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A regolith depth map of the Australian continent

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ABSTRACT

The regolith is defined as weathered in situ and transported material overlying unweathered bedrock. As fresh bedrock exposures form a small proportion of the landscape, regolith is common in Australia and varies in depth from less than a metre in upland settings to many hundreds of metres (e.g. the Cenozoic Basins). Because of crucial fluxes in gases, water, nutrients, and dissolved salts and variation in permeability and connectivity, knowledge of the nature and depth of regolith is important to many land-based industries, including agriculture and forestry. The minerals industry sees regolith as a barrier to discovery of mineralised rock at depth or as a host of minerals in economic concentrations. There are clearly a range of important characteristics of regolith; depth (and therefore the quantity of regolith) is fundamental for resource inventory and biophysical modelling applications.

A method is described that maps the depth of regolith (with estimates of mapping uncertainty) to the moderately weathered/saprock boundary for the whole of Australia. Our approach draws on an extensive legacy of publically available drillhole data (of variable attribute consistency), and applies an environmental correlation-style of digital mapping prediction that utilises relevant spatial covariates, e.g. terrain analysis, climate and gamma radiometric datasets. From the original database of >350,000 records we filtered and harmonised a useable dataset of 128,000 records. Key predictive datasets used in the depth model included weathering intensity, lithology age, distance to out crop, elevation and relief. Shallowest cover corresponded to high relief erosional landscapes and deepest corresponded to Cenozoic basin sediments. The final map with a ground resolution of approximately 90 m (3 arcsec) was generated using 100 bootstrap model iterations. The reliability of the model was assessed using measures of r-square (0.38), Lin's concordance (0.51), mean error (−5.73 m) and root mean squared error (24.56 m) calculated on a withheld test dataset.

The regolith depth map is consistent with known areas of deep in-situ weathering and accumulation of recent sediment associated with the distribution of Cenozoic Basins and provides a testable estimate in areas with little drilling or survey history. The predictive modelling approach provides a framework to further build and improve regolith depth prediction across varying spatial scales where sufficient quality drillhole data and environmental predictors exist and set priorities for new data acquisition.

1. Introduction

The regolith is defined as the interval between fresh rock and fresh air that covers to varying degrees the Earth's surface (Pain, 2008). Factors controlling the nature and distribution of the regolith are complex and reflect the interplay through time of processes occurring within the lithosphere, hydrosphere, atmosphere and biosphere (Taylor and Eggleton, 2001). A regolith profile can be broadly divided into two zones — the pedolith and the saprolith. The pedolith or mobile layer (i.e. A and B horizons — National Committee on Soil and Terrain, 2009) describes the zone where pedological processes have destroyed the original bedrock structure, principally through the weathering of primary bedrock minerals and the formation and re-distribution of secondary materials (e.g. clays, oxides). The pedolith can develop in-situ or on transported materials and may constitute the whole of the regolith profile or more commonly represent only its upper part (Fig. 1). The saprolith refers to the zone where the bedrock fabric is weathered (largely isovolumetrically) but primary bedrock structures are still recognised. The saprolith includes saprolite and saprock. Saprolite contains more than 20% altered minerals, whereas saprock has less than 20% altered minerals (Eggleton, 2001). The latter therefore has a closer affinity both compositionally and texturally to unweathered bedrock. The saprolith is equivalent to the soil C horizon. Unweathered bedrock

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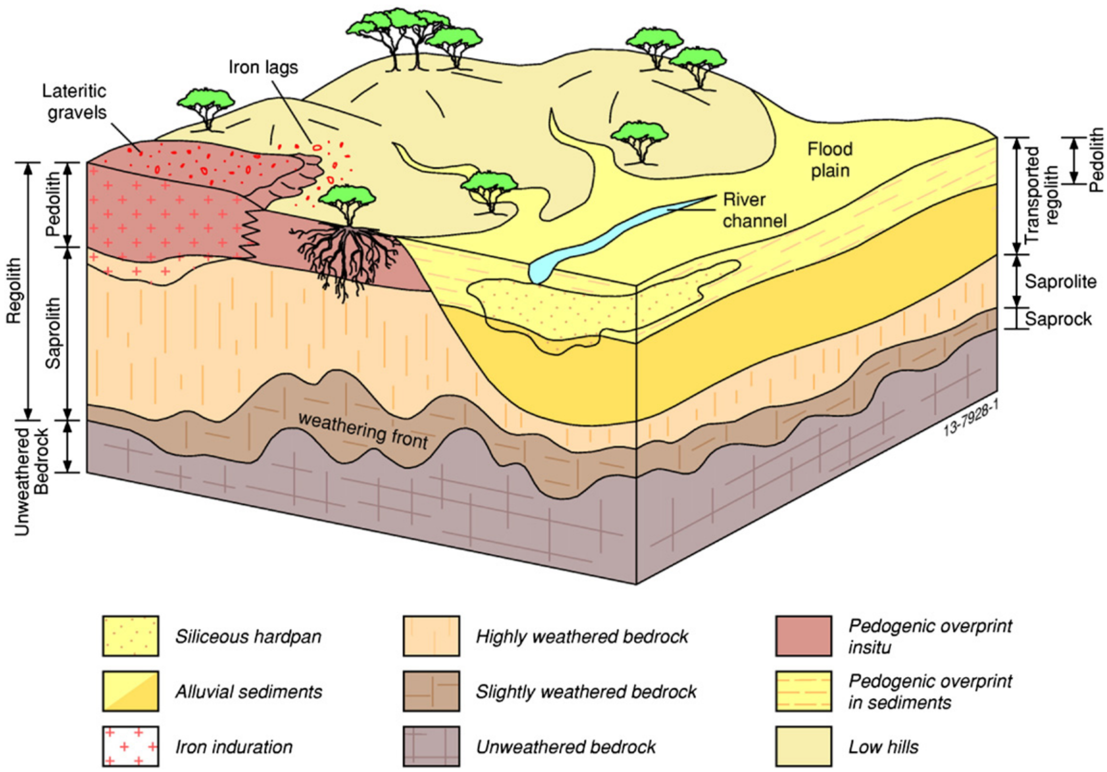

Fig. 1. Idealised regolith profile developed on in-situ and transported materials. The map of regolith thickness described in this paper estimates the depth of the saprolite/saprock boundary.

equates to the soil R horizon. In places the pedolith and or the saprolith may exhibit secondary induration, including for example cementing by silica, iron, aluminium and carbonate. The base of the regolith is defined by the chemical weathering front that may form a sharp or a gradational boundary over many 100s of metres to unweathered bedrock (Fig. 1).

Knowledge of the nature and distribution of regolith materials within the Australian landmass is particularly important because the regolith blankets most of the continent. Unweathered to slightly weathered rocky exposures account for less than 15% of the 7.7 million km^2 of the Australian continent; the rest is regolith (Pain, 2001). Many rocks over the Australian continent have been exposed to surface weathering for hundreds of millions of years (Pillans, 2001). Ollier (2001) argues that the landscape evolution of Australia and by association the regolith developed within those landscapes is on the same time scale as global tectonics and biological evolution. The preservation and accumulation of weathered materials on the surface of the Australian crust reflect the continent's overall low-relief, geological stability and more recent arid climate (Pain et al., 2012). Thus and with the age of the Australian landscape, processes that led to weathering and accumulation or retention of regolith materials have dominated over erosive processes over much of the continent. Furthermore although the Australian landmass is generally geological stable recent tilting and warping of the continent during the Cenozoic with associated uplift and drainage incision have added further complexity to the Australian landscape (Sandiford, 2007 and Czarnota et al., 2014).

The regolith is significant economically, environmentally and socially. It can contain minerals in economic concentrations, supports agriculture and forestry and, may act as a barrier to the discovery of minerals at depth. The thickness and composition of the regolith strongly influence the way water is stored and moves through the landscape, the fluxes of gases and dissolved salts and the fate of nutrients. The degree of weathering and geochemical processes influence the supply and availability of plant nutrients. Intensely weathered Australian landscapes tend to have soils that are low in fertility and resilience and therefore susceptible to degradation. Many of the soils in these highly weathered landscapes are deficient in phosphorus, potassium and nitrogen, which can limit agricultural productivity (McKenzie et al., 2004). The Australian regolith in many places contains high concentrations of salt in the matrix or dissolved in groundwater. These landscapes are then susceptible to secondary salinity and demand well-informed land management. The ability to map the characteristics and qualities of regolith, therefore, can contribute strongly to many needs, including whole-of-landscape resource evaluations, biogeochemical and carbon simulation and research, and mineral exploration. The regolith includes most of the 'Critical Zone', a term used by northern hemisphere researchers who study life sustaining processes occurring between unweathered bedrock and the vegetation canopy (Brantley et al., 2006).

Maps of the Australian regolith are geographically patchy and the scale of mapping is limiting for many medium to fine scale uses. Regolith maps at 1:250,000 scale cover less than 30% of the continent and the only national coverage is at 1:10,000,000. These regolith maps are 2D constructs where information on regolith thickness is usually only described in a relative sense based on the degree of surface weathering and distribution of transported materials. Rarely is regolith depth depicted in a spatially explicit manner, for example in the form of a continuous predictive grid. This reflects the inherent challenges and cost of sampling and observing regolith deeper than approximately 5 m. Many of the practical issues of sampling and observing regolith characteristics at depth are described by Thomas et al. (2014).

Recent developments in digital soil mapping (DSM) are providing new approaches that can also be utilised to predict the nature and thickness of the regolith. Digital soil mapping is a quantitative, statistically-based method of predicting soil properties. DSM methods have been described more fully by others (e.g. McBratney et al., 2003; McKenzie and Ryan, 1999). The development and implementation of DSM have increased significantly over the last 15 years reflecting advances in computing, software, geographic information systems and new digital thematic datasets to support both local and global scale mapping (e.g. digital elevation models (DEMs)), satellite remote sensing and site quantification (e.g. proximal and laboratory) of soil characteristics.