A Paleoelevation History of the Basin and Range and Its Relation to Cenozoic Extensional Tectonism

Nathan A. Niemi

Cires Sabbatical Fellow and University of Michigan

Abstract

The Basin and Range Province of the western United States is one of the premier examples of diffuse continental extension in the world. Estimates of extension across the Basin and Range during the Cenozoic range from 200% province-wide to locally as great as 400%. However, crustal thicknesses across this region are assessed from a variety of geo-physical methods, are remarkably uniform and, at ~35 km thick, are similar to global averages. Reconciling large-magnitude crustal extension with observed crustal thicknesses is difficult without calling on one of three possible alternatives: (1) an Andean-plateau crustal thickness of ~65 km at the termination of the Saber Orogeny and prior to extension; (2) substantial addition of material to the crust by syn-extensional magmatism or (3) mobilization and redistribution of fluid lower crust during extension. Quantitative paleoelevation histories can help discriminate between these competing mechanisms for widespread Cenozoic extension. New estimates of pre-extensional paleoelevations for the northern and central Basin and Range are presented using clumped isotopes (47) thermometry of lacustrine carbonates that suggest modest (~2–3 km) pre-extensional elevations for the northern Basin and Range and quite low (~1 km) elevations for the southern Basin and Range. These paleoelevations are incompatible with mass balance considerations based on the observed magnitude of crustal extension and modern crustal thicknesses, and imply that crustal mass was added to the Basin and Range during extension, either from magma- or crustal flow.

Background and Methods

Study Area

Map of sample locations. Upper map shows carbonate sample locations (using in modern geographic coordinates with major physiographic provinces of the western US shown in gray lower map shows sample site locations of paired Miocene retrodeformed state boundaries and physical setting of Sheep Pass and Goler Formations carbonate sample locations. Both lacustrine carbonates and fossil mud units were collected from the same location within Sheep Pass (J. Kulp)."

Clumped Isotope Thermometry

Clumped isotope thermometry is based on the temperature dependence of the "clumping" of rare heavy isotopes in isotopologues. For paleoelevation studies, the isotope composition of mass of 47 CO2 in carbonate is frequently used to measure the formation temperature of a carbonate, a ubiquitous geo-logic material in lakes, soils, and other archives. The occurrence of this particular isotope isogeochemistry makes it feasible to infer paleo-temperature histories.

Eocene Paleoelevations

Biogeochemical setting of Sheep Pass and Goler Formations carbonate sample locations. (A) Geologic map of the Basin and Range Province of southern California. The Paleogene Goler Formation unconformably overlies metamorphic rocks of the Palaeozoic Granite For- mation and Mesozoic esotonic rocks associated with the onset of regional Sierra Nevada arc magmatism and is unconformably overlain by Miocene Ricardson Formation volcanics. Red star marks location of Goler Formation Member A-Hassic carbonate sample. (B) Simplified geologic map of Sheep Pass Canyon; southern Egan Range, Nevada where the type section of the late Cretaceous-Eo- cene Goler Formation Member 4A micritic carbonate sample. (C) Detailed geology of Sheep Pass and Goler Formations carbonate sample locations. (A) Geologic setting of Sheep Pass and Goler Formations carbonate sample locations. Both lacustrine carbonates and fossil mud units were collected from the same location within Sheep Pass (J. Kulp)."

Mioecene Paleoelevations

Biogeochemical setting of sampled Miocene localities in the Sierra Nevada and Death Valley region. (A) Hillock map of the southern Sierra Nevada-Death Valley region with extents of Cottonwood Crater (black), Marble Canyon (blue), and Amargosa Valley (green) geologic maps. Map extents are outlined and color-coded by sample locations, as shown in stratigraphic columns below. Heat map and Cottonwood Crater area map of the Cottonwood Mountains (modified from Staude and Lux [1998]) with sample location of Bena Gravels in the middle Cottonwood Mountains. (B) Simplified geologic map of the Cottonwood Creek area of the southern Sierra Nevada where the fluvial deposits of the Bena Gravels were sampled (red modified from Bartow and McDougall [1984]). (C) Simplified geologic map of the Marble Canyon area of the Cottonwood Mountains (modified from Staude and Lux [1998]) with sample location of Ubelheber Spring Formation. (D) Simplified geologic map of the Amargosa Valley where the Roots of Paso Spring were sampled (purple; modified from Bartow et al. [1998]). Thin, black lines on geologic map reflect mapped surface lithologies."

Paleoelevation Results from Clumped-isotope Thermometry

Carbonate clumped isotope temperature record. Age-temperature plot for Bena Gravels and Death Valley carbonate samples. Dashed gray line marks average carbonate clumped isotope temperature for Sheep Pass Formations Member B and E (~30°C; Ponton et al., 1981). Gray area marks 2σ range of δ47 values for non-metamorphic Triassic and Jurassic aged carbonates. Here, carbonates are determined by normalizing mea- sured δ47 values using reference δ47 values for Triassic and Jurassic carbonates. Temperature calibrations are derived from the δ47/δ18O correlation and the results yield a δ47 temperature and calculated temperature.

Conclusions

This preliminary study of Basin and Range paleoelevations from the Palaeocene, just at the end of the compressional Saber Orogeny, and from the Miocene, just prior to the onset of Basin and Range extension, suggests that paleoelevations of the Basin and Range are similar to observed modern elevations, despite ~400% extension. These results suggest that crustal extension and thinning must be countered by another process that adds material to the crust to compens- ate for extensional strain. Lower crustal flow and magmatic addition are both possible mechanisms to accomplish this. Further work is required to discrimi-nate between these two possibilities.

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