https://doi.org/10.56295/1ACEG01

SLOPE STABILITY IN WEATHERED BASALTS

Stephen Fityus, Michael Gawn
Douglas Partners P/L, Newcastle

ABSTRACT

Tertiary basalts are widespread along the eastern Australian continental margin, extending from The Torres Strait to Melbourne in the south. In many instances, they have been extruded on, or adjacent to the Great Dividing Range, and remain prominent in the steep and elevated topography. By their nature, they weather deeply and rapidly, to form soils with undesirable engineering properties, which in the geomorphically-immature topography of the Great Dividing Range and the Great Eastern Escarpment, leads to engineering challenges for transportation infrastructure. This paper provides a description of the occurrence of these basalts around the margins of the Hunter Valley, with consideration of their control on topographic stability and geomorphic evolution. Factors such as their bedded structure, the presence of palaeosoils, and their tendency to creep are described and evaluated in the geological profiles in which they are encountered, and the engineering problems associated with them are discussed. Experiences from a recent project involving the remediation of a road, affected by basalt-hosted slope instability, are presented and discussed to provide insights into good and bad engineering practices in these geological environments.

1 EAST AUSTRALIAN BASALTS

Tertiary (Cainozoic) basalts occur sporadically along the Great Dividing Range of Eastern Australia. They have particular geological characteristics which make them problematic for civil engineering works. In particular, they are associated with slope instability of both natural and engineered slopes.

The basalt occurrences vary from localized small flows and diatremes with areas of hectares, up to areas of thousands of square kilometers. The basalts have a typical thickness of 300 m - 400 m (Knutson 1989), but smaller occurrences may have thicknesses considerably less than this. Compositions range from silica over-saturated tholeiites (less common, and often occurring as basal units) to silica over-saturated basalts (Sutherland, 1978; Knutson, 1989), which include olivine basalts, mugearites, basanites and hawaiites (more dominant in most provinces). In some sequences, units of tuff and breccia occur. Although these are generally not dominant in the sequence, they can occur locally in significant thicknesses with high clay contents including montmorillonites and halloysites (Won et al. 1983).

Basalt sequences typically comprise sequences of relatively thin flows (3 m to 10 m) which can vary in composition and structure for successive flows. Flow structures include both massive with random fracturing, or columnar, and amygdaloidal horizons within flows are relatively common. Also occurring occasionally in some sequences are palaeosol units which present as weakly-cemented, oxidized soil layers that are chemically resistant to weathering.

2 BASALT GROUND PROFILES

Basalts are renown for deep weathering to produce clay soils. This stems from their mineralogy of olivine, pyroxene and plagioclase, which are all highly susceptible to alteration and weathering in temperate environments. Less well appreciated is the presence of glass in the interstices of basalt, arising from their rapid cooling (Exon et al. 1970). Eggleton et al. (1987) reports that for Eastern Australian basalts, glass and olivine have the highest (and similar) weathering susceptibility, followed by plagioclase, then pyroxene, and then K-feldspar. The weathering process for the minerals and glass in basalt are complex, but in general, the end products are clays and oxides, amongst which halloysite and the smectites (montmorillonite, nontronite and saponite) often feature significantly (Craig and Loughnan, 1964). In addition to the rate of weathering of the minerals of basalt rocks being very fast, it has been observed that mineral alteration may even begin as the basalt cools post-eruption (Coleman, 1960).

The thickness of residual basaltic soils can vary locally, even over relatively short distances. Dahlhaus and O'Rourke (1992) suggest that this, at least in part, may be due to soil formation on different basalt flows of variable composition and texture. Residual basaltic clay soil profiles are typically many metres thick, and profiles of up to 10 m deep are not uncommon. Because of the lithological variations that can occur between adjacent flows, the texture of the residual materials in the weathered horizon can vary widely, from heavy red-brown clays of high plasticity to friable brown rotten rock which crumbles and ravels when exposed in a steep face.

Figure 1. Four weathered basalt profiles: highly plastic clay (left); crumbling friable rock (middle); tuff (right).

3 BASALT LANDSCAPES

Basalt landscapes exhibit some characteristic geomorphic features, many of which are related to landslide activity. The stacking of lava sequences on the elevated topography of the Great Divide and/or subsequent uplift has produced land slopes that are over-steep and prone to mass movement (Galloway, 1967; Young, 1983). These are typified by concave upper slopes below ridge lines and crests, and convex land surfaces adjacent to creeks (Figure 2). This is contrary to more mature landscapes in sedimentary rock landscapes in the Hunter Valley, where ridge tops are round and convex, and lower slopes are concave as they transition to valley floors. This reflects a tendency for valley walls to cut back by slides in the upper slopes on ridges, and for slide debris to accumulate in gullies faster than it can be subsequently removed.

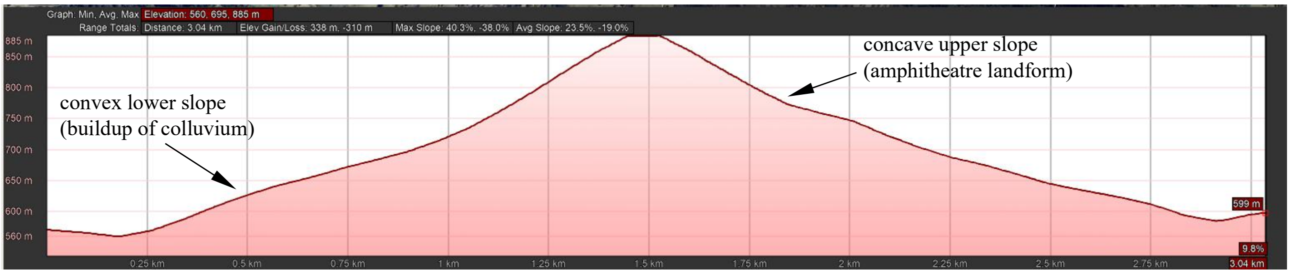

Figure 2. Ground profile through a basalt ridge extending from the Great Dividing Range, Murrurrundi.

4 SLOPE INSTABILITY MECHANISMS.

The deep weathering profiles developed on the basalts, combined with the over-steep, immature topography in many basalt areas, leads to a variety of slope movement mechanisms that vary in scale and rate. These are summarised here.

The heavy smectite-rich clays developed over the basalts are inherently shrink-swell prone, and prone to a phenomenon known as “self-mulching” (Grant and Blackmore, 1991) whereby surface soil debris which falls into desiccation cracks when the soil is dry inhibits closure of the cracks, causing the deeper soils to be displaced toward the surface. When heavy clay soils (see Figure 1 left) occur on relatively steeper slopes, the self-mulching phenomenon can manifest as a mechanism whereby there is a downslope component of displacement in the shrink swell cycle that slowly but consistently causes the upper layers of clay soil to creep downslope. The thicknesses involved are relatively small (of the order of metres) and the process rates are slow (unmeasured, but likely to be centimetres per year), but since the phenomenon affects entire hillsides, the volumes can be collectively huge.

Where clay soils become thick and over-steep on slopes, rafts of clay soil can undergo a combination of rotational and translational sliding, leaving a scarp at the top of the slide, and creating a bulge at the toe. Such slides are almost exclusively associated with saturated ground conditions. The sliding mass may or may not break-up into a series of slices during detachment or movement. Rates of movement are likely to be of the order of metres per hour. The high cohesion in the basaltic clay soils mostly prevents the slide mass from fluidising and becoming a mudslide, but excess surface water flowing through the slide-affected area can mobilise significant soil and mud through erosion.

Despite being physically weak, palaeosol horizons present units of low chemical weathering susceptibility within deeply weathered basalt sequences, which can express (outcrop) as resistive capping levels in basalt slopes, disrupting the slope evolution process and causing the slope to become locally over-steep. Undercutting of these capping levels by more rapid erosion of deeply weathered basalt can trigger instability which penetrates the weathered rock mass. This mechanism is described in Fityus et al (2017).

Shallow instability triggered by palaeosols or local over-steepening can destabilise the ground immediately above the scarp, leading to progressive back-cutting of a slope, which may involve increasing depth with successive slices of ground. Geomorphic evidence suggests that substantial rotational rockmass slides can occur in upper slopes to leave large amphitheatre landforms which are more than half a kilometre wide and hundreds of metres high.

Figure 3. Shallow translational slide in plastic basalt soils (left); systematic upslope progression of slides (middle); amphitheatre landform below crest caused by a large deep-seated slide (right).

Roadworks which cut into weathered basalt slopes can remove slope support and induce increased loads in upslope soil masses. Creep resulting from sustained shear stresses in deeply weathered basalt soils can slowly reduce soil strengths to residual values. Where interbedded tuffs and palaeosols are present, failure can develop relatively rapidly and be difficult to arrest, once initiated.

REFERENCES

Colman, S. M. (1982) Chemical weathering of basalts and andesites: Evidence from weathering rinds: U.S. Geol. Surv. Prof. Pap. 1246, 51 pp.

Craig, D. C., & Loughnan, F. C. (1964). Chemical and mineralogical transformations accompanying the weathering of basic volcanic rocks from New South Wales. *Soil Research*, *2*(2), 218-234.

Dalhaus PG and O'Rourke MO. (1992) The Newer Volcanics. In Engineering Geology of Melbourne. Peck, Neilson, Olds and Seddon. Balkema, Rotterdam. 205 – 212.

Knutson J. (1989) East Australian volcanic geology, in Intraplate Volcanism in Eastern Australia and New Zealand. (eds. Johnson R.W, Knutson, J. and Taylor S.R.) Cambridge University Press, Sydney. pp. 89-156.

Eggleton, R. A., Foudoulis, C., & Varkevisser, D. (1987). Weathering of basalt: changes in rock chemistry and mineralogy. Clays and Clay Minerals, 35(3), 161-169.

Exon, N, Langford-Smith, T. & McDougall, I. (1970). The age and geomorphic correlations of deep-weathering profiles, silcrete, and basalt in the Roma-Amby region, Qld. Journal of the Geological Society of Australia, 17(1), 21-30.

Fityus S, Hancock G and Gibson J (2014) Landslides in Tertiary basalts at Murrurundi, Australia. Proceedings of XII International Association of Engineering Geology Congress, Torino. 1061-1064

Galloway, R. (1967). Pre-basalt, sub-basalt and post-basalt surfaces of the Hunter Valley. New South Wales, 293-314.

Grant, C. D., & Blackmore, A. V. (1991). Self mulching behavior in clay soils-Its definition and measurement. Soil Research, 29(2), 155-173.

Schon R. W. 1985. Petrology of the Liverpool range volcanics, eastern New South Wales. In: Volcanism in Eastern Australia: with case histories from New South Wales, Geol. Soc. Australia, NSW Division, Abstracts, 73–89.

Sutherland, F. L. (1978). Mesozoic-Cainozoic volcanism of Australia. Tectonophysics, 48(3-4), 413-427.

Won, G. Vickery, J and McQueen, L. (1983) Geotech investigation for a deep road cutting adjacent to the Ardglen railway tunnel Murrurundi NSW. In Collected Case Studies in Engineering Geology, Hydrogeology, and Environmental Geology. The Engineering Geology Specialist Group of the GSA, Sydney, v. 11, 423 pp.

Young, R. W. (1983). The tempo of geomorphological change: evidence from southeastern Australia. The Journal of Geology, 91(2), 221-230.