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Comment on "Apatite $^4He/^3He$ and (U-Th)/He Evidence for an Ancient Grand Canyon"

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Flowers and Farley (Reports, 21 December 2012, p. 1616; published online 29 November 2012) propose that the Grand Canyon is 70 million years old. Starkly contrasting models for the age of the Grand Canyon—70 versus 6 million years—can be reconciled by a shallow paleocanyon that was carved in the eastern Grand Canyon 25 to 15 million years ago (Ma), negating the proposed 70 Ma and 55 Ma paleocanyons. Cooling models and geologic data are most consistent with a 5 to 6 Ma age for western Grand Canyon and Marble Canyon.

The "old" Grand Canyon hypothesis, reinvigorated by modeling of recent $^4He/^3He$ data in Flowers and Farley (*1*), posits that an early phase of canyon carving was accomplished by a northeast-flowing river 80 to 70 million years ago (Ma) followed by establishment of a west-flowing river by 55 Ma, such that the western Grand Canyon was "excavated to within a few hundred meters of modern depths by ~70 million years ago" (*1*, *2*). The dramatically different "young" Grand Canyon hypothesis states that a majority of the canyon was carved by the west-flowing Colorado River in the past 5 to 6 million years (*3*, *4*). Geologic data supporting the "young" canyon model include (i) 5.3-million-year age of earliest Colorado Plateau–derived sediments in the Salton Trough (*5*); (ii) 4.4-million-year age of oldest known Colorado River gravels (*6*); (iii) lack of pre-6 Ma Colorado River sediment immediately downstream of the mouth of Grand Canyon (*7*); (iv) geometry of north-flowing 70 to 18 Ma paleocanyons in western Grand Canyon (*8*); (v) southward-transported 60 to 50 Ma Hindu fanglomerate that was deposited across the modern course of the western Grand Canyon (*9*); (vi) semisteady incision rates over the past 4 million years sufficient to carve most of the Grand Canyon in 6 million years (*10*); and (vii) lack of Colorado Plateau detritus in early Tertiary deposits of the Los Angeles basin (*11*).

We believe that the thermochronologic data and modeling of Flowers and Farley also are consistent with a "young" Grand Canyon when reinterpreted to correct for tenuous assumptions. Their thermal models were generated from $^4He/^3He$ diffusion profiles and apatite $^4He/^3He$ and (U-Th)/He (Ahe) data for the eastern and western Grand Canyon (Fig. 1A), but we question their geological interpretations of these models for several reasons. Incomplete understanding of He diffusion in apatite poses considerable difficulties in assigning constrained cooling paths, requiring critical examination of modeling assumptions. One assumption used (*1*) was that apatite grains from each four-sample "ensemble" in the eastern and western Grand Canyon shared common cooling histories and can be modeled together. However, this is suspect because of structural complexities in both regions (*12*). Instead, existing AHe and apatite fission-track (AFT) data (*12–15*) show variability in thermochronologic ages and therefore nullify the extrapolation of results from a few samples to the entire Grand Canyon. Another questionable assumption (*1*) (see below) is that western Grand Canyon samples were heated enough to completely anneal apatite at 80 to 120 Ma.

Joint inversion of independent AHe and AFT data sets is especially powerful and provides well-constrained cooling histories for river samples in the eastern Grand Canyon (*14*); these show that basement rocks cooled slowly from 80° to 70°C between 65 and 25 Ma, then cooled rapidly from 25 to 15 Ma. The geometry of their published rim-level samples (shown in our Fig. 1A) is not optimal for resolving paleocanyons, but all available data (*12–15*) suggest that rim- and river-level samples, now separated vertically by 1 to 1.5 km, resided at 45° to 55° and 80°C, respectively, from 60 to 25 Ma. There is no evidence for a paleocanyon until after 25 Ma, when rim- and river-level cooling paths converge (Fig. 1B). Similar data show that the Marble Canyon section of the eastern Grand Canyon was buried by ~2 km of rock, and hence no canyons existed there until after 10 Ma (*14*). The combined data (Fig. 1B) refute the hypothesis for carving of the eastern Grand Canyon by 55 Ma (*1*, *2*).

The western Grand Canyon cooled earlier than the eastern Grand Canyon because of its proximity to the ancient Sevier/Laramide highlands. This region was eroded by northeast-flowing Laramide paleocanyons (*9*) and is cut by numerous faults with a history of recurring movement (*12*). A model from one $^4He/^3He$ sample (CP06-69) (Fig. 1C) suggests that rocks cooled to <30°C (~200 m depth) and have resided at these cool temperatures since 70 Ma (*1*). However, this interpretation conflicts with the joint inversion of AFT and AHe data from nearby samples (*14*), which suggests that these rocks cooled from ~60° to 40°C between 60 and 25 Ma (01-GC86) (Fig. 1C), compatible with ~1-km burial depth (the present depth below the rim). These conflicting results (*1*, *14*) have several plausible explanations: (i) Sample "ensembles" from (*1*) span several known faults and therefore may not have shared a common cooling history. (ii) Western Grand Canyon samples accumulated considerable radiation damage during residence in the AHe partial retention zone for >600 million years and may not have been heated enough during the Cretaceous time to fully anneal grains, such that western Grand Canyon models should be rerun starting ~600 Ma to account for any incomplete annealing and inherited helium. (iii) When the combined AFT and AHe data sets (*1*, *12–14*) are merged, the results of (*1*) are more closely reproduced by the "young" canyon than the "old" canyon model (Fig. 1E). The conflicting models (Fig. 1C) could both be correct if (iv) sample CP06-69 (*1*) was situated beneath a north-flowing paleocanyon near Separation Canyon, whereas sample 01GC-86 (*14*) was from an interfluve; or (v) CP06-69 was cooled on the upthrown side of an unrecognized Laramide reverse fault relative to 01GC-86. Although our knowledge of the north-flowing Laramide paleocanyon system is incomplete, existing thermochronologic data argue against a 70-Ma western Grand Canyon that followed the same path with nearly the same depth as the modern canyon.

A simple dichotomy of "old" canyon versus "young" canyon hypotheses is overly simplistic because the Grand Canyon includes different sections with different geologic histories. Older paleocanyons likely were reused or re-excavated once the river found its modern path and began eroding rapidly. Despite these complexities, existing data do not support the model for a 80- to 70-Ma northeast-flowing California river, nor a 55-Ma southwest-flowing Arizona river, that collectively carved the Grand Canyon to within a few hundred meters of its modern depth by Early Tertiary time. Instead, an overwhelming body of published geologic and thermochronologic evidence shows that a majority of the Grand Canyon—the canyon that we see from the rim today—has been carved in the past 5 to 6 million years by

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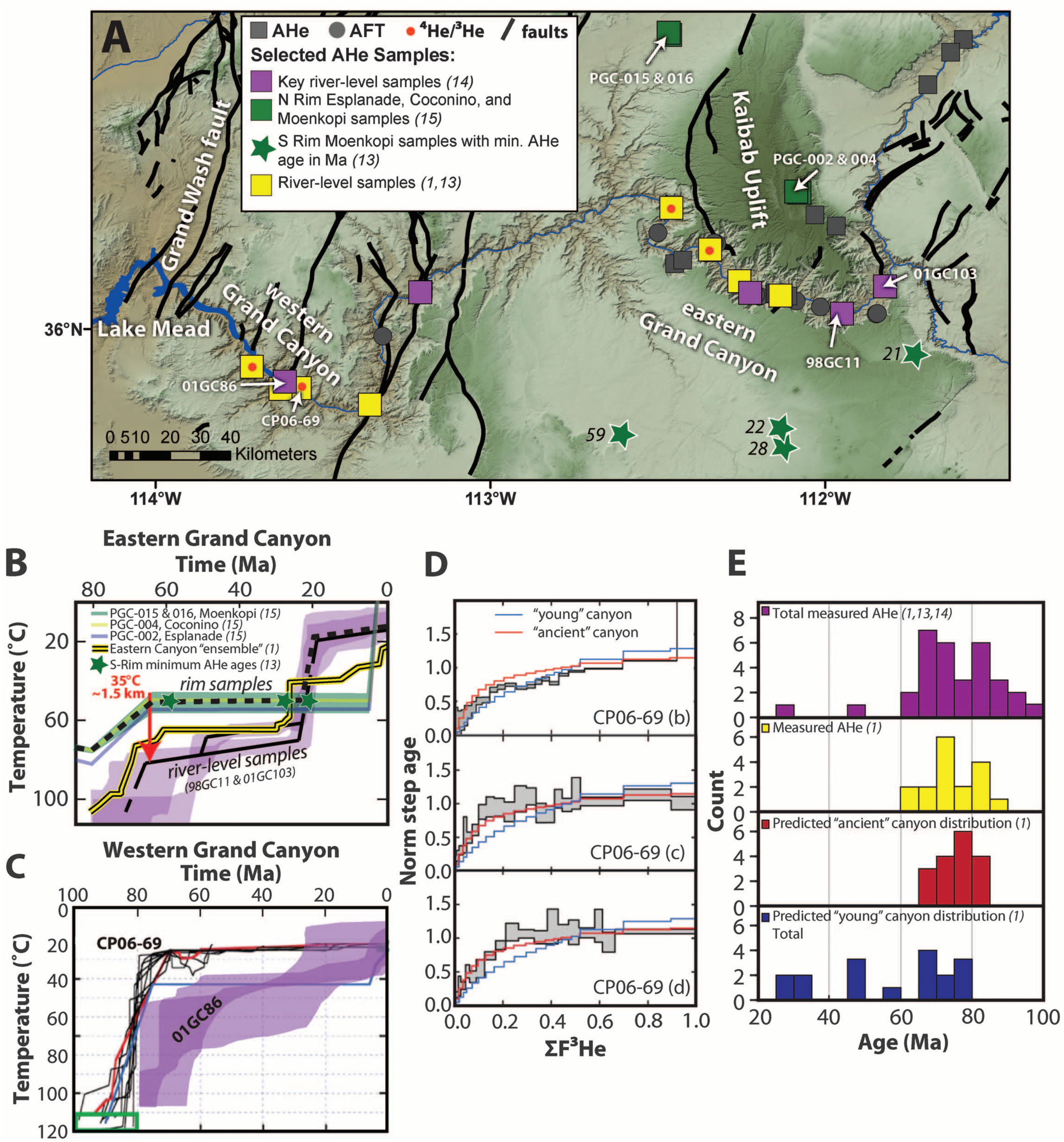

Fig. 1. Thermochronology data from the Grand Canyon region. (**A**) Map of the Grand Canyon region showing apatite helium samples discussed in the text (*1*, *13–15*). (**B**) Carving of an Eastern paleocanyon from 25 to 15 Ma is indicated by different temperatures of rim- and river-level samples until ~25 Ma. (**C**) Western Grand Canyon thermal models are in conflict, but joint inversion of AFT and AHe data [purple curves, from (*14*)], suggest that the western Grand Canyon was carved in the the past 6 million years. (**D**) The top left diffusion profile (*1*) may fit the "young canyon" model if modeled without the highest temperature step. (**E**) Full data set of AHe ages (top) resembles predicted "young" canyon distribution of (*1*).

the Colorado River. Drainage integration at 5 to 6 Ma was likely facilitated by older paleocanyon segments, whose geometry is now coming into focus.

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