Response to Comments on “Apatite $^4$He/$^3$He and (U-Th)/He Evidence for an Ancient Grand Canyon”

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We reiterate that geological observations do not require Grand Canyon carving coeval with Colorado River integration. (U-Th)/He data from the western canyon, totaling 29 reproducible analyses from six samples and two labs, compellingly support an ancient canyon. Three dispersed analyses from one anomalous sample do not refute this conclusion, nor do the claimed shortcomings of our modeling have validity.

W e presented apatite $^4$He/$^3$He and (U-Th)/He (AHe) evidence for carving of the western Grand Canyon to within a few hundred meters of modern depths by ~70 million years ago (Ma) (1). These data contradict the prevailing view of post-6 Ma carving of the entire canyon and instead support an ancient canyon model (2). Below, we first offer an alternative explanation for the geological observations of Lucchitta (3). We then address the claims of Karlstrom et al. (4), which are based almost entirely on selected data interpretation, and show that the additional results support, rather than refute, an ancient canyon.

We appreciate the care and detail of the classic geologic mapping studies in the Grand Wash Trough west of the Grand Canyon (5). However, we disagree that the observations outlined by Lucchitta (3) preclude the presence of an ancient canyon. First, the argument that substantial ~70-Ma western canyon carving is not possible because the canyon looks young is disproved by the presence of nearby major paleocanyons of similarly ancient age (Fig. 1). The well-characterized Milkweed, Hindu, and Peach Springs paleocanyons contain relief of ≥1200 m, intersect the western Grand Canyon, are Late Cretaceous–early Tertiary in age (6–8), and record east-northeastward drainage similar to the ancestral river proposed to have excavated the 70-Ma Grand Canyon (2). These gorges provide concrete and uncontroversial evidence for a paleocanyon system of which an ancient Grand Canyon would logically have been part. Several hundred meters of post-6 Ma canyon deepening and widening would have imparted the more precipitous form of the modern Grand Canyon after integration of the Colorado River drainage.

Second, we again emphasize that the absence of pre-6 Ma Colorado River deposits in the Grand Wash Trough does not preclude pre-6 Ma carving of the western Grand Canyon (2, 9). In the model of (2), during most of Miocene time the river flowing westward through the Grand Canyon would have contained <5% of the modern discharge and occupied a far smaller drainage basin in predominantly carbonate lithologies. Combined with a more arid Miocene climate, such a system would not transport substantial fluvial detritus to the trough. Moreover, the evidence of any limited aggradation would have been removed during the 530-m excavation of the Grand Wash Trough after integration of the modern, far larger Colorado River (2, 9). Pierce Canyon fan deposition in the Grand Wash Trough was accomplished by a high-gradient stream issuing from a steep channel and yet was restricted to within a few kilometers of its canyon. Thus, contrary to Lucchitta’s assertion (3), a coeval Grand Canyon containing a river with an order-of-magnitude shallower gradient and the drainage basin characteristics described above would not be expected to have deposited abundant detritus over a broad area of the trough. In addition, debris delivered by high-gradient tributaries into the Grand Canyon itself could choke the gorge (6), which would further limit transport into the Grand Wash Trough.

We are eager to continue a scientifically rigorous discussion of the origin of the Grand Canyon. Unfortunately, the Karlstrom et al. Comment (4) is based on an abstract (10) that includes neither the analytical data nor a description of the methodology used to generate the models shown. In the absence of such critical information, we used the master’s thesis (11) that is the source of the primary data. Contrary to the claims of (4), we find that these data reinforce our original interpretation.

Both (10) and (11) report mean AHe dates for three western canyon samples, two of which yield reproducible results of 82.5 ± 7 Ma (seven analyses) and 69.8 ± 8.7 Ma (three analyses). These 10 measurements are entirely consistent with our 19 individual analyses from four western canyon samples, with mean AHe dates from 71 ± 3 Ma to 89 ± 7 Ma [ uncertainties are 1σ sample standard deviation (1, 12)]. Karlstrom et al. (4) ignore these two additional samples and instead mention only sample 01GC86. The three individual AHe dates for 01GC86 are extremely

Fig. 1. Grand Canyon shaded relief map showing all western canyon-bottom sample locations, mean AHe dates, uncertainties, and number of individual analyses. Gray box denotes the anomalous western canyon sample, which is characterized by extreme AHe data scatter, and forms the basis of the arguments in Karlstrom et al. (4). The ancient Grand Canyon would logically have been part of the well-documented system of Late Cretaceous–early Tertiary paleocanyons. (B) The distribution of measured AHe dates from the reproducible samples in (A) strengthens the case for an ancient western canyon.
We disagree with Karlstrom et al. (4) that a modeling result based on three scattered AHe dates from a single sample disproves the conclusions drawn from 29 reproducible single-grain AHe dates from the six other western canyon samples analyzed by two different labs. Indeed, exclusion of the suspect 01GC86 results from the date histogram yields a combined data distribution that even more compellingly supports an ancient canyon than our initial data set and increases the deviation from a “young” canyon model (Fig. 1B). We maintain that the reproducibility of the western canyon data eliminates the need for speculation about substantial displacement along unidentified faults in the western canyon (4).

Karlstrom et al. (4) also suggest that our effort to fit multiple samples simultaneously has inadvertently mixed samples with possibly different thermal histories and therefore may be invalid. Our rationale for honoring data from multiple samples was to meet a more challenging standard than one using a single sample by demanding internal consistency of AHe and 4He/3He data for the entire western canyon. Nevertheless, it is straightforward to perform the modeling using just the single sample for which we have 4He/He and AHe data: CP06-69. The key conclusions from such modeling (Fig. 2A) are identical to those of our original broader approach (1), with all statistically acceptable paths requiring cooling to temperatures <30°C by ~70 Ma. Although we excluded the 4He/3He data for one spectrum (grain b) of CP06-69 from the simulations in (1) owing to an anomalous final step in the spectrum, including these 4He/3He results as another constraint in the modeling also leaves our conclusions unchanged (Fig. 2A). Thus, contrary to the contention of Karlstrom et al. (4), even modeling of a single sample supports ancient canyon carving and is incompatible with a young canyon.

Karlstrom et al. (4) imply that western canyon apatites may be more He retentive than our modeling allowed because we did not consider the possibility of incomplete radiation damage annealing during peak burial at ~80 to 90 Ma. However, incomplete annealing of radiation damage is inconsistent with apatite fission-track data and length data in the region (13). Furthermore, in addition to the old He dates, a key feature of the western canyon AHe data set is a lack of correlation between He date and effective U (eU) concentration, despite a factor of 15 variation in eU among dated grains (Fig. 2B). Models that invoke incomplete annealing of radiation damage and associated He retention before peak heating instead invariably yield extremely strong date-eU correlations (Fig. 2B). We thus conclude that this criticism has no merit.

Our eastern Grand Canyon results were also challenged by Karlstrom et al. (4). In (12), we argued for carving of a kilometer-scale paleocanyon by 55 Ma in this region based on AHe data indicating that rim and canyon-bottom samples experienced similar early through mid-Tertiary temperatures. Use of a revised He diffusion kinetic model (14) and comparing rim-sample simulation results (14) with all statistically viable thermal histories for eastern canyon-bottom samples in (1) similarly supports carving of a paleocanyon by early Tertiary time (Fig. 2C). Unfortunately, the Karlstrom et al. (4) criticism of this conclusion compares results from the earlier kinetic model with those of the later model; although either model alone is internally consistent, it is inappropriate to compare across them. Karlstrom et al.’s analysis (4) is also problematic because they use selected time-temperature paths rather than the larger suite of thermal histories that are statistically viable. Finally, plotting the youngest individual AHe dates from samples across the larger region at a single arbitrarily selected temperature on this thermal history diagram [green stars in Fig. 1B in (4)] is nonsensical.

Karlstrom et al. (4) include other misleading statements that bear on Colorado River integration but not on canyon carving. In particular, they state that they have no backing in the cited literature. For example, the authors declare that (15) describes the southward-transported 60- to 50-Ma Hindu fanglomerate, yet inspection of this reference reveals no mention of the Hindu fanglomerate or its age or documentation of any southward-transported gravel of any kind. The Comment states that semisteady incision rates over the past 4 million years would be sufficient to carve the canyon, but this conflicts with the fact that the oldest direct constraint on western canyon incision is 3.9 Ma and only 290 m
above river level \((/6)\), which constrains just \(~30\%\) of total canyon incision here \((/1)\). Our results imply that the remainder of canyon carving occurred \(~70\ Ma\).

In summary, contrary to the assertions of the Comments, we maintain that the geologic evidence is compatible with ancient carving of much of the western Grand Canyon. The additional thermochronologic data discussed by Karlstrom et al. \((/4)\) only strengthens the case for the canyon’s antiquity.

References and Notes

Acknowledgments: This work was supported by NSF grant EAR-1019896 to K.A.F.

22 January 2013; accepted 25 February 2013
10.1126/science.1234203
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*Science* **340** (6129), 143.
DOI: 10.1126/science.1234203