Compilation of the 1:2 000 000 State regolith map of South Australia – a summary

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Carmen Krapf, Jonathan Irvine and Wayne Cowley

ABSTRACT

This report summarises the mapping compilation process of the 1:2 000 000 regolith map of South Australia and provides an overview of major regolith features. Map compilation was undertaken in ArcGIS and was based on the integration of a variety of input datasets including existing geology data and regolith maps, interpretation of remote sensing imagery, digital elevation data and their derivative products and geophysical data at various scales.

Compilation progressed by standard 1:250 000 map series, complemented by the 1:100 000 digital geology, using the RTMAP (Regolith-Terrain Map) scheme, which had to be adjusted and revised for South Australia's regolith conditions.

The map consists of three main data components: regolith materials and landforms, regolith material induration (ferruginous, calcareous, siliceous, gypsiferous, mixed and undifferentiated) and surface lag. The State regolith map will also be an integral part of an Australia-wide regolith map and will edge-match other existing state regolith maps.

INTRODUCTION

A major challenge that bedrock mineral exploration faces in many parts of South Australia is exploring efficiently and effectively through extensive and thick regolith cover. In addition, the regolith itself hosts important resources.

The Geological Survey of South Australia (GSSA) has committed to the compilation of a state-wide regolith map at 1:2 000 000 scale. This map will be an integral part of an Australia-wide regolith map being compiled by Geoscience Australia and will, as far as possible, edge-match with the other existing state regolith maps from Northern Territory and Queensland using the RTMAP (Regolith Terrain Map) scheme (Pain et al. 2007).

Regolith can be described as the entire unconsolidated or secondarily re-cemented cover that overlies more coherent bedrock that has been formed by weathering and erosion of the older material, and by transport and/or deposition of younger overlying materials. The regolith thus includes fractured and weathered basement rocks, saprolites, soils, organic accumulations, volcanic material, glacial deposits, colluvium, alluvium, evaporitic sediments, aeolian deposits and ground water (adapted from Eggleton 2001, p. 101), or in a shorter form as ‘everything between fresh rock and fresh air’ (Eggleton 2001, p. 101). Thus regolith is continuously formed and modified, and what we observe in today’s landscape is a product/result of past, present and ongoing events. Regolith is an integrated expression of geology, climate, groundwater, topography, geomorphic processes and landscape evolution and has a very close empirical relationship with landforms, both present-day and past. Landforms are themselves a reflection of climate, geology and predominantly near-surface geomorphic processes (Craig 2005).

Regolith mapping can assist in the development of landscape evolution models and promote the understanding of the genesis and history of various regolith types and correlations between various regolith units across the landscape (Pain et al. 2007).

Mapping and hence understanding regolith composition and distribution can potentially be a cost effective and powerful exploration tool. Regolith maps can provide a framework for understanding the dispersion of regolith material within the landscape, the occurrence of extractive and placer minerals, groundwater potential and can inform environmental geoscience and management issues. They can also assist in unravelling the relationships between regolith type and mineral deposits, and the distribution of various regolith types with economic potential (Chan 1989).

Regolith maps which distinguish between in-situ and transported regolith are particularly useful for geochemical sampling programs in mineral exploration. Regolith material can be used as a pathfinder to bedrock-hosted mineralisation, but its suitability, and thus the sampling techniques which are effective, depend on this distinction. Furthermore, regolith can host mineralisation in its own right.

AIM AND OBJECTIVES

The aim of the project was to compile a seamless state-wide 1:2 000 000 scale hardcopy regolith map of South Australia and an accompanying GIS dataset that portrays regolith materials, as well as landforms and regolith overprints (induration, lag). It is complementary to existing thematic state-wide maps and datasets like 1:2 000 000 geology (Cowley 1999, 2001), Palaeodrainage and Tertiary coastal barrier systems (Hou et al. 2007, 2012), radiometric and ASTER Geoscience Map of South Australia.

The regolith map aims to provide a state-wide representation of regolith materials and landforms and thus presents a broad-scale framework for guiding geochemical prospecting for a wide range of minerals as well as addressing land use, groundwater and other environmental issues.

BACKGROUND

Between 2002 and 2008 GSSA was a key participant in the Cooperative Research Centre for Landscape Environments and Mineral Exploration (CRC LEME, http://crcleme.org.au/), which was established and supported under the Australian Government Cooperative Research Centre Program. During this period 31 regolith maps were compiled for South Australia, mainly for areas in the Curnamona Province and the Gawler Craton, ranging in scale from 1:2 000 to 1:500 000 (Table 1). Furthermore, two guide books for mineral exploration through the regolith in these provinces (Fabris et al. 2008; Sheard et al. 2008) and a variety of other regolith reports and papers have been published (http://crcleme.org.au).

During the period of CRCLEME two state-wide regolith maps and datasets were compiled, one for the Northern Territory (Craig 2006) and one for Queensland (Craig et al. 2008). In addition, the Geological Survey of Western Australia compiled a state-wide seamless regolith data layer for Western Australia (Marnham and Morris 2003).

Table 1. CRCLEME Regolith Map products for South Australia

Map name	Central longitude/latitude	Region
Anabama 1:100 000 (2 Mb)	140.25E 32.75S	Curnamona Craton
Bimbowrie Station 1:150 000 (1 Mb)	140.21E 32.04S	Curnamona Craton
Blue Rose 1:12 000 (0.1 Mb)	140.24E 32.64S	Curnamona Craton
Bon Bon/Eba 1:100 000 (3.1 Mb)	135.5E 30.13S	Curnamona Craton
Curnamona 1:500 000 (11 Mb)	140E 31S	Curnamona Craton
Earea Dam 1:25 000 (0.1 Mb)	140.98E 30.87S	Curnamona Craton
Edoldah Tank (ET) 1:10 000 (3.1 Mb)	133.32E 30.9S	Curnamona Craton
Faugh-a-ballagh 1:5000 (0.6 Mb)	140.21E 32.18S	Curnamona Craton
Faugh-a-ballagh 1:12 000 (0.2 Mb)		
Glen Osmond 1:25 000 (0.6 Mb)	138.65E 34.97S	Mount Lofty Ranges, Delamerian Orogen
Half Moon Lake 1:100 000 (5.6 Mb)	133.5E 30.13S	Gawler Craton
Jumbuck 1:50 000 (38.8 Mb)	133.68E 29.87S	Gawler Craton
Kalabity region 1:100 000 regolith-landform map	140.37E 31.82S	Curnamona Craton
Kalkaroo 1:25 000 regolith-landform map	140.47E 31.7S	Curnamona Craton
Luxemburg 1:2500 regolith-landform map	140.57E 32.27E	Curnamona Craton
Mingary 1:100 000 (8.1 Mb)	140.75E 32.25S	Curnamona Craton
Moonta SA 1:25 000 (3.4 Mb)	137.58E 34.05S	Gawler Craton
Mount Babbage Inlet 1:25 000 (5.2 Mb)	139.62E 29.86S	Mt Babbage Inlier
Olary 1:100 000 (1.5 Mb)	140.25E 32.25S	Curnamona Craton
Onkaparinga River 1:25 000 (0.6 Mb)	138.51E 35.16S	St Vincent Basin/Delamerian Orogen
Parabarana 1:25 000 (2.8 Mb)	139.72E 29.99S	Mt Painter Inlier
Pinjarra Lakes 1:40 000 (0.5 Mb)	134.8E 32.12S	Gawler Craton
Tunkillia 1:62 500 (2.5 Mb)	134.75E 31.15S	Curnamona Craton
Wadnaminga 1:5000	140.25E 32.55S	Curnamona Craton
White Dam Region 1:30 000 (11.1 Mb)	140.58E 32.14S	Curnamona Craton
White Dam 1:2000 (10.6 Mb)	140.57E 32.1S	Curnamona Craton
White Dam 1:4000 (0.5 Mb)	140.57E 32.1S	Curnamona Craton
Wilkins Prospect 1:10 000 (0.2 Mb)	134.55E 32.2S	Gawler Craton
Woomera/Koolymilka 1:100 000 (8.3 Mb)	136.88E 31S	Stuart Shelf
Wudinna North Part A 1:20 000 (3.2 Mb)	135.46E 32.81S	Gawler Craton
Wudinna North Part B 1:20 000 (5.2 Mb)	135.46E 32.9S	Gawler Craton

http://crcleme.org.au/Pubs/regmaps.html#sa
http://www.ga.gov.au/oracle/agsocat/geocat_brief.php?title=CRC+LEME&cattype=&catsub=&cattheme%5B%5D=&catno=&author=&maxrecords=500&north=&south=&east=&west=&sort=

METHODOLOGY

REGOLITH CLASSIFICATION – RTMAP SCHEME

The GSSA has chosen to adopt the RTMAP scheme, although adapted, to suit South Australian regolith occurrences, to maintain a level of consistency in regolith classification with the existing Northern Territory and Queensland state regolith maps (Pain et al. 2007; Pain pers. comm. 2008). Together, these will form part of an Australian-wide regolith map being compiled by Geoscience Australia using the same classification scheme.

The RTMAP scheme captures the dominant surface regolith material accompanied by its associated landform attribute. The units mapped are thus regolith-landform units (Pain et al. 2007, Pain et al. 1991). Initial boundaries are drawn on the basis of landforms, and the resulting map polygons are described in terms of both regolith materials and landforms. In the RTMAP scheme landforms have become a surrogate for regolith and hence are the basis for mapping (Craig 2005). Regolith-landform units are generally easy to recognise from remotely sensed images such as aerial photographs, Landsat and ASTER images and are scale-independent units. Observations which can be made or inferred from remote sensing images include: landform characteristics (morphology), geomorphic processes (images from different years), degree and type of dissection, and regolith composition. Regolith materials occur rarely, if ever, as single or pure end members in the real world, as their spatial arrangement and associated landforms are the result of complex interactions of geomorphic processes in the natural environment (Craig 2005); this mixed nature is most evident when mapping at small scales, as in the State regolith map.

For the South Australian regolith map 15 regolith materials and 10 regolith landform types were captured based on the RTMAP scheme (Table 2) in the regolith materials (RM) and regolith landforms (RLF) data layer. Information about whether the material if it is in-situ or has been transported (TI-scheme) was also assigned to each mapped regolith polygon. The basic subdivision between areas dominated by in-situ and transported regolith is largely a result of landform evolution, and reflects the relationships between weathering and erosion on the one hand, and deposition on the other. In addition, each regolith polygon has been attributed with the RED classification, which is based on the premise that the landscape can be divided into three regimes: relict (R), erosional (E) and depositional (D) (Anand and Smith 1993; Anand et al. 1993).

For the South Australian regolith map the RTMAP scheme has been slightly modified in order to accommodate our State-specific regolith features, data availability and the small-scale (1:2 000 000) nature of the map. Mound springs, previously absent in regolith materials in the RTMAP classification (Pain et al. 2007) have now been added as a separate unit (Pain pers. comm. 2008), as well as lacustrine and playa beach sediments (Craig pers. comm. 2012). The regolith landform classification has been adopted from the RTMAP scheme (Pain et al. 2007; Pain pers. comm. 2008) without changes. Due to the small scale of the State regolith map, a more detailed subdivision of regolith materials and landforms has not been undertaken and only major materials and landforms have been recorded.

As very limited information about bedrock weathering intensity was available from existing datasets the RTMAP subdivision of fresh and weathered bedrock into five categories (Pain et al. 2007) could not be applied. Therefore, outcropping bedrock undifferentiated by geological province, lithology and stratigraphy has been subdivided into two map units on the South Australian regolith map: fresh to moderately weathered bedrock and moderately to highly weathered bedrock.

Induration is recorded in the RTMAP scheme under the regolith type field (Pain et al. 2007). For the State regolith map information on various induration types was recorded in a separate data layer. By contrast, surface lag is normally recorded in the RTMAP scheme within the regolith materials as *lag on transported* or *lag on in-situ* materials (Pain et al. 2007). For the South Australian regolith map compilation, lag is now treated similarly to induration and is captured in a separate data layer. Whether mapped lag overlies in-situ or transported regolith material can be established by reference to the corresponding regolith materials polygon. This approach has been taken because, conceptually, induration and lag can be considered to constitute a modification of regolith materials; it is proposed as an enhancement of the RTMAP scheme.

Induration and lag data layers are used as overlay patterns on the regolith material in the hardcopy map. For more information about the compilation process of these two data layers see below (Induration and Lag).

Table 2. Regolith attributes captured in ArcGIS based on revised RTMAP scheme classification

TI_scheme	RED_ scheme	RM_UNIT	RM_ CODE	RM_ MAP SYM	RM_DESC	RLF_UNIT	RLF_ CODE	RLF_ MAP SYM	RLF_DESC
transported	depositional	transported sediments	STR	TR	Materials deposited by terrestrial geomorphic processes. Including undifferentiated sediments of mixed -colluvial, alluvial, aeolian, lacustrine- or unknown origin and some Cenozoic formations and palaeochannel sediments.	depositional plain	PL01	pd	Level landform pattern with extremely low relief formed by unspecified depositional processes.
transported	depositional	aeolian sediments	SDE00	I	Sediment deposited from transport by wind forming inland and coastal dunes, dunefields, sandsheets and interdunal areas.	aeolian landforms	DU00	u	Landform pattern built up or locally excavated, eroded or aggraded by wind.
transported	depositional	alluvial sediments	SDA00	A	Sediments deposited by channelled and over-bank stream flow confined to a channel or valley floor.	alluvial landforms	AL00	a	A complex landform pattern on valley floors with active, inactive or relict erosion and aggradation by channelled and over-bank stream flow.
transported	depositional	colluvial sediments	SDC00	C	Heterogeneous material of variable grain size accumulated on slopes by gravity, creep, sheet flow, rainwash, mudflows or solifluction.	erosional landforms	ER00	e	Landform pattern of very low to high relief and very gentle to steep slopes. The pattern is eroded by continuously active to slightly active or inactive geomorphic processes.
transported	depositional	sheet flow deposits	SDC05	CH	Distal slope sediments deposited by unconfined sheet flow or a network of rills. Often characterized by distinct contour banding/tiger bush surface pattern. Subunit of colluvial sediments.	erosional landforms	ER00	e	Landform pattern of very low to high relief and very gentle to steep slopes. The pattern is eroded by continuously active to slightly active or inactive geomorphic processes.
transported	depositional	lacustrine sediments	SDL00	L	Sediment deposited from solution and suspension in still water in an inland lake, playa or pan.	lacustrine and playa plains	PL01	pl	Level landform pattern with extremely low relief occupied by a lake or playa. Build up by aggradation of waves and deposition of material from suspension and solution in standing water. Bounded by cliffs, rock platforms, beaches, berms and lunettes.
transported	depositional	lacustrine and playa beach sediments	SDS01	OB	Inland beach deposits resulting from wave and wind actions along the shores of lakes and playas.	beach	PL05	pb	Level landform pattern with extremely low relief built up by coastal processes along an inland lake or playa margin.
transported	depositional	coastal sediments	SDS00	O	Sediments deposited in the coastal zone including beach and tidal deposits.	coastal landforms	CO00	c	Level to gently undulating landform pattern of extremely low relief eroded or aggraded by waves, tides, overbank or channel flow, or wind. The landform pattern may be either active or relict.

TI_scheme	RED_ scheme	RM_UNIT	RM_ CODE	RM_ MAP SYM	RM_DESC	RLF_UNIT	RLF_ CODE	RLF_ MAP SYM	RLF_DESC
transported	depositional	paludal sediments	SDP00	P	Swamp deposits accumulated in a closed or almost closed depression with seasonal or permanent water table at or above the surface.	plain	PL00	p	Level to undulating or, rarely, rolling landform pattern of extremely low relief (<9 m). Some types of plains are described under alluvial landforms, and some are also described under erosional landforms.
transported	depositional	spring deposits	SDD00	DS	Modern and fossil mound spring deposits formed by groundwater discharge, often surrounded by wetland.	mound spring	MS00	ms	A low hill formed by springs and surrounded by wetland. The term mound spring is applied to any spring that has its source in the Great Artesian Basin.
transported	depositional	volcanic materials	VOL00	V	Volcanic sediments including tephra and lava flows on depositional, erosional and volcanic landforms.	volcano	VV00	v	Typically very high and very steep landform pattern without stream channels, or with erosional stream channels forming a centrifugal or radial tributary pattern. The landform is built up by volcanism, and modified by erosional agents.
in-situ	erosional	fresh to moderately weathered bedrock	SFM	BUSM	Fresh to moderately weathered bedrock on erosional plains, rises, low hills, hills, mountains and plateau surfaces.	erosional landforms	ER00	e	Landform pattern of very low to high relief and very gentle to steep slopes. The pattern is eroded by continuously active to slightly active or inactive geomorphic processes.
in-situ	erosional	moderately to highly weathered bedrock	SMH	SMH	Moderately to highly weathered bedrock on erosional plains, rises, low hills, hills, mountains and plateau surfaces.	erosional landforms	ER00	e	Landform pattern of very low to high relief and very gentle to steep slopes. The pattern is eroded by continuously active to slightly active or inactive geomorphic processes.
in-situ	residual	residual material	WIR20	R	Material derived from in-situ weathering of bedrock of undifferentiated origin (including Cenozoic formations) without significant lateral movement of the solid weathered products. Includes residual clay and sand.	erosional landforms	ER00	e	Landform pattern of very low to high relief and very gentle to steep slopes. The pattern is eroded by continuously active to slightly active or inactive geomorphic processes.
in-situ	residual	soil on bedrock	WIR24	RB	Soil material of 0.5 to 1.5 m thickness formed on bedrock of various types and weathering intensity.	erosional landforms	ER00	e	Landform pattern of very low to high relief and very gentle to steep slopes. The pattern is eroded by continuously active to slightly active or inactive geomorphic processes.

DATA SOURCES

The broad scale for which the State regolith map has been compiled determined which datasets were most suitable to use for its compilation. Due to its 1:2 000 000 scale, state-wide datasets were preferably used to maintain a consistent interpretation in order to achieve a coherent state-wide regolith map.

Map and data compilation was undertaken in ArcGIS and was based on the integration and compilation of a variety of input datasets at various scales (see Table 3 for details and data links) including:

- geology data, maps and explanatory notes;
- existing regolith data and maps;
- South Australian Palaeochannel and Tertiary Coastal Barriers maps (Hou et al. 2007; Hou et al. 2012);
- remotely-sensed data and imagery;
- topographic data and digital elevation model;
- DEM derivative products;
- geophysical State images;
- weathering intensity map of Australia (Wilford 2011);
- soil and land system data;
- calcrete analysis and reanalysis layer SARIG;
- SA GEODATA field observations database.

Table 3. Data and data sources used for State regolith map compilation

Data sources	Hyperlink
100k geology layer	https://sarig.pir.sa.gov.au/Map
2M geology layer	https://sarig.pir.sa.gov.au/Map
Geophysics (radiometrics, magnetics, gravity)	https://sarig.pir.sa.gov.au/Map
ASTER Geoscience Map of South Australia	https://sarig.pir.sa.gov.au/Map
Landsat ETM7 images	http://zulu.ssc.nasa.gov/mrsid/
Multiresolution Index of Valley Bottom Flatness (MrVBF)	http://www.ga.gov.au/resources/multimedia/world-wind.jsp
Weathering intensity map of the Australian continent (Wilford 2011)	http://www.ga.gov.au/ausgeonews/ausgeonews201103/weathering.jsp
Digital Atlas of Australian Soils (Northcote)	http://data.gov.au/dataset/atlas-of-australian-soils/
Datasets, interpretations and meta-data available for download through the Australian Soil Resource Information System ASRIS	http://www.asris.csiro.au/themes/Atlas.html
DWLBC Soil Landscape Map Units of Southern South Australia *(former Department of Water, Land and Biodiversity Conservation (DWLBC); now Department of Environment, Water and Natural Resource (DEWNR))*	LAND and SOIL SPATIAL DATA CD for Southern South Australia – GIS format http://www.naturemaps.sa.gov.au/sim/dataSet-display.do?cmd=DataSetDto&dsNumber=1444
Regolith Terrains of Australia 1:5M, Geoscience Australia	http://www.ga.gov.au/meta/ANZCW0703002403.html
CRCLEME Regolith Map products for South Australia	http://crcleme.org.au/Pubs/regmaps.html#sa http://www.ga.gov.au/oracle/agsocat/geocat_brief.php?title=CRC+LEME&cattype=&catsub=&cattheme%5B%5D=&catno=&author=&maxrecords=500&north=&south=&east=&west=&sort=

Additional knowledge of the South Australian regolith and weathering history is based on Sheard et al. (2008) and Fabris et al. (2008).

MAP COMPILATION METHODOLOGY

Mapping was based on the 1:250 000-scale (250k) geological map series and its updated, digital equivalent, the 1:100 000 (100k) geology map dataset on SARIG (South Australian Resource Information Geoserver). The polygon linework for the regolith map dataset was newly compiled using ArcGIS 9.3 for 68 250k-scale mapsheets. For each regolith polygon ten attributes were captured during the mapping process including regolith materials and landform name, description, RTMAP code and map symbol, as well as the TI (transported – in-situ) and RED schemes (see Table 2).

Mapping and map compilation was based on a variety of data as stated above, with the 100k and 1:2 000 000 (2M) State geology datasets, Landsat images, high resolution digital elevation model (DEM) radiometrics and 3D view Google Earth imagery used as the key layers for a state-wide map compilation.

Spatial accuracy and linework detail was highly improved compared to the 2M State geology dataset (Cowley 2001), by reference to higher resolution images with better spatial control. This also makes the linework of the digital regolith dataset usable at scales of less than 2M.

It should be noted that the South Australian regolith map represents the surface distribution and expression of the regolith and it does not include any information about regolith thickness, stratigraphy and age. Therefore, no in-situ regolith profile nomenclature has been applied (including saprolith, saprock, saprolite and pedolith).

During a previous project in 2008/09 a first draft dataset for the South Australian regolith map was compiled in GSSA by K. Brownlie and W. Cowley. This dataset was based on re-attributing the existing 2M digital geology layer. Existing polygons were re-attributed with regolith material and landform attributes based on the RTMAP scheme. As the existing polygon boundaries for the 2M State geology were used, this dataset over-represented the bedrock geology. Nevertheless this dataset and the reasoning developed for adapting the RTMAP scheme to a State map was a useful supplement to the other key datasets.

MAJOR FACTORS IMPEDING MAPPING OF REGOLITH IN SOUTH AUSTRALIA

Using state-wide, uniform datasets for the compilation of the South Australian regolith map, especially Landsat ETM7 imagery and a high resolution, 1sec DEM, favoured a consistent mapping approach. Nevertheless, some of the datasets used and the nature of the surface expression of the regolith had some effects on a consistent map compilation throughout the State. For example the geological mapping now presented in the 100k digital geology layer on SARIG was compiled by a variety of geologists over a long period of time and was captured at a variety of scales from 1:250 000 down to 1:20 000. Notably, much of this geological mapping provides minimal or no regolith information. There are also inconsistencies within and between standard mapsheets. In particular, many discrepancies were encountered for Cenozoic stratigraphic units where different interpretations of the same or similar unit or varying degrees of subdivision were noted.

It is only since the CRCLEME involvement that GSSA has incorporated regolith geology and mapping formally into its programme. Prior to that, mapping, field profile descriptions and relevant studies and reports were ad-hoc and used a range of mapping procedures and classification schemes, and areal coverage of the State was minimal.

Significant vegetation cover, anthropogenic and agricultural overprinting, as well as fire scarring are major hindrances to reliably classifying the regolith material in many areas of the State. The lack of diagnostic features in remotely sensed data over terrain with subdued topography, intense weathering, similar geology, intense vegetation cover, overprint by various land use (e.g.

agriculture, infrastructure, mining) or intense fire scarring meant that regolith material origin and composition could not consistently be interpreted in these areas.

UPSCALING

As spatial accuracy and linework detail was highly improved for the digital regolith data set (2M regolith detail) a generalised data set (2M regolith) had to be produced for the hardcopy compilation of the map. Map generalising was accomplished using the *automated generalisation of the surficial geology maps module* of the GeoScaler software. GeoScaler was developed at the Laboratoire de Cartographie Numerique et de Photogrammetrie (LCNP) of the Quebec division of the Geological Survey of Canada (Version 2009).

THE GEOSCALER SOFTWARE

GeoScaler 2009 is a freely downloadable plug-in for ArcGIS (http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/710409f8-8705-513b-8e16-b664159c759a.html), which requires ArcMap 9.3 with an ArcInfo licence and ArcInfo Workstation. The tool was developed at LCNP exclusively for the purpose of generalising surficial and bedrock geology maps. The surficial module was used to generalise the regolith polygons from a grid file based on the iterative Cellular Automata (CA) procedure, using a set of Arc Macro Language (AML) scripts to implement its algorithm. The AML tools execute selected ArcGIS utilities in a certain sequence to achieve clarity at the target scale. The polygons found on the generalised map, while being legible, must remain as close as possible to those found on the source map.

GENERAL METHODOLOGY

The GeoScaler software consists of two central modules designed for surficial and bedrock geology generalisation. The two major tools underlying the generalisation procedure are the principle of CA and the method of near analysis.

The CA model represents a finite state machine consisting of a raster image of cells with each cell capable of taking one of the finite numbers of states corresponding to the number of regolith units found on the original map (Fig. 1a). The state calculation rule used, says that if a cell is in the same state as most cells in its neighbourhood, the state is kept unchanged, otherwise, it is changed to reflect the state of the majority. As shown in Figure 1b, the neighbourhood radius is described by the width of the belt formed by state controlling cells around the cell whose future state is being evaluated (Moore's neighbourhood). The final generation is defined as the one after which no further polygon alterations occur (Fig. 1c).

GENERALISATION PROCEDURE

The first step in the generalisation process was to convert the regolith vector map into a single raster. This was achieved with the data preparation tool. An additional attribute column was added to the regolith polygon vector shape file, the unique geological code served as the first input parameter. The second required parameter needed to be defined at this step was the resolution of the output raster. Preliminary tests showed that 90 m resolution is a good balance for the required scale change (1:250 000 to 1:2 000 000). Tests at a higher resolution (40 m) resulted in preservation of unnecessary details in the shape of polygons, while lower resolution (200 m) tests yielded overgeneralised maps.

The next step included the actual raster generalisation; five parameters are required for the polygon generalisation procedure using the CA model. The previously created input grid file is a raster representation of the map being generalised. Moore's neighbourhood radius is a numeric value in the range of 1 to 5 that represents the number of cells on each side of the cell being analysed included in its neighbourhood. Only the cells within the chosen neighbourhood radius can affect the state of the cell under consideration. The final CA generation is the last cell generation produced by the algorithm before the processing stops and is saved by the tool. The valid range of iterations is from 1 to 250 with higher generations yielding greater generalisation levels. The minimum polygon size is the minimal number of cells required for a polygon to remain on the map. If a polygon is represented by fewer cells than the specified number, it will be eliminated and its cells will be replaced by the values of their nearest neighbours. If not entered, all polygons resulting from the CA process will remain on the map. The output interval parameter allows intermediate cell generations to be saved for further examination and used to determine the most appropriate generalisation level. The parameter values used for the generalisation procedure are listed in Table 4.

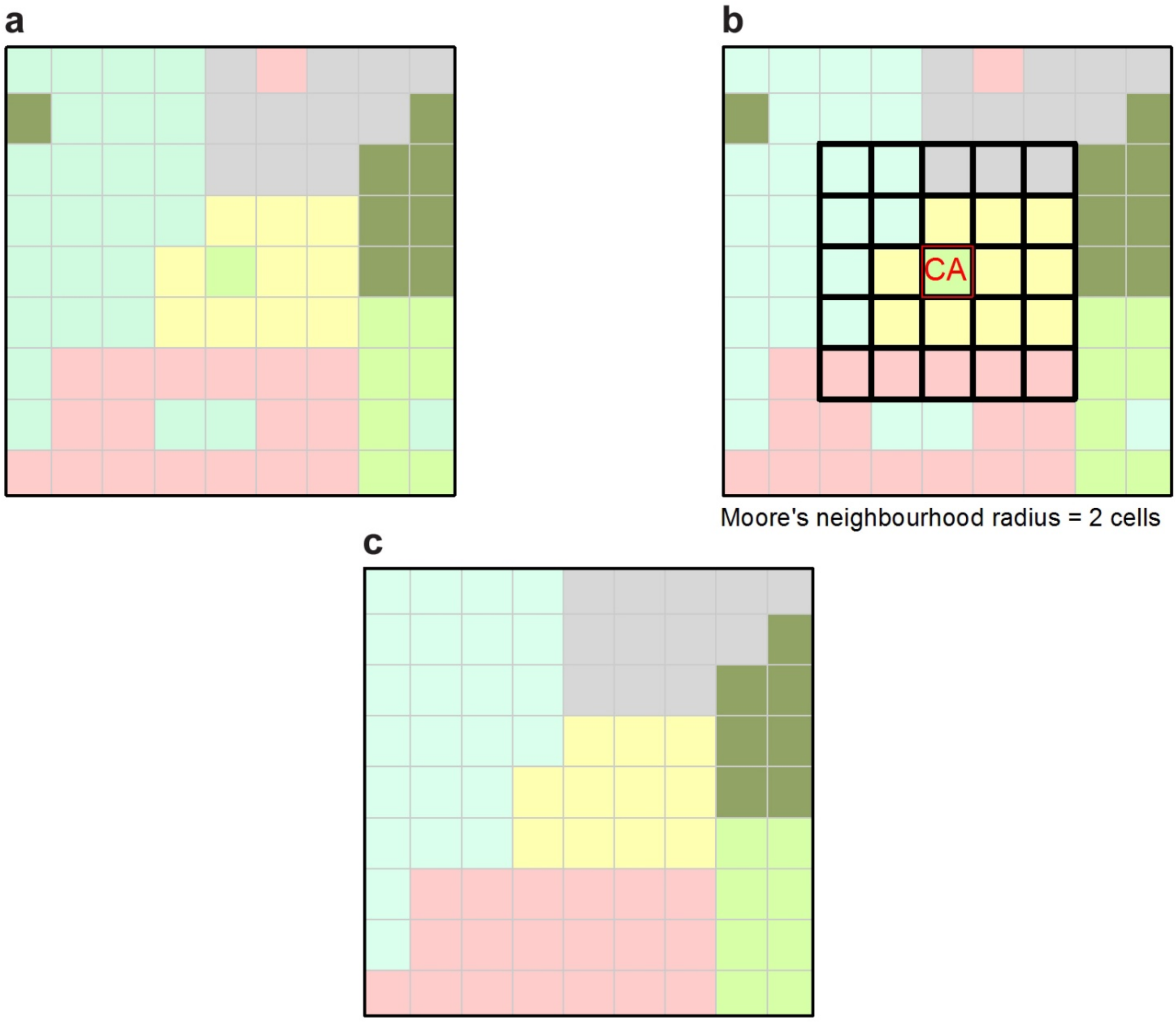

Figure 1. Cellular automata generalisation.
a. An input raster map with different colours representing different units.
b. The decision making: The next state of cell CA will match the state most frequently occurring in its neighbourhood, which includes the two closest cells in every direction.
c. Final generation of cells after alterations occur.

Table 4. Surficial generalisation model parameters and their respective values

Parameter name	Parameter value Surficial
Input grid file (raster resolution)	90 m
Moore's neighbourhood radius	2 cells
Final cellular automata generation	10
Minimal polygon size (cells)	0
Output interval (optional)	2

After the appropriate level of generalisation is achieved, the resulting raster was converted back into a vector polygon shape file. As the minimum number of cells required for a polygon to remain on the map was purposely unspecified, further post processing occurred to replace small overgeneralised remnant polygons. These over-generalised polygons were either merged or replaced with up-scaled polygons (Fig. 2).

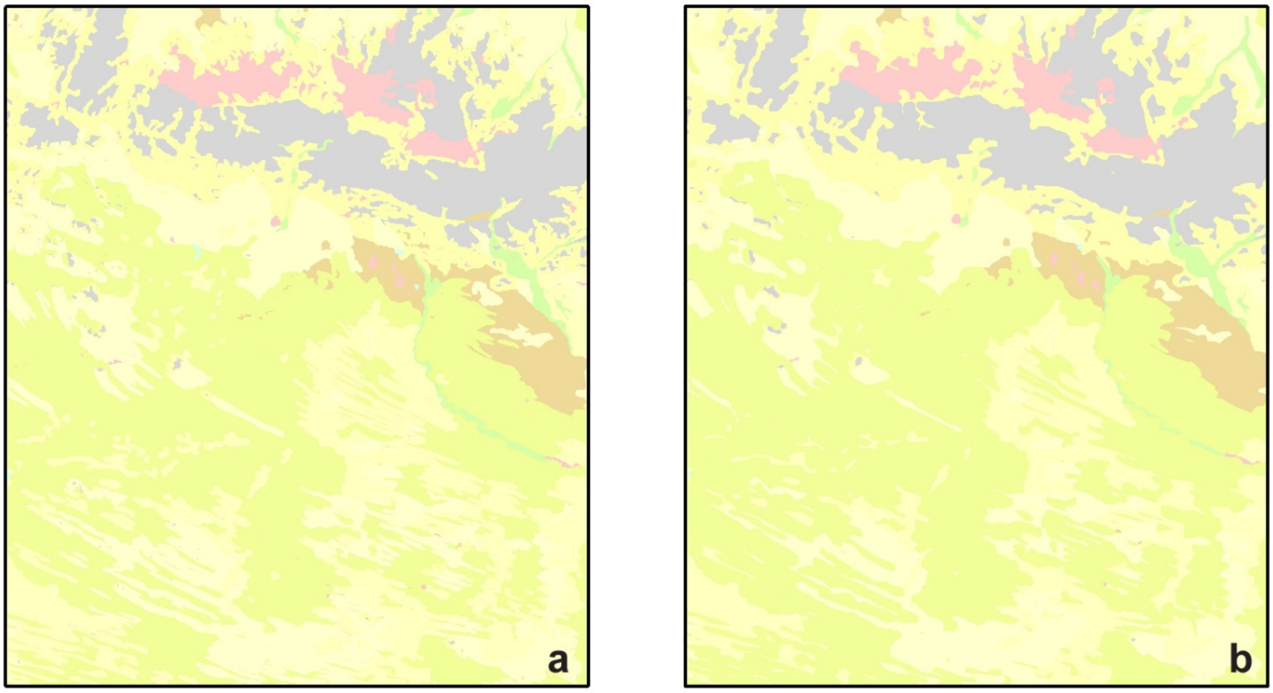

Figure 2. Geoscaler generalisation results.
a. A sample area from the original map reduced to the new scale (1:2 000 000) before generalisation. **b.** The same area after the polygon generalisation.

ACCURACY ASSESSMENT

Due to the wide variety and complexity of South Australian's regolith material and landforms, the 2M state-wide regolith map is designed to provide a broad regional overview and should not be used to draw conclusions about conditions at specific locations.

Comprehensive regolith mapping requires detailed field and laboratory work, and subsequent data analysis. This detailed work has not been undertaken for the compilation of this map. Therefore, information describing specific features has been applied to broad areas, and unrecorded variations from the assigned classification will occur. It is also probable that additional regolith materials, landforms, induration and lags are present that have not been described and attributed.

Due to the 2M scale of the mapping, variations within mapping units will occur. Most of the information used to delineate and attribute the polygons is derived from pre-existing digital data, and interpretations based on the personal experience or judgement by the author and other GSSA geoscientists have been used where data were unavailable.

DELIVERABLES AND AVAILABILITY

- Generalised hardcopy map of the regolith of South Australia at 1:2 000 000 scale with induration and lag information overprint and additional map products (regolith landforms, TI and RED scheme) and conceptual regolith cross sections;
- South Australian regolith digital dataset (GIS) based on 1:250 000-scale mapping including regolith material and landforms attributes (Table 2) for each regolith polygon and additional induration and lag GIS layers, to be available though SARIG in ESRI shapefile, MapInfo and Google Earth formats.

SHORT SUMMARY OF MAJOR REGOLITH FEATURES IN SOUTH AUSTRALIA

South Australia has a wide variety and diversity of regolith features. To capture them in high resolution for a 1:2 000 000-scaled hardcopy map as well as for the more detailed State regolith digital dataset is impractical. Therefore, many generalisations have had to be made, especially using only broad regolith material and landform classes (see Table 2).

TRANSPORTED REGOLITH

Transported regolith includes undifferentiated transported, aeolian, alluvial, beach, coastal, colluvial, lacustrine, paludal (swamp), sheet flow, spring, and volcanic sediments. Transported regolith material accounts for 75% of the State by area (Table 5).

Transported sediments is the most generalised transported regolith material class as it includes all regolith material that is either of mixed or unknown origin but has experienced transport. For the State regolith map transported sediments dominantly represent a mixed origin of various regolith materials (mainly colluvial/fluvial/aeolian/lacustrine) especially in areas of transitional or spatially complex regolith landform regimes. They are often overprinted by calcareous induration or they represent the source sediments of an overlying lag ('lag on transported sediments' in the RTMAP scheme of Pain et al. 2007). Most of the surface occurrences of palaeochannel and palaeo-shoreline deposits have also been mapped as terrestrial sediments as they are mainly referred to as mixed, fluvial-lacustrine-aeolian, in origin (Hou et al. 2007, 2012).

Aeolian sediments and their associated aeolian landforms are the dominant regolith material in South Australia, covering more than 43% of the State (Table 5). Aeolian landforms, such as dunefields and sandplains, are widely preserved in today's landscape and form extensive parts of the Great Victoria, Tirari, Pedirka-Simpson-Strzelecki deserts. Coastal dunes and foredunes are also included in this regolith unit.

Alluvial sediments include fluvial channel and overbank/floodplain as well as alluvial plain deposits. They occupy less than 5.4% by area (Table 5). Alluvial deposits occur mainly along rivers and creeks, with the Murray, Cooper, Warburton, Macumba and Neales rivers accounting for the largest river systems in the State. Most of the river systems in South Australia are ephemeral and experience discharge/flooding on an irregular basis.

Colluvial sediments are widespread along range fronts, slopes, rises, and depositional and erosional plains and make up to 8.7% of the regolith material by area (Table 5). They are variably thick and bedrock-masking heterogeneous deposits of variable grain size. They are typically coarse and angular on upper slopes, where they dominantly represent debris flow deposits (Eggleton 2001). Downslope they decrease in grain size and transition into sheet flow deposits.

Sheet flow deposits are a subclass of colluvial sediments. They are included on the Queensland and Northern Territory State regolith map within the colluvial regolith material class. For the South Australian regolith dataset, sheet flow deposits have been assigned as a separate class, as they often have a finer grain size spectrum than higher angle colluvial slope deposits and therefore represent a more homogeneous sampling medium within the colluvial class. They cover up to 5.4% of the State by area (Table 5). Sheet flow deposits are associated with lower slopes and generally display a distinct contour banding/ tiger bush/striping surface pattern. This surface expression is due to banded mosaic vegetation patterns separated by bare ground, that run roughly parallel to contour lines of equal elevation, formed on gently sloping plains (Wakelin-King 1999).

Lacustrine sediments comprise fresh water lake deposits as well as playa and salt lake deposits. Playas and salt lakes have been included in this class as most of them are underlain by stratified clay, silt or sand. Soluble salts form often only a thin salt crust on the surface. Coastal freshwater lagoons have been also incorporated into this regolith class.

Lacustrine and playa beach sediments are situated along the shores of the large inland lakes and playas (e.g. Lake Frome and Lake Gairdner) and also includes prominent remnants of Pleistocene beach ridges near Lake Eyre South. They are a subclass of lacustrine sediments.

Coastal sediments occur along the marine coastal zone of South Australia and include coastal barrier, back barrier lagoon, shoreface, tidal and delta deposits. Beaches along the coastal zone are in most cases too narrow to capture for the State regolith map and were mostly incorporated into the coastal sediments class.

Paludal sediments occur only along and inland of the State’s South-East coast as carbonate-precipitating lakes and swamps. They represent almost level, closed or almost closed depressions with a seasonal or permanent water table at or above the surface, commonly aggraded by overbank stream flow and sometimes with biological (peat) accumulation (Eggleton 2001). Today most of these areas are drained and dry.

Spring deposits are associated with the mound springs of the southern margin of the Great Australian Basin. These springs can arise from a mound, rock fracture or a seep and form low hills of limestone and gypsiferous, calcareous and carbonaceous/organic silt surrounded by wetlands around their base (Habermehl 1982; Sheard and Smith 1993).

Volcanic material is restricted to the Quaternary basaltic lava and ash deposits of the Mount Gambier and Mount Burr groups in the Lower South-East of the State. Several cones, domes and maars that punctuate today’s landscape characterise the volcanism in this area (Sheard 1993). It should be noted that the Gawler Range Volcanics and other known pre-Quaternary volcanic units have not been included in the volcanic material regolith class but have been mapped as variably weathered in-situ bedrock.

IN SITU REGOLITH

In situ regolith refers to weathered bedrock that has undergone no or minimal physical transport (Eggleton 2001) and accounts for 24.3% of South Australia’s regolith by area (Table 5). There is hardly any outcropping bedrock in South Australia that hasn’t experienced some degree of weathering. Weathering intensity can vary dramatically over short distances within an outcrop area. Variably weathered bedrock can be found in many areas of the State and occurs in all geological provinces, with extensive exposures of bedrock mainly in the Flinders, Willouran and Mount Lofty Ranges, Gawler Ranges, Peake and Denison Ranges, Musgrave Ranges and the tablelands of the Eromanga Basin. Landforms associated with in-situ regolith are exclusively erosional and include eroding uplands and mountains, ranges, hills, tablelands, inselbergs and whalebacks, ridges, and erosional windows in areas of transported regolith.

For the South Australian regolith map a simplified bedrock classification approach has been applied due to limited availability of reliable weathering intensity data. Therefore, a division into the following two sub-categories has been used: ***fresh to moderately weathered bedrock*** and ***moderately to highly weathered bedrock***. A subdivision into in-situ regolith profile units like saprolith (including saprock, saprolite) and pedolith, as used for the Northern Territory and Queensland state regolith maps, has not been applied as more information on three dimensional weathering profiles in outcrops and subsurface would be needed.

In-situ regolith also includes ***residual material*** which 'results from the weathering of rock without significant lateral movement of the solid weathered products' (Eggleton 2001, p. 103). Residual material makes up to 10% of regolith material on the State regolith map (Table 5). It includes large areas of the Nullarbor Plain, where residual clay and sand is the result of in-situ weathering of the limestones of the Eucla Group. Loss of volume mainly through solution is a characteristic of this regolith class.

A subclass of residual material is ***soil on bedrock***, which, in this map and dataset, represents all soil material of 0.5 to 1.5 m thickness formed on bedrock of various types and weathering intensity. Main input data for this regolith class was derived from the 'depth to hardrock' attribute from DWLBC 'Soil landscape of South Australia' data layer (Table 5).

Table 5. Regolith material units by area and percentage

Regolith material unit	Area in sq km	Area in %
transported sediments	69304.44	7.05
aeolian sediments	429955.94	43.76
alluvial sediments	52894.60	5.38
colluvial sediments	85602.62	8.71
sheet flow deposits	53286.47	5.42
lacustrine sediments	39114.82	3.98
lacustrine and playa beach sediments	954.26	0.10
paludal sediments	8036.47	0.82
coastal sediments	4282.08	0.44
spring deposits	279.50	0.03
volcanic materials	78.28	0.01
SUM transported regolith material	*743789.47*	*75.70*
fresh to moderately weathered bedrock	43481.04	4.43
moderately to highly weathered bedrock	90126.05	9.17
residual material	98452.61	10.02
soil on bedrock	6709.09	0.68
SUM in-situ regolith material	*238768.79*	*24.30*

INDURATION

Induration is defined as 'the hardening of a rock, rock material or regolith by the action of heat, pressure, or the introduction of some cementing material not commonly contained in the original mass: especially the process by which relatively consolidated rock is made harder or more compact' (Eggleton 2001, p. 51).

Induration of regolith material (both in-situ and/or transported) has and is still occurring as part of South Australia's weathering history mainly by the introduction and precipitation of silica, iron oxides, carbonates and sulphate (gypsum). The indurated material is generally present as distinctive cemented horizons (termed duricrust and hardpan/pan), which increase the substrate's resistance to weathering and erosion. Hence the indurated regolith material is often preserved through topographic inversion as profiles capping topographic highs in the modern day landscape.

Six different induration classes have been compiled as an additional layer for the State regolith dataset: ferruginous, siliceous, calcareous, gypsiferous, mixed calcareous-gypsiferous and undifferentiated (including mixed induration of various types) (Table 6). The information for the induration dataset has been extracted and compiled mainly from the 100k and 2M geology layers (SARIG). For the calcareous layer additional data sources were used including the Digital Atlas of Australian Soils and the DWLBC Soil Landscape Map Units of Southern South Australia ‘surface carbonate layer’ (see Table 6).

Table 6. Data sources for regolith induration and lag layer

Induration	Source data
Siliceous	Extract 100k geology layer (si)
	Extract 2M geology layer (si)
Ferruginous	Extract 100k geology layer (fe)
	Extract 2M geology layer (fe)
Calcareous	Extract 100k geology layer (ca)
	Extract 2M geology layer (ca)
	Digital Atlas of Australian Soils (Northcote)
	DWLBC Soil Landscape Map Units of Southern South Australia: surface carbonate layer
	SARIG calcrete sample layer
	Fig. 3 Distribution of calcrete and associated soils (Lintern, 1997) Malcolm Sheard (pers.comm. 2012)
Gypsiferous	Extract 100k geology layer (gy)
Mixed calcareous-gypsiferous	Calcarous layer
	Goyder line
	Malcolm Sheard (pers.comm. 2012)
Undifferentiated	Extract 100k geology layer (sf, bx, po)
	Extract 2M geology layer (ca/fe, ca/si, fe/si, si/gy)

Search function in ArcGIS 9.3 for 100k geology layer: Select by attribute: field calculator: Mapunit=’%si%’

Lag	Source data
	Extract 100k geology layer (lag)
	Extract 2M geology layer
	DWLBC soil map of SA: Gibber Landsystem

Search function in ArcGIS 9.3 for 100k geology layer: field calculator: Mapunit =’%lag%’

LAG

Surface lags are common and widespread in many parts of South Australia, e.g. the Stony Desert and the Moon Plain northeast of Coober Pedy. Lag is a general term for a surface accumulation of materials of diverse origin, such as various regolith materials, rocks, and mineral particles. Most lags range from granules to cobbles (2 to 256 mm) and are dominated by chemically and physically resistant minerals and rocks. They result from the removal of finer material by aeolian and/or sheet flow processes, or by matrix removal as a result of differential weathering (Eggleton 2001, p. 57). In Australia the term ‘gibber; is often used as a synonym for particularly pebble- to cobble-sized lags.

The type of lag present in an area is partly a function of the local regolith, landform and bedrock lithology. It can reflect the immediately underlying bedrock or regolith material, a local source, a distant source or a mixture of all three. The lag dataset was compiled using the 100k and 2M geology layers (SARIG) and the DWLBC Gibber Landsystem data (see Table 6).

FEEDBACK AND FUTURE DEVELOPMENT

The South Australian regolith data set will become an integral part of the Australian regolith map currently being compiled by Mike Craig at Geoscience Australia. It will also represent a base data set for upcoming regolith mapping projects within GSSA. Feedback is welcomed and will be assessed for incorporation into future editions.

GSSA intends to continue regolith mapping as an integral part of current geological mapping projects focusing on the production of higher resolution regolith maps at scales of 100k and 250k. This will especially allow the capture of more detail and subclasses of regolith material and landform map units.

In order to compile consistent regolith maps throughout the State it will be crucial to establish a standardised regolith mapping procedure based on 100k mapping. Fist steps have been taken by developing a regolith tab within the new digital field mapping data capture program of the GSSA mapping team. Field trials in the Musgrave Province have taken place, with good results.

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