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Landforms and soils of Black Mountain

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Abstract. Black Mountain comprises two main landforms, the ridges and steep-sided slopes of the Umbarra soil-landscape unit, and the gentler fan slopes of the Russell soil-landscape unit that form the mountain's footslopes. Black Mountain's soils have been developed by weathering of its sandstone rocks over millions of years. The ridges and their steep flanks are characterised by shallow lithosols. The footslopes have strongly duplex soils with a pale sandy loam A horizon overlying sodic, clay B horizons that are red where there is unimpeded drainage and yellow where the soil remains wet for long periods. These B horizons are highly erodible, but can be managed by careful infrastructure maintenance and/or development, and maintaining high woody and tree-leaf litter cover throughout the reserve. Both landforms are currently eroding at about the geological rate under present management which is minimising stress and disturbance, allowing biological processes to control erosive forces.

1. Introduction

Black Mountain is a remnant sandstone 'island' (Abell 1991), rising from around 560 m altitude just above Parkes Way to 812 m at its summit. It is characterised by steep slopes on the south, west and north sides and a series of ridges and gullies on the east. The steep slopes give way to gentler footslopes (McDonald et al. 1984), especially to the south-west and west. The 720 m high Little Black Mountain occurs to the north of the main peak and together with a series of more rounded ridges, footslopes and broad valleys covers most of the northern part of Black Mountain Nature Reserve. Its geological evolution is described by Finlayson (2018).

2. Soil formation from parent material

The soils are derived from the slow weathering of Black Mountain Sandstone on the rocky uplands and ridge tops, transport downslope and soil profile development over a very long time period. There are no specific records of soil materials from other sources such as wind-blown dust. Fanglomerates near the ANU quarry on the east side of the mountain were formed from rock weathering into smaller fragments, transported to a fan and then cemented by clay to an almost rock-like structure (Fig. 1). This pedimentation of the sandstone cap has been proceeding for probably millions of years.

The weathering of sandstone into fine particles that eventually become soil is the result of physical, chemical and biological processes, the latter related to the influence of cyanobacteria (Budel et al. 2004; see Fig. 2). The steepness of the ridges results in some slopes being oriented in a northerly or westerly direction, with others oriented to the east and south. The northerly–westerly slopes have higher soil temperatures, causing rapid drying after rain and higher rates of soil respiration due to biological breakdown of plant residues. The easterly/southerly slopes remain moister for longer and are cooler, slowing the rate of soil respiration and litter breakdown. The extent to which these temperature and moisture effects may cause different soil properties related to aspect is not known. Differences in botanical composition, abundance and biomass on the different slopes (Pook and Moore 1966) is most likely due to different temperature and evaporation rates, rather than intrinsic differences in soil type or mineral composition.

3. Soil-landscape units

The soil types on Black Mountain are strongly related to terrain (Grant 1976; Walker 1978). Within the overall ACT landscape, Walker classified Black Mountain's terrain into two soil-landscape units, called Umburra and Russell.

Fig. 1. Fanglomerates near the ANU quarry. Small rock fragments have been transported downslope then cemented, possibly by clay, into a rock-like mass. Photo: R Purdie.

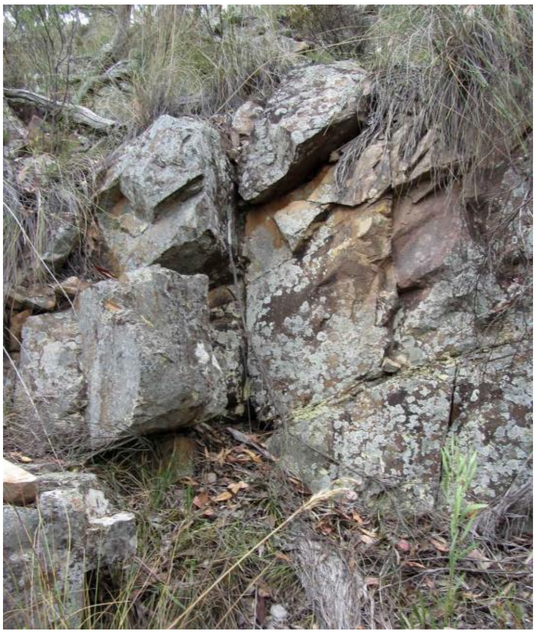

Fig. 2. A sandstone fragment with both vertical and horizontal cracking allowing water to enter, furthering chemical weathering. Lichens and cyanobacteria have also colonised and will be ‘dissolving’ the cementing agent between sand particles. Photo: D Tongway.

3.1 Umbarra soil-landscape unit

Umburra is characterised as *ridges* and *steep side slopes* and is located from the top of the mountain to approximately above the 650 m contour. The average slope is from 25 to over 30 degrees and the unit is comprised of massive sandstone outcrops (Fig. 3) or roughly cubic rock fragments 10–50 cm in width that appear to have gradually moved downslope due to gravity, forming a colluvial strew (Fig. 4**)**. The horizontal and vertical cracking of the rock outcrops are evidence of the continuing physical, chemical and biological weathering processes. Rock fragments in this unit are close to the surface, so that soil depth is both variable and hard to ascertain, but it is likely that rock fragmentation continues for a few metres and that tree roots explore soil-filled cracks between the rocks **(**Fig. 5) and contribute to current soil formation by biological weathering processes (Fig. 6).

Fig. 3. A massive sandstone outcrop near the top of Black Mountain. This has yet to undergo the more extensive weathering into smaller blocks, but reddish ‘new soil’ weathered from the rear face is apparent. Photo: D Tongway.

Fig. 4. A strew of sandstone colluvial fragments on the soil surface. As weathering proceeds sandstone fragments roll down hill and for a period act as overland flow regulators. In this image a log has been burnt and the layer of tree litter has been reduced for a period. Photo: D Tongway.

Fig. 5. This fallen tree shows how the roots have helped to fragment rocks by penetrating and expanding within soil-filled cracks. Photo: D Tongway.

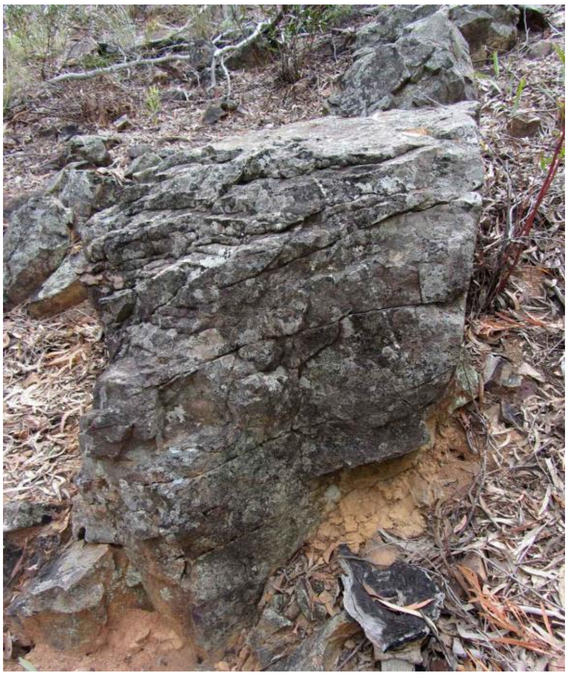

Fig. 6. Fresh soil at the foot of a large sandstone fragment that is undergoing weathering by water, temperature variations and cyanobacterial dissolution. Photo: D Tongway.

The upper slopes on the southern and western sides are curved planes with relatively few incised drainage lines. The cross-section of these drainage lines is limited in depth and width by erosion resistant rock fragments, so that deepening and widening is hardly possible and surface outflow of water across the broad faces is by thin overland sheets. Deeper percolation through rock cracks probably also occurs, but few if any springs are present in the lower slopes. The northern and eastern flanks have more steep-sided ridges and more drainage lines. This would be due to variations in underlying rock breakdown patterns.

3.2 Russell soil-landscape unit

Russell is characterised as *fan slopes* and is the waning footslope approximately below the 650 m contour, inclined at a slope of 5–12 degrees. The footslopes have formed through long-term deposition of sediment derived from erosion on the upper slopes. On the western edge of the park it forms coalescing fans, each probably with a wedge-shaped cross-section from east to west, in which the soil thickness increases downslope to about 6 m deep over the geological Pittman formation. The footslope formation is very old and in some gully exposures exhibits different styles of erosion and deposition, with beds ranging from fine, soil-like alluvium to layers of water-rounded pebbles **(**Fig. 7). These reflect different climatic circumstances over time, from quiescent phases when soil/clay alluvium was deposited, to more pluvial times when gravel and rounded stones were laid down across the fan.

Fig. 7. An erosion gully low in the footslope revealing several different layers of alluvial deposits—well-rounded stone, gravels and soils. Note that this exposure is due to a poorly designed culvert pipe which directs high speed water flow directly onto this drainage line wall. Similar walls close by are not eroding and are covered in cyanobacteria. Photo: R Purdie.

The drainage lines of the footslope tend to be both distributary and divergent, due to the layers of sediment and more easily transported small rock fragments in the soil, and the lower slope angles allowing water outflow to take different pathways over time as the fans build up. The footslopes are comprised of a number of sub-units, including low crests, ridge tops, ridge flanks, drainage lines and gently inclined plains. Nearly all the sub-units are in 'runoff' situations, so that the rate of runoff is variable and strongly dependant on ground cover, here dominated by plant litter, rather than rock fragments, to minimise runoff rate, infiltration and hence plant habitat types. The shape and orientation of the ridges is such that opposite sides have contrasting insolation, resulting in hotter and drier faces on north-facing slopes and cooler, moister faces on the southerly and easterly faces. Sleeman and Watson (1979) recoded a number of duplex brown and red earths in these circumstances.

4. Soil profiles

There appears to be no systematic classification, survey or mapping of Black Mountain's soils as a whole. However, surveys done in the 1970s for an extension to the National Botanic Gardens (Sleeman and Watson 1979) include fairly detailed soil profiles that are probably representative of the variation in the reserve and can be interpolated to describe soil properties.

4.1 Soils associated with the Umbarra soil-landscape unit

Sleeman and Walker (1979) characterised the soils on the ridgetops and flanks as comprised of shallow lithosols of variable but shallow soil depth to stone or rock, and with a uniform texture trend of sandy clay loam (loamy fine sand to fine sandy loam). Being ‘new’ soils, there has not been enough time to develop a differentiated texture profile. These soils are pale brown to pink (Munsell 2.5 YR 7/3 dry). The rock fracturing may be quite deep, allowing tree roots to access water deeper in the profile. The absence of springs on the flanks of Black Mountain (except for short periods after seasonally wet conditions) suggest that most of the water stored in the profile is taken up by the vegetation and transpired.

4.2 Soils associated with the Russell soil-landscape unit

The parent material for the footslope soils is transported from the steep rocky upper parts of Black Mountain and deposited as a series of overlapping alluvial fans on the lower slopes. Soil profiles have been exposed by track-making operations and gully erosion on the footslope. They show a strongly duplex profile with a yellow (Munsell 10YR 8/8) or red (2.5 YR 5/8) clay B horizon overlain with a sharp boundary by a pale sandy loam A horizon (Munsell 2.5YR 7/2 and 5Y 7/2) (Fig. 8**).**

These soils are called ‘texture contrast’ because of the sharp boundary between the sandy loam A horizon and the light clay B horizon. They are formed after deposition of the alluvial fans, when clay particles migrate deeper into the local profile (Sleeman and Walker 1979), enriching the lower horizons with clay and leaving behind coarser particles in surface horizons. The soil colour differences are likely due to differences in water relations. The red colour indicates unimpeded drainage (higher water percolation rates) and aerobic conditions, so that iron is predominantly in the ferric or oxidised state. The yellow colour indicates the soil profile has been subject to longer periods of inundation due to slow water percolation rates, and remains wet and anaerobic after rain for some time, reducing some of the iron to the ferrous form. When these yellow duplex soils are exposed in gullies, undercutting or caving and mass wasting is highly likely (Fig. 9).

Fig. 8. Examples of yellow (left) and red (right) texture contrast soils. The coloured horizons are rich in clay-sized particles and both are sodic and prone to gully erosion. These soils are located well down the footslope where the fine clay particles would have been deposited. Photos: R Purdie (left) and D Tongway (right).

Both the above B horizon materials are highly dispersive (Fig. 10) due to sodicity (i.e. sodium ions being electrostatically attached to clay particles), a likely residual property from the initial marine sedimentation that ultimately resulted in sandstone formation (see Finlayson 2018). The sodium confers undesirable soil physical properties such as tendency to rapidly erode, have low water storage and low water percolation rates. The management implications of sodicity are discussed in section 6.

Fig. 9. An example of erosion in an exposed sodic texture contrast soil. The yellow-coloured clay-rich B horizon is eroded by undercutting or ‘caving’, ultimately allowing the more stable A horizon to simply fall away (mass wasting). Photo: D Tongway.

Fig. 10. Dispersive yellow clay from Black Mountain, identified by a simple field test. A dry natural fragment was gently immersed in rain water and its behaviour observed. Dispersive properties were indicated by (i) slaking (the fragment collapsed into smaller ones) and (ii) dispersion (a pale cloud of clay particles formed at the edges of the slaked mass). Stable soils neither slake nor disperse, usually because of abundant organic matter bonding the soil aggregates together. Photo: D Tongway.

5. Current natural soil erosion

Erosion is a natural process that occurs over geological time periods. Over millions of years on Black Mountain, soil particles weathered from the sandstone have migrated down the rocky upland slopes and formed soils on the footslope. Today, there is little or no evidence of overt or accelerated erosion/deposition on the faces of most of the ridge flanks. This is likely due to the dominantly sheet overland flow nature of runoff on the slopes not being focussed into a drainage line network because of the coarse textured nature of the surface soils (Sleeman and Watson 1979), and water flow being regulated by large rock fragments together with a generally continuous cover of wood and leafy litter and often dense perennial grass tussocks. Under current conditions, the rate of outflow and energy of water after a rainfall event is too low to mobilise either soil or plant litter, and the energy of the outflow is dissipated by a generous and diverse litter cover (Fig. 11). The current dynamics of soil movement on slope faces is so slow as to be imperceptible due to the density and complexity of the ground cover.

6. Management issues

Because of their thickness, lower rock content and sodic B horizons (section 4.2), the soils associated with the footslope have the potential for significant erosion. Erosion of these soils was probably not an issue prior to European settlement, as the A horizon would have confined and 'protected' the subsoil below for millions of years and limited the rate of soil wetting by water percolation to it, and there was no 'escape path' for dispersed clay particles to discharge. Erosion gullies currently present on some western footslopes are mostly in a quiescent erosion phase. However, some texture contrast soils with a dispersive yellow clay B horizon appear to have been recently exposed, signalling a potentially rejuvenated erosion phase.

Fig. 11. A complete cover of plant litter, ranging from large woody debris to finer leaf and stem material, provides rain-splash protection and obstructs the overland flow of water. There are almost no signs of movement of even the soft, light litter by wind or water, implying that runoff rates are slow and distributed evenly across the ground surface as sheet flow. Photo: D Tongway.

The presence of a highly erodible B horizon fairly close to the surface means that either increased upslope runoff and/or increased exposure of the horizon can rapidly cause tunnel and gully erosion and result in deeper and wider erosion gullies. The clay matrix becomes destabilised after wetting and exposure allows a dispersed slurry to run off as suspended load. This can be managed best by careful infrastructure maintenance and/or development (especially along roads, Fig. 12), with monitoring after rain storms, and maintenance of woody and tree-leaf litter cover throughout the reserve. Wood often minimises overland transport of lightweight litter (Fig. 13) and a dense cover of leaves prevents the formation of water-shedding physical crusts (Fig. 14). Management of steeper walking tracks to minimise exposure of the soil surface and the formation of such crusts is also important (Fig. 15).

Fig. 12. This 50-cm deep channel along the edge of the Powerline Track has been caused by exposure of the erodible red clay B horizon. Photo: R Purdie.

Fig. 13. Heavy woody litter can obstruct overland flow and accumulate mobile organic matter, including seeds. Situations like this are rare on Black Mountain, but show that if the ground cover is persistently lost by inappropriate burning, the nutrient cycle may be seriously interrupted. Photo: D Tongway.

Fig. 14. An example of a physical crust on the south-west footslope formed by direct raindrop action on an unprotected soil surface. Such crusts may reduce the infiltration rate by an order of magnitude, causing net water loss and increasing water flow speed, possibly initiating soil erosion. Photo: D Tongway.

Fig. 15. Litter washed off a walking track on Black Mountain during a rain storm. The exposed soil surface is both prone to erosion and increases runoff that causes further erosion downslope. Photo: R Purdie.

Some of the south-western footslopes between 5% and 12% were cleared for pastoral/agricultural purposes, probably in the late 19th century. While woody species that have regrown in areas such as Smith's paddock since the early 1980s (see Purdie 2018) have presumably contributed to the recovery of surface litter, the extent to which full nutrient cycling and obstruction of overland flow has recovered to a functional level comparable with the original grassy woodland vegetation is not clear. Monitoring the impact on the soil cover of kangaroo and/or rabbit grazing in this area may be warranted.

Fire has been an integral part of the Black Mountain environment (Costin and Polach 1973; Doherty 2018), but prescribed fire regimes in the reserve need to be carefully monitored to ensure that ground litter cover remains sufficient to slow the rate of water runoff and prevent soil mobilisation after rainfall; image standards could be developed to aid such monitoring. Hot fires that consume woody fuel are likely to sterilise the surface soil and lose the influence of cryptogams in resisting erosion. Cool fires using grassy fuel often permit cyanobacteria to survive and continue photosynthesising and fixing nitrogen (personal observation elsewhere).

Although some surface soils under *Eucalyptus* trees have mild water repellence, due to waxes and oils from the leaves coating the faces of sand grains in the soil, this is not a management issue needing attention.

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