A First-Order Clue to Mantle Composition and Behavior?

Complications: assimilation of crustal wallrock during magma ascent or ponding
Remedy: limit study to basalts (the more primitive, the better)





Major Elements (Interpreted in terms of melting peridotite):

Increasing FeO*, decreasing SiO_2 consistent with generally increasing depth of melting
(Crustal thickening towards the NE? Increasing mantle potential T? Lower solidus?).
Unchanging Na_2O argues against gross changes in extent of melting.
Unchanging MgO argues against gross changes in extent of crystal fractionation.

Trace Elements and Radiogenic Isotopes:

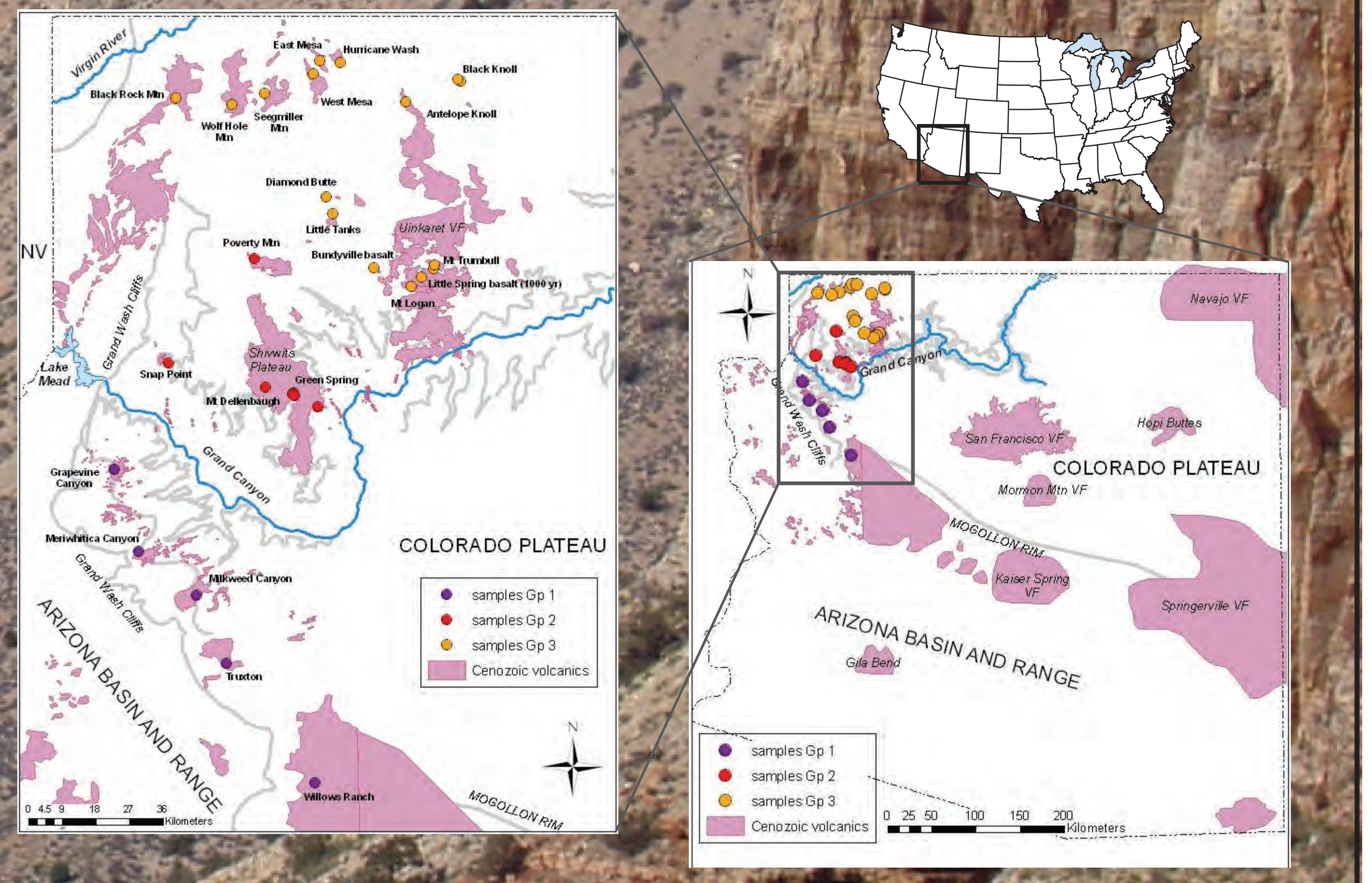
Increasing Nb/La, Rb/Cs consistent with generally decreasing arc signature.
(decreasing assimilation of Proterozoic arc-derived crust, or increasing asthenospheric component to mantle source?)
Increasing $^{143}Nd/^{144}Nd$, decreasing $^{87}Sr/^{86}Sr$ towards depleted MORB mantle (DMM).

Planned Work: Oxygen isotopes in olivines

Typical $\delta^{18}O$ of possible mantle components [7]:

mantle peridotite: $\delta^{18}O$ = 5.5 ± 0.2 ‰
marine carbonates: $\delta^{18}O$ = 25-32 ‰
siliceous oozes: $\delta^{18}O$ = 35-42 ‰
pelagic clays: $\delta^{18}O$ = 15-25 ‰
hydrothermally altered upper oceanic crust: $\delta^{18}O$ = 7-15 ‰
hydrothermally altered lower oceanic crust: $\delta^{18}O$ = 0-6 ‰
hydrothermally altered ultramafics (serpentinite): $\delta^{18}O$ = 0-6 ‰
pore water in marine sediments: $\delta^{18}O$ = 0 to -3, to -15 ‰

Samples Collected:



References:
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