ESTIMATES OF SOIL PRODUCTION IN THE BLUE MOUNTAINS, AUSTRALIA, USING COSMOGENIC ^{10}BE

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INTRODUCTION: SOIL PRODUCTION AND SOIL THICKNESS

The soil production function has recently been quantified in several lithologic and geomorphic settings (Heimsath *et al.* 1997, 1999, 2000). A well-defined negative-exponential dependence of soil production rate on soil thickness was empirically derived using cosmogenic radionuclides at several study areas. Theoretically, on convex-up spurs where soil is transported by diffusive creep and downslope flux is proportional to slope, surface convexity is a proxy for soil production. Morphometric analysis at sites described by Heimsath *et al.* (1997, 1999, 2000) reveals an inverse relationship between convexity with soil thickness, supporting the cosmogenically derived relationship.

These findings contrast with a long held assumption that soil production is maximised under a soil cover of finite thickness, d_m (Gilbert 1877), and diminishes with increasing soil depth beyond d_m. The Gilbert model has received empirical support for convex-up slopes (Small *et al.* 1999) and is supported on theoretical grounds by Anderson (2002), who notes that soil of thickness less than d_m is unlikely to exist. Thus, where soil thickness is in equilibrium with both soil production and transport, the Gilbert (or "humped") soil production model would predict that there would be few sites with soil thicknesses between 0 and d_m.

CONTRASTS IN VEGETATION AND SOIL DEPTH: BLUE MOUNTAINS

Many sites in the western Blue Mountains, Australia, display evidence for a humped soil production function. While much of the sandstone plateau is treed, there are many shrub-dominated spurs (Figure 1). Soil depth changes sharply from tree vegetation (open-forest and woodland) to treeless heath and heathlands (*sensu* Specht 1970). In our study catchment, soil depths either side of the vegetation boundary are 66 cm and 28 cm in the forest and heath respectively, with $p(H_0) < 0.001$. These vegetation patterns do not appear to be a result of slope aspect (Wilkinson & Humphreys, in review), and there are no significant differences in measured soil nutrients except that treed soils contain higher magnesium concentrations, which we consider to be unimportant. Furthermore, on the distal spurs, sub-horizontal bands of heath alternate with rock benches. These features, together with the sharp soil depth change about the treed-treeless vegetation interface, may be signatures of a humped soil production function.

We explore three models of soil production as a function of soil thickness, using *in situ* cosmogenic ^{10}Be. The first is the negative-exponential function of Heimsath *et al.* (2000); the second is a humped function with d_m equal to the forest soil thickness at the vegetation boundary; and the third is humped with d_m equal to the soil depth in heath bands adjacent to rock benches.

Figure 1: Treeless distal spurs (nose heath) with sharp transitions in vegetation and soil depth to treed vegetation in Marrangaroo Creek, western Blue Mountains. Bare bedrock benches frequently outcrop in nose heath and ‘pagodas’ may also be present.

STUDY SITE AND SAMPLING

Our study area, Marrangaroo Creek (150º 10' E, 33º 25' S), is cut into near-horizontal Triassic Narrabeen sandstones with interbedded siltstones and mudstones. Altitudes range from 960 – 1,180 m ASL. Summits are treed and gently undulating with ridgelines that grade into treeless spurs, which then descend relatively steeply. The forest-heath vegetation boundary is characterised by moderately steep slopes (20-25º), often partially cliffed adjacent to tributaries. Bands of heath, approximately contour-parallel, alternate with rock benches; similar though less common and less distinct patterns occur in the forest. Benches typically are 2-50 m long, 2-25 m wide and have a local relief of 0.5-1 m. Benches follow bedding and reflect differential erosion of sandstone and silt/mudstone lithologies. Sandstone indurated with centimetre-scale iron bands forms shallow shelves and protrusions on outcrops and at the base of soil pits. In summary, the mesoscale morphology is not smooth, but is benched with smaller ironstone irregularities. Gross slope morphology is also influenced by sandstone towers 2-15 m high, known locally as 'pagodas', which are generally restricted to distal spur areas.

We sampled bedrock for cosmogenic ^{10}Be from 10 sites on a spur in Marrangaroo. These included rock from benches in heath and from a pagoda-top, and from rock immediately beneath the soil mantle at forest sites. Samples were reduced to highly purified quartz, from which cosmogenic ^{10}Be was measured at the ANU Accelerator Mass Spectrometry facility.

To estimate soil production from surface lowering rates calculated from *in situ* ^{10}Be in soil-mantled rock, it is assumed that soil thickness has remained constant for the time taken for several metres of lowering to occur. However, late Pleistocene dunes and sand sheets were active at similar elevations in the Blue Mountains, less than 15 km away (Hesse *et al.* 2003). To minimise the likelihood of Pleistocene sand inputs or losses, we chose our sampling site above a valley upwind of the reported sand activity. We also took 7 samples from a 70-cm pit in the forest soil at 10-cm depth intervals, to assess the soil age profile using OSL measurements. Furthermore a sample from Mt York, ~15 km to the south was taken, for cosmogenic ^{10}Be counts to act as a control.

RESULTS

Measured concentrations of ^{10}Be and calculated surface lowering rates at the sample sites are listed in Table 1. The rates are highly consistent over all sampled soil depths, and average 13.2 m Myr^{-1} in heath and 11.4 m Myr^{-1} in forest. These figures are very similar to the longer-term lowering rates of about 14 m Myr^{-1} derived from Miocene basalts in the Grose River catchment, nearby (van der Beek *et al.* 2001).

In their uniformity regardless of soil thickness, our calculated rates of results contrast with the inverse exponential function reported from granite slopes in the Bega Valley, NSW by Heimsath *et al.* (2000) but are more similar in this respect to results from slopes at about 1,000 m altitude south of Canberra (Heimsath *et al.* 2001).

Preliminary OSL ages increase exponentially with increasing soil depth (r^2 = 0.96), with soil at 60 cm ~150 ka and 70 cm saturated. The data indicate no observable aeolian activity here. Furthermore, the Mt York control sample is consistent with the Marrangaroo data set.

If soil production rates are mildly, if at all, influenced by overlying soil thicknesses, this suggests that soil-producing mechanisms, lithological weatherability or slope transport processes may be markedly different from those study areas where a steep inverse exponential relationship exists. Soil transport processes such as rainwash (*sensu* Paton *et al*. 1995) and bioturbation by lyrebirds, wombats and invertebrates are likely to be important at Marrangaroo, as is weathering by fire (Adamson *et al*. 1983). However, it is difficult to envisage that these are substantially different from study areas where an inverse exponential soil production function has been elucidated. Thus lithology remains the most likely factor. Substantial parts of the adjacent plateau are underlain by friable sandstones (Pecover 1986) which we suggest have been stripped from the flanks, exposing relatively unweathered, well-cemented strata. This may explain our findings.

REFERENCES

ADAMSON D., SELKIRK P.M. & MITCHELL P.B. 1983. The role of fire and Lyre Birds in the sandstone landscape of the Sydney Basin. *In:* YOUNG R.W. & NANSON G.C. eds. *Aspects of Australian sandstone landscapes*. University of Wollongong, pp. 81-93.

ANDERSON R.S. 2002. Modeling the tor-dotted crests, bedrock edges, and parabolic profiles of high alpine surfaces of the Wind River Range, Wyoming. *Geomorphology* **46**, 35-58.

GILBERT G.K. 1877. *Report on the Geology of the Henry Mountains (Utah)*, United States Geographical and Geological Survey, Washington. D. C.

HEIMSATH A.M., CHAPPELL J., DIETRICH,W.E., NISHIIZUMI K. & FINKEL R.C. 2001. Late Quaternary erosion in southeastern Australia: a field example using cosmogenic nuclides. *Quaternary International* **83-85**, 169-185.

HEIMSATH A.M., DIETRICH W.E., NISHIIZUMI K. & FINKEL R.C. 1997. The soil production function and landscape equilibrium. *Nature* **388**, 358-361.

HEIMSATH A.M., DIETRICH W.E., NISHIIZUMI K. & FINKEL R.C. 1999. Cosmogenic nuclides, topography, and the spatial variation of soil depth. *Geomorphology* **27**, 151-172.

HEIMSATH A., CHAPPELL J., DIETRICH W.E., NISHIIZUMI K. & FINKEL R.C. 2000. Soil production on a retreating escarpment in southeastern Australia. *Geology* **28**, 787-790

HESSE P., HUMPHREYS G.S., SELKIRK P.M., ADAMSON D.A., GORE D.B., NOBES D.C., PRICE D.M., SCHWENNINGER J-L., SMITH B., TULAU M., & HEMMINGS F. 2003. Late Quaternary aeolian dunes on the presently humid Blue Mountains, Eastern Australia. *Quaternary International* **108**, 13-32.

PATON T.R., HUMPHREYS G. S. & MITCHELL P.B. 1995. *Soils: a new global view*. London, UCL Press Limited.

PECOVER S.R. 1986. *Construction and industrial sand resources of the Newnes Plateau*, Geological Survey of New South Wales, Department of Mineral Resources, Sydney.

SMALL E.E., ANDERSON R.S. & HANCOCK G.S. 1999. Estimates of the rate of regolith production using ^{10}Be and ^{26}Al from an alpine hillslope. *Geomorphology* **27**, 131-150.

SPECHT R. 1970. Vegetation. *In:* LEEPER G.W. ed. *The Australian environment*. CSIRO and University of Melbourne, Melbourne.

VAN DER BEEK P., PULFORD A. & BRAUN J. 2001. Cenozoic Landscape Development in the Blue Mountains (SE Australia): Lithological and Tectonic Controls on Rifted Margin Morphology. *Journal of Geology* **109**, 35-56.

WILKINSON M.T. & HUMPHREYS G.S. in review. The limited role of modelled exposure and slope aspect on heath distribution, Blue Mountains, Australia. *Catena*.

Table 1: Cosmogenic ^{10}Be data and erosion/soil production rates, Marangaroo site, Blue Mountains.

Sample	10Be (atoms/g) x1000	s(10Be) (atoms/g) x1000	Po (a/g/yr)	P(z) (a/g/yr)	Erosion (m/Myr)	Depth (cm)
HEATH						
BM-1 spur crest	389.4024	20.94113	10.9	10.9	15	0
BM-2 spur crest	434.9351	21.87107	10.9	10.9	13	0
BM-3 north-facing slope 10 m below crest	334.0924	20.11446	10.9	10.9	17	0
BM-4 hard rock band 10 m below BM3	518.2299	24.99638	10.9	10.9	11	0
BM-5 Top of pagoda	542.4331	25.33837	10.9	10.9	10	0
				Mean	13.2	
FOREST						
BM-6 Pit 1, rock at 55 cm depth	304.8614	22.32844	11.7	5.9	10	55
BM-7 Pit 1, ironstone at surface	549.4133	33.64009	11.7	11.7	11	0
BM-8 Pit 1, Pit 1, ironstone at 25 cm depth	380.8349	23.07144	11.7	8.6	12	25
BM-9 Pit 1, second ironstone at surface	548.4958	23.97826	11.7	11.7	11	0
BM-10 Pit 2, saprolite at 50 cm depth	246.0344	21.15539	11.7	6.3	13	50
				Mean	11.4	
BM-11 Mt York, sandstone on crest ridge	403.2792	24.9381	11.5	11.5	15	0