Constraining the Uplift of the Southeastern Sierra Nevada, CA using Multi-Mineral Detrital Thermochronology from Active Catchments

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Motivation

- Debate remains as to how much of the modern relief of the Sierra Nevada of California was established in the Cretaceous and how much is of Cenozoic age.
- Active deformation along the Sierra Nevada Frontal Fault Zone (SNFFZ) on the eastern side of the Sierra is frequently invoked as responsible for recent block uplift of the central range. The Garlock Fault also likely played an important role in uplift of the southern end of the range. How these structures interact to accommodate uplift and exhumation of the southeastern Sierra Nevada, and how far this interaction can be extended back in time are primary motivators for the present study.
- Thermochronologic studies aimed at constraining exhumation rates typically focus on the development and interpretation of bedrock datasets. Our approach is somewhat different, relying instead on detrital thermochronologic studies of sediments in steep, active catchments draining the eastern flank of the range.
- We are developing multichronometric – U/Pb, $^{40}Ar/^{39}Ar$, and (U-Th)/He – datasets for numerous catchments and intend to employ an extended version of the method of Gallagher and Parra (2020) to explore the implications of these data for the tectonics and uplift history of the southeastern Sierra Nevada.

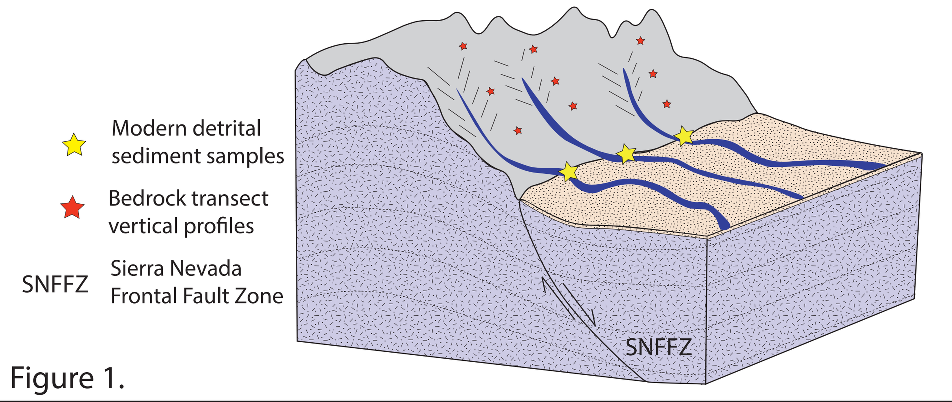

Figure 1.

Figure 1. A conceptual model (adapted from Ehlers, 2005) of detrital distributions for thermochronological data in the context of the southeastern Sierra Nevada range, bounded to the east by the Sierra Nevada Frontal Fault Zone (SNFFZ). Our studies will use detrital sediment samples from active catchments draining the southeast Sierra Nevada at the intersection of the SNFFZ and Garlock Fault.

Foundational Method and Study Area

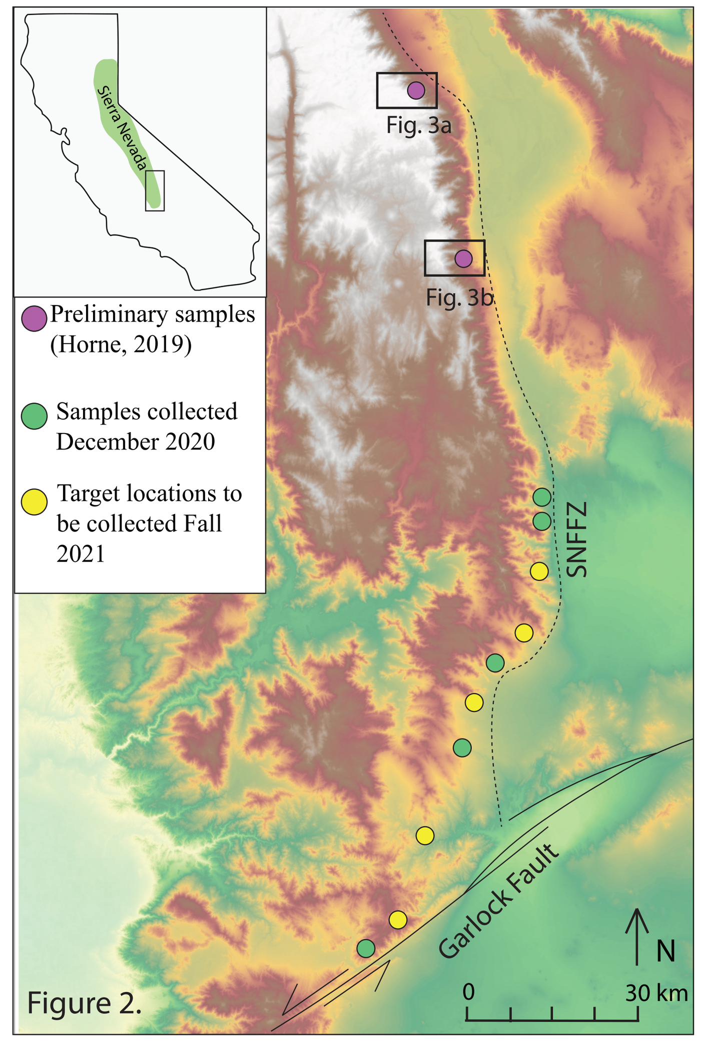

Figure 2.

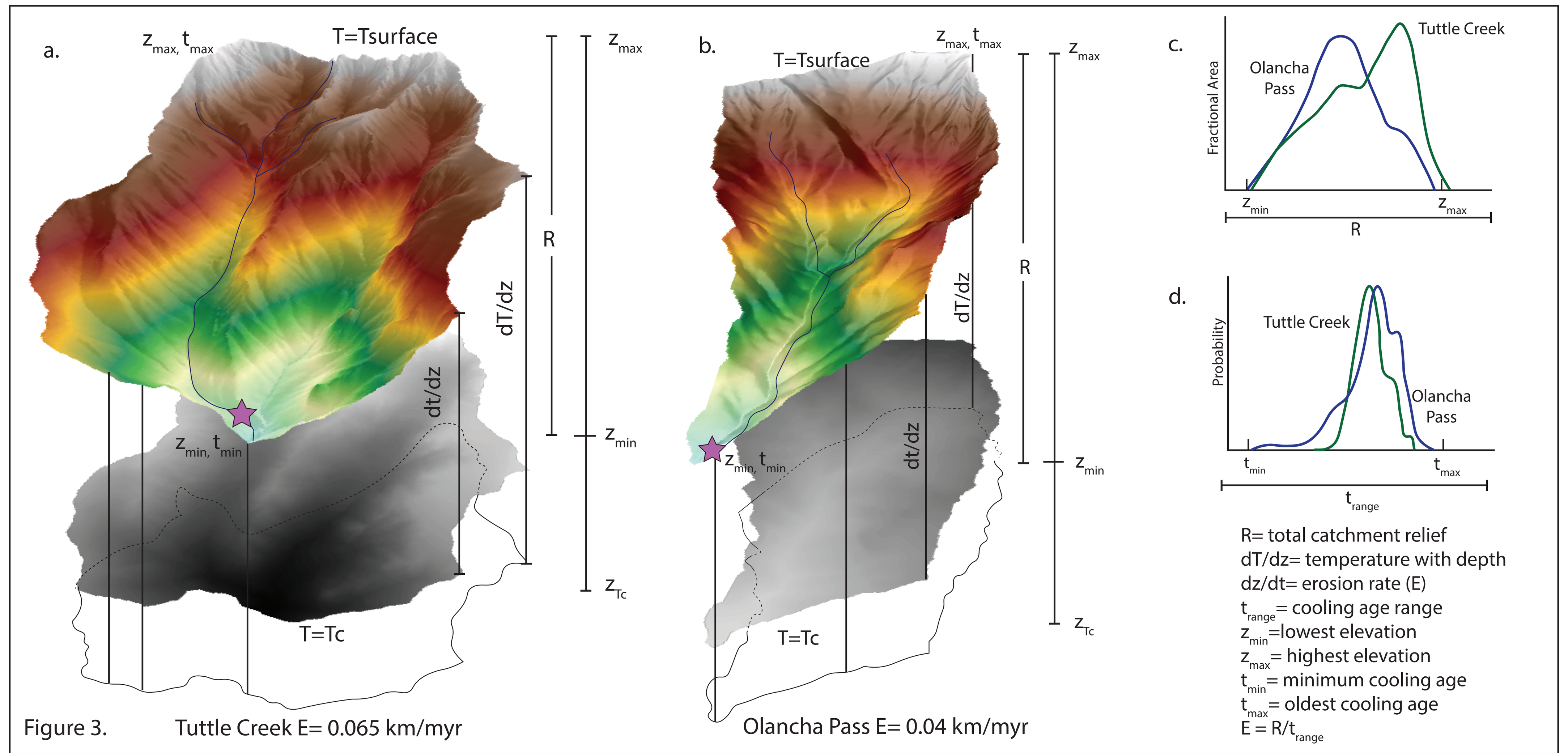

Figure 3. Tuttle Creek E= 0.065 km/myr Olancha Pass E= 0.04 km/myr

Figure 2. Digital elevation model (DEM) of the southeastern Sierra Nevada showing the intersection of the Sierra Nevada Frontal Fault Zone (SNFFZ) and the Garlock Fault, as well as preliminary sample locations of samples collected by Horne (2019) as well as samples collected (or to be collected soon) for this study.

Figure 3. Schematic diagram outlining method of Ruhl and Hodges (2005) for estimating long-term, catchment-averaged erosion rates using distribution of detrital mineral cooling ages from modern stream sediment and the hypsometry of the catchment. a.) Active catchment 3D DEM of Tuttle Creek b.) Active catchment 3D DEM of Olancha Pass. c.) Hypsometric curves determined from the catchment DEMs d.) Zircon (U-Th)/He cooling-age synoptic probability density function (SPDF), used to describe detrital cooling age distribution for single-grain analyses.

Our approach is an extension of several previous studies that successfully used detrital thermochronology of modern sediments as a powerful proxy for bedrock age-elevation profiles. Most such studies require the following assumptions (e.g., Ruhl and Hodges, 2005):

1. A detrital sample represents bedrock in proportion to its outctop area.
2. A catchment's long-term erosional history has been spatially uniform.
3. The erosion rate was constant during closure interval of the chronometer used, although it may have varied afterwards.
4. The closure temperature isotherm was approximately horizontal over the topographic wavelength of interest.
5. The closure temperature isotherm was at a constant depth during the closure interval, though that depth need not be assumed.

When such assumptions are correct, an averaged exhumation rate can be calculated from the catchment relief and detrital date range.

Model Setup and Preliminary Results

As a first step toward building a more detailed understanding of the exhumation history of the southeastern Sierra Nevada, we are using the method presented in Gallagher and Parra (2020) to model the thermal history of detrital data using at minimum, a detrital data set and present-day distribution of elevation in the catchment (i.e., its hypsometry).

This method is based on predicting a vertical profile in a catchment for a given thermal history and then sampling according to the topographic sampling function (TSF). The TSF can be equivalent to the input hypsometric curve or can be varied using iterative, non-negative, least squares to estimate an ideal TSF for a given thermal history. The original Gallagher and Parra (2020) approach was designed for applications using only low-temperature thermochronometers. We are working to expand this method to incorporate data from higher temperature chronometers as well, either through using them as priors for the modeling or by directly modeling them. We will combine a large number of the resulting models for different catchments along the eastern Sierra Nevada to establish a regional view of exhumation histories.

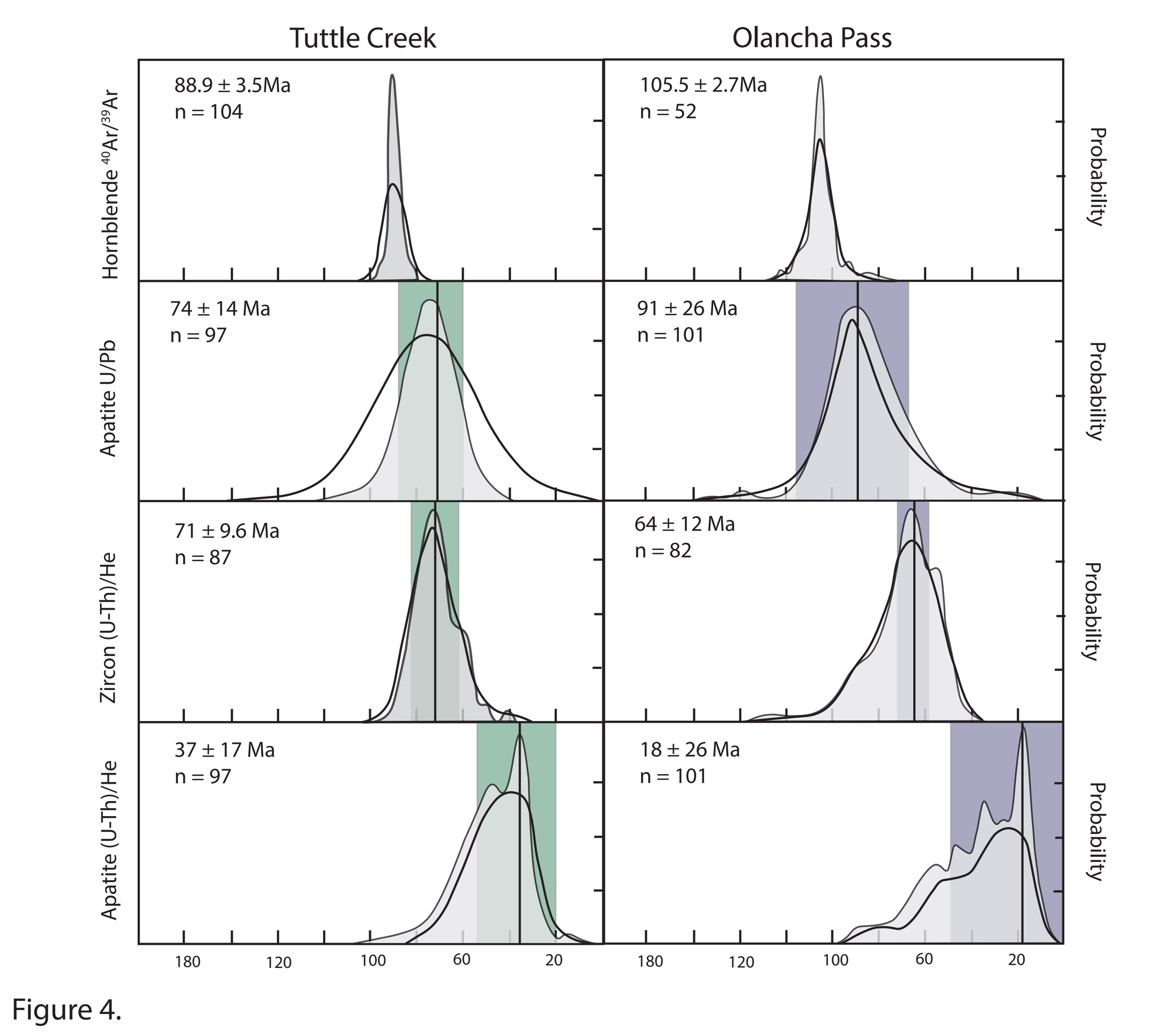

Figure 4.

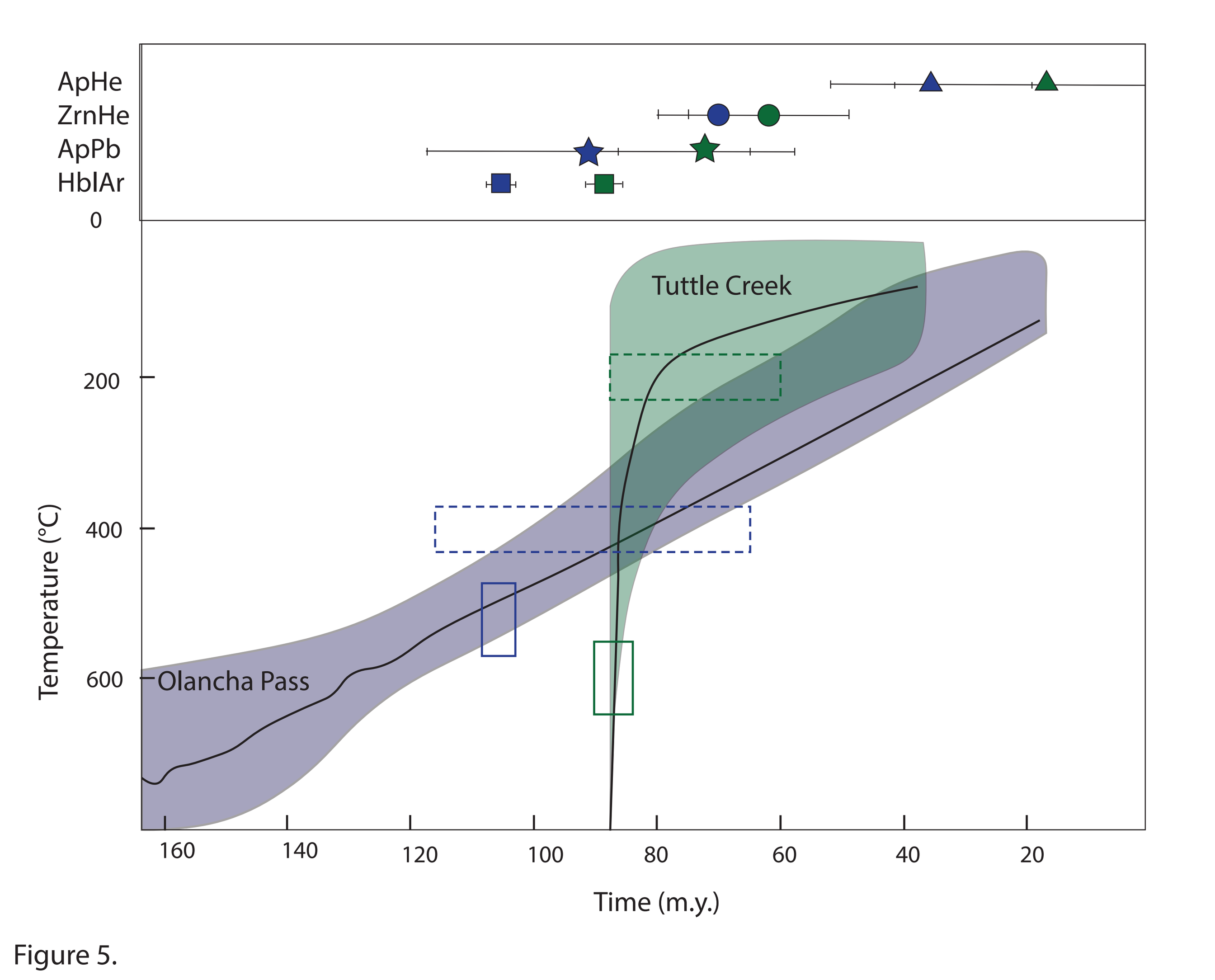

Figure 5.

Figure 4. Distributions of detrital thermochronologic dates from Tuttle Creek and Olancha Pass (Horne, 2019). Summed probability density (shaded areas) and kernel density estimation (black curves) following data visualization approach of Vermeesch (2012). Vertical thick lines are plotted at the principle mode dates used as proxies for the models shown in Figure 5. Colored boxes indicate the 2σ uncertainty bounds estimated via bootstrap model.

Figure 5. QTQt cooling history model results for Tuttle Creek and Olancha Pass using their respective catchment hypsometry as the model input TSF. Apparent ages (and 2σ uncertainties) used to constrain each model are plotted in the top bar. Colored rectangle boxes of higher-temperature chronometers of $^{40}Ar/^{39}Ar$ hornblende (solid line) and U/Pb apatite (dashed line) were used as model priors.

Until the expanded form of QTQt is available, it is possible to explore possible outcomes of future modelling exercises by applying the standard form of QTQt to a pre-existing dataset (Horne, 2019). For such tests, we modeled detrital apatite and zircon (U-Th)/He data but used available higher-temperature chronometric data ($^{40}Ar/^{39}Ar$ hornblende and U/Pb apatite) as priors.

Shown here are results from the Tuttle Creek and Olancha Pass catchments. They indicate distinctive cooling histories in both catchments, implying that the intended studies of numerous catchments should provide a regional understanding of variations in catchment-scale cooling and exhumation histories along the eastern flank of the Sierra Nevada.

References

1. Ehlers, T. (2005). Crustal thermal processes and the interpretation of thermochronometer data. Rev in Min and Geochem, 58(1), 315–350. 2. Gallagher, K. and Parra, M. (2020) A new approach to thermal history modelling with detrital low temperature thermochronological data. Earth and Planetary Science Letters 529. 3. Horne, A. M. (2019) Tools, Techniques, and Applications for Detrital Thermochronology: From the Lab to the Eastern Sierra Nevada, California. Ph.D. Thesis Dissertation, ASU. 4. Ruhl, K. W. and Hodges, K. V. (2005) The use of detrital mineral cooling ages to evaluate steady state assumptions in active orogens: An example from the central Nepalese Himalaya. Tectonics 24(4). 5. Vermeesch, P. (2012) On the visualisation of detrital age distributions. Chemical Geology 312, 190–194.