Sandy Creek gorge; humans, palaeofloods & landscape evolution

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Three themes are treated here under the headings:

1) Humans—stuff from the bottom drawer that will probably never see the light of day again;

2) Palaeoflood history and bedrock channel processes—published research[2,3] of which the briefest overview is given here (pdf copies available at http://www.ges.gla.ac.uk/staff/jjansen); and

3) Landscape evolution; bedrock erosion rates from cosmogenic nuclides—new unpublished research on long-term bedrock erosion rates measured with cosmogenic nuclides.

1. Humans

A large number of petroglyphs, some grinding slabs and a few fire-hearths suggest something, not a lot, about the people living in the *Wa Ya Boorla* area later known as Fowlers Gap. The earliest human evidence dates to >10 ky[4], and eight ^{14}C-dated hearths in Sandy Creek gorge yield ages spanning 3610–470 cal. BP[5], consistent with the idea that occupation intensified over the past 2.0–1.5 ky[6]. Sandy Creek gorge is the possible site of a dreaming track linked to the *two gnatji cycle*[7], and petroglyph figurative styles show close affinity with those in the Flinders Ranges 300 km to the west. The first European to visit the Barrier Range, Charles Sturt[8], in 1844 observed deliberate large-scale burning; however, virtually nothing is known of how Aboriginal people interacted with the landscape[6]. Within a decade of pastoral expansion into this area in the 1860s, Aboriginal people were subjugated and Europeans had appropriated the most valuable and productive country[9].

Much better known are the impacts of European pastoralism, involving huge numbers of non-native herbivores, mainly sheep and cattle, followed by ferals (rabbits, foxes and goats), with disastrous consequences. What follows are just a few snippets; details are given elsewhere[5]. The rock-holes along Sandy Creek gorge hold long-standing water, and were probably important in the early nomadic days of pastoralism before the widespread excavation of wells[10]. For example, in early 1872 the Wallaces[11] camped for 2 months with 13,000 sheep on a rapidly drying Lake Bancannia, shifted to Cobham Lake for 6 weeks, and then with 18,000 sheep, camped for 3 months at Packsaddle Creek. The Sandy Creek rock-holes were probably visited on the return journey to Sturts Meadows. With an effective grazing range of ~3 km from water, such numbers represent >600 sheep/km^2. Although visits to the gorge would have been episodic, the extreme stock densities are certain to have caused heavy damage to riparian vegetation. The establishment of wells in the 1870s alleviated the pressure on surface waters, but created the need for fencing and therefore destruction of large numbers of *Acacia aneura* (mulga) trees. A 1908 pastoral map of the Sandy Creek catchment[5] indicates 15.4 km of fenceline comprising 3962 posts and 254 droppers, which equates to ~4089 trees cut from an area of 30 km^2 (136 trees/km^2). When Europeans arrived the hills likely supported a tall open shrubland of *A. aneura–A. tetragonophylla–Casuarina pauper*[12]. Of what remains at Fowlers Gap a century later, 25–95% of the mulga is dead and many of the remaining trees are senescent[13].

Further historical accounts exist for the pastoral holding *Corona Run*, which included Fowlers Gap until 1949. A representative sample is from a Corona manager[14] describing conditions barely a decade after the first established grazing on the Barrier Range:

> *This year* [1883] *was a most trying and deplorable one, sheep dying in their hundreds in the yards during shearing. About the paddocks after shearing those that survived being just living skeletons. Between May and October only 1 inch of rain fell thus completing the havoc the previous year had started. I soon became aware that the paddocks were considerably overstocked and that the country now was fast depreciating the salt bush being killed over the greater portion of the paddocks and they have never since recovered.*

By the following year (1884), 30% of the stock lay dead in the paddocks[14]:

> *The season got worse and worse ... I had to resort to cutting scrub to keep the sheep alive ... Large parties of men were employed cutting down the trees and scrub in each paddock. My losses during this time were 23 644 sheep. The remainder were just walking skeletons. Men were also employed at the watering places in clearing the sheep as they died. The aspect of the country was something deplorable not a vestige of anything to be seen... A contractor who was making an addition to the woolshed had to keep his horses alive by baking bread for them.*

Tragically, rabbits arrived at Corona in the following year of 1885, and by October 1886, ten men were employed killing 1000 rabbits per month, yet still they were increasing to plague proportions[14]. By 1895, up to 90,000 rabbits were being poisoned per month on the adjoining Poolamacca Station[15]. A devastating drought hastened the inevitable collapse of the NSW pastoral industry at the turn of the 19th century. Stock numbers fell by ~70% between 1893 and 1902, and the environmental and economic collapse instigated a Royal Commission inquiry[16]:

> *That the story of our western country makes such a gloomy page in the history of the pastoral industry of the State is probably due to the general failure in the past of those interested—under the seductive influence of a short run of good seasons—to recognise that drought is the predominant characteristic of the west, and not merely an enemy to be occasionally encountered*.

According to a 1948 study[17]: *The area of country destroyed by erosion in the Barrier Ranges is far greater than in any other part of the* [NSW] *Western Division*. The consequences for the biological productivity of the rangelands are not easily quantified, but the most obvious shift has been the decline and replacement of perennial, long-lived trees and chenopods with annual and ephemeral shrubs and herbage[17,18]. At Umberumberka (110 km SW) a comparison of the sedimentation rate in a reservoir with that on the alluvial fan downstream indicate that sedimentation rates post-1915 increased by a factor of 50–90 over the preceding 3000 years[19]. This magnitude of change may be representative, to first-order, of sediment flux shifts in the Barrier Range since the arrival of Europeans[20]. In the Fowlers Gap area, fine-grained post-European sediments are generally indicated by their intact sedimentary structures in contrast to older basal materials, which tend to be strongly bioturbated (Fig. 1). Small volumes of post-European sediment are preserved within channel-scale units in Sandy Creek gorge. The main depositional record lies in the piedmont and floodout zones. Analyses of air photos back to 1954 indicate significant localized channel expansion in the piedmont zone, with loss of several metres of concave bank along extensive lengths of channel that today stand with unstable vertical faces[5].

2. Palaeoflood history & bedrock channel processes

Two papers[2,3] give the full story of what is summarised here. Sandy Creek drains 44 km^2 of the northern Barrier Range, 100 km N of Broken Hill. The gorge cuts transverse to steep Devonian quartzite/sandstone cuestas ridges, with summits 100–200 m above the piedmont and alluvial plains. The gorge floor comprises a sequence of pools at bedrock outcrops interspersed by coarse boulder riffles, or expansion bars. Alluvial bed cover is generally <1 m thick and bedrock is widely exposed. Excavations into channel-scale sedimentary units (1.5–3 m thick) at pools reveal a cut-fill sequence of muddy and gravelly units with a consistent morphology and stacking order in response to floods. Based on morphology, sedimentology and ^{14}C dating of these *pool-fills* a late Holocene palaeoflood history is proposed[2].

Increased sediment load since pastoralism has altered pool-fill sedimentation, but the 100-y flood in December 1992 had remarkably little effect on coarse boulder riffles. To determine the magnitude of geomorphically-effective floods, the HEC-RAS flow model was used in conjunction with boulder transport equations to simulate flow conditions generated by the bankfull flood, the 1992 flood, plus two much larger floods determined from field evidence (see Fig. 3). The modelling results indicate that sediment transport and storage is governed by stage-dependent contrasts in stream power linked to competence-reversal along the riffle-pool sequence. By mobilising the boulder cover and eroding the underlying bedrock, high-magnitude floods determine gorge morphology. Such floods have recurrence intervals of several centuries; the most recent major formative flood occurred ~300 cal BP, and a *superflood*, or series of large floods, flushed-out much of the alluvium ~3390–1710 cal BP[3].

3. Landscape evolution; bedrock erosion rates from cosmogenic nuclides

The stepped topography in the Barrier Range has prompted various interpretations of landscape evolution going back to Mawson[21-25]. In the Fowlers Gap area, recent debate has revolved around three issues: i) the age and distribution of Cretaceous rocks exposed along the eastern rangefront[26-28]; ii) the interpretation of duricrust residuals[5,27-30]; and iii) the relative importance of tectonics versus lithology for relief development[5,27-30]. As outlined above, gorge bedrock incision is a function of interactions between lithology and the hydraulics of large, rare floods. Terrestrial in situ cosmogenic nuclides offer a means of quantifying bedrock erosion rates over timescales of 10^3–10^5 y (for an overview[31]), and here we present preliminary (^{10}Be) results and interpretations of analyses on bedrock surfaces in the gorge.

Where Sandy Creek gorge meets the eastern rangefront, the Devonian rocks indicate monoclinal flexing probably linked to a basement fault whose movements drive the long-term incision of the gorge[5,28]. Two strath terraces indicate former levels of the gorge floor created during discontinuous down-cutting (Fig. 2). The *High terrace* is best preserved close to the rangefront where it stands ~20 m above the channel bed; fragments of this terrace grade smoothly to the perched valley upstream of the gorge. The *Low terrace* stands ~3–6 m above the channel, and is associated with a knickpoint that has propagated about mid-way through the gorge (Fig. 2). Samples for cosmogenic analysis were collected from bare bedrock surfaces on both terraces at four transects shown in Figs 2 and 3, and the results are summarised in Table 1.

The bedrock surfaces are assumed to have formed via fluvial erosion as the bedrock channel progressively lowered its bed, thereby abandoning first the *High Terrace* and then the *Low Terrace* more recently. The ^{10}Be concentrations (Table 1) can be interpreted as either i) steady state maximum erosion rates, or ii) surface exposure ages. The first case assumes that the bedrock surface has been subject to an ongoing steady rate of erosion for a length of time sufficient to incrementally erode ~0.6 m of rock. The second case requires negligible erosion of the continuously exposed bedrock surface since abandonment by the incising stream. Of the six sampled bedrock surfaces, only the Low Terrace at G1 retains evidence of fluvial abrasion; rare, extreme floods do overtop this surface (Fig. 3a), but the well-developed desert varnish indicates a lack of contemporary erosion. Therefore, we read the ^{10}Be concentration at G1 as a minimum surface exposure age. The other sampled surfaces are characterised by granular disintegration suggesting slow but ongoing erosion; hence, we interpret these ^{10}Be concentrations in terms of maximum erosion rate (Fig. 3).

Table 1. Cosmogenic exposure ages and erosion rates determined from ^{10}Be concentrations on bedrock surfaces[32]. Blanks indicate incomplete results.

Sample	Bedrock Surface	Elevation (m)	($*10^5$ atoms/g)	Zero Erosion Exposure Age (ky)	Maximum Erosion Rate (m/My)
EP1	High Terrace	178.5	13.99 ± 0.40	284.9 ± 27.3	2.27 ± 0.22
EP2	Ledge below EP1	172.5	-	-	-
H1	High Terrace	176.3	-	-	-
RP1	Low Terrace	174.8	4.09 ± 0.13	80.6 ± 7.4	9.69 ± 0.78
G1	Low Terrace	187.9	8.24 ± 0.23	160.9 ± 14.9	4.38 ± 0.38
G2	Channel-bed	184.9	1.71 ± 0.07	33.7 ± 3.1	25.32 ± 1.94

We are satisfied that EP1 on the High Terrace represents close to steady state erosion; therefore, treating the surface age as a minimum and assuming zero inherited ^{10}Be concentration at the channel bed, yields a maximum gorge incision rate of 68.2 ± 2.3 m/My over the past ~285 ky. Applying the same approach to RP1 on the Low Terrace; the steady state erosion rate treated as a minimum surface age and assuming zero inheritance at the channel bed, yields a maximum gorge incision rate of 100.4 ± 3.5 m/My over the past ~80 ky. Further upstream at G2 we sampled the bedrock channel bed directly and obtained a steady state erosion rate of 25.3 ± 1.9 m/My. It is unlikely that the steady state criterion is satisfied here, because channel bed erosion occurs via plucking of ~1 m thick joint blocks; thus, depending on the timing of the last plucking event, the deduced erosion rate varies between being greater or less than the true mean erosion rate[33]. Yet combining the G2 bed sample with the surface exposure age, G1, on the adjoining Low Terrace, yields a maximum erosion rate of 23.9 ± 1.8 m/My. Given the similarity of these two erosion rates we suggest that the mean incision rate along this confined reach of the gorge is close to ~24 m/My—a rate much lower than the maximum rates deduced from EP1 and RP1—but the erosion rates reported here will be better constrained with the addition of results for samples EP2 and H1 (Fig. 3).

Incision rates for Sandy Creek Gorge generally fall well below those measured also using cosmogenic ^{10}Be at Yudnamutana gorge[34] in the northern Flinders Ranges (~300 km W) where maximum bedrock channel incision rates below straths are 228 ± 21 m/My, and 53 ± 7 m/My—a time-averaged incision rate of 127 ± 15 m/My—and a sample from the bedrock channel bed yields a maximum erosion rate of 98.05 ± 54.18 m/My. Such comparatively high erosion rates presumably reflect first, the larger drainage area of Yudnamutana Creek (~945 km^2) and second, the ongoing tectonic activity in the northern Flinders Ranges, which is thought to have undergone significant acceleration in rock uplift through the Pliocene-Quaternary[35]. Our preliminary results from Sandy Creek gorge suggest that no such pulse of rock uplift has affected the northern Barrier Ranges over the past ~0.3 My. The importance for bedrock river incision of shifts in the magnitude and frequency of extreme floods remains uncertain, but will be examined in a study to follow.

Notes

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[2] Jansen JD & Brierley GJ. 2004. Pool-fills: a window to palaeoflood history and response in bedrock-confined rivers. Sedimentology 51:901-925.
[3] Jansen JD. 2006. Flood magnitude-frequency and lithologic controls on bedrock river incision in post-orogenic terrain. Geomorphology 82:39-57.
[4] Dragovich D. 1986. Minimum age of some desert varnish near Broken Hill, NSW. Search 17:149-151.
[5] Jansen JD. 2001. Bedrock Channel Morphodynamics and Landscape Evolution in an Arid Zone Gorge. Unpub. PhD thesis. Macquarie University. 513 pp.
[6] Holdaway SJ, Witter D, Fanning PC, Musgrave R, Cochrane G, Doelman T, Greenwood S, Pigdon D & Reeves J. 1998. New approaches to open site spatial archaeology in Sturt National Park, NSW, Australia. Archaeology in Oceania 33:1-19.
[7] A gnatji is a rainbow serpent—a creation being. This interpretation is according to Dan Witter, based on an account from a Maljangapa man, Alf Barlow, interviewed by Jeremy Beckett in 1957.
[8] Sturt C. 1849. Narrative of an Expedition to Central Australia. 2 Vols. Boone, London.
[9] Hardy B. 1976. Lament for the Barkindji. Rigby, Sydney.
[10] Gow RB. 1860-61. Reminiscences; Diary of Robert Biggart Gow, Highgate, Beith, Ayrshire, Scotland. Unpub. MS. Australian National Lib.
[11] Wallace M. not dated. Twelve years' life in Australia; from 1859 to 1871. State Lib. S. Australia.
[12] Pickard J & Norris EH. 1994. The natural vegetation of north-western New South Wales: notes to accompany the 1:100 000 vegetation map sheet. Cunninghamia 3:423-464.
[13] Burrell JP. 1973. Vegetation of Fowlers Gap Station. In: Mabbutt JA (ed) Lands of Fowlers Gap Station, NSW. UNSW Research Series 5:175-195.
[14] Patterson DWH. 1886. Rental Appraisement of Corona Pastoral Holding; LA no. 195. Unpub. report by the Corona lessee (25.10.1886).
[15] Kearns RHB. 1973. Broken Hill. Broken Hill Historical Society, Broken Hill.
[16] Royal Commission. 1901. Royal Commission to Inquire Into the Condition of the Crown Tenants of the Western Division of NSW. Legislative Assembly of NSW, 2 Vols.
[17] Beadle NCW. 1948. The Vegetation and Pastures of Western NSW with Special Reference to Soil Erosion. NSW Gov. Printer.
[18] Milthorpe PL. 1991. Lands of the North-west Corner of NSW. Soil Conservation Service of NSW.
[19] Wasson RJ & Galloway RW. 1986. Sediment yield in the Barrier Range before and after European settlement. Australian Rangelands J. 8:79-90.
[20] Fanning PC. 1999. Recent landscape history in arid western NSW, Australia: a model for regional change. Geomorphology 29:191-209.
[21] Mawson D. 1912. Geological investigations in the Broken Hill area. Mem. Roy. Soc. S. Aust. 2.
[22] Andrews EC. 1922. The geology of the Broken Hill district. Mem. Geol. Surv. NSW 8.
[23] Langford-Smith T & Dury GH. 1964. A pediment survey at Middle Pinnacle, near Broken Hill, NSW. J. Geol. Soc. Australia 11:79-88.
[24] Mabbutt JA. 1972. Geomorphology of the Fowlers Gap–Calindary area. In: Mabbutt, JA (ed) Lands of the Fowlers Gap–Calindary area, NSW. UNSW Research Series 4:81-99.
[25] Mabbutt, JA. 1973. Geomorphology of Fowlers Gap Station. In: Mabbutt JA (ed) Lands of Fowlers Gap Station, NSW. UNSW Research Series 5:85-122.
[26] Neef G, Bottrill RS & Ritchie A. 1995. Phanerozoic stratigraphy of the northern Barrier Ranges, western NSW. Australian J. Earth Sc. 42:557-570.
[27] Gibson DL. 1998. Regolith and its relationships with landforms in the Broken Hill region, western NSW. In: Eggleton RA (ed) The State of Regolith, Proceedings of the 2nd Australian Conf. on Landscape Evolution and Mineral Exploration, Brisbane. Geol. Soc. Australia Spec. Pub. 20:80-85.
[28] Gibson DL. 2000. Post-Early Cretaceous landform evolution along the western margin of the Bancannia

Trough, western NSW. Australian Rangeland J. 22:32-43.
[29] Hill SM, Eggleton RA & Taylor G. 1996. Duricrust inter-relationships and environmental change in the Broken Hill region, southeastern central Australia. In: Bottrell SH (ed) 4th International Symposium on the Geochemistry of the Earth's Surface, Short Papers 188-193.
[30] Hill SM, Eggleton RA & Taylor G. 1997. A regional regolith-landform framework for mineral exploration in the Broken Hill region. Resourcing the 21st Century, the Australasian Inst. Mining and Metallurgy 1997 Ann. Conf. 1/97:131-138.
[31] Bierman PR & Nichols KK. 2004. Rock to sediment–slope to sea with ^{10}Be–rates of landscape change. Ann. Rev. Earth Planet. Sc. 32:215-255.
[32] D. Fabel prepared the samples for measurement at the Scottish Universities Environmental Research Centre. To calculate apparent exposure ages, standard models were employed (Lal D. 1991. Cosmic-ray labeling of erosion surfaces: in situ nuclide production rates and erosion models. Earth Planet. Sc. Lett. 104:424-439), with nuclide production rates scaled to altitude and latitude (Stone JO. 2000. Air pressure and cosmogenic isotope production. J. Geophys. Res. 105:23753-23759). A correction was applied for sample thickness using an attenuation coefficient of 160 g cm^{-2} and density of 2.7 g cm^{-3} for rock. Uncertainties represent propagation of concentration errors defined above and production rate uncertainties of 9%.
[33] Small EE, Anderson RS, Repka JL, Finkl R. 1997. Erosion rates of alpine bedrock summit surfaces deduced from in situ ^{10}Be and ^{26}Al . Earth Planet. Sc. Lett. 150:413-425.
[34] Quigley M, Sandiford M, Fifield K & Alimanovic A. 2007. Bedrock erosion and relief production in the northern Flinders Ranges, Australia. Earth Surf. Proc. Landf. 32:929-944.
[35] Sandiford M. 2003. Neotectonics of southeastern Australia: linking the Quaternary faulting record with seismicity and in situ stress. In: Hillis RR & Muller D (eds) Evolution and Dynamics of the Australian Plate. Geol. Soc. Australia Spec. Pub. 22:101-113.

Figure 1. A pre-1950s bush-basher partly buried by ~70 cm of overbank deposits on the Fowlers Creek floodplain. A nearby bank exposure indicates that the vehicle rests on a sharp contact marking well-laminated post-European sediments from basal massive/bioturbated muds and fine sands. Is this an indication of the 50 to 90-fold increase in sedimentation rates since European settlement?[19]

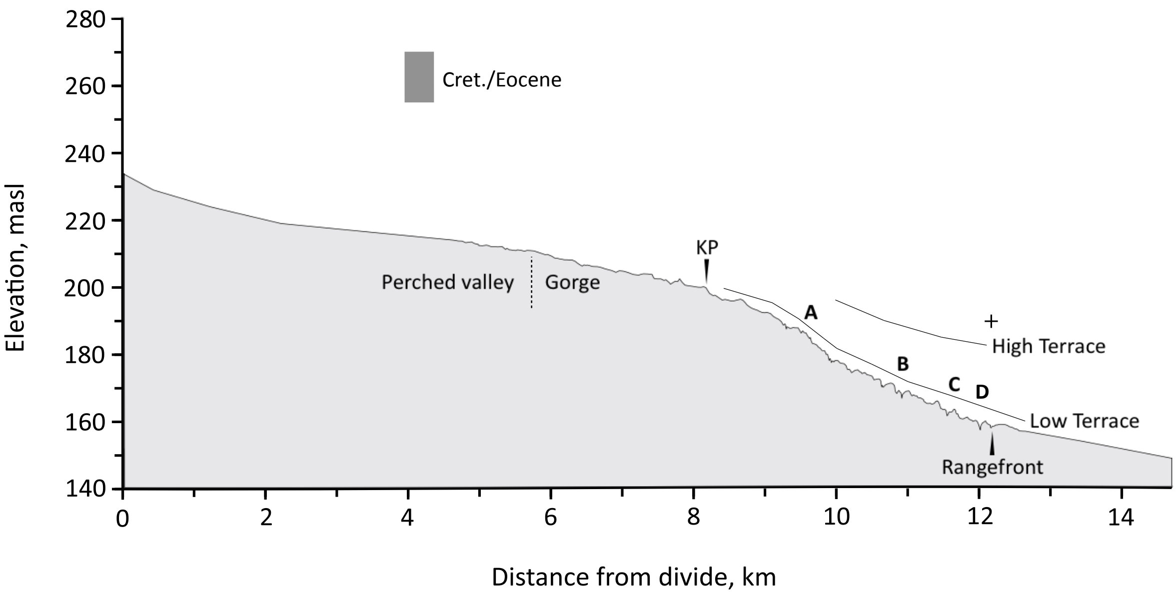

Figure 2. Sandy Creek long profile, with the High and Low Terraces, and knickpont (KP). Remnants of Eocene and Cretaceous sediments cap a line of hills above the Perched valley at elevations shown, and a Cretaceous residual (+) stands above the rangefront. Fig. 3 cross-sections are indicated A - D.

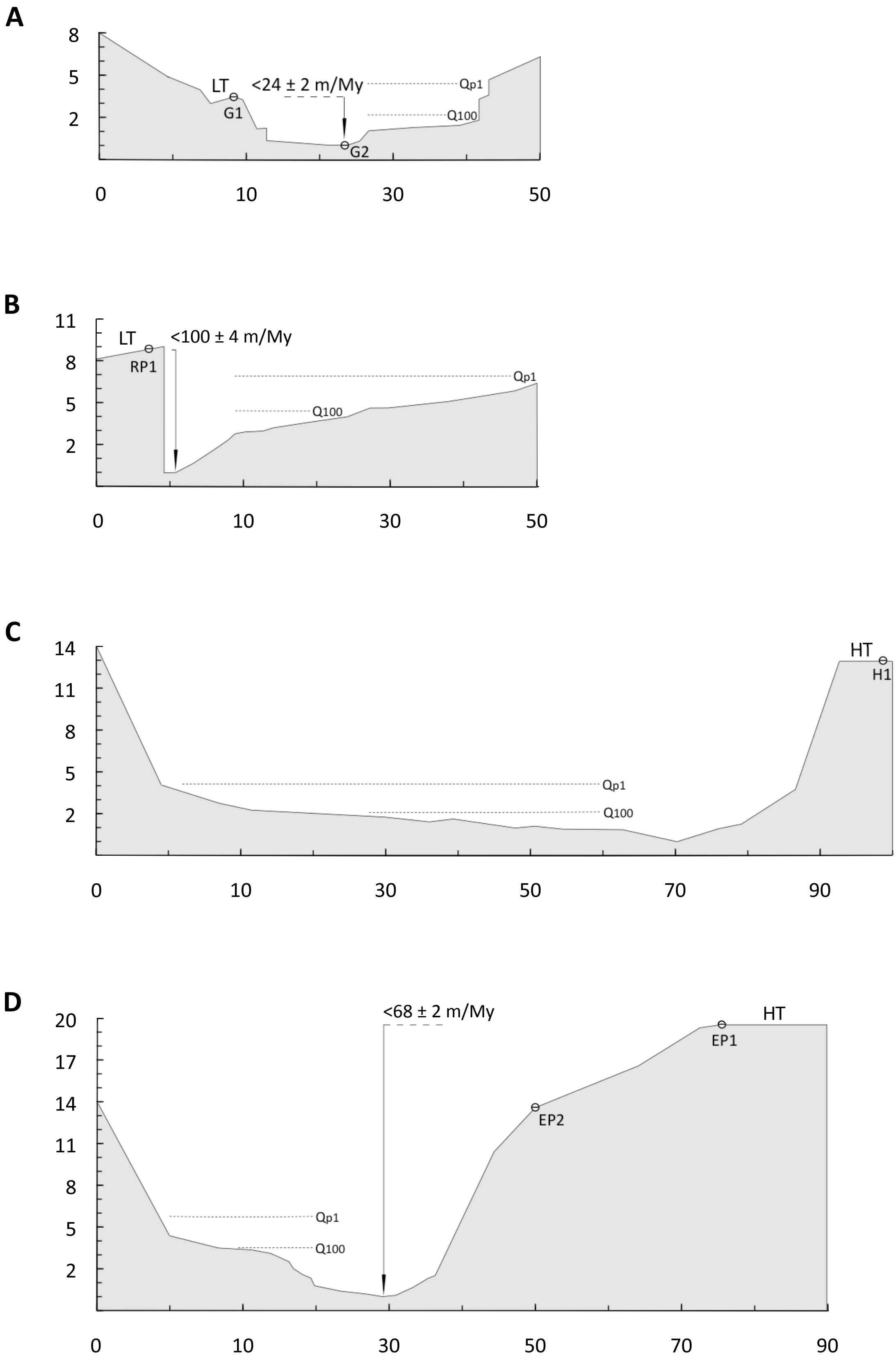

Figure 3. Cross-sections (in metres) down Sandy Creek gorge, with cosmogenic sample locations (⊖) on the High Terrace (HT) and Low Terrace (LT), and deduced bedrock incision rates. Qp1 (750 m^3/s) and Q100 (170 m^3/s) indicate the floodstages of discharges with recurrence intervals of ~1000 y and 100 y, respectively[3].