

1 **Did incision of the Three Gorges begin in the Eocene?**

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15

16 **Abstract**

17 Like the other large river systems that drain the India-Asia collision, the Yangtze River was
18 assembled through a series of Cenozoic capture events. These events are important for
19 orogenic erosion and sediment delivery, but their timing remains largely unknown. Here we
20 identify enhanced cooling in the Three Gorges region in central China, a key capture site
21 during basin development, beginning at 40-45 Ma. This event is not visible in regional
22 thermochronological data but is near-contemporaneous with the onset of widespread
23 denudation in the Sichuan Basin, just upstream of the Three Gorges. While we cannot rule out
24 alternative explanations, the simplest mechanism that links these events is progressive capture

25 of the middle Yangtze River by the lower Yangtze and the onset of incision in the Three
26 Gorges. This model agrees with independent mid-Cenozoic estimates for the timing of middle
27 Yangtze River diversion and capture, and provides a plausible outlet for large volumes of
28 erosional detritus from the Sichuan Basin.

29

30 **Keywords:** Yangtze River, low-temperature thermochronology, Three Gorges, fluvial incision

31

32 **Introduction**

33 The India-Asia collision zone is drained by large river systems that convey enormous
34 sediment loads to the Asian marginal seas (Métivier et al., 1999; Clift et al., 2004). It has long
35 been argued that these rivers have grown in part by large-scale capture events (Brookfield,
36 1998), such as diversion of Punjab drainage from the Ganges to the Indus (Clift and
37 Blusztajn, 2005) and diversion of the upper and middle Yangtze away from the Red River
38 (Clark et al., 2004; Clift et al., 2004). Such events have major effects on patterns of erosion
39 and sediment dispersal, but their recognition onshore is often hampered by later erosion or the
40 lack of datable sedimentary deposits. Offshore sedimentary basins can record the timing of
41 large-scale drainage diversion, but their utility may be limited by incomplete data or onshore
42 storage (Clift et al., 2004; Clift, 2006).

43

44 Here, we use low-temperature thermochronology to infer the timing of Yangtze River
45 evolution in the Three Gorges region of central China (Fig. 1). Several lines of evidence have
46 been used to argue that the Yangtze grew by the amalgamation of several smaller rivers,
47 beginning with the progressive capture of the southwest-flowing middle Yangtze River by the
48 east-flowing lower Yangtze River at the Three Gorges (Barbour, 1936; Clark et al., 2004;
49 Clift et al., 2006) (Fig. 1). This capture led to integration of the Sichuan Basin into the lower
50 Yangtze system. While the presence of barbed tributaries and tilted terraces has been used to
51 argue that the middle Yangtze reversed course to flow east through the Three Gorges at some
52 point in the Cenozoic (Clark et al., 2004), there is no direct onshore evidence of the timing of
53 capture, and offshore records are obscured by sediment storage in the lower Yangtze basin
54 (Clift, 2006; Chappell et al., 2006). Prior work has suggested a Pleistocene age for the Three
55 Gorges (e.g., Li et al., 2001; Yang et al., 2006), but these studies generally yield minimum

56 estimates based on the age or provenance of young (post-Pliocene) rocks, and are thus unable
57 to rule out older events.

58

59 An indirect clue to the timing of middle Yangtze capture was provided by Richardson et al.
60 (2008), who argued for widespread erosion of 1.5 to 4 km across the Sichuan Basin beginning
61 at about 40 Ma. This erosion marked the end of sustained Triassic-Eocene(?) clastic
62 sedimentation in the basin (Burchfiel et al., 1995), and Richardson et al. (2008) proposed that
63 erosion was driven by linkage of the middle and lower Yangtze rivers and establishment of an
64 outlet at the Three Gorges, through which sediment could be removed. Capture of the middle
65 Yangtze would have resulted in a large increase in drainage area of the lower Yangtze,
66 leading to rapid incision in the Three Gorges area and localized cooling of the upper crust.
67 The timing of this cooling is thus a test of the link between Yangtze River evolution and
68 erosion in the Sichuan Basin. If cooling rates in the gorge increased at or just before 40 Ma,
69 and if the Three Gorges area underwent a cooling event that did not extend more regionally,
70 then it is plausible to suggest a causal relationship between erosion within the Sichuan Basin,
71 the capture of the middle Yangtze River, and the inception of the Three Gorges.

72

73 **Study Area**

74 The Three Gorges region, with up to 3 km of relief, separates the low-elevation, low-relief
75 areas of eastern China and the Sichuan Basin (Fig. 1). While most of the area is underlain by
76 Paleozoic and Mesozoic carbonate rocks (Ma et al., 2002), the Yangtze River transects the
77 Huangling anticline at the eastern margin of the gorges (Fig. 2) and exposes approximately
78 two vertical kilometers of the Proterozoic Huangling Granite massif (Li et al., 2002; Ling et
79 al., 2006). Folding of the anticline occurred before Early Cretaceous time, because Lower

80 Cretaceous Shimen Formation rocks are draped unconformably on both flanks of the
81 anticline, with dips of 5-15° (Fig. 2).

82

83 We use apatite (U-Th)/He (AHe) and fission-track (AFT) techniques to constrain the low
84 temperature (<100°C) thermal history of the Huangling Granite near Sandouping, site of the
85 Three Gorges Dam (see Data Repository for analytical details). Samples were obtained along
86 a pseudo-vertical transect from altitudes of 190 m to 1923 m within 27 km of the Yangtze
87 River. The AFT and AHe ages are sensitive to the time at which the samples passed through
88 temperatures as low as 45°C depending on cooling rates, grain size and other factors such as
89 radiation damage (Reiners and Brandon, 2006; Shuster et al., 2006). The topography in the
90 area precludes a true vertical profile, and we discuss the implications of this below.

91

92 **Results**

93 Mean AHe single-grain ages (Fitzgerald et al., 2006) range from 46 ± 16 Ma (2σ) for sample
94 H1 at the base of the section (190 m) to 45 ± 12 Ma for sample H4 (Table DR1), which marks
95 a break in slope in the age-elevation relationship at 1350 m (Fig. 2). Samples above this break
96 in slope yield older single-grain ages. The exception to this pattern is sample H3, which yields
97 widely scattered ages; the reasons for this are not clear but may involve the presence of
98 microscopically undetectable zircon or other U-bearing inclusions.

99

100 The AFT samples (Table DR2) yield scattered central ages ranging from 86 ± 10 Ma (2σ) to
101 133 ± 11 Ma, and show no systematic variation with elevation (Fig. 2). To explore the AFT
102 results in more detail, thermal forward modelling of apparent ages and horizontal confined
103 fission-track lengths were undertaken using the HeFTY software (Ketcham, 2005), including

104 Dpar measurements (Donelick, 1993) as a proxy for chemistry. The modelling was completed
105 without the AHe data, to avoid forcing the sample time-temperature paths through the AHe
106 ages. The lowermost sample (H1, Fig. 3) remained in the AFT partial annealing zone (APAZ)
107 at $T \sim 70^{\circ}\text{C}$ until the onset of more rapid cooling ($1\text{-}2^{\circ}\text{C}/\text{Myr}$) at about 40 Ma. At higher
108 elevations, samples H1.5, H3, and H5 record broadly similar, monotonic post-Cretaceous
109 cooling paths which permit, but do not require, a comparable acceleration in cooling rate at
110 $\sim 40\text{-}45$ Ma. The highest sample, H6, was already at temperatures of $< 60^{\circ}\text{C}$ by 40 Ma (Fig.
111 3), and thus lies outside the temperature range at which the model results can be confidently
112 interpreted. All samples spent prolonged periods in the APAZ.

113

114 **Discussion and Conclusions**

115 What is the expected thermochronologic signature of gorge incision, and how can we
116 differentiate this from regional exhumation? We suggest two potential signatures: (1) more
117 rapid cooling of the lower samples relative to those at higher elevations, indicating an
118 increase in relief (Braun, 2002; Schildgen et al., 2007), or (2) a cooling event which involved
119 all samples (and thus no increase in local relief), but which is not observed outside the gorge
120 area. It is tempting to interpret the steep AHe age-elevation relationship below 1350 m (Fig.
121 2) as evidence for rapid cooling of the lower samples at 40-45 Ma. We can only tentatively
122 exploit this relationship, however, because of the large horizontal span of our transect (27
123 km). The admittance ratio α , the ratio of relief on the AHe closure isotherm to topographic
124 relief, is ~ 0.7 (Braun, 2002; Reiners et al., 2003), implying that the slope of the AHe age-
125 elevation relationship is greater than the likely exhumation rate by at least a factor of three.
126 Prolonged residence in the APAZ most likely accounts for the large scatter in fission-track

127 age, and we infer that there has been insufficient cooling to expose the base of the APAZ and
128 yield an unambiguous AFT age-elevation relationship.

129

130 One indication of gorge incision after 45 Ma is that AFT sample H1 has cooled by 50°C,
131 whereas sample H6 has cooled by only 5-40°C, since that time (Fig. 3). implying differential
132 cooling of 10-45°C. Present-day geothermal gradients in the region range from ~15°C km⁻¹ at
133 the western margin of the Gorges (Xie and Yu, 1988) to 23-40°C km⁻¹ in the extensional
134 Jiangnan Basin to the east (Xie et al., 1988). Using an average value of 20°C km⁻¹, this
135 implies differential exhumation of the lower samples by 0.5 to 2.3 km since 45 Ma.

136 Compression of isotherms beneath the gorge could increase the local geothermal gradient by
137 ~20% (Stüwe et al., 1994), decreasing these estimates to ~0.2 to 2.0 km. Thus, while we
138 cannot entirely rule out uniform cooling on this basis, it is likely that the lower samples record
139 some degree of differential incision.

140

141 A second argument in support of gorge incision comes from thermal modelling of the AHe
142 data. Following Reiners et al. (2003), we calculate the depth to the closure isotherm for each
143 AHe sample using 1d numerical models (Brandon et al., 1998). Total exhumation of each
144 sample is the model closure depth plus the difference between sample elevation and elevation
145 smoothed over a 10 km circle, to account for bending of near-surface isotherms. Model
146 exhumation rate is then the total exhumation divided by the sample age. Again assuming a
147 geothermal gradient of 20°C km⁻¹, model closure temperatures are 46-51°C, and model
148 exhumation rates are 13 to 39 m Myr⁻¹. The highest rates are limited to samples at or below
149 1350 m (H1, H2, and H4), while rates for the upper samples are lower by a factor of ~2-3,
150 again consistent with greater differential incision of the lowermost samples. Total model

151 exhumation of sample H6 is 1.7 km, meaning that gorge incision most likely began in the
152 Precambrian-Paleozoic sedimentary cover overlying the Huangling Granite.

153

154 In summary, our AFT forward models are consistent with a moderate increase in exhumation
155 rate at 45-40 Ma, although only sample H1 actually requires this increase, and both AFT and
156 AHe data support more rapid cooling of the lower samples in the transect. If this cooling
157 event occurred, how widespread was it? Reiners et al. (2003) concluded that the Dabie Shan,
158 east of the Three Gorges (Fig. 1), underwent slow exhumation throughout the Cenozoic, with
159 no increase in rates after 60 Ma. AFT samples from the eastern Qinling Shan, to the north of
160 the study area, likewise show slow cooling since at least 70-100 Ma (Enkelmann et al. 2006),
161 with no indication of more rapid cooling during the Cenozoic. Finally, Hu et al. (2006)
162 reported AHe and AFT ages and AHe model exhumation rates that are comparable to ours
163 (Fig. 2). Their samples from the southern Qinling Shan and northern Huangling areas cooled
164 show no evidence for enhanced cooling rates after 60 Ma (Hu et al. 2006). In contrast, their
165 sample QL-34 (Fig. 1) records a very similar cooling history to H1: prolonged residence at
166 $\sim 70^{\circ}\text{C}$, followed by an increase in cooling rate (to $1\text{-}5^{\circ}\text{C Myr}^{-1}$) at ~ 40 Ma. Hu et al. (2006)
167 cited the sample's proximity to the Yangtze River but gave no reasons for its anomalous
168 behavior. Enhanced cooling at 45-40 Ma thus appears to be limited to the area near the
169 Yangtze River, and there is no evidence for a regional cooling event at this time.

170

171 If differential incision in the Three Gorges occurred, and was unrelated to regional cooling
172 events, how can that be linked to the development of a through-going Yangtze River? The
173 fact that gorge incision is effectively synchronous with the onset of erosion across the
174 Sichuan Basin at ~ 40 Ma (Richardson et al., 2008) supports a causal link, and we argue that

175 capture of the middle Yangtze and Sichuan Basin by the lower Yangtze is the simplest
176 mechanism that can account for near-simultaneous gorge incision and large-scale basin
177 denudation (Fig. 4). Progressive capture would have generated increased discharge in the
178 lower Yangtze as the capture site migrated upstream (Fig. 4), leading to locally increased
179 exhumation rates in the gorge area. This migration (e.g., Clark et al., 2004) would have
180 lowered base level in the Sichuan Basin, leading to extensive regional denudation, and would
181 also have provided an outlet for the removal of erosional detritus. The inferred timing of
182 gorge incision is broadly consistent with existing constraints on middle Yangtze capture –
183 before 24 Ma based on isotopic data in the Gulf of Tonkin (Clift et al., 2006), or before Oligo-
184 Miocene time based on structural interpretations (Clark et al., 2004).

185

186 We cannot rule out cooling mechanisms in the Three Gorges that were coeval with, but
187 unrelated to, erosion in the Sichuan Basin, although given the proximity of the two areas these
188 would require a degree of serendipity. For example, it is possible that samples H1 and QL-34
189 were perturbed by a local thermal event or by pre-existing, short-wavelength topography
190 which we are unable to resolve. There is also poorly-documented evidence of late Eocene
191 normal faulting in the Jiangnan Basin (Ulmishek, 1992), which could have triggered local
192 footwall erosion and more rapid cooling of the Huangling Granite. This faulting does not
193 explain the near-simultaneous onset of erosion in the Sichuan Basin, however, and does not
194 necessarily exclude gorge incision; in fact, fault activity may well have steepened the lower
195 Yangtze River and enhanced its capacity to incise headward, thus aiding capture. In any case,
196 our results provide the first indication that incision of the Three Gorges may have occurred as
197 early as the Eocene, consistent with independent estimates of middle Yangtze capture, and

198 that this incision provided a plausible outlet for the progressive removal of large volumes of
199 sediment from the Sichuan Basin.

200

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208

209 **References**

- 210 Barbour, G. B., 1936, Physiographic history of the Yangtze: *Geogr. J.*, v. 87, p. 17-34.
- 211 Brandon, M.T., Roden-Tice, M.K., and Garver, J.I., 1998, Late Cenozoic exhumation of the
212 Cascadia accretionary wedge in the Olympic Mountains, Northwest Washington State:
213 *Geol. Soc. Am. Bull.*, v. 110, p. 985-1009.
- 214 Braun, J., 2002, Quantifying the effect of recent relief changes on age-elevation relationships:
215 *Earth Plan. Sci. Lett.*, v. 200, p. 331-343.
- 216 Brookfield, M.E., 1998, The evolution of the great river systems of southern Asia during the
217 Cenozoic India-Asia collision: rivers draining southwards: *Geomorphology*, v. 22, p.
218 285-312.
- 219 Burchfiel, B.C., Chen, Z., Liu, Y., and Royden, L.H., 1995, Tectonics of the Longmen Shan
220 and adjacent regions: *Int. Geol. Rev.*, v. 37, p. 661-735.

221 Chappell, J., Zheng, H., and Fifield, K., 2006, Yangtse River sediments and erosion rates
222 from source to sink traced with cosmogenic ¹⁰Be: sediments from major rivers:
223 Palaeogeog. Palaeoclim. Palaeoecol. v. 241, p. 79-94.

224 Clark, M.K., Schoenbohm, L.M., Royden, L.H., Whipple, K.X., Burchfiel, B.C., Zhang, X.,
225 Tang, W., Wang, E., and Chen, L., 2004, Surface uplift, tectonics, and erosion of Eastern
226 Tibet from large-scale drainage patterns: Tectonics, v. 23, TC1006,
227 doi:10.1029/2002TC001402.

228 Clift, P.D., 2006, Controls on the erosion of Cenozoic Asia and the flux of clastic sediment to
229 the ocean: Earth and Planetary Science Letters, v. 241, p. 571-580.

230 Clift, P.D., Layne, G.D., and Blusztajn, J., 2004, Marine sedimentary evidence for monsoon
231 strengthening, Tibetan uplift and drainage evolution in East Asia, *in* Clift, P., Wang,
232 P.X., Kuhnt, W., and Hayes, D., eds., Continent-ocean interactions within East Asian
233 marginal seas: Amer. Geophys. Union Geophys. Mono. 149, p. 255-282.

234 Clift, P.D., and Blusztajn, J., 2005, Reorganization of the western Himalayan river system
235 after five million years ago: Nature, v. 438, doi:10.1038/nature04379.

236 Clift, P.D., Blusztajn, J., and Nguyen, A.D., 2006, Large-scale drainage capture and surface
237 uplift in eastern Tibet-SW China before 24 Ma inferred from sediments of the Hanoi
238 Basin, Vietnam: Geophys. Res. Lett., v. 33, L19403, doi:10.1029/2006GL027772.

239 Donelick, R.A., 1993, Apatite etching characteristics versus chemical *composition*: Nuclear
240 Tracks Rad. Meas., v. 21, p. 604.

241 Enkelmann, E., Ratschbacher, L., Jonckheere, R., Nestler, R., Fleischer, M., Gloaguen, R.,
242 Hacker, B.R., Zhang, Y., and Ma, Y., 2006, Cenozoic exhumation and deformation of
243 northeastern Tibet and the Qinling: is Tibetan lower crustal flow diverging around the
244 Sichuan Basin? Geol. Soc. Am. Bull., v. 118, p. 651-671.

245 Fitzgerald, P.G., Baldwin, S.L., Webb, L.E., and O'Sullivan, P.B., 2006, Interpretation of (U–
246 Th)/He single grain ages from slowly cooled crustal terranes: a case study from the
247 Transantarctic Mountains of southern Victoria Land: *Chem. Geol.*, v. 225, p. 91-120.

248 Hu, S., Raza, A., Min, K., Kohn, B.P., Reiners, P.W., Ketcham, R.A., Wang, J., and Gleadow,
249 A.J.W., 2006, Late Mesozoic and Cenozoic thermotectonic evolution along a transect
250 from the north China craton through the Qinling orogen into the Yangtze craton, central
251 China: *Tectonics*, v. 25, TC6009, doi:10.1029/2006TC001985.

252 Ketcham, R.A., 2005, Forward and inverse modeling of low-temperature thermochronometry
253 data, *in* Reiners, P.W. & Ehlers, T.A., eds., *Low-temperature thermochronology:*
254 *techniques, interpretations, and applications: Min. Soc. Am. Rev. Mineral. Geochem.*, v.
255 58, p. 275-314.

256 Li, J., Xie, S., and Kuang, M., 2001, Geomorphic evolution of the Yangtze Gorges and the
257 time of their formation: *Geomorphology*, v. 41, p. 125-135.

258 Li, Z., Wang, G., and Zhang, Z., 2002, Isotopic age spectrum of the Huangling granitic
259 batholith, western Hubei: *Geol. Min. Resour. South China*, v. 3, p. 19-28.

260 Ling, W.L., Gao, S., Cheng, J.P., Jiang, L.S., Yuan, H.L., and Hu, Z.C., 2006, Neoproterozoic
261 magmatic events within the Yangtze continental interior and along its northern margin
262 and their tectonic implication: constraint from the ELA-ICPMS U-Pb geochronology of
263 zircons from the Huangling and Hannan complexes: *Acta Petrologica Sinica*, v. 22, p.
264 387-396.

265 Ma, L., Qiao, X., Min, L., Fan, B., Ding, X., and Liu, N., 2002, *Geological Atlas of China:*
266 *Geological Publishing House, Beijing.*

267 Métivier, F., Gaudemer, Y., Tapponnier, P., and Klein, M., 1999, Mass accumulation rates in
268 Asia during the Cenozoic: *Geophys. J. Int.*, v. 137, p. 280-318.

269 Reiners, P.W., Zhou, Z., Ehlers, T.A., Xu, C., Brandon, M.T., Donelick, R.A., and Nicolescu,
270 S., 2003, Post-orogenic evolution of the Dabie Shan, eastern China, from (U-Th)/He and
271 fission-track thermochronology: *Am. J. Sci.*, v. 303, p. 489-518.

272 Reiners, P.W., and Brandon, M.T., 2006, Using thermochronology to understand orogenic
273 erosion: *Ann. Rev. Earth Planet. Sci.*, v. 34, p. 419-466.

274 Richardson, N.J., Densmore, A.L., Seward, D., Wipf, M., Li, Y., Ellis, M.A., and Zhang, Y.,
275 2008, Extraordinary denudation in the Sichuan Basin: insights from low-temperature
276 thermochronology adjacent to the eastern margin of the Tibetan Plateau: *J. Geophys.*
277 *Res.*, v. 112, doi:10.1029/2006JB004739.

278 Schildgen, T.F., Hodges, K.V., Whipple, K.X., Reiners, P.W., and Pringle, M.S., 2007, Uplift
279 of the western margin of the Andean plateau revealed from canyon incision history,
280 southern Peru: *Geology*, v. 35, p. 523-526.

281 Shuster, D.L., Flowers, R.M., and Farley, K.A., 2006, The influence of natural radiation
282 damage on helium diffusion kinetics in apatite: *Earth Plan. Sci. Lett.*, v. 249, p. 148–161.

283 Stüwe, K., White, L., and Brown, R., 1994, The influence of eroding topography on steady-
284 state isotherms: application to fission track analysis: *Earth Plan. Sci. Lett.*, v. 124, p. 63-
285 74.

286 Ulmishek, G.F., 1992, Geology and hydrocarbon resources of onshore basins in eastern
287 China: U.S. Geol. Surv. Open-File Report 93-4, 150 p.

288 Xie, X., and Yu, H., 1988, Geothermal character of Sichuan Basin (in Chinese): *J. Chengdu*
289 *Coll. Geol.*, v. 15, p. 107-112.

290 Xie, T., Wu, L., and Jiang, J., 1988, Oil and gas fields in the Jiangnan Basin, Hubei Province,
291 China, *in* Wagner, H.C., Wagner, L.C., Wang, F.F.H. & Wong, F.L., eds., *Petroleum*

292 Resources of China and Related Subjects: Circum-Pacific Council for Energy and
293 Mineral Resources Earth Science Series, v. 10, p. 345-358.
294 Yang, S., Li, C., and Yokoyama, K., 2006, Elemental compositions and monazite age patterns
295 of core sediments in the Changjiang Delta: implications for sediment provenance and
296 development history of the Changjiang River: Earth Plan. Sci. Lett., v. 245, p. 762-776.

297

298 **Figure Captions**

299 Fig. 1. A, location map showing upper, middle, and lower reaches of the Yangtze River
300 (separated by dashed lines). Box shows Three Gorges study area. B, geological map of the
301 eastern end of the Three Gorges (modified from Ma *et al.* 2002). Samples H1 to H6 from this
302 study are marked with stars, while those from Hu et al. (2006) that fall within our transect are
303 marked with circles. HGr, Huangling Granite and related intrusive rocks; pC, Precambrian;
304 Pz, Palaeozoic; TJ, Triassic-Jurassic; K, Cretaceous.

305

306 Fig. 2. Age-elevation relationships for apatite (U-Th)/He (AHe) and fission track (AFT)
307 samples from the Huangling Granite. White symbols mark samples from this study, grey
308 symbols mark those from Hu et al. (2006). All age errors (x-axis) are ± 2 s.d.; all elevation
309 errors (y-axis) are ± 50 meters.

310

311 Fig. 3. Results of AFT thermal modelling, derived from HeFTy model (Ketcham, 2005).
312 Light grey regions show 95% confidence envelopes on the temperature-time path, defined by
313 the Kolmogorov-Smirnov test applied to the track length distribution; dark grey regions show
314 50% confidence envelopes. Grey bar on each plot indicates the time period 45-40 Ma for

315 reference. Single-crystal AHe ages are plotted as circles at a model closure temperature of
316 50°C.

317

318 Fig. 4. Proposed model of Three Gorges incision and Yangtze River evolution. A, prior to
319 ~45 Ma the Sichuan Basin was isolated from the proto-lower Yangtze River. Location of
320 eastern Tibetan Plateau is shown for reference; our data do not constrain the timing of plateau
321 growth. B, gorge incision beginning at ~45 Ma (shown by Vs) and progressive capture of the
322 middle Yangtze River lowered base level and drove rapid erosion in the Sichuan Basin. C, by
323 ~35 Ma erosion had propagated headwards across the Sichuan Basin.

Figure 1
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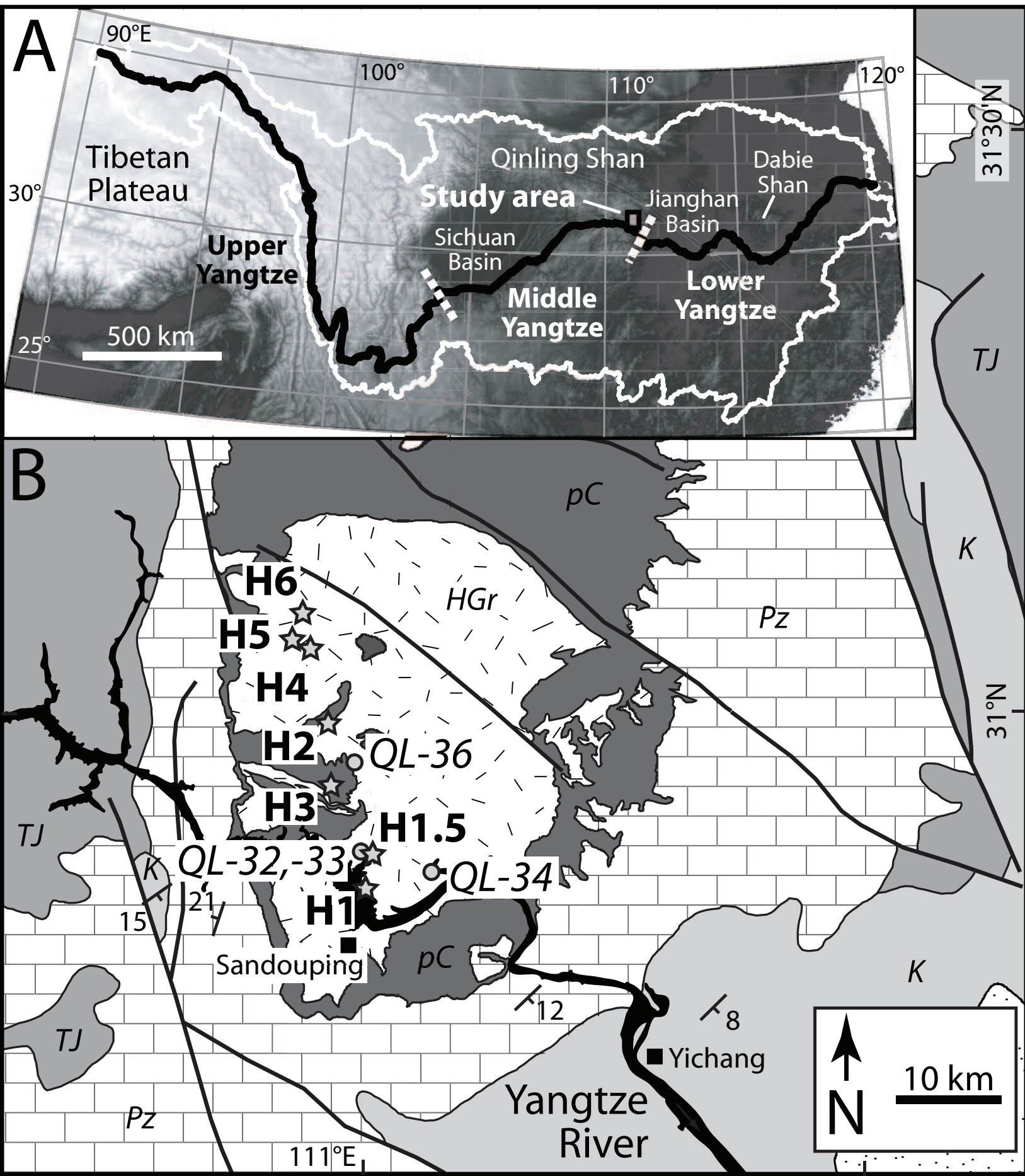


Figure 2
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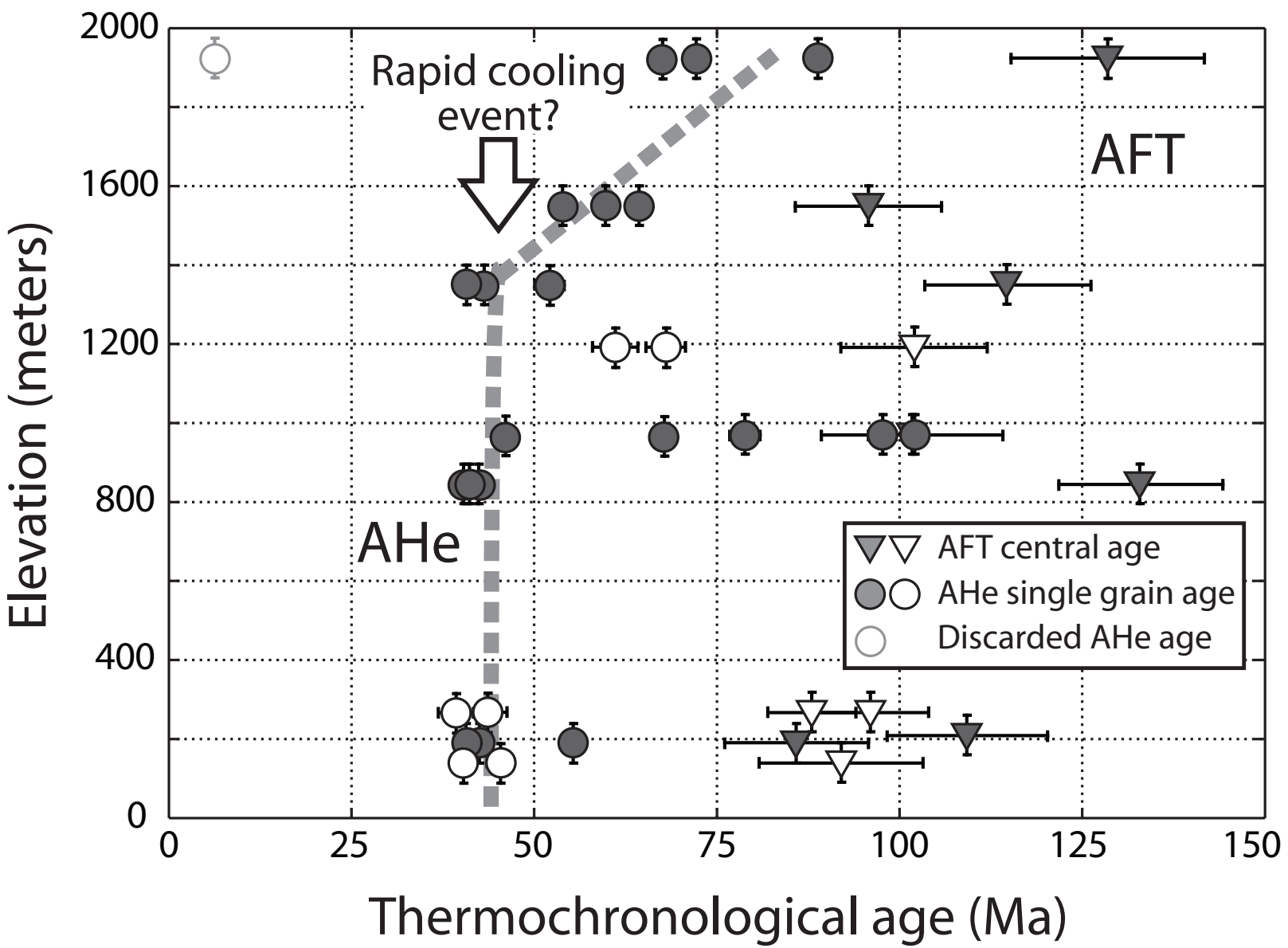
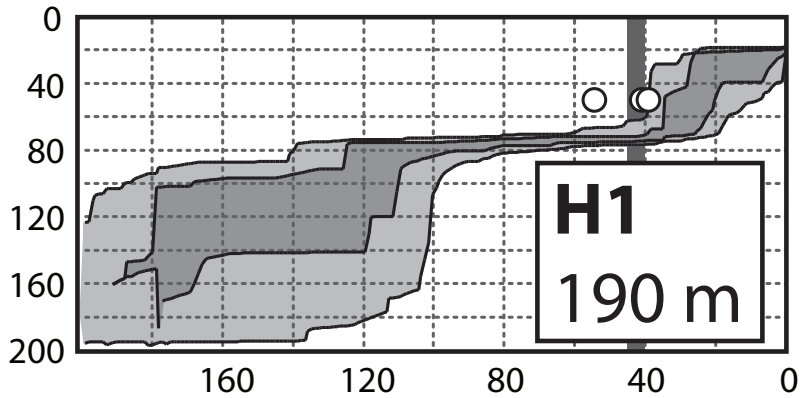
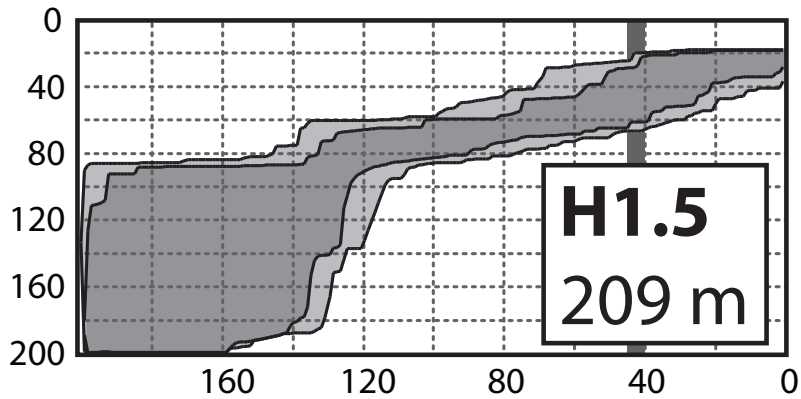
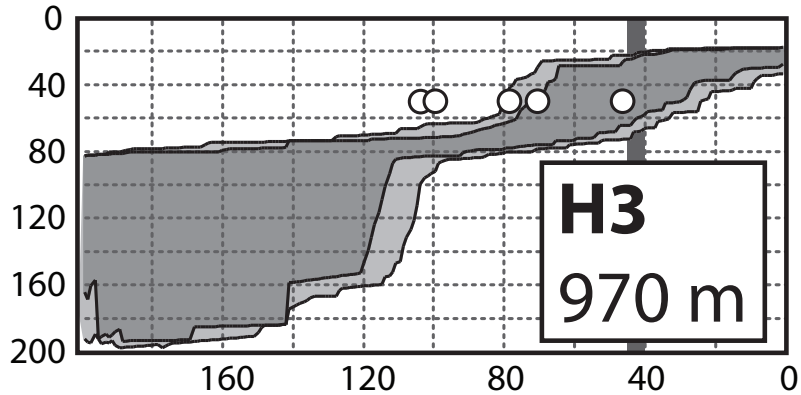
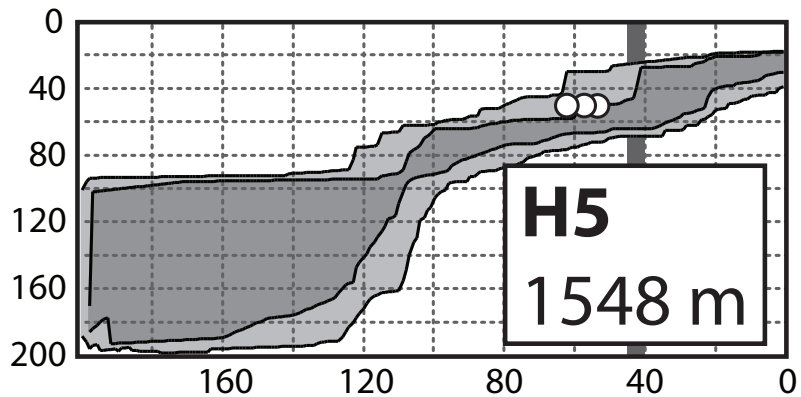
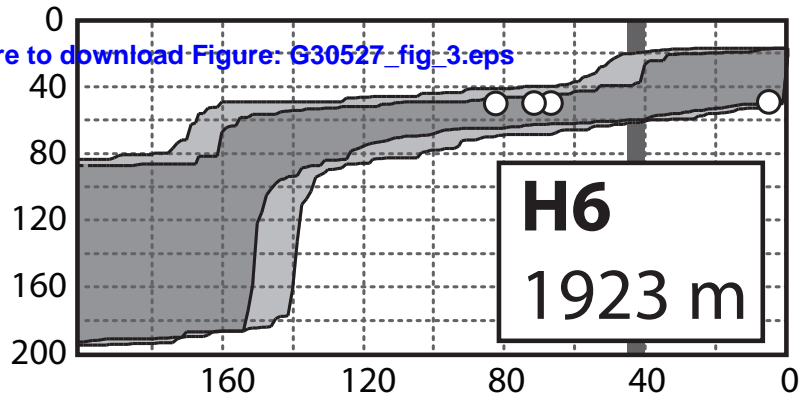


Figure 3

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Temperature (°C)



Time before present (Myr)

Figure 4
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