Elevated Cenozoic geothermal gradients and later post-6 Ma incision of the Uncompahgre Plateau and Unaweep Canyon (western Colorado) revealed by low temperature thermochronology

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Overview

- New apatite and zircon fission track and (U-Th)/He data presented from the Unaweep Canyon area of the Uncompahgre Plateau.
- Data used to constrain timing of late Cenozoic canyon incision (and/or paleocanyon exhumation).
- Samples collected from close to top of canyon (just below Precambrian / Mesozoic nonconformity at 2644m) and from base of canyon in both Precambrian rocks and Permian sedimentary rocks of the Cutler Formation (1445-1689m).

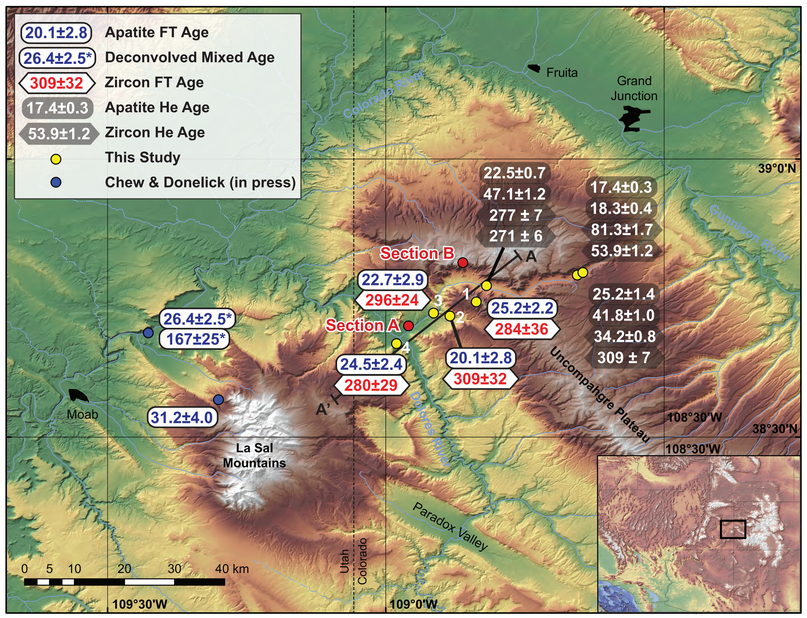


Figure 1: Location map DEM of the Uncompahgre Plateau and Unaweep Canyon area of the Colorado/Utah border showing thermochronologic age data collected in this study (as well as new published data from two other samples). Numbers next to yellow dots (AFT data) mark sample number shown for HeFTy modeling in Figure 2, Section A and B mark approximate locations of stratigraphic sections shown in Figure 3; (b) ENE-WSW topographic profile with age data.

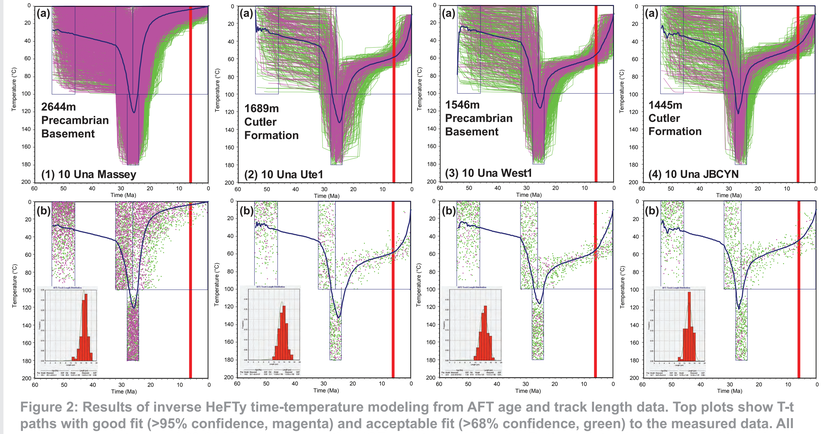
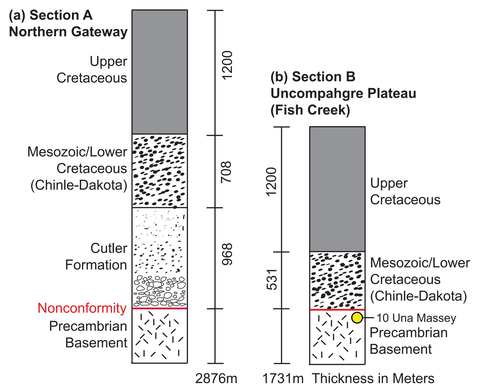


Figure 2: Results of inverse HeFTy time-temperature modeling from AFT age and track length data. Top plots show T-t paths with good fit (>95% confidence, magenta) and acceptable fit (>68% confidence, green) to the measured data. All ages are reset at around 28-24 Ma, so earlier paths NOT constrained by data. Bottom plots show measured track length histograms (red) and best fit track length prediction (green) and constraint points of paths in upper plots (to show minimum temperature required to reset ages at 28-24 Ma). Blue paths show best fit T-t path. Paths from low elevations require accelerated cooling starting at around 6 Ma from temperatures of ~50°C (red line) to produce observed shorter track lengths in these samples.

Results and Time-temperature Modeling

- AFT data from near top of canyon (25 Ma age, mean track length of 14.85 µm) require this sample was heated to >120°C at ~25 Ma then cooled rapidly to <30°C with a few Myr, then sat near the surface with little erosion until present day.
- Estimates of former Mesozoic overburden (~1731m; Fig 3) requires an increase in geothermal gradient to >65-70°C/km during late Oligocene.
- Unreset Ancestral Rocky Mountain ZFT ages (280-310 Ma) imply Oligocene heating did not exceed ~180°C.
- AFT ages from base of canyon (20-25 Ma) and shorter mean track lengths (13.3 to 13.8 µm) require these samples cooled to ~70-40°C following Oligocene heating, then cooled to surface starting at ~ 6 Ma.



- Difference in post 6 Ma paleo-temperature at top and base of canyon is ~30°C. Elevation difference (1200m) thus reveals geothermal gradient had returned to modern day values of ~30°C/km by the late Miocene.

Figure 3: Stratigraphic sections showing estimated amount of Paleozoic-Mesozoic sedimentary deposits above nonconformity with Precambrian basement (based on local geologic mapping)

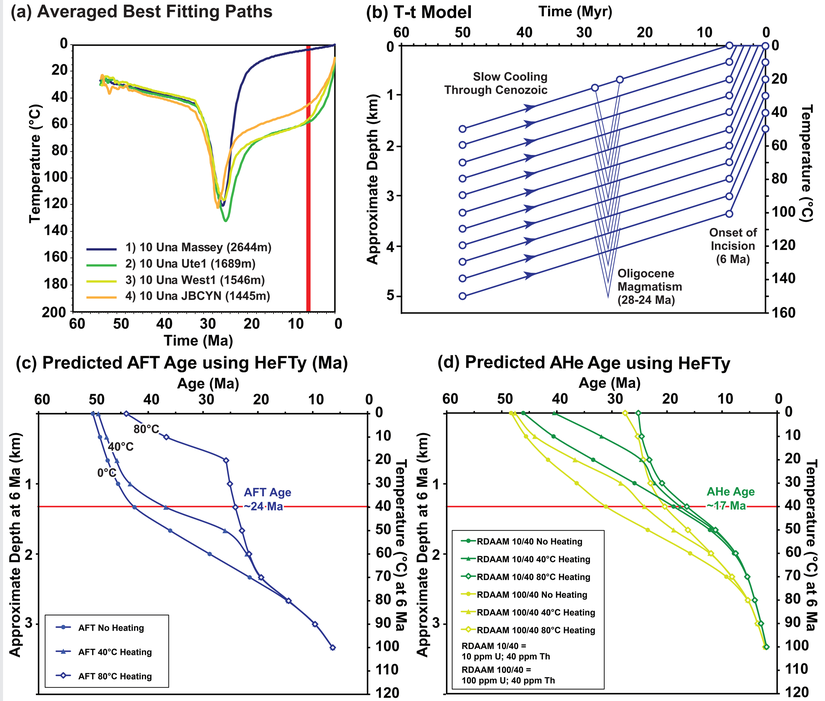


Figure 4: (a) Plot showing averaged best fitting T-t paths for each sample in Figure 2; (b) Time temperature paths used for forward modelling in HeFTy to produce predicted AFT and AHe ages for samples that resided at different temperatures at 6 Ma followed by accelerated cooling of 50°C to present day surface temperatures (0°C) to simulate canyon incision; (c) Plots showing predicted AFT age-temperature (depth) relationships given T-t paths shown in (b) for varying amounts of late Oligocene reheating (0°C, 40°C and 80°C); (d) Predicted AHe data using the RDAAM He diffusion model for both average effective Uranium (10ppm U; 40ppm Th) and high effective Uranium (100ppm U; 40ppm Th).

Plots show the approximate age-elevation (or age-depth) relationships expected to be observed in the eastern Colorado Plateau given thermal histories recorded by samples from Unaweep Canyon area. Note that similar AHe age ages of around 25 Ma can be expected over >1000m of elevation (assuming modern geothermal gradient of 30°C/km).

Some Implications

- AFT Data much better constrain onset of rapid incision in upper Colorado / Gunnison River to ~6 Ma (improvement on ~6-10 Ma inferred from AHe data from Colorado Plateau).
- Post 6 Ma incision rate of western Unaweep Canyon is ~200 m/Myr (~240 m/Myr if canyon abandoned at ~1 Ma) matching well post 6 Ma incision rates estimated from Grand Canyon.
- Data imply ~6 Ma onset of rapid incision was near synchronous along at least 750 km stretch of Colorado river system following integration of upper Colorado river drainage at this time. This can be better explained by ongoing regional uplift rather than upstream knick-point migration.
- Elevated geothermal gradients associated with late Oligocene La Sal magmatism observed at least 25 km in all directions from laccolith.
- By not considering the possibility of variable and higher paleo-geothermal gradients, most thermochronologic studies that assume a steady geothermal gradient (typically 20-25°C/km) on the Colorado Plateau may seriously over-estimate total amount of Cenozoic regional erosion (exhumation), as well as misrepresent patterns and regional distribution of such inferred erosion.