Forum Reply

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Zircon (U-Th)/He thermochronology reveals pre-Great Unconformity paleotopography in the Grand Canyon region, USA

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In Peak et al. (2021), we reported zircon (U-Th)/He (ZHe) data from Grand Canyon basement and proposed a model of Great Unconformity development driven by Neoproterozoic faulting and resultant spatial variation in topography, erosion, and deposition. Thurston et al. (2021) subsequently reported additional ZHe data for Grand Canyon basement. The Comment by Karlstrom et al. (2022)—written by the authors of Thurston et al. (2021)—makes false statements about our work and presents time-temperature (*t-T*) models that should not be interpreted because of invalidation by basic Grand Canyon geology.

Karlstrom et al. include numerous inaccurate and misleading claims. They falsely declare that we asserted our "ZHe data preclude" deposition of the Grand Canyon Supergroup in the Lower Granite Gorge (LGG) (or western Grand Canyon, WGC). However, based on endmember *t-T* models designed to test the Neoproterozoic exhumation (NeoExh)/no Supergroup burial hypothesis and the Supergroup burial hypothesis, we concluded that "of the two hypotheses tested, the NeoExh model is most consistent with the LGG ZHe data, compatible with the preserved Supergroup extent." Karlstrom et al. erroneously state that we "prefer" a single *t-T* path. In fact, we show and base our interpretations on all viable *t-T* paths yielded by our models (our figure 3, Peak et al., 2021). They further assert that our model results are inconsistent with a K-spar Multi Diffusion Domain (MDD) model; however, the NeoExh model that we favor yields *t-T* paths compatible with those results (Fig. 1). The statements by Karlstrom et al. regarding the Sinyala fault and sample depths misrepresent our exhumation model, which we clearly labeled "schematic" as a visualization of a possible end-member scenario (our figure 4, Peak et al., 2021). As we explained in the text, this scenario is not Unkar-age exhumation across a single fault, but instead is a depiction of spatial variation in exhumation and burial between the WGC and EGC accommodated across multiple faults from late Mesoproterozoic through early Cambrian time.

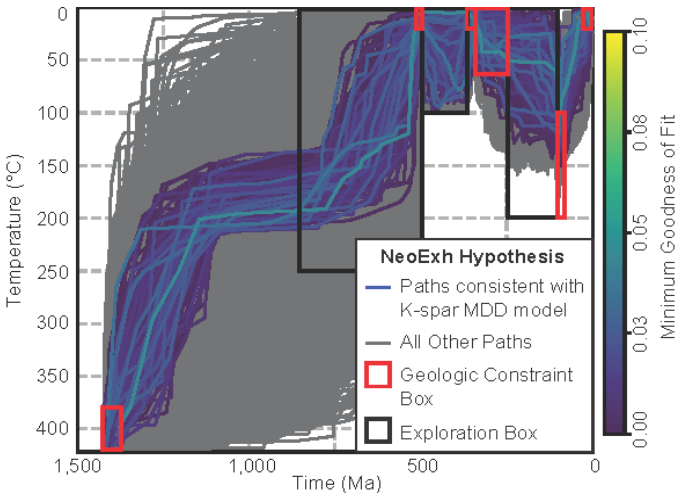

Figure 1. NeoExh hypothesis *t-T* results from Peak et al. (2021). Paths consistent with K-spar MDD thermal history in Karlstrom et al. (2022) colored by minimum goodness of fit. For full explanation, see Peak et al. (2021).

A core element of Karlstrom et al.'s Comment is the presentation of a thermal history model for our ZHe data (their figure 1). Unfortunately, this model contradicts basic Grand Canyon geology, and as such is not a viable interpretation. Their highest-probability *t-T* paths cool and exhume basement continuously through the Phanerozoic, the interval during which the basement was being heated and buried by thick sedimentary rock sequences now famously exposed in Grand Canyon. Reliable interpretations cannot be drawn from a model that is irreconcilable with geologic facts. (U-Th)/He dates reflect a time-integrated *t-T* path such that earlier and later segments may be dependent on each other. Thus, all segments must be geologically plausible for any segment to be reliably interpreted. Karlstrom et al. report insufficient information to reproduce or reformulate their model without this fatal flaw.

Problems like those in Karlstrom et al. are also present in Thurston et al. (2021), which simulated new EGC ZHe dates that are Devonian and younger. While their post-Proterozoic dates cannot tightly constrain any portion of the Proterozoic *t-T* path, they incorrectly assert that the ZHe data of Peak et al. (2021) are similarly insensitive to Proterozoic thermal events. In contrast, our results from the EGC and WGC include 17 Neoproterozoic dates that *can* be used to evaluate Proterozoic hypotheses for the origin of the Great Unconformity. Thurston et al. (2021) also falsely state that their results are inconsistent with the ancient canyon model (e.g., Flowers and Farley, 2012), but this model posited partial carving of the modern western gorge by 70 Ma, and late Cenozoic incision of the modern eastern canyon, entirely compatible with the Thurston et al. (2021) conclusions. They additionally ground key interpretations about Grand Canyon evolution on a thermal history model (their figure 4) that yields solutions inconsistent with geologic facts. For example, at ca. 510 Ma their model predicts temperatures of ~200 °C for their basement samples, implying ~7–8 km crustal depths, but at that time those samples were exposed at or very near the surface during unconformable deposition of the Tapeats sandstone atop the basement. As in Karlstrom et al., inadequate documentation is provided to allow replication and redesign of this simulation.

In summary, Karlstrom et al. mis-state our conclusions and adopt our actual conclusions as their own, while presenting nonsensical *t-T* results. Thurston et al. (2021) also misrepresent our work and present geologically invalid *t-T* solutions. We maintain that our data and the geology support a fault-controlled paleotopography model for the origin of the composite Great Unconformity erosion surface in Grand Canyon.

REFERENCES CITED

Flowers, R.M., and Farley, K.A., 2012, Apatite 4He/3He and (U-Th): He Evidence for an Ancient Grand Canyon: Science, v. 338, p. 1616–1619, https://doi.org/10.1126/science.1229390.

Karlstrom, K.E., Guenthner, W.R., Thurston, O.G., Heizler, M.T., Ricketts, J.W., and Timmons, J.M., 2022, Zircon (U-Th)/He thermochronology reveals pre-Great Unconformity paleotopography in the Grand Canyon region, USA: Geology: Comment, v. 50, p. e543, https://doi.org/10.1130/G49843C.1.

Peak, B.A., Flowers, R.M., Macdonald, F.A., and Cottle, J.M., 2021, Zircon (U-Th)/He thermochronology reveals pre-Great Unconformity paleotopography in the Grand Canyon region, USA: Geology, v. 49, p. 1462–1466, https://doi.org/10.1130/G49116.1.

Thurston, O.G., Guenthner, W.R., Karlstrom, K.E., Ricketts, J.W., Heizler, M.T., and Timmons, J.M., 2021, Zircon (U-Th)/He thermochronology of Grand Canyon resolves 1250 Ma unroofing at the Great Unconformity and < 20 Ma canyon carving: Geology, v. 50, p. 222–226, https://doi.org/10.1130/G48699.1.