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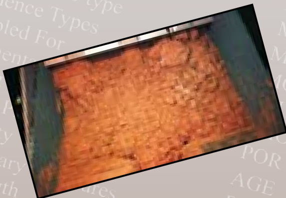
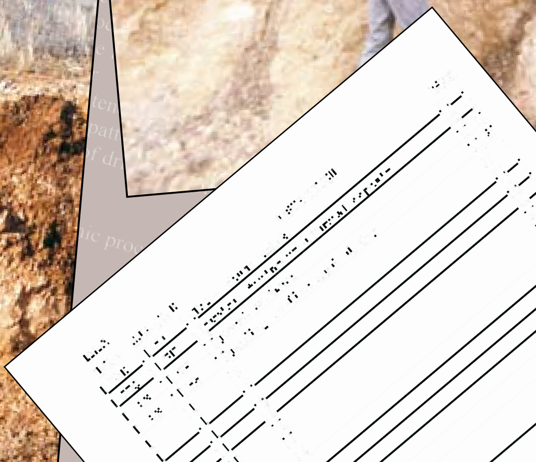
Field Guide for Describing Regolith and Landforms

C.F. Pain





FIELD GUIDE FOR DESCRIBING REGOLITH AND LANDFORMS

C. F. Pain

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Field Guide for Describing Regolith and Landforms

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CONTENTS

PREFACE

The use of standard terminology for the characterisation of site attributes, such as landform and vegetation, and for the description of regolith has obvious benefits for the various organisations in Australia concerned with regolith investigations. Some uniformity in the description of regolith has been achieved over the years with the publication of *RTMAP Regolith Database Field Book and Users Guide* (Pain *et al.*, 1991, 2007), *Regolith landform mapping in the Yilgarn Craton, Western Australia: towards a standardised approach* (Craig *et al.*, 1999) and *Genesis, classification and atlas of ferruginous materials, Yilgarn Craton* (Anand *et al.*, 2002).

Because there are a number of possible approaches (for example, in setting class limits) for many attributes, the classes adopted here are taken, where possible, from Australian standards—and in particular *The Australian Soil and Land Survey Field Handbook* (McDonald *et al.*, 1990, NCST 2008), which is considered to be most appropriate for Australian conditions.

This Guide is based largely on the field component of Pain *et al.*, (2007). It covers a range of field observations that are convenient to measure or observe, and are relevant both to practical problems of mineral exploration and natural resource management, and the scientific study of regolith. *Improvements* will depend to a degree on the use of more systematic methods in the recording of field observations, in order to test the underlying, often un-stated models that often guide the recording of such observations. It is hoped that the use of this Guide will allow the development of more concise, or more relevant, field observations than those recommended in it. Improvements will come only from knowledge of the precise needs of clients.

Colin Pain
Canberra
July 2008

1. PURPOSE AND USE OF THE FIELD GUIDE

1.1 Purpose

This Field Guide—with its definitions, concepts and codes—is an aid for making or reading descriptions of regolith and landforms, and sampling regolith, as presently practiced within CRC LEME, Geoscience Australia (GA) and some Australian state and territory agencies. It contributes to the systematic recording of field observations of regolith by:

- listing attributes that are necessary to adequately describe site and regolith characteristics
- defining these attributes, wherever possible, in a manner consistent with their use elsewhere in the world, but giving particular emphasis to Australian conditions
- briefly defining terms and categories for landform, land surface, soil and regolith that are based on current use by practising professionals
- suggesting codes for the various attributes, terms and categories so that concise recording systems may be developed for field and database use.

The Field Guide also provides a basis for interpreting regolith materials. Regolith properties are measured or inferred from direct observations in the field or laboratory. Field observations provide the basis for prediction and extrapolation of regolith knowledge into areas that are not visited (see Pain 2008 for a more detailed discussion). These observations may be supplemented by data from aerial photos, remotely sensed images, maps, records, laboratory analyses, experiments, local information, and so on. Such prediction and extrapolation is clearly successful only some of the time and, where it is not, the weakest link may be the collection of relevant field data.

This Field Guide was prepared to meet the needs of regolith surveys for both mineral exploration and natural resources management: covering a range of scales from very detailed to state and regional. The observations proposed are therefore relevant to surveys at diverse scales, although surveys at very large scales commonly demand both more detailed observations, and also observations of particular attributes that probably have not been included here. At such large scales, many attributes of the site surrounding each point of regolith observation may be uniform over most of the points and thus of little interest within the context of the given survey. However, if site attributes are recorded for at least a few of the observation points, they may prove extremely valuable in later, broader scale work.

The recording of regolith and landform attributes of the site and adjacent areas has two distinct purposes. First, they may be directly relevant to land use—to mining and earthmoving costs, erosion hazards, scenic resources, costs of clearing, likelihood of salinity, and so on. Second, they are a link between the hidden physical and chemical properties of the soil, regolith or bedrock, for which data will always be scarce, and the visible properties of landform, surface material and vegetation that may be more readily mapped and catalogued.

Site attributes link to other attributes both within a site and beyond it. On one hand, they are intended to be correlated with regolith and other subsurface properties observed at the site in an effort to discover significant relationships between them. Validation is required to justify extrapolative mapping and the setting up of regolith units or land components. On the other hand, the site data are intended to establish local 'ground truth' values for the landform, surface material and vegetative properties that contribute to the more extensively developed characteristic image, 'signature', or pattern on an aerial photo or other remotely-sensed record.

1.2 Use

The Field Guide is designed as a reference to attributes necessary for describing systematically the site, soil and regolith conditions as they relate to landform, vegetation, land surface, soil profile and regolith. The definitions of terms will assist users to a uniform understanding of the meaning of words used in field notes, in discussion and in publications. This will enhance communication and, in this sense, continues the work of the CRC LEME Glossary (Eggleton 2001).

The attributes to be recorded in a specific survey will depend on its purpose and scale and will be decided upon by the organisation conducting the survey. In reconnaissance surveys, fewer site and profile attributes will be described than in high-intensity surveys. For detailed site and profile descriptions, such as those required for geoscience research, or in the legend-making stage of detailed surveys, most of the attributes given in this Field Guide will be recorded, if present.

Most of the attributes of regolith to be observed, layer by layer, are widely accepted among regolith geoscientists, as well as other geoscientists and pedologists.

Importantly, sites and profiles should be described as they are and not as they may or may not have been. It is also important that sites and profiles be described as factually as practicable, but genetic inferences are inevitable. Where these are used, the basis on which the inference is made should be noted so the user is aware of assumptions made.

1.3 Background

The methodology of regolith descriptions has been developed by regolith geoscientists since CSIRO and GA become involved in regolith studies in the 1980s (see Pain 2008 for a more detailed discussion). CSIRO prepared a number of reports especially for mineral exploration companies, and GA developed a database (RTMAP) and first published a field handbook in 1991 (Pain *et al.*, 1991).

1.4 Standards and sources

This Field Guide draws on CRC LEME, CSIRO, the Australian Collaborative Land Evaluation Program (ACLEP) and GA conventions for describing landforms and regolith (Anand *et al.*, 2002; McDonald *et al.*, 1990; Pain *et al.*, 1991, 2007; Craig *et al.*, 1999; NCST 2008). This book is not a guide on 'how to use RTMAP' (the GA regolith database), although it is strongly influenced by the successful use of RTMAP over a number of years. It is intended to be both current and usable by the entire regolith science community. It is hoped that RTMAP will benefit from feedback from users of this Field Guide. Standard procedures and terms for describing regolith have developed in recent years. Coincident with this has been the development and use of computer databases to store descriptions and information. The nature of databases—for better or worse—requires consistent and 'correct' use of terms. All dimensions are expressed in SI units.

Eggleton (2001) should be consulted as a standard source for definitions. The *CRC LEME regolith database field handbook and users guide* (Pain *et al.*, 2007) expands on material covered in this Field Guide, including details on survey procedures and definitions of most terms included in this Field Guide.

1.5 Brevity

In a field guide, brevity is efficiency. Although this Field Guide may appear lengthy, the criteria, definitions and concepts presented here are condensed. Users are urged to review the more comprehensive information in Pain *et al.* (2007), Pain (2008) and the original sources to avoid errors arising from this brevity.

1.6 Codes

A code is listed for each descriptor (the codes are from RTMAP, and are suggested as a guide only). Where appropriate, the codes are hierarchical to facilitate searches.

1.7 Standard terms versus creativity

Describe and record what you observe. Lists in this document are a minimal set of descriptors. Use additional descriptors, notes and sketches to record pertinent information and/or features for which no data type exists. Record such information as free-hand notes under *Remarks*.

1.8 Changes

Regolith Science is an evolving field. Changes to this Field Guide should and will occur. Please send comments or suggestions to Geoscience Australia, GPO Box 378, Canberra ACT 2601.

1.9 Field observations

Field observations can be recorded in a notebook or recorded electronically on a suitable field computer. Observations can conveniently be divided into those about a site and those about a regolith profile. Pain (2008) provides more details.

Figure 1 shows the notebook pages from RTMAP. Page 1 provides a guide to the capture of field site data; the fields used are those listed in Section 2. Page 2 provides a place for zone data entry. Zone data (Section 3) consist mainly of attributes, or *data types*. Values allowed for each data types are called *sub-types*. Each row provides for one sub-type observation. There is also room for free text description and a rank. The latter is used if there is more than one observation of a data type. The following is an example for a zone of alluvial sediments (SDA00):

```
 DATA
 TYPE   SUB-TYPE                 DESCRIPTION                         RANK
[_BED__][_ME____][150 - 250mm thick_____________________________][__]
[_SEQ__][_FU____][typical fining up alluvial deposit____________][__]
[__GS__][_GV____][gravel at base________________________________][_1]
[__GS__][_FS____][grading to fine sand at top___________________][_2]
```

BED is bedding thickness (in this case medium), SEQ is sequence type (in this case fining up) and GS is grain size (in this case two main sub-types, gravel and fine sand). The rank indicates that there is more gravel than fine sand in this zone.

ORIG [_____] **SITE ID** [_____________] DATE [__-___-___] **STATE** [____]

REGION [__________________] LOC DESCR [_______________________]

[____]

1:100K [______] **AMGEAST** [_____________] **AMGNORTH** [______________]

LOC METHOD [____] **ABS ACC** [_____] AIRPHOTO [____________________]

EXPOSURE [________] SLOPE [_________] ASPECT [___________]

LANDFORM [________________________] GEOMORPH1 [_______________]

GEOMORPH2 [______________________] STRATUNIT [__________________]

ROCKTYPE [___] QUAL_1 [_________________] LITHNAME [_____________]

SOIL [____]

[____]

VEG [____]

HAZARDS [____]

PHOTO [____]

ABSTRACT [____]

[____]

SKETCH

Figure 1a. Page 1 from RTMAP field notebook, representing a logical methodology for capturing field data. Fields in bold font are mandatory in RTMAP.

ZONE [___] **THICKNESS** [_____] DEPTH TO LOWER BOUNDARY [__________]

FRESH BEDROCK BELOW [__] **REGOLITH** [______________________________]

DEGREE OF WEATHERING [__] DESCR[______________________________]

[____]

DATA TYPE	SUB-TYPE	DESCRIPTION	RANK
[______]	[______]	[______________________________]	[__]
[______]	[______]	[______________________________]	[__]
[______]	[______]	[______________________________]	[__]
[______]	[______]	[______________________________]	[__]
[______]	[______]	[______________________________]	[__]
[______]	[______]	[______________________________]	[__]
[______]	[______]	[______________________________]	[__]
[______]	[______]	[______________________________]	[__]
[______]	[______]	[______________________________]	[__]
[______]	[______]	[______________________________]	[__]
[______]	[______]	[______________________________]	[__]
[______]	[______]	[______________________________]	[__]
[______]	[______]	[______________________________]	[__]
[______]	[______]	[______________________________]	[__]
[______]	[______]	[______________________________]	[__]
[______]	[______]	[______________________________]	[__]
[______]	[______]	[______________________________]	[__]
[______]	[______]	[______________________________]	[__]
[______]	[______]	[______________________________]	[__]
[______]	[______]	[______________________________]	[__]
[______]	[______]	[______________________________]	[__]

SAMPLE ID	DESCRIPTION
[__________]	[______________________________________]
[__________]	[______________________________________]
[__________]	[______________________________________]
[__________]	[______________________________________]
[__________]	[______________________________________]
[__________]	[______________________________________]
[__________]	[______________________________________]
[__________]	[______________________________________]

CARRY OVER [_] SHEET [_] OF [_]

Figure 1b. Page 2 from the RTMAP field notebook.

2. SITE DESCRIPTION

Site refers to the general area around which a regolith observation is made. The following list is comprehensive, and in many cases information about some attributes may not be available.

2.1 Project Name

Record the Project name.

2.2 Observer(s) Name

Record the name(s) of the person(s) who describe the site.

2.3 Site ID

Record the site ID, making sure that there is no duplication of site IDs.

2.4 Date

This is the date of data collection in the field.

2.5 Country

Record the country within which the site lies.

2.6 State

Record the state within which the site lies.

2.7 Geographic area

Record the general geographic location of the site.

2.8 Location Description

Record any details of the site location.

2.9 Air Photo

Record information about the air photo on which the site occurs (run and photo number, scale).

2.10 1:100 000 Map

Record the 1:100 000 map number and name.

2.11 1:250 000 Map

Record the 1:250 000 map number and name.

2.12 GDA94 Easting and Northing

Record the AMG map coordinates.

2.13 Datum

The datum for Australian sites should be GDA94.

2.14 Method

Record the method by which the site was located. The following is the GA list:

Number	Method Name	Accuracy
0	Unknown	
1	GPS observation (WGS84 - World Geodetic System 1984)	100
2	GPS observation (AGD66 - Australian Geodetic Datum 1966)	100
3	GPS observation (AGD84 - Australian Geodetic Datum 1984)	100
4	GPS observation (GDA94 - Geocentric Datum of Australian 1994)	100
5	Astronomical observation	
6	Surveyed from ground control	5
7	Published report	
8	Unpublished report	
10	Non-standard topographic map	
11	1:25,000 topographic map	25
12	1:50,000 topographic map	50
13	1:100,000 topographic map (AMG66)	100
14	1:250,000 topographic map	250
15	1:500,000 topographic map	500
16	1:1,000,000 topographic map	1000
20	Non-standard geological map	
21	1:25,000 geological map	25
22	1:50,000 geological map	50
23	1:100,000 geological map (AMG66)	100
24	1:250,000 geolog ical map	250
25	1:500,000 geological map	500
26	1:1,000,000 geological map	1000
30	Differential GPS - survey quality (WGS84)	1
31	Differential GPS (AGD66)	2
35	Averaged GPS (GDA94)	50
40	Orthophoto map	
41	Orthophoto image 1:25,000 scale	10
50	Company supplied location - method unknown	
51	State/NT supplied location - method unknown	

2.15 Elevation

Record the elevation of the site, together with an error margin, to the nearest integer.

2.16 Exposure type

The type of site is selected from the following list:

AUGER	Auger hole (soil/otherwise)	OUTCR	Outcrop
CANAL	Canal	PIT	Hand dug pit
CLIFF	Cliff	PROSP	Prospect
CORE	Drill core	QUARR	Quarry
COST	Costean	RAILW	Railway
CUTRA	Drill cuttings - RAB	ROAD	Road/highway cutting
CUTRC	Drill cuttings - RC	RUBBL	Rubble
DAM	Dam	SOIL	Soil
FLOAT	Float	STREA	Stream (for creeks/rivers)
GRAVE	Gravel scrape	SURF	Surface
GULLY	Gully (for gullies/washouts)	TRENC	Trench
MINE	Mine	OTHR	Other

2.17 Geological Information

Record the following:

2.17.1 Geological Region

Table 1. Geological Regions (Geoscience Australia 2008) (see Figure 2).

2	Adelaide	30	Dundas	105	Northeast Tas
3	Albany	31	Eromanga	64	Officer
4	Amadeus	33	Eucla	65	Ord
6	Anakie	282	Fly-Highlands	66	Otway
5	Arafura	100	Fraser	67	Paterson
7	Arnhem	34	Galilee	68	Pedirka
8	Arrowie	35	Gascoyne	69	Perth
9	Arunta	36	Gawler	70	Pilbara
112	Ashburton	37	Georgetown	71	Pine Creek
10	Bancannia	38	Georgina	72	Polda
11	Bangemall	39	Gippsland	106	Proserpine
12	Birrindudu	40	Halls Creek	48	Quinkan
13	Bonaparte	41	Hamersley	73	Rocky Cape
14	Bowen	44	Kanmantoo	107	Savory
15	Bremer	46	Kimberley	75	South Nicholson
94	Bresnahan	101	King Island	78	St Vincent
16	Broken Hill	102	King Leopold	77	Stuart
95	Burke River	47	Lachlan	79	Styx
43	Cairns	49	Leeuwin	80	Surat
97	Caloola	50	Litchfield	81	Sydney

17	Canning	51	Maryborough	82	Sylvania
19	Carnarvon	103	Marymia	85	Tanami
20	Carpentaria Lowlands	52	McArthur	84	Tennant Creek
83	Central Tasmania	53	Money Shoal	108	Tibooburra
98	Charters Towers	54	Mount Isa	86	Torrens
21	Clarence - Moreton	55	Mount Painter	18	Torres Strait
99	Clarke River	56	Murphy	87	Tyennan
22	Coen	57	Murray	88	Victoria River
24	Daly River	58	Musgrave	96	Wilsons Promontory
25	Darling	59	Nabberu	109	Winnecke
26	Davenport	60	New England	90	Wiso
27	Denison	61	Ngalia	91	Wonominta
28	Drummond	104	Nongra	93	Yilgarn
29	Duaringa	62	Northampton	0	unknown

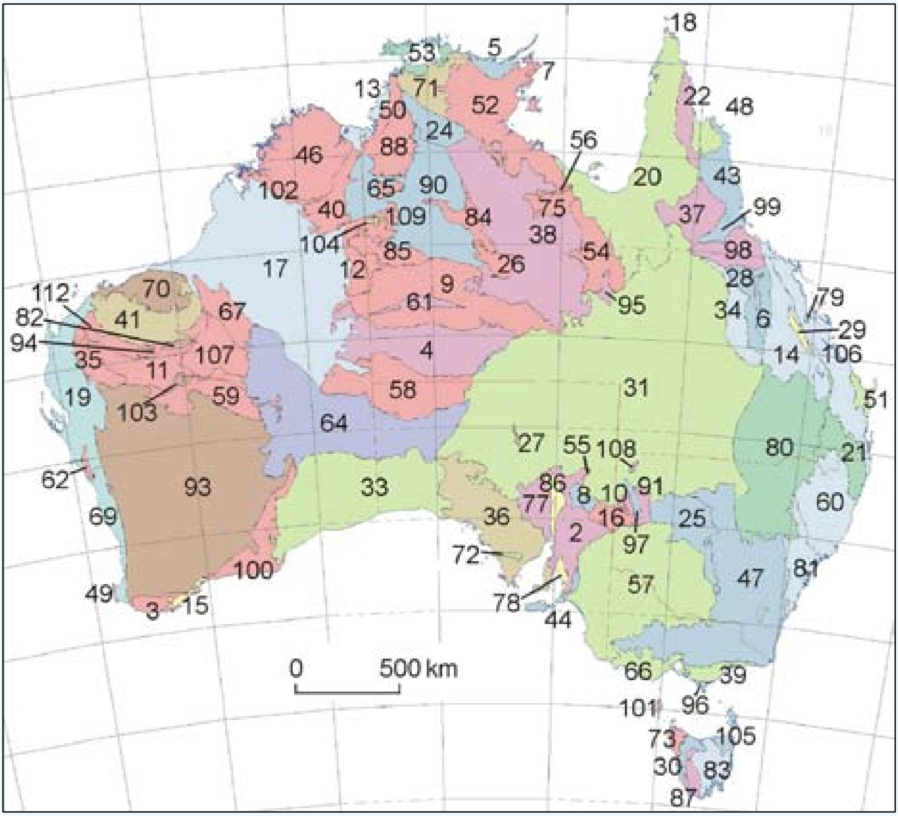

Figure 2. Geological regions (Geoscience Australia 2008).

2.17.2 Bedrock Type

Record the bedrock type from the following list:

Igneous

Sedimentary

Metamorphic

Hydrothermal

Extraterrestrial

Unknown

2.17.3 Lithology Name

The following list (*Table 2*) is from one proposed by the Government Geoscience Information Policy Advisory Committee (GGIPAC). There are many other lists that can be used for lithology, including GA, and state and territory geological survey agencies.

Table 2. GGIPAC Dominant Lithology Group

GGIPAC Dominant Lithology Group	Suggested Code
igneous	I
igneous volcanic	IV
igneous intrusive	II
alkaline ultrabasic	Iua
igneous felsic-intermediate volcanic	IVfi
igneous felsic volcanic	IVf
igneous intermediate volcanic	IVi
igneous mafic volcanic	IVm
igneous ultramafic volcanic	IVu
igneous foid-bearing volcanic	IVfe
igneous felsic-intermediate intrusive	IIfi
igneous felsic intrusive	IIf
igneous intermediate intrusive	IIi
igneous mafic intrusive	IIm
igneous ultramafic intrusive	IIu
igneous feldspathoid-bearing intrusive	IIfe
sedimentary	S
sedimentary siliciclastic	Ss
argillaceous detrital sediment	Sa
quartz-rich detrital sediment	Sq
feldspar- or lithic-rich arenite to rudite	Sf
sedimentary carbonate	Sc
sedimentary non-carbonate chemical or biochemical	Sncc
organic-rich rock	So
metamorphic	M

metasedimentary	MS
metasedimentary siliciclastic	MSs
metasedimentary argillaceous	MSa
metasedimentary carbonate	MSc
metasedimentary non-carbonate chemical or biochemical	MSncc
meta-igneous	MI
meta-igneous felsic	MIf
meta-igneous felsic volcanic	MIVf
meta-igneous felsic intrusive	MIIf
meta-igneous mafic	MIm
meta-igneous mafic volcanic	MIVm
meta-igneous mafic intrusive	MIIm
meta-igneous ultramafic	MIu
meta-igneous ultramafic volcanic	MIVu
meta-igneous ultramafic intrusive	MIIu
metamorphic protolith unknown	M
High grade metamorphic rock	Mhg
high-P metamorphic rock	Mhp
fault / shear rock	Msh
metamorphosed hydrothermal	Mhy
regolith	R
hydrothermal	H
metasomatic	Hmet
mineralisation	Hmin
vein	Hv
extraterrestrial	E
unknown	U

2.17.4 Bedrock Stratigraphy

Enter the bedrock stratigraphic name, if known. This can be derived from published maps, or from the Stratigraphic Units Database on the GA website: www.ga.gov.au/oracle/stratnames/index.jsp.

2.18 Geomorphic Information

See Section 5.1 for complete lists.

Australian Soil Resources Information System (McKenzie *et al.*, 2005) *Physiographic Information* (Section 5.1)

Landform Pattern or Element (Section 5.2)

The *Slope Gradient* at a site is usually measured with a hand level or clinometer as an angle between 0 and 90 degrees.

The *Slope Aspect* is measured clockwise from true north as an angle between 0 and 360 degrees.

Environmental hazard (Section 5.3)

Geomorphic Processes (Section 5.4)

Weathering Processes (Section 5.5)

2.19 Soil

Record the soil at the site (see Section 4).

2.20 Vegetation

This field is for a description of the vegetation at the site. Hnatiuk *et al.* (2008) provide a comprehensive discussion and classification tables for those who wish to include more data about vegetation.

2.21 Sketches/photos

Record details of any sketches/photos of the site.

2.22 Abstract

The abstract field is for a summary description of the site, including brief comments about the zones.

3. REGOLITH PROFILE DESCRIPTION

The *Regolith Profile* refers to the arrangement of layers of the regolith at a site. Each layer is called a zone. In the case of transported regolith the zones are equivalent to stratigraphic units in geology, although in many cases they will be informal rather than named units. However, zones in a weathering profile are not the equivalent of stratigraphic units and should not be treated in the same way. Pain and Ollier (1995) provide a discussion of layering in regolith.

3.1 Regolith Profile

This is a descriptive field for recording the total known gross profile characteristics of the regolith, including any truncation or covering that may have occurred.

3.2 Zone (General Data)

The following fields are for general information about a single zone within a regolith profile. Usually there will be several zones at each field site.

3.2.1 Zone Number

The zone number is a 2-digit number in the format 01, 02, 03 etc., increasing with depth. Usually this means increasing depth from surface, but for transported regolith it may mean elevation or other indicator of relative age. If the latter, a sketch should be provided in the notebook.

3.2.2 Zone Thickness

This is a number field for the average thickness of the zone.

3.2.3 Depth to Lower Boundary

Enter the depth of the lower boundary of the zone.

3.2.4 Regolith Type

Record the regolith type (see section 5.6 for definitions):

Code	Name	Code	Name
SDT00	terrestrial sediments	SDC00	coastal sediments
SDT01	lag on transported regoli	SDS00	beach sediments
SDA00	alluvial sediments	SDE00	estuarine sediments

SDA10	channel deposits	EVA00	evaporite
SDA20	overbank deposits	EVA01	halite
SDC00	colluvial sediments	EVA02	gypsum
SDC01	scree	EVA03	acid sulphates
SDC02	landslide deposit		
SDC03	mudflow deposit	VOL00	volcanic materials
SDC04	creep deposit	VOL01	lava flow
SDC05	sheet flow deposit	VOL02	tephra
SDC06	colluvial fanglomerate	IE00	Impact ejecta
SDE00	aeolian sediments		
SDE01	aeolian sand	BU00	unweathered bedrock
SDE02	loess	WIR10	saprolith
SDE03	parna	WIR11	saprock
SDF00	fill	WIR12	moderately weathered bedrock
SDG00	glacial sediments	WIR13	highly weathered bedrock
SDG01	moraine	WIR14	very highly weathered bedrock
SDG02	ground moraine	WIR15	completely weathered bedrock
SDG03	terminal moraine	WIR16	saprolite
SDG04	lateral moraine	WIR20	residual material
SDG05	glacial outwash	WIR21	lag on*in situ*regolith
SDL00	lacustrine sediments	WIR22	residual sand
SDL01	Clastic lacustrine sediments	WIR23	residual clay
SDL02	Calcareous lacustrine sediments	WIR24	soil on bedrock
SDL03	Organic lacustrine sediments	UOC00	clay (unknown origin)
SDL04	diatomite	UOL00	soil (unknown origin)
SDM00	marine sediments	UOM00	weathered (unknown origin)
SDM01	Biogenic marine carbonates	UOS00	and (unknown origin)
SDS02	spiculite		
SDB00	microbial sediments		
SDP00	swamp (paludal) sediments		
SDP01	peat		

3.2.5 Zone description

Free text field for comments on the zone that cannot be placed elsewhere.

3.3 Zone Data Types

A range of attributes can be recorded for each zone; these are listed in *Table 3*. See the Section 5.6 for more details.

Each attribute, or data type, has a number of sub-types, which are listed under the appropriate heading below. The sub-type field can be followed by a free text description (see *Figure 1*), which is for descriptor values (such as pH or magnetic susceptibility), or any additional information relating to the data type or sub-type. Though this field is free text, values for instrument readings should be recorded as numbers only. This allows them to be easily retrieved for use in a GIS. For example, values for magnetic susceptibility or gamma-ray counts should be entered without any units or comments. Additional comments relating to the readings, including units, should be recorded as a separate record using the remarks data type (REM).

Table 3. Data types that are relevant to regolith and available in the GA corporate database.

AGE	Age information	QZGS	Quartz grain size
BED	Bedding Thickness	QZSP	Quartz grain sphericity
BNDS	Lower boundary-shape	RAD	Gamma Ray Spectrometry (cps)
BNDT	Lower boundary-type	RCC	Regolith clast composition
BST	Bedrock structures	REM	Remarks
CFD	Coarse fragment orientation	RSTR	Rock Strength
COL	Colour	SEGA	Segregations-abundance
CON	Consi stence	SEGC	Segregations-composition
COP	Colour pattern	SEGS	Segregations-size
DRMA	Nature of drilled material	SEGT	Segregations-type
FAB	Fabric	SEQ	Sequence Types
FOS	Fossil	SF	Sampled For
GP	Geomorphic processes	SOM	Sedimentary Occurrence Mode
GS	Grain Size	SOR	Sorting
IN	Induration	SP	Sample Provenance
IS	Internal Stratification	SPH	Sphericity
MAG	Magnetic. sus. (SI Units x 10-5)	SS	Sedimentary Structures
MAGS	Sample container size	SSTR	Soil strength
MC	Munsell colour	ST	Sample type
MOTA	Mottles-abundance	STK	Stickiness
MOTS	Mottles-size	STX	Sedimentary Texture
PH	pH level	VEIN	Vein, dyke or sill
PHO	Photo data	WEA	Degree of Weathering
POR	Porosity	WP	Weathering processes

Rank is an optional single integer field for a number from 1 to 9. When a particular data type is used more than once, the corresponding sub types can be ranked in order of importance or dominance at the site. This is useful when interrogating the data with a GIS because it provides users with a method of identifying and displaying only the dominant sub-type in a group of identical data types.

3.3.1 Age Determination

Enter any comments about the age of the zone, including any dates that have been obtained from samples (see Pillans 2008).

3.3.2 Bedding Thickness

Data type		Sub-type	
BED	Bedding Thickness	LA	laminated (<10 mm)
BED		VTN	very thin (10-30 mm)
BED		TN	thin (30-100 mm)
BED		ME	medium (100-300 mm)
BED		TK	thick (300-1000 mm)
BED		VTK	very thick (>1000 mm)

3.3.3 Internal Stratification

Data type		Sub-type	
IS	Internal Stratification	CLA	corrugated lamination
IS		CLR	climbing ripples
IS		CMI	cryptomicrobial (algal laminae)
IS		CTS	contorted stratification
IS		CV	convolute
IS		HO	horizontal
IS		HPL	horizontal parallel laminae
IS		HX	hummocky cross bedding
IS		HXS	herringbone cross-stratification
IS		LAM	lamination (within a bed)
IS		LPX	low-angle planar cross bedding
IS		LTX	low-angle trough cross bedding
IS		MAS	massive
IS		OXB	overturned cross bedding
IS		PID	pillowed
IS		RG	reverse grading
IS		RXL	ripple cross laminae
IS		STRL	stromatolitic lamination
IS		WB	wavy bedding
IS		XB	cross-bedded

3.3.4 Sequence Types

Data type		Sub-type	
SEQ	Sequence Types	CU	coarsening upward sequence
SEQ		FU	fining upward sequence
SEQ		TKU	thickening upward
SEQ		TNU	thinning upward

3.3.5 Sedimentary Occurrence Mode

Data type		Sub-type	
SOM	Sedimentary Occurrence Mode	CLAS	clast
SOM		CMT	cement
SOM		CNC	concretion
SOM		MT	matrix
SOM		SDY	dyke

3.3.6 Sedimentary Structures

Data type		Sub-type	
SS	Sedimentary Structures	ADR	adhesion ripples
SS		AMB	armoured mud balls
SS		ASYM	asymmetrical ripple mark
SS		BIO	bioturbated
SS		BP	ball-and-pillow
SS		BU	burrows
SS		BUB	bubble prints
SS		CC	current crescents
SS		CHB	churned bedding
SS		CIC	cone-in-cone
SS		CNC	concretions
SS		COP	coprolite
SS		CRY	crystal casts
SS		CSP	cusp structures
SS		DC	desiccation cracks
SS		DS	dish structure
SS		DWS	de-watering structures

SS	ES	erosive structures
SS	FGNS	faceted grains
SS	FLM	flame structures
SS	GEO	geopetal
SS	GSP	gas pits
SS	HMK	harrow marks
SS	ICL	intraclast (eg. mudflake)
SS	IM	imbricated
SS	INV	involution
SS	IR	interference ripples
SS	LC	load casts
SS	MC	mud cracks
SS	MSV	mud and sand volcanoes
SS	MT	matrix
SS	PTG	parting
SS	PM	percussion marks
SS	PN	pseudonodules
SS	POP	polished pebbles
SS	RHP	rain and hail prints
SS	RIP	ripple marks
SS	RS	reactivation surface
SS	SC	striated clasts
SS	SD	sandstone dykes
SS	SHC	shale clasts
SS	SHR	shrinkage cracks
SS	SLN	streaming lineation
SS	SMR	symmetrical ripple mark
SS	SLS	slump structures
SS	SSD	soft sediment deformation
SS	STY	stylolites
SS	SYN	synaeresis cracks
SS	TM	tool marks
SS	TO	toroids
SS	TR	trails

SS		VCLA	vertical clasts
SS		WBL	whirl-balls
SS		WM	wrinkle marks (runzelmarken)

3.3.7 Sedimentary Texture

Data type		Sub-type	
STX	Sedimentary Texture	BX	breccia
STX		CEM	cemented
STX		GP	geopetal
STX		MCC	micritic
STX		ON	oncolitic
STX		OO	oolitic
STX		PE	peloidal

3.3.8 Bedrock structures

This data type is for bedrock structures which remain within the regolith, so will refer to saprolith only.

Data type		Sub-type	
BST	Bedrock structures	BE	bedding
BST		CL	cleavage
BST		CO	corestones
BST		DY	dykes
BST		JT	joints
BST		VN	veins

3.3.9 Boundary

The first two data types describe the lower boundary of each zone, and are from McDonald and Isbell (1990, 2008).

Data type		Sub-type	
BNDS	Lower boundary shape	SM	smooth
BNDS		D	discontinuous
BNDS		I	irregular
BNDS		T	tongued
BNDS		W	wavy

BNDT	Lower boundary type	SH	sharp
BNDT		A	abrupt
BNDT		C	clear
BNDT		D	diffuse
BNDT		G	gradual

The next lower boundary data type is interpretive, and refers to processes that form the lower boundary.

BNDI	Lower boundary interpretation	BP	bedding plane
BNDI		U	unconformity
BNDI		SL	stone line
BNDI		PF	pedoplasmation front
BNDI		WF	weathering front
BNDI		BOCO	base of complete oxidation
BNDI		BOPO	base of partial oxidation

3.3.10 Nature of drilled material

Data type		Sub-type	
DRMA	Nature of drilled material	AGG	aggregate
DRMA		CHPS	chip strong
DRMA		CHPW	chip weak
DRMA		DISAGG	disaggregate

3.3.11 Regolith clast composition

This data type is for the composition of the >2 mm fraction. The code for the data type is RCC. Data sub-types can be taken from *Table 2*, or from another standard lithology list.

3.3.12 Coarse fragment orientation

Data type		Sub-type	
CFD	Coarse fragment orientation	U	undisturbed
CFD		D	dispersed randomly
CFD		R	reoriented
CFD		S	stratified (*e.g.* stone lines)

3.3.13 Colour

These data types can be used for descriptions of colour, colour changes or combinations. The use of Munsell colour (MC) is preferred if meaningful comparisons are to be made (Munsell Color Company 2000, RCAFF 1970, Rock-Color Chart Committee 1991).

Data type		Sub-type	
COL	Colour	BK	black
COL		BL	blue
COL		BR	brown
COL		BU	buff
COL		CH	chocolate
COL		CR	cream
COL		FA	fawn
COL		GR	green
COL		GY	grey
COL		KH	khaki
COL		MA	maroon
COL		OL	olive
COL		OR	orange
COL		PI	pink
COL		PU	purple
COL		RE	red
COL		VC	varicoloured
COL		VI	violet
COL		WH	white
COL		YE	yellow
COP	Colour pattern	MO	mottled
MC	Munsell colour	Enter code from Munsell colour book	

3.3.14 Consistence

Consistence refers to the strength of cohesion and adhesion in soil and regolith materials. (For unweathered bedrock and strongly indurated materials, refer to Section 3.3.16, rock strength) Strength will vary according to water status. Strength is the resistance to breaking or deformation. Stickiness is a characteristic determined on wet material. NCST (2008) discuss these properties further, and provide definitions and means of determination.

Data type		Sub-type	
SSTR	Soil Strength	S0	loose
SSTR		S1	very weak (<25 kPa)
SSTR		S2	weak (25-50 kPa)
SSTR		S3	firm (50-100 kPa)
SSTR		S4	very firm (100-200 kPa)
SSTR		S5	strong (200-400 kPa)
SSTR		S6	very strong (>400 kPa)
STK	Stickiness	NS	non-sticky
STK		SS	slightly sticky
STK		MS	moderately sticky
STK		VS	very sticky

3.3.15 Porosity

Data type		Sub-type	
POR	Porosity	0	non porous, dense
POR		1	Slightly porous
POR		2	Porous

3.3.16 Rock Strength

Data type		Sub-type	
RSTR	Rock Strength	R1	very low rock strength (1.5-3 Mpa)
RSTR		R2	low rock strength (3-10 Mpa)
RSTR		R3	medium rock strength (10-25 Mpa)
RSTR		R4	high rock strength (25-80 Mpa)

RSTR		R5	very high rock strength (>800 Mpa)

3.3.17 Fabric

In pedology fabric describes the appearance of the soil material (NCST 2008), and the term can be extended to regolith materials. Differences in fabric are associated with the presence or absence of aggregations, and the presence, size and arrangement of voids in the regolith mass. More sub types will be added to this data type.

Data type		Sub-type	
FAB	Fabric	RP	relict primary
FAB		EA	earthy
FAB		GS	sandy (grains prominent)
FAB		RO	rough-ped
FAB		SM	smooth-ped

3.3.18 Fossil

Data type		Sub-type	
FOS	Fossil	FOSI	fossil invertebrates
FOS		FOSP	fossil plants
FOS		FOST	trace fossils
FOS		FOSV	fossil vertebrates
FOS		STRO	stromatolite

3.3.19 Geomorphic Processes

This data type is used for geomorphic processes responsible for the formation of the zone.

Data type		Sub-type	
GP	Geomorphic processes	BI00	biological agents; coral
GP		DI00	diastrophism; earth movements
GP		GR00	gravity
GP		GR01	vertical collapse
GP		GR02	particle fall
GP		GR03	creep
GP		GR04	landslide

GP	GR05	mudflow
GP	HU00	human agents
GP	IC00	ice
GP	IC01	frost
GP	IC02	glacial erosion
GP	IC03	glacial deposition
GP	MT00	impact by meteors
GP	VO00	volcanism
GP	VO01	lava flow
GP	VO02	ash flow
GP	VO03	ash fall
GP	WI00	wind
GP	WI01	wind erosion (deflation)
GP	WI02	sand deposition (wind)
GP	WI03	dust deposition (wind)
GP	WT00	water
GP	WT01	channelled stream flow
GP	WT02	over-bank stream flow
GP	WT03	sheet flow, sheet or surface wash
GP	WT04	waves
GP	WT05	tides
GP	WT06	detrital deposition still water
GP	WT07	rilling/gullying
GP	WT08	subsurface solution/piping

3.3.20 Grain size

Enter the size of particles in the zone, from the following list. This list is derived from several sources. Choose the size ranges best suited to the materials in the zone.

Data type		Sub-type	
GS	Grain Size	MUD	clay (<0.002 mm)
GS		SLT	silt (0.002-0.062 mm)
GS		SA	sand (0.062-2 mm)
GS		VFS	very fine sand (0.062-0.125 mm)

GS	FS	fine sand (0.125-0.5 mm)
GS	MS	medium sand (0.25-0.5 mm)
GS	CS	coarse sand (0.5-1 mm)
GS	VCS	very coarse sand (1-2 mm)
GS	GV	gravel (2-60 mm)
GS	FG	fine gravel (2-6 mm)
GS	MG	medium gravel (6-20 mm)
GS	CG	coarse gravel (20-60 mm)
GS	CB	cobble (64-256 mm)
GS	ST	stone (256-600 mm)
GS	BO	boulder (>256 mm)
GS	LPL	lapilli (4-64 mm)
GS	BM	bomb (>64 mm)
GS	GL	granule (2-4 mm)
GS	PB	pebble (4-64 mm)
GS	F	fine (<1 mm)
GS	M	medium (1-5 mm)
GS	C	coarse (>5 mm)
GS	MX	microcrystalline
GS	PEG	pegmatitic
GS	VC	very coarse
GS	VF	very fine
GS	CLAY	clay (<0.002 mm)
GS	CSLT	coarse silt (0.031-0.0625 mm)
GS	FSLT	fine silt (0.0078-0.0156 mm)
GS	MSLT	medium silt (0.0156-0.031 mm)
GS	RMUD	clay/silt (<0.0625 mm)
GS	VFSLT	very fine silt (0.0039-0.0078 mm)

3.3.21 Quartz grains

Quartz clasts have been separated out because of their importance in sedimentary regolith materials. There are two data types, quartz grain size and quartz sphericity.

Data type		Sub-type	
QZGS	Quartz Grain Size	BO	boulder (>256 mm)
QZGS		CB	cobble (64-256 mm)
QZGS		CLAY	clay (<0.002 mm)
QZGS		CSA	coarse sand (0.5-1 mm)
QZGS		CSLT	coarse silt (0.031-0.0625 mm)
QZGS		FSA	fine sand (0.125-0.25 mm)
QZGS		FSLT	fine silt (0.0078-0.0156 mm)
QZGS		GL	granule (2-4 mm)
QZGS		GV	gravel (>2 mm)
QZGS		MSA	medium sand (0.25-0.5 mm)
QZGS		MSLT	medium silt (0.0156-0.031 mm)
QZGS		PB	pebble (4-64 mm)
QZGS		RMUD	clay/silt (<0.0625 mm)
QZGS		SA	sand (0.0625-2 mm)
QZGS		SLT	silt (0.002-0.0625 mm)
QZGS		VCS	very coarse sand (1-2 mm)
QZGS		VFSA	very fine sand (0.0625-0.125 mm)
QZGS		VFSLT	very fine silt (0.0039-0.0078 mm)
QZSP	Quartz Sphericity	ANG	angular
QZSP		RO	rounded
QZSP		SANG	sub-angular
QZSP		SRO	sub-rounded
QZSP		VANG	very angular
QZSP		WRO	well-rounded

3.3.22 Induration

This data type (IN) covers the degree and type of induration.

			Indurated material							
			Undifferentiated	Bauxitic	Calcareous	Clay	Ferruginous	Gypsum	Siliceous	Humic
Undifferentiated			IN00	IN10	IN20	IN30	IN40	IN50	IN60	IN70
Duricrust	Completely cemented	Undifferentiated	DC00	DC10	DC20	DC30	DC40	DC50	DC60	DC70
		Continuous	DC01	DC11	DC21	DC31	DC41	DC51	DC61	DC71
		Discontinuous	DC02	DC12	DC22	DC32	DC42	DC52	DC62	DC72
	Moderately cemented	Undifferentiated	DM00	DM10	DM20	DM30	DM40	DM50	DM60	DM70
		Continuous	DM01	DM11	DM21	DM31	DM41	DM51	DM61	DM71
		Discontinuous	DM02	DM12	DM22	DM32	DM42	DM52	DM62	DM72
	Partially cemented	Undifferentiated	DP00	DP10	DP20	DP30	DP40	DP50	DP60	DP70
		Continuous	DP01	DP11	DP21	DP31	DP41	DP51	DP61	DP71
		Discontinuous	DP02	DP12	DP22	DP32	DP42	DP52	DP62	DP72
Nodules			NO00	NO10	NO20	NO30	NO40	NO50	NO60	NO70

3.3.23 Mottling

These data types are used for comments about the size and abundance of any mottling present. Contrast with surrounding material, and strength or induration, are currently dealt with in the remarks data type (REM).

Data type	Sub-type	
MOTA Mottles-abundance	0	no mottles
MOTA	1	very few (< 2%)
MOTA	2	few (2 - 10%)
MOTA	3	common (10 -20%)
MOTA	4	many (20 -50%)
MOTS Mottles-size	FIN	fine (< 5 mm)
MOTS	MED	medium (5 – 15 mm)
MOTS	CSE	coarse (15 – 30 mm)
MOTS	VCS	very coarse (30 – 100 mm)
MOTS	MEG	megamottles (> 100 mm)

3.3.24 Nodules

Nodules can be regarded as a type of induration (see section 3.3.22). Comments about any nodules present—including size, abundance, contrast with surrounding material, and strength or induration—may also be dealt with in the remarks data type (REM). The data type Segregations can also be used for nodules (see section 3.3.26.

3.3.25 Matrix

Comments on, and a description of the matrix of the zone, are currently dealt with in the remarks data type (REM).

3.3.26 Segregations

This refers to discrete segregations that have accumulated in the regolith because of the concentration of some constituent, usually caused by chemical or biological action. Segregations may be relict or formed *in situ* by current processes. These data types are for the abundance, composition, size and type of segregations in the zone.

Data type		Sub-type	
SEGA	Segregations-abundance	0	no segregations
SEGA		1	very few (< 2%)
SEGA		2	few (2 - 10%)
SEGA		3	common (10 - 20%)
SEGA		4	many (20 - 50%)
SEGA		5	very many (> 50%)
SEGC	Segregations-composition	U	unidentified
SEGC		A	aluminous
SEGC		E	earthy
SEGC		F	ferruginous
SEGC		H	organic
SEGC		K	calcareous
SEGC		L	argillaceous
SEGC		M	manganiferous

SEGC		O	other
SEGC		Y	gypseous
SEGC		Z	saline

SEGS	Segregations-size	FIN	fine (< 2 mm)
SEGS		MED	medium (2 – 6 mm)
SEGS		CSE	coarse (6 – 20 mm)
SEGS		VCS	very coarse (20 – 60 mm)
SEGS		ECS	extremely coarse (> 60 mm)

SEGT	Segregations-type	C	concretions
SEGT		F	fragments
SEGT		N	nodules
SEGT		P	pisoliths
SEGT		T	tubules

3.3.27 Sorting

This data type describes the particle sorting:

Data type		Sub-type	
SOR	Sorting	W	well sorted
SOR		MSO	moderately sorted
SOR		P	poorly sorted
SOR		VP	very poorly sorted
SOR		UNS	unsorted

3.3.28 Sphericity

This data type describes the particle sphericity:

Data type		Sub-type	
SPH	Sphericity	ANG	angular
SPH		RO	rounded
SPH		SAN	sub-angular
SPH		VA	very angular
SPH		WR	well-rounded

3.3.29 Veins

This field is for comments about any veins present.

Data type		Sub-type	
VEIN	Vein	QZ	quartz
VEIN		APL	aplite
VEIN		CARB	carbonate
VEIN		DAC	dacite
VEIN		DLT	dolerite
VEIN		GRD	granodiorite
VEIN		GRSN	greisen
VEIN		GRT	granite
VEIN		LPY	lamprophyre
VEIN		PEG	pegmatite
VEIN		PHY	porphyry
VEIN		QMG	multi-generation quartz veins

3.3.30 Weathering Degree

This is for the degree of weathering:

Data type		Sub-type	
WEA	Weathering degree	0	unknown
WEA		1	fresh
WEA		2	slightly weathered
WEA		3	moderately weathered
WEA		4	highly weathered
WEA		5	very highly weathered
WEA		6	completely weathered
WEA		7	varied weathering

3.3.31 Weathering Processes

Enter the weathering processes, the rank and the active or relict (A/R) code. The active code allows present day weathering processes to be recorded, while the relict code allows recognition of weathering processes active in the past. The weathering process code comes from the following table:

WE00	weathering	CH06	hydrolysis
PH00	physical weathering	CH07	ferrolysis
PH01	abrasion	CH08	precipitation/evaporation
PH02	frost weathering	IN00	induration
PH03	induced fracture	IN01	bauxitic induration
PH04	insolation weathering	IN02	calcareous induration
PH05	moisture swelling	IN03	clay induration
PH06	sheeting	IN04	ferruginous induration
PH07	salt weathering	IN05	gypsiferous induration
PH08	volume increase	IN06	siliceous induration
PH09	wetting and drying	BI00	biotic weathering
CH00	chemical weathering		
CH01	solution		
CH02	oxidation and reduction		
CH03	carbonation		
CH04	hydration		
CH05	chelation		

3.3.32 Weathering Structures

The REM data type can be used for any comments about weathering characteristics of the zone.

3.3.33 Magnetic Susceptibility

Data type		Sub-type	
MAG	Magnetic sus. (SI Units x 10^{-5})	MAX	maximum
MAG		MN	mean
MAG		MIN	minimum

Because magnetic susceptibility measured in the laboratory varies with the container size, there is an additional data type, sample container size.

Data type		Sub-type	
MAGS	Container size	PETRI1	petri dish (85 x 10 mm)
MAGS		PETRI1	petri dish (52 x 10 mm)
MAGS		TRAY1	tray 5 compartments (190 x 35 x 10 mm)
MAGS		TRAY2	tray 5 compartments (190 x 35 x 20 mm)
MAGS		TRAY3	tray 20 compartments (24 x 48 x 28 mm)

3.3.34 Gamma Ray Spectrometry

Readings for K, Th, U and total count should be entered separately, and the values placed in the description field, as numbers only without any units or comments. Additional comments relating to the readings should be recorded as a separate record using the remarks data type (REM).

Data type		Sub-type	
RAD	Gamma Ray Spectrometry (cps)	K	potassium
RAD		TH	thorium
RAD		U	uranium
RAD		TC	total count

3.3.35 pH

Enter the general pH level. If a pH measurement is made enter the result in the description column.

Data type		Sub-type	
PH	pH level	ACID	acidic (0-6.9)
PH		BASIC	basic (8-14)
PH		NEUT	neutral (7-7.9)

3.3.36 Photo data

Enter data on photographs taken at the site.

Data type		Sub-type	
PHO	Photodata	BN	black and white negative
PHO		CN	colour negative
PHO		CP	colour positive
PHO		D	digital

3.3.37 Remarks

The REM data type can be used for any free-text additional comments about the zone. The sub data type is GE.

3.3.38 Samples

The following 3 data types may be entered in the Zones Data block.

Data type		Sub-type	
SF	Sampled for	UNK	unknown
SF		GC	geochronology
SF		HS	hand specimen
SF		MIPA	micropaleontology
SF		MAPA	macropaleontology
SF		PI	PIMA
SF		SO	soil chemistry
SF		SS	stream sediment chemistry
SF		TS	thin section
SF		XRD	X-Ray Diffraction
SP	Sample provenance	UNK	unknown
SP		ADTS	aeolian detritus
SP		COLV	colluvium
SP		DSPB	displaced block (near situ)
SP		GLE	glacial erratic
SP		RB	alluvial detritus
SP		VD	volcanic ejectamenta
ST	Sample type	OC	outcrop sample
ST		AUG	auger
ST		CORE	core sample
ST		CUTT	cuttings sample
ST		FLT	float sample
ST		PERC	open hole percussion
ST		RAB	rotary airblast
ST		REVC	reverse circulation percussion
ST		SIDE	sidewall sample
ST		SOIL	soil

4. SOILS DEFINITIONS

Soil refers to the organically affected upper part of the regolith. Soils are formed by interactions between the mineral material of the regolith and organic matter derived largely from vegetation growing in the regolith. Here we refer to three classifications that are used in Australia.

4.1 Principal profile form

The principal profile form comes from Northcote (1979). The simple definitions given here will allow people without any knowledge of soil science to place soils in one of the groups listed in the soils table. The definitions are taken largely from Northcote (1979) and readers should refer to that publication for further details. Northcote's classification refers to the arrangement of horizons in the soil.

O Organic

Organic soils are dominated by plant remains in at least the top 30 cm, but they can be much deeper. Any soil containing more than 30% organic matter may be considered to be organic.

Uc Uniform, coarse textured

Uniform soils are dominated by mineral material and have small, if any, differences in grain size (texture) throughout the profile. The range of texture falls within the span of one texture group (see texture classes in Northcote, 1979). Uc soils have textures in the sand and sandy loam or coarser classes.

Um Uniform, medium textured

Uniform soils with textures in the loams and clay loams classes.

Uf Uniform, fine textured, not cracking

Uniform soils with textures in the clay classes, and seasonal cracking of the soil material does not occur.

Ug Uniform, fine textured, cracking

Uniform soils with textures in the clay classes, and the soil material is characterised by seasonal cracking.

Gc Gradational, calcareous throughout

Gradational soils are dominated by the mineral fraction and show increasingly finer (more clayey) texture grades on passing to greater depths. The changes in texture are gradual and, over the whole profile, span more than one texture group. Gc soils are calcareous throughout.

Gn Gradational, not calcareous throughout

Gn soils are gradational, but are not calcareous throughout. However, calcium carbonate may be present in the lower parts of the soil, either as nodules or dispersed through the soil material.

Dr Duplex, red clay B horizons

Duplex soils are dominated by the mineral fraction and have a texture contrast of more than 1.5 texture groups between the A (surface) and B (subsurface) horizons. Further, the boundary between the two horizons is less than 10 cm thick. Dr soils have red B horizons, which in the Munsell Notation means a hue as red, or redder than, 5YR.

Db Duplex, brown clay B horizons

Db soils are duplex, with brown B horizons, which in the Munsell Notation means a hue yellower than 5YR.

Dy Duplex, yellow-grey clay B horizons

Dy soils are duplex, with yellow-grey B horizons.

Dd Duplex, dark clay B horizons

Dd soils are duplex, with dark B horizons, which in the Munsell Notation means a value/chroma less than 3/2 or 2/2.

Dg Duplex, gley clay B horizons

Dg soils are duplex, with gley B horizons, which in the Munsell Notation means any value on the Munsell 'gley' chart.

4.2 Great soil group

Stace *et al.* (1968) provide a description and classification of Australian soils into great soil groups and interested readers are referred to this publication. The great soil groups are based on both soil morphology and soil genesis. The following are the great soil groups. Codes are taken from Isbell and McDonald (1990, 2008).

SK	Solonchak	SS	Siliceous sand
A	Alluvial soil	ES	Earthy sand
L	Lithosol	GBK	Grey brown calcareous soil
KS	Calcareous sand	RK	Red calcareous soil
DL	Desert loam	GE	Grey earth
RBH	Red-brown hardpan soil	YE	Yellow earth
GC	Grey clay	TR	Terra rossa soil
BC	Brown clay	E	Euchrozem
RC	Red clay	X	Xanthozem
BE	Black earth	K	Krasnozem
R	Rendzina	GBP	Grey brown podzolic soil
CM	Chernozem	RP	Red podzolic soil
PS	Prairie soil	YP	Yellow podzolic soil
W	Wiesenboden	BP	Brown podzolic soil
SZ	Solonetz	LP	Lateritic podzolic soil
SDS	Solodized solonetz	GP	Gleyed podzolic soil
SC	Solodic soil	P	Podzol
SH	Soloth	HP	Humus podzol
SB	Solonized brown soil	PP	Peaty podzol
RBE	Red brown earth	AH	Alpine humus soil
NKB	Non calcic brown soil	HG	Humic gley
C	Chocolate soil	NP	Neutral peat
BRE	Brown earth	ALP	Alkaline peat
KRE	Calcareous red earth	ACP	Acid peat
RE	Red earth	NSG	No suitable group

4.3 Australian soil classification

The Australian Soil Classification (Isbell 1996)—now the standard for soil surveys in Australia—is based on morphological, chemical and physical properties. The following classes are used:

AN	Anthroposols	KU	Kurosols
CA	Calcarosols	OR	Organosols
CH	Chromosols	PO	Podosols
DE	Dermosols	RU	Rudosols
FE	Ferrosols	SO	Sodosols
HY	Hydrosols	TE	Tenosols
KA	Kandosols	VE	Vertosols

4.4 Fabric

The following description is from McDonald and Isbell (1990, 2008). Fabric describes the appearance of the soil material (under a ×10 hand lens). Differences in fabric are associated with the presence or absence of peds, the lustre or lack of lustre of the ped surfaces, and the presence, size and arrangement of pores (voids) in the soil mass. The descriptions given below apply primarily to B horizons.

RP Relict primary

Fabric in weathered regolith that has been inherited from the original material, whether *in situ* bedrock or transported material.

EA Earthy (or porous) fabric

The soil material is coherent and characterised by the presence of pores (voids) and few, if any, peds. Ultimate soil particles (sand grains, for example) are coated with oxides and/or clays and are arranged (clumped) around the pores.

GS Sandy fabric

The soil material is coherent, with few, if any, peds. The closely packed sand grains provide the characteristic appearance of the soil mass.

RO Rough-ped fabric

Peds are evident and characteristically more than 50% of the peds are *rough-faced*; that is, they have relatively porous surfaces. (Rough-faced peds generally have less clearly defined faces than smooth-faced peds and the pedality of the soil may be questioned. However, if the soil mass is pressed gently, the characteristic size and shape of the soil aggregates will confirm its pedality.) Granular peds with common or many macropores are always rough-faced, but this condition varies in other ped forms.

SM Smooth-ped fabric

Peds are evident and characteristically more than 50% of them are dense and *smooth-faced*, although the degree of lustre may vary.

5. GEOMORPHOLOGY

5.1 ASRIS Physiographic Information

If known, record ASRIS information. This can be obtained from the ASRIS web site [www.asris.csiro.au].

Division

Province (*Table 4*, *Figure 3*)

Zone

District

System

Facet

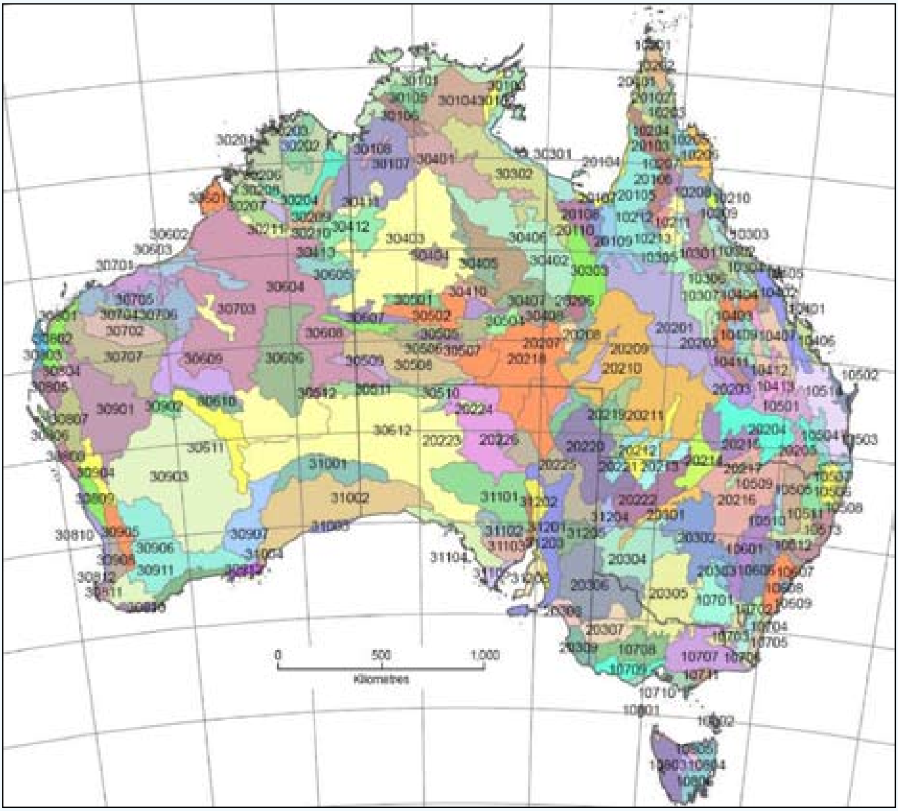

Figure 3. ASRIS level 2 Provinces (see Table 4). Map prepared by Linda Gregory, ASRIS, CSIRO Land and Water.

Table 4. ASRIS level 2 Provinces (see Figure 3)

10101	North Reefs	10507	Clarence Fall	20202	Jericho Plain
10102	South Reefs	10508	Clarence Lowlands	20203	Maranoa Lowland
10201	Torres 'High' Islands	10509	Nandewar Peaks	20204	Charleville Tableland
10202	Jardine Uplands	10510	Gunnedah Lowland	20205	Condamine Lowlands
10203	Wenlock Uplands	10511	Armidale Plateau	20206	Boulia Downs
10204	Coleman Plateau	10512	Liverpool-Barrington Plateaux	20207	Whelan Lowlands
10205	Laura Plain	10513	Macleay-Barrington Fall	20208	Eyre Creek Plain
10206	Cooktown Ranges	10601	Mitchell Slopes	20209	Eromanga Lowlands
10207	Palmerville Hills	10602	Warrumbungle Peaks	20210	Diamantina Plain
10208	Garnet Uplands	10603	Merriwa Plateau	20211	Cooper Plain
10209	Cairns Ranges	10604	Hunter Valley	20212	Bulloo Plain
10210	Atherton Tableland	10605	Goulburn Corridor	20213	Paroo Plain
10211	Newcastle Ranges	10606	Bathurst Tablelands	20214	Warrego Plains
10212	Gilbert Hills	10607	Hawkesbury-Shoalhaven Plateaux	20215	St George Plain
10213	Gregory Range	10608	Cumberland Lowland	20216	Upper Darling Plains
10214	Einasleigh Plains	10609	Illawarra Plain	20217	Lightning Ridge Lowland
10301	Burdekin Plateaux	10701	Hume Slopes	20218	Simpson Desert Dunefield
10302	Burdekin Hills and Lowlands	10702	Werriwa Tablelands	20219	Sturt Desert Plains
10303	Hervey Tablelands	10703	Australian Alps	20220	Strzelecki Desert Plains
10304	Townsville Lowland	10704	Tinderry Gourock Ranges	20221	Grey Range
10305	Gilberton Plateau	10705	Monaro Fall	20222	Warwick Lowland
10306	Cape River Plains	10706	Monaro Tableland	20223	Oodnadatta Tablelands
10307	Alice Tableland	10707	East Victorian Uplands	20224	Alberga Dunefield
10308	Bulgonunna Tableland	10708	West Victorian Uplands	20225	EyreFrome Plains
10401	Connors Ranges	10709	West Victorian Plains	20226	Denison Ranges
10402	Carborough Ranges	10710	South Victorian Uplands	20301	Lower Darling Plain
10403	Belyando Plains	10711	Gippsland Plain	20302	Cobar Plains
10404	Scartwater Hills	10801	Bass Plateaux	20303	Condobolin Plain
10405	Townshend Ranges and Lowlands	10802	Bass Plains	20304	Ivanhoe Plains
10406	Broad Sound Plains	10803	Tasmanian Ridges	20305	Riverine Plain
10407	Mackenzie-Dawson Lowlands	10804	Lakes Plateau	20306	Mallee Dunefield
10408	Cotherstone Plateau	10805	Midlands Plain	20307	Wimmera Plain
10409	Springsure-Clermont Plateaux	10806	East Tasmanian Plateaux	20308	Coorong Plain
10410	Drummond Uplands	20101	Weipa Plateau	20309	Millicent Plain
10411	Nagoa Scarplands	20102	Merluna Plain	30101	BonaparteDiemen Lowlands
10412	Buckland Plateau	20103	Holroyd Plains	30102	Arnhem Ridges
10413	Expedition Scarplands	20104	Karumba Plain	30103	East Arnhem Plateau
10414	Bunya-Burnett Ranges	20105	Clara Mitchell Plains	30104	West Arnhem Plateau
10501	Taroom Hills	20106	Bulimba Plateau	30105	Pine Creek Ridges
10502	Maryborough Lowland	20107	Normanton Tableland	30106	Daly Lowland
10503	Moreton Lowland	20108	Armraynald Plain	30107	Ord-Victoria Plateaux
10504	Toowoomba Plateau	20109	Wondoola Plain	30108	Whirlwind Plain
10505	Cunningham Slopes	20110	Donors Tableland	30201	Kimberley Plateau
10506	Tenterfield Plateau	20201	Winton-Blackall Downs	30202	Drysdale Lowlands

Table 4. ASRIS level 2 Provinces (continued)

30203	Couchman Uplands	30508	Amadeus Lowland	30809	Dandaragan Tablelands
30204	Leopold-Durack Ranges	30509	Rawlinson-Petermann Ranges	30810	Swan Plain
30205	Yampi Peninsula	30510	Kulgera Hills	30811	Donnybrook Lowland
30206	Richenda Foothills	30511	Musgrave Ranges	30812	Leeuwin Peninsula
30207	Fitzroy Plains	30512	Warburton Ranges	30901	Murchison Plateau
30208	Napier Limestone Ranges	30601	Dampier Tablelands	30902	Glengarry Hills
30209	Springvale Foothills	30602	Eighty Mile Plain	30903	Salinaland Plateau
30210	Halls Creek Ridges	30603	Anketell Hills	30904	Woodramung Hills
30211	Fitzroy Ranges	30604	Great Sandy Desert Dunefield	30905	Northam Plateau
30301	Manangoora Plains	30605	Stansmore Dunefield and Ranges	30906	Narrogin-Ongerup Plateau
30302	Borroloola Fall	30606	Gibson Desert Plains	30907	Coonana-Ragged Plateau
30303	Isa Ridges	30607	Redvers Dunefield	30908	Darling Range
30401	Larrimah Plateau	30608	Macdonald Sandplain	30909	Collie-Kalgan Slopes
30402	Barkly Tableland	30609	Stanley Hills and Dunes	30910	Albany Headlands and Inlets
30403	Wiso Sandplain	30610	Carnegie Hills	30911	Stirling and Bareen Hills
30404	Lander Dunefield	30611	Leemans Sandplain	30912	Esperance Hills
30405	Ashburton-Davenport Ranges	30612	Great Victoria Desert Dunefield	31001	Carlisle Plain
30406	Frew-Sandover Sandplain	30701	De Grey Lowlands	31002	Bunda Plateau
30407	Tobermory Plain	30702	Nullagine Hills	31003	Roe Plain
30408	Toko Plateaux	30703	Rudall Tablelands	31004	Israelite Plain
30409	Jervois Ranges	30704	Hamersley Plateaux	31101	Gairdner Plain
30410	Barrow Dulcie Plateaux	30705	Chichester Range	31102	Gawler-Cleve Ranges
30411	Birrundudu Plain	30706	Fortescue Valley	31103	Eyre Dunefield
30412	Tanami Sandplain and Ranges	30707	Augustus Ranges	31104	Ceduna Dunefield
30413	Sturt Creek Floodout	30801	Onslow Plain	31105	Lincoln Hills
30501	Doreen-Reynolds Ranges	30802	Carnarvon Dunefield	31201	Flinders-Lofty Ranges
30502	Burt Plain	30803	North West Cape Ridges	31202	Torrens-Gulf Plains
30503	Alcoota Tablelands	30804	Kennedy Range	31203	Andamooka Tableland
30504	Plenty River Plains	30805	Carnarvon Plain	31204	Barrier Ranges
30505	Macdonnell Ranges	30806	Shark Bay Peninsulas	31205	Olary Spur
30506	Missionary Lowland	30807	Yaringa Sandplain	31206	Yorke Peninsula
30507	Henbury Ranges	30808	Greenough Hills		

5.2 Landform definitions

Landforms are an expression of the evolution of the landscape in which they occur. They are a culmination of processes, both past and present, acting on that landscape. Landforms are also highly visible in the landscape and can be recognised from topographic maps and from various kinds of imagery—both airborne and orbital.

The landform units listed here are the landform patterns and elements of Speight (1990, 2008). In this technique for describing landforms, the whole land surface is viewed as a mosaic of tiles of odd shapes and sizes. To impose order, the mosaic is treated as if the tiles are of two distinct sizes: the larger ones being themselves mosaics of the smaller ones. The larger tiles, which are more than 600 m across, are called *landform patterns*. They include, for example, flood plain, dune field and hills. The smaller tiles, which form mosaics within landform patterns, are about 40 m or more across. These are called *landform elements*.

The listing for landform patterns and landform elements are grouped together into related landform types under general headings, to give a hierarchical classification. Speight (1990, 2008) defines most of the landform units listed in this table. Other definitions, and more details, can be found in Fairbridge (1968) Eggleton (2001) and Goudie (2004). The lists provided here are from the Corporate Data Model of Geoscience Australia.

5.2.1 Landform patterns

AL00 Alluvial landforms

A complex landform pattern on valley floors, with active, inactive or relict erosion and aggradation by channelled and over-bank stream flow.

AL10 Alluvial plain

A level, gently sloping or slightly undulating land surface produced by extensive deposition of alluvium, generally adjacent to a river that periodically overflows its banks; it may be situated on a flood plain, a delta, or an alluvial fan.

AL11 Flood plain

An alluvial plain characterised by frequently active aggradation by over-bank stream flow (i.e. by flooding more often than every 50 years) and erosion by channelled stream flow.

AL12 Anastomosing plain

A flood plain on which the stream channels join and divide, as do the veins on a leaf. Flood plain with slowly migrating, deep alluvial channels, usually moderately spaced, forming a divergent to unidirectional integrated reticulated network. There is frequently active aggradation by over-bank and channelled stream flow.

AL13 Bar plain

A flood plain having sub-parallel stream channels that both aggrade and erode so as to develop a generally corrugated surface with numerous bars. Flood plain with numerous rapidly migrating shallow alluvial channels forming a unidirectional integrated reticulated network. There is frequently active aggradation and erosion by channelled stream flow.

AL14 Covered plain

A flood plain with a number of alluvial channels that are widely-spaced (i.e. a little under 1 km), migrating, more or less parallel, and deep (i.e. width–depth ratio <20:1). Aggradation by over-bank stream flow occurs at least once every 50 years, providing further alluvial cover.

AL15 Meander plain

A flood plain aggraded and eroded by meandering streams. Flood plain with widely spaced, rapidly migrating, moderately deep alluvial stream channels that form a unidirectional integrated non-tributary network. There is frequently active aggradation and erosion by channelled stream flow, with subordinate aggradation by over-bank stream flow.

AL16 Flood out

A flat inclined radially away from a point on the margin, or at the end, of a stream channel, aggraded by over-bank stream flow, or by channelled stream flow associated with channels developed within the over-bank part.

AL17 Stream channel

A linear, generally sinuous open depression—eroded in parts—excavated, built up and aggraded by channelled stream flow. This element comprises stream beds and banks.

AL20 Alluvial terrace

A former flood plain on which erosion and aggradation by channelled and over-bank stream flow is slightly active or inactive because of deepening or enlargement of the stream channel has lowered the level of flooding. A pattern that includes a significant active flood plain, or former flood plains at more than one level, becomes terraced land.

AL30 Stagnant alluvial plain

An alluvial plain on which erosion and aggradation by channelled and over-bank stream flow is slightly active or inactive because of reduced water supply, without apparent incision or channel enlargement that would lower the level of stream action.

AL40 Terraced land

A landform pattern including one or more terraces and often a flood plain. Relief is low or very low (9–90 m). Terrace plains or terrace flats occur at stated heights above the top of the stream bank.

AL50 Alluvial swamp

An almost level, closed, or almost closed, depression with a seasonal or permanent water table at or above the surface, commonly aggraded by over-bank stream flow and sometimes biological (peat) accumulation.

CO00 Coastal lands

A level to gently undulating landform pattern of extremely low relief eroded or aggraded by waves, tides, over-bank or channel flow, or wind. The landform pattern may be either active or relict.

CO01 Beach ridge plain

A level to gently undulating landform pattern of extremely low relief on which stream channels are absent or very rare; it consists of relict parallel linear ridges built up by waves and modified by wind.

CO02 Chenier plain

A level to gently undulating landform pattern of extremely low relief on which stream channels are very rare. The pattern consists of relict, parallel linear ridges built by waves, separated by, and built over, flats aggraded by tides or over-bank stream flow.

CO03 Reef

A continuously active or relict landform pattern built up to the present sea level, or that of a former time, by corals and other organisms. It is mainly level, with moderately inclined to precipitous slopes below sea level. Stream channels are generally absent, but there may occasionally be fixed deep erosional tidal stream channels forming a disintegrated non-tributary pattern.

CO04 Marine plain

A plain eroded or aggraded by waves, tides or submarine currents, and aggraded by deposition of material from suspension and solution in sea water, elevated above sea level by earth movements or eustacy, and little modified by subaerial agents such as stream flow or wind.

CO05 Tidal flat

A level landform pattern with extremely low relief and slowly migrating deep alluvial stream channels that form dendritic tributary patterns; it is aggraded by frequently active tides.

CO06 Coastal dunes

A level to rolling landform pattern of very low to extremely low relief— without stream channels—built up or locally excavated, eroded or aggraded by wind. This landform pattern occurs in usually restricted coastal locations.

CO07 Coastal plain

A level landform pattern with extremely low relief either with or without stream channels, built up by coastal—usually tidal—processes.

CO08 Beach

A short, low, very wide slope, gently or moderately inclined, built up or eroded by waves, forming the shore of a lake or sea.

DE00 Delta

A flood plain projecting into a sea or lake, with slowly migrating deep alluvial channels, usually moderately spaced, typically forming a divergent distributary network. This landform is aggraded by frequently active over-bank and channelled stream flow that is modified by tides.

DU00 Aeolian landforms

A landform pattern built up or locally excavated, eroded or aggraded by wind. Mabbutt (1977) provides a useful summary of the variety of aeolian landforms found in arid climates.

DU10 Aeolian dunes

Low mounds, ridges, banks, or hills of loose, windblown granular material (generally sand; in some places volcanic ash), either bare or covered with vegetation, capable of being moved from place to place by wind, but always retaining their own characteristic shape.

DU11 Longitudinal dune field

A dune field characterised by long narrow sand dunes and wide flat swales. The dunes are oriented parallel with the direction of the prevailing wind and, in cross section, one slope is typically steeper than the other.

DU12 Transverse dune field

A dune field characterised by long narrow sand dunes and wide flat swales. The dunes are oriented normal to the direction of the prevailing wind and, in cross section, the windward slope is typically steeper than the lee slope.

DU13 Irregular dune field

A dune field with a mixture of longitudinal and transverse dunes, as well as other more complicated forms.

DU14 Source bordering dune

A dune formed adjacent to the source of the wind-blown material. Most commonly the source is a river or floodplain that supplies aeolian sediment during periods of low or no flow.

DU15 Lunette

An elongated, gently curved, low ridge built up by wind on the margin of a playa, typically with a moderate, wave-modified slope towards the playa and a gentle outer slope.

DU20 Aeolian sheet

A sheet of aeolian material—generally sand—formed when wind moulding of the surface is prevented either by vegetation or, more usually, because the sand grains are too coarse. They are commonly associated with sources that give rise to coarse sand grains, such as alluvial plains, or the weathering of coarse-grained granite, as occurs in the Yilgarn of Western Australia.

ER00 Erosional landforms

A 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.

ER10 Erosional plain

A level to undulating or, rarely, rolling landform pattern of extremely low relief (< 9 m) eroded by continuously active to slightly active or inactive geomorphic processes.

ER11 Pediment

A gently inclined to level (<1% slope) landform pattern of extremely low relief, typically with numerous rapidly migrating, very shallow incipient stream channels that form a centrifugal to diverging integrated reticulated pattern. It is eroded, and locally aggraded, by frequently active channelled stream flow or sheet flow, with subordinate wind erosion. Pediments characteristically lie down-slope from adjacent hills with markedly steeper slopes.

ER12 Pediplain

A level to very gently inclined landform pattern with extremely low relief and no stream channels, eroded by slightly active sheet flow and wind. Largely relict from more effective erosion by stream flow in incipient channels as on a pediment.

ER13 Peneplain

A level to gently undulating landform pattern with extremely low relief and sparse slowly migrating alluvial stream channels that form a non-directional integrated tributary pattern. It is eroded by slightly active sheet flow, creep and channelled and over-bank stream flow.

ER14 Etchplain

A level to undulating or, rarely, rolling landform pattern of extremely low relief, initially formed by deep weathering and then erosion of the resulting weathered regolith. Removal of the weathered material may be either partial or complete (see also Ollier 1984).

ER20 Rises

A landform pattern of very low relief (9–30 m) and very gentle to steep slopes. Fixed erosional stream channels are closely to very widely spaced and form a dendritic to convergent, integrated or interrupted tributary pattern. The pattern is eroded by continuously active to slightly active creep and sheet flow.

ER21 Residual rise

A landform facet of very low relief (9–30 m) and very gentle to steep slopes. This term is used to refer to an isolated rise surrounded by other landforms.

ER30 Low hills

A landform pattern of low relief (30–90 m) and gentle to very steep slopes, typically with fixed erosional stream channels that are closely to very widely spaced and form a dendritic or convergent integrated tributary pattern. There is continuously active sheet flow, creep and channelled stream flow.

ER31 Residual low hill

A landform of low relief (30–90 m) and gentle to very steep slopes. This term is used to refer to an isolated low hill surrounded by other landforms.

ER40 Hills

A landform pattern of high relief (90–300 m) with gently sloping to precipitous slopes. Fixed, shallow erosional stream channels are closely to very widely spaced and form a dendritic or convergent integrated tributary network. There is continuously active erosion by wash and creep and, in some cases, rarely active erosion by landslides.

ER50 Mountains

A landform pattern of very high relief (>300 m) with moderate to precipitous slopes and fixed erosional stream channels that are closely to very widely spaced and form a dendritic of diverging integrated tributary network. There is continuously active erosion by collapse, landslide, sheet flow, creep and channelled stream flow.

ER60 Escarpment

A steep to precipitous landform pattern forming a linearly extensive, straight or sinuous inclined surface that separates terrains at different altitudes, that above the escarpment commonly being a plateau. Relief within the landform pattern may be high (hilly) or low (planar). An included cliff or scarp often marks the upper margin of the scarp.

ER70 Badlands

A landform pattern of low to extremely low relief (<9 m) and steep to precipitous slopes, typically with numerous fixed erosional stream channels that form a dendritic to parallel integrated tributary network. There is continuously active erosion by collapse, landslide, sheet flow, creep and channelled stream flow.

ER80 Drainage depression

A depression cut into a surface by erosional processes. This term should be used only in cases where a single depression or valley is incised into a plateau or other surface, and where the scale of mapping does not allow the depression to be subdivided into its component parts (*e.g.* rises, floodplain).

FA00 Fan

A level (<1% slope) to moderately inclined complex landform pattern of extremely low relief with a generally fan-shaped plan form. The channels form a centrifugal to divergent, integrated, reticulated to distributary pattern.

FA01 Alluvial fan

A level (<1% slope) to very gently inclined complex landform pattern of extremely low relief with a generally fan-shaped plan form. The rapidly migrating alluvial stream channels are shallow to moderately deep, locally numerous, but elsewhere widely spaced. The channels form a centrifugal to divergent, integrated, reticulated to distributary pattern. The landform pattern includes areas that are bar plains—being aggraded or eroded by frequently active channelled stream flow—and other areas comprising terraces or stagnant alluvial plains with slopes that are greater than usual, formed by channelled stream flow but now relict. Incision in the up-slope area may give rise to an erosional stream bed between scarps.

FA02 Colluvial fan

A very gently to moderately inclined complex landform pattern of extremely low relief with a generally fan-shaped plan form. Divergent stream channels are commonly present, but the dominant process is colluvial deposition of materials. The pattern is usually steeper than an alluvial fan.

FA03 Sheet-flood fan

A level (<1% slope) to very gently inclined landform pattern of extremely low relief with numerous rapidly migrating very shallow incipient stream channels forming a divergent to unidirectional, integrated or interrupted reticulated pattern. Frequently active sheet flow and channelled stream flow, with subordinate wind erosion aggrade the landform pattern.

GL00 Glacial landforms

This term covers a wide range of landforms that are produced by glacial processes. In Australia most landforms of this type are all relict, with the exception of Heard Island. For more details, see Fairbridge (1968) or Davies (1969).

GL10 Depositional glacial landforms

This collective term includes features such as moraines of various kinds, as well as irregular landforms made up of glacial deposits. For more details, see Fairbridge (1968) or Davies (1969).

GL20 Erosional glacial landforms

Glacial erosion produces a variety of streamlined forms such as cirques and U-shaped valleys. For more details, see Fairbridge (1968) or Davies (1969).

KA00 Karst

A landform pattern of unspecified relief and slope (for specification use terms such as 'karst rolling hills') typically with fixed deep erosional stream channels forming a non-directional disintegrated tributary pattern and many closed depressions without stream channels. It is eroded by continuously active solution and rarely active collapse, with the products being removed through underground channels.

MA00 Made land

A landform pattern typically of very low or extremely low relief and with slopes in the classes level and very steep. Sparse, fixed deep artificial steam channels form a non-directional interrupted tributary pattern. The landform pattern is eroded and aggraded, and locally built up or excavated, by rarely active human agency.

ME00 Meteor crater

A rare landform pattern comprising a circular closed depression with a raised margin; it is typically of low to high relief and has a large range of slope values, without stream channels, or with a peripheral integrated pattern of centrifugal tributary streams. The pattern is excavated, heaved up and built up by a meteor impact and now relict.

PL00 Plain

A 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.

PL01 Depositional plain

A level landform pattern with extremely low relief formed by unspecified depositional processes.

PL02 Lacustrine plain

A level landform pattern with extremely low relief formerly occupied by a lake, but now partly or completely dry. It is relict after aggradation by waves and by deposition of material from suspension and solution in standing water. The landform pattern is usually bounded by wave-formed cliffs, rock platforms, beaches, berms and lunettes that may be included or excluded.

PL03 Playa plain

A level landform pattern with extremely low relief, typically without stream channels, aggraded by rarely active sheet flow and modified by wind, waves and soil phenomena. Playa plains are sediment sinks and are the lowest parts of the landscape.

PL04 Sand plain

A level landform pattern with extremely low relief—typically without stream channels—aggraded by active wind deposition and rarely active sheet flow.

PT00 Plateau

A level to rolling landform pattern of plains, rises or low hills standing above a cliff, scarp or escarpment that extends around a large part of its perimeter. A bounding scarp or cliff may be included or excluded; a bounding escarpment would be an adjacent landform pattern.

PT01 Plateau edge

The cliff, scarp or escarpment that extends around a large part of the perimeter of a plateau.

PT02 Plateau surface

The low relief surface of a plateau.

VO00 Volcano

A 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.

VO01 Caldera

A rare landform pattern typically of very high relief and steep to precipitous slopes. It has no stream channels or has fixed erosional channels forming a centripetal integrated tributary pattern. The landform has subsided or was excavated as a result of volcanism.

VO02 Cone (volcanic)

A typically low to high relief and very steep landform pattern without stream channels, or with erosional rills forming a radial tributary pattern. The landform is built up by volcanism and slightly modified by erosional agents.

VO03 Lava plain

A level to undulating landform pattern of very low to extremely low relief, typically with widely spaced fixed stream channels that form a non-directional integrated or interrupted tributary pattern. The landform pattern is aggraded by volcanism (lava flow) that is generally relict; it is subject to erosion by continuously active sheet flow, creep and channelled stream flow.

VO04 Ash plain

A level to undulating landform pattern of very low to extremely low relief typically with widely spaced fixed stream channels that form an integrated or interrupted tributary pattern. The landform pattern is aggraded by volcanism (ash fall) that is generally relict; it is subject to erosion by continuously active sheet flow, creep and channelled stream flow.

VO05 Lava flow

A landform produced on the land surface by flowing magma. It is generally relict and subject to erosion by continuously active sheet flow, creep and channelled stream flow.

VO06 Lava plateau

A plateau aggraded by volcanism (lava flow) that is generally relict and subject to erosion by continuously active sheet flow, creep and channelled stream flow.

5.2.2 Landform elements

CHCR Hillcrest

A very gently inclined to steep crest, smoothly convex, eroded mainly by creep and sheet wash. A typical element of mountains, hills, low hills and rises.

CSUS Summit surface (broad crest)

A very wide level to gently inclined crest with abrupt margins, commonly eroded by water-aided mass movement or sheet wash.

CREC Rise crest

A crest of hillock of low relief (9–30m) (see also Residual Rise).

CDUC Dune crest

A crest built up or eroded by the wind (see Dune).

HTOR Tor

A steep to precipitous hillock, typically convex, with a surface mainly of bare rock—either coherent or comprising subangular to rounded large boulders (exhumed core-stones, also themselves called tors) separated by open fissures—eroded by sheet wash or water-aided mass movement.

HRER Residual rise

A hillock of very low relief (9–30 m) and very gentle to steep slopes. This term is used to refer to an isolated rise surrounded by other landforms.

HTUM Tumulus

A hillock heaved up by volcanism (or, elsewhere, built up by human activity at a burial site).

HDUN Dune

A moderately inclined to very steep ridge or hillock built up by the wind. This element may comprise Dune crest and Dune slope.

HDUH Hummocky (weakly oriented) dune

A very gently to moderately inclined rises or hillocks built up or eroded by wind and lacking distinct orientation of regular pattern.

HDUB Barchan

A crescent-shaped dune with tips extending leeward (downwind), making this side concave and the windward (upwind) side convex. Barchan dunes tend to be arranged in chains extending in the dominant wind direction.

HDUP Parabolic dune

A sand dune with a long, scoop-shaped form—which is convex in the downwind direction so that its horns point upwind—the ground plan of which, when perfectly developed, approximates the form of a parabola.

HDUT Transverse dune

A large, sharp-crested, elongated, longitudinal (linear) dune or chain of sand dunes, which is oriented transverse (perpendicular) to the prevailing wind.

HDUF Linear or longitudinal (Seif) dune

Large, sharp-crested, elongated, longitudinal (linear) dune or chain of sand dunes, oriented parallel, rather than transverse (perpendicular), to the prevailing wind.

HCON Cone (volcanic)

A hillock with a circular symmetry built up by volcanism. The crest may form a ring around a crater.

HMOS Mound spring

A hillock formed where an artesian spring deposits and/or trap sediments resulting in a mound or ridge. In active springs, water emerges from at, or near to, the top of the mound or ridge, the height of which is dependent on the hydraulic head. Mounds are composed of deposited carbonate, silica and sulphate, and trapped sand and clay.

HMOU Mound

A hillock built up by human activity.

RLEV Levee

A very long, very narrow, nearly level sinuous ridge immediately adjacent to a stream channel, built up by over-bank flow. Levees are built, usually in pairs bounding the two sides of a stream channel, at the level reached by frequent floods. This element is part of a covered plain landform pattern. For an artificial levee, use Embankment. See also Prior stream.

RBAR Bar (stream)

Elongated, gently to moderately inclined low ridge built up by channelled stream flow; part of a stream bed.

RSCR Scroll

A long, curved very low ridge built up by channelled stream flow and left relict by channel migration. Part of a meander plain landform pattern.

RPST Prior stream

A long, generally sinuous low ridge built up from materials originally deposited by stream flow along the line of a former stream channel. The landform element may include a depression marking the old stream bed and relict levees.

RDUN **Dune**

A moderately inclined to very steep ridge or hillock built up by the wind. This element may comprise Dune crest and Dune slope.

RFOR **Foredune**

A very long, nearly straight, moderately inclined to very steep ridge built up by the wind from material from an adjacent beach.

RLUN **Lunette**

An elongated, gently curved, low ridge built up by wind on the margin of a playa, typically with a moderate, wave-modified slope towards the playa and a gentle outer slope.

RBRI **Beach ridge**

A very long, nearly straight low ridge, built up by waves and usually modified by wind. A beach ridge is often a relict feature remote from the beach.

REMB **Embankment**

A ridge or slope built up by human activity.

RDAM **Dam**

A ridge built up by human activity so as to form and close a depression.

UCLI **Cliff**

A very steep (greater than 72º) maximal slope usually eroded by gravitational fall as a result of erosion of the base by various agencies; sometimes built up by marine organisms (cf. Scarp).

USCA **Scarp**

A very wide steep to precipitous maximal slope eroded by gravitational fall water-aided mass movement or sheet flow (cf. Cliff).

UHSL **Hill slope**

A gently inclined to precipitous slope—commonly simple and maximal—eroded by sheet wash, creep or water-aided mass movement. A typical element of mountains, hills, low hills and rises.

UCUT **Cut face**

A slope eroded by human activity.

ULDS Landslide

A moderately inclined to very steep slope, eroded in the upper part and aggraded in the lower part by water-aided mass movement, characterised by irregular hummocks.

UEMB Embankment

A ridge or slope built up by human activity.

SBAN Bank (stream)

A very short, very wide slope, moderately inclined to precipitous, forming the marginal upper parts of a stream channel and resulting from erosion or aggradation by channelled stream flow.

SBEA Beach

A short, low, very wide slope—gently or moderately inclined—built up or eroded by waves, forming the shore of a lake or sea.

SDUS Dune slope

A slope built up or eroded by the wind (see Dune).

SRES Rise slope

A slope of hillock of very low relief (9–30 m) (see Residual rise).

MBRK Breakaway

A steep maximal mid slope or upper slope, generally comprising both a very short scarp (free face) that is often bare rockland and a stony scarp-foot slope (debris slope); often standing above a pediment.

MCFS Cliff-foot slope

A slope situated below a cliff, with its contours generally parallel to the line of the cliff, eroded by sheet wash or waiter-aided mass movement, and aggraded locally by collapsed material from above.

MSFS Scarp-foot slope

A waning or minimal slope situated below a scarp, with its contours generally parallel to the line of the scarp.

MBEN Bench

A short, gently or very gently inclined minimal mid-slope element eroded or aggraded by any agent.

MBER Berm (artificial)

A short, very gently inclined to level minimal mid slope in an embankment or cut face, eroded or aggraded by human activity.

LCFS Cliff-foot slope

A slope situated below a cliff, with its contours generally parallel to the line of the cliff, eroded by sheet wash or waiter-aided mass movement, and aggraded locally by collapsed material from above.

LSFS Scarp-foot slope

A waning or minimal slope situated below a scarp, with its contours generally parallel to the line of the scarp.

LPED Pediment

A large gently inclined to level (<1%) waning lower slope, with slope lines inclined in a single direction—or somewhat convergent or divergent—eroded or sometimes slightly aggraded by sheet flow (cf. Foot slope). It is underlain by bedrock.

LFOO Foot slope

A moderately to very gently inclined waning lower slope resulting from aggradation or erosion by sheet flow, earth flow or creep (cf. Pediment).

LTAL Talus

A moderately inclined or steep waning lower slope, consisting of rock fragments aggraded by gravity.

LCFS Cliff-foot slope

A slope situated below a cliff—with its contours generally parallel to the line of the cliff—eroded by sheet wash or waiter-aided mass movement, and aggraded locally by collapsed material from above.

FPLA Plain

A large very gently inclined or level element, of unspecified geomorphological agent or mode of activity.

FRFL Rock flat

A flat of bare consolidated rock, usually eroded by sheet wash.

FRPL **Rock platform**

A flat of consolidated rock eroded by waves.

FCOS **Cut-over surface**

Flat eroded by human activity.

FSCD **Scald**

A flat—bare of vegetation—from which soil has been eroded or excavated by surface wash or wind.

FPED **Pediment**

A large gently inclined to level (<1%) waning lower slope, with slope lines inclined in a single direction—or somewhat convergent or divergent—eroded or sometimes slightly aggraded by sheet flow (cf. Foot slope). It is underlain by bedrock.

FFAN **Fan**

A large gently inclined to level element with radial slope lines inclined away from a point, resulting from aggradation—or occasionally from erosion—by channelled, often braided, stream flow, or possibly by sheet flow.

FVLF **Valley flat**

A small, gently inclined to level flat, aggraded or sometimes eroded by channelled or over-bank stream flow, typically enclosed by hill slopes; a miniature alluvial plain landform pattern.

FTEF **Terrace flat**

A small flat aggraded or eroded by channelled or over-bank stream flow, standing above a scarp and no longer frequently inundated; a former valley flat or part of a former flood plain.

FCBE **Channel bench**

A flat at the margin of a stream channel aggraded and in part eroded by over-bank and channelled stream flow; an incipient flood plain. Channel benches have been referred to as ‘low terraces’, but the term terrace should be restricted to landform patterns above the influence of active stream flow.

FBKP Back plain

A large flat resulting from aggradation by over-bank stream flow at some distance from the stream channel and in some cases biological (peat) accumulation; often characterised by a high water table and the presence of swamps or lakes; part of a covered plain landform pattern.

FSRP Scroll plain

A large flat resulting from aggradation by channelled stream flow as a stream migrates from side to side; the dominant element of a meander plain landform pattern. This landform element may include occurrences of scroll, swale and ox-bow.

FFLD Flood-out

A flat inclined radially away from a point on the margin or at the end of a stream channel, aggraded by over-bank stream flow, or by channelled stream flow associated with channels developed within the over-bank flow; part of a covered plain landform pattern.

FTEP Terrace plain

A large or very large flat aggraded by channelled or over-bank stream flow, standing above a scarp and no longer frequently inundated; part of a former flood plain.

FTDF Tidal flat

A large flat subject to inundation by water that is usually salt or brackish, and aggraded by tides. An intertidal flat (ITF) is frequently inundated; a supratidal flat (STF) is seldom inundated.

FITF Intertidal flat

See Tidal flat.

FSTF Supratidal flat

See Tidal flat.

FFILFill-top

A flat aggraded by human activity.

FBER Berm (coastal)

A flat built up by waves above a beach.

FREF **Reef flat**

A flat built up to sea level by marine organisms.

VALC **Alcove**

A moderately inclined to very steep, short open depression with a concave cross-section, eroded by collapse, landslides, creep or surface wash.

VGUL **Gully**

An open depression with short, precipitous walls and a moderately inclined to very gently inclined floor or small stream channel, which is eroded by channelled stream flow and consequent collapse and water-aided mass movement. Sapping may also play a role.

VCIR **Cirque**

A precipitous to gently inclined, typically closed depression with a concave contour and profile that has been excavated by ice. The closed part of the depression may be shallow, the larger part being an open depression like an alcove.

VDDE **Drainage depression**

A level to gently inclined, long, narrow, shallow open depression with smoothly concave cross-section, rising to moderately inclined side slopes, which is eroded or aggraded by sheet wash.

VSTC **Stream channel**

A linear, generally sinuous open depression—eroded in parts—excavated, built up and aggraded by channelled stream flow. This element comprises stream bed and banks.

VSTB **Stream bed**

A linear, generally sinuous open depression forming the bottom of a stream channel that is eroded and locally excavated, aggraded or built up by channelled stream flow. The built up parts include bars.

VTDC **Tidal creek**

An intermittently water-filled open depression—eroded in parts—excavated, built up and aggraded by channelled tide-water flow; type of stream channel (qv) characterised by a rapid increase in width downstream.

VEST **Estuary**
A stream channel close to its junction with a sea or lake, where the action of channelled stream flow is modified by tide and waves. The width typically increases downstream.

VSWP **Swamp**
An almost level, closed, or almost closed, depression with a seasonal or permanent water table at or above the surface, commonly aggraded by over-bank stream flow and sometimes biological (peat) accumulation.

VSWH **Channel swale**
A long, curved open or closed depression left relict between scrolls built up by channelled stream flow.

VSWD **Dune swale**
A linear, level-floored open depression excavated by wind, or left relict between ridges built up by wind.

VSWC **Coastal swale**
A linear, level-floored open depression excavated by wind, or left relict between ridges built up by coastal wind or waves

VTRE **Trench**
An open depression excavated by human activity.

DLAK **Lake**
A large water-filled closed depression.

DPLY **Playa**
A large, shallow, level-floored closed depression, intermittently water-filled, but mainly dry due to evaporation, which is usually bounded by flats aggraded by sheet flow and channelled stream flow.

DDBA **Deflation basin**
A basin excavated and maintained by wind erosion that removes unconsolidated material and commonly leaves a rim of resistant material surrounding the depression.

DDOL Solution doline

A steep-sided closed circular or elliptical depression—commonly funnel-shaped—characterised by subsurface drainage and formed by dissolution of the surface or underlying bedrock.

DDOC Collapse doline

A steep-sided closed, circular or elliptical depression—commonly funnel-shaped—characterised by subsurface drainage and formed by collapse of underlying caves within bedrock.

DOXB Ox-bow

A long, curved, commonly water-filled closed depression eroded by channelled stream flow but closed as a result of aggradation by channelled or over-bank stream flow during the formation of a meander plain landform pattern. The floor of an ox-bow may be more or less aggraded by over-bank stream flow, wind and biological (peat) accumulation.

DLAG Lagoon

A closed depression filled with water that is typically salt or brackish, bounded at least in part by forms aggraded or built up by waves or reef-building organisms.

DSWP Swamp

An almost level, closed, or almost closed, depression with a seasonal or permanent water table at or above the surface, commonly aggraded by over-bank stream flow and sometimes biological (peat) accumulation.

DBOU Blow-out

A usually small, open or closed depression excavated by the wind.

DCIR Cirque

A precipitous to gently inclined, typically closed depression with a concave contour and profile that has been excavated by ice. The closed part of the depression may be shallow: the larger part being an open depression like an alcove.

DMAA Maar

A level-floored, commonly water-filled closed depression with a nearly circular steep rim, excavated by volcanism.

DCRA Crater

A steep to precipitous closed depression excavated by explosions due to volcanism, human action or the impact of an extraterrestrial object.

DPIT Pit

A closed depression excavated by human activity.

5.3 Environmental hazard definitions

Evidence of environmental hazards can be observed in the field and assessments of hazard liability can be made. The hazards listed here are those that are either directly related to the regolith and landforms (*e.g.* landslides), or their impacts are restricted to particular landscape types that are identified as part of a regolith landform map (*e.g.* floods). Readers who want more information about environmental hazards should refer to Heathcote and Thom (1979) or Blong and Johnson (1986) in the first instance.

AV Snow avalanche

The rapid movement of snow down mountain slopes.

CO Coastal erosion

The erosion of coastal land by waves and wind. This may be brought about by several factors, including human disturbance of the foredune and various effects of climatic change such as rising sea level and increased storminess.

FF Flash flood

The rapid rise of the water level in rivers, sometimes with over-bank flow, resulting from high intensity rain storms. These events are common in lower rainfall areas and may occur downstream of the location of rainfall.

FL Flood

The rise of water in rivers followed by over-bank flow, resulting from prolonged heavy rainfall. Flood waters may affect areas beyond the area of rainfall.

LA Landslide
A rapid mass movement of regolith material down hillslopes.

RO Rockfall
The fall of rock from vertical, or near vertical, cliffs.

SA Salinity
The accumulation of salts at the surface or within the near-surface soil. This can arise from a number of causes, ranging from a rise in water table levels in irrigated areas to emergence of subsurface water in lower footslope areas.

SC Solution cavities
In some circumstances, particularly on calcareous rock types, solution processes within the underlying rock can lead to the development of cavities and possibly collapse.

SD Sand drift
The movement of sand by wind erosion, transport and deposition.

SO Soil erosion
The loss of soil by erosion processes, including surface wash and rill erosion, as well as wind erosion.

ST Storm surge
An unusually high temporary sea levels resulting from storms that force sea water onto the land through a combination of strong onshore winds, high tides and lowered barometric pressure.

SU Subsidence
The sinking of the ground surface—either slowly or by more rapid collapse—due to, for example, underground caves in limestone, mines, or removal of water from aquifers.

TS Tsunamis
Ocean waves generated by either volcanic or seismic activity, usually on the sea floor. Tsunamis are sometimes (erroneously) called tidal waves.

VE Volcanic activity
The effects resulting from volcanic eruption.

5.4 Geomorphic process definitions

In the database, geomorphic processes are those that form or modify landform units. They can refer to either present or past activity. This means that processes occurring now, as well as those responsible for the evolution of a regolith terrain unit, can be entered into the database. An active/relict (A/R) code is used to distinguish the two.

Brief definitions are included here. For more detailed descriptions of these processes the user is referred to textbooks on geomorphology, such as Chorley *et al.* (1984). Other suitable references are given below.

GR00 Gravity

Any geomorphic process that acts mainly as a result of gravity. For more details see Selby (1993).

GR01 Vertical collapse

The collapse of large fragments of rock and/or soil, commonly from cliff faces. The collapsed materials accumulate where they fall and may be acted upon by other processes.

GR02 Particle fall

The more-or-less free fall of small particles of rock and/or soil from or near vertical faces.

GR03 Creep

The slow movement of rock and/or soil particles down slope under the influence of gravity. Creep operates at rates of a few millimetres per year, with wetting and drying, shrinking and swelling and freezing and thawing all contributing to the movement of material downslope.

GR04 Landslide

The translational movement of material along a shearplane under the influence of gravity. The moving material may be either a single coherent mass, or it may consist of a number of sliding fragments. In this type of movement, the material generally maintains its orientation relative to the land surface. The resulting deposit contains unbroken blocks or rafts of material.

GR05 Mudflow

The turbulent movement of material down slope under the influence of gravity. In this type of movement the moving mass tumbles, rolls and flows down slope. The resulting deposit is a mixture of material of all sizes, with no obvious orientation or indication of original structure.

WT00 Water

The movement and deposition of material through the agency of water. For more details see Morisawa (1985).

WT01 Channelled stream flow

The erosion, transport and deposition of material in stream channels. These commonly give well-sorted deposits that are confined to river channels—either modern or relict (channel deposits).

WT02 Over-bank stream flow

Erosion, transport and deposition of material on flood plains and other areas adjacent to rivers by water that has flowed out of a confined channel (over-bank deposits).

WT03 Sheet flow, sheet wash, surface wash

The erosion, transport and deposition of material by sheets of water flowing over the ground surface. This unconfined flow occurs on hill slopes and on low-angle landform units. It commonly removes fine material, leaving coarser material behind as a lag deposit.

WT04 Waves

The erosion, transport and deposition of material by wave action either on the sea coast or along lake edges. For more details on coastal processes see Davies (1980).

WT05 Tides

The erosion, transport and deposition of material by movement of tidal currents.

WT06 Detrital deposition in still water

The deposition of detrital material from a body of standing water onto the floor of the basin. In terrestrial landscapes this occurs in lakes. Sources of detrital material include channel flow into the lake and wave action along lake edges.

WT07 Rill/gully erosion

Linear erosion by water, producing steep sided channels. Rills are less than 0.3 m deep and gullies are more than 0.3 m deep.

IC00 Ice

The erosion, transport and deposition of material by moving ice. For more details see Davies (1969).

IC01 Frost

The freezing and thawing of water, which leads to shattering and movement of rock fragments and disturbance of soil material. Processes include solifluction and the development of patterned ground.

IC02 Glacial erosion

The erosion and transport of material by glacial ice, giving rise to distinctive landforms such as U-shaped valleys and cirques.

IC03 Glacial deposition

The deposition of material from melting ice. The deposits are generally referred to as moraine.

WI00 Wind

The erosion, transport and deposition of material by wind. For more details see Mabbutt (1977).

WI01 Wind erosion (deflation)

The erosion of material by the action of wind. This may involve entrainment of sand and dust particles, and their movement to other locations. It also includes the action of sand corrasion to produce ventifacts.

WI02 Sand deposition (wind)

The deposition of sand by wind to form various landform types, including dunes and sand sheets.

WI03 Dust deposition (wind)

The deposition of dust being transported by wind in the atmosphere as suspended load. This process is responsible for deposition of loess.

Where the dust is composed of clay pellets, it forms a special kind of loess, sometimes called parna in Australia.

DI00 Diastrophism; earth movements

Diastrophic movements are those that result directly or indirectly in relative or absolute changes of position, level or attitude of rocks forming the Earth's crust. This includes uplift and faulting.

VO00 Volcanism

Volcanism refers to the group of processes generated by volcanic activity on the land surface (see Ollier 1988).

VO01 Lava flow

The flow of molten rock across the land surface.

VO02 Ash flow

The flow of volcanic ash material across the land surface. This includes nuée ardentes. The resulting deposits are sometimes called ignimbrites.

VO03 Ash fall

The fall of volcanic ash on to the land surface, typically leading to mantles of volcanic ash (tephra) over all parts of the landscape.

BI00 Biological agents

The formation or changes in the shape of landforms by animals or plants; for example, the development of coral reefs.

HU00 Human agents

The formation or changes in the shape of landforms by human activity.

MT00 Impact by meteors

The formation or changes in the shape of landforms by meteorite impact, typically producing craters.

5.5 Weathering process definitions

Weathering is an essential first step in landscape development. Without weathering, there can be no soil formation, nor can there be any erosion and transportation of rock materials. Weathering processes range from simple physical breaking of rocks into smaller pieces to complex chemical alteration of rock materials. Ollier (1984) provides a detailed discussion of weathering and landforms.

WE00 Weathering

Weathering refers to any process that modifies rocks, either physically by reducing the size of fragments, or chemically by altering the composition of constituent rock materials.

PH00 Physical weathering

Physical weathering is any process that leads to a reduction in the size of rock fragments.

PH01 Abrasion

Abrasion is the mechanical breaking of rocks or minerals by either friction or impact. Friction is common at the base of glaciers, for example, whereas impact abrasion is more common in streams and in areas of wind transport.

PH02 Frost weathering

The breaking and separation of rock fragments by the force exerted when water freezes to ice. Freeze–thaw cycles are very important in the breakdown and mixing of rock and soil material.

PH03 Induced fracture

An induced fracture occurs when a large rock rests on an underlying rock. This sets up stresses that can act on both the underlying and overlying rock.

PH04 Insolation weathering

Insolation weathering occurs when temperature changes cause expansion and/or shrinkage of rocks. Repeated temperature changes may cause rocks to fracture; the heating agent is the sun.

PH05 Moisture swelling

Considerable changes in rock volume can be caused by a reversible absorption of moisture, and the volume changes may be enough to cause physical weathering.

PH06 Sheeting

Sheeting is the division of rock into sheets by joint-like fractures that are generally parallel to the ground surface. It is caused by pressure release and expansion of rock masses following erosion. Another name for this process is topographic jointing.

PH07 Salt weathering

The growth of salt crystals from solution can sometimes cause breakdown of rock materials in a manner similar to that caused by freezing of water.

PH08 Volume increase

The chemical alteration of rocks and minerals may cause an increase in volume. This volume increase usually leads to exfoliation, the peeling of thin shells of material from the parent rock.

PH09 Wetting and drying

Repeated wetting and drying of rock materials can lead to physical beak down of the materials into smaller fragments.

CH00 Chemical weathering

Chemical weathering occurs with any chemical alteration of rocks or minerals. It results from chemical reactions of minerals with air and water.

CH01 Solution

Solution is usually the first stage of chemical weathering and may take place in running water or in a thin film of water round a solid particle. Dissolved chemicals are removed from the weathering rock.

CH02 Oxidation and reduction

Oxidation is a reaction between minerals and oxygen to produce oxides or, combined with water, hydroxides. Reduction is the opposite of oxidation and usually takes place in waterlogged and other anaerobic sites. Alternating oxidation and reduction in, for example, a zone of fluctuating water level often leads to mottling of weathered materials.

CH03 Carbonation

Carbonation is the reaction of carbonate or bicarbonate ions with minerals.

Carbon dioxide is common in soil air, and carbonation can be quite rapid where carbonic acid is readily available.

CH04 Hydration

Hydration is the addition of water to a mineral to form hydrated mineral forms, or hydroxides. Hydration is an important process in clay mineral formation.

CH05 Chelation

Chelation, or complexing, is the holding of an ion—usually a metal—within a ring structure of organic origin. It is an important process involving both mineral and organic materials.

CH06 Hydrolysis

Hydrolysis—a very important chemical weathering process—involves a chemical reaction between minerals and the H^+ and OH^- ions of water.

CH07 Ferrolysis

Originally used by Brinkman (1970) to refer to the gradual destruction of clays in a soil through repeated cycles of replacement of exchange ions by Fe^{2+} during reducing conditions, followed by oxidation of the iron, consequent drop in pH, partial dissolution of the clays and the introduction of alumina in the exchange sites. More recently, it has been used to refer only to the decrease in pH caused by hydromorphic oxidation of iron, according to the equation:

$$Fe^{2+} + 3H_2O = Fe(OH)_3 + 3H^+ + e^-.$$

CH08 Chemical precipitation/evaporation

In suitable chemical environments, various chemicals precipitate from solution and are deposited in various parts of the landscape. This may be an important source of materials in some parts of the landscape, especially *in situ*ations where water comes to the surface and is then evaporated.

IN00 Induration

Induration processes lead to either absolute or relative accumulation of a cementing agent, to form a duricrust. Sometimes the cementing agent replaces regolith materials. A duricrust is a hard crust formed by weathering processes.

IN01 **Bauxitic induration**

Cementation largely by aluminous materials.

IN02 **Calcareous induration**

The *in situ* cementation and/or replacement of regolith by carbonate.

IN03 **Clay induration**

The induration of regolith by clay.

IN04 **Ferruginous Induration**

Cementation by ferruginous materials.

IN05 **Gypsiferous induration**

The *in situ* cementation and/or replacement of regolith by gypsum.

IN06 **Siliceous induration**

The *in situ* cementation and/or replacement of regolith by silica.

HA00 **Hydrothermal alteration**

Hydrothermal alteration is produced by chemical changes in rock materials caused by hot water and steam rising through country rock. This is not weathering, but produces very similar effects. The best field distinction between clay bodies formed by weathering and hydrothermal alteration is that weathering decreases with depth, and hydrothermal alteration increases with depth.

BI00 **Biotic weathering**

Biotic weathering is a combination of chemical and physical weathering brought about by biological agents. It has a wide variety of effects, but is not usually more than locally important. See Ollier (1984) for more details.

5.6 Regolith definitions

The list presented here contains the basic regolith types, derived in part from Speight and Isbell (1990, 2008) and developed more fully in Pain *et al.* (2007). There is potential for expansion of this list—see Anand *et al.* (2002) for a classification of ferruginous materials that could be incorporated here.

5.6.1 Regolith type

BU00 Unweathered bedrock

In some areas, particularly on steep slopes, or on young surfaces, the regolith consists of soil material formed directly on the underlying bedrock. Commonly the soil has a skeletal profile and is less than 1 m thick. These areas are mapped as bedrock.

EVA00 Evaporite

Sediments formed by the precipitation of solutes from water bodies on the land surface, typically as lacustrine sediments.

EVA01 Halite

Evaporite consisting of sodium chloride.

EVA02 Gypsum

Evaporite consisting of hydrated calcium sulphate.

EVA03 Calcrete

Calcrete broadly refers to regolith carbonate accumulations, forming more-or-less-well cemented aggregates composed largely of calcium carbonate, but not excluding dolomitic or magnesitic material. Although some regolith carbonates clearly cement fragmental regolith to form duricrusts, others may be pisolitic, nodular, pebbly, slabby or powdery. Calcrete is a convenient field term for all such carbonate accumulations.

SDT00 Sediments (terrestrial)

Materials deposited on the land surface by terrestrial geomorphic processes.

SDA00 Alluvial sediments

Materials deposited on the land surface from transport by flowing water confined to a channel or valley floor.

SDA10 Channel deposits

Alluvium that is deposited in an alluvial channel. It is commonly coarser than surrounding deposits and is found in both active and relict channels. It includes deposits in cut-off meanders and point bar deposits.

SDA20 Over-bank deposits

Alluvium that is deposited outside an alluvial channel from flowing water that has overflowed from the channel. It includes levees and back swamp deposits.

SDC00 Colluvial sediments

Sediment mass deposited from transport down slope by gravity. Compared with alluvium, colluvium lacks bedding structure, is more variable in grain size and contains mainly material derived locally.

SDC01 Scree

Scree—sometimes called talus—is colluvium deposited after falling or rolling from cliffs or precipitous slopes and consists of loose rock fragments of gravel size or larger.

SDC02 Landslide deposit

Colluvium rapidly displaced down slope by failure of a mass of earth or rock. If the mass was not already part of the regolith, the landslide incorporates it into the regolith. Original rock structures are fragmented and tilted by the action of the landslide.

SDC03 Mudflow deposit

Colluvium rapidly displaced down slope mixed with water to form a dense fluid. The material is more thoroughly disaggregated than that of a landslide deposit, but lacks the bedding and sorting of grain sizes seen in alluvium.

SDC04 Creep deposit

Normally a thin layer of rocky or earthy colluvium that moves very slowly down slope. In some circumstances, it may be recognised by, for example, bending of rock bands down slope, but in other cases can only be inferred.

SDC05 Sheet flow deposit

Colluvium deposited from transport by a very shallow flow of water as a sheet, or network of rills on the land surface. Sheet flow deposits are very thin, except at the foot of a slope and beneath sheet flood fans.

SDC06 Fanglomerate

Sedimentary regolith consisting of slightly water-worn, heterogeneous fragments of all sizes, deposited in an alluvial fan.

SDE00 Aeolian sediments

Sediments deposited from transport by wind.

SDE01 Aeolian sand

Wind-blown sediment of sand size, often taking the form of dunes, with characteristic bedding structures.

SDE02 Loess

Aeolian sediment of silt size, often deposited over the landscape as a blanket.

SDE03 Parna

Aeolian sediment of clay size, commonly transported as flakes of larger size, up to sand size.

SDF00 Fill

Artificial sediment mass formed by earth-moving works. Fill is sometimes compacted to the status of a very weak rock, but typically remains an earth mass.

SDG00 Glacial sediments

Sediments deposited from transport by moving ice. It is neither bedded nor sorted. It has a matrix of clay or silt enclosing larger particles of unweathered rock ranging up to large boulders.

SDL00 Lacustrine sediments

Sediments deposited from transport by waves and from solution and suspension in still water in a closed depression on land.

SDM00 Marine sediments

Sediments deposited from transport by waves and from solution and suspension in sea water. Marine sediments may occur in the regolith where the sea has withdrawn from an area during the Quaternary Period.

SDP00 Swamp (paludal) sediments

Fine-grained regolith material accumulated in a closed, or almost closed, depression with a seasonal or permanent water table at or above the surface, commonly consisting of over-bank stream deposits and sometimes by biological (peat) accumulation.

SDP01 Peat

Black or brown, partly decomposed, fibrous vegetative matter that has accumulated in a waterlogged environment, such as a bog.

SDS00 Coastal sediments

Sediments deposited in the coastal zone by coastal processes.

SDS01 Beach sediments

A sediment mass deposited from transport by waves or tides at the shore of a sea or lake.

SDS02 Estuarine sediments

Sediments deposited in an estuary or lagoon, from transport by tidal currents.

SDS03 Coral

Material accumulated by the growth of coral in place.

UOC00 Clay (unknown origin)

Some clay deposits cannot be attributed to any particular origin. Such deposits should be placed in this category.

WMU00 Weathered material (origin unknown)

This category covers those materials that are weathered—and so are regolith—but contain no features that allow them to be characterised as being either *in situ* or transported.

UOS00 Sand (unknown origin)

Some sand deposits, particularly in inland locations, cannot be attributed to any particular origin. Such deposits should be placed in this category.

VOL00 Volcanic material

Material derived from igneous activity at the surface.

VOL01 Lava

Igneous rocks solidified after eruption on to the land surface.

VOL02 Volcanic ash (tephra)

Material deposited on the land surface after ejection from a volcano. It often contains a proportion of highly weatherable glass, and mantles the landscape.

WIR00 ***In situ*** **weathered rocks**

Rock masses that have suffered chemical, mineral and physical changes on exposure to land surface processes, resulting in a loss of up to 85% of the rock strength (Speight and Isbell 1990, 2008). Weathered rocks have thus been altered by weathering processes: they have been broken into smaller fragments and/or changed in composition. The degree of weathering can vary from slight to complete (see Section 5.6.3).

WIR10 Saprolith

In situ regolith produced by weathering of rock masses due to exposure to land surface processes. A number of terms are in general use for naming all or parts of a weathering profile. Some definitions are given here, with preferred terms indicated. An undisturbed deep weathering profile consists of an upper soil layer and a lower *in situ* weathered layer. The former is developed from the material below, but may have been disturbed. It is best classed as residual material. The latter is quite undisturbed.

The various layers or zones in deep weathered regolith are often assumed to be genetically related. In some cases this may be true, but there are so many exceptions reported in the literature that we have chosen to leave out all genetic connotations in our definitions. Moreover, the various layers do not always occur in the same sequence, making genetic implications suspect in many cases.

The term *lateritic profile* is sometimes used to refer to a particular type of deep weathered regolith that has ferruginous upper layers and kaolinised lower layers.

WIR11 Saprock

Compact, slightly weathered rock with low porosity; defined as having less than 20% of weatherable minerals altered, but generally requiring a hammer blow to break. It may still contain rock structure.

WIR16 Saprolite

The term *saprolite* (Becker 1895) is used to refer to all those parts of a weathering profile that have been formed strictly *in situ*, with interstitial grain relationships being undisturbed. This contrasts with residual material, which has been disturbed (see WIR20 below). Saprolite is altered from the original rock by mainly chemical alteration and loss without any change in volume. This is sometimes referred to as constant volume alteration. Saprolite is often equivalent to the C horizon in pedology. Some workers confine the use of the term to weathered material below the zone of pedological alteration (or pedoplasmation—Flach *et al.*, 1968).

WIR20 Residual material

Material derived from weathering of rock and remaining in place after part of the weathered material has been removed. It results from loss of volume from the weathered mass. This is similar in concept to the pedolith and the mobile zone (see Eggleton 2001 for definitions).

WIR21 Lag

A deposit—commonly thin—of fragments larger than sand size, spread over the land surface. Its most common origin is as the coarse material left behind after fine material has been transported away by wind or, less commonly, sheet flow.

WIR22 Residual sand

A deposit of sand-sized material—commonly composed largely of quartz—covering the land surface and derived from the removal of finer material either in solution or suspension in subsurface water. It includes the sandy top of some soil types.

WIR23 Residual clay

Clay material that remains behind after weathering has removed part of the original rock. A common example is the clay soil material found on limestone after solution has removed the calcareous part of the rock.

WIS00 Shallow soil on fresh bedrock

In some areas, particularly on steep slopes, or on young surfaces, the regolith consists of soil material up to 2 m thick formed directly on the underlying bedrock. Commonly the soil has a skeletal profile and is less than 1 m thick.

5.6.2 Induration

See section 3.3.22 for a complete list.

IN00 Indurated material

Regolith material that has been hardened and/or cemented to some degree. Note that induration is treated as a modifier of regolith types rather than a regolith type in its own right. This category can be further subdivided according to the dominant indurating material.

DU00 Duricrust

A mass of hard material formed within the regolith by either relative or absolute accumulations of natural cements in sediment (which may be variably weathered), saprolite or partially weathered rock.

DC00 Completely cemented duricrust

A smooth textured duricrust where more than 90% of the material has been cemented. The suffix 'crete' is used for these materials.

DM00 Moderately cemented duricrust

Duricrust where the material is 70–90% cemented. It often has a grainy texture and may be mottled.

DP00 Partially cemented duricrust

Duricrust with less than 70% cemented material, often with an open texture, for which the term hardpan is used. This category can be further subdivided:

NO00 Nodules

Nodules are irregular to spherical units of regolith material that occur enclosed within the regolith, as lag, or in duricrusts. They generally have rounded edges. They are distinctive because of a greater concentration of some constituent, a difference in internal fabric or a distinct boundary with the surrounding material. We use the term as more or less equivalent to the *glaebule* of Brewer (1964). It does not include fragments of weathered rock, or coarse sedimentary particles unless they have been modified. For example, a fragment of rock weathered and coated with a cutan would fit our definition.

There are many possible subdivisions of this category, such as pisoliths and concretions. These may be included in revisions.

5.6.3 Degree of weathering

For each regolith type it is preferable to assess the degree of weathering. Speight and Isbell (1990, 2008) have developed a schema for *in situ* rocks. There is also an Australian Standard, AS1726-1993 (Table 5), for rock material weathering classification.

Table 5. AS1726-1993—Rock material weathering classification.

Term	Code	Definitions
Residual soil	RS	Soil developed on extremely weathered rock; the mass structure and substance fabric are no longer evident; there is a large change in volume but the soil has not been significantly transported
Extremely weathered rock	XW	Rock is weathered to such an extent that it has "soil" properties, i.e. it either disintegrates, or can be remoulded, in water.
Distinctly weathered rock	DW	Rock strength usually changed by weathering. The rock may be highly discoloured, usually by iron staining. Porosity may be increased by leaching, or may be decreased due to deposition of weathering products in pores.
Slightly weathered rock	SW	Rock is slightly discoloured but shows little or no change of strength from fresh rock.
Fresh rock	FR	Rock shows no sign of decomposition or staining.

The definitions here provide for transported as well as *in situ* regolith, and include practical tests from Ollier (1965). It should be noted that this assessment is for chemical weathering only. Physical weathering can be assessed on the degree to which rocks have been broken into smaller particles.

0 Unknown

This category is used during reconnaissance mapping when an RTU has been recognised on imagery or maps, but has not been visited in the field.

1 Unweathered

Regolith with no visible signs of weathering. Normally this class will be confined to sedimentary regolith types because, by definition, fresh bedrock is not regolith.

2 Slightly weathered

Slightly weathered rock has traces of alteration, including weak iron staining and some earth material. Corestones, if present, are interlocked; there is slight decay of feldspars and a few microfractures. Slightly weathered rock is easily broken with a hammer.

Slightly weathered sediments have traces of alteration on the surfaces of sedimentary particles, including weak iron staining. Some earth material may be present, filling voids between coarse particles.

3 Moderately weathered

Moderately weathered rock has strong iron staining and up to 50% earth material. Corestones, if present, are rectangular and interlocked. Most feldspars have decayed and there are microfractures throughout. Moderately weathered rock can be broken by a kick (with boots on), but not by hand.

Moderately weathered sediments have strong iron staining and up to 50% earth material. Labile particles up to gravel size are completely weathered. Larger particles have thick weathering skins. Most feldspars in larger particles have decayed.

4 Highly weathered

Highly weathered rock has strong iron staining and more than 50% earth material. Core stones, if present, are free and rounded. Nearly all feldspars are decayed and there are numerous microfractures. The material can be broken apart in the hands with difficulty.

Highly weathered sediment has strong iron staining and more than 50% earth material. All except the largest particles are weathered right through. Boulders have thick weathering skins.

5 Very highly weathered

Very highly weathered rock is produced by the thorough decomposition of rock masses due to exposure to land surface processes. The material retains structures from the original rock. It may be pallid in colour and is composed completely of earth material. Corestones, if present, are rare and rounded. All feldspars have decayed. It can easily be broken by hand.

Very highly weathered sediment is thoroughly decomposed, but still retains the shapes of the original sediment particles, as well as laminations and bedding. It is composed completely of earth material.

6 Completely weathered

Completely weathered rock retains no structures from the original rock. There are no corestones, but there may be mottling. It is composed completely of earth material.

Completely weathered sediment retains no structures from the original sediment. It is composed completely of earth material. There may be mottling.

5.6.4 Zone data

This section defines some of the attributes recorded for zones.

5.6.4.1 Boundary

The following definitions are from McDonald and Isbell (1990, 2008).

Lower boundary-shape

SM	smooth	almost a plain surface
W	wavy	undulations with depressions wider than they are deep
I	irregular	undulations with depressions deeper than they are wide
T	tongued	depressions considerably deeper than they are wide
D	discontinuous	the zone is itself discontinuous

Lower boundary-type

SH	sharp (<5 mm wide)	D	diffuse (50-100 mm wide)
A	abrupt (5-20 mm wide)	G	gradual (>100 mm wide)
C	clear (20-50 mm wide)		

5.6.4.2 Consistence

Consistence refers to the strength of cohesion and adhesion in soil and regolith materials. Strength will vary according to water status. Strength is the resistance to breaking or deformation. Stickiness is a characteristic determined on wet material. McDonald and Isbell (1990, 2008) discuss these properties further and provide definitions and means of determination.

Soil strength is determined subjectively by the force just sufficient to break or deform a 20 mm piece of material when a compressive force is applied between thumb and forefinger.

S0	loose	No force required. Separate particles such as loose sand
S1	very weak (<25 kPa)	Very small force, almost nil
S2	weak (25-50 kPa)	Small but significant force
S3	firm (50-100 kPa)	Moderate or firm force
S4	very firm (100-200 kPa)	Strong force but within power of thumb and forefinger
S5	strong (200-400 kPa)	Beyond power of thumb and forefinger. Crushes underfoot
S6	very strong (>400 kPa)	Either crushes under foot with difficulty, or not at all

Stickiness is determined on wet material by pressing the wet sample between thumb and forefinger and then observing the adherence of material to the fingers.

NS	non-sticky	Little or no material adheres
SS	slightly sticky	Soil adheres to thumb and forefinger but is not stretched notably and comes off rather cleanly
MS	moderately sticky	Soil adheres to thumb and forefinger and tends to stretch rather than pull free of fingers
VS	very sticky	Soil adheres strongly to thumb and forefinger and stretches notably

5.6.4.3 Rock strength

Rock strength is the strength of the intact material rather than that of the mass, the strength of which has generally been reduced by jointing, fracturing and other processes.

	strength	knife	pick	hammer
R1	very low, (1.5-3 Mpa)	deep cut	crumbles	flattened or powdered
R2	low, (3-10 Mpa)	Shallow cut or scratch	Deep indent	Shattered into many small fragments
R3	medium, (10-25 Mpa)	Nil or slight mark	Shallow indent	Breaks readily into a few large and some small fragments
R4	high, (25-80 Mpa)	Nil	Nil	Breaks into one or two large fragments
R5	very high, (>800 Mpa)	Nil	Nil	Nil

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NOTES

CRC LEME FIELD GUIDES

This *CRC LEME Field Guide* is one of a number of Field Guides designed to complement the CRC LEME series of Guides for Mineral Exploration through the Regolith. Primarily written for use by mineral explorers, scientists and students dealing with natural resource management, it presents a useful aid when used in the systematic recording of field observations of regolith: that layer of weathered material between fresh rock and fresh air that blankets much of Australia.

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