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Weathering intensity map of the Australian continent

New framework provides new insights into an old continent

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A recent study by Geoscience Australia scientists has integrated and modelled geoscientific datasets to generate a weathering intensity index for the Australian continent. Weathering intensity is a fundamental characteristic of the regolith, the often discontinuous and highly variable layer of weathered bedrock and sediments that overlies fresh bedrock at depth. The weathering intensity index has broad applications for a range of natural resource management, environmental, mineral exploration and engineering issues.

Regolith materials cover over 85 per cent of the Australian continent and range from thin, skeletal, soils over slightly weathered bedrock through to very highly weathered bedrock at depths of more than 100 metres below the surface. Important geological and biochemical cycles operate within the regolith zone, including groundwater systems and nutrient cycles involving carbon, nitrogen, oxygen, phosphorus and sulfur, and all elements necessary for life and the biomass. Biogeochemical cycles within this zone are complex and occur across diverse spatial and temporal scales. Northern hemisphere researchers use the term 'critical zone' to describe this life-sustaining environment. Critical zone research involves integrated studies of water with soil, air and biota in the near-surface terrestrial environment (Lin 2010).

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The regolith and weathering intensity

The degree to which the regolith is weathered (or its weathering intensity) is intrinsically linked to the factors involved in soil formation including parent material, climate, topography, biota and time. These processes operate within, and are characteristic of, the critical zone. Typically there is a correlation between the degree of weathering intensity and the degree of soil development. With changes in weathering intensity we see changes in the geochemical and physical features of rocks, ranging from essentially unweathered parent materials through to intensely weathered and leached regolith where all traits of the original protolith (original unweathered rock) is overprinted or lost altogether. These relationships are summarized in figure 1. An example of these changes is the generation of clays; depending on the parent material and climatic conditions, clays are formed by combining alumina, hydroxide ions and silica. Generally, the amount of clay produced increases as weathering intensity increases and two-layer clays transition to more stable one-layer clays. Since clays have an extremely high surface area and are able to retain water, minerals and nutrients, they are favoured sites for chemical reactions and biological activity in soil.

Geochemical indices have been used to quantify and measure the degree of weathering intensity based on the relative proportions of stable versus mobile elements measured from regolith samples

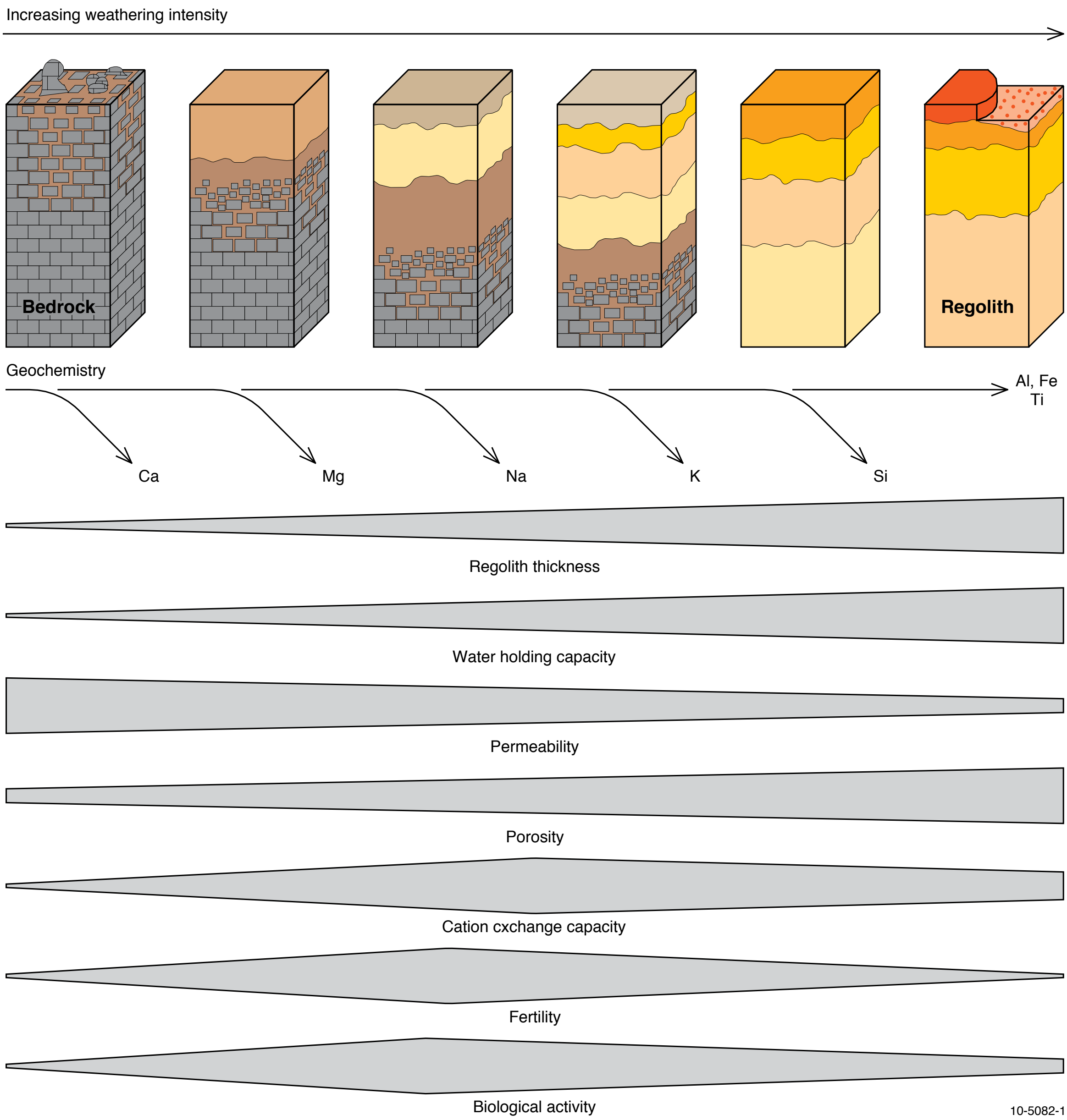

Figure 1. Physical, chemical and biological changes associated with increasing weathering intensity. The trends (shown left to right) are generalised and will change in response to bedrock type and climate. Evolving regolith materials are stylistic and shown in warm hues.

that have been collected down a weathering profile. As weathering intensity increases, soluble elements such as potassium, sodium and calcium are lost in solution while the more stable oxides and resistate minerals (such as zircon) are retained in the regolith. However, a limitation of this approach is that they are single-point/single profile measurements and consequently do not inform on spatial weathering variations across a landscape. This limitation has been addressed in the new study which integrates and models two national geoscientific datasets to generate a prediction of weathering intensity across the surface of the continent as a whole.

Building a weathering intensity model for Australia

The national weathering intensity prediction has been developed using airborne gamma-ray spectrometric data from Geoscience Australia's Radiometric Map of Australia and NASA's 90 metre resolution Shuttle Radar Topography Mission (SRTM) elevation data (see Related articles/websites). Airborne gamma-ray spectrometry effectively measures the distribution of three radioelements—potassium, thorium and uranium—in surface bedrock and soil. Most gamma-rays measured at airborne survey heights emanate from the uppermost 30 to 40 centimetres of soil and rock. Variations in concentrations of these radioelements largely relate to changes in the mineralogy and geochemistry of rock and regolith materials. Distributions of these elements change as the primary minerals in the rock weather to secondary components including clay minerals and oxides. Potassium abundance is measured directly as gamma-rays emitted when potassium (^{40}K) decays to argon (^{40}Ar). Uranium and thorium abundances are derived indirectly by measuring gamma-ray emissions associated with the daughter radionuclides bismuth (^{214}Bi) and thallium (^{208}Tl) respectively. As a result they are expressed as equivalent concentrations of uranium and thorium.

The SRTM elevation data provide digital terrain attributes, such as slope or relief, which are useful because they can indicate geomorphic processes. Areas where bedrock outcrops are relatively unweathered and uneroded can be conspicuous, whilst in other areas, the relative rates of soil removal verses accumulation (that is, denudation balance) can be depicted.

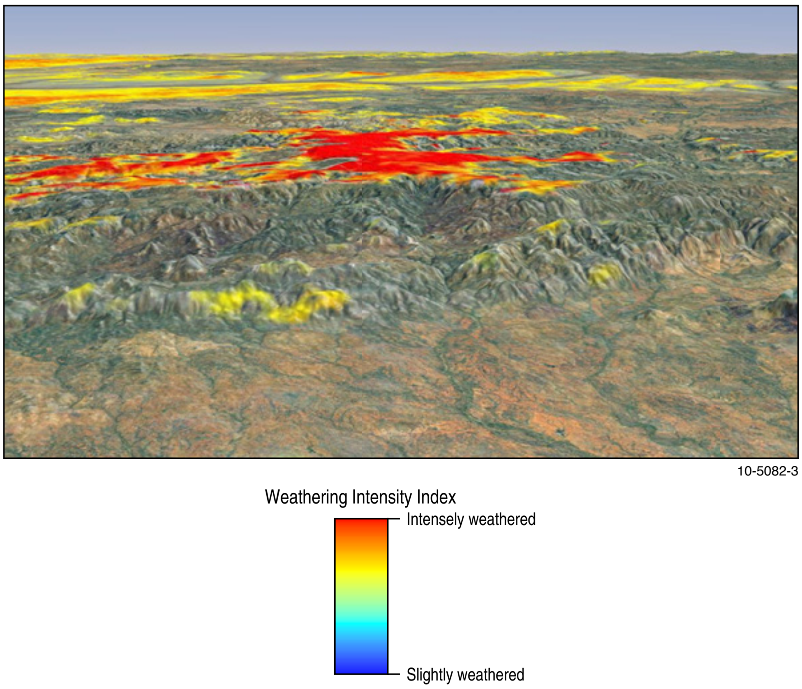

Figure 2. Weathering intensity model from a 3D landscape perspective, showing highly weathered Proterozoic granites and Jurassic sandstones over the southern half of the Mt Isa Inlier. Only moderately to highly weathered bedrock is shown.

For generation of the national weathering intensity index, the degree of bedrock weathering was assessed using a six-level, field-based classification scheme. Level 1 describes largely unweathered landscapes with a high proportion of fresh bedrock exposed at the surface, whilst level 6 relates to areas where bedrock is completely weathered to secondary minerals (such as clays and oxides: see figure 1). Over 300 classified field sites were used to establish regression model relationships between the degree of weathering intensity and the environmental covariates (the total count of the three radioelements) and a terrain relief image derived from the elevation model data. A forward stepwise regression model approach resulted in a strong correlation (r^2 = .86) between the environmental covariates and weathering intensity observed in the field.

Some rock types contain few or no gamma-emitting radioelements, for example, highly siliceous sandstones or ultramafic rock. Where such materials are exposed at the landscape surface the radioelement distribution obviously cannot be used to predict the degree of weathering. In these cases, a terrain attribute such as relief is used to estimate weathering intensity based on the assumption that those landscapes with high relief are likely to have or maintain thin soil and slightly weathered bedrock. In contrast,

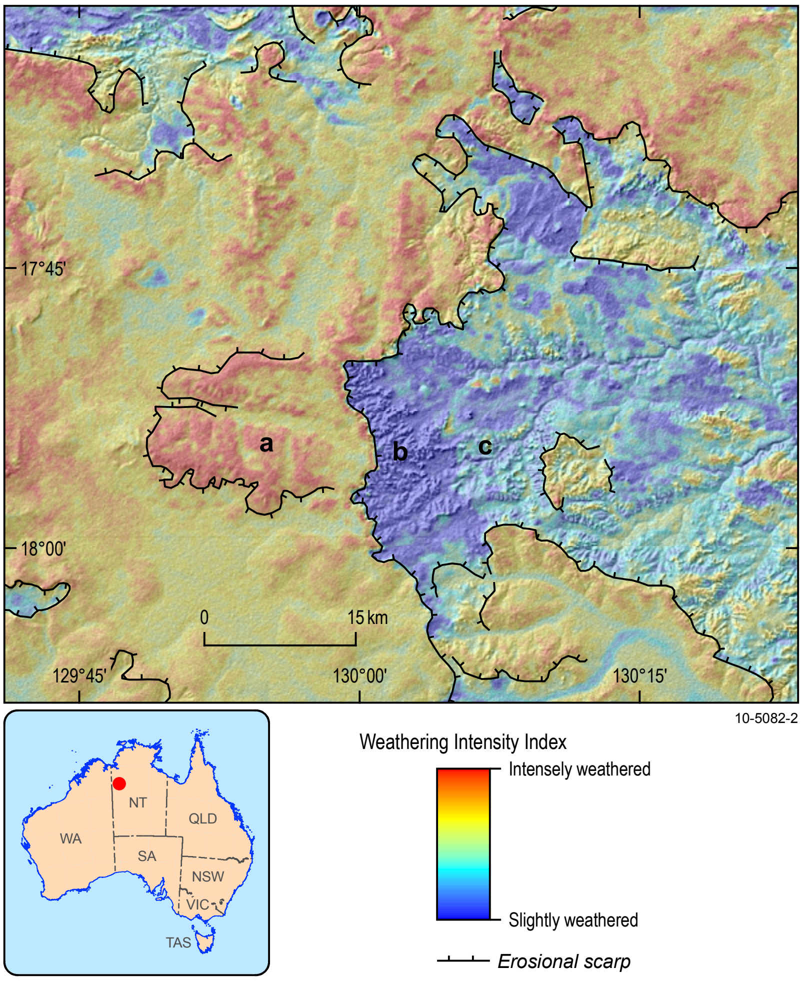

Figure 3. The weathering intensity index has the potential to encapsulate landscape evolution in the context of surface age, weathering, and geomorphic processes, and the associated physical and chemical characteristics of the regolith. In this example landscape denudation is largely controlled through a series of retreating erosional scarps. The oldest surface and more intensely weathered regolith occur above the scarp (a) and least weathered materials are exposed at the base of the scarp (b). Surface age increases down-slope and away of the edge of the scarp (c).

low relief landscapes are likely to accumulate and preserve weathered materials (that is, paleo-surfaces) with correspondingly higher weathering intensities. Rocks and sediments with low radioelement emissions are identified using the total count or dose channel of the gamma-ray dataset. For materials emitting low levels of gamma-rays a second regression model has been generated with predictions based solely on terrain relief. The two regression models were subsequently combined to generate the final weathering intensity prediction. Details of the approach are provided in Wilford (2011).

The index and soil property predictions

The weathering intensity index has broad application in understanding weathering and geomorphic processes across a range of spatial and temporal landscape scales (figure 2). The index can pinpoint highly weathered paleo-surfaces, assess chemical and physical denudation processes, and map the relative rates of regolith formation and its removal through erosion across different landscapes (figure 3). Calibration of, or linking the weathering intensity model with observed physical, chemical and biological changes within the regolith has the potential to improve our understanding of biogeochemical processes within the critical zone and across large areas, including soil-water interactions and nutrient cycling. The index also has the potential to be used in combination with other environmental covariates in a range of soil property predictions including texture, chemical composition, depth, fertility, pH, porosity and permeability. The latter two properties are important for understanding the way in which solutes move through groundwater and the interflow pathways within the regolith and the consequent hydropedological processes and characteristics within different landscapes. The weathering intensity index is currently being integrated with other datasets to develop an improved hydrogeological framework to assist in improved salinity and groundwater management (*AusGeo News* 97). Correlations are expected when using the weathering index for broad-scale ecological studies where biological processes are underpinned by soil fertility and water availability. The index is therefore likely to be useful in mapping and modelling plant types and/or for predicting the distribution of plant communities as well as assisting a more general understanding of the interrelationships between regolith, climate (present and paleo) and vegetation at local, regional or continental scales.

References

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Related websites/articles

Radiometric map of Australia
www.ga.gov.au/energy/projects/awags.html

Shuttle Radar Topography Mission (SRTM) elevation data
www.ga.gov.au/topographic-mapping/digital-elevation-data.html

AusGeo News 97: Hydrogeological–Landscapes system: a framework for managing water resources
www.ga.gov.au/ausgeonews/ausgeonews201003/hydro.jsp

AusGeo News 92: New Radiometric Map of Australia
www.ga.gov.au/ausgeonews/ausgeonews200812/radiometrics.jsp