# New regolith mapping approaches for old Australian landscapes

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# Australian regolith

A B C D E

*Australian regolith profiles. A – Highly weathered saprolite (gruss) with granitic core stones party covered with snow, Snowy Mountains NSW (vertical height (VH) 4m); B – Mega mottling, Adelaide Hills, South Australia (VH 2.8m); C – Floodplain sediments over very highly weathered bedrock, central West NSW (VH 4.2m); D – highly ferruginous saprolite, Tanami gold fields central Northern Territory (VH 42m) and E – ferruginous saprolite (in situ weathering as indicated by the quartz vein) largely weathered to residual clay (VH 2.5m), central West NSW.*

# Dedication

For Anna and Sarah in the words of the great Albert Einstein “Learn from yesterday, live for today, hope for tomorrow. The important thing is to not stop questioning.”

# Table of contents

# List of Figures

# List of tables

# Thesis Declaration

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution to John Richard Wilford and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis when deposited in the University Library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968.

The PhD consists of 3 published journal research papers and one that is currently in review. Two of the research papers are co-authored. Statements of the contributions from the jointly authored papers are detailed in the next two pages.

The author acknowledges that copyright of published works contained within this thesis (as listed below) resides with the copyright holder(s) of those works. However in accordance with Australian Government policy these papers have been published under Creative Commons Attribution 3.0. I also give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the Library catalogue, and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

Wilford, J., 2009. Using airborne geophysics to define the 3D distribution and landscape evolution of Quaternary valley-fill deposits around the Jamestown area, South Australia, Australian Journal of Earth Sciences, 56, S67-S88.

Wilford, J., 2012. A weathering intensity index for the Australian continent using airborne gamma-ray spectrometry and digital terrain analysis, Geoderma, 183-184, 124-142.

Wilford, J and Thomas, M. 2013. Predicting regolith thickness in the complex weathering setting of the central Mt Lofty Ranges, South Australia. Geoderma, 206, 1-13.

Wilford, J., Caritat, P. de and Bui, E., 2014. Digital mapping of regolith carbonate in the Australian regolith using environmental covariates. In review – AGU Earth Surface Processes.

# Statement of Authorship

Published: Wilford, J and Thomas, M. 2013. Predicting regolith thickness in the complex weathering setting of the central Mt Lofty Ranges, South Australia. Geoderma, 206, 1-13.

John Wilford

Led the conceptual thinking and research direction. Implemented all aspects of the cubist modelling and evaluation including compilation of site datasets and environmental covariates. I wrote 90% of the manuscript including background, aims, objectives, methods, results, discussion and conclusions. Acted as corresponding author.

Mark Thomas

Shared in project conceptualisation, fieldwork and some writing

## Statement of Authorship

Wilford, J., Caritat, P. de and Bui, E., 2014. Digital mapping of regolith carbonate in the Australian regolith using environmental covariates. In review – AGU Earth Surface Processes.

John Wilford

Developed the ideas and conceptual thinking that underpins the study. I wrote the manuscript and ran the cubist models. Compiled all datasets for modelling including site and environmental covariates. I interpreted the results within the context of existing maps and discussed strengths and limitations of the modelling approach. Acted as corresponding author.

Dr Patrice de Caritat

Calculated normative calcium carbonate abundances, assisted with statistical analysis and modelling strategy

Dr Elisabeth Bui

Guided running of Cubist for modelling; helped with interpretation of results.

# Acknowledgements

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Colin Pain was working in GA during the first year of the PhD and I wish to thank you Colin for the debates and discussion we had, in particular when I was writing the weathering intensity paper. Our collaboration goes back to our regolith mapping days in Cape York in the early nineties. You instilled a healthy scepticism of 'black box' approaches to regolith mapping. I am grateful for the support from Dr Mike Grundy who has provided me with opportunities to further develop digital regolith mapping research in Australia.

I wish to thank my co-authors on the regolith depth and the regolith carbonate papers including Drs Mark Thomas, Patrice de Caritat and Elisabeth Bui. Working with all of you was most enjoyable and the discussion and interactions we had led to more robust analysis and interpretation of the results. I also wish to thank reviewers of the papers including Dr Ian Roach, Dr Andrew McPherson, Dr Geoff Fraser and Mr David Gibson and Dr Colin Pain from Geoscience Australia, Dr Bob McMillian from Canada, Dr Mark Thomas and Dr John Gallant (CSIRO) and Dr Budiman Minasny (University Sydney). I appreciated all your constructive comments on early drafts of the research papers.

My beautiful children Anna and Sarah were a wonderful distraction throughout writing the PhD and I think they are the only children in their school that know what regolith is and how it forms!. "Yes dad it's a regolith profile and yes we know why it's red in colour" was common banter when passing road cuttings. I wish to thank Margaret who thought this thing would never get finished – well it's done – thanks for your support and reviewing parts of the thesis.

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Finally I wish to thank my parents who provided me with an opportunity to study and complete my under graduate degree all those years ago! Dad you instilled a passion for the natural world and a curiosity to understand some of its complexity.

# Executive Summary


The regolith, or 'critical zone', forms a discontinuous layer that covers large areas of Earth's terrestrial surface. It is a dynamic zone that forms and changes through time in response to interactions between air, rocks (minerals), water and biota. Knowledge of regolith is critical because of its key role in supporting terrestrial life, through physical, chemical and biological processes that operate at mineral-water interaction scales up to the regional scale through geological and tectonic activity.

There are many disciplines or areas of applied integrated research that rely on an improved understanding of regolith formation and information on surface and sub-surface regolith properties at appropriate spatial scales. These areas of study include; agriculture, land use sustainability, hydrology, salinity management, ecology, mineral exploration, natural hazard risk assessment and civil engineering. Furthermore, mapping regolith is critical in understanding the origin and evolution of regolith through space and time.

Mapping the regolith and formulation of associated robust process models are in their infancy compared with geological and soil mapping, which have had a long history of development and refinement. Regolith mapping can be seen as a hybrid approach combining elements from the existing mapping disciplines of geology, soil and geomorphology. The regolith-landform approach, used extensively in Australia, is broadly similar to soil-landscape mapping where landforms are used as the principal surrogate to map regolith. Regolith-landform and soil-landscape mapping are inherently empirical and qualitative. However, in the last ten years there has been a move from the qualitative land resource survey (i.e. soil-landscape mapping) approaches to quantitative, digital survey underpinned by statistical methods. These new quantitative approaches are enabling the prediction of specific soil properties with associated estimates of model confidence or uncertainty not possible using traditional approaches.

The aim of the thesis is to demonstrate and assess the application of quantitative soil mapping approaches in predicting regolith properties. Four case studies are presented that illustrate the application of quantitative mapping approaches in predicting regolith across a range of spatial scales and within different landscape settings. These four investigations include:

1. A continent-wide prediction of weathering intensity using a step-wise multiple regression-based model using airborne gamma-ray imagery and terrain relief;
2. A continent-wide prediction of near-surface secondary carbonate using environmental correlation and regolith geochemistry;
3. A regional-scale prediction of soil-regolith thickness over the Mt Lofty Ranges in southern South Australia using environmental correlation, drilling and legacy data, and
4. A regional-scale 3D regolith-landscape evolution model of valley-fill deposits from the Jamestown area in South Australia based on dataset integration, regression analysis and optically stimulated luminescence dating.

The investigations are interpreted within a landscape evolutionary framework and future research directions are discussed.

Digital regolith mapping shows considerable potential in predicting regolith properties over different landscape scales. This mapping is also important for understanding the complex interaction of environmental factors that control regolith formation, removal and preservation. Addressing gaps in predictive datasets that describe or reflect properties within the sub-surface (i.e. 5–100 m depth interval) and systematic collection of quantitative regolith attributes such as weathering depth and geochemistry will greatly enhance the future applications of digital regolith mapping in Australia.