Geology

Rapid Plio-Pleistocene erosion of the central Colorado Plateau documented by apatite thermochronology from the Henry Mountains

--Manuscript Draft--

Manuscript Number:	G37733R1
Full Title:	Rapid Plio-Pleistocene erosion of the central Colorado Plateau documented by apatite thermochronology from the Henry Mountains
Short Title:	Rapid Plio-Pleistocene erosion of the Henry Mountains
Article Type:	Article
Keywords:	Colorado Plateau; low-temperature thermochronology; Henry Mountains; geochronology; erosion
Corresponding Author:	Kendra Murray University of Arizona Tucson, Az UNITED STATES
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	University of Arizona
Corresponding Author's Secondary Institution:	
First Author:	Kendra Murray
First Author Secondary Information:	
Order of Authors:	Kendra Murray
	Peter Reiners
	Stuart Thomson
Order of Authors Secondary Information:	
Manuscript Region of Origin:	UNITED STATES
Abstract:	Apatite thermochronology is, in principal, uniquely suited to document the Cenozoic erosion of the Colorado Plateau and settle generations of debate regarding the region's history of uplift, erosion, and fluvial incision. The protracted near-surface history of the Colorado Plateau's bedrock, however, complicates the temperature sensitivity of apatite thermochronometers. This has confounded efforts to see clear evidence of late Cenozoic erosion, especially in the central Colorado Plateau where this problem is compounded by the diverse detrital apatite grains in the region's sedimentary bedrock. We overcome this problem in the thermal aureole of the Oligocene Henry Mountains intrusive complex, where these sandstones have <26 Ma apatite (U-Th-Sm)/He ages with positive-slope age-eU trends (3-25 Ma, 5-180 ppm eU) that resolve a distinctive late Cenozoic history. Thermal modeling results strongly suggest the central Colorado Plateau was a stable Miocene landscape that rapidly exhumed ~1.5-2 km during the last 5 Ma, likely in the last 3-2 Ma, at time-averaged rates of ~250-700 m/Ma. This demonstrates that substantial late Cenozoic erosion of the north-central Plateau interior postdates the ca. 5.6 Ma integration of the Colorado River that lowered regional base level.
Response to Reviewers:	Please see uploaded Cover Letter, which contains reviewer comments and our responses.

Publisher: GSA
Journal: GEOL: Geology
DOI:10.1130/G37733.1

1 Rapid Plio-Pleistocene erosion of the central Colorado
2 Plateau documented by apatite thermochronology from the
3 Henry Mountains

4 **K.E. Murray*, P.W. Reiners, and S.N. Thomson**

5 *Department of Geosciences, University of Arizona, 1040 East 4th Street, Tucson, Arizona*
6 *85721, USA*

7 *E-mail: kemurray@email.arizona.edu

8 **ABSTRACT**

9 Apatite thermochronology is, in principal, uniquely suited to document the
10 Cenozoic erosion of the Colorado Plateau and settle generations of debate regarding the
11 region's history of uplift, erosion, and fluvial incision. The protracted near-surface
12 history of the Colorado Plateau's bedrock, however, complicates the temperature
13 sensitivity of apatite thermochronometers. This has confounded efforts to see clear
14 evidence of late Cenozoic erosion, especially in the central Colorado Plateau where this
15 problem is compounded by the diverse detrital apatite grains in the region's sedimentary
16 bedrock. We overcome this problem in the thermal aureole of the Oligocene Henry
17 Mountains intrusive complex, where these sandstones have <26 Ma apatite (U-Th-
18 Sm)/He ages with positive-slope age-eU trends (3–25 Ma, 5–180 ppm eU) that resolve a
19 distinctive late Cenozoic history. Thermal modeling results strongly suggest the central
20 Colorado Plateau was a stable Miocene landscape that rapidly exhumed ~1.5–2 km
21 during the last 5 Ma, likely in the last 3–2 Ma, at time-averaged rates of ~250–700 m/Ma.
22 This demonstrates that substantial late Cenozoic erosion of the north-central Plateau

interior postdates the ca. 5.6 Ma integration of the Colorado River that lowered regional base level.

INTRODUCTION

The Colorado Plateau is a tectonically and geomorphically enigmatic high-elevation part of the North American Cordillera cut by the spectacular kilometer-scale canyons of the Colorado River and its tributaries. Numerous studies have used low-temperature thermochronology to constrain the timing and rate of regional Cenozoic rock exhumation in order to resolve the relationship between erosion, Plateau uplift, and the evolution of the Colorado River system (Dumitru et al., 1994; Flowers et al., 2008; Hoffman et al., 2011; Lee et al., 2013; Karlstrom et al., 2014). The thermal history of the region's bedrock, however, is challenging to interpret from apatite fission-track (AFT) and apatite (U-Th-Sm)/He (apatite He) results, as highlighted by the renewed debate over the age of the Grand Canyon (Flowers and Farley, 2012; Lee et al., 2013; Karlstrom et al., 2014). This is because these rocks resided in the near surface (<120 °C) throughout the Phanerozoic, which had a substantial effect on the temperature sensitivity of the apatite thermochronometers during recent exhumation (Carter and Gallagher, 2004; Fox and Shuster, 2014) that is difficult to reconstruct. This complication is amplified in the region's iconic Paleozoic-Mesozoic sandstones, which have detrital apatite populations with diverse pre-depositional cooling ages variably reset by burial in both radiation damage and radiogenic daughter content.

To overcome this challenge in the central Colorado Plateau, we collected samples from the Oligocene Henry Mountains intrusive complex (Fig. 1A), where plutons (i.e., laccoliths, Gilbert, 1877) intruded the Paleozoic-Mesozoic strata, overprinted their

convoluted thermal history, and primed them to document only the post-Oligocene history of rock cooling. Using zircon U/Pb geochronology and apatite thermochronology, we characterize the timing and extent of this heating in order to find and interpret a robust record of late Cenozoic rock exhumation of the Plateau interior.

GEOLOGIC BACKGROUND

The Colorado Plateau is a relatively undeformed ~350,000-km² province in the North American Cordillera (Fig. 1A). During the Paleozoic and Mesozoic, the region was near sea level and accumulated 3–5 km of sedimentary rock that today sits at an average elevation of ~2 km. The Plateau's Cenozoic rock record is sparse, so constraining the timing and rate of erosion using thermochronology is one of the few approaches that can improve models of how the Cenozoic evolution and collapse of the North American Cordillera modified the Plateau's lithosphere and resulted in isostatic and/or dynamic uplift (Flowers, 2010 and references therein). Although the modern Colorado River did not exist until the latest Miocene (5.6 to 5.3 Ma; House et al., 2008, and references therein), the southwestern Plateau margin has a multiphase Cenozoic history of canyon cutting (Elston and Young, 1991; Flowers et al., 2008; Karlstrom et al., 2014). In contrast, kilometer-scale erosion of the Plateau interior appears to be younger than 10 Ma (Hoffman et al., 2011; Karlstrom et al., 2012; Lee et al., 2013; Lazear et al., 2013). Modern channel profiles and variable late Pleistocene bedrock incision rates inferred from fluvial strath terrace ages, locally reaching rates as high as ~500 m/Ma, suggest this region is transiently responding to regional base-level fall driven by the integration of the Colorado River (Cook et al., 2009; Darling et al., 2012), perhaps modulated by feedback between erosion and isostatic rebound since river integration (Pederson et al., 2013) or

dynamic uplift since 10 Ma (Karlstrom et al., 2012, and references therein). Previous apatite He results from the central Colorado Plateau suggest onset or acceleration of exhumation ca. 10–4 Ma (Hoffman et al., 2011), though highly variable apatite He ages precluded robust thermal history interpretations.

The Henry Mountains are in the central Colorado Plateau northwest of Glen Canyon (i.e., Lake Powell) in southeastern Utah (Fig. 1A). The mountain range is cored by Oligocene laccoliths and related intrusions up to ~4 km in diameter, which uplifted and deformed the Paleozoic-Mesozoic strata during emplacement (Gilbert, 1877; Hunt et al., 1953; Jackson and Pollard, 1990; Nelson et al., 1992). This intrusive complex is a volumetrically minor (~70 km³) component of the magmatic flare-up that swept across the western USA in the mid-Cenozoic (Nelson and Davidson, 1993). Today, the highest peaks in the Henry Mountains rise ~2 km above the surrounding canyon country and the sedimentary domes and laccoliths are variably exhumed (Fig. 1B).

METHODS

We collected 36 bedrock samples (Table DR1) from the diorite porphyry of the Henry Mountains intrusive complex and the Permian-Cretaceous sandstones in the country rocks (Fig. 1A). Zircon U/Pb dating of the porphyry samples documents the timing of laccolith crystallization and local heating. Apatite thermochronology identifies the extent of the thermal aureole and documents the Oligocene-Recent thermal history of the region (AFT, ~120–90 °C; apatite He, ~80–40 °C; see Data Repository for analytical methods)¹. Apatite U-Th-Sm composition is discussed as the effective U concentration ($[eU] = [U] + 0.234[Th] + 0.0047[Sm]$). To complement the thermochronologic results, we calculated the minimum total erosion since the Oligocene (i.e., the amount of Mesozoic

strata missing at each sampled location; see DR2) using a structure contour map of the Henry Mountains and the thickness of the Mesozoic section preserved in the Henry Mountains basin (Hunt et al., 1953).

Thermochronology results (Figs. 1B-C, 2A; Tables DR1, DR3, DR4) vary by rock type because the porphyries and sandstones have different formation ages and apatite populations. Porphyry apatites are low-[eU] (<30 ppm) whereas sandstone apatites have a range of [eU] (3–180 ppm) typical of detrital populations. Apatite He results for most samples have larger-than-expected age variability. Implantation of excess ^4He from the U-Th-rich grain boundary phases (GBPs), previously investigated in these rocks (Murray et al., 2014), affects low-[eU] grains most severely. GBPs are not a useful source of apatite He age variability, so we filtered GBP effects from 17 samples by identifying the distinctive negative-slope age-[eU] trends typical of affected data sets (DR3, Fig. DR1, Murray et al., 2014). In contrast, results from many sandstone samples have useful positive-slope He age-[eU] patterns characteristic of radiation damage accumulation and annealing effects (RDAA, Flowers et al., 2009; Gautheron et al., 2009), which we model using HeFTy (v8.3.1, Ketcham, 2005).

RESULTS

Zircon Geochronology

Zircon U/Pb ages from the Henry Mountains porphyries are 25–28 Ma (Fig. 1B; Table DR2), a narrower range than previous $^{40}\text{Ar}/^{39}\text{Ar}$ age determinations of 20–31 Ma (Nelson et al., 1992). The oldest (27.8 ± 0.58 Ma) are at Mt. Ellen and the youngest (25.5 ± 0.37 Ma) are at Mts. Pennell and Hillers. Many zircon grains contain Mesoproterozoic inherited cores.

115 **Apatite Thermochronology**

116 Sandstone AFT ages are either Eocene (39.5 ± 4.6 – 54.1 ± 6.5 Ma) or Oligocene
117 and similar to those of the porphyry zircon U/Pb ages (27.5 ± 3.3 – 32.1 ± 4.7 Ma). A
118 sample from the upper Jurassic Morrison Formation, collected >7 km from the nearest
119 laccolith at the northern end of the study area (Fig. 1B), has a Late Jurassic AFT age and
120 long track lengths (14.61 ± 0.26 μ m) and is therefore not reset by magmatism or burial,
121 which is consistent with AFT results from the nearby Waterpocket fold (Fig. 1A;
122 Dumitru et al., 1994). Apatite He ages from this and other samples from some upper
123 Jurassic and Cretaceous rocks have single-grain ages >30 Ma (Table DR4) and therefore
124 were not fully reset by Oligocene magmatism. In contrast, at the southern flank of Mt.
125 Hillers, where Permian-Jurassic strata are exhumed and dip sub-vertically against the side
126 of a large laccolith (Jackson and Pollard, 1990), He ages are ~5–25 Ma with single-grain
127 ages as young as 3.42 ± 0.36 Ma. Most of these samples have positive-slope age-[eU]
128 trends (Figs. 1C, 2A): Ages increase from ~5 to ~15–20 Ma with [eU] from 5 to ~50
129 ppm, and show a 20–25 Ma plateau at [eU] from 50 to 180 ppm. Two additional samples
130 from the Entrada Formation collected near the Trachyte Mesa laccolith have a similar
131 age-[eU] pattern. Each sample with this age-[eU] trend has an Eocene AFT age. The
132 apatite He age-[eU] patterns in these samples is typical of radiation damage effects and
133 can thereby be modeled to constrain the Neogene thermal history of the Henry
134 Mountains.

135 Porphyry AFT ages are 24.5 ± 2.8 – 27.9 ± 4.3 Ma and within error of the zircon
136 U/Pb ages (Fig. 1B), which require rapid (<3 Ma) post-emplacement cooling to <80 °C
137 across the entire range. In contrast, porphyry apatite He ages are dominantly Oligocene

>2500 m and Miocene-Pliocene <2500 m (Fig. 1C, Table DR4). The lowest elevation Mt. Ellen sample (2453 m) has He ages 3–16 Ma. He ages younger than U/Pb ages (~15–20 Ma) at the summits of Mts. Ellen and Pennell require that, with the exception of some parts of Mt. Hillers, samples remained >40 °C long after magmatic cooling. Because the apatite He ages from the porphyries are largely unreliable due to GBP effects (DR3), we do not interpret these results further.

THERMAL HISTORIES

Positive-slope He age-[eU] trends with minimum ages as young as ~5 Ma (Fig. 2A) qualitatively suggest residence at partial-retention temperatures (~40–60 °C) for radiation damage to produce the observed range of cooling ages. We model these age-[eU] patterns jointly with AFT results from each sample to find the thermal (temperature-time, t - T) histories consistent with them (DR4). Thermal history constraints (Fig. 2B, inset) include: (a) depositional age, (b) Mesozoic overburden thickness deposited by ~85 Ma, which was still present at the time of laccolith emplacement, (c) the laccolith-generated heating 28–25 Ma, and (d) the modern surface temperature, which is the only post-Oligocene model constraint. We used HeFTy's Monte Carlo inversion mode to model hundreds of thousands of t - T paths and find 100 good-fit paths (GOF > 0.5) for each sample (DR4, Fig. DR2).

The good-fit thermal histories require that all samples remained >40 °C during the Miocene and cooled rapidly to surface temperatures after ~5 Ma (Figs. 2B, 3, DR3). In all good-fit t - T paths, samples are ~45 °C at the start of the Pliocene, with the majority (50%–95%), including the ten best-fit t - T histories for each sample, not cooling <40 °C until after the start of the Pleistocene at 2.6 Ma (Fig. 3).

Assuming a ~ 25 °C/km geotherm (Blackett, 2004) and surface temperatures of ~ 5 – 10 °C since 20 Ma, our modeling results require that these samples stayed at ~ 1.5 – 2 km depth throughout the Miocene. This is the thickness of the Mesozoic overburden missing from the sample locations today (Fig. 1B, DR2) and therefore this result is most simply explained by the entire Permian-Cretaceous sedimentary section (~ 2.5 km) sitting undisturbed, at least locally, until the Plio-Pleistocene. This precludes the presence of a significant volcanic edifice at the Henry Mountains intrusive center and requires that thick Paleogene sediments in the region—if deposited at all—were largely eroded prior to the Miocene.

ERODING THE CENTRAL COLORADO PLATEAU

Apatite thermochronology results from the Henry Mountains strongly suggest that most or all Neogene rock cooling, and thereby erosion, in this region is younger than 5 Ma and postdates the major late Cenozoic perturbation of this landscape: The integration of the Colorado River. This refines previous apatite He results from the central Colorado Plateau that suggested late Cenozoic erosion started after 10 Ma (Canyonlands, Hoffman et al., 2011; Lees Ferry, Lee et al., 2013). Our modeled age-[eU] trends from multiple samples in the Henry Mountains (Fig. 2) strongly suggest cooling to surface temperatures started no earlier than 5 Ma, with ~ 40 °C of cooling during the last 3–2 Ma in the vast majority of the good-fit t - T paths (Fig. 3). These results are best explained by erosion rates < 30 m/Ma prior to the Pliocene and time-averaged rates of ~ 250 – 700 m/Ma since that time.

These Plio-Pleistocene erosion rates are consistent with the rapid mid- to late-Pleistocene bedrock incision rates derived from strath terrace ages along the Colorado

184 River and its tributaries in the Henry Mountains and Glen Canyon region (Cook et al.,
185 2009; Darling et al., 2012; Pederson et al., 2013, and references therein), though they are
186 averaged over a longer time. Thermochronology cannot resolve the transient waves of
187 erosion that likely migrated through the region in response to evolving regional base
188 level, rock strength variability, and proposed isostatic rebound (Cook et al., 2009; Darling
189 et al., 2012; Pederson et al., 2013; Bursztyn et al., 2015), but by defining an upper bound
190 on the onset of this erosion event in the Henry Mountains we confirm that this part of the
191 Plateau interior experienced rapid erosion during the ~5 m.y. since the integration of the
192 Colorado River.

193 Although our results clearly agree with independent evidence for recent rapid
194 erosion, a component of rapid Pleistocene rock cooling in the high-relief, high-elevation
195 Henry Mountains could be the result of increased mountain snowpack during cooler and
196 wetter glacial periods, for two reasons. First, increased flux of snowmelt-sourced
197 groundwater flowing downslope through the sampled sandstones could have driven rock
198 cooling by depressing near-surface isotherms (e.g., Whipp and Ehlers, 2007), though
199 ~1.5-2 km of exhumation is still necessary to cool these samples from ~40-50 °C to the
200 surface since ~5 Ma. Second, increased spring snowmelt discharge could have increased
201 the bedrock erosion rate. Snowmelt-driven erosion is a proposed driver of late Cenozoic
202 erosion in the region (Pelletier, 2009) and modern monitoring of bedrock incision in the
203 Henry Mountains tributaries documents that seasonal snowmelt is the principal driver of
204 erosion in channels around Mt. Hillers (Johnson et al., 2010).

205 In sum, by exploiting the unique thermal history of sandstones in Henry
206 Mountains intrusive complex we discovered a clear thermochronologic signal of rapid

Plio-Pleistocene erosion of the central Colorado Plateau. This result fills a critical gap in our understanding of the region's recent landscape evolution over million-year timescales and limits the possible drivers of this rapid erosion to the integration of the Colorado River and other processes active during the last 5 Ma.

ACKNOWLEDGMENTS

KEM acknowledges support from a NSF GRFP award, ARCS and P.E.O. Scholar Awards, and NSF grant EAR-1219653 to PWR. NSF-EAR 1338583 supports the Arizona LaserChron Center. Thanks to Matt Dettinger, Jordan Murray, and Xavier Robert for assistance in the field; to Alexis Ault and Devon Orme for conversations about apatite He age variability; and Kelin Whipple for discussions of Colorado Plateau geomorphology. Uttam Chowdury, Erin Abel, Mauricio Ibañez-Mejia, Nicky Geisler assisted in the lab. This manuscript benefited from constructive reviews by Cécile Gautheron, Joel Pederson, and one anonymous reviewer.

REFERENCES CITED

- Blackett, R.E., 2004, Geothermal Gradient Data for Utah: Utah Geological Survey, a division of Utah Department of Natural Resources, p. 1–49.
- Bursztyn, N., Pederson, J.L., Tressler, C., Mackley, R.D., and Mitchell, K.J., 2015, Rock strength along a fluvial transect of the Colorado Plateau – quantifying a fundamental control on geomorphology: *Earth And Planetary Science Letters*, v. 429, no. C, p. 90–100, doi: 10.1016/j.epsl.2015.07.042.
- Carter, A., and Gallagher, K., 2004, Characterizing the significance of provenance on the inference of thermal history models from apatite fission-track data—A synthetic data

- 229 study: Geological Society of America. Special Paper, v. 378, p. 7–23, doi:10.1130/0-
230 8137-2378-7.7.
- 231 Cook, K.L., Whipple, K.X., Heimsath, A.M., and Hanks, T.C., 2009, Rapid incision of
232 the Colorado River in Glen Canyon—Insights from channel profiles, local incision
233 rates, and modeling of lithologic controls: *Earth Surface Processes and Landforms*,
234 v. 34, p. 994–1010, doi:10.1002/esp.1790.
- 235 Darling, A.L., Karlstrom, K.E., Granger, D.E., Aslan, A., Kirby, E., Ouimet, W.B.,
236 Lazear, G.D., Coblenz, D.D., and Cole, R.D., 2012, New incision rates along the
237 Colorado River system based on cosmogenic burial dating of terraces: Implications
238 for regional controls on Quaternary incision: *Geosphere*, v. 8, p. 1020–1041,
239 doi:10.1130/GES00724.1.
- 240 Dumitru, T., Duddy, I., and Green, P., 1994, Mesozoic-Cenozoic burial, uplift, and
241 erosion history of the west-central Colorado Plateau: *Geology*, v. 22, p. 499–502,
242 doi:10.1130/0091-7613(1994)022<0499:MCBUAE>2.3.CO;2.
- 243 Elston, D.P., and Young, R.A., 1991, Cretaceous- Eocene (Laramide) landscape
244 development and Oligocene-Pliocene drainage reorganization of transition zone and
245 Colorado Plateau, Arizona: *Journal of Geophysical Research*, v. 96, no. B7, p. 12–
246 389–12–406, doi: 10.1029/90JB01978.
- 247 Flowers, R., Wernicke, B.P., and Farley, K.A., 2008, Unroofing, incision, and uplift
248 history of the southwestern Colorado Plateau from apatite (U-Th)/He
249 thermochronometry: *Geological Society of America Bulletin*, v. 120, p. 571–587,
250 doi:10.1130/B26231.1.

- 251 Flowers, R.M., 2010, The enigmatic rise of the Colorado Plateau: *Geology*, v. 38, p. 671–
252 672, doi:10.1130/focus072010.1.
- 253 Flowers, R.M., and Farley, K.A., 2012, Apatite $4\text{He}/3\text{He}$ and (U–Th): He Evidence for an
254 Ancient Grand Canyon: *Science*, v. 338, p. 1616–1619,
255 doi:10.1126/science.1229390.
- 256 Flowers, R.M., Ketcham, R.A., Shuster, D.L., and Farley, K.A., 2009, Apatite (U–Th)/He
257 thermochronometry using a radiation damage accumulation and annealing model:
258 *Geochimica et Cosmochimica Acta*, v. 73, p. 2347–2365,
259 doi:10.1016/j.gca.2009.01.015.
- 260 Fox, M., and Shuster, D.L., 2014, The influence of burial heating on the (U–Th)/He
261 system in apatite: Grand Canyon case study: *Earth and Planetary Science Letters*,
262 v. 397, p. 174–183, doi:10.1016/j.epsl.2014.04.041.
- 263 Gautheron, C., Tassan-Got, L., Barbarand, J., and Pagel, M., 2009, Effect of alpha-
264 damage annealing on apatite (U–Th)/He thermochronology: *Chemical Geology*,
265 v. 266, p. 157–170, doi:10.1016/j.chemgeo.2009.06.001.
- 266 Gilbert, G.K., 1877, Report on the Geology of the Henry Mountains: Government
267 Printing Office, Washington, D.C., doi:10.5962/bhl.title.51652
- 268 Hintze, L.F., Willis, G.C., Laes, D.Y.M., Sprinkel, D.A., and Brown, K.D., 2000, Digital
269 Geologic Map of Utah: Utah Geological Survey.
- 270 Hoffman, M.D., Stockli, D.F., Kelley, S.A., Pederson, J.L., and Lee, J., 2011, Mio-
271 Pliocene Erosional Exhumation of the Central Colorado Plateau, Eastern Utah—New
272 Insights from Apatite (U–Th)/He Thermochronometry, *in* Beard, L.S., Karlstrom,

- 273 K.E., Young, R.A., and Billingsley, G.H. eds., CRevolution 2—Origin and Evolution
274 of the Colorado River System, Workshop Abstracts, p. 132–136.
- 275 House, P.K., Pearthree, P.A., and Perkins, M.E., 2008, Stratigraphic evidence for the role
276 of lake spillover in the inception of the lower Colorado River in southern Nevada
277 and western Arizona, *in* Special Paper 439: Late Cenozoic Drainage History of the
278 Southwestern Great Basin and Lower Colorado River Region: Geologic and Biotic
279 Perspectives, Geological Society of America, p. 335–353.
- 280 Hunt, C.B., Averitt, P., and Miller, R.L., 1953, Geology and geography of the Henry
281 Mountains region, Utah: A survey and restudy of one of the classic areas in geology:
282 US Geological Survey Professional Paper, v. 228, p. 234.
- 283 Jackson, M.D., and Pollard, D.D., 1990, Flexure and faulting of sedimentary host rocks
284 during growth of igneous domes, Henry Mountains, Utah: Journal of Structural
285 Geology, v. 12, p. 185–206, doi:10.1016/0191-8141(90)90004-I.
- 286 Johnson, J.P.L., Whipple, K.X., and Sklar, L.S., 2010, Contrasting bedrock incision rates
287 from snowmelt and flash floods in the Henry Mountains, Utah: Geological Society of
288 America Bulletin, v. 122, p. 1600–1615, doi:10.1130/B30126.1.
- 289 Karlstrom, K.E., et al., 2012, Mantle-driven dynamic uplift of the Rocky Mountains and
290 Colorado Plateau and its surface response: Toward a unified hypothesis: Lithosphere,
291 v. 4, p. 3–22, doi:10.1130/L150.1.
- 292 Karlstrom, K.E., et al., 2014, Formation of the Grand Canyon 5 to 6 million years ago
293 through integration of older palaeocanyons: Nature Geoscience, v. 7, p. 239–244,
294 doi:10.1038/ngeo2065.

- 295 Ketcham, R.A., 2005, Forward and inverse modeling of low-temperature
296 thermochronometry data: *Reviews in Mineralogy and Geochemistry*, v. 58, p. 275–
297 314, doi:10.2138/rmg.2005.58.11.
- 298 Lazear, G., Karlstrom, K., Aslan, A., and Kelley, S., 2013, Denudation and flexural
299 isostatic response of the Colorado Plateau and southern Rocky Mountains region
300 since 10 Ma: *Geosphere*, v. 9, doi:10.1130/GES00836.1.
- 301 Lee, J.P., Stockli, D.F., Kelley, S.A., Pederson, J.L., Karlstrom, K.E., and Ehlers, T.A.,
302 2013, New thermochronometric constraints on the Tertiary landscape evolution of
303 the central and eastern Grand Canyon, Arizona: *Geosphere*, v. 9, p. 216–228,
304 doi:10.1130/GES00842.1.
- 305 Murray, K.E., Orme, D.A., and Reiners, P.W., 2014, Effects of U–Th-rich grain
306 boundary phases on apatite helium ages: *Chemical Geology*, v. 390, p. 135–151,
307 doi:10.1016/j.chemgeo.2014.09.023.
- 308 Nelson, S., and Davidson, J.P., 1993, Interactions Between Mantle-Derived Magmas and
309 Mafic Crust, Henry Mountains, Utah: *Journal of Geophysical Research. Solid Earth*,
310 v. 98, p. 1837–1852, doi:10.1029/92JB02689.
- 311 Nelson, S.T., Davidson, J.P., and Sullivan, K.R., 1992, New age determinations of central
312 Colorado Plateau laccoliths, Utah: Recognizing disturbed K-Ar systematics and re-
313 evaluating tectonomagmatic relationships: *Geological Society of America Bulletin*,
314 v. 104, p. 1547–1560, doi:10.1130/0016-7606(1992)104<1547:NADOCC>2.3.CO;2.
- 315 Pederson, J.L., Cragun, W.S., Hidy, A.J., Rittenour, T.M., and Gosse, J.C., 2013,
316 Colorado River chronostratigraphy at Lee’s Ferry, Arizona, and the Colorado Plateau
317 bull’s-eye of incision: *Geology*, v. 41, p. 427–430, doi:10.1130/G34051.1.

Pelletier, J.D., 2009, The impact of snowmelt on the late Cenozoic landscape of the southern Rocky Mountains, USA: GSA Today, v. 19, p. 4–11, doi:10.1130/GSATG44A.1.

Whipp, D.M., and Ehlers, T.A., 2007, Influence of groundwater flow on thermochronometer-derived exhumation rates in the central Nepalese Himalaya: Geology, v. 35, no. 9, p. 851–4, doi: 10.1130/G23788A.1.

FIGURE CAPTIONS

Figure 1. Overview of study area and results. (A) Geologic map of the Henry Mountains region (after Hintze et al., 2000). E—Mt. Ellen; P—Mt. Pennell; H—Mt. Hillers. Inset shows the location of this study area and the Colorado Plateau (gray field). (B) Elevation versus latitude swath profile of the Henry Mountains, with sample locations colored by net minimum erosion calculated using the thickness of the missing Mesozoic strata at each sample location (DR2). (C) Multi-chronometer results summary. Pink reference line—laccolith zircon U/Pb ages 25–28 Ma. Only minimum apatite He ages are plotted because they are the most reliable results from the GBP-effected samples and show the presence <10 Ma ages across the Henry Mountains.

Figure 2. Apatite He and thermal modeling results for samples with positive-slope age-[eU] trends. (A) Age-[eU] plots with observed ages, model inputs, and modeling results. Input grain age, [eU], and grain size determined by binning results by [eU], excluding very small and large grains (light gray symbols), and imposing 15%–40% error. Samples

collected <3 m apart were combined for modeling. Fields show modeling results as the mean, minimum, and maximum ages from t - T paths modeled starting at the sample depositional age (colorful field; our preferred models) or 28 Ma (grey field; see DR4 for discussion). (B) Weighted mean t - T paths summarize results (Fig. DR2) for the best constrained part of the sample thermal histories: The time since Oligocene heating. Grey boxes—model constraints. Inset shows entire weighted mean t - T paths; letters refer to geologic constraints.

Figure 3. A summary of when the good-fit t - T paths—those that best match the observed positive-slope age-[eU] trends (Figs. 2A, DR2)—cool below apatite He partial-retention temperatures (40-60 °C). The light grey lines, one for each modeled sample in Figure 2A, show the fraction of good-fit t - T paths (GOF > 0.5; n=100 per sample) colder than 50 °C as a function of time; similarly, dark grey lines indicate the fraction of these paths <40 °C. At the start of the Pliocene (5.3 Ma), the majority have cooled below 50 °C, but all (99 %) are warmer than 40 °C and the majority remain so through the end of the Pliocene. 70%–100% of the best good-fit t - T paths (black lines) for each sample are >40 °C until the Pleistocene (2.6 Ma).

¹GSA Data Repository item 2016xxx, detailing analytical methods (DR1), data tables (Tables DR1-4), net erosion calculations (DR2), GBP effects (DR3, Fig. DR1), and thermal modeling (DR4, Figs. DR2,3), is available online at www.geosociety.org/pubs/ft2016.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

Figure 1, Murray et al.

Figure 2, Murray et al.

Figure 3, Murray et al.

DATA REPOSITORY

Supplemental material for: **Rapid Plio-Pleistocene erosion in the central Colorado Plateau documented by apatite thermochronology from the Henry Mountains**

Contents

Section DR1: Analytical methods

- (a) Sample preparation
- (b) Zircon U/Pb
- (c) Apatite fission track
- (d) Apatite (U-Th-Sm)/He

Section DR2: Calculation of net exhumation from erosion of Mesozoic sediments

Section DR3: Grain boundary phase (GBP) effects on apatite He ages

Fig. DR1: Age-[eU] trends and photo evidence for GBPs in these samples

Section DR4: Supporting information for thermal history modeling

- (a) Methods
- (b) Model parameters
- (c) Results

Fig. DR2: Thermal history results from RDAAM in HeFTy

Fig. DR3: Expanded version of Fig. 3 with results for each sample

Table DR1: Sample information and summary of apatite (U-Th)/He results.

Table DR2: Zircon U/Pb data.

Table DR3: Apatite fission track data.

Table DR4: Apatite (U-Th-Sm)/He age data.

References

Section DR1: Analytical methods

(a) Sample preparation

Standard rock crushing, density, and magnetic separation techniques were used to separate apatite and zircon grains from rock samples at Apatite to Zircon, Inc. (Viola, Idaho) and Zirchron, Inc. (Tucson, Arizona).

(b) Zircon U/Pb

We conducted zircon U/Pb analyses by laser ablation multicollector inductively coupled plasma mass spectrometry (LA-MC-ICPMS) at the Arizona LaserChron Center (Gehrels et al., 2008). We picked and mounted ~50 zircon crystals from each igneous sample on an 1-inch epoxy mount with Sri Lanka and Fish Canyon Tuff zircon standards. The mounts were sanded down to a depth of ~20 μm , polished, imaged, and cleaned prior to isotopic analysis. The analyses involve ablation of zircon with a Photon Machines Analyte G2 Excimer laser using a spot diameter of 30 μm . The ablated material is carried in He into the plasma source of a Nu HR ICPMS, which is equipped with a flight tube of sufficient width that U, Th, and Pb isotopes are measured simultaneously. All measurements are made in static mode, using Faraday detectors with 3×10^{11} ohm resistors for ^{238}U , ^{232}Th , ^{208}Pb - ^{206}Pb , and discrete dynode ion counters for ^{204}Pb and ^{202}Hg . Several samples with very small zircons were analyzed using a 10 μm spot size and an Ion Counter detector. Each analysis consists of one 15-second integration on peaks with the laser off (for backgrounds), 15 one-second integrations with the laser firing, and a 30 second delay to purge the previous sample and prepare for the next analysis. The ablation pit is ~15 microns in depth. ^{204}Hg interference with ^{204}Pb is accounted for measurement of ^{202}Hg during laser ablation and subtraction of ^{204}Hg according to the natural $^{202}\text{Hg}/^{204}\text{Hg}$ of 4.35. A common Pb correction uses the Hg-corrected ^{204}Pb and assuming an initial Pb composition from Stacey and Kramers (1975). Uncertainties of 1.5 for $^{206}\text{Pb}/^{204}\text{Pb}$ and 0.3 for $^{207}\text{Pb}/^{204}\text{Pb}$ are applied to these compositional values based on the variation in Pb isotopic composition in modern crystal rocks. Analytical data are shown in Table DR2. Uncertainties shown in this table are at the 1-sigma level, and include only measurement errors. Reported weighted mean $^{206}\text{Pb}/^{238}\text{U}$ ages calculated using the routines in Isoplot (Ludwig, 2008) with a final uncertainty determined by quadratic addition of the weighted mean and external uncertainties.

(c) Apatite fission track

Apatite grains were mounted in epoxy resin, alumina and diamond polished, and spontaneous fission tracks were revealed by etching with 5.5M HNO_3 at 20°C for 20 seconds. Samples were analyzed by applying the external detector method (Gleadow, 1981) using very low uranium, annealed muscovite mica detectors, and irradiated at the Oregon State University Triga Reactor, Corvallis, U.S.A. The neutron fluence was monitored using European Institute for Reference Materials and Measurements (IRMM) uranium-dosed glasses IRMM 540R. After irradiation, induced tracks in the mica external detectors were revealed by etching with 40-48% HF for 20 minutes. Spontaneous and induced FT densities were counted using an Olympus BX61 microscope at 1250x magnification with an automated Kinetek Stage system. Apatite FT lengths and Dpar values were measured using FTStage software, and an attached drawing tube and digitizing tablet supplied by T. Dumitru of Stanford University calibrated against a stage micrometer. Central ages (Galbraith, 2005), quoted with 1σ errors, are

75 calculated using the IUGS recommended zeta-calibration approach of Hurford and Green
76 (1983). For young ages with low track counts a binomial (or Z) age was calculated with 95%
77 confidence intervals using the F-distribution method described by Galbraith (2005). An
78 apatite IRMM 540R zeta calibration factor of 368.1 ± 14.9 was obtained by repeated
79 calibration against a number of internationally-agreed age standards including Durango and
80 Fish Canyon apatite according to the recommendations of Hurford (1990). Mean AFT ages
81 and supporting data are presented in Table DR3; complete data formatted for HeFTy
82 modeling available from the authors. Most AFT analyses in this study lack track-length
83 measurements because the low [U] apatite grains in the porphyries and small grain sizes in
84 the sandstones resulted in low fission-track densities.

86 (d) Apatite (U-Th-Sm)/He

87 We selected individual apatite crystals for dating under a 120-160x stereo-zoom microscope
88 based on crystal clarity, morphology, size, and the lack of visible inclusions or grain
89 boundary phases (Murray et al., 2014; see section DR3). We dated these apatite crystals
90 following the general methods described by Reiners et al. (2004) and Reiners (2005).
91 Dimensions of each dated grain were measured from digital photographs and used to
92 calculate the alpha-ejection (F_T) correction (Ketcham et al., 2011). Individual apatite grains
93 were wrapped in niobium foil packets and heated to 1065 °C for 3 minutes using a Nd-YAG
94 laser in a laser cell attached to an ultra-high vacuum gas extraction. Extracted He gas was
95 spiked with ^3He , purified using cryogenic and gettering methods, and analyzed on a
96 quadrupole mass spectrometer. Analysis of a known quantity of ^4He was performed after
97 every 4-5 unknown analyses to monitor instrumental sensitivity drift. Then, apatite grains
98 were dissolved in HNO_3 at ~90 °C for 1 hour. U, Th, and Sm contents of each grain were
99 measured by isotope dilution and solution ICP-MS, as described by Reiners (2005), using
100 ^{233}U - ^{229}Th and ^{147}Sm spikes; after 2012 a ^{44}Ca spike was used to calculate the stoichiometric
101 apatite mass and volume. Isotopes were measured on an Element 2 ICP-MS. Precision on
102 measured U-Th ratios was typically better than 0.5%. Single-grain apatite He ages and
103 supporting data are presented in Table DR4.

Section DR2: Calculation of net exhumation from erosion of Mesozoic sediments

We calculated the thickness of the missing Mesozoic strata at each sample location and across the entire region by subtracting modern elevations (from sample locations from Table DR1 and a DEM-derived surface, respectively) from the projected, contoured elevation of top of the upper Cretaceous Mesa Verde Sandstone (Hunt et al., 1953). We assume the entire Mesozoic section was still present in the region during the Oligocene because the laccoliths are in intrusive contact with the upper Cretaceous sedimentary rocks across the mountain range (Figure 2A). This approach calculates minimum total rock exhumation because it does not account for additional thickness of possible Paleogene sediments or thickening of the stratigraphic section by emplacement of sills and laccoliths at multiple stratigraphic levels. It likely underestimates the total overburden thickness where the main laccoliths are exposed (at the summits of each mountain) because the amount of laccolith removed is unconstrained by this method.

This is useful because it provides an independent estimate of the amount of erosion during the Cenozoic, which does not correspond with sample elevation in the Henry Mountains because of the differential rock uplift accommodating laccolith emplacement.

Section DR3: Grain boundary phase (GBP) effects on apatite He ages

Seventeen of the 36 samples in this study have apatite He age-[eU] trends typical of the effects of U-Th-rich GBPs. As investigated in detail by Murray et al. (2014), GBPs are a source of parent and/or daughter nuclides outside the apatite grain that violate the assumptions of the alpha-particle ejection correction (Farley et al., 1996; Ketcham et al., 2011) routinely applied to all He ages. For apatite grains free of GBPs at the time of grain selection for dating, like those in this study, GBPs can only make He ages ‘too old’ because excess He implanted by the GBPs is not accounted for by the routine alpha-ejection correction. It is not possible to measure or reconstruct the specific GBP thickness, [eU], coverage on apatite grain, formation age, and diffusion properties for each dated grain, so we cannot quantitatively account for GBP effects and retrieve useful thermal history information from affected grains. GBPs effects are, however, distinctive. They can coexist with other (useful) sources of AHe age variability, including grain size (Reiners and Farley, 2001) and the accumulation and annealing of radiation damage (Flowers et al., 2009; Gautheron et al., 2009). Whereas those two useful sources of age variability have positive-slope trends with age (i.e., increasing age with increasing grain size and/or [eU]), GBP effects result in negative-slope trends because small and low-[eU] grains are the most severely effected by excess He implantation. Therefore, it is possible to qualitatively distinguish between these different sources of age variability and filter out the ages affected by GBPs. Even after this filtering effort, described below, GBP effects are suspect in this entire dataset. However, these GBP effects will only make AHe ages—and our interpretations—too old, not too young, and so do not diminish the findings of this study.

In order to identify and remove apatite grains likely affected by GBPs, we plotted apatite He age vs. [eU] for each sample to identify GBP effects, which result in distinctive negative-slope age-[eU] trends and significant age variability in low-[eU] apatites (Fig. DR1). In this dataset, samples with apatite grains of [eU] <10 ppm have He ages as old as 670 Ma, ~2700% older than the oldest possible cooling age of apatite grains that crystallized in the Oligocene (Table DR4, Fig. DR1B). This is consistent with the findings of Murray et al. (2014), who observed GBPs in the Henry Mountains porphyries with 50 to >1000 ppm [eU] capable of generating this magnitude of age variability at low [eU]. In this study, samples exhibiting negative-slope age-[eU] trends, >15% age variability at higher [eU] values, or both, we report the youngest He age as a maximum cooling age but do not further interpret the ages from this sample. All but one of the samples filtered for GBP effects are porphyries. One sandstone sample, 10HEN08 (Fig. DR1C), has two (of 18 dated) apatites with [eU] < 5 ppm and apparent He ages of 80 and 387 Ma that we filtered out prior to interpretation.

Figure DR1. Examples of apatite He age vs. [eU] plots used to identify grains likely affected by GBPs and therefore not useful for geological interpretations. (A) All but one apatite grain dated from porphyry sample 10HEN44 is older than the oldest zircon U/Pb ages from Mt. Hillers—geologically impossible ages because these grains did not exist prior to ca. 28 Ma. This sample has a negative-slope age-[eU] pattern shape typical of GBP effects (Murray et al., 2014). (B) Porphyry sample 10HEN49 also has a negative-slope trend, but some low-eU grains are younger than or within error of this sample’s U/Pb age, and therefore possibly meaningful cooling ages. Inset is a photomicrograph of apatite grains from this sample covered in rusty-reddish-orange flakey precipitates characteristic of GBPs in the Henry Mountains (e.g., Figure 1 from Murray et al., 2014). No GBP-coated grains were dated for this study. (C) One sandstone sample, 10HEN08, has two (of 18) very old apatite grains with <5 ppm [eU]. If these grains were old due to partial resetting, and thereby meaningful to the cooling history of this sample, they would have very high [eU] (i.e., be very damaged), but the opposite is true. Prior to RDAA modeling of this sample, several more grains were dropped from consideration because they are very small ($R_s < 30 \mu\text{m}$), see Section DR4a.

Section DR4: Supporting information for thermal history modeling

(a) Methods.

We use the radiation damage accumulation and annealing model (RDAAM), as implemented in HeFTy v. 1.8.3 (Ketcham, 2005), to model positive-slope He age-[eU] trends from seven sandstone samples and constrain the sample thermal histories (Flowers et al., 2009; Gautheron et al., 2009). The full modeling results for each sample are shown in Figure DR2. To model the apatite He data, we generated a suite of 3-5 synthetic grains for each sample representative of the age-[eU]-size distribution of the dated apatite grains; some additional age variability could be the result of currently poorly understood but minor effects of Cl-F-OH compositional variation on RDAA (Gautheron et al., 2013). Samples 10HEN09 and 10HEN10, as well as 12HEN03 and 12HEN04, were collected <3 m from each other in the same formation and so were modeled jointly. To remove one source of age variability, we limited the range of grain sizes of dated apatites used to generate these synthetic grains for the following samples (Figure 2A, light grey symbols): 10HEN08, 10HEN09, and 10HEN10: excluded all $R_s < 30 \mu\text{m}$; 10HEN21: excluded all $35 \mu\text{m} < R_s < 50 \mu\text{m}$; 10HEN13, 12HEN03, and 12HEN04: excluded all $R_s < 35 \mu\text{m}$. Then, we binned ages into 3-5 representative [eU] ranges. Each synthetic grain is an average of the [U], [Th], [Sm], R_s , and uncorrected He age within each bin. In some models, the youngest grain was used for the lowest [eU] bin. We imposed a 15-40% error on each synthetic grain—significantly higher than analytical error—so the modeled t - T paths explored a range of age-[eU] values.

(b) Model parameters.

The following model parameters were used for each apatite He age in HeFTy: Calibration: “Flowers et al., 2009 RDAAM (Apatite)”; Abraded: “0”; Precision: “Best”; Stopping Distance: “Ketcham et al., 2011”; Alpha Calculation: “Redistribution”; rmr0 : “0.83”; Age alpha correction: “Ketcham et al., 2011”. Apatite He data were jointly modeled with AFT data for all samples except 10HEN13 (no AFT data available). The AFT annealing model parameters used were as follows: Annealing model: “Ketcham et al., 2007”; C-axis projection: “Ketcham et al., 2007, 5.5 M”; Model c-axis projected lengths? “No”; Use Cf Irradiation: “No”; Default initial mean track length: “From Dpar (μm), 16.3 μm ” (default); Length reduction in standard: “0.893” (default); Kinetic parameter: “Dpar (μm)” (default). For each sample we used HeFTy’s “inversion mode” to randomly generate a large number of t - T paths (usually >100,000) used to make forward predictions of apatite He and AFT data using the above assigned kinetic models. The t - T paths were constrained by the following t - T boxes:

1. Sandstone depositional age (Hunt et al., 1953; Hintze and Kowallis, 2009) at $T=15 \pm 5 \text{ }^\circ\text{C}$;
2. A temperature range ca. 85-80 Ma, the end of Cretaceous sedimentation in the region, given the Mesozoic sediment thickness in the Henry Mountains region (Hunt et al., 1953) and 20-30 $^\circ\text{C}/\text{km}$ geothermal gradient;
3. A large constraint box 80-28 Ma with temperatures of 160 $^\circ\text{C}$ to the lowest T from constraint b, because the Late Cretaceous through Eocene history is poorly constrained and needs to accommodate possible Laramide-related burial and exhumation; we know that none of the Mesozoic strata were removed prior to

- laccolith emplacement because the laccoliths are in intrusive contact with the Upper Cretaceous formations in the Henry Mountains;
4. The Oligocene magmatic activity requires three constraint boxes
 - a. 28-27 Ma from 100 °C to the lowest temperature from b and c;
 - b. 27-25 Ma from 160-60 °C
 - c. 25-23 Ma from 100-20 °C
 5. Modern surface temperature, ± 5 °C, calculated using the mean annual temperature of Hanksville, Utah (11.6 °C at 1313 m, <http://www.worldclimate.com/cgi-bin/data.pl?ref=N38W110+1302+423611C>) adjusted for a lapse rate of 6.5 °C/km (Minder et al., 2010).
 6. Note there is no Neogene constraint box.
- We used the following parameters for the inverse modeling: Search method: “Monte Carlo”; Subsegment spacing: “Random”; Ending condition: “100 paths” or at least “250,000 paths” if no good-fit paths were found; Merit value for ‘good’ fit: “0.5” (default); Merit value for ‘acceptable’ fit: “0.05” (default). Path segments had the following parameters between constraint boxes:
1. depositional age to 85 Ma: 1G
 2. 80-28 Ma: 0G, 1Ev
 3. 28-23 (magmatic heating and cooling): 0E,0E
 4. 23 Ma to present: 2E

(c) Results.

Thermal modeling results support temperatures >40 °C until least 9 Ma in two samples and until the latest Miocene in the other five (considering all acceptable- and good-fit t - T paths, Fig. DR2). We summarize the good-fit (GOF > 0.5) results as a plot of the fraction of paths colder than 40 °C or 50 °C as a function of time from 20 Ma to the present (Fig. 3). This plot was generated by finding the temperature of each good-fit path at 0.5 Ma intervals (using a simple linear interpolation function in Matlab) and then counting the number of those paths colder or warmer than a reference temperature at 0.5 Ma intervals. Figure DR3 shows this analysis for each sample and reference temperatures of 35, 40, 45, and 50 °C, to demonstrate the 40 °C and 50 °C values selected for Figure 3 capture a key feature of the best modeling results—the overwhelming majority of good-fit t - T paths cool below 40 °C (essentially below apatite He partial retention temperatures) in the Pleistocene.

All our best-fit t - T paths start at the sandstone depositional age, not in the Oligocene, despite the <25 Ma apatite He ages (Fig. DR2, compare results in right panel to those in center panel for each sample). In all samples except 10HEN08, if we predict only the apatite He results and start at 28 Ma, the range of He ages and shape of the age-[eU] trend does not fit the data well (Fig. 2A, grey fields); this is reflected in the calculated goodness-of-fit (i.e., no good paths with GOF > 0.5 ; Fig. DR2). Sample 10HEN08 age-[eU] trends can be matched with a 28 Ma start with a very narrow range of good-fit t - T paths, in which the sample sits at 45 ± 1 °C from 22 to <2 Ma (Fig. DR2). A 28 Ma start, however, cannot accommodate the 46.8 ± 4.8 Ma AFT age from this sample (Table DR3). The Neogene acceptable-fit t - T paths ($0.05 < \text{GOF} < 0.5$) for other samples modeled in this way support the results from our preferred thermal histories that start in the Mesozoic (Fig. 2B), but are similarly incompatible with the measured AFT ages and predict age-[eU] trends that are too shallow in slope (Fig. 2A).

Clearly, both the Eocene AFT ages and the apatite He age-[eU] patterns require incomplete annealing of radiation damage during laccolith heating. Because there is a sensitive counterbalance between the peak temperature and timing of early Cenozoic (probably Laramide) cooling and the peak temperature of Oligocene heating in the modeled t - T paths, and because radiation damage annealing in apatite is incompletely understood, the pre-Oligocene history of these samples is a necessary but poorly constrained part of the thermal history documented by these apatite thermochronometers. Regardless, the Neogene history of these samples, which we are most interested in, is clear.

284 **Figure DR2.** Thermal history modeling results from HeFTy for samples with positive-slope age-
 285 [eU] trends. Pink paths—good-fit ($GOF > 0.5$); green paths—acceptable-fit ($0.05 < GOF < 0.5$);

286 blue line—weighted mean of good- and acceptable-fit paths (shown together in Fig. 2B); black
287 line—best-fit path; blue and green boxes—constraint boxes, see Section DR4b). The left panel
288 for each sample shows the complete t - T space for models that start at the sandstone depositional
289 age. The center panel is zoomed into the last 30 Myr of this t - T space, which is the best
290 constrained part of the model. The right panel shows t - T modeling results for models that start at
291 28 Ma, which show the same results but do not, in most cases, yield any good-fit paths.

Figure DR3. Plotting the fraction of good-fit paths vs. time for each sample modeled is a way to quantitatively summarize the timing and magnitude of the late Cenozoic cooling event suggested by all the thermal modeling results in Figure DR2. (A) The last 30 My of the thermal history modeling results from Fig. DR2C. (B) The results shown in panel A transformed into a fraction of the number of paths vs. time plot. Three lines (dotted, dashed, solid) for each reference temperature showing the fraction of all the good-fit paths, the top 50 good-fit paths, and the top 10 good fit paths, respectively. (C) The same plot as B for each of the other samples RDAA modeled.

References Cited

- Farley, K.A., Wolf, R., and Silver, L., 1996, The effects of long alpha-stopping distances on (U-Th)/He ages: *Geochimica et Cosmochimica Acta*, v. 60, no. 21, p. 4223–4229.
- Flowers, R.M., Ketcham, R.A., Shuster, D.L., and Farley, K.A., 2009, Apatite (U–Th)/He thermochronometry using a radiation damage accumulation and annealing model: *Geochimica et Cosmochimica Acta*, v. 73, no. 8, p. 2347–2365, doi: 10.1016/j.gca.2009.01.015.
- Galbraith, R.F., 2005, *Statistics for Fission Track Analysis*: Chapman & Hall/CRC, Boca Raton.
- Gautheron, C., Tassan-Got, L., Barbarand, J., and Pagel, M., 2009, Effect of alpha-damage annealing on apatite (U–Th)/He thermochronology: *Chemical Geology*, v. 266, no. 3–4, p. 157–170, doi: 10.1016/j.chemgeo.2009.06.001.
- Gautheron, C., Barbarand, J., Ketcham, R.A., Tassan-Got, L., van der Beek, P., Pagel, M., Pinna-Jamme, R., Couffignal, F., and Fialin, M., 2013, Chemical influence on α -recoil damage annealing in apatite: Implications for (U–Th)/He dating: *Chemical Geology*, v. 351, p. 257–267, doi: 10.1016/j.chemgeo.2013.05.027.
- Gehrels, G.E., Valencia, V.A., and Ruiz, J., 2008, Enhanced precision, accuracy, efficiency, and spatial resolution of U–Pb ages by laser ablation-multicollector-inductively coupled plasma-mass spectrometry: *Geochemistry Geophysics Geosystems*, v. 9, no. 3, p. n/a–n/a, doi: 10.1029/2007GC001805.
- Gleadow, A.J.W., 1981, Fission-Track Dating Methods: What Are the Real Alternatives: *Nuclear Tracks and Radiation Measurements*, v. 5, no. 1–2, p. 3–14, doi: 10.1016/0191-278X(81)90021-4.
- Hintze, L.F., and Kowallis, B.J., 2009, *Geologic History of Utah* (S. M. Ritter, Ed.): Provo, Utah.
- Hunt, C.B., Averitt, P., and Miller, R.L., 1953, Geology and geography of the Henry Mountains region, Utah: a survey and restudy of one of the classic areas in geology: *USGS Professional Paper*, v. 228, p. 234.
- Hurford, A.J., 1990, Standardization of fission track dating calibration: Recommendation by the Fission Track Working Group of the IUGS Subcommittee on Geochronology: *Chemical Geology; Isotope Geoscience Section*, v. 80, no. 2, p. 171–178, doi: 10.1016/0168-9622(90)90025-8.
- Hurford, A.J., and Green, P.F., 1983, The zeta age calibration of fission-track dating: *Isotope Geoscience*, v. 1, p. 285–317, doi: 10.1016/S0009-2541(83)80026-6.
- Ketcham, R.A., 2005, Forward and inverse modeling of low-temperature thermochronometry data: *Reviews in Mineralogy and Geochemistry*, v. 58, p. 275–314.
- Ketcham, R.A., Gautheron, C., and Tassan-Got, L., 2011, Accounting for long alpha-particle stopping distances in (U–Th–Sm)/He geochronology: Refinement of the baseline case:

- 338 *Geochimica et Cosmochimica Acta*, v. 75, no. 24, p. 7779–7791, doi:
339 10.1016/j.gca.2011.10.011.
- 340 Ludwig, K.R., 2008, Isoplot 3.60: Berkeley Geochronology Center, Special Publication,, p. 1–77.
- 341 Minder, J.R., Mote, P.W., and Lundquist, J.D., 2010, Surface temperature lapse rates over
342 complex terrain: Lessons from the Cascade Mountains: *Journal of Geophysical Research*, v.
343 115, no. D14, p. D14122–13, doi: 10.1029/2009JD013493.
- 344 Murray, K.E., Orme, D.A., and Reiners, P.W., 2014, Effects of U–Th-rich grain boundary phases
345 on apatite helium ages: *Chemical Geology*, v. 390, p. 135–151, doi:
346 10.1016/j.chemgeo.2014.09.023.
- 347 Reiners, P.W., 2005, Zircon (U–Th)/He thermochronometry: *Reviews in Mineralogy and*
348 *Geochemistry*, v. 58, p. 151–179.
- 349 Reiners, P.W., and Farley, K.A., 2001, Influence of crystal size on apatite (U–Th)/He
350 thermochronology: an example from the Bighorn Mountains, Wyoming: *Earth And*
351 *Planetary Science Letters*, v. 188, no. 3–4, p. 413–420.
- 352 Reiners, P.W., Spell, T., Nicolescu, S., and Zanetti, K., 2004, Zircon (U–Th)/He
353 thermochronometry: He diffusion and comparisons with $^{40}\text{Ar}/^{39}\text{Ar}$ dating: *Geochimica et*
354 *Cosmochimica Acta*, v. 68, no. 8, p. 1857–1887.
- 355 Stacey, J.S., and Kramers, J.D., 1975, Approximation of terrestrial lead isotope evolution by a
356 two-stage model: *Earth And Planetary Science Letters*, v. 26, no. 2, p. 207–221, doi:
357 10.1016/0012-821X(75)90088-6.

358

TABLE DR1: SAMPLE INFORMATION AND SUMMARY OF APATITE (U-Th-Sm)/He RESULTS

apatite He summary											
Sample	Longitude (°W)	Latitude (°N)	Elevation (m)	Rock type	Formation	Depositional age	Number of grains	Age range (Ma)	R _s range* (µm)	[eU] range (ppm)	Principal source(s) of age variability [†]
Mount Hillers											
10HEN06 [§]	-110.7289	37.9031	2225	Porphyry	N.A. [#]	N.A.	8	7-21	30-44	2-18	GBPs
10HEN08	-110.6949	37.8598	2208	Sandstone	Lower Wingate sandstone	Triassic	18	3-397	26-46	3-129	RDAA, GBPs
10HEN09	-110.6949	37.8596	2202	Sandstone	Wingate sandstone, 1 m from sill	Triassic	15	6-18	26-37	15-185	RDAA
10HEN10	-110.6949	37.8596	2200	Sandstone	Wingate sandstone, 30 cm from sill	Triassic	16	5-21	26-35	14-161	RDAA
10HEN11 [§]	-110.6949	37.8596	2199	Porphyry	Sill in Wingate sandstone	N.A.	10	1-26	28-59	3-84	GBPs, RDAA(?)
10HEN12	-110.6926	37.8656	2450	Sandstone	Cedar Mesa sandstone	Permian	3	5-93	32-37	7-89	GBPs, RDAA
10HEN13	-110.6929	37.8638	2386	Sandstone	White Rim formation	Permian	8	11-68	30-43	13-69	RDAA
10HEN15 [§]	-110.6927	37.8626	2326	Porphyry	Sill in Moenkopi formation	N.A.	8	8-26	29-53	5-19	RDAA, GS
10HEN16	-110.6923	37.8589	2151	Sandstone	Kayenta formation	Jurassic	N.D.**	N.D.	N.D.	N.D.	N.D.
10HEN19	-110.6900	37.8560	2034	Sandstone	Lower Entrada sandstone	Jurassic	17	7-39	28-42	5-82	RDAA
10HEN20	-110.6898	37.8550	2019	Sandstone	Upper Entrada sandstone	Jurassic	26	4-35	30-53	3-67	RDAA
10HEN21	-110.6894	37.8537	2009	Sandstone	Morrison formation, Salt Wash mbr.	Jurassic	14	4-31	30-56	11-83	RDAA
10HEN39	-110.6968	37.8873	3274	Porphyry	N.A.	N.A.	6	21-30	29-39	15-23	GBPs, GS
10HEN40	-110.6981	37.8870	3262	Porphyry	N.A.	N.A.	N.D.	N.D.	N.D.	N.D.	N.D.
10HEN42	-110.7023	37.8920	3062	Porphyry	N.A.	N.A.	5	27-29	47-94	5-11	N.A.
10HEN43	-110.7039	37.8948	2904	Porphyry	N.A.	N.A.	7	20-53	36-70	3-11	GBPs
10HEN44	-110.7046	37.8951	2857	Porphyry	N.A.	N.A.	13	23-199	56-93	1-20	GBPs
10HEN45	-110.7052	37.8995	2740	Porphyry	N.A.	N.A.	6	15-28	33-92	4-22	GBPs, RDAA, GS
10HEN46	-110.7593	38.0795	2636	Porphyry	N.A.	N.A.	12	9-37	28-71	6-23	GBPs
Mount Pennell											
10HEN28 [§]	-110.7560	37.9725	2398	Porphyry	N.A.	N.A.	7	16-24	44-90	26-49	GBPs
10HEN29	-110.7593	38.0795	2636	Porphyry	N.A.	N.A.	N.D.	N.D.	N.D.	N.D.	N.D.
10HEN30 [§]	-110.7875	37.9572	3380	Porphyry	N.A.	N.A.	6	16-25	48-95	27-62	GBPs
10HEN35 [§]	-110.7603	37.9684	2512	Porphyry	N.A.	N.A.	4	15-19	49-68	30-53	GBPs
Mount Ellen											
10HEN01	-110.7623	38.1233	2453	Porphyry	N.A.	N.A.	12	3-16	43-68	7-35	RDAA
10HEN47	-110.7593	38.0795	2636	Porphyry	N.A.	N.A.	N.D.	N.D.	N.D.	N.D.	N.D.
10HEN48	-110.7728	38.0877	2787	Porphyry	N.A.	N.A.	6	13-24	33-79	2-30	RDAA, GS
10HEN49	-110.8146	38.1213	3507	Porphyry	N.A.	N.A.	10	17-672	32-68	1-26	GBPs, GS, RDAA
10HEN52	-110.8136	38.1090	3511	Porphyry	N.A.	N.A.	5	13-20	31-41	5-29	GBPs, RDAA
10HEN54	-110.8039	38.0984	3379	Porphyry	N.A.	N.A.	N.D.	N.D.	N.D.	N.D.	N.D.
10HEN57	-110.8029	38.0879	3205	Porphyry	N.A.	N.A.	N.D.	N.D.	N.D.	N.D.	N.D.
Satellite intrusions and neighboring country rocks											
12HEN02	-110.5785	37.9519	1552	Porphyry	Trachyte Mesa intrusion	N.A.	4	7-23	50-75	3-9	GBPs
12HEN03	-110.5781	37.9521	1533	Sandstone	Trachyte Mesa Entrada sandstone	Jurassic	4	7-22	34-45	13-132	RDAA, GS
12HEN04	-110.5781	37.9521	1532	Sandstone	Trachyte Mesa Entrada sandstone	Jurassic	11	7-20	30-46	8-44	RDAA, GS
10HEN27	-110.6333	37.9114	1556	Porphyry	Sill in Entrada sandstone	N.A.	9	8-53	40-92	1-26	GBPs, RDAA, GS
10HEN38	-110.7960	38.0003	2595	Porphyry	The Horn	N.A.	4	28-36	51-65	3-7	GBPs
Sedimentary samples not fully reset											
10HEN04	-110.7110	38.2191	1533	Sandstone	Morrison formation, Salt Wash mbr.	Jurassic	6	10-37	39-56	7-31	RDAA, GS
10HEN05	-110.7293	37.9050	2210	Sandstone	Mancos shale, Ferron sandstone mbr.	Cretaceous	7	14-28	39-47	11-26	RDAA, GBPs(?)
10HEN07	-110.7299	37.8635	2054	Sandstone	Mancos shale, Ferron sandstone mbr.	Cretaceous	14	18-76	33-54	13-156	GBPs(?)
10HEN22	-110.6906	37.8501	1947	Sandstone	Dakota sandstone	Cretaceous	3	12-67	24-38	16-54	RDAA
10HEN24	-110.6458	37.9653	1614	Sandstone	Morrison formation, Salt Wash mbr.	Jurassic	6	20-56	34-64	11-38	RDAA

*R_s = effective spherical radius of apatite grain.[†]GBPs = U-Th-rich grain boundary phases (Murray et al., 2014), RDAA = radiation damage accumulation and annealing (Flowers et al., 2009; Gautheron et al., 2009), GS = grain size (Reiners and Farley, 2001).[§]Some or all He ages from this sample from Murray et al. (2014).[#]N.A. = not applicable.^{**}N.D. = not determined.

TABLE DR2: ZIRCON U/Pb GEOCHRONOLOGIC ANALYSES

Analysis	U (ppm)	²⁰⁶ Pb/ ²⁰⁴ Pb	U/Th	²⁰⁶ Pb*/ ²⁰⁷ Pb*	± (%)	Isotope ratios						Apparent ages (Ma)						Best age (Ma)	± (Ma)	Conc (%)
						²⁰⁷ Pb*/ ²³⁵ U*	± (%)	²⁰⁶ Pb*/ ²³⁸ U	± (%)	error corr.	²⁰⁶ Pb*/ ²³⁸ U*	± (Ma)	²⁰⁷ Pb*/ ²³⁵ U	± (Ma)	²⁰⁶ Pb*/ ²⁰⁷ Pb*	± (Ma)				
10HEN11	Mean = 25.6 ± 0.51 Ma, MSWD = 0.32, probability = 0.98, n = 11																			
10HEN11-25	474	5263	14.5	24.8387	31.9	0.0216	32.1	0.0039	3.8	0.12	25.0	0.9	21.7	6.9	-334.2	838.7	25.0	0.9	N.A.	
10HEN11-06	372	12545	21.6	23.6752	17.5	0.0227	17.6	0.0039	1.8	0.10	25.1	0.5	22.8	4.0	-212.3	443.4	25.1	0.5	N.A.	
10HEN11-13	325	4685	20.2	22.9178	18.3	0.0235	18.6	0.0039	3.5	0.19	25.1	0.9	23.6	4.3	-131.3	455.8	25.1	0.9	N.A.	
10HEN11-02	342	17334	21.2	23.0171	21.8	0.0235	22.3	0.0039	4.9	0.22	25.2	1.2	23.6	5.2	-142.0	545.3	25.2	1.2	N.A.	
10HEN11-05	429	11278	14.6	24.0819	22.3	0.0226	22.7	0.0040	4.6	0.20	25.4	1.2	22.7	5.1	-255.2	569.9	25.4	1.2	N.A.	
10HEN11-23	447	4142	15.5	19.9373	16.1	0.0275	16.3	0.0040	2.5	0.16	25.6	0.6	27.5	4.4	202.3	375.6	25.6	0.6	N.A.	
10HEN11-11	423	1401	21.9	18.3638	15.4	0.0300	16.1	0.0040	4.7	0.29	25.7	1.2	30.0	4.8	389.9	348.4	25.7	1.2	N.A.	
10HEN11-01	397	4398	19.3	21.8307	15.6	0.0252	15.9	0.0040	2.9	0.18	25.7	0.7	25.3	4.0	-12.5	379.2	25.7	0.7	N.A.	
10HEN11-04	550	8664	15.5	21.8330	19.5	0.0254	19.6	0.0040	1.9	0.10	25.9	0.5	25.5	4.9	-12.8	475.8	25.9	0.5	N.A.	
10HEN11-19	660	17817	12.7	22.1517	16.1	0.0251	16.3	0.0040	2.5	0.15	25.9	0.6	25.1	4.0	-47.9	393.9	25.9	0.6	N.A.	
10HEN11-21	315	3724	21.0	19.9398	11.8	0.0284	12.4	0.0041	3.8	0.31	26.4	1.0	28.5	3.5	202.0	275.1	26.4	1.0	N.A.	
10HEN11-03	506	31545	10.7	15.8944	7.4	0.0559	8.1	0.0064	3.4	0.42	41.4	1.4	55.2	4.4	705.4	157.1	41.4	1.4	N.A.	
10HEN11-12	804	153611	14.0	11.6419	0.9	0.7744	2.5	0.0654	2.3	0.93	408.3	9.2	582.3	11.1	1335.8	17.6	408.3	9.2	30.6	
10HEN11-24	156	81902	6.1	11.6856	1.1	1.0097	3.2	0.0856	3.1	0.94	529.3	15.5	708.7	16.5	1328.6	21.0	1328.6	21.0	39.8	
10HEN11-14	65	55845	1.2	11.3211	1.0	2.9618	1.8	0.2432	1.5	0.83	1403.3	18.8	1397.9	13.6	1389.7	18.9	1389.7	18.9	101.0	
10HEN11-16	30	27086	6.4	11.2085	1.7	2.9864	2.3	0.2428	1.6	0.68	1401.1	19.6	1404.2	17.4	1408.8	32.0	1408.8	32.0	99.4	
10HEN11-18	38	40651	1.8	11.2041	1.7	2.9780	2.2	0.2420	1.3	0.62	1397.0	16.9	1402.0	16.5	1409.6	32.7	1409.6	32.7	99.1	
10HEN11-17	159	127839	19.3	11.1568	0.7	3.0243	0.9	0.2447	0.6	0.69	1411.2	8.1	1413.8	7.0	1417.7	12.7	1417.7	12.7	99.5	
10HEN11-10	300	258077	26.0	10.2158	0.8	3.6765	1.5	0.2724	1.3	0.84	1553.0	17.9	1566.3	12.3	1584.2	15.5	1584.2	15.5	98.0	
10HEN11-15	131	94483	1.9	9.8029	0.7	4.0819	1.0	0.2902	0.7	0.70	1642.6	9.9	1650.7	8.0	1661.0	13.0	1661.0	13.0	98.9	
10HEN11-07	288	198233	5.5	9.7970	0.2	4.0309	2.4	0.2864	2.3	1.00	1623.6	33.6	1640.4	19.1	1662.1	4.1	1662.1	4.1	97.7	
10HEN11-08	121	1661	32.4	7.6343	220.6	0.0721	220.8	0.0040	7.8	0.04	25.7	2.0	70.7	151.9	2111.2	148.4	2111.2	148.4	1.2	
10HEN06	Mean = 25.5 ± 1.53 Ma, MSWD = 0.021, probability = 1.00, n = 10																			
10HEN06-22	121	2030	142.5	23.4972	58.7	0.0224	60.1	0.0038	12.7	0.21	24.6	3.1	22.5	13.4	-193.4	1599.6	24.6	3.1	N.A.	
10HEN06-24	126	2267	136.3	27.9404	46.0	0.0192	47.0	0.0039	9.9	0.21	25.0	2.5	19.3	9.0	-646.9	1321.9	25.0	2.5	N.A.	
10HEN06-21	95	1736	75.8	14.8419	36.3	0.0364	38.4	0.0039	12.5	0.32	25.2	3.1	36.3	13.7	849.5	780.0	25.2	3.1	N.A.	
10HEN06-02	162	1609	9.1	14.0304	101.0	0.0389	101.5	0.0040	9.5	0.09	25.4	2.4	38.7	38.6	965.3	336.5	25.4	2.4	N.A.	
10HEN06-06	180	5171	103.0	17.9710	53.7	0.0304	54.1	0.0040	7.1	0.13	25.5	1.8	30.4	16.2	438.2	1286.0	25.5	1.8	N.A.	
10HEN06-15	297	6275	9.0	24.2915	24.0	0.0226	24.9	0.0040	6.5	0.26	25.6	1.7	22.7	5.6	-277.2	618.9	25.6	1.7	N.A.	
10HEN06-16	222	4611	12.7	20.3975	17.6	0.0270	18.9	0.0040	6.9	0.36	25.7	1.8	27.0	5.0	149.1	416.5	25.7	1.8	N.A.	
10HEN06-18	156	1346	25.7	29.5736	35.7	0.0186	36.9	0.0040	9.5	0.26	25.7	2.4	18.8	6.9	-805.5	1040.0	25.7	2.4	N.A.	
10HEN06-07	54	1568	31.3	10.9002	75.5	0.0511	77.0	0.0040	15.1	0.20	26.0	3.9	50.6	38.0	1462.0	1754.9	26.0	3.9	1.8	
10HEN06-14	50	793	58.3	19.2993	102.0	0.0289	102.9	0.0040	13.4	0.13	26.0	3.5	28.9	29.4	277.3	834.8	26.0	3.5	N.A.	
10HEN06-08	34	37240	11.9	11.3948	2.3	2.9126	2.7	0.2407	1.4	0.53	1390.4	17.9	1385.2	20.4	1377.2	43.9	1377.2	43.9	101.0	
10HEN06-17	484	259377	6.7	11.1543	0.6	2.8159	3.2	0.2278	3.1	0.98	1323.0	37.7	1359.8	24.1	1418.1	12.1	1418.1	12.1	93.3	
10HEN06-01	9	11722	2.8	11.0489	7.9	2.8921	9.6	0.2318	5.4	0.57	1343.7	66.0	1379.8	72.6	1436.2	151.3	1436.2	151.3	93.6	
10HEN06-05	709	966102	2.9	10.3381	0.4	3.4782	0.7	0.2608	0.6	0.85	1493.9	7.9	1522.3	5.5	1562.0	6.8	1562.0	6.8	95.6	
10HEN06-19	322	237392	16.2	10.1612	0.4	2.8993	1.2	0.2137	1.1	0.93	1248.3	12.7	1381.7	9.1	1594.3	8.3	1594.3	8.3	78.3	
10HEN06-25	384	326842	29.1	9.8752	0.1	3.8690	2.9	0.2771	2.9	1.00	1576.8	40.6	1607.2	23.5	1647.4	2.6	1647.4	2.6	95.7	
10HEN06-13	62	3957	42.9	8.3201	84.4	0.0699	86.0	0.0042	16.2	0.19	27.1	4.4	68.6	57.1	1959.0	390.0	1959.0	390.0	1.4	
10HEN06-04	49	1124	89.3	5.9549	123.1	0.0901	124.8	0.0039	20.6	0.16	25.0	5.1	87.6	105.1	2537.1	537.8	2537.1	537.8	1.0	
10HEN06-11	67	1192	28.4	5.3961	297.6	0.1002	298.2	0.0039	17.9	0.06	25.2	4.5	96.9	282.8	2701.0	14.5	2701.0	14.5	0.9	
10HEN15	Mean = 25.8 ± 0.44 Ma, MSWD = 0.114, probability = 1.00, n = 19																			
10HEN15-22	259	3200	21.9	22.4456	24.0	0.0241	24.4	0.0039	4.4	0.18	25.3	1.1	24.2	5.8	-80.1	594.8	25.3	1.1	N.A.	
10HEN15-01	332	10222	24.8	20.3566	27.9	0.0267	28.5	0.0039	5.6	0.20	25.3	1.4	26.7	7.5	153.8	665.4	25.3	1.4	N.A.	
10HEN15-14	282	6100	29.1	23.6233	34.0	0.0231	34.3	0.0040	4.2	0.12	25.5	1.1	23.2	7.9	-206.8	875.6	25.5	1.1	N.A.	
10HEN15-17	311	5615	22.6	20.0318	25.6	0.0273	26.8	0.0040	7.8	0.29	25.5	2.0	27.4	7.2	191.3	604.3	25.5	2.0	N.A.	
10HEN15-24	322	6800	35.9	26.5944	30.2	0.0206	30.3	0.0040	2.3	0.08	25.6	0.6	20.7	6.2	-513.2	821.7	25.6	0.6	N.A.	
10HEN15-05	386	4748	22.8	20.9435	14.4	0.0263	14.8	0.0040	3.4	0.23	25.7	0.9	26.3	3.8	86.8	342.2	25.7	0.9	N.A.	
10HEN15-04	418	8116	17.4	22.6025	17.8	0.0244	18.5	0.0040	5.0	0.27	25.7	1.3	24.4	4.5	-97.1	439.5	25.7	1.3	N.A.	
10HEN15-25	257	7327	24.1	10.7268	243.1	0.0514	243.1	0.0040	6.2	0.03	25.7	1.6	50.9	121.2	1492.4	737.0	25.7	1.6	1.7	
10HEN15-03	621	9855	14.7	20.5192	9.5	0.0269	9.8	0.0040	2.2	0.22	25.7	0.6	26.9	2.6	135.1	224.1	25.7	0.6	N.A.	
10HEN15-21	445	4200	14.9	24.1872	20.8	0.0228	21.3	0.0040	4.3	0.20	25.8	1.1	22.9	4.8	-266.3	533.5	25.8	1.1	N.A.	
10HEN15-11	570	10277	14.1	19.9374	12.8	0.0277	12.9	0.0040	1.8	0.14	25.8	0.5	27.8	3.5	202.3	297.2	25.8	0.5	N.A.	
10HEN15-12	834	11889	10.9	22.1654	7.0	0.0250	7.1	0.0040	1.2	0.17	25									

TABLE DR2: ZIRCON U/Pb GEOCHRONOLOGIC ANALYSES (continued)

Analysis	Isotope ratios										Apparent ages (Ma)						Best age (Ma)	± (Ma)	Conc (%)	
	U (ppm)	²⁰⁶ Pb/ ²⁰⁴ Pb	U/Th	²⁰⁶ Pb*/ ²⁰⁷ Pb*	± (%)	²⁰⁷ Pb*/ ²³⁵ U*	± (%)	²⁰⁶ Pb*/ ²³⁸ U	± (%)	error corr.	²⁰⁶ Pb*/ ²³⁸ U*	± (Ma)	± (Ma)	²⁰⁷ Pb*/ ²³⁵ U	± (Ma)	²⁰⁶ Pb*/ ²⁰⁷ Pb*				± (Ma)
	Mean = 25.6 ± 0.33 Ma, MSWD = 1.7, probability = 0.055, n = 14																			
10HEN29	Mean = 25.6 ± 0.33 Ma, MSWD = 1.7, probability = 0.055, n = 14																			
C-10HEN29-9RI	1356	23014	41.3	20.8716	1.3	0.0250	2.1	0.0038	1.7	0.80	24.3	0.4	25.0	0.5	94.9	30.6	24.3	0.4	N.A.	
C-10HEN29-7C	2285	10216	0.6	17.1441	12.1	0.0304	14.1	0.0038	7.1	0.51	24.4	1.7	30.5	4.2	542.2	265.8	24.4	1.7	N.A.	
C-10HEN29-9	2238	23096	64.7	21.4342	0.7	0.0252	1.1	0.0039	0.8	0.75	25.2	0.2	25.3	0.3	31.6	17.3	25.2	0.2	N.A.	
C-10HEN29-6	760	11703	1.8	21.4625	0.8	0.0253	1.5	0.0039	1.2	0.83	25.3	0.3	25.3	0.4	28.4	20.1	25.3	0.3	N.A.	
C-10HEN29-16	2769	25013	0.7	21.4528	1.0	0.0253	1.3	0.0039	0.8	0.64	25.3	0.2	25.4	0.3	29.5	23.1	25.3	0.2	N.A.	
C-10HEN29-7	2494	81473	0.7	21.2511	1.3	0.0256	1.7	0.0039	1.1	0.64	25.4	0.3	25.7	0.4	52.1	31.5	25.4	0.3	N.A.	
C-10HEN29-20	297	3087	3.1	21.8287	1.7	0.0251	3.0	0.0040	2.4	0.82	25.5	0.6	25.1	0.7	-12.3	41.2	25.5	0.6	N.A.	
C-10HEN29-2	503	2941	1.6	13.2716	5.2	0.0413	8.1	0.0040	6.2	0.76	25.6	1.6	41.1	3.3	1077.8	105.1	25.6	1.6	2.4	
C-10HEN29-3(F)	2793	39803	0.5	21.4720	0.8	0.0256	1.2	0.0040	0.9	0.78	25.6	0.2	25.6	0.3	27.4	18.3	25.6	0.2	N.A.	
C-10HEN29-8	677	6787	1.1	18.7833	8.6	0.0292	8.9	0.0040	2.2	0.25	25.6	0.6	29.3	2.6	339.0	195.3	25.6	0.6	N.A.	
C-10HEN29-10(C)	2881	28873	0.5	21.4854	0.5	0.0258	1.5	0.0040	1.4	0.93	25.8	0.3	25.8	0.4	25.9	12.6	25.8	0.3	N.A.	
C-10HEN29-11	438	5190	1.6	20.6671	2.7	0.0268	2.9	0.0040	0.9	0.32	25.9	0.2	26.9	0.8	118.2	64.6	25.9	0.2	N.A.	
C-10HEN29-5	444	6888	29.5	21.2802	2.4	0.0262	3.1	0.0040	1.9	0.62	26.0	0.5	26.2	0.8	48.8	58.2	26.0	0.5	N.A.	
C-10HEN29-12	701	11142	1.1	21.0367	1.1	0.0269	1.4	0.0041	0.9	0.62	26.4	0.2	26.9	0.4	76.2	26.6	26.4	0.2	N.A.	
C-10HEN29-1	2386	81780	1.1	12.8107	4.2	0.0925	5.5	0.0086	3.5	0.64	55.1	1.9	89.8	4.7	1148.4	83.8	55.1	1.9	4.8	
C-10HEN29-17	91	78001	2.0	11.2861	1.2	2.9780	1.7	0.2438	1.2	0.69	1406.2	15.0	1402.0	13.0	1395.6	23.7	1395.6	23.7	100.8	
C-10HEN29-23	66	64770	2.5	11.2352	0.8	3.0247	1.4	0.2465	1.2	0.82	1420.2	15.1	1413.9	11.0	1404.3	15.7	1404.3	15.7	101.1	
C-10HEN29-18	126	132412	2.9	11.1289	1.1	3.0983	1.2	0.2501	0.6	0.46	1438.9	7.2	1432.3	9.4	1422.5	20.8	1422.5	20.8	101.2	
C-10HEN29-13	251	546667	2.7	11.0612	1.2	2.8836	2.4	0.2313	2.1	0.86	1341.5	25.4	1377.6	18.3	1434.1	23.5	1434.1	23.5	93.5	
10HEN35	Mean = 25.5 ± 0.37 Ma, MSWD = 4.5, probability = 0.000, n = 12																			
C-10HEN35-2	1046	6472	1.3	16.4462	4.1	0.0334	4.1	0.0040	0.6	0.14	25.7	0.1	33.4	1.4	632.3	88.5	25.7	0.1	N.A.	
C-10HEN35-8	1215	8133	1.7	18.0657	10.1	0.0295	10.2	0.0039	0.8	0.08	24.9	0.2	29.5	3.0	426.5	226.2	24.9	0.2	N.A.	
C-10HEN35-18	866	11364	1.8	21.3535	1.8	0.0250	2.2	0.0039	1.2	0.54	24.9	0.3	25.1	0.5	40.6	43.7	24.9	0.3	N.A.	
C-10HEN35-15F	1814	48338	2.5	21.1055	0.8	0.0254	1.1	0.0039	0.7	0.62	25.0	0.2	25.4	0.3	68.5	19.9	25.0	0.2	N.A.	
C-10HEN35-9	714	10550	2.6	20.9276	2.1	0.0258	4.2	0.0039	3.6	0.86	25.2	0.9	25.8	1.1	88.6	49.7	25.2	0.9	N.A.	
C-10HEN35-15	215	5037	102.6	20.6715	4.3	0.0261	4.4	0.0039	0.6	0.13	25.2	0.1	26.2	1.1	117.7	102.0	25.2	0.1	N.A.	
C-10HEN35-5	770	3500	1.8	14.5665	19.0	0.0372	19.0	0.0039	1.1	0.06	25.3	0.3	37.1	6.9	888.2	395.2	25.3	0.3	N.A.	
C-10HEN35-17	1012	12618	1.4	21.3756	1.3	0.0255	1.7	0.0040	1.1	0.64	25.4	0.3	25.5	0.4	38.1	30.3	25.4	0.3	N.A.	
C-10HEN35-8RI	1353	22260	1.1	21.2512	0.9	0.0257	1.6	0.0040	1.2	0.80	25.4	0.3	25.7	0.4	52.1	22.5	25.4	0.3	N.A.	
C-10HEN35-19	753	9704	1.6	21.2268	2.3	0.0259	2.8	0.0040	1.5	0.55	25.6	0.4	25.9	0.7	54.8	55.1	25.6	0.4	N.A.	
C-10HEN35-11	997	10267	1.3	18.6077	14.1	0.0297	14.1	0.0040	0.9	0.06	25.8	0.2	29.8	4.1	360.2	318.5	25.8	0.2	N.A.	
C-10HEN35-14	754	18378	1.6	20.3417	1.2	0.0274	1.3	0.0040	0.5	0.38	26.0	0.1	27.5	0.4	155.4	28.2	26.0	0.1	N.A.	
C-10HEN35-12	218	30746	2.0	19.8599	1.2	0.2380	1.8	0.0343	1.3	0.73	217.3	2.8	216.8	3.5	211.3	28.7	217.3	2.8	N.A.	
C-10HEN35-20	118	232838	1.9	9.4752	1.0	4.4308	1.5	0.3045	1.1	0.75	1713.5	16.6	1718.1	12.3	1723.7	18.1	1723.7	18.1	99.4	
C-10HEN35-13	247	200456	1.7	9.4749	1.5	3.9675	2.8	0.2726	2.3	0.84	1554.2	32.2	1627.6	22.6	1723.8	28.1	1723.8	28.1	90.2	
C-10HEN35-6	241	162851	1.6	9.4160	1.5	4.1696	2.9	0.2847	2.5	0.86	1615.2	35.9	1668.1	24.0	1735.2	27.9	1735.2	27.9	93.1	
C-10HEN35-4(1)	609	986	2.5	5.8433	18.8	0.1094	19.6	0.0046	5.3	0.27	29.8	1.6	105.4	19.6	2568.8	318.2	2568.8	318.2	1.2	
10HEN40	Mean = 26.3 ± 0.74 Ma, MSWD = 0.23, probability = 0.997, n = 13																			
10HEN40-10	268	2948	23.1	23.4376	21.3	0.0224	22.5	0.0038	7.3	0.33	24.6	1.8	22.5	5.0	-187.0	536.8	24.6	1.8	N.A.	
10HEN40-04	189	4519	4.2	24.2077	39.0	0.0225	39.4	0.0039	5.8	0.15	25.4	1.5	22.6	8.8	-268.5	1023.4	25.4	1.5	N.A.	
10HEN40-12	151	1655	3.1	9.5866	233.8	0.0568	234.0	0.0039	10.4	0.04	25.4	2.6	56.1	128.3	1702.2	517.6	25.4	2.6	1.5	
10HEN40-02	249	2218	13.0	24.6708	38.9	0.0224	39.6	0.0040	7.3	0.18	25.7	1.9	22.5	8.8	-316.8	1031.7	25.7	1.9	N.A.	
10HEN40-03	282	5246	29.0	26.9767	66.4	0.0205	66.6	0.0040	4.9	0.07	25.8	1.2	20.6	13.6	-551.5	1998.2	25.8	1.2	N.A.	
10HEN40-16	165	2121	5.6	21.7588	41.6	0.0255	41.9	0.0040	5.0	0.12	25.8	1.3	25.5	10.6	-4.5	1043.0	25.8	1.3	N.A.	
10HEN40-08	201	4055	2.5	19.0326	29.8	0.0295	30.2	0.0041	5.4	0.18	26.2	1.4	29.5	8.8	309.1	691.2	26.2	1.4	N.A.	
10HEN40-09	232	4860	5.5	17.5516	83.0	0.0321	83.2	0.0041	6.6	0.08	26.3	1.7	32.0	26.3	490.6	2342.2	26.3	1.7	N.A.	
10HEN40-13	219	9474	6.0	21.2368	38.8	0.0267	39.2	0.0041	5.6	0.14	26.4	1.5	26.7	10.3	53.7	957.8	26.4	1.5	N.A.	
10HEN40-05	254	2508	8.9	18.0088	19.1	0.0315	19.9	0.0041	5.6	0.28	26.5	1.5	31.5	6.2	433.5	429.0	26.5	1.5	N.A.	
10HEN40-14	428	6453	13.1	24.5225	25.7	0.0232	25.9	0.0041	3.0	0.12	26.5	0.8	23.3	5.9	-301.4	665.7	26.5	0.8	N.A.	
10HEN40-20	316	4177	7.4	22.9107	25.6	0.0248	25.9	0.0041	4.2	0.16	26.6	1.1	24.9	6.4	-130.5	641.7	26.6	1.1	N.A.	
10HEN40-21	460	7912	12.2	21.2445	17.8	0.0272	18.1	0.0042	2.8	0.15	27.0	0.8	27.2	4.9	52.8	428.5	27.0	0.8	N.A.	
10HEN40-25	97	79353	2.1	11.3741	0.9	2.8781	1.8	0.2374	1.5	0.85	1373.3	18.5	1376.2	13.3	1380.7	18.1	1380.7	18.1	99.5	
10HEN40-24	82	73906	2.0	11.3646	0.7	2.8914	1.1	0.2383	0.9	0.81	1378.0	11.4	1379.7	8.6	1382.3	12.7	1382.3	12.7	99.7	
10HEN40-19	42	30825	5.4	11.2563	1.9	2.8763	5.9	0.2348	5.6	0.94	1359.7	68.4	1375.7	44.6	1400.7	37.2	1400.7	37.2	97.1	
10HEN40-17	113	171242	2.8	11.1659	0.7	3.0083	1.1	0.2436	0.8	0.77	1405.5	10.6	1409.7	8.3	1416.1	13.2	1416.1	13.2	99.3	
10HEN40-15	290	512001	7.9</																	

TABLE DR2: ZIRCON U/Pb GEOCHRONOLOGIC ANALYSES (continued)

Analysis	U (ppm)	²⁰⁶ Pb/ ²⁰⁴ Pb	U/Th	²⁰⁶ Pb*/ ²⁰⁷ Pb*	± (%)	Isotope ratios						Apparent ages (Ma)						Best age (Ma)	± (Ma)	Conc (%)
						²⁰⁷ Pb*/ ²³⁵ U*	± (%)	²⁰⁶ Pb*/ ²³⁸ U	± (%)	error corr.	²⁰⁶ Pb*/ ²³⁸ U*	± (Ma)	²⁰⁷ Pb*/ ²³⁵ U	± (Ma)	²⁰⁶ Pb*/ ²⁰⁷ Pb*	± (Ma)				
10HEN57	Mean = 27.4 ± 0.90 Ma, MSWD = 0.31, probability = 0.98, n = 12																			
10HEN57-1	167	3047	6.1	16.5664	58.4	0.0340	59.1	0.0041	9.3	0.16	26.3	2.4	34.0	19.8	616.6	1383.5	26.3	2.4	N.A.	
10HEN57-12	186	4604	4.8	22.7221	32.1	0.0249	34.0	0.0041	11.0	0.33	26.4	2.9	24.9	8.4	-110.1	808.8	26.4	2.9	N.A.	
10HEN57-16	171	2839	4.4	29.6866	52.0	0.0194	52.6	0.0042	7.6	0.14	26.9	2.0	19.5	10.2	-816.4	1572.6	26.9	2.0	N.A.	
10HEN57-23	196	4889	2.2	21.8463	28.8	0.0265	29.3	0.0042	5.5	0.19	27.0	1.5	26.5	7.7	-14.2	708.9	27.0	1.5	N.A.	
10HEN57-22	342	4347	5.8	23.4473	20.8	0.0247	20.9	0.0042	2.5	0.12	27.0	0.7	24.8	5.1	-188.0	524.0	27.0	0.7	N.A.	
10HEN57-25	158	2069	1.4	29.0561	42.7	0.0200	43.4	0.0042	7.7	0.18	27.1	2.1	20.1	8.6	-755.7	1247.9	27.1	2.1	N.A.	
10HEN57-8	232	4650	7.6	26.6151	35.6	0.0220	36.3	0.0043	7.0	0.19	27.4	1.9	22.1	7.9	-515.3	976.5	27.4	1.9	N.A.	
10HEN57-2	326	3351	33.0	19.2693	27.6	0.0308	28.1	0.0043	5.2	0.19	27.7	1.4	30.8	8.5	280.9	642.6	27.7	1.4	N.A.	
10HEN57-7	92	1960	6.7	27.3188	62.7	0.0217	64.5	0.0043	15.1	0.23	27.7	4.2	21.8	13.9	-585.5	1868.2	27.7	4.2	N.A.	
10HEN57-15	267	8791	9.8	21.0392	28.8	0.0283	29.0	0.0043	3.7	0.13	27.8	1.0	28.3	8.1	75.9	696.6	27.8	1.0	N.A.	
10HEN57-9	119	2688	2.5	17.6751	42.1	0.0349	42.6	0.0045	6.8	0.16	28.8	2.0	34.8	14.6	475.1	971.0	28.8	2.0	N.A.	
10HEN57-5	144	3369	2.7	18.9116	18.9	0.0351	20.6	0.0048	8.2	0.40	30.9	2.5	35.0	7.1	323.5	431.9	30.9	2.5	N.A.	
10HEN57-13	210	397470	2.6	11.2249	0.4	2.8619	1.0	0.2330	0.9	0.90	1350.2	10.5	1371.9	7.2	1406.0	7.9	1406.0	7.9	96.0	
10HEN57-10	194	182685	1.2	9.7519	0.4	4.0691	1.2	0.2878	1.2	0.96	1630.5	16.6	1648.1	9.8	1670.7	6.6	1670.7	6.6	97.6	
10HEN57-14	317	524303	4.5	9.6564	0.4	2.9974	2.3	0.2099	2.3	0.99	1228.4	25.3	1407.0	17.4	1688.8	6.6	1688.8	6.6	72.7	
10HEN57-24	95	65740	4.9	9.6011	0.5	4.2548	0.7	0.2963	0.5	0.70	1672.8	6.7	1684.7	5.4	1699.4	8.5	1699.4	8.5	98.4	
10HEN57-3	228	283239	1.8	9.5083	0.5	4.3480	1.6	0.2998	1.5	0.94	1690.5	21.7	1702.5	12.8	1717.3	9.7	1717.3	9.7	98.4	
10HEN57-19	117	148285	2.9	9.5013	0.4	4.3777	0.9	0.3017	0.8	0.90	1699.6	12.5	1708.1	7.7	1718.6	7.3	1718.6	7.3	98.9	
10HEN57-18	104	32038	2.3	9.2158	4.5	3.7238	4.8	0.2489	1.5	0.31	1432.8	19.1	1576.5	38.2	1774.5	82.8	1774.5	82.8	80.7	
10HEN57-6	91	2158	4.0	5.0173	223.2	0.1118	223.4	0.0041	9.4	0.04	26.2	2.5	107.6	232.1	2820.5	331.3	2820.5	331.3	0.9	
10HEN49	Mean = 27.8 ± 0.58 Ma, MSWD = 0.38, probability = 0.97, n = 12																			
10HEN49-2	447	9475	5.1	24.0773	21.6	0.0243	21.8	0.0042	3.1	0.14	27.3	0.8	24.4	5.2	-254.8	551.5	27.3	0.8	N.A.	
10HEN49-14	410	6969	2.3	23.0743	21.1	0.0254	21.9	0.0043	5.8	0.27	27.4	1.6	25.5	5.5	-148.1	528.4	27.4	1.6	N.A.	
10HEN49-11	326	6187	3.3	22.2816	21.7	0.0265	21.8	0.0043	1.8	0.08	27.5	0.5	26.5	5.7	-62.1	534.4	27.5	0.5	N.A.	
10HEN49-4	464	8434	2.7	22.4356	13.2	0.0264	13.6	0.0043	3.5	0.26	27.6	1.0	26.4	3.6	-79.0	323.3	27.6	1.0	N.A.	
10HEN49-7	310	5361	5.0	28.5799	22.0	0.0207	22.2	0.0043	3.1	0.14	27.6	0.8	20.8	4.6	-709.4	618.1	27.6	0.8	N.A.	
10HEN49-18	377	7427	2.9	22.3371	32.1	0.0265	32.2	0.0043	3.4	0.11	27.6	0.9	26.6	8.5	-68.2	800.8	27.6	0.9	N.A.	
10HEN49-1	603	18776	21.8	22.0478	13.0	0.0269	13.5	0.0043	3.9	0.29	27.7	1.1	26.9	3.6	-36.5	315.5	27.7	1.1	N.A.	
10HEN49-5	560	11355	2.1	24.7092	11.1	0.0240	11.3	0.0043	2.5	0.22	27.7	0.7	24.1	2.7	-320.8	284.6	27.7	0.7	N.A.	
10HEN49-10	358	9180	4.6	27.2665	34.6	0.0221	34.8	0.0044	3.5	0.10	28.1	1.0	22.2	7.6	-580.3	961.2	28.1	1.0	N.A.	
10HEN49-13	537	5494	2.2	20.5647	16.6	0.0294	16.9	0.0044	3.0	0.18	28.2	0.8	29.4	4.9	129.9	392.9	28.2	0.8	N.A.	
10HEN49-15	316	6341	2.5	21.1785	19.9	0.0295	20.2	0.0045	3.6	0.18	29.1	1.0	29.5	5.9	60.3	477.6	29.1	1.0	N.A.	
10HEN49-17	209	2637	9.2	21.6140	28.0	0.0290	28.3	0.0045	4.3	0.15	29.2	1.3	29.0	8.1	11.5	685.0	29.2	1.3	N.A.	
10HEN49-6	407	647373	5.9	10.0799	1.7	1.7312	10.6	0.1266	10.5	0.99	768.2	75.7	1020.2	68.2	1609.2	31.0	1609.2	31.0	47.7	
10HEN49-12	740	648306	11.6	9.7924	0.4	3.9185	3.8	0.2783	3.7	0.99	1582.8	52.4	1617.5	30.4	1663.0	7.3	1663.0	7.3	95.2	
10HEN49-9	875	742139	3.6	9.6265	0.2	4.0300	0.9	0.2814	0.8	0.97	1598.2	11.8	1640.3	7.0	1694.5	3.8	1694.5	3.8	94.3	
10HEN49-19	906	576149	5.3	9.6080	0.1	4.1273	1.9	0.2876	1.9	1.00	1629.5	26.9	1659.7	15.3	1698.1	2.1	1698.1	2.1	96.0	
10HEN49-3	326	679064	7.3	9.5759	0.2	4.2551	2.7	0.2955	2.7	1.00	1669.1	39.9	1684.7	22.4	1704.3	3.8	1704.3	3.8	97.9	
10HEN49-20	367	408063	2.0	9.5570	0.1	4.1073	1.4	0.2847	1.4	1.00	1615.0	20.3	1655.8	11.6	1707.9	1.8	1707.9	1.8	94.6	
10HEN49-8	304	197114	1.9	9.4898	0.1	4.6897	0.8	0.3228	0.8	0.99	1803.3	12.7	1765.4	6.8	1720.9	2.6	1720.9	2.6	104.8	
10HEN52	Mean = 27.0 ± 0.66 Ma, MSWD = 0.24, probability = 0.998, n = 15																			
10HEN52-18	236	3644	13.4	20.8424	23.6	0.0270	24.4	0.0041	5.9	0.24	26.3	1.5	27.1	6.5	98.2	566.4	26.3	1.5	N.A.	
10HEN52-14	191	9543	7.1	23.8365	57.7	0.0238	58.2	0.0041	7.8	0.13	26.4	2.1	23.8	13.7	-229.4	1576.3	26.4	2.1	N.A.	
10HEN52-9	527	5830	11.0	25.2923	15.8	0.0224	16.1	0.0041	3.3	0.21	26.4	0.9	22.5	3.6	-381.0	411.5	26.4	0.9	N.A.	
10HEN52-3	177	4347	11.5	19.9437	28.5	0.0286	29.2	0.0041	6.2	0.21	26.6	1.7	28.6	8.2	201.6	674.1	26.6	1.7	N.A.	
10HEN52-8	273	4136	8.6	20.8960	23.1	0.0273	23.5	0.0041	4.4	0.19	26.6	1.2	27.3	6.4	92.2	554.4	26.6	1.2	N.A.	
10HEN52-20	328	4627	8.7	24.9234	34.3	0.0229	34.6	0.0041	4.5	0.13	26.7	1.2	23.0	7.9	-343.0	907.0	26.7	1.2	N.A.	
10HEN52-4	319	6870	3.9	21.8617	25.4	0.0263	25.6	0.0042	3.2	0.13	26.8	0.9	26.4	6.7	-15.9	622.0	26.8	0.9	N.A.	
10HEN52-1	300	2858	14.9	24.8047	20.4	0.0232	20.7	0.0042	3.6	0.17	26.9	1.0	23.3	4.8	-330.7	527.9	26.9	1.0	N.A.	
10HEN52-11	179	2514	14.1	26.8189	57.5	0.0216	57.8	0.0042	6.2	0.11	27.0	1.7	21.7	12.4	-535.7	1665.6	27.0	1.7	N.A.	
10HEN52-10	380	5707	9.3	26.0656	17.6	0.0224	17.8	0.0042	2.6	0.15	27.2	0.7	22.4	3.9	-459.9	466.6	27.2	0.7	N.A.	
10HEN52-5	205	4164	9.5	25.6507	41.2	0.0228	41.5	0.0042	4.7	0.11	27.3	1.3	22.9	9.4	-417.7	1119.7	27.3	1.3	N.A.	
10HEN52-12	394	5032	5.7	19.1042	21.1	0.0310	22.0	0.0043	6.3	0.29	27.6	1.7	31.0	6.7	300.5	484.8	27.6	1.7	N.A.	
10HEN52-2	219	4489	8.8	28.5222	32.3	0.0208	32.4	0.0043	3.1	0.10	27.6	0.9	20.9	6.7	-703.8	916.3	27.6	0.9	N.A.	
10HEN52-13	260	3739	6.7	22.4180	21.6	0.0265	23.0	0.0043	8.1	0.35	27.7	2.2	26.6	6.0	-77.0	532.7	27.7	2.2	N.A.	
10HEN52-16	242	6007	5.7	26.8033	45.7	0.0231	46.1	0.0045	5.6	0.12	28.9	1.6	23.2	10.6	-534.2	1283.9	28.9	1.6	N.A.	
10HEN52-19	336	166683	10.3	10.7070	1.7	2.9577	2.1	0.2297	1.3	0.62	1332.8	15.9	1396.8	16.3	1495.9	31.9	1495.9	31.9	89.1	
10HEN52-17	307	305177	5.5	9.6155	0.3	3.7017	1.5	0.2582	1.5	0.99	1480.4	20.1	1571.7	12.3	1696.7	4.7	1696.7	4.7	87.3	
10HEN52-15	173	155951	3.8	9.5411	0.4	4.2686	1.0	0.2954	0.9	0.91	1668.4	12.9	1687.3							

TABLE DR3: APATITE FISSION TRACK DATA

Sample No.	No. of Crystals	Track Density (x 10 ⁶ tr cm ⁻²)			Mean Dpar (μm)	Age Dispersion (Px2)	Central Age (Ma) (±1σ)	Apatite Mean Track Length (μm ± 1 s.e.) (no. of tracks)	Standard Deviation (μm)
		ps (Ns)	pi (Ni)	pd (Nd)					
Igneous									
Hillers									
10 HEN 06	20	0.0483 (34)	0.4773 (336)	1.381 (4421)	2.08±0.58	<0.01% -99.70%	25.7±4.8	-	-
10 HEN 11 B	20	0.0789 (50)	0.7071 (448)	1.359 (4349)	2.06±0.14	<0.01% -99.90%	27.9±4.3	-	-
10 HEN 15	20	0.0854 (57)	0.8105 (541)	1.337 (4278)	1.84±0.22	<0.01% -96.40%	25.9±3.8	-	-
10 HEN 27	17	0.1148 (104)	1.091 (988)	1.315 (4207)	2.14±0.22	<0.01% -99.10%	25.4±2.8	-	-
10 HEN 42	20	0.0732 (74)	0.6096 (616)	1.228 (3922)	2.2±0.20	<0.01% (>99.9%)	27.1±3.5	-	-
Pennell									
10 HEN 28	20	0.1925 (143)	1.737 (1291)	1.292 (4136)	1.98±0.15	<0.01% (>99.9%)	26.3±2.6	-	-
10 HEN 35	8	0.1501 (44)	1.307 (383)	1.270 (4065)	2.03±0.14	<0.01% -99.20%	26.8±4.4	-	-
10 HEN 38	20	0.1336 (135)	1.160 (1172)	1.248 (3993)	2.17±0.19	<0.01% (>99.9%)	26.4±2.7	-	-
Ellen									
10 HEN 01	10	0.1939 (52)	1.950 (523)	1.448 (4634)	2.38±0.26	<0.01% -98.10%	26.4±4.0	-	-
10 HEN 47	12	0.2279 (117)	2.055 (1055)	1.203 (3851)	2.19±0.13	<0.01% -99.90%	24.5±2.8	-	-
10 HEN 49	18	0.2088 (207)	1.774 (1759)	1.181 (3780)	1.97±0.16	<0.01% (>99.9%)	25.5±2.2	15.26±0.12 (34)	0.67
10 HEN 52	20	0.1162 (102)	0.9749 (856)	1.159 (3708)	1.97±0.10	<0.01% (>99.9%)	25.4±2.9	-	-
Sedimentary									
Hillers									
10 HEN 05	16	0.4112 (210)	1.774 (906)	1.404 (4492)	2±0.27	28.70% -2.50%	54.1±6.5 mixed age	-	-
10 HEN 08	18	0.9531 (147)	0.3624 (559)	0.971 (3107)	2.22±0.31	<0.01% -90.60%	46.8±4.8	13.78±0.71 (4)	1.23
10 HEN 10	20	0.4328 (95)	3.139 (689)	1.561 (4995)	1.91±0.17	<0.01% -99.90%	39.5±4.6	-	-
10 HEN 12	15	0.3316 (52)	3.246 (509)	1.539 (4925)	2.03±0.18	<0.01% (>99.9%)	28.9±4.4	-	-
10 HEN 16	10	0.4710 (85)	4.804 (867)	1.528 (4890)	2.2±0.41	<0.01% (>99.9%)	27.5±3.3	-	-
10 HEN 19	12	0.194 (38)	1.808 (354)	1.517 (4854)	2.32±0.28	<0.01% (>99.9%)	29.9±5.3	-	-
10 HEN 21	21	0.1414 (58)	1.221 (501)	1.506 (4819)	2.28±0.41	10.20% -62.90%	32.1±4.7	-	-
12 HEN 03	3	0.6579 (32)	0.2220 (108)	0.979 (108)	2.83±0.95	<0.01% ((99.9%)	53.1±11.0	-	-
Ellen									
10 HEN 04	20	0.5187 (326)	0.9292 (584)	1.426 (4563)	2.71±0.53	13.90% -27.50%	143.7±12.7 mixed age	14.61±0.26 (29)	1.39

Notes:

- (i). Analyses by external detector method using 0.5 for the $4\pi/2\pi$ geometry correction factor;
(ii). Ages calculated using dosimeter glass: IRMM540R with $\zeta_{540R} = 368.1 \pm 14.9$ (apatite);
(iii). Px2 is the probability of obtaining a χ^2 value for v degrees of freedom where v = no. of crystals - 1;

TABLE DR4: APATITE (U-Th-Sm)/He AGE DATA

TABLE DR4: APATITE (U-Th-Sm)/He AGE DATA													
crystal ID	mass (μg)	R_s (μm)	[U] (ppm)	[Th] (ppm)	[Sm] (ppm)	[eU] (ppm)	^4He (nmol/g)	raw age (Ma)	F_T	corrected			
										age (Ma)	$\pm 2\sigma$ (Ma)	2σ % error	
Mount Hillers, igneous rocks													
15A928_km_10HEN11a_10	0.0764	33	2.3	2.5	43.4	2.9	0.19	11.7	0.58	20.3	7.5	36.9	
15A929_km_10HEN11a_11	0.0523	30	4.0	2.6	40.3	4.6	0.17	6.8	0.55	12.4	4.3	34.5	
15A930_km_10HEN11a_12	0.0433	28	5.0	4.8	66.8	6.2	0.31	9.1	0.52	17.7	4.2	23.7	
15A931_km_10HEN11a_13	0.3824	59	5.0	1.3	116.2	5.3	0.26	8.9	0.76	11.8	2.2	18.3	
15A933_km_10HEN11a_14	0.1123	37	3.7	4.4	55.7	4.7	0.29	11.1	0.63	17.7	2.7	15.5	
15A936_km_10HEN15a_12	0.1671	45	4.5	1.2	102.7	4.7	0.29	11.2	0.69	16.3	3.1	15.9	
15A934_km_10HEN15a_10	0.1755	46	4.7	14.5	193.5	8.2	0.60	13.1	0.69	19.2	1.0	5.1	
15A935_km_10HEN15a_11	0.2277	50	13.3	23.1	50.2	18.7	1.46	14.3	0.72	20.3	1.4	8.8	
15A937_km_10HEN15a_13	0.3792	53	4.0	3.6	65.5	4.9	0.30	11.3	0.73	15.6	2.7	17.6	
15A326_km_10HEN27a_10	0.6499	70	0.7	0.6	14.1	0.8	0.11	23.0	0.79	29.1	2.5	8.6	
15A328_km_10HEN27a_11	0.4614	58	20.1	12.6	64.7	23.0	1.18	9.5	0.75	12.7	0.55	4.3	
15A329_km_10HEN27a_12	1.4880	92	25.5	1.3	95.8	25.8	1.82	13.0	0.84	15.5	0.58	3.7	
15A330_km_10HEN27a_13	0.1918	47	1.5	1.3	24.5	1.7	0.07	7.6	0.70	10.9	2.1	19.1	
15A331_km_10HEN27a_14	0.6930	68	7.4	16.2	117.7	11.2	0.65	10.6	0.79	13.6	0.59	4.4	
15A332_km_10HEN27a_15	0.1054	40	1.7	2.1	40.1	2.2	0.06	5.3	0.65	8.15	3.0	36.4	
10HEN27a-1	0.5678	61	2.7	3.4	25.4	3.5	0.31	16.5		21.8	0.76	3.5	
10HEN27a-2	0.2291	45	0.9	1.4	23.5	1.2	0.24	35.8		52.9	3.2	6.1	
10HEN27a-3	0.2691	50	1.8	3.9	31.8	2.7	0.24	16.6		23.6	0.99	4.2	
10HEN39a_1	0.2267	38	10.3	43.0	203.0	20.4	2.19	19.6	0.67	30.3	1.1	3.6	
10HEN39a_2	0.1356	34	8.4	29.8	164.7	15.4	1.52	17.9	0.62	29.8	1.2	4.2	
10HEN39a_3	0.1005	30	8.7	26.2	185.3	14.9	1.16	14.2	0.58	25.2	1.5	5.9	
10HEN39a_4	0.0692	29	11.5	48.8	135.2	22.9	1.65	13.2	0.55	25.0	1.6	6.3	
10HEN39a_5	0.2119	39	9.5	43.6	266.9	19.7	1.50	13.8	0.67	21.4	0.80	3.7	
10HEN39a_6	0.1338	36	10.2	32.2	182.0	17.7	1.39	14.3	0.63	23.4	0.98	4.2	
10HEN42a_1	0.2987	52	6.0	6.7	109.4	7.6	0.84	20.0	0.74	27.3	1.2	4.4	
10HEN42a_2	0.1761	47	3.2	5.6	201.4	4.5	0.49	19.0	0.70	27.5	1.7	6.3	
10HEN42a_3	1.7330	76	5.9	5.0	208.4	7.1	0.88	22.3	0.82	27.3	0.84	3.1	
10HEN42a_4	1.5122	94	2.8	17.9	166.9	7.0	0.88	22.5	0.83	27.5	0.75	2.7	
10HEN42a_5	0.9165	73	9.2	9.1	136.4	11.4	1.45	23.2	0.80	29.2	0.96	3.3	
15A334_km_10HEN43a_1	0.6009	66	7.1	6.4	54.4	8.6	1.15	24.5	0.78	31.5	1.3	4.1	
15A335_km_10HEN43a_2	0.7632	71	6.6	3.0	223.9	7.3	0.99	24.1	0.79	30.3	1.3	4.4	
15A336_km_10HEN43a_3	0.4114	64	4.9	12.6	196.4	7.9	1.32	29.9	0.77	39.1	1.6	4.2	
15A337_km_10HEN43a_4	0.2426	49	8.8	9.0	192.9	10.9	1.38	23.0	0.71	32.6	1.4	4.2	
15A340_km_10HEN43a_5	0.1638	45	7.4	6.9	47.0	9.1	0.67	13.6	0.69	20.0	3.1	15.8	
15A341_km_10HEN43a_6	0.0684	36	3.2	6.4	94.6	4.7	0.46	17.6	0.61	29.1	3.0	10.1	
15A342_km_10HEN43a_7	0.3775	59	1.9	3.3	50.6	2.6	0.59	39.9	0.75	53.2	2.9	5.4	
15A343_km_10HEN44a_10	0.4335	65	2.2	5.5	78.1	3.5	0.66	34.0	0.78	44.2	1.8	4.1	
15A344_km_10HEN44a_11	0.4697	58	0.7	0.9	27.8	1.0	0.81	149.9	0.75	199	9.2	4.6	
15A346_km_10HEN44a_12	0.8506	72	1.4	2.4	93.2	2.0	0.45	39.4	0.80	49.4	2.5	5.1	
15A347_km_10HEN44a_13	0.6375	66	8.4	14.4	170.7	11.8	1.14	17.6	0.78	22.8	0.8	3.5	
15A348_km_10HEN44a_14	0.4283	57	6.5	3.2	183.6	7.2	0.86	21.4	0.75	28.5	1.2	4.2	
15A349_km_10HEN44a_15	0.4511	60	4.2	3.7	39.7	5.1	0.78	27.8	0.76	36.8	1.4	3.8	
10HEN44a_1	0.6326	65	1.5	2.0	166.2	2.0	0.54	45.4	0.78	59.0	3.5	6.0	
10HEN44a_2	0.4304	56	2.8	2.5	90.5	3.4	0.48	25.4	0.75	34.3	1.7	5.0	
10HEN44a_3	1.0912	82	2.2	2.0	77.5	2.6	0.53	36.1	0.81	44.7	1.8	4.0	
10HEN44a_4	1.2780	78	2.3	3.4	56.1	3.1	0.84	49.1	0.82	60.6	1.9	3.2	
10HEN44a_5	0.9813	74	18.6	5.1	112.7	19.8	2.33	21.7	0.82	26.6	0.93	3.5	
10HEN44a_6	0.8301	78	4.1	2.3	69.3	4.6	0.87	34.3	0.80	43.2	1.6	3.6	
10HEN44a_7	1.9881	93	4.3	7.0	121.1	5.9	1.26	38.4	0.84	45.9	1.4	3.0	
15A350_km_10HEN45a_1	1.3200	92	12.9	17.9	161.8	17.1	2.17	23.2	0.84	27.7	0.72	2.6	
15A352_km_10HEN45a_2	0.1140	41	6.4	7.6	147.4	8.2	0.43	9.6	0.66	14.6	1.1	7.7	
15A353_km_10HEN45a_3	0.1310	38	9.9	15.0	160.7	13.4	0.85	11.7	0.64	18.5	3.2	17.1	
15A354_km_10HEN45a_4	0.2150	50	16.7	24.3	142.6	22.4	2.38	19.5	0.71	27.6	1.1	4.1	
15A355_km_10HEN45a_5	0.0888	33	2.5	5.6	52.6	3.8	0.24	11.2	0.59	19.3	2.0	10.2	
15A356_km_10HEN45a_6	0.3200	56	13.8	4.9	80.6	14.9	1.53	18.9	0.74	25.5	1.0	3.9	

TABLE DR4: APATITE (U-Th-Sm)/He AGE DATA (CONTINUED)

crystal ID	mass (μg)	R _s (μm)	[U] (ppm)	[Th] (ppm)	[Sm] (ppm)	[eU] (ppm)	⁴ He (nmol/g)	raw age (Ma)	F _T	corrected		
										age (Ma)	±2σ (Ma)	2σ % error
Mount Hillers, igneous rocks (continued)												
15A358_km_10HEN46a_10	0.0778	32	9.6	7.3	298.6	11.3	0.62	9.8	0.58	16.7	1.0	6.0
15A359_km_10HEN46a_11	0.1163	38	5.2	18.4	89.7	9.6	0.83	15.8	0.64	25.5	3.7	14.4
15A360_km_10HEN46a_12	0.0873	40	5.3	9.6	96.7	7.5	0.50	12.1	0.65	19.0	1.5	7.9
15A361_km_10HEN46a_13	0.1302	41	4.7	18.1	84.6	9.0	0.64	12.9	0.66	20.1	1.9	9.3
15A362_km_10HEN46a_14	0.0398	28	7.2	23.8	108.7	12.8	0.71	10.1	0.53	19.9	2.6	13.3
15A364_km_10HEN46a_15	0.2508	51	5.0	16.2	105.4	8.8	1.16	23.9	0.72	33.8	2.1	6.1
10HEN46a_1	0.0000	71	3.7	9.0	90.6	5.8	0.81	25.2	0.78	32.9	1.1	3.2
10HEN46a_2	0.0000	46	6.3	18.6	82.4	10.7	1.48	25.2	0.69	37.3	1.6	4.3
10HEN46a_3	0.0000	40	18.9	16.8	80.6	22.8	0.74	6.0	0.65	9.40	0.46	4.8
10HEN46a_4	0.0000	51	6.9	15.1	109.8	10.4	1.03	18.0	0.73	25.2	0.86	3.4
10HEN46a_5	0.0000	39	7.0	15.9	84.8	10.7	0.82	14.0	0.66	21.6	1.0	4.8
10HEN46a_6	0.0000	40	6.3	26.4	88.2	12.5	1.27	18.6	0.64	30.1	1.5	5.0
Mount Hillers, sedimentary rocks												
10HEN12a_1	0.1091	32	71.5	72.8	237.5	88.6	3.29	6.8	0.60	11.6	0.48	4.2
10HEN12a_2	0.1397	37	11.2	20.5	138.9	16.0	0.28	3.2	0.64	5.07	0.53	10.6
10HEN12a_3	0.0904	33	5.7	7.6	80.2	7.4	2.31	56.7	0.62	93.0	9.8	10.5
14A307_km_10HEN13a_1	0.1003	36	21.6	41.1	162.2	31.2	1.47	8.6	0.62	14.2	1.8	12.9
14A308_km_10HEN13a_2	0.1330	43	13.9	18.6	248.7	18.3	0.73	7.3	0.68	10.8	2.1	19.6
14A309_km_10HEN13a_3	0.0791	36	44.9	12.2	174.4	47.8	3.23	12.5	0.62	20.2	1.0	5.1
14A310_km_10HEN13a_4	0.1471	39	14.4	20.8	89.3	19.2	1.30	12.4	0.65	19.5	1.3	6.9
14A312_km_10HEN13a_5	0.0981	36	11.1	7.5	132.9	12.9	0.75	10.6	0.61	17.4	2.7	15.3
14A313_km_10HEN13a_6	0.0484	30	21.0	37.2	180.4	29.7	1.22	7.5	0.55	14.0	1.7	12.3
14A315_km_10HEN13a_8	0.0768	34	42.8	62.2	42.2	57.4	12.31	39.6	0.59	68.0	2.2	3.3
14A319_km_10HEN13a_11	0.1291	37	44.8	103.0	409.9	69.0	4.96	13.2	0.62	21.6	0.77	3.5
14B099_km_10HEN08a_20	0.0589	32	7.9	28.2	287.2	14.5	0.36	4.5	0.57	8.05	0.84	10.4
14B100_km_19HEN08a_21	0.0413	28	5.3	28.5	126.4	12.0	0.25	3.8	0.53	7.58	1.7	22.5
14B101_km_10HEN08a_22	0.0443	33	11.6	56.0	232.6	24.8	0.75	5.5	0.59	9.83	0.83	8.5
14B102_km_10HEN08a_23	0.0343	27	13.6	22.5	59.9	18.9	0.56	5.5	0.51	11.1	1.8	16.6
14B104_km_10HEN08a_24	0.0427	27	21.5	23.0	213.6	26.9	0.79	5.4	0.51	10.7	1.1	10.2
14B105_km_10HEN08a_25	0.0516	29	9.9	72.8	480.1	27.0	0.72	4.8	0.53	9.45	0.79	8.3
14B106_km_10HEN08a_26	0.0451	29	6.0	23.1	105.1	11.4	0.53	8.6	0.55	16.4	1.96	12.0
14B107_km_10HEN08a_27	0.0486	26	110.3	81.0	109.2	129.3	3.55	5.1	0.50	10.4	1.3	12.7
14B109_km_10HEN08a_28	0.0399	32	3.1	23.7	233.6	8.6	0.21	4.3	0.57	7.88	2.0	25.1
14B110_km_10HEN08a_29	0.0397	29	16.7	32.4	87.0	24.3	0.73	5.5	0.54	10.5	1.4	13.6
10HEN08-1a	0.0930	33	20.2	71.2	892.9	37.0	0.00	9.9	0.57	17.2	0.68	3.9
10HEN08-2a	0.0840	32	4.0	28.7	223.6	10.7	0.00	2.8	0.54	5.06	0.84	16.5
10HEN08-3a	0.2204	46	2.6	2.4	4.1	3.1	0.00	275.6	0.69	397	12	3.0
10HEN08-4a	0.0709	34	3.6	2.6	0.6	4.2	0.00	53.1	0.59	89.1	4.3	4.8
10HEN08-5a	0.0626	30	12.7	35.3	313.5	21.0	0.00	1.8	0.53	3.37	0.67	20.0
10HEN08a_1	0.0578	31	68.1	21.7	124.6	73.2	0.00	10.7	0.55	19.6	0.72	3.7
10HEN08a_2	0.0524	31	64.8	43.2	176.2	75.0	0.00	10.9	0.54	20.6	0.68	3.3
10HEN08a_3	0.0553	29	7.7	31.0	114.1	15.0	0.00	5.7	0.54	11.3	0.59	5.3
14B111_km_10HEN09a_20	0.0402	27	21.7	15.9	322.4	25.5	0.77	5.5	0.52	10.7	1.2	11.0
14B112_km_10HEN09a_21	0.0502	32	14.7	21.4	316.9	19.8	0.78	7.2	0.58	12.5	1.3	10.8
14B114_km_10HEN09a_22	0.0492	27	22.3	55.1	129.6	35.2	1.30	6.8	0.51	13.9	0.95	6.8
14B115_km_10HEN09a_23	0.0396	28	29.0	90.1	666.7	50.2	1.76	6.4	0.52	12.7	1.2	9.6
14B116_km_10HEN09a_24	0.0454	28	45.1	28.0	172.4	51.6	1.94	6.9	0.52	13.4	2.4	17.9
14B117_km_10HEN09a_25	0.0373	27	36.5	95.2	136.5	58.9	1.43	4.5	0.51	9.05	0.73	8.1
14B119_km_10HEN09a_26	0.0411	29	26.5	21.1	170.5	31.5	1.34	7.8	0.54	14.7	1.2	7.9
14B120_km_10HEN09a_27	0.0363	27	12.9	23.2	88.8	18.3	0.28	2.8	0.51	5.56	1.4	25.5
14B121_km_10HEN09a_28	0.0472	30	7.7	31.1	75.6	15.0	0.42	5.1	0.55	9.54	1.7	17.9
14B122_km_10HEN09a_29	0.0210	26	180.7	16.5	286.7	184.6	9.16	9.2	0.50	18.6	2.5	13.5
14B124_km_10HEN09a_30	0.0323	27	43.8	63.3	241.1	58.7	2.59	8.1	0.51	16.4	1.5	9.1
14B125_km_10HEN09a_31	0.0493	29	10.6	18.0	197.5	14.9	0.60	7.3	0.55	13.7	2.5	18.6
10HEN09a_2	0.0618	31	18.8	82.4	177.8	38.2	1.94	9.3	0.55	17.7	0.48	2.7
10HEN09a_3	0.0583	33	13.9	42.4	128.0	23.8	1.15	8.8	0.55	16.7	0.57	3.4
10HEN09a_4	0.0948	37	16.4	41.7	69.6	26.2	0.72	5.1	0.61	8.64	0.27	3.1

TABLE DR4: APATITE (U-Th-Sm)/He AGE DATA (CONTINUED)

crystal ID	mass (μg)	R_c (μm)	[U] (ppm)	[Th] (ppm)	[Sm] (ppm)	[eU] (ppm)	^4He (nmol/g)	raw age (Ma)	F_T	corrected age (Ma)	$\pm 2\sigma$ (Ma)	2σ % error
Mount Hillers, sedimentary rocks (continued)												
14B126_km_10HEN10a_20	0.0565	33	18.9	77.0	241.1	37.0	1.53	7.6	0.59	13.4	3.3	24.5
14B127_km_10HEN10a_21	0.0671	35	62.1	125.0	98.8	91.5	6.04	12.2	0.61	20.6	0.80	3.8
14B128_km_10HEN10a_22	0.0529	33	133.2	119.1	264.4	161.2	6.40	7.3	0.59	12.6	0.62	4.8
14B133_km_10HEN10a_23	0.0356	27	16.2	35.5	52.0	24.6	0.67	5.0	0.51	10.3	1.4	13.6
14B134_km_10HEN10a_24	0.0399	30	9.7	42.4	153.7	19.7	0.34	3.1	0.55	5.99	1.2	19.7
14B135_km_10HEN10a_25	0.0507	29	19.8	62.8	244.1	34.6	0.73	3.9	0.54	7.44	0.66	8.9
14B136_km_10HEN10a_26	0.0408	27	15.6	47.3	64.7	26.7	0.55	3.8	0.51	7.77	0.92	11.9
14B138_km_10HEN10a_27	0.0536	31	19.7	25.5	91.9	25.7	0.85	6.1	0.57	11.0	0.72	6.6
14B139_km_10HEN10a_28	0.0449	30	11.1	34.6	113.6	19.2	0.56	5.3	0.55	9.94	1.5	14.9
14B140_km_10HEN10a_29	0.0349	27	21.7	24.4	128.8	27.5	0.70	4.7	0.51	9.34	1.1	11.4
14B141_km_10HEN10a_30	0.0413	29	14.3	57.2	154.8	27.8	0.84	5.6	0.54	10.8	1.0	9.3
14B143_km_10HEN10a_31	0.0451	31	9.1	18.7	55.3	13.5	0.21	2.8	0.56	5.22	1.6	30.8
10HEN10a_1	0.0472	26	26.0	39.2	65.9	35.2	1.61	8.5	0.51	17.1	0.59	3.5
10HEN10a_2	0.0538	31	32.7	89.4	214.2	53.7	2.34	8.0	0.54	15.5	0.50	3.2
10HEN10a_3	0.0568	32	22.1	19.4	95.2	26.6	1.25	8.7	0.55	16.1	0.66	4.1
10HEN10a_4	0.0571	30	49.1	157.2	170.2	86.0	5.10	10.9	0.54	21.1	0.57	2.7
14B144_km_10HEN19a_20	0.1477	42	45.3	45.2	524.1	55.9	4.52	14.8	0.67	22.3	0.82	3.7
14B145_km_10HEN19a_21	0.0676	33	23.6	54.2	254.9	36.4	0.87	4.4	0.58	7.71	0.56	7.3
14B146_km_10HEN19a_22	0.0781	35	48.0	88.4	244.7	68.8	4.59	12.3	0.60	20.8	1.0	4.9
14B148_km_10HEN19a_23	0.0753	34	29.3	43.6	93.6	39.6	2.93	13.6	0.59	23.4	1.5	6.2
14B149_km_10HEN19a_24	0.1070	42	32.2	14.1	257.3	35.5	2.09	10.8	0.66	16.3	0.96	5.9
14B151_km_10HEN19a_26	0.0917	35	41.1	93.0	76.4	62.9	4.27	12.5	0.61	21.1	0.76	3.6
14B153_km_10HEN19a_27	0.0504	31	73.4	38.4	212.1	82.4	5.78	13.0	0.56	23.2	1.1	4.6
14B154_km_10HEN19a_28	0.0872	38	24.1	9.9	295.8	26.4	1.15	8.0	0.64	12.5	2.3	18.2
14B155_km_10HEN19a_29	0.0903	36	14.1	42.2	262.3	24.0	3.08	23.4	0.62	39.0	2.1	5.3
14B156_km_10HEN19a_30	0.0636	33	22.3	115.2	633.7	49.4	1.75	6.4	0.59	11.4	1.5	13.1
14B158_km_10HEN19a_31	0.0412	28	78.7	11.2	327.4	81.3	4.52	10.3	0.52	19.7	1.9	9.4
14B159_km_10HEN19a_32	0.0825	34	10.9	26.5	39.0	17.1	0.71	7.6	0.60	13.0	0.85	6.5
14B160_km_10HEN19a_33	0.0712	32	19.3	46.5	259.4	30.2	0.62	3.7	0.57	6.71	0.47	7.0
14B161_km_10HEN19a_34	0.0578	30	11.7	30.1	182.8	18.7	0.49	4.8	0.55	9.05	0.89	9.9
10HEN19a_1	0.0523	29	15.6	55.6	104.0	28.7	1.01	6.5	0.56	12.0	0.97	8.0
10HEN19a_2	0.1812	41	19.1	46.3	239.4	30.0	1.39	8.5	0.67	13.0	0.68	5.2
10HEN19a_3	0.1325	38	2.5	10.8	55.9	5.0	0.17	6.4	0.64	10.4	1.6	15.0
15A298_km_10HEN20a_30	0.1022	36	23.5	14.8	200.1	27.0	1.90	12.9	0.61	21.1	3.7	17.6
15A299_km_10HEN20a_31	0.1190	39	6.5	18.0	54.2	10.7	0.67	11.4	0.65	18.1	3.9	21.8
15A300_km_10HEN20a_32	0.0865	35	50.0	10.4	380.4	52.5	2.39	8.4	0.60	13.9	0.83	6.0
15A301_km_10HEN20a_33	0.0517	30	5.2	72.4	423.2	22.2	0.57	4.6	0.56	8.80	0.78	8.9
15A302_km_10HEN20a_34	0.1240	40	12.8	54.3	92.9	25.6	1.36	9.8	0.65	15.5	2.0	12.9
15A304_km_10HEN20a_35	0.0727	33	4.6	17.5	152.6	8.7	0.32	6.6	0.58	11.7	1.3	11.3
15A305_km_10HEN20a_36	0.0783	33	12.6	41.7	454.1	22.4	0.51	4.1	0.59	7.10	0.64	9.0
15A306_km_10HEN20a_37	0.0866	35	48.3	15.1	163.5	51.8	2.67	9.5	0.61	15.6	0.98	6.3
15A307_km_10HEN20a_38	0.0403	30	12.8	19.1	102.1	17.3	0.36	3.8	0.55	7.10	1.4	19.7
15A308_km_10HEN20a_39	0.0729	32	10.2	11.1	144.0	12.8	0.16	2.3	0.58	4.01	0.78	19.5
15A310_km_10HEN20a_40	0.0757	34	16.8	58.5	303.6	30.6	0.57	3.4	0.60	5.91	0.41	6.9
15A311_km_10HEN20a_41	0.0725	30	12.6	45.8	355.4	23.3	0.46	3.5	0.56	6.57	0.54	8.2
14B163_km_10HEN20a_20	0.1198	36	10.9	53.0	98.8	23.3	2.64	20.8	0.62	34.7	1.7	4.8
14B164_km_10HEN20a_21	0.0831	35	4.2	13.1	69.8	7.3	0.17	4.4	0.60	7.44	1.5	20.1
14B165_km_10HEN20a_22	0.1066	39	50.0	71.5	228.7	66.8	5.73	15.8	0.64	25.0	0.88	3.5
14B166_km_10HEN20a_23	0.0991	40	7.7	19.4	179.8	12.3	0.31	4.6	0.65	7.14	0.87	12.2
14B168_km_10HEN20a_24	0.0607	32	36.5	115.1	397.7	63.5	1.60	4.6	0.58	8.30	1.6	19.5
14B169_km_10HEN20a_25	0.0935	37	17.0	53.1	233.7	29.4	1.94	12.1	0.63	19.8	1.4	6.9
14B170_km_10HEN20a_26	0.0588	31	19.8	26.2	445.4	26.0	0.51	3.6	0.57	6.36	0.57	9.0
14B171_km_10HEN20a_27	0.0850	37	36.7	25.2	410.7	42.6	3.54	15.2	0.63	24.4	0.98	4.0
14B172_km_10HEN20a_28	0.0603	32	8.4	28.5	113.5	15.1	0.47	5.6	0.58	10.1	1.1	10.6
10HEN20_Ap2	0.3426	53	1.3	6.6	148.5	2.8	0.27	16.9	0.71	23.5	0.75	3.2
10HEN20_Ap3	0.1861	44	14.4	49.7	203.9	26.1	2.06	14.6	0.66	22.1	0.63	2.8
10HEN20_Ap4	0.1566	41	7.3	17.9	108.0	11.5	0.48	7.7	0.64	12.0	0.44	3.7
10HEN20_Ap5	0.1291	38	12.4	118.5	88.7	40.3	2.76	12.7	0.60	21.0	0.61	2.9
10HEN20_Ap6	0.1379	39	5.5	19.8	119.9	10.2	0.52	9.4	0.62	15.1	1.6	10.6

TABLE DR4: APATITE (U-Th-Sm)/He AGE DATA (CONTINUED)

crystal ID	mass (μg)	R_s (μm)	[U] (ppm)	[Th] (ppm)	[Sm] (ppm)	[eU] (ppm)	^4He (nmol/g)	raw age (Ma)	F_T	corrected age (Ma)	$\pm 2\sigma$ (Ma)	2σ % error
<u>Mount Hillers, sedimentary rocks (continued)</u>												
15A312_km_10HEN21a_10	0.0922	35	54.3	114.6	115.7	81.2	4.59	10.4	0.61	17.5	0.80	4.6
15A313_km_10HEN21a_11	0.0592	32	17.0	135.9	228.5	49.0	1.09	4.1	0.57	7.55	0.82	10.9
15A314_km_10HEN21a_12	0.0718	32	8.2	81.5	283.9	27.4	0.92	6.1	0.58	11.2	0.87	7.8
15A316_km_10HEN21a_13	0.1226	38	65.9	70.3	578.5	82.5	5.64	12.6	0.64	19.9	0.90	4.5
15A317_km_10HEN21a_14	0.0682	32	8.2	140.7	539.1	41.3	3.80	16.7	0.58	30.5	2.0	6.5
15A318_km_10HEN21a_15	0.1962	47	3.0	33.6	212.3	10.9	0.24	4.0	0.70	5.94	0.54	9.2
15A319_km_10HEN21a_16	0.2984	54	9.2	53.5	168.0	21.7	1.39	11.7	0.74	16.2	0.78	4.8
15A320_km_10HEN21a_17	0.0540	30	34.8	196.4	583.7	80.9	3.08	7.0	0.55	13.3	1.6	12.0
15A322_km_10HEN21a_18	0.0783	34	24.7	143.5	351.7	58.4	0.78	2.4	0.60	4.27	0.25	6.0
15A323_km_10HEN21a_19	0.0772	34	6.5	58.9	120.1	20.4	0.57	5.2	0.60	9.10	0.80	8.8
10HEN21a_1	0.2136	46	8.9	102.6	136.0	33.0	1.58	8.8	0.69	13.3	0.55	4.1
10HEN21a_2	0.4409	56	16.7	81.2	246.6	35.8	1.94	9.9	0.77	13.2	0.37	2.8
10HEN21a_3	0.1349	40	4.8	30.5	85.9	12.0	0.44	6.7	0.64	10.8	2.1	19.2
10HEN21a_4	0.1445	39	8.6	79.3	98.3	27.3	1.29	8.7	0.65	14.1	0.78	5.6
15A324_km_10HEN22a_10	0.0559	32	53.3	1.9	294.7	53.7	11.38	39.0	0.58	67.4	3.0	4.5
15A325_km_10HEN22a_11	0.0248	24	27.0	6.2	404.4	28.4	1.35	8.7	0.46	18.6	3.1	16.9
10HEN22a_2	0.1715	38	10.8	20.6	179.4	15.6	0.71	8.3	0.68	12.3	0.68	5.5
<u>Mount Ellen</u>												
15A921_km_10HEN01a_10	0.1781	44	7.7	14.6	116.4	11.1	0.26	4.3	0.68	6.44	0.58	9.1
15A922_km_10HEN01a_11	0.4482	58	9.6	12.2	128.6	12.5	0.57	8.4	0.75	11.3	0.63	5.6
15A923_km_10HEN01a_12	0.2044	47	7.3	18.3	175.1	11.6	0.26	4.1	0.70	5.98	0.73	12.3
15A924_km_10HEN01a_13	0.2330	49	7.6	10.6	168.8	10.1	0.23	4.1	0.71	5.84	0.53	9.0
15A925_km_10HEN01a_14	0.5930	67	33.5	7.6	141.8	35.3	2.10	11.0	0.78	14.1	0.61	4.3
15A927_km_10HEN01a_15	0.4347	68	9.3	14.2	161.1	12.6	0.75	10.8	0.78	13.8	0.62	4.5
10HEN_01_Ap4	0.0000	60	15.6	8.2	98.0	17.6	1.15	12.3	0.75	16.2	0.51	3.1
10HEN_01_AP5	0.0000	55	6.1	6.2	67.6	7.5	0.14	3.6	0.73	4.87	1.4	29.4
10HEN01_AP1	0.0000	43	7.3	11.4	88.0	10.0	0.30	5.6	0.66	8.47	2.4	28.1
10HEN01_AP2	0.0000	54	10.1	10.5	89.4	12.5	0.28	4.2	0.73	5.73	0.54	9.5
10HEN01_AP3	0.0000	66	6.4	6.9	82.1	8.0	0.26	6.1	0.77	7.91	0.27	3.4
10HEN01_AP6	0.0000	52	5.6	7.6	69.2	7.4	0.08	2.0	0.72	2.79	0.50	17.8
15A941_km_10HEN48a_1	0.1181	37	12.6	5.9	75.4	14.0	1.08	14.2	0.63	22.6	4.45	19.7
15A942_km_10HEN48a_2	0.0798	33	4.5	4.5	54.7	5.6	0.24	7.8	0.59	13.5	2.06	15.3
15A943_km_10HEN48a_3	0.4185	58	1.6	3.2	139.2	2.4	0.18	13.2	0.75	17.5	3.25	18.6
15A945_km_10HEN48a_4	0.2475	50	7.5	3.8	52.1	8.3	0.61	13.5	0.72	18.9	2.96	15.7
15A946_km_10HEN48a_5	0.1461	43	9.3	4.4	62.2	10.3	0.56	9.9	0.68	14.7	1.29	8.8
15A947_km_10HEN48a_6	0.9961	79	28.8	4.0	51.9	29.8	3.13	19.5	0.81	23.9	0.80	3.4
15A948_km_10HEN49a_10	0.0748	32	7.2	14.2	202.2	10.5	0.57	9.8	0.57	17.5	1.5	8.7
15A951_km_10HEN49a_12	0.2012	44	3.5	9.6	152.3	5.7	0.40	12.5	0.68	18.6	3.2	17.4
15A952_km_10HEN49a_13	0.5137	68	6.2	5.2	194.1	7.5	0.89	21.5	0.79	27.3	1.2	4.4
15A953_km_10HEN49a_14	0.1584	42	24.8	6.7	137.5	26.4	3.21	22.4	0.67	33.6	1.5	4.3
15A954_km_10HEN49a_15	0.2765	53	4.0	5.9	123.7	5.4	0.37	12.5	0.73	17.3	3.2	18.6
15A955_km_10HEN49a_16	0.1375	41	6.5	6.6	153.0	8.0	0.62	14.0	0.66	21.3	2.5	11.7
10HEN49a-1	0.3020	55	2.6	4.8	97.5	3.7	0.46	22.5	0.00	30.7	1.0	3.3
10HEN49a-2	0.1673	40	0.3	0.9	0.1	0.5	1.25	433.9	0.00	672	54	8.0
10HEN49a-3	0.2115	44	1.3	2.9	73.6	2.0	0.31	28.0	0.00	41.6	2.1	5.2
10HEN49a-4	0.1439	39	3.9	11.5	158.8	6.6	0.74	20.3	0.00	32.5	1.7	5.2
10HEN52a-1	0.1512	39	5.8	13.5	112.1	8.9	0.47	9.7	0.63	15.3	0.51	5.3
10HEN52a-2	0.0742	31	28.2	4.6	56.1	29.2	2.43	15.7	0.56	28.1	0.65	4.1
10HEN52a-3	0.0963	38	13.4	5.4	90.9	14.7	1.49	19.1	0.64	29.9	0.69	3.6
10HEN52a-4	0.1302	41	3.2	7.4	62.3	4.9	0.22	8.4	0.65	12.9	2.9	35.0
10HEN52a-5	0.1356	35	3.9	4.0	81.9	4.9	0.45	17.1	0.60	28.2	1.5	8.7
<u>Satellite intrusions and neighboring country rocks</u>												
13A576_km_12HEN02a_1	0.3282	51	2.0	1.9	13.5	2.5	0.06	4.8	0.71	6.68	0.65	9.7
13A577_km_12HEN02a_2	0.2948	50	2.1	2.9	25.7	2.8	0.19	12.3	0.70	17.4	1.2	6.6
13A578_km_12HEN02a_3	0.9383	75	6.3	9.4	103.6	8.6	0.40	8.6	0.80	10.8	0.29	2.7
13A579_km_12HEN02a_4	0.3720	54	3.7	4.4	129.9	4.8	0.45	16.9	0.73	23.1	0.77	3.3

TABLE DR4: APATITE (U-Th-Sm)/He AGE DATA (CONTINUED)

crystal ID	mass (μg)	R_s (μm)	[U] (ppm)	[Th] (ppm)	[Sm] (ppm)	[eU] (ppm)	^4He (nmol/g)	raw age (Ma)	F_T	corrected age (Ma)	$\pm 2\sigma$ (Ma)	2σ % error
Satellite intrusions and neighboring country rocks (continued)												
13A581_km_12HEN03a_1	0.0844	34	18.7	83.0	242.3	38.3	0.82	3.9	0.57	6.87	0.31	4.5
13A582_km_12HEN03a_2	0.2016	45	6.0	28.1	82.4	12.6	0.43	6.3	0.67	9.42	0.34	3.7
13A583_km_12HEN03a_3	0.2038	45	102.8	125.8	150.1	132.4	10.54	14.7	0.68	21.6	0.55	2.6
13A584_km_12HEN03a_4	0.1194	38	61.1	94.2	241.5	83.3	5.40	12.0	0.62	19.2	0.64	3.3
15A365_km_12HEN04a_1	0.0778	30	9.3	29.2	227.0	16.2	0.37	4.1	0.55	7.72	1.1	14.3
15A366_km_12HEN04a_2	0.2084	46	11.7	69.8	200.4	28.1	1.39	9.1	0.69	13.5	0.94	6.9
15A367_km_12HEN04a_3	0.0982	36	7.5	36.8	109.1	16.1	0.35	4.0	0.62	6.69	0.65	9.8
15A368_km_12HEN04a_4	0.1082	40	7.0	29.6	102.3	14.0	0.34	4.5	0.65	7.18	0.62	8.6
15A370_km_12HEN04a_5	0.0631	31	6.9	35.9	84.4	15.3	0.50	6.0	0.56	11.3	1.6	14.1
15A371_km_12HEN04a_6	0.1412	44	27.6	24.8	596.8	33.4	1.70	9.2	0.68	13.7	1.0	7.6
15A372_km_12HEN04a_7	0.1311	40	24.8	11.2	104.1	27.5	1.68	11.3	0.65	17.3	1.1	6.5
15A373_km_12HEN04a_8	0.1599	43	18.0	13.8	309.3	21.2	1.19	10.2	0.67	15.2	1.5	9.6
15A377_km_12HEN04a_11	0.1314	40	39.5	23.0	275.2	44.9	3.21	13.2	0.65	20.2	0.90	4.5
15A378_km_12HEN04a_12	0.0646	33	4.1	17.1	103.5	8.2	0.24	5.3	0.58	9.37	1.7	18.5
15A379_km_12HEN04a_13	0.0994	38	9.7	58.8	312.1	23.5	0.73	5.6	0.63	9.21	0.90	9.7
10HEN38a-1	0.5424	60	4.9	5.7	29.8	6.2	0.80	24.0	0.75	31.8	1.0	3.2
10HEN38a-2	0.5555	69	2.3	2.8	12.7	3.0	0.38	24.4	0.78	31.2	1.3	4.1
10HEN38a-3	0.3296	53	4.6	11.1	95.1	7.2	0.78	19.9	0.72	27.7	0.95	3.5
10HEN38a-4	0.2399	53	4.2	10.5	82.1	6.7	0.93	25.8	0.72	35.9	1.1	3.1
Sedimentary samples not fully reset												
10HEN04_AP1	0.1280	39	16.2	62.8	268.0	31.0	1.82	10.9	0.62	17.5	0.60	3.5
10HEN04_AP2	0.3758	51	15.9	65.1	270.1	31.2	1.21	7.1	0.70	10.2	0.31	3.1
10HEN04_AP3	0.2612	48	3.3	13.3	150.6	6.5	0.51	14.2	0.68	20.7	0.70	3.4
10HEN04_AP4	0.4281	56	11.2	60.4	228.0	25.4	2.83	20.6	0.72	28.4	0.75	2.7
10HEN04_AP5	0.3229	51	6.9	13.1	95.6	10.0	1.43	26.5	0.71	37.3	1.1	3.0
10HEN04_AP6	0.2192	46	6.7	26.9	101.6	13.1	0.68	9.6	0.68	14.2	0.66	4.6
10HEN05a_1	0.2252	45	8.1	36.5	145.5	16.7	0.82	9.0	0.66	13.6	0.58	4.2
10HEN05a_2	0.2885	47	5.3	23.1	157.5	10.7	0.69	11.7	0.68	17.2	0.64	3.7
10HEN05a_3	0.1915	40	5.7	46.6	86.8	16.7	0.91	10.0	0.63	16.0	0.68	4.2
10HEN05a_4	0.1042	39	8.2	22.3	166.9	13.4	1.29	17.5	0.62	27.9	1.5	5.3
10HEN05a_5	0.2516	47	23.2	10.7	139.0	25.8	1.96	14.1	0.70	20.2	0.69	3.4
10HEN05a_6	0.1711	42	13.6	10.1	19.7	16.0	1.49	17.3	0.66	26.0	0.91	3.5
10HEN05a_8	0.2215	46	17.6	12.9	79.5	20.6	1.31	11.7	0.69	17.1	0.61	3.5
14B089_km_10HEN07a_20	0.2556	50	65.8	342.1	421.5	146.1	14.26	17.9	0.71	25.9	0.67	2.6
14B090_km_10HEN07a_21	0.1539	40	15.0	46.4	296.1	25.9	1.83	12.9	0.65	20.2	0.87	4.3
14B091_km_10HEN07a_22	0.2078	50	65.6	254.6	508.2	125.4	11.33	16.6	0.71	23.8	0.69	2.9
14B092_km_10HEN07a_23	0.0994	37	112.2	106.8	697.7	137.2	13.28	17.8	0.62	28.8	0.91	3.2
14B094_km_10HEN07a_24	0.1012	38	39.9	91.1	387.6	61.3	4.21	12.6	0.64	20.2	0.74	3.6
14B095_km_10HEN07a_25	0.0582	33	114.6	175.8	280.6	155.9	8.69	10.3	0.59	17.8	0.62	3.5
14B096_km_10HEN07a_26	0.0895	37	17.5	60.1	176.8	31.6	2.71	15.7	0.62	26.0	1.5	5.7
14B097_km_10HEN07a_27	0.1382	42	22.7	30.1	480.6	29.8	2.47	15.1	0.66	22.9	0.85	3.7
10HEN07a_AP1	0.2339	52	29.5	85.1	563.3	49.5	5.00	18.6	0.71	26.1	0.66	2.5
10HEN07a_AP2	0.2206	45	9.3	33.5	490.4	17.2	4.86	50.9	0.67	75.6	1.9	2.5
10HEN07a_AP3	0.2409	54	64.4	120.6	285.3	92.8	7.74	15.6	0.72	21.6	0.55	2.6
10HEN07a_AP4	0.2823	53	8.2	21.9	93.6	13.3	0.92	12.8	0.72	17.8	0.53	3.0
10HEN07a_AP5	0.1827	47	11.5	23.8	401.2	17.1	1.40	15.0	0.68	21.8	0.71	3.3
10HEN07a_AP6	0.1458	43	27.4	70.6	147.5	44.0	5.40	22.9	0.66	34.8	0.84	2.4
10HEN24a_AP1	0.0705	38	8.3	32.7	125.2	16.0	1.75	20.2	0.61	32.9	0.97	3.0
10HEN24a_AP2	0.5696	63	15.8	96.1	355.8	38.4	5.30	25.4	0.75	33.7	0.76	2.2
10HEN24a_ap3	0.1119	37	6.8	79.3	374.9	25.5	4.65	33.2	0.59	55.8	2.6	4.7
10HEN24a_ap4	0.5832	64	8.0	44.1	201.0	18.4	1.51	15.1	0.76	19.9	0.68	3.4
10HEN24a_ap5	0.0642	34	11.8	22.4	228.9	17.1	1.25	13.5	0.58	23.0	5.2	22.7
10HEN24a_AP6	0.1017	36	5.4	22.9	58.7	10.8	1.13	19.3	0.59	32.5	1.1	3.3

* R_s = crystal effective spherical radius, F_T = alpha ejection correction