Using Detrital Apatite U-Th/He Thermochronology in Slowly Eroding Orogens: An Appalachian Perspective

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1. Introduction

The Appalachians have long been described as the archetypal old mountain range and their form has shaped the way geomorphologists view landscape evolution through the models of Davis (1889, 1899) and Hack (1960). However, the persistence of rugged topography and moderate relief in conjunction with unsteady delivery of sediment to offshore basins suggest a more eventful history then that of slow decay following rifting in the Triassic. Until now, this nuanced history was not detectable using apatite U-Th/He thermochronometry due to poor age reproducibility. The samples discussed in this study were part of an effort to use detrital sampling and the natural selection of chemical and physical weathering processes to derive more detailed cooling history information than was available with traditional bedrock sampling.

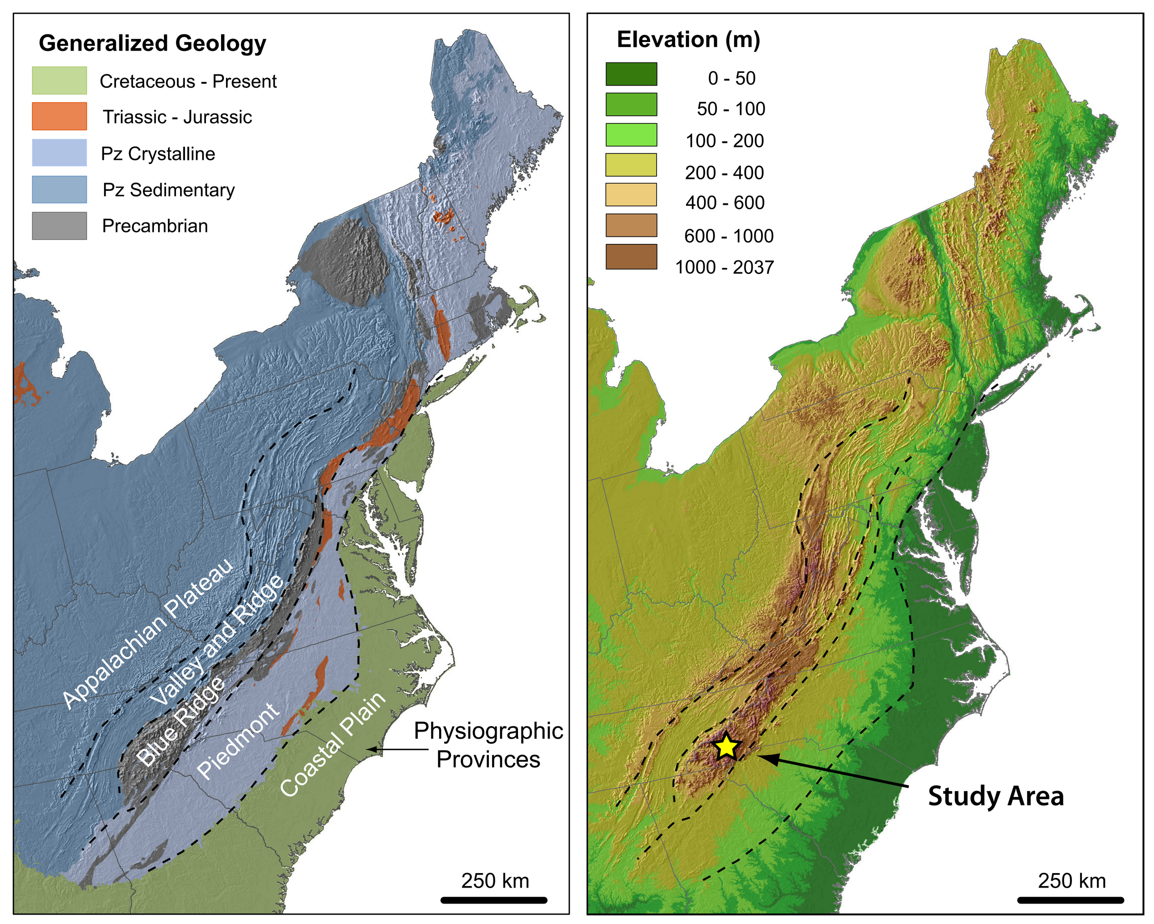


Figure 1: Maps showing the relationship (or lack there of) between bedrock geology, modern topography, and the major physiographic provinces of the Appalachian landscape.

2. Detrital Apatite U-Th/He Thermochronometry

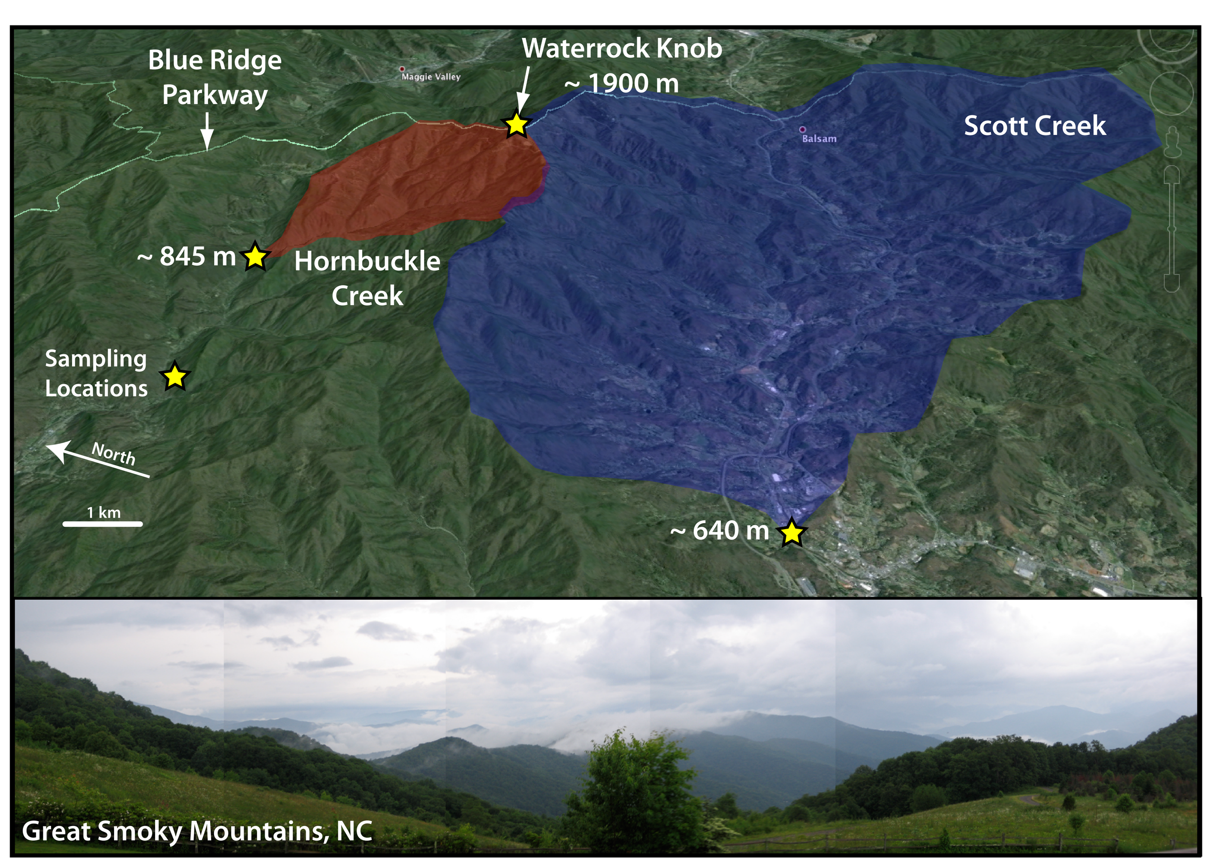


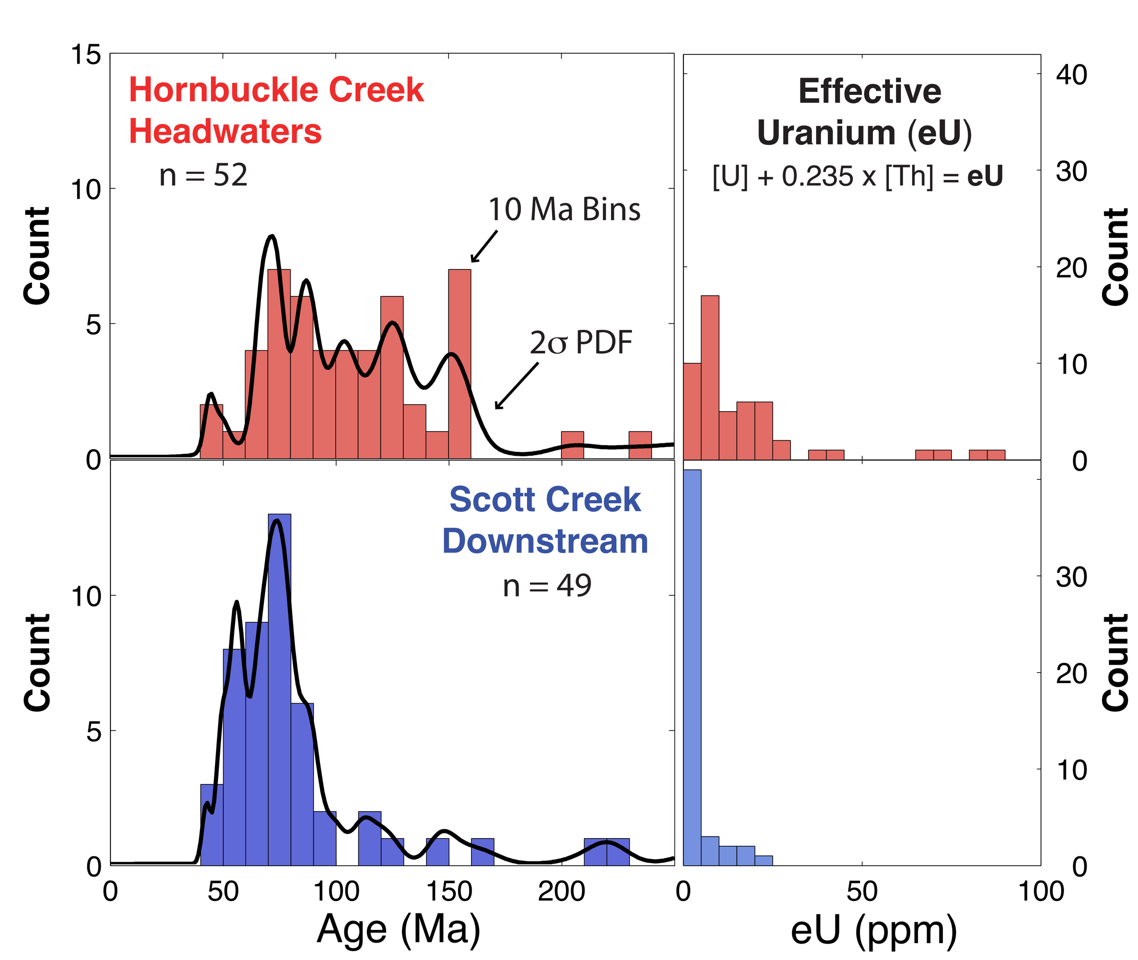
Figure 2: Google Earth image showing the two drainages sampled for this study. The image and the photograph below it illustrate the rugged nature of the topography of this portion of the southern Appalachian Mountains.

Although the landscape is quite rugged, due to the modern humid climate, it is difficult to find fresh bedrock outcrop in the Blue Ridge Mountains of western North Carolina, making traditional bedrock sampling techniques. Here I sampled two adjacent valleys that drain different sides of Waterrock Knob, which at just under 2000 m in elevation is the highest point along the Blue Ridge Parkway and concordant with surround summit ridges as seen in the photo (Figure 2). Geologically these two drainages sample different units of Proterozoic gneiss which are separated by a fault that has been inactive since the end of Paleozoic orogenesis.

These drainages were selected for sampling because the goal was to try and understand the relationship between U-Th/He cooling and elevation, such that one could then interpret the cooling history that the area experienced. A very narrow distribution would be suggestive of fast cooling, whereas a broad range in ages would be interpreted as evidence for protracted cooling over a long period.

When only the age populations are considered, the results appear to be contradictory, because Hornbuckle Creek produced a wide range in ages, whereas, Scott Creek produced a narrow range of comparatively young ages. Because these two drainages are small and adjacent, it is implausible to assume that they experienced profoundly different thermal histories. The modeling that follows attempts to explain the difference in the two age populations through the effective uranium (eU) populations using a single thermal history.

Figure 3: Results of U-Th/He Thermochronometry of detrital apatite (AHe) grains collected from the Hornbuckle (red) and Scott Creek (blue) drainages. Of particular note is the difference between the populations of age and U and Th concentration derived from these adjacent drainages.



3. Modeling Radiation Damage Effects

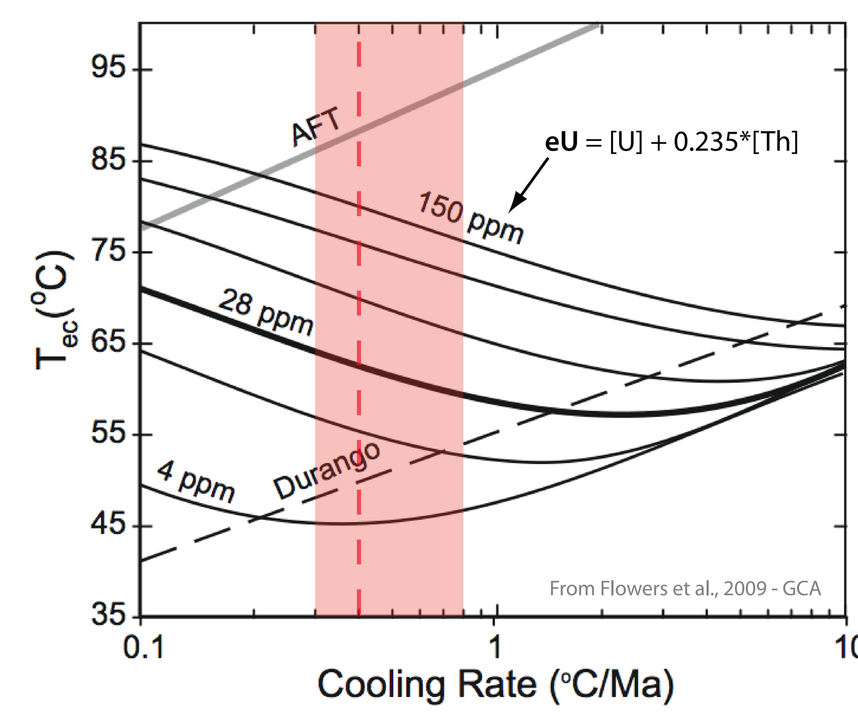


Figure 4: Plot from Flowers et al. (2009) of cooling rate vs. closure temperature for apatite U-Th/He thermochronometry. The contours illustrate the range of closure temperatures that are possible for different concentrations of eU (which convolves the helium production of U and Th into a single number). The red shading indicates the range of plausible cooling rates for the Appalachian landscape and the red dashed line shows the cooling rate used for the forward model.

A fundamental assumption of detrital thermochronometry is that the age of grain is representative of the position in the landscape from which it was derived. However, radiation damage within apatite grains has been shown to alter the closure temperature based on the concentration radiogenic material (eU) and is magnified by slow rates of cooling. This study forward models the impact of radiation damage on the two data sets collected from the southern Appalachians.

Geologic Model Assumptions

20 m/Myr Erosion Rate - corroborated by long-term and short-term estimates from throughout the Appalachians and locally by radiation damage modeling of a sample from the summit of Waterrock Knob.

20 °C/km Geothermal Gradient - Intended as a long term average for the orogen from the post-rift through to decay phase.

Geomorphology is Simple! - Meaning uniform sampling of the landscape through sampling the hypsometric distribution.

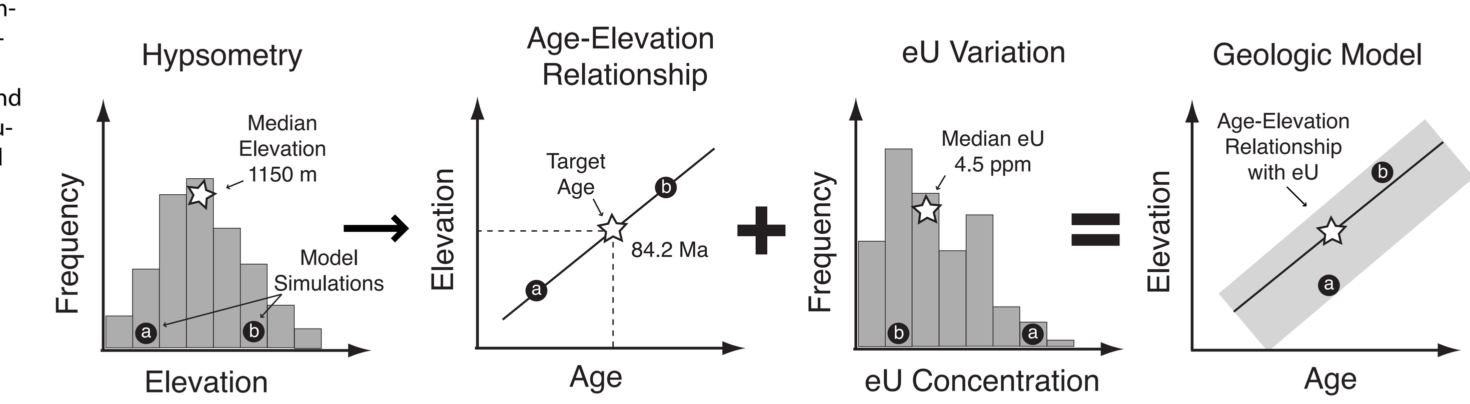


Figure 5: Schematic diagram of the input datasets and implications of the Geologic Model. The stars indicate the controls on the model that were derived from poolling the observed data from the Hornbuckle and Scott Creek dat sets.

Model Inputs

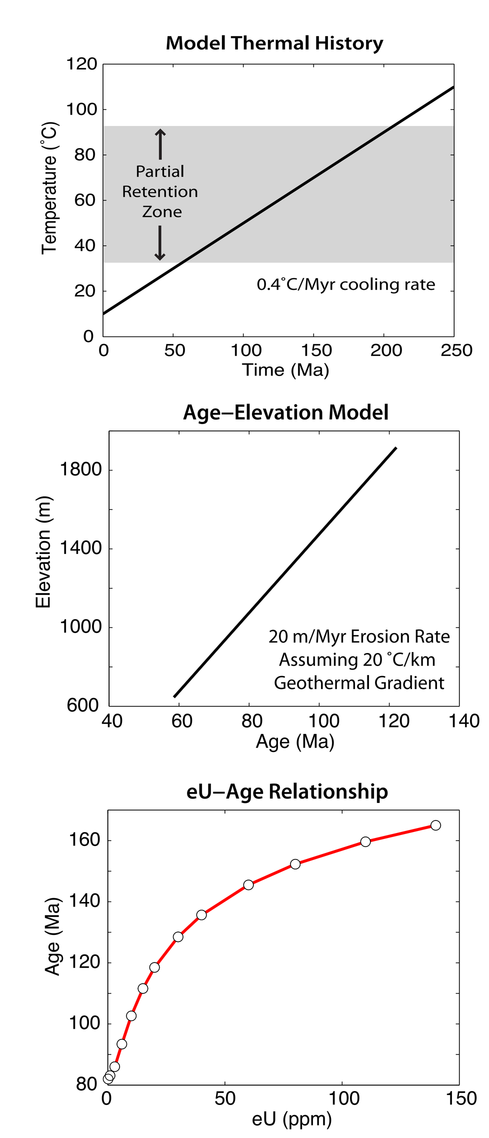


Figure 6: Plots showing the inputs for forward modeling the effect of radiation damage for detrital AHe data sets.

Model Outputs

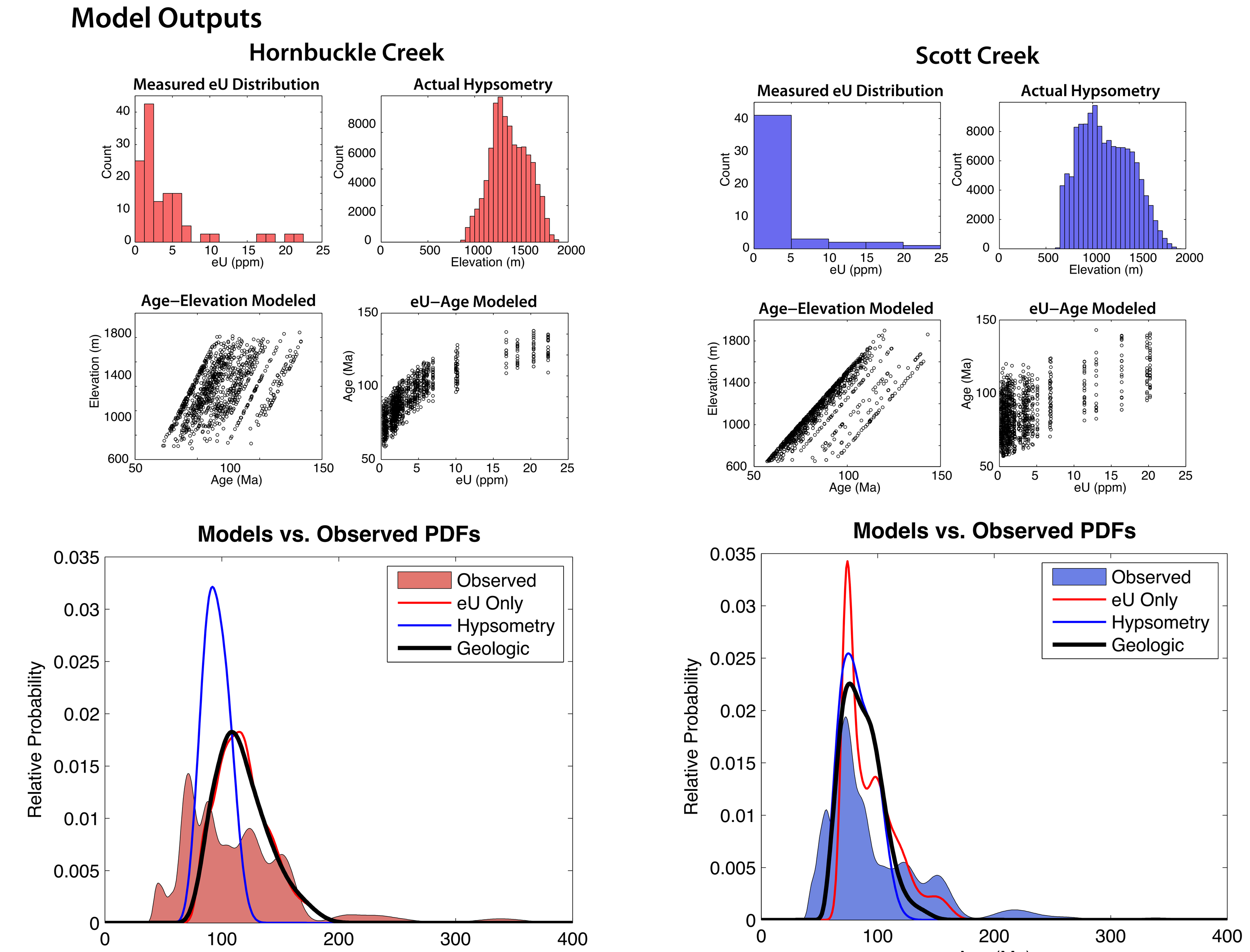


Figure 7: Summary plots of observed and forward model results for the Hornbuckle and Scott Creek data sets. Histograms show the input elevation and eU data sets that were randomly sampled to generate 1000 model detrital "grains". Age-elevation and eU-age plots illustrate the results of the modeled "grains" which the bottom plots present as probability density functions. The observed data for each watershed is shown by the shaded region, which is compared to modeled results where only the effect of hypsometry is considered (blue line), only radiation damage is considered (red line) or both the effect of elevation and radiation damage is considered – the so called Geologic Model – (black line).

4. Conclusions

* **In slowly eroding regions the differences in closure temperature caused by radiation damage can have a profound impact on detrital apatite U-Th/He datasets.**

* **Seemingly contradictory data sets gathered from adjacent watersheds can be explained by a shared thermal history as recorded by apatites with significantly different effective uranium (eU) concentrations.**