The Bidahochi Basin hypothesis: Hopi Buttes volcanics and paleolake marks location of local, small-scale lithosphere foundering and asthenosphere upwelling beneath the Colorado Plateau

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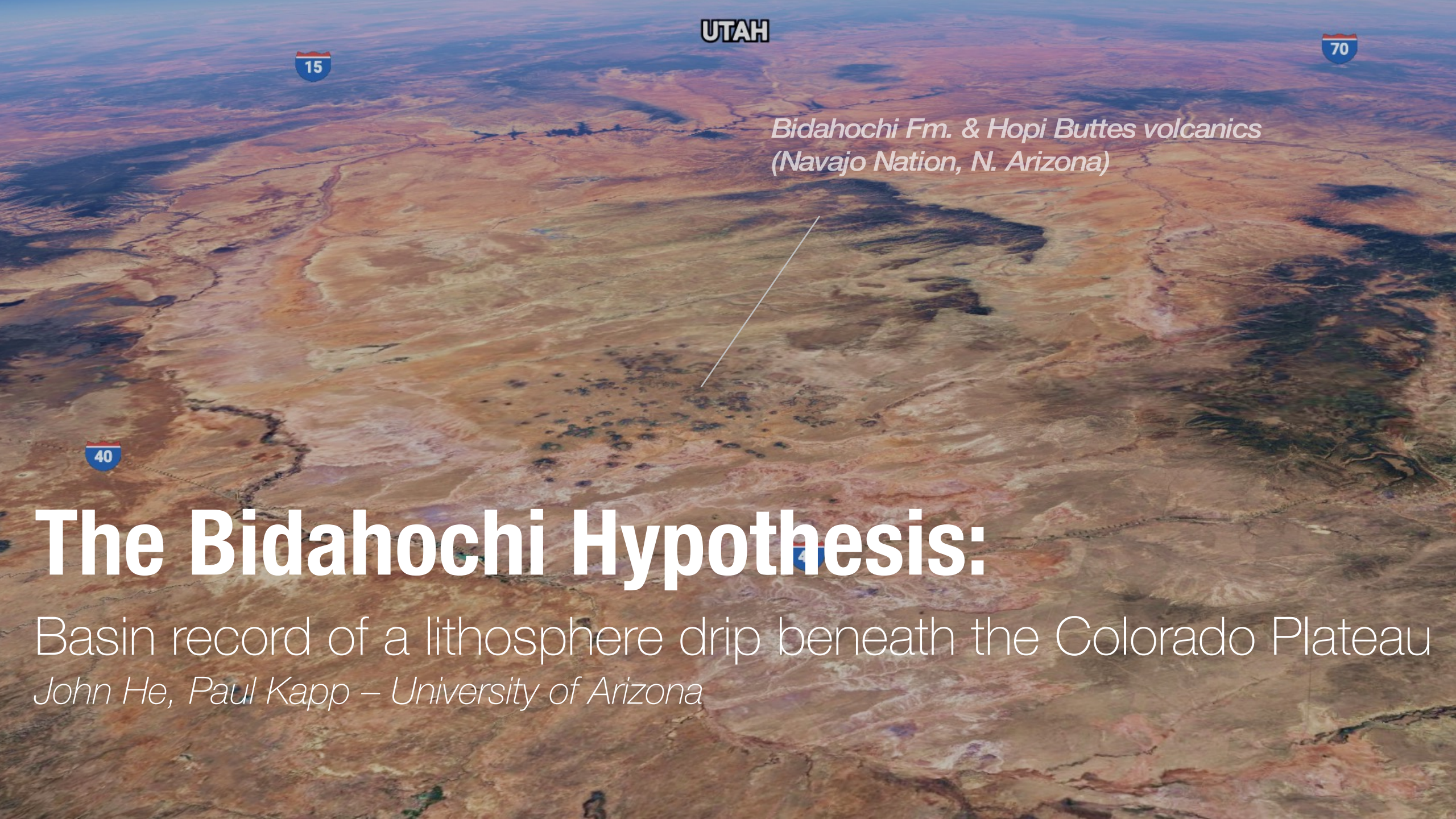
Abstract

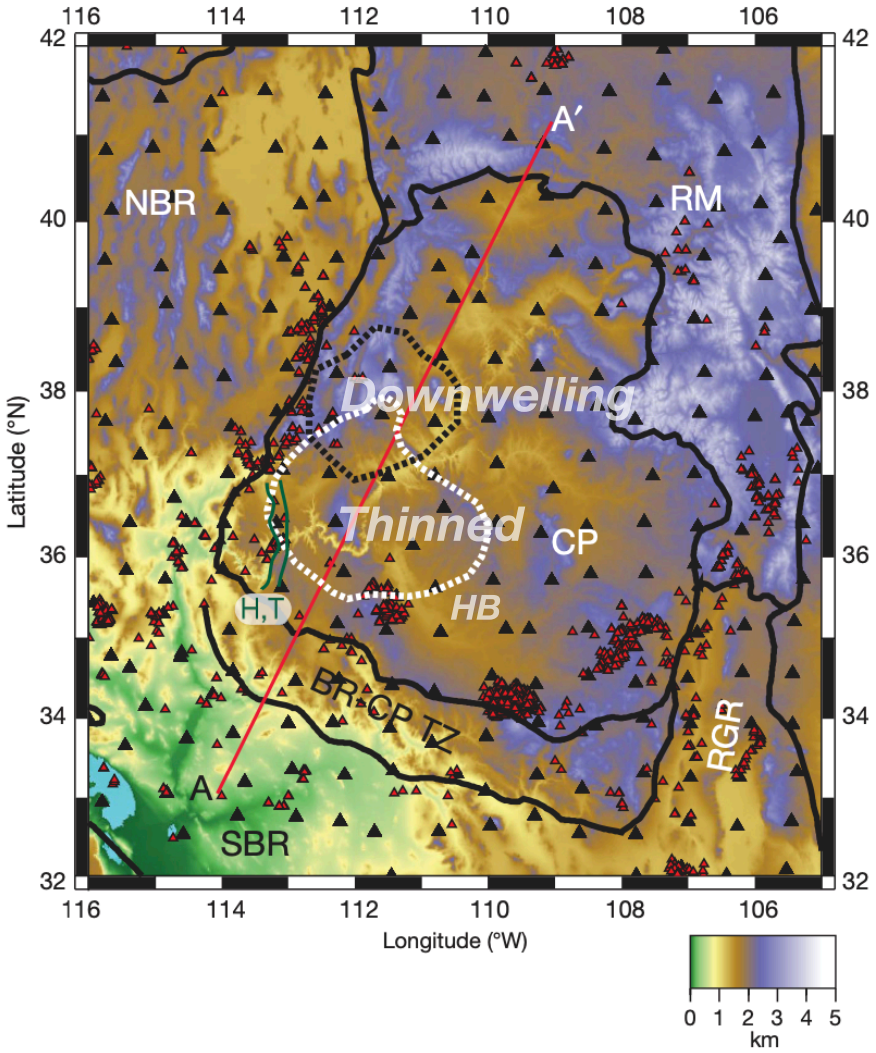
Spatial correspondence of topographic features, upper mantle structure, and locations of heightened late Miocene exhumation rates has led to the proposal that lithosphere-asthenosphere interaction plays a central role in driving the uplift and incision of the Colorado Plateau. These observations have generally been based on long wavelength features (> c. 250 km) indicative of large scale removal of the Colorado Plateau mantle lithosphere and subsequent asthenosphere upwelling, and has led to the hypothesis that convective removal may be responsible for much of the 2-3 km of Colorado Plateau surface uplift. However, except one currently active downwelling that can be seismically imaged, there is little evidence of the individual occurrences of lithosphere foundering that contributed to the bulk removal of lithosphere. We propose that the lacustrine lower member of the Bidahochi formation in the Navajo Nation may be evidence of such an occurrence. Fine grained lacustrine sedimentation from 16-14 Ma was associated with rapid sediment accumulation, followed by a condensed section deposited from 14-8 Ma, and finally mantle-derived late Miocene to Pliocene magmatism (Hopi Buttes volcanic field) from 8-5 Ma. The Pliocene Hopi Buttes volcanic rocks likely erupted into an ephemeral lake or playa, and are generally nephelinites with up to 10% MgO, originating from high-T decompression melting from as deep as 70 km. Juvenile epsilon Nd values up to +4 indicates at least a partial melt component from an isotopically depleted mantle source. The most plausible explanation for the spatial coincidence and temporal sequence of lacustrine deposition, slowed sedimentation, high-Mg, mantle-derived magmatism is that these are all associated with 1.) descent of lithosphere and associated subsidence, 2.) subsequent lithosphere removal, rising asthenosphere, and local uplift (on the order of tens or hundreds meters), 3.) magmatism derived from asthenosphere upwelling. Alternative hypotheses for the local subsidence at the Bidahochi Basin include deposition in the regional syncline associated with the adjacent Defiance uplift, but this is less likely, given that apatite thermochronology dates indicate that Defiance uplift was rapidly exhumed at c. 55 Ma, far before active lacustrine deposition in the Bidahochi Basin.

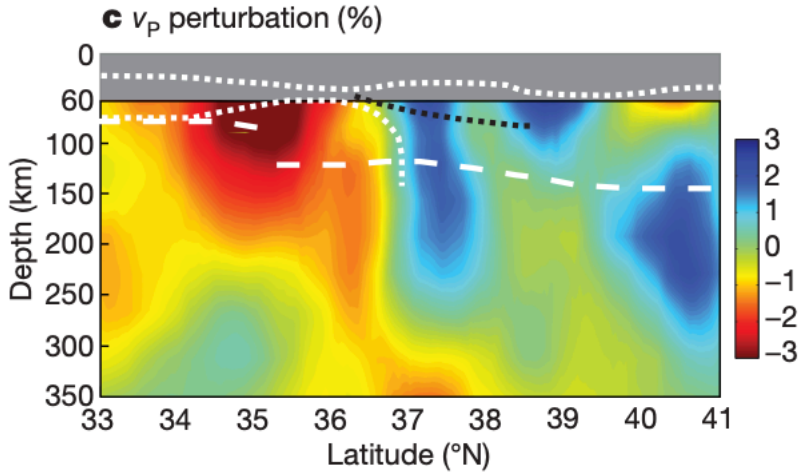


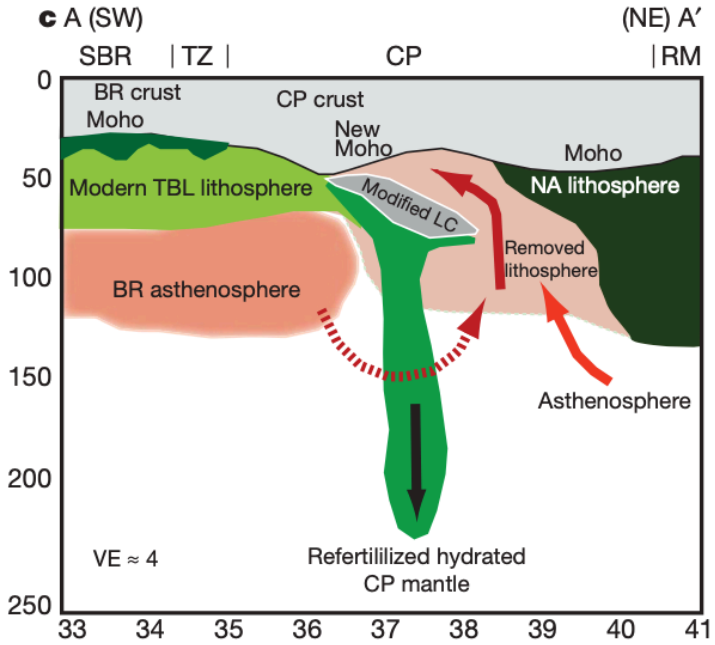
The Bidahochi Hypothesis:

Basin record of a lithosphere drip beneath the Colorado Plateau

John He, Paul Kapp – University of Arizona







Geophysical evidence of recent or ongoing lithosphere foundering beneath the Colorado Plateau

Levander et al. 2011, Nature

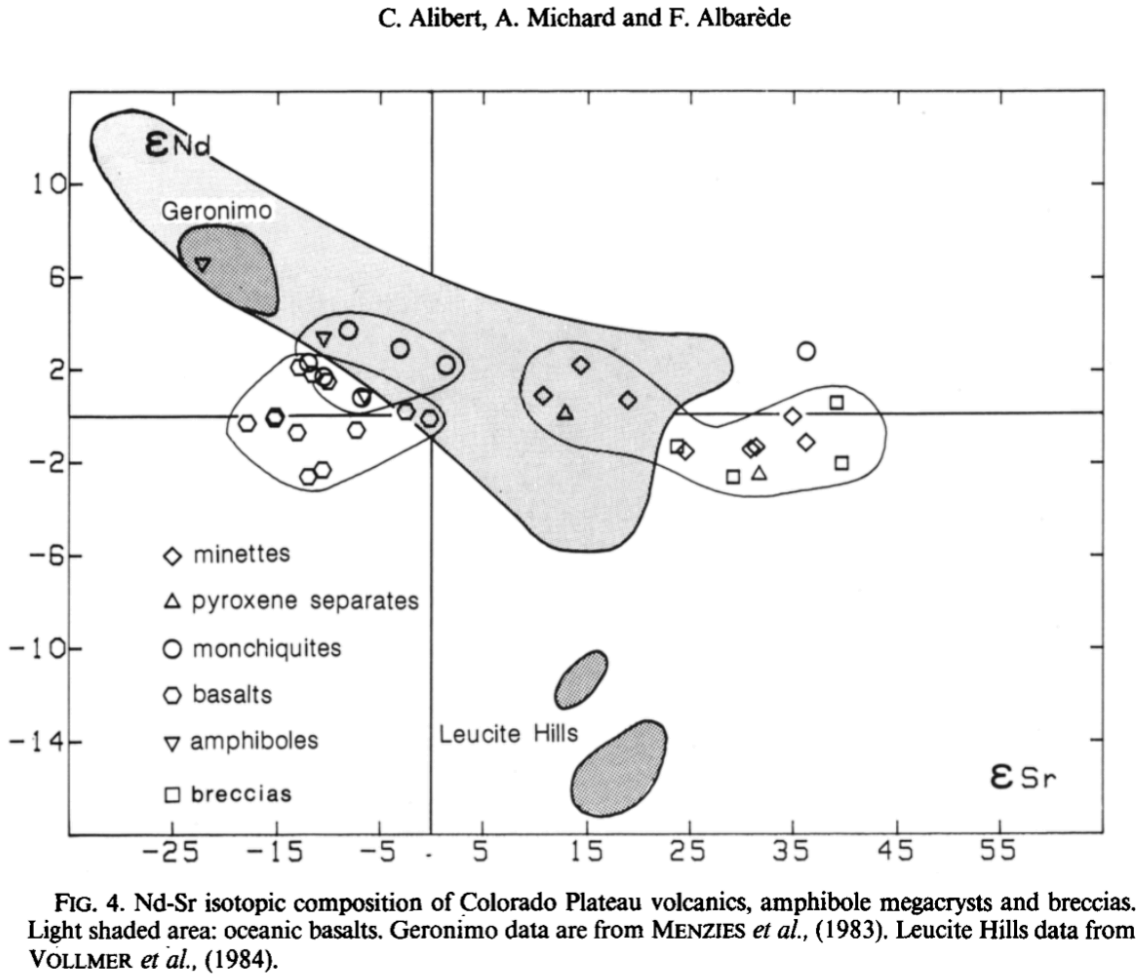
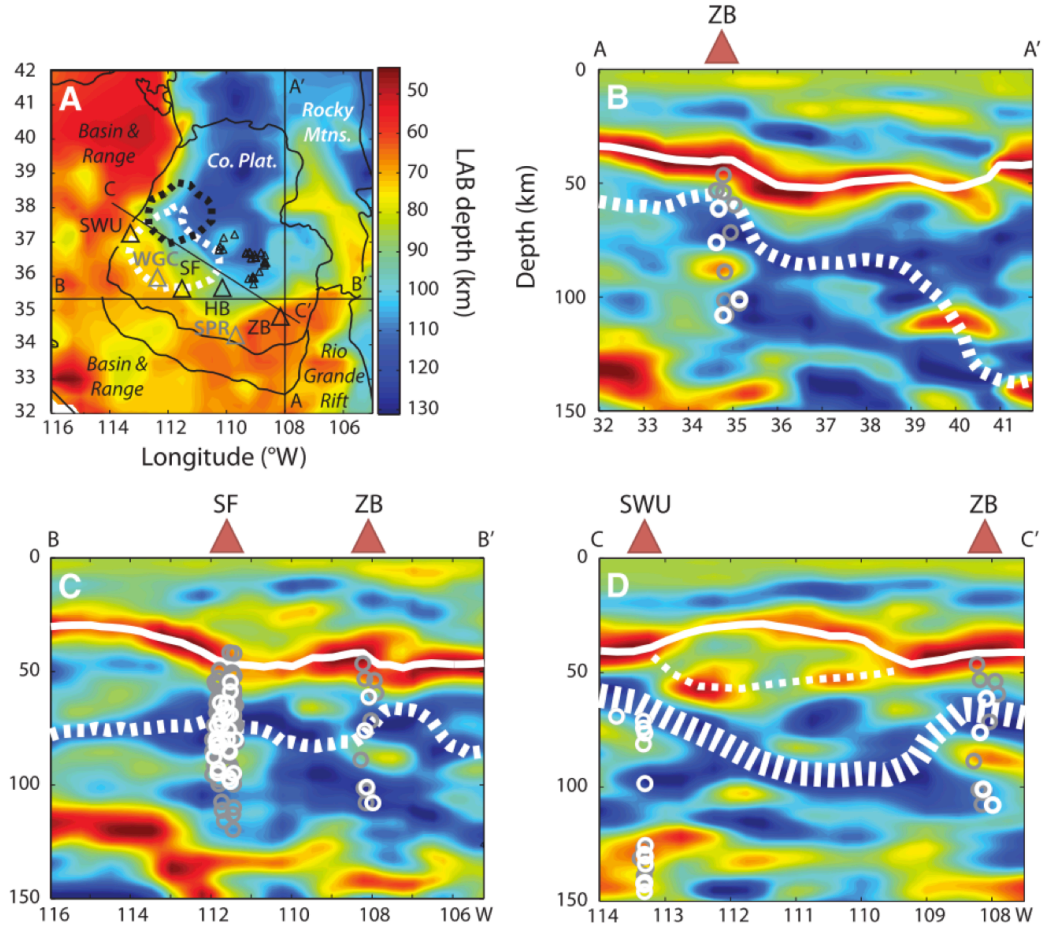
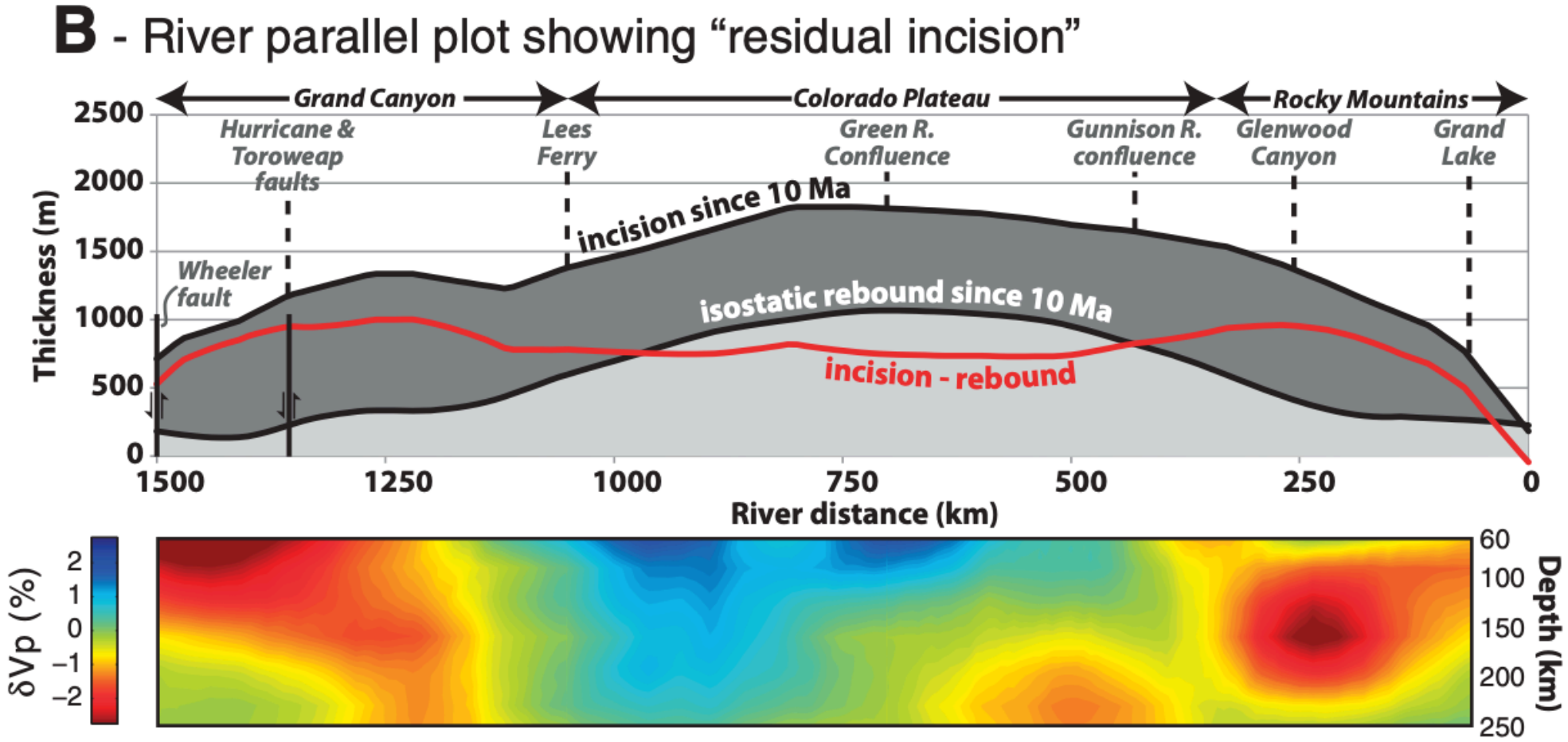


FIG. 4. Nd-Sr isotopic composition of Colorado Plateau volcanics, amphibole megacrysts and breccias. Light shaded area: oceanic basalts. Geronimo data are from MENZIES *et al.*, (1983). Leucite Hills data from VOLLMER *et al.*, (1984).

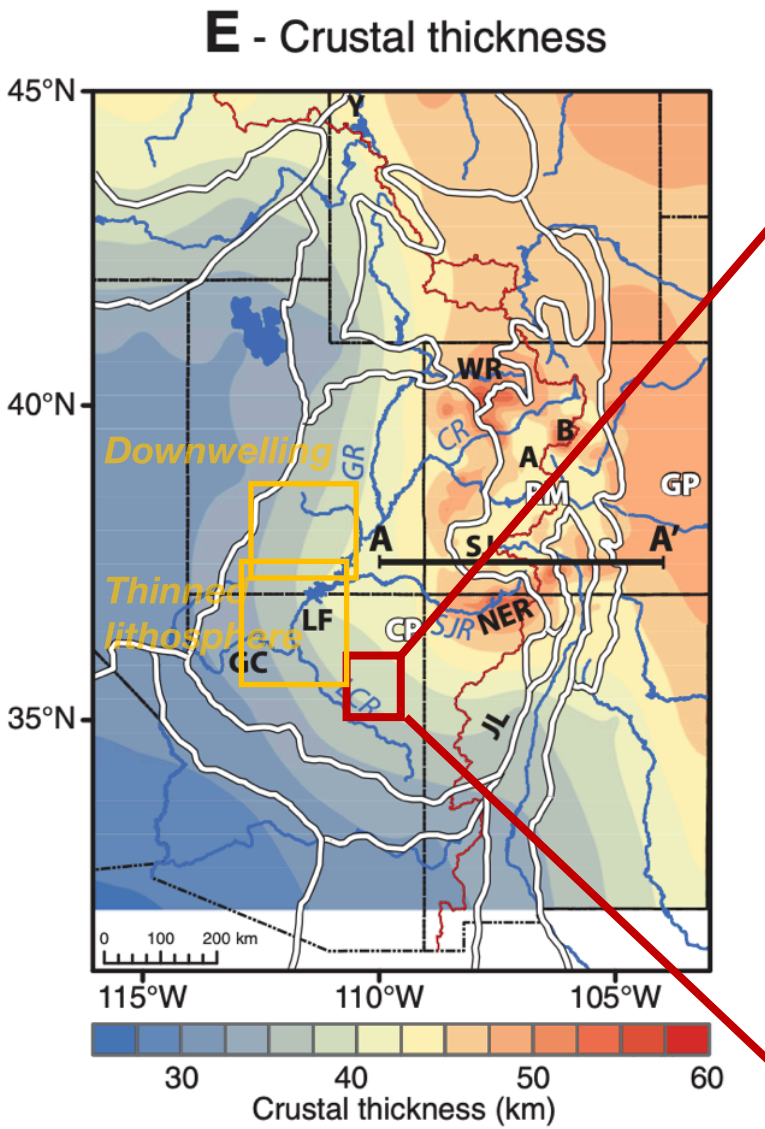


Geochemical evidence of recent or ongoing lithosphere foundering

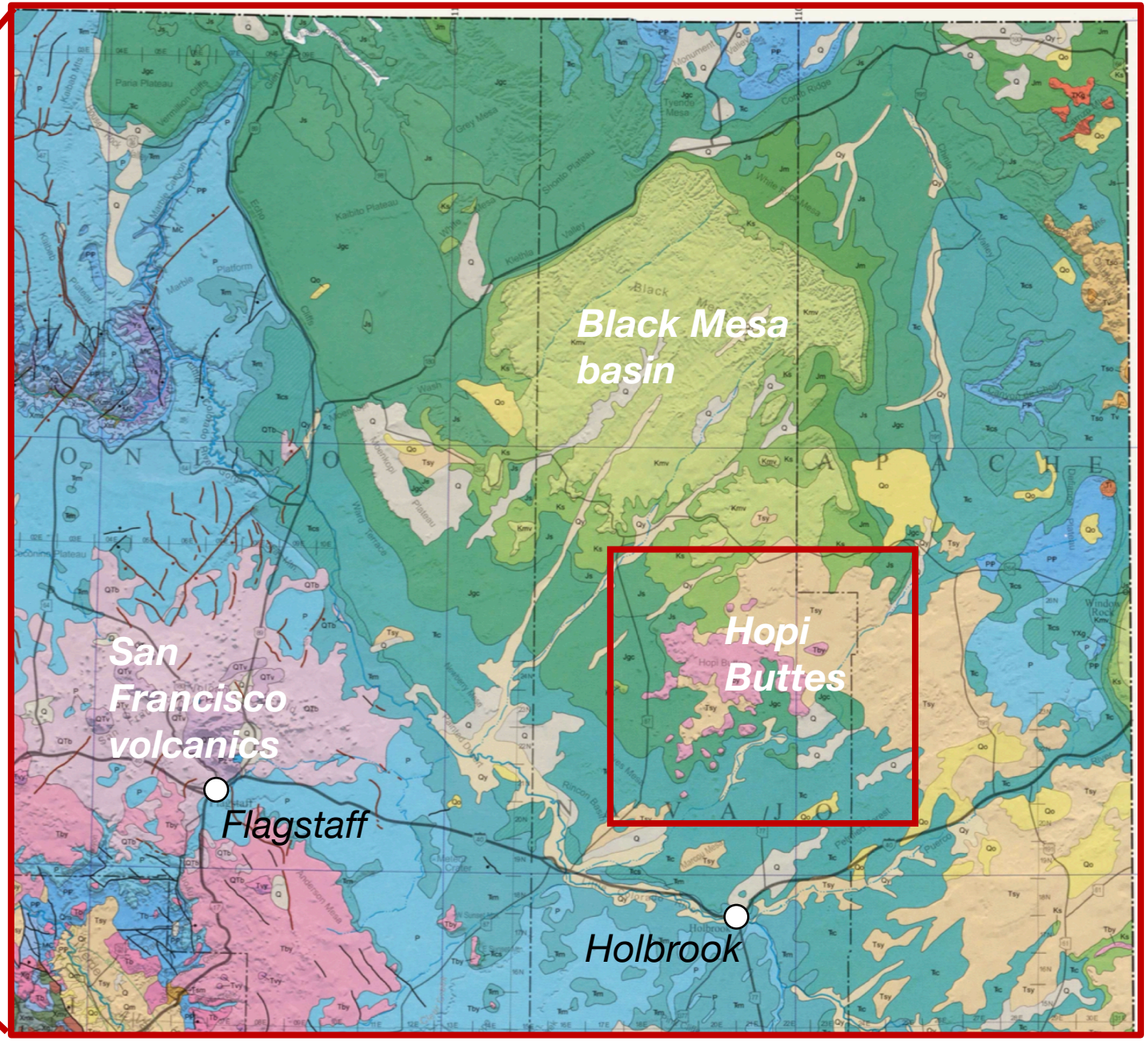
Alibert et al., 1986, GCA; Reid et al., 2012, Geology



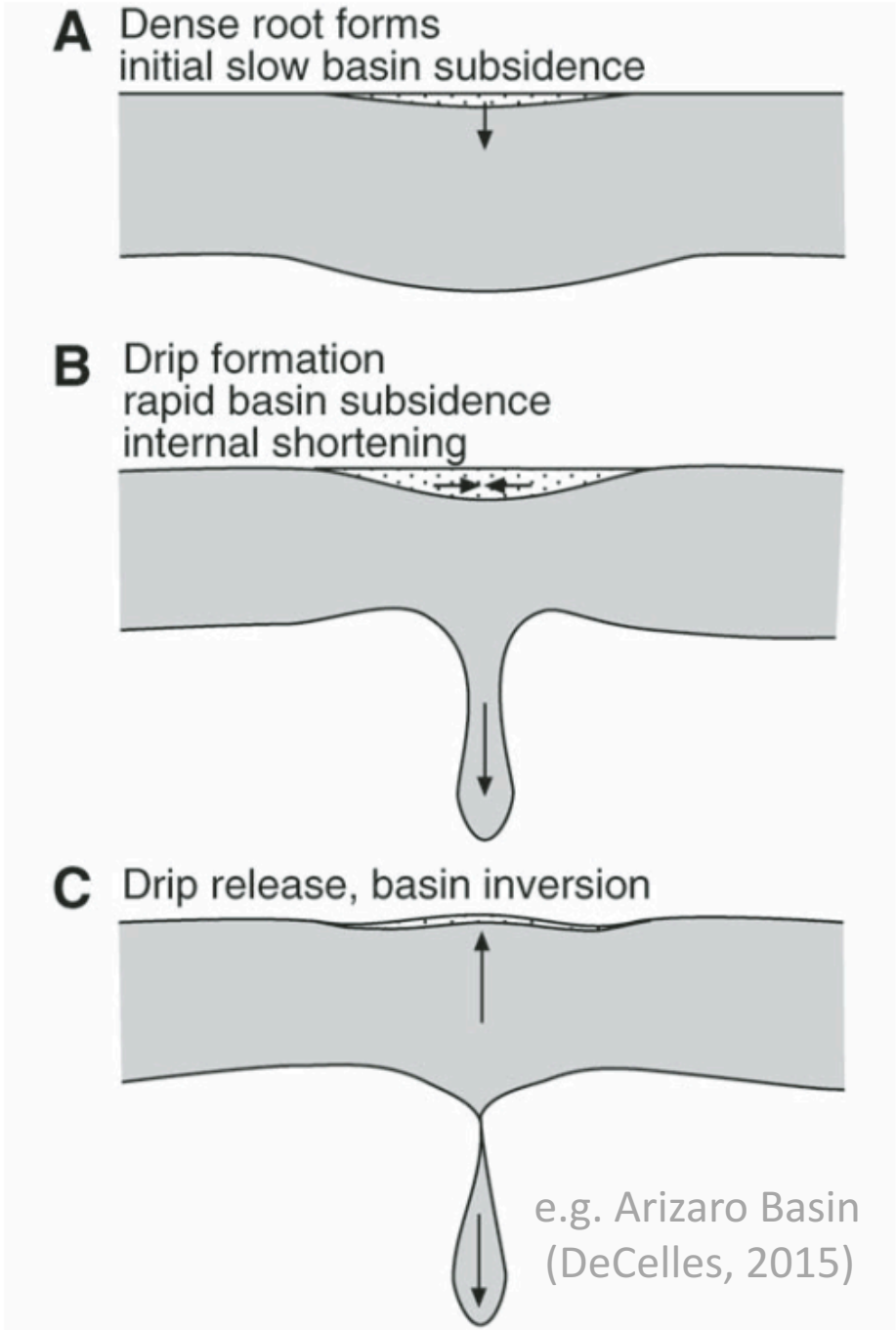
Correspondence of long wavelength topography, crustal thickness, mantle tomography, incision
Karlstrom et al. 2012



Karlstrom et al. 2012 **Figure 1**



AZGS Geologic Map of AZ



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Continental Delamination and the Colorado Plateau

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Probable Geological Consequences

The preceding effects of delamination leave no permanent record and can only be observed where it has happened in the Late Tertiary. This section considers the geological consequences that might mark an ancient event: gas-rich eruptions, basalt extrusion, silicic intrusion, and uplift. Each of these involves an all-or-nothing, nonlinear process like fault slip or a phase change. Therefore lack of one response does not rule out an ancient delamination.

Generalized Bidahochi Formation (Dallegge 1999)

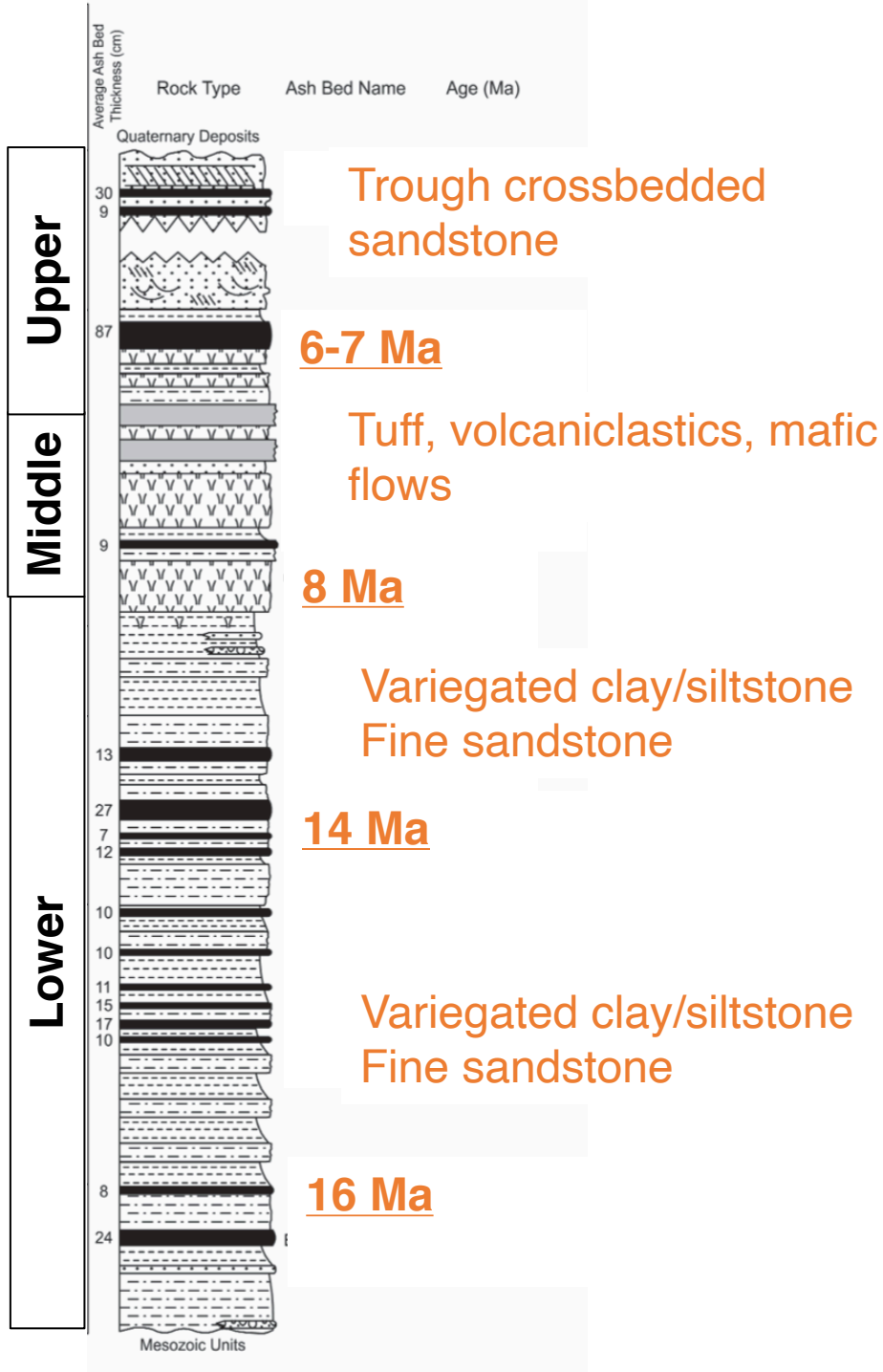
Lower Bidahochi

- **16-14 Ma** Fine grained lacustrine sedimentation
- **14-8 Ma** condensed section of slower sedimentation

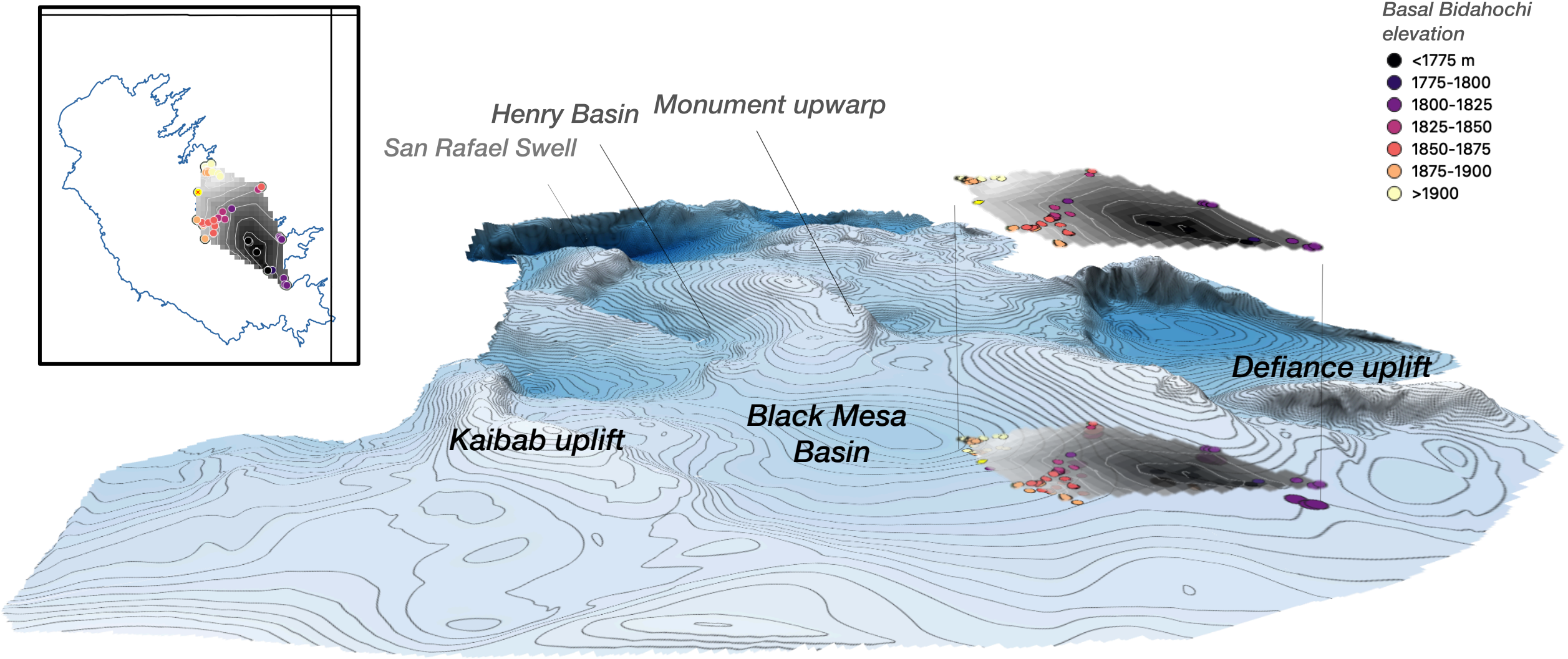
Middle Bidahochi (Hopi Buttes Volcanic Field)

- **8-6 Ma**
  - nephelinites (~ 10% MgO, silica undersaturated)
  - high-T decompression melting (~ 70 km)
  - Juvenile eNd values (c. +4)
    - At least partial component of melt from an isotopically depleted mantle source

  - (Alibert 1986, Reid et al., 2012)



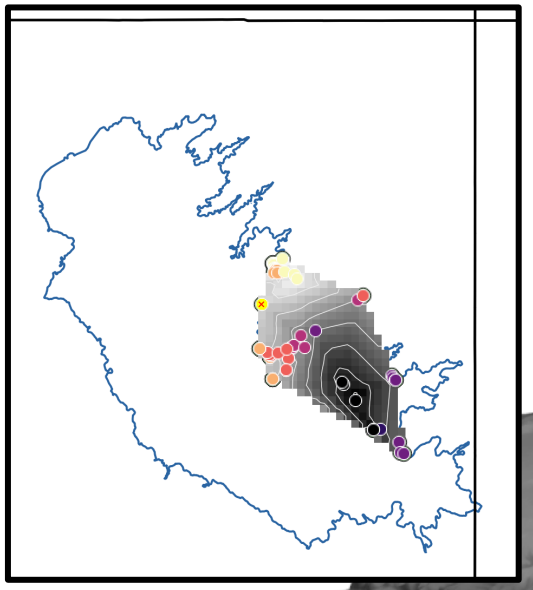

Middle Bidahochi – 6-7 Ma max depo age
Chinle

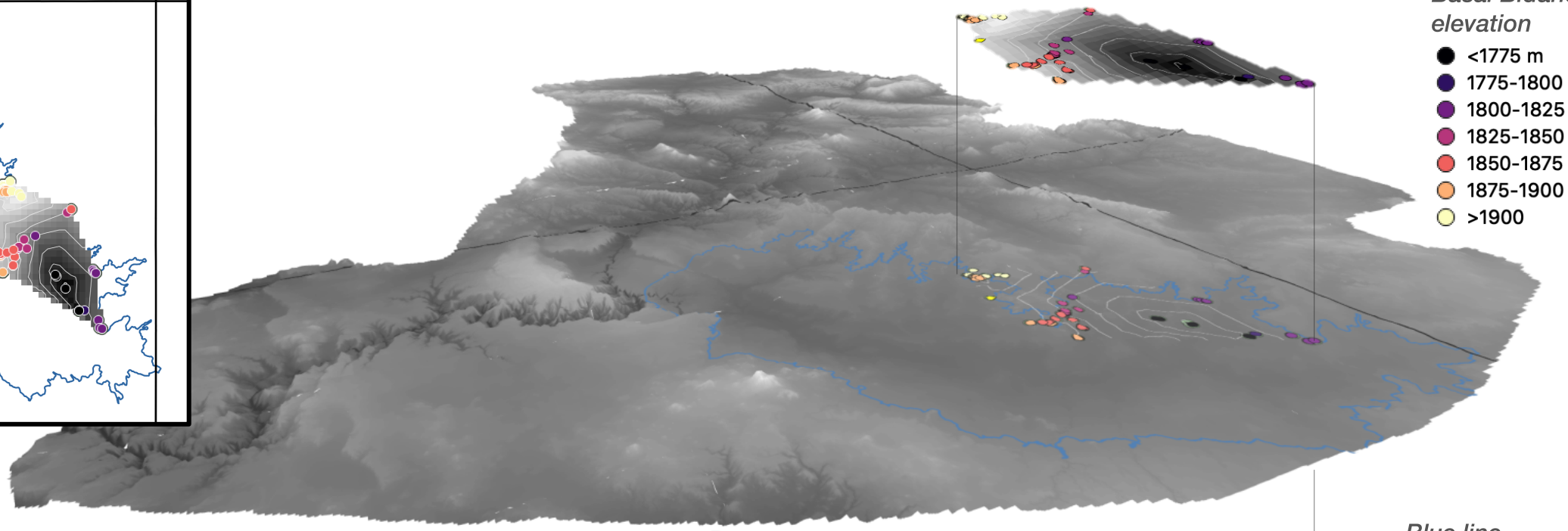


Structure contour of Laramide monoclines and uplifts

(DEM of Pz-Mz boundary/top of Kaibab limestone)

10x vertical exaggeration; data from Flowers et al. (2008); Hunt (1956)

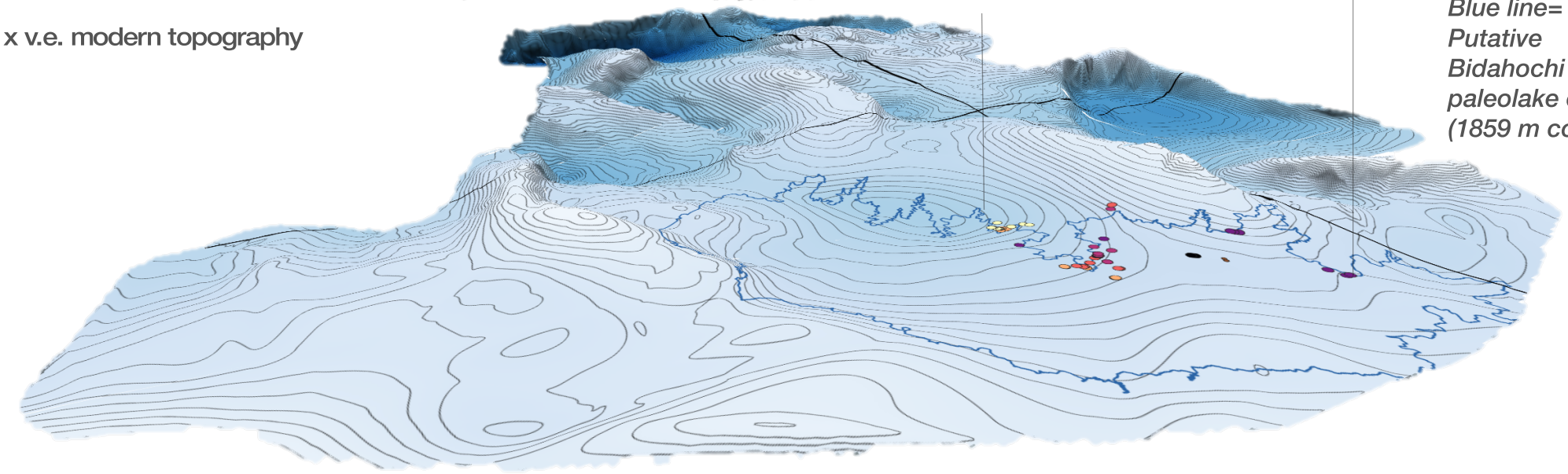




Basal Bidahochi elevation

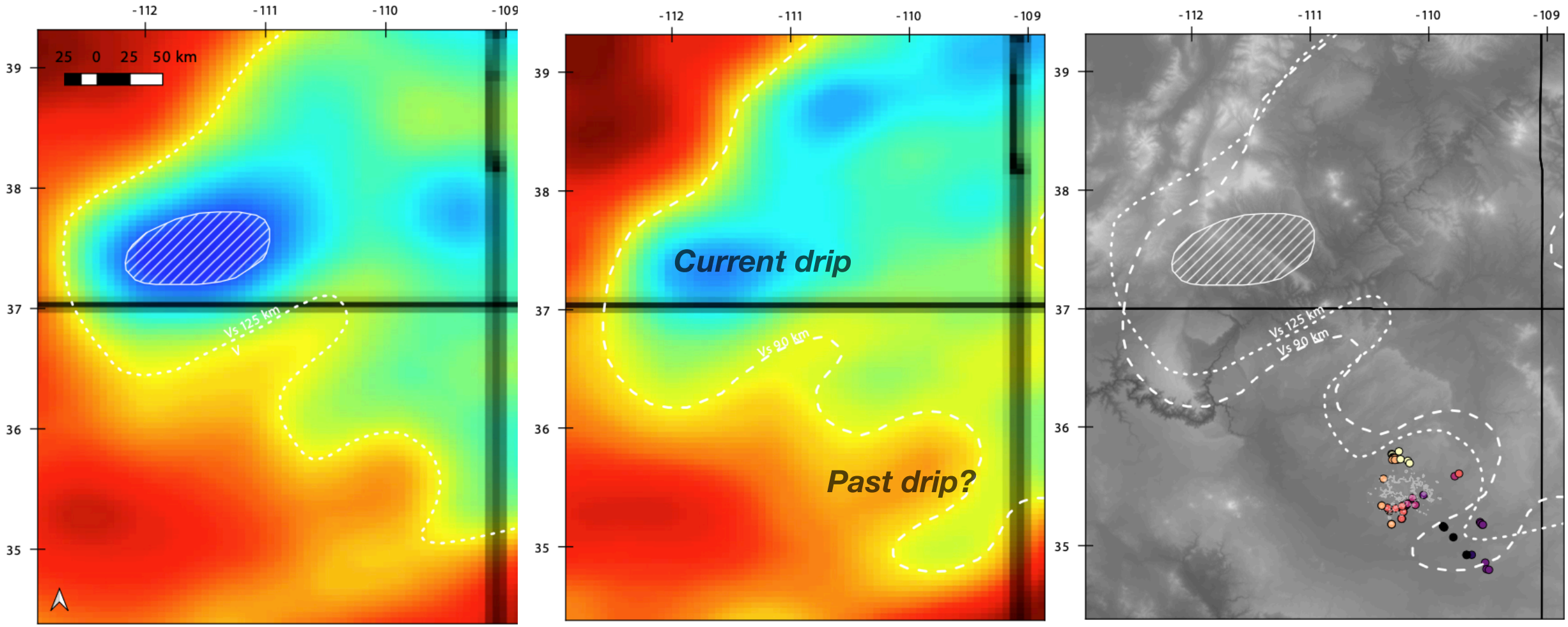
- <1775 m
- 1775-1800
- 1800-1825
- 1825-1850
- 1850-1875
- 1875-1900
- >1900

5 x v.e. modern topography



Blue line= Putative Bidahochi paleolake outline (1859 m contour)

10 x v.e. Mz-Pz boundary



Vs 125 km

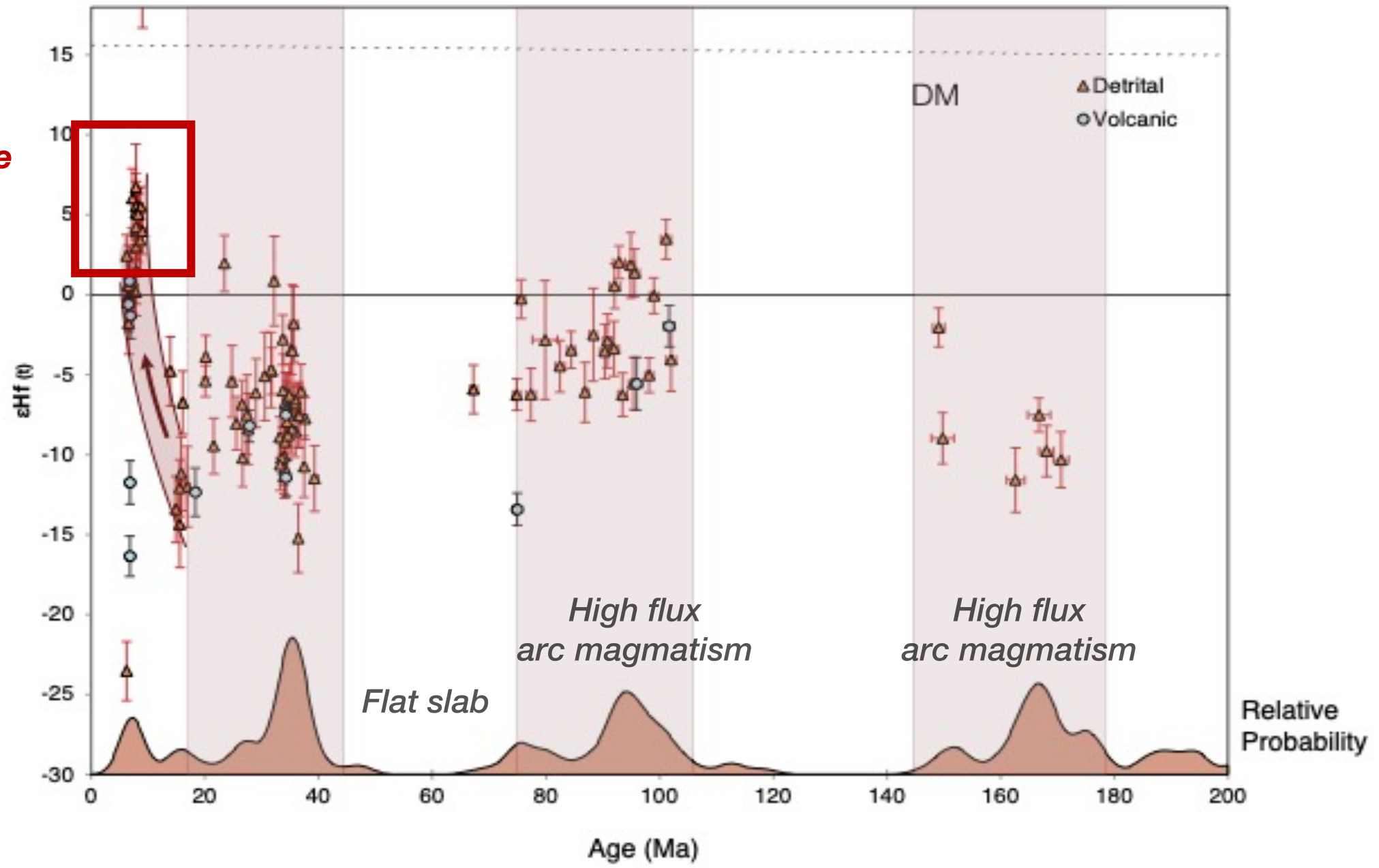
Schmandt and Humphrey 2010

Vs 90 km

U-Pb/Lu-Hf of detrital zircon grains in the Bidahochi Fm

+
Isotopically Juvenile asthenosphere

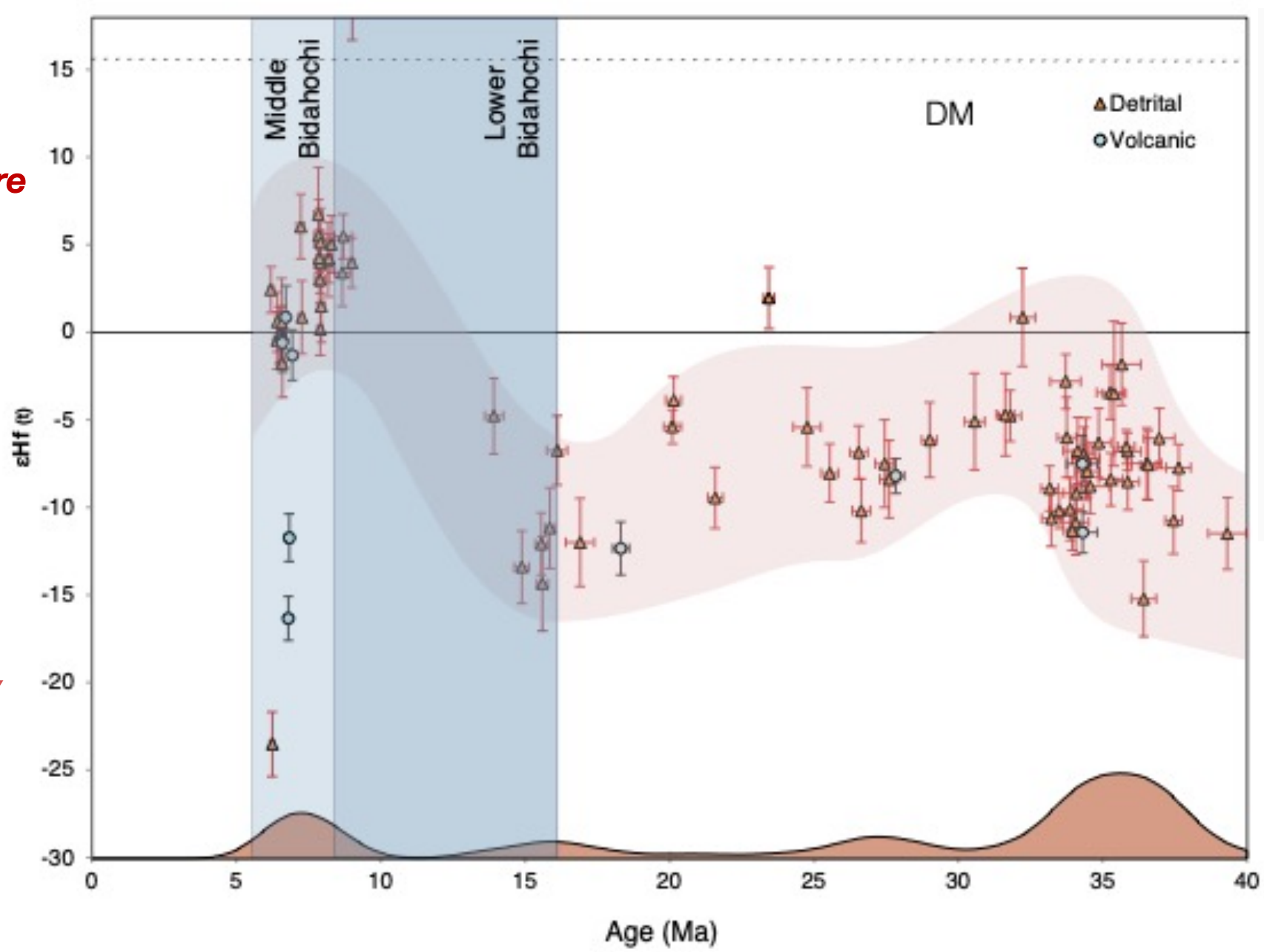
-
Isotopically evolved lithosphere

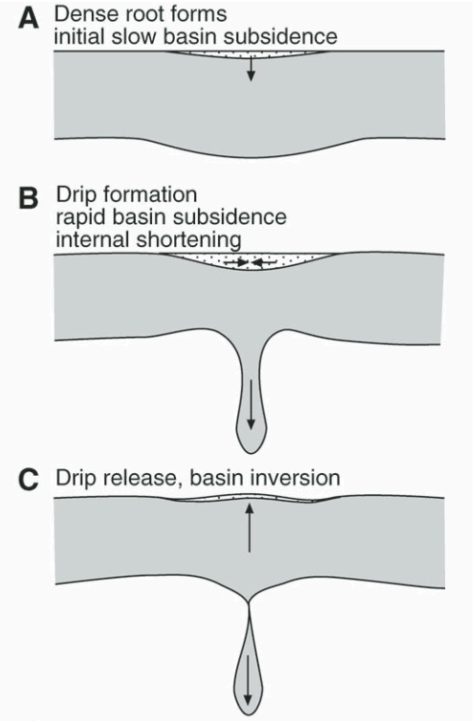


U-Pb/Lu-Hf of detrital zircon grains in the Bidahochi Fm

+

Isotopically Juvenile asthenosphere





Relative Probability

-

Isotopically evolved lithosphere

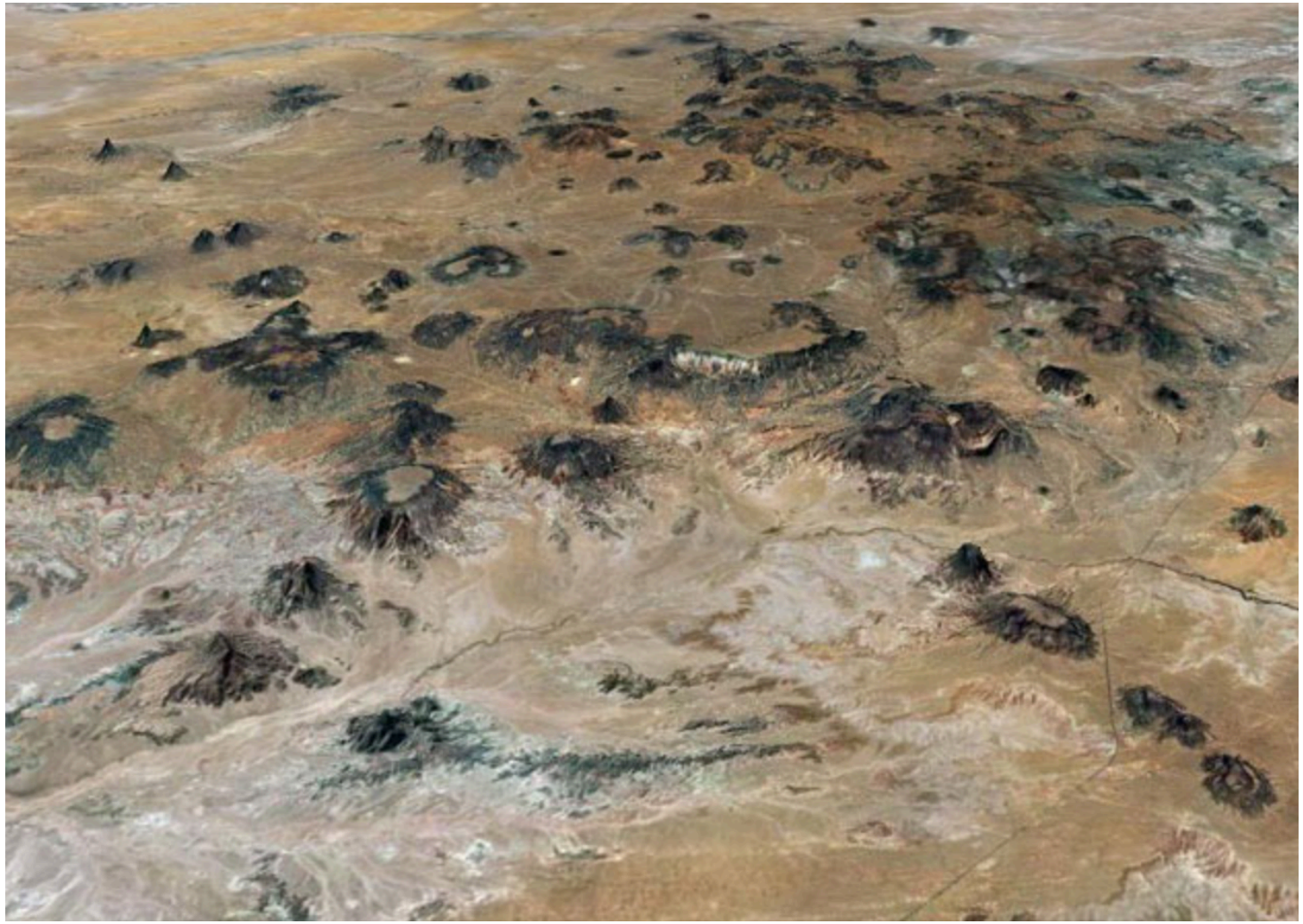
Summary:

1. Localized lacustrine deposition high on the Colorado Plateau

2. Subsequently uplifted and now mostly eroded

3. Spatially coincident with mafic/nephelinitic mantle-derived, decompression melt

4. Temporally coincident with Hf isotopic trend in proximal detrital record



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