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PROTOCOL FOR SAMPLING IN REGIONAL GEOCHEMICAL SURVEYS: LESSONS FROM PILOT PROJECTS

Megan Lech and Patrice de Caritat

CRC LEME OPEN FILE REPORT 229

November 2007

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CRC LEME is an unincorporated joint venture between CSIRO-Exploration & Mining, and Land & Water, The Australian National University, Curtin University of Technology, University of Adelaide, Geoscience Australia, Primary Industries and Resources SA, NSW Department of Primary Industries and Minerals Council of Australia, established and supported under the Australian Government's Cooperative Research Centres Program.

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Through the research of the Regional Geochemical Pilots Project from 2003-2007, a sampling strategy for the consistent sampling of low density geochemical surveys in Australia has been developed. Regional geochemical surveys, like these, can be used for mineral exploration, environmental management and geohealth studies.

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PREFACE AND EXECUTIVE SUMMARY

This report outlines the sampling protocol for regional geochemical surveys in Australia. It was developed during the course of several pilot projects conducted in New South Wales, Victoria and South Australia from 2003 to 2007. The pilot studies were purposely conducted in regions of varying climate, relief, drainage definition and regolith to ensure the developing methodology would suit many parts of Australia. Up to six grain-size fractions, various depth ranges as well as complete soil profiles were sampled. Partial leaches (including Mobile Metal Ions®), heavy mineral fractions, and other sampling media (e.g., soil, groundwater, and vegetation) were tested during the pilot projects.

The regional geochemical pilot projects aim to:

1. Help develop a suitable geochemical sampling methodology that can be adapted for other regional geochemical studies across Australia (this document),
2. Provide internally consistent background geochemical data and suitable maps for various test regions, and
3. Enhance global attractiveness to mineral exploration, and improve our resource management and environmental protection in Australia.

This report details the:

1. Methodology underpinning the determination of the theoretical sampling points using terrain and hydrological analysis; and
2. Protocols necessary for standardised site selection, sample collection and site documentation.

Patrice de Caritat
Project Leader

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ABSTRACT

This report outlines the sampling protocol for standardised collection of samples for regional geochemical surveys in Australia. It was developed during the course of several pilot projects conducted in New South Wales, Victoria and South Australia from 2003 to 2007.

Software generated target sample sites were determined by conducting a hydrological analysis using Geoscience Australia's 9 second Digital Elevation Model and nested catchment coverage of Australia produced in 2000 by the Centre for Resource and Environmental Studies (CRES), The Australian National University, Canberra. This analysis was carried out using the ArcHydro extension of ESRI®'s ArcGIS™ 8.3 in order to determine the lowest point in each catchment, which is the target sampling site. The sites established using this technique are not on a uniform grid but are controlled by the regional drainage systems and are designed to represent the catchment. The sample sites determined by ArcHydro were then carefully adjusted using drainage and road coverages, and field considerations such as land accessibility, landscape position and possible anthropogenic interferences at the site.

Top outlet sediment (TOS, 0-10 cm depth) and bottom outlet sediment (BOS, a ~ 10-cm interval generally sampled from ~60-90 cm depth) samples (~2-3 kg of each) were collected at each target site. A list of equipment that was used in the sampling, including augers, safety equipment, and sampling bags, is included to help with the planning of future sample collection. Site descriptions and sample details (e.g. Munsell colour and pH) can be recorded in a standardised way using look-up-tables, and entered on the data entry sheet provided. To ensure the integrity of the sample is maintained during sampling, it is important to consider and minimise contamination relating to: anthropogenic activities at the site, like the proximity to buildings and roads; and, contamination by equipment/staff when sampling.

By following the standardised protocol for site selection and sample collection outlined in this report, internal consistency is ensured. This allows direct comparison between samples collected during different projects allowing a national geochemical baseline to be established across Australia.

1. INTRODUCTION

Low-density regional geochemical surveys have been conducted in many countries for applications in resource evaluation, land use management and the health of humans and animals. These studies add to the development of a global geochemical database, which requires the systematic and standardised sampling and collection of geochemical samples across the globe (Darnley *et al.* 1995). The surveys provide vital information on the natural concentration of chemical elements and compounds in the regolith. These natural concentrations vary greatly due to local influences such as geology, biological processes and other factors (Reimann and Caritat 1998, 2005).

Knowing the natural concentrations and regional geochemical patterns across a country can contribute to that nation's triple bottom line (i.e. economy, environment and society) by:

1. Providing potential targets for mineral exploration (e.g., Xie and Ren 1993, Wang *et al.* 1999),
2. Establishing a baseline to help determine the natural state of the environment (e.g., Shacklette & Boerngen 1984; Reimann *et al.* 1998; Jiaxi & Wu 1999; Reimann *et al*. 2003) from which future changes can be assessed,
3. Contributing valuable information to help develop more informed environmental policies, and
4. Providing information for geohealth studies by gaining knowledge of anomalies, contaminations or deficiencies.

A series of collaborative pilot projects between Geoscience Australia (GA), the Cooperative Research Centre for Landscape Environments and Mineral Exploration (CRC LEME) and State geoscience agencies were conducted to develop a consistent methodology applicable to low density regional geochemical mapping in Australia.

The pilot studies were conducted in regions of varying climate, relief, drainage definition and regolith. Up to six grain-size fractions, various depth ranges as well as complete soil profiles were sampled. Partial leaches (including Mobile Metal Ions®), heavy mineral fractions, and other sampling media (e.g., soil, groundwater, and vegetation) were tested during the pilot projects.

The pilot studies have demonstrated that:

- The lateral dispersion of elements is generally no greater than the catchment scale;
- The chemical variability is greater between sample sites than between various size fractions at the same site (e.g., < 75 µm and < 2 mm);
- Geochemical signatures reflecting bedrock lithology (e.g., ultramafic rocks or various igneous rock types) or mineralisation (e.g., Au and base metal occurrences) are recognisable in the surface regolith even through thick sedimentary and/or aeolian cover; and
- The geochemical maps for U and Th correspond closely to the distributions shown by independent methods (e.g., airborne radiometric surveys).

1.1 Principal objectives

The regional geochemical pilot projects aimed to:

- *Help develop a suitable geochemical sampling methodology that can be adapted for other regional geochemical studies across Australia* (this document);
- Provide internally consistent background geochemical data and suitable maps for the various test regions; and
- Enhance global attractiveness to mineral exploration, and improve our resource management and environmental protection in Australia.

1.2 Location

The surveys were conducted in the Riverina region of New South Wales (NSW) and Victoria, the Gawler region of South Australia and the Thomson region of NSW (Figure 1) from 2003-2007 (Caritat *et al.* 2004a; Caritat *et al.* 2004b; Lech *et al.* 2004; Caritat *et al.* 2005a; Caritat *et al.* 2005b; Caritat *et al.* 2005c; Caritat *et al.* 2006a; Caritat *et al.* 2006b; Greenfield *et al.* 2006a; Greenfield *et al.* 2006b; Lech *et al.* 2006; Lech and Caritat, 2007).

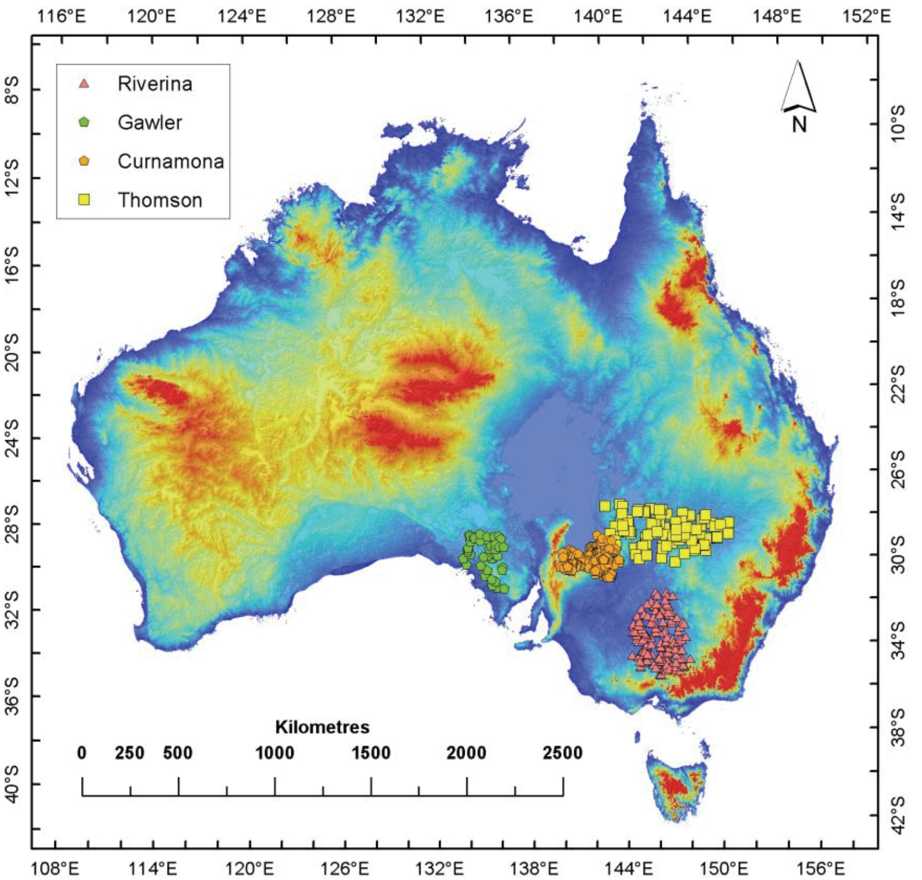


Figure 1: Clusters of points indicating the location of pilot projects conducted by GA, CRC LEME and State geoscience agencies.

2. BACKGROUND

Geochemical surveys provide vital information on the natural concentration of chemical elements and compounds in the environment suitable for a multitude of applications. These natural concentrations vary greatly due to local influences such as geology, biological processes and other factors (Reimann & Caritat 1998, 2005). Low-density geochemical baseline surveys have been conducted in many countries for applications in resource evaluation, land use management, and research into the health of humans, animals and plants (Xie & Ren 1993; Shacklette & Boerngen 1984; Reimann *et al.* 1998; Jiaxi & Wu 1999; Reimann *et al*. 2003).

The sampling protocol for the pilot projects was adapted from Äyräs & Reimann (1995), itself the basis for the Forum of European Geological Surveys (FOREGS) geochemical mapping field manual (Salminen *et al.* 1998). The main sampling medium targeted by Äyräs & Reimann (1995) and Salminen *et al.* (1998) was transported regolith; more specifically overbank (or floodplain) sediments in the lower portion of (large) catchments, which are deposited as fine-grained sediments in lowenergy environments, generally by receding floodwaters. They provide a sampling medium that is ubiquitous and comparable throughout Australia and beyond.

This sampling medium was selected because it is more likely than other media to represent an average composition of an entire catchment, enabling cost-effective sampling of large areas (Ottesen *et al.* 1989; Bølviken *et al.* 2004). It also exhibits a high geochemical signal-to-noise contrast due to the fine-grained nature of the material. Consequently, overbank sediments are commonly used in geochemical surveys (e.g., McConnell *et al.* 1993; Eden and Bjørklund 1996; Volden et al 1997; Swennen *et al.* 1998; Pavlovic *et al.* 2004). Where overbank sediments are absent, transported materials are targeted (e.g., fine sediments in depositional environments or regolith from the swales of dunes in aeolian environments).

The pilot projects were conducted at varying sample densities (**Error! Reference source not found.**). The preferred sample particle size fractions used for analysis in the pilot project were the <180 μm and <75 μm fractions. Both fractions require no milling, which is a time-consuming preparation step that may introduce contamination. The <180 μm fraction represents the bulk sample (minus larger rock, vegetal and animal fragments in floodplain setting) and was routinely used in other related geochemical surveys (Reimann, 1998, 2003). The <75 μm fraction is representative of the finer (mostly silt- and clay-sized) sediment and regolith particles and exhibits a stronger geochemical contrast compared to background (signal-to-noise ratio).

Table 1: Sample densities for the various pilot geochemical surveys

Pilot survey	Approx area (km2)	Number of sampling sites	Average sampling density (1 site per X km2)
Curnamona	61,915	199	311
Riverina	122,976	142	866
Gawler	53,636	48	1117
Thomson	209,824	99	2119

3. SITE SELECTION

3.1 Software generated sampling sites

Because the main sampling medium selected were overbank sediments, the landscape units relevant to sampling are hydrologic catchments. Before going out in the field, theoretical sampling sites (target sample sites) near the outlet of catchments were established according to the following procedure:

- Datasets used:
    - GEODATA 9 Second Digital Elevation Model (DEM-9S) Version 2 (ANZLIC unique identifier: ANZCW0703005624)

  - Australian Nested Catchments and Sub-Catchments at 500 km^2 scale (ANZLIC unique identifier: ANZCW1202000005) produced in 2000 by the Centre for Resource and Environmental Studies (CRES), Australian National University, Canberra (Hutchinson *et al.* 2004). This dataset represents the most consistent, systematically-derived national scale drainage catchment coverage available for Australia.
- The lowest point (outlet) of each catchment was determined by hydrological analysis using the ArcHydro® Tools (v.1.2 beta) extension (Maidment and Djokic, 2000) of ESRI's ArcGIS® software (v.9.1) (ESRI, 2007). The DEM-9S was filled and flow direction and flow accumulation analyses were conducted. Finally drainage point processing was conducted to determine outlet points.
- The sites established using this technique are not on a uniform grid and their position and distribution are controlled by the regional drainage systems.

All theoretical sampling sites were carefully checked with topographic, drainage and road coverages (Geoscience Australia, 2007) to see if the locations were representative of the catchment. Where necessary, the sampling sites were moved from the software-generated ('theoretical') position to manually selected locations before going in the field. Where a defined catchment showed connection to through-flowing trunk streams that were unrepresentative of the catchment, the sampling point was re-positioned as far downstream as practical on the tributary to capture the largest possible area of the catchment, but remain above the floodplain of the trunk stream. This minimised the sampling of the trunk stream overbank or floodplain sediments, which probably represent the larger drainage basin rather than the locally-defined catchment.

3.2 In-field site selection

Upon arrival at the theoretical sampling site, the exact location of the holes to be augered to collect the samples must be determined. The following criteria were developed for this purpose:

- Sample at a representative location (avoid those sites that are locally atypical);
- Where multiple stream branches of equivalent size or importance are contained within a defined catchment, samples are to be collected downstream of the confluence, but above the floodplain of any trunk stream that flows through the catchment;
- To avoid contamination, sample at least:
  - 200 m upstream/upslope of roads (particularly major roads);
  - 100 m upstream/upslope of buildings, dams;
  - 50 m upstream/upslope of fields, paddocks; and
  - 10 m upstream/upslope of fences;

- If it is not possible to move upstream/upslope from areas of possible contamination/disturbance, move at least twice the recommended distance in a direction perpendicular to the main slope or, as a last resort, downstream/downslope from it;
- Where possible, avoid sites that are obviously disturbed by human activities such as camping sites (e.g., presence of fire places, cans and/or bottles), graded areas, levelled fields (for irrigation), mines (disused or active), landfills, and rehabilitated sites;
- Sampling near or within an open cluster of established (mature) trees will increase the likelihood that the land surface is at 'natural' level (no massive recent erosion or major land rehabilitation);
- Obtain access permission to private land, national parks and reserves prior to sampling. Otherwise, move the sample location slightly (preferably upstream), bearing in mind the size of the catchment being sampled;
- Try to sample on natural drainages as artificial drainage/irrigation channels may not necessarily represent the natural flow of water and sediments;
- Where defined creeks are present, sample the floodplain/overbank sediment (not within the channel or on top of the banks/levees);
- Where there are no defined creeks, sample at the lowest practical point in the catchment. Ensure that the regolith material sampled is transported sediment that has been preserved in a depositional environment (e.g., sheet wash/sheet flow or colluvial, etc.) and **not** *in situ* on weathered bedrock;
- In sand dune-dominated terrain where no creeks are present, sample at the lowest point in the catchment in the swale of a dune, where finer-grained sediments have accumulated. It is becoming clear that most dune systems in Australia are fairly stationary and well vegetated (Fitzsimmons, 2006). A study by Sheard *et al.* (2006) found that the sand dunes in the Great Victoria Desert have been stable for about 70 ka and secondary migration of Au into the dune occurred within 10-20 ka. This indicates that dune swales are an appropriate sampling location if overbank sediments are absent; and,
- Radiation screen the site prior to digging and do not collect if the radiation monitor registers a value **>5 µSv/hr.**

4. SAMPLE COLLECTION AND DOCUMENTATION

4.1 General comments on sample collection

- Limit contamination by sunscreen (e.g., Zn), watches, and jewellery such as rings (e.g., Au, Ag) by wearing gloves (e.g., natural leather) while handling the sampling material;
- When the surface sample is collected, use a white plastic scoop rather than a steel shovel;

- Avoid cross-contamination by 'conditioning' all digging tools (augers, shovel, crowbar and scoop) with the soil at the site to remove remnants of soil from the previous site. This 'conditioning' is done by inserting or rubbing the tools in the soil at the site (e.g., sinking the shovel in the ground a few times, using the augers on site a few times, etc.) before retrieving the samples;
- Take measures to preserve the selected site until the sample is taken (i.e., don't drive or walk over the area to be sampled);
- For all aspects of field work, the field parties must refer to the Occupational Health and Safety procedures of their organisation (see Section 4.7); and,
- Be sure to refill all holes for the safety of people and stock and restore the surface as much as possible to pre-existing conditions.

4.2 Sampling equipment

The following equipment list was developed for the collection of geochemical samples:

- Shovel
- Crowbar
- Tanaka JEA-50 petrol-driven power auger with 6 inch bit
- Stainless steel hand auger kit
- 25 x 35 cm (150 μm thick) plastic sample bags (4/site)
- 30 x 45 cm calico (cotton) bags (2/site) with draw string
- Tags with printed sample number for inserting into plastic bags
- Paper field data entry forms, clipboard and rain-proof map case
- Inoculo™ pH testing kit (1 kit per ~50 analyses/25 sites)
- Munsell™ Colour Chart
- 1M HCl (carbonate reaction test) in 45 mL dropper
- Pop-top water bottle for moist Munsell colour
- Large screwdriver (for scraping caked soil off auger, as needed)
- Measuring stick (to measure depth to bottom sample)
- White plastic scoop (metal free)
- Hard bristle brush (for cleaning plastic scoop)
- Stapler and staples
- Permanent black markers, pens and pencils
- Flat bastard metal file (for sharpening hand auger blade as necessary)
- Plastic ground sheet/tarpaulin
- Leather gloves

- Dust masks
- Ear plugs
- Safety glasses
- High tensile bolts & nuts (for auger bit attachment in the event of failure)
- Materials Safety Data Sheet (MSDS) for pH kits and HCl
- Radiation monitor for screening site and samples
- Toolbox for small equipment
- Field-ruggedised notebook or laptop computer (CPU), charger/spare batteries, inverter, backup system, portable storage devise (USB memory stick) for backup of field data and photos.
- GPS, charger/spare batteries, cable to download waypoints to CPU
- Digital camera, charger/spare batteries, storage media, cable to download photos to CPU
- Jerry can with unleaded fuel
- Two-stroke oil for mixing with unleaded fuel (fuel to oil ratio 25:1)
- First aid kit
- Communication equipment like CB radios and satellite phone is also desirable for communication with landholders and daily back-to-base log-in calls.

4.3 Sample collection of TOS and BOS

At each site, two ~10-cm thick intervals are sampled. The first sample is taken from 0 to 10 cm (or just below the root zone, if present) and is the 'top outlet sediment' (TOS). The second sample is taken within a depth range of ~60 to 90 cm and is the 'bottom outlet sediment' (BOS). For each interval, two bags of ~2-3 kg of material are collected. The contents of the 2 TOS bags will be thoroughly mixed during sample preparation (likewise for the 2 BOS bags) so it is not necessary to make both bags absolutely equivalent. More detail on sampling procedures for the above sample types are provided below.

4.3.1 Sampling of the TOS

- Using the shovel, remove surface vegetation and organic litter and scrape off the root layer (if any) to clear an area of ~50 x 80 cm.
- Loosen the soil down to 10 cm depth with the crowbar over an area of ~30 x 60 cm.
- It is possible that some samples may experience minor contamination from paint flakes coming off the crowbar. This is not considered to be a significant concern, but where possible, try to avoid collecting soil with paint contamination.

- Label both TOS plastic bags using pre-printed sticky labels (2005 861 xxx 001, where xxx is a 3-digit site identification code). Ensure plastic bags have a loose tag inside them. Label the calico bag with the same number as the plastic bags (2005 861 xxx 001).
- With the white plastic scoop, collect and transfer the 0-10 cm sample interval into the 2 TOS plastic sample bags, ensuring the full ~30 x 60 cm area and depth profile to 10 cm is sampled (composite sample). Collect 2-3 kg of sample in each bag (bag 1/2 to 2/3 full).
- Fold the top of the bags over several times and staple twice.
- Place the 2 TOS samples in the labelled calico bag and close with draw string.

4.3.2 Sampling of the BOS

- With the power or hand auger drill 3 to 6 holes in a ~10 x 10 m area to ensure a sample representative of the location is taken.
- Once the holes are all at the required (and same) starting depth (typically 60-90 cm), clean out the bottom of the holes with a gloved hand to ensure no loose material remains.
- Label both BOS plastic bags using pre-printed sticky labels (2005 861 xxx 002, where xxx is a 3-digit site identification code). Ensure plastic bags have a loose tag inside them. Label the calico bag with the same number as the plastic bags (2005 861 xxx 002).
- With a clean (pre-conditioned) hand auger, collect the regolith material in approximately equal proportions from each hole (composite sample) and place into the plastic sample bags. As with the TOS, collect 2-3 kg of sample in each bag (bag 1/2 to 2/3 full). Only sample bottom material that has been disaggregated by the mechanical auger as a last resource. We normally want to always collect the bottom sample with the manual, stainless steel hand auger.
- On rare occasions, the material can not be retrieved with the hand auger (e.g., too loose or too hard). In these cases, carefully loosen the material with the power auger or crowbar and collect the sample by reaching down the holes with a gloved hand. **NB:** *It is important to ensure that no soil falls down the hole (from surface or sidewalls) and contaminates the BOS sample.*
- Where the soil is too hard for power or hand auger combinations, or the soil is sandy and falls back down the hole, a trench must be dug (~50 cm wide and between 70 and 150 cm long) to the desired depth using the shovel and crowbar.
    - Just before reaching the desired depth, clean out the trench with the white plastic scoop;
    - Use the crowbar to then loosen the soil at the collection interval; and
    - Collect the disaggregated material from several locations across the trench floor with the cleaned white plastic scoop.
- At some locations, indurations like hardpans may occur at or before reaching the targeted sample depth. Try several holes to ensure it is not an isolated case. If widespread, the samples

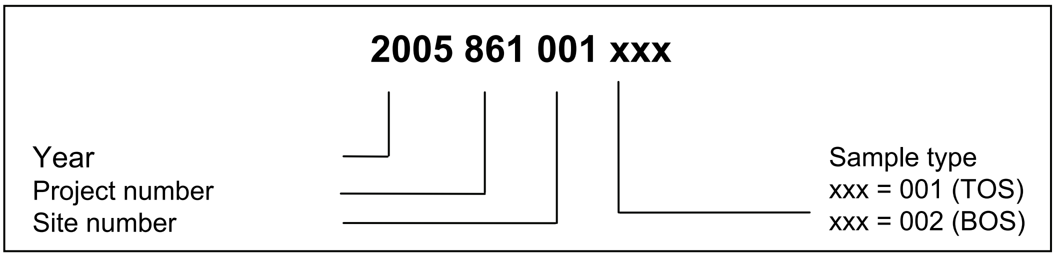
should be collected *above* the hardpans to avoid secondary modifications of the sampling medium sought.

- Fold the top of the bags over several times and staple twice.
- Place the 2 BOS samples in the labelled calico bag and close with draw string.

It is prudent to radiation screen all samples prior to transport and record on the data entry template (see section 4.6, and Appendix 1). This is in accordance with GA's Radiation safety policy. If the monitor registers a value < 5 μSv/hr the appropriate value range should be recorded. If the value is > 5 μSv/hr the sample should be returned to where it was collected.

4.4 Sample numbering

The following numbering system was developed for the Thomson pilot project according to the Geoscience Australia numbering standard and can be used if other numbering protocols are not in place.



The allocation of site numbers should be randomised (Plant, 1973). Randomising samples prior to sample collection helps to distinguish real anomalies from false ones, and enable the determination of meaningful estimates of variance as the duplicates are not analysed sequentially.

If, for some reason, the sample bag is damaged, use a clean, unlabelled plastic bag to double bag the damage sample bag. Ensure that the sample number is recorded on the outer bag. It is important that the bags have a labelled tag within the bag too, even if it means slipping a piece of hand labelled paper inside. ***NB:*** *Plastic bags labelled with permanent marker often rubbed off during transit so it is very important that a tag is placed in each bag*.

4.5 Field measurements

The following field measurements are recommended when routinely collecting samples:

Munsell colour

Soil colour is important as it gives information about mineral content, soil moisture and oxidation state. Red soils are more oxidised and contain more Fe-oxyhydroxides, whereas yellower soils contain more goethite. Fe-oxyhydroxides may absorb or adsorb trace metals.

Munsell soil colour is determined in the field using a Munsell™ soil colour chart (Figure 2) (Munsell Color Company, 1975) according to standard protocols outlined by Northcote (1979). Moist and dry colours are recorded as hue, value and chroma (e.g., 7YR5/4) (see lookup in Appendix 3).

Figure 2: Munsell soil colour chart

Soil colour is determined on a freshly broken soil aggregate held as close as possible to the colour chip. Where soil colour does not match any colour chip, the closest chip colour is used. Care should be taken to ensure the broken surface is not smeared as this may result in an incorrect colour of the soil matrix. The aggregate is then moistened with a few drops of water and soil colour recorded once the visible moisture film disappeared from the soil aggregate's surface. ***NB:*** *If the soil is too moist for a dry colour then only record the moist colour.* ***NB:*** *For soil that does not have a homogeneous colour, e.g. because they are mottled or contain nodules, record the dominant soil matrix colour.*

Field pH

pH provides information that can be related to element mobility and stability within regolith materials. It can be correlated with various chemical and environmental factors that influence soils and plants. It must be recognised, however, that soil pH can vary markedly within a short distance.

The Inoculo™ Soil pH Testing Kit (Figure 3) designed by the CSIRO Division of Soils is used to determine in-field soil pH measurements as follows:

- Remove any coarse fragments greater than 2 mm (if necessary)
- A teaspoon of soil is placed on the white plastic tray provided in the test kit
- A few drops of the green dye indicator liquid are added to the soil
- Use the mixing straw to mix the indicator liquid and soil to form a paste

- Lightly dust a little of the white $BaSO_4$ powder over the moist soil
- Although the colour of the $BaSO_4$ powder changes immediately, it should be left a few minutes before the colour is matched to the accompanying indicator card to determine the pH value
- The Munsell colour best matching the dominant colour of the $BaSO_4$ powder is also recorded (e.g., 5YR 4/6)

Figure 3: Inoculo™ soil pH test kit

Determination of shape and abundance of coarse fragments and segregations

Coarse fragments are those greater than 2 mm in size (McDonald *et al.* 1990). They include unattached rock fragments and other fragments like charcoal and shells (see Appendix 3), and are not pedogenic in origin. *Segregations* refer to discrete pedogenic aggregations, such as nodules and concretions, which have accumulated in the soil/regolith due to concentration by chemical or biological processes (see Appendix 3). ***NB:*** *Charcoal in the sample may be an indication of contamination.*

The charts in Figure 4 andFigure 5 are used to provide a visual estimate of the shape and abundance of coarse fragments and segregations within a regolith profile.

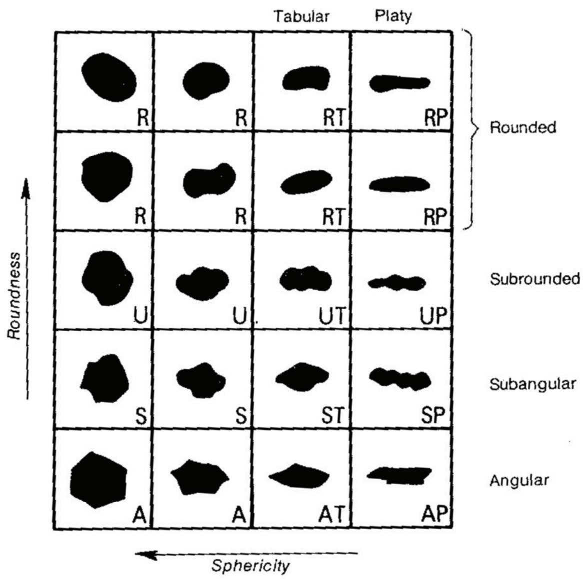


Figure 4: Visual guide for estimating the shape of coarse fragments (McDonald et al. 1990, modified after Powers, 1953)

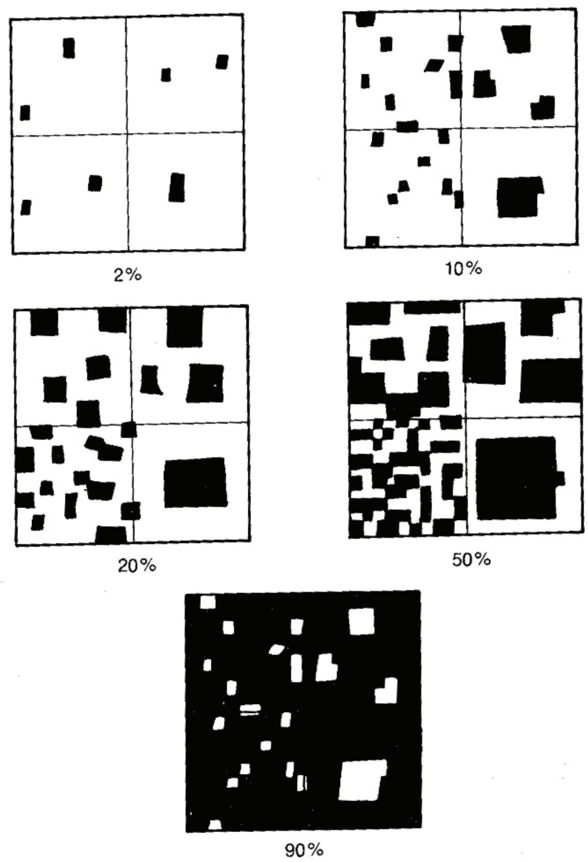


Figure 5: Visual guide for estimating the abundance of coarse fragments (McDonald et al. 1990).

4.6 In-field documentation

Below are a few general comments for in-field site documentation:

- Digital photos are to be recorded in the field. The pilot projects recorded photos in the jpg format with a resolution of about 3200 x 2400 pixels (file size ~2 Mb).
- Ensure the camera's batteries are fresh and replacements are available. Before going in the field, set the camera's date and time, so this metadata can be used in case of identification issues later on.
- Take a close-up photo of the sample bag label immediately before the site photos. This will aid in identifying the photos at the end of a day.
- Take a photo showing the holes with a shovel or crowbar down the hole to indicate depth. Take a few photos that are representative of the landscape. At least one of these should be taken toward the main drainage (river, creek) if appropriate, and another upslope (toward the centre of the catchment or the upland areas).
- Photos should be relabelled with the site ID as a prefix (e.g., 2005861001) followed by an underscore (_) and a unique identifier (e.g., the camera's default running number), for instance: **2005861001_dscn0001.jpg**. It is useful to do this on a daily basis when the various sites visited are still fresh in people's memory!
- Sample sites should be saved as waypoints in the GPS and be labelled with GA's site number (e.g., 2005861001).

4.6.1 Collection of field duplicates

Ten percent (10%) of sites should be re-sampled as field duplicates. A field duplicate aims to characterise the robustness of the sampling sites, and is usually the weakest link (greatest error) in any geochemical project. To collect a duplicate of a particular site, walk approximately 100 metres up the catchment and resample using exactly the same procedures. Make sure the site at which a duplicate has been taken is noted on the field data entry template.

4.6.2 Field data entry template

At each site, field data should be entered on the paper field data entry templates (Appendix 1). The data entry template was modified from Salminen *et al.* (1988) to suit Australian conditions. At each site, the data entry template should be completed to record the characteristics of the site, such as: date, GPS location, regolith landscape position, geomorphic processes and field parameters such field pH and Munsell soil colour. Some of the fields to be captured on the form are necessary for entry of the sites and samples into GA databases. Appendix 2 provides further information regarding the entry fields. For consistency, lookups are provided (Appendix 3) and should be referred to where a 🄻 appears on the entry sheet. Descriptions for the landform types, geomorphic processes and land use are also provided (Appendix 4, 5 & 6).

If the information is intended for entry into GA's "FIELD GEOLOGY" database, it should be then transferred into GA's bulk loading templates.

4.7 Occupational health & safety precautions for sample collection

It is important to ensure the safety of all field party members while conducting field work. Relevant personal protective equipment (PPE) such as enclosed leather boots, broad brimmed hats, long pants and shirts to protect against the sun should be worn at all times during sample collection. At least one field party member should be first-aid trained. The NEPC (1999a,b) documents are freely available on the web and contain information regarding protection of health and the environment during field investigations. They also refer to relevant State, Territory and Commonwealth legislation.

Specifically relating to soil sampling it is recommended that field party members:

- use gloves when handling soil samples;
- wear a dust mask and safety goggles if face is to come into close contact with the soil; and,
- wear eye and ear protection when using the power auger.

Power Auger

The checklist below relates to the operation of the Tanaka JEA-50 two-person 2-stroke petrol-driven auger used to drill holes for sample acquisition. *<u>It is essential that the operator's manual provided with the auger is read and understood prior to use</u>*, as it contains information on the safe operation and maintenance of this equipment. In addition the following points should be understood.

- Wear appropriate PPE: gloves, eye and hearing protection, protective footwear; tie back or remove loose clothing and restrain loose/long hair.
- Inspect for and inquire about underground hazards/utilities (DIAL BEFORE YOU DIG).
- Assess the soil type before digging.
- Operate equipment safely (e.g. bend at the knees when operating the auger; ensure thumbs are not locked inside the auger handlebar frame).
- Never leave machine unattended when running.
- Make sure engine has cooled down prior to refueling. Avoid ignition sources when fueling/refueling.
- Immediately report damaged equipment to Supervisor. Secure and label damaged equipment and do not use.
- Secure all equipment prior to transportation.

Radiation Safety

In accordance with GA's Radiation Safety Policy, it is a requirement for all geological samples to be tested for radioactive emission before they enter the ACT. The field kit should include a radiation monitor to screen samples.

4.8 In-field navigation

A digital navigation system consisting of a palmtop, field-ruggedised notebook or laptop computer (CPU) and a GPS (with communication between the GPS and the CPU via Bluetooth or other link) is useful for navigating to a target sample site. Ability to overlay digital topographic maps, satellite imagery, radiometrics and/or catchment boundaries help with determining access roads to the location and also ensure that the site selected is in a depositional setting and within the correct catchment.

Laminated regional scale maps with sample point locations, topographic information and catchment boundaries can also be used to provide an overview of site accessibility and for day-to-day planning.

4.9 Freighting of samples

The regolith samples to be collected are fragile. There were cases in the pilot projects where bags were punctured resulting in sample loss and contamination during transit. It is therefore very important to ensure that samples are adequately protected in 20 litre sample drums or similar containers.

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.

APPENDIX 1: FIELD DATA ENTRY TEMPLATE

Regional Geochemical Surveys - Data Template

SITE_ID: _ _ _ _ _ _ _ _ _ _

Date _ _/_ _/_ _ _ _ (dd/mm/yyyy)
Time: Entered by:

LOCATION

LATITUDE_GDA94: -___________°S
LONGITUDE_GDA94: _____________ °E

SL ELEVATION: __________ m
MAPSHEET_1:250K: _________________
STATE: _________________

SITE DETAILS

HOLE_TYPE 🄻: ____________
PROPERTY_NAME: _____________________

TARGET_SITEID: TS _ _ _ _
WATERCOURSE: __________________

LANDFORM_TYPE 🄻: ____________

GEOMORPH_PR 🄻: ____________
GEOMORPH_PR2 🄻: ____________

Site
LANDUSE_TYPE_SITE 🄻: ________________
LANDUSE_SUBTYPE_SITE 🄻: ________________

Catchment
LANDUSE_TYPE_CATCH 🄻: ________________
LANDUSE_SUBTYPE_CATCH 🄻: ________________

Sources of Contamination:

Comments:

SAMPLE DETAILS

Top Outlet Sediment (TOS) SITE_ID+001	*Bottom Outlet Sediment (BOS) SITE_ID+002*
TOS ___ - ____m	BOS ____ - ____ m
SAMPLE_TYPE 🄻: AUGER ☐, PIT/TRENCH ☐ (tick)	SAMPLE_TYPE 🄻: AUGER ☐, PIT/TRENCH ☐ (tick)
field_pH_TOS 🄻: _________	field_pH_BOS 🄻: _________
TMunCol_dry 🄻: _________	BMunCol_dry 🄻: _________
TMunCol_moist 🄻: _________	BMunCol_moist 🄻: _________
Radiation screen: Yes, ≤5 μSv/hr ☐ (tick)	**Radiation screen: Yes, ≤5 μSv/hr ☐ (tick)**

Induration? 🄻: _____________________
Depth to induration: ______ (m)

No. of holes augered:

SAMPLE DETAILS (CONT)

Top Outlet Sediment (TOS)	*Bottom Outlet Sediment (BOS)*
T_Mottles-abundance 🄻: _____________________	B_Mottles-abundance 🄻: _____________________
T_Mottles-size 🄻: _____________________	B_Mottles-size 🄻: _____________________
T_Segregations-type 🄻: _____________________	B_Segregations-type 🄻: _____________________
T_Segregations-comp 🄻: _____________________	B_Segregations-comp 🄻: _____________________
T_Segregations-size 🄻: _____________________	B_Segregations-size 🄻: _____________________
T_Segregations-abundance 🄻: _________________	B_Segregations-abundance 🄻: _________________
T_efferves_test: HCl ☐ (tick)	B_efferves_test: HCl ☐ (tick)
T_effervesce (HCl) 🄻: __________________	B_effervesce (HCl) 🄻: __________________
T_frags-type 🄻: _____________________	B_frags-type 🄻: _____________________
T_frags-comp 🄻: _____________________	B_frags-comp 🄻: _____________________
T_frags-size 🄻: _____________________	B_frags-size 🄻: _____________________
T_frags-abundance 🄻: __________________	B_frags-abundance 🄻: __________________

🄻 **= Lookup available, see appendix 3 for the appropriate lookups**

APPENDIX 2: EXPLANATION OF HEADINGS FOR THE DATA ENTRY TEMPLATE

Field	Description	Format	Validation
Site_ID	A concatenation of 1) the year of sampling, 2) GA assigned project ID for the databases, 3) the geologist number, 4) the sample site number	Concatenation of year, project ID & site number	nil
Date	The date of sampling	date is in dd/mm/yyyy format	must be between 01/02/2007 & 01/02/2010
Time	Time of arrival at sample site in 24 hour notation. **NB:** This will help with relabelling of photos.	Text with format hh:mm	nil
Entered by	The name of the person recording the information.	Initial of given name & up to 7 letters surname e.g., pdecarit	entry between 3 and 8 characters
Latitude_GDA94	Latitude of the sample site captured in GDA94	6-digit negative numeric	value between -44 & -9
Longitude_GDA94	Longitude of the sample site captured in GDA94	8-digit positive numeric	value between 108 & 156
SL Elevation (m)	Elevation above mean sea level	Numeric (metres)	nil
State	State or Territory where site is located	Use lookup provided	nil
Mapsheet_1:250K	Name of 1:250K map sheet on which the site is located e.g., Bourke, Robinson Ranges	limited to 50 characters	cannot exceed 50 characters

Field	Description	Format	Validation
Hole_Type	Refers to the dominant method of digging the entire hole. This will generally be hand auger hole, power auger hole or soil pit. This field is a GA database requirement.	Use partial lookup provided	nil
Target_SiteID	Target number assigned to the theoretical sampling site. In the format: 4-digit number with TS as the prefix	TSxxxx	6 characters long
Property_Name	The name of the station, national park, etc. where the sample was collected.	limited to 50 characters	cannot exceed 50 characters
Watercourse	Name of creek, river, etc. by which the sample was taken. e.g., Bogan River, Mulga Creek. Do not complete if there is no water course nearby.	limited to 50 characters	cannot exceed 50 characters
Landform_Type	Obtained from the RTMAP classification scheme (See Appendix 4). **NB:** This is site specific and not related to the entire catchment. The dominant landform type within a 75 m radius around the sampling site, i.e., as it would be mapped for a 1:25,000 regolith landform map.	Use lookup provided	nil
Geomorph_Pr	The dominant geomorphic process derived using the RTMAP classification scheme. These processes form/modify landform units. (See Appendix 5). **NB:** This is *site specific* and not related to the entire catchment. The dominant landform type within a 75 m radius around the sampling site, i.e., as it would be mapped for a 1:25,000 regolith landform map.	Use lookup provided	nil
Geomorph_Pr2	Use if more than one active geomorphic process evident at site. Described as per Geomorph_Pr.	Use lookup provided	nil
Landuse_type_ site	The dominant landuse type *for the sample site*. **NB:** If cropping or livestock selected from landuse_type lookup then add more details in the landuse_subtype_site column (See Appendix 6).	Use lookup provided	nil
Landuse_subtype_site	Detailed landuse *for the sample site*. This is used if cropping or livestock is selected from landuse_type lookup. If unknown, leave blank.	Use lookup provided	nil
Landuse_type_catch	The dominant landuse type *for the entire catchment*. **NB:** If cropping or livestock selected from landuse_type lookup then add more details in the landuse_subtype_catch column.	Use lookup provided	nil
Landuse_subtype_catch	Detailed landuse *for the entire catchment*. This is used if cropping or livestock is selected from landuse_type lookup. If unknown, leave blank.	Use lookup provided	nil
Contamination	Note any possible sources of contamination or disturbance, e.g.,	limited to 100 characters	cannot exceed 100

	100 m down slope of rubbish dump. Further scenarios are supplied in Appendix 1.		characters
Entered by	The name of the person recording the information at the site of sampling.	Initial of given name & up to 7 letters surname e.g., pdecarit or amcphers or mlech	entry between 3 and 8 characters
Comments	Anything else that might be relevant about the field site that could later be useful when interpreting the geochemistry.	limited to 250 characters	cannot exceed 250 characters

Sample details

Field	**Description**	**Format**	**Validation**
Sample_Type_TOS	Mandatory for GA databases. Sample type for the TOS. Generally as the TOS is taken from a hole created by a shovel, it is a PIT/TRENCH SAMPLE. Definitions for GA's sample type lookup are as follows: AUGER SAMPLE: Sample collected by hand or mechanical auger which enable samples to be taken at intervals down profile. For example regolith, soil or sediment. FLOAT: Sample taken of an isolated rock fragment, displaced from its original outcrop. Typically derived from weathering of bedrock. LAG: Deposit, commonly thin, or 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. PIT/TRENCH SAMPLE: Samples taken at depth from a regolith and/or soil profile. This includes profiles that are exposed by gullies, costeans, railway cuttings, trenches or rivers as well as those profiles dug as a pit. SURFACE REGOLITH SAMPLE: Samples of regolith taken at the ground surface including soil material and organic matter. VEGETATION: Any part of a plant whether it be moss, grass, sedge, or the roots, bark, twigs or leaves of trees and shrubs.	Use the partial lookup provided	nil
TOS depth (m)	Start depth and end depth for the TOS. Measured in metres and mostly starts at zero.	numeric to 2 decimal places	must be between 0 and 2 m

field_pH_TOS	pH of the TOS sample. Use Inoculo™ Soil pH testing kit applying the methods described in Appendix 1.	Use lookup provided	nil
TMunCol_dry	TOS Munsell Colour determined on the raw sample. It should be on the dominant matrix colour (not the mottles). If soil is already moist (e.g., from rain), disregard this field. Use the method for colour determination as described in Appendix 1.	Use lookup provided	nil
TMunCol_moist	TOS Munsell Colour determined on the moistened sample. It should be on the dominant matrix colour (not the mottles). As per dry sample, use the method for colour determination as described in Appendix 1.	Use lookup provided	nil
Radiation Screen (TOS)	Has the sample been radiation screened using the "Monitor 4 Radiation Alert Monitor" provided? **NB:** If screening has not been done then samples cannot be accepted by Geoscience Australia due to OH&S requirements.	Y or N	
Sample_Type_BOS	Sample type for the BOS. Generally as the BOS is an AUGER SAMPLE or a PIT/TRENCH SAMPLE. Definitions for GA's sample type lookup are as follows: AUGER SAMPLE: Sample collected by hand or mechanical auger which enable samples to be taken at intervals down profile. For example regolith, soil or sediment. FLOAT: Sample taken of an isolated rock fragment, displaced from its original outcrop. Typically derived from weathering of bedrock. LAG: Deposit, commonly thin, or fragments of 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. PIT/TRENCH SAMPLE: Samples taken at depth from a regolith and/or soil profile. This includes profiles that are exposed by gullies, costeans, railway cuttings, trenches or rivers as well as those profiles dug as a pit. SURFACE REGOLITH SAMPLE: Samples of regolith taken at the ground surface including soil material and organic matter. VEGETATION: Any part of a plant whether it be moss, grass, sedge, or the roots, bark, twigs or leaves of trees and shrubs.	Use the partial lookup provided	nil
BOS depth (m)	Start depth and end depth for the BOS. Measured in metres and is	numeric to 2 decimal places	must be between 0.3

	usually between 0.75-0.90 m.		and 2 m
field_pH_BOS	pH of the BOS sample. Use Inoculo™ Soil pH testing kit applying the methods described in Appendix 1.	Use lookup provided	nil
BMunCol_dry	BOS Munsell Colour determined on the raw sample. It should be on the dominant matrix colour (not the mottles). If soil is already moist (e.g., from rain), disregard this field. Use the method for colour determination as described in Appendix 1.	Use lookup provided	nil
BMunCol_moist	BOS Munsell Colour determined on the moistened sample. It should be on the dominant matrix colour (not the mottles). As per dry sample, use the method for colour determination as described in Appendix 1.	Use lookup provided	nil
Radiation Screen (BOS)	Has the sample been radiation screened using the "Monitor 4 Radiation Alert Monitor" provided? **NB:** If screening has not been done then samples cannot be accepted by Geoscience Australia due to OH&S requirements.	Y or N	
Induration?	Regolith material that has been hardened by heat, pressure, or the addition of a cementing agent not commonly contained within the original material e.g., development of hardpans or duricrust (Eggleton *et al.* 2001).	use lookup provided	nil
Depth to Induration	If induration is present, record the depth to the top of the induration.	nil	nil
No. of holes augered	Enter the number of holes augered. This number should be greater than 3 as it makes the geochemical sampling more representative. (If a trench was dug then leave blank).	nil	nil

Sample details (cont.)

Field	Description	Format	Validation
T_Mottles-abundance	Mottles are the streaks, blotches or spots of subdominant colours found within a soil matrix (McDonald *et al.* 1990). A visual estimation for the TOS as a % can be determined using the visual guide for estimating the abundance of course fragments (Figure 6).	Use lookup provided	nil
T_Mottles-size	The size of the mottles present in the TOS along their greatest dimension, unless they are streaks where the width is used.	Use lookup provided	nil
T_Segregations-type	Segregations refer to discrete groups (like nodules and concretions) that have accumulated TOS due to concentration, generally by chemical or biological action. These are pedogenic in origin.	Use lookup provided	nil
T_Segregations-comp	Record the composition of the segregations (concretions, pisoliths, nodules) that have accumulated in the TOS.	Use lookup provided	nil
T_Segregations-size	Determine the size (fine-coarse) for the maximum dimension of equidimensional segregations (concretions, pisoliths, nodules) or the minimum dimension for linear features (tubules) in the TOS.	Use lookup provided	nil
T_Segregations-abundance	A visual estimation in the TOS as a % can be determined using Figure 6.	Use lookup provided	nil
T_Efferves_test	The effervescence reaction test for the TOS determines whether the soil reacts to HCl and generates tiny gas bubbles. To perform effervescence test, put 2-3 drops of 1M HCl (carbonates) on a thumbnail size piece of soil.	Use lookup provided	nil
T_Effervesce	Quantifies the effervescence (release of tiny gas bubbles) for the TOS as follows: NO REACTION: no audible or visible effervescence SLIGHT REACTION: slightly audible but no visible effervescence MODERATELY REACTIVE: audible & slightly visible effervescence HIGHLY REACTIVE: moderate visible effervescence VERY HIGHLY REACTIVE: strong visible effervescence	Use lookup provided	nil
T_frags_lith	The dominant lithology of the coarse fragments/particles greater than 2 mm in size (McDonald *et al.* 1990) within the TOS horizon.	Use lookup provided	nil
T_frags_abundance	The abundance of the coarse fragments/particles greater than 2 mm in size (McDonald *et al.* 1990) within the TOS horizon.	Use lookup provided	nil

T_frags_size	The size of coarse fragments/particles greater than 2 mm in size (McDonald *et al.* 1990) within the TOS. The average maximum dimension of used to determine in which class the fragment belongs. The regolith clasts are not considered to be pedogenic in origin and are present within a soil/regolith profile. They include unattached rock fragments and other fragments like charcoal and shells.	Use coarse fragments_size lookup provided	nil
T_frags_shape	Determine the shape of fragments within TOS using a visual guide (Figure 5). Coarse fragments/particles are greater than 2 mm in size (McDonald *et al.* 1990). The fragments are not considered to be pedogenic in origin and are present within a soil/regolith profile. They include unattached rock fragments and other fragments like charcoal and shells.	use lookup provided	nil
SampleID_BOS	Automatically transferred from locations worksheet. Site ID + "002" which recognises samples as the Top Outlet Sediment (BOS).	Concatenation of site_ID and BOS identifier "002"	nil
B_Mottles-abundance	Mottles are the streaks, blotches or spots of subdominant colours found within a soil matrix (McDonald *et al.* 1990). A visual estimation for the TOS as a % can be determined using the visual guide for estimating the abundance of course fragments (Figure 6)	Use lookup provided	nil
B_Mottles-size	The size of the mottles present in the BOS along their greatest dimension, unless they are streaks where the width is used.	Use lookup provided	nil
B_Segregations-type	Segregations refer to discrete groups (like nodules and concretions) that have accumulated BOS due to concentration, generally by chemical or biological action. These are pedogenic in origin.	Use lookup provided	nil
B_Segregations-comp	Record the composition of the segregations (concretions, pisoliths, nodules) that have accumulated in the BOS.	Use lookup provided	nil
B_Segregations-size	Determine the size (fine-coarse) for the maximum dimension of equidimensional segregations (concretions, pisoliths, nodules) or the minimum dimension for linear features (tubules) in the BOS.	Use lookup provided	nil
B_Segregations-abundance	A visual estimation in the BOS as a % can be determined using Figure 6.	Use lookup provided	nil

B_Efferves_test	The effervescence reaction test for the BOS determines whether the soil reacts to HCl and generates tiny gas bubbles. To perform effervescence test, put 2-3 drops of 1M HCl (carbonates) on a thumbnail size piece of soil.	Use lookup provided	nil
B_Effervesce	Quantifies the effervescence (release of tiny gas bubbles) for the BOS. NO REACTION: no audible or visible effervescence SLIGHT REACTION: slightly audible but no visible effervescence MODERATELY REACTIVE: audible & slightly visible effervescence HIGHLY REACTIVE: moderate visible effervescence VERY HIGHLY REACTIVE: strong visible effervescence	Use lookup provided	nil
B_frags_lith	The dominant lithology of the coarse fragments/particles greater than 2 mm in size (McDonald *et al.* 1990) within the BOS horizon.	Use lookup provided	nil
B_frags_abundance	The abundance of the coarse fragments/particles greater than 2 mm in size (McDonald *et al.* 1990) within the BOS horizon.	Use lookup provided	nil
B_frags_size	The size of coarse fragments/particles greater than 2 mm in size (McDonald *et al.* 1990) within the BOS. The average maximum dimension of used to determine in which class the fragment belongs. The regolith clasts are not considered to be pedogenic in origin and are present within a soil/regolith profile. They include unattached rock fragments and other fragments like charcoal and shells.	Use coarse fragments_size lookup provided	nil
B_frags_shape	Determine the shape of fragments within BOS using a visual guide (Figure 5). Coarse fragments/particles are greater than 2 mm in size (McDonald *et al.* 1990). The fragments are not considered to be pedogenic in origin and are present within a soil/regolith profile. They include unattached rock fragments and other fragments like charcoal and shells.	Use lookup provided	nil

APPENDIX 3: DATABASE LOOKUPS

SAMPLE_TYPE (subset)
AUGER SAMPLE
FLOAT
LAG
PIT/TRENCH SAMPLE
SURFACE REGOLITH SAMPLE
VEGETATION

Mottles_size
coarse (15 - 30mm)
fine (< 5mm)
medium (5 - 15mm)
megamottles (> 100mm)
very coarse (30 - 100mm)

HOLE_TYPE (subset)
Costean or trench section
Hand auger hole
Pit
Power auger hole
Soil pit

Mottles_abundance
common (10 -20%)
few (2 - 10%)
many (20 -50%)
no mottles
very few (< 2%)

LANDUSE
1.0.0 Conservation and Natural Environments

2.1.0 Grazing natural vegetation
2.2.0 Production forestry of natural vegetation

3.1.0 Dryland Plantation forestry
3.2.0 Dryland Grazing modified pastures
3.3.0 Dryland Cropping
3.4.0 Dryland Perennial horticulture
3.5.0 Dryland Seasonal horticulture
3.6.0 Dryland Land in transition

4.1.0 Irrigated plantation forestry
4.2.0 Irrigated modified pastures
4.3.0 Irrigated cropping
4.4.0 Irrigated perennial horticulture
4.5.0 Irrigated seasonal horticulture
3.6.0 Irrigated land in transition

5.2.0 Intensive animal production
5.3.0 Manufacturing and industrial
5.4.0 Residential
5.5.0 Services
5.6.0 Utilities
5.8.0 Mining

6.1.0 Lake
6.2.0 Reservoir/dam
6.3.0 River
6.5.0 Marsh/wetland
6.6.0 Estuary/coastal waters

LANDUSE_SUBTYPE
3.3.0 Dryland Cropping
3.3.1 Dryland cereals
3.3.2 Dryland beverage & spice crops
3.3.3 Dryland hay & silage
3.3.4 Dryland oil seeds
3.3.5 Dryland sugar
3.3.6 Dryland cotton
3.3.7 Dryland tobacco
3.3.8 Dryland legumes

4.3.0 Irrigated cropping
4.3.1 Irrigated cereals
4.3.2 Irrigated beverage & spice crops
4.3.3 Irrigated hay & silage
4.3. 4 Irrigated oil seeds
4.3.5 Irrigated sugar
4.3.6 Irrigated cotton
4.3.7 Irrigated tobacco
4.3.8 Irrigated legumes

5.2.0 Intensive animal production
5.2.1 Dairy
5.2.2 Cattle
5.2.3 Sheep
5.2.4 Poultry
5.2. 5 Pigs
5.2.6 Aquaculture

LANDFORM_TYPE

alluvial plain
flood plain
anastomatic plain
bar plain
covered plain
meander plain
floodout
alluvial terrace
stagnant alluvial plain
terraced land
alluvial swamp

coastal lands
beach ridge
chenier plain
coral reef
marine plain
tidal flat
coastal dunes
coastal plain
beach
delta

aeolian landforms
aeolian dunes
longitudinal dunefield
transverse dunefield
irregular dunefield
source bordering dune
lunette
aeolian sheet
climbing sheet

erosional landforms
erosional plain
pediment
pediplain
peneplain
etchplain
rises
residual rise
low hills
residual low hills
hills
mountains
escarpment
badlands
drainage depression

plain
depositional plain
lacustrine plain
playa plain
sand plain
plateau
plateau edge
plateau surface

fan
alluvial fan
colluvial fan
sheet-flood fan

glacial features
depositional glacial features

erosional glacial features

karst

made land

meteor crater

volcano
caldera
cone (volcanic)
lava plain
ash plain
lava flow
lava plateau

unknown

GEOMORP_PR

water
tides
waves
channelled stream flow
over-bank stream flow
sheet flow,sheet or surface wash
detrital deposition still water
rilling/gullying
subsurface solution/piping

wind
wind erosion (deflation)
sand deposition (wind)
dust deposition (wind)
biological agents; coral
diastrophism; earth movements
frost
glacial deposition
glacial erosion

gravity
vertical collapse
particle fall
creep
landslide
mudflow

impact by meteors

human agents

volcanism
lava flow
ash flow
ash fall

MUNSELL	10R3/3	10Y4/1	10YR7/6	2.5Y8/1	2.5YR7/1	5G6/2	5Y6/2	5YR5/8	
10B2.5/1	10R3/4	10Y5/1	10YR7/8	2.5Y8/2	2.5YR7/2	5G7/1	5Y6/3	5YR6/1	
10B3/1	10R3/6	10Y6/1	10YR8/1	2.5Y8/3	2.5YR7/3	5G7/2	5Y6/4	5YR6/2	
10B4/1	10R4/1	10Y7/1	10YR8/2	2.5Y8/4	2.5YR7/4	5G8/1	5Y6/6	5YR6/3	
10B5/1	10R4/2	10Y8/1	10YR8/3	2.5Y8/6	2.5YR7/6	5G8/2	5Y6/8	5YR6/4	
10B6/1	10R4/3	10YR2/1	10YR8/4	2.5Y8/8	2.5YR7/8	5GY2.5/1	5Y7/1	5YR6/6	
10B7/1	10R4/4	10YR2/2	10YR8/6	2.5YR2.5/1	2.5YR8/1	5GY3/1	5Y7/2	5YR6/8	
10B8/1	10R4/6	10YR3/1	10YR8/8	2.5YR2.5/2	2.5YR8/2	5GY4/1	5Y7/3	5YR7/1	7.5YR5/6
10G2.5/1	10R4/8	10YR3/2	2.5Y2.5/1	2.5YR2.5/3	2.5YR8/3	5GY5/1	5Y7/4	5YR7/2	7.5YR5/8
10G3/1	10R5/1	10YR3/3	2.5Y3/1	2.5YR2.5/4	2.5YR8/4	5GY6/1	5Y7/6	5YR7/3	7.5YR6/1
10G4/1	10R5/2	10YR3/4	2.5Y3/2	2.5YR3/1	5B2.5/1	5GY7/1	5Y7/8	5YR7/4	7.5YR6/2
10G5/1	10R5/3	10YR3/6	2.5Y3/3	2.5YR3/2	5B3/1	5GY8/1	5Y8/1	5YR7/6	7.5YR6/3
10G6/1	10R5/4	10YR4/1	2.5Y4/1	2.5YR3/3	5B4/1	5PB2.5/1	5Y8/2	5YR7/8	7.5YR6/4
10G7/1	10R5/6	10YR4/2	2.5Y4/2	2.5YR3/4	5B5/1	5PB3/1	5Y8/3	5YR8/1	7.5YR6/6
10G8/1	10R5/8	10YR4/3	2.5Y4/3	2.5YR3/6	5B6/1	5PB4/1	5Y8/4	5YR8/2	7.5YR6/8
10GB2.5/1	10R6/1	10YR4/4	2.5Y4/4	2.5YR4/1	5B7/1	5PB5/1	5Y8/6	5YR8/3	7.5YR7/1
10GB3/1	10R6/2	10YR4/6	2.5Y5/1	2.5YR4/2	5B8/1	5PB6/1	5Y8/8	5YR8/4	7.5YR7/2
10GB4/1	10R6/3	10YR5/1	2.5Y5/2	2.5YR4/3	5BG2.5/1	5PB7/1	5YR2.5/1	7.5YR2.5/1	7.5YR7/3
10GB5/1	10R6/4	10YR5/2	2.5Y5/3	2.5YR4/4	5BG3/1	5PB8/1	5YR2.5/2	7.5YR2.5/2	7.5YR7/4
10GB6/1	10R6/6	10YR5/3	2.5Y5/4	2.5YR4/6	5BG4/1	5Y2.5/1	5YR3/1	7.5YR2.5/3	7.5YR7/6
10GB7/1	10R6/8	10YR5/4	2.5Y5/6	2.5YR4/8	5BG5/1	5Y2.5/2	5YR3/2	7.5YR3/1	7.5YR7/8
10GB8/1	10R7/1	10YR5/6	2.5Y6/1	2.5YR5/1	5BG6/1	5Y3/1	5YR3/3	7.5YR3/2	7.5YR8/1
10GY2.5/1	10R7/2	10YR5/8	2.5Y6/2	2.5YR5/2	5BG7/1	5Y3/2	5YR3/4	7.5YR3/3	7.5YR8/2
10GY3/1	10R7/3	10YR6/1	2.5Y6/3	2.5YR5/3	5BG8/1	5Y4/1	5YR4/1	7.5YR3/4	7.5YR8/3
10GY4/1	10R7/4	10YR6/2	2.5Y6/4	2.5YR5/4	5G2.5/1	5Y4/2	5YR4/2	7.5YR4/1	7.5YR8/4
10GY5/1	10R7/6	10YR6/3	2.5Y6/6	2.5YR5/6	5G2.5/2	5Y4/3	5YR4/3	7.5YR4/2	7.5YR8/6
10GY6/1	10R7/8	10YR6/4	2.5Y6/8	2.5YR5/8	5G3/1	5Y4/4	5YR4/4	7.5YR4/3	N2.5/
10GY7/1	10R8/1	10YR6/6	2.5Y7/1	2.5YR6/1	5G3/2	5Y5/1	5YR4/6	7.5YR4/4	N3/
10GY8/1	10R8/2	10YR6/8	2.5Y7/2	2.5YR6/2	5G4/1	5Y5/2	5YR5/1	7.5YR4/6	N4/
10R2.5/1	10R8/3	10YR7/1	2.5Y7/3	2.5YR6/3	5G4/2	5Y5/3	5YR5/2	7.5YR5/1	N5/
10R2.5/2	10R8/4	10YR7/2	2.5Y7/4	2.5YR6/4	5G5/1	5Y5/4	5YR5/3	7.5YR5/2	N6/
10R3/1	10Y2.5/1	10YR7/3	2.5Y7/6	2.5YR6/6	5G5/2	5Y5/6	5YR5/4	7.5YR5/3	N7/
10R3/2	10Y3/1	10YR7/4	2.5Y7/8	2.5YR6/8	5G6/1	5Y6/1	5YR5/6	7.5YR5/4	N8/

FIELD_pH

1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
10.5
11
11.5
12

Induration (subset)

bauxitic induration
bauxitic, partially cemented
calcareous induration
calcareous, moderately cemented
calcrete
calcrete (bauxite)
clay hardpan
clay induration
completely cemented duricrust
duricrust
ferricrete
ferruginous hardpan
ferruginous induration
ferruginous, moderately cemented
gypcrete
gypseous induration
humic hardpan
humic induration
indurated material
massive ferricrete
moderately cemented duricrust
nodular ferricrete
partially cemented duricrust
silcrete
silcrete pods
silcrete sheet
siliceous hardpan
siliceous induration
siliceous, moderately cemented
silcrete pods
silcrete sheet
siliceous hardpan
siliceous induration
siliceous nodules
siliceous, moderately cemented

Segregations_abundance

common (10 - 20%)
few (2 - 10%)
many (20 - 50%)
no segregations
very few (< 2%)
very many (> 50%)

Segregations_composition

aluminous
argillaceous
calcareous
earthy
ferruginous
gypseous
manganiferous
organic
other
saline
unidentified

Segregations_size

coarse (6 - 20mm)
extremely coarse (> 60mm)
fine (< 2mm)
medium (2 - 6mm)
very coarse (20 - 60mm)

Segregations_type

concretions
fragments
nodules
pisoliths
tubules

gregations_effervescence

reaction
ght reaction
oderately reactive
ghly reactive
ry highly reactive

effervescence reaction test

HCl
H2O2

coarse fragments_abundance

no coarse fragments (0)
very few (<2%)
few (2 - 10%)
common (10 - 20%)
many/moderate (20 - 50%)
abundant (50 - 90%)
very abundant (>90%)

coarse fragments_size

fine gravelly; small pebbles (2-6 mm)
medium gravelly; medium pebbles (6-20 mm)
coarse gravelly; large pebbles (20-60 mm)
cobbly; or cobbles (60-200 mm)
stony; stones (200-600 mm)
bouldery; or boulders (600 mm - 2 m)
large boulders (>2m)

coarse fragments in profile_shape

angular
subangular
subrounded
rounded
angular tabular
subangular tabular
subrounded tabular
rounded tabular
angular platy
subangular platy
subrounded platy
rounded platy

coarse fragments in profile_lithology

agglomerate
alkali feldspar granite
alkali feldspar syenite
amphibolite
andesite
anorthosite
aplite
arenite
argillite
arkose
basalt
basanite
biocarbonate
bomb, block tephra
breccia
calcrete
carbonatite
chalk
charcoal
charnockite
chert
chromitite
claystone
conglomerate
dacite
diamictite
diatomite
diorite
dolerite
dolostone
dunite
eclogite
evaporite
fanglomerate
ferricrete
flint
gabbro
gabbronorite
gneiss
gossan
grainstone
granite
granodiorite
granofels
granulite
grapestone
greenstone
greisen
greywacke
grus
harzburgite
hornblende gabbro
hornblendite
hornfels
ignimbrite
iron formation
ironstone
kimberlite
komatiite
lamproite
lamprophyre
latite
lherzolite
limestone
marble
marl
metasomatite
migmatite
monzodiorite
monzogabbro
monzogranite
monzonite
mudstone
mylonite
norite
obsidian
olivine hornblendite
ophiolite
opx alkali feldspar syenite
opx syenite
pegmatite
pelite
peralkaline rhyolite
peridotite
phosphorite
phyllite
plagioclase-bearing hornblendite
porcellanite
porphyry
psammite
pyroxene hornblende peridotite
pyroxene hornblendite
pyroxene peridotite
pyroxenite
quartz
quartz alkali feldspar syenite
quartz anorthosite
quartz diorite
quartz gabbro
quartz latite
quartz monzonite
quartz syenite
quartz trachyte
quartzite
quartzolite
quartz-rich granitoid
rhyodacite
rhyolite
sandstone
saprolite
schist
serpentinite
shale
shell
shoshonite
silcrete
siltstone
skarn
slate
sparagmite
spilite
syenite
tillite
tilloid
tonalite
trachyandesite
trachybasalt
trachydacite
trachyte
travertine
tuff
tuffite
turbidite
wehrlite

APPENDIX 4: LANDFORM TYPES

The contents of this section are modified after "The Australian Soil and Land Survey Field Handbook" (McDonald *et al.* 1990).

Mode of Activity	**Land-forming agent**	**Name**	**Definition**
alluvial deposition	flowing water	alluvial landforms	A complex landform pattern on valley floors with active, inactive or relict erosion and aggradation by channelled and over-bank stream flow.
		alluvial plain	A level, or 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.
		flood plain	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.
		anastomosing plain	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.
		bar plain	Flood plain having sub-parallel stream channels which 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.
		covered plain	Flood plain with a number of alluvial channels which are widely-spaced (i.e., a little under a 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.
		meander plain	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.
		floodout	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.
		stream channel	
		alluvial terrace	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.
		stagnant alluvial plain	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.
		terraced land	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.
		alluvial swamp	Almost level, closed or almost closed depression with a seasonal or permanent water table at or above the surface, commonly aggraded by overbank stream flow and sometimes biological (peat) accumulation.
coastal and marine activity	waves, tides, channel flow and wind	coastal lands	Level to gently undulating landform pattern of extremely low relief eroded or aggraded by waves, tides, overbank or channel flow, or wind. The landform pattern may be either active or relict.
		beach ridge plain	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.
		chenier plain	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.
		coral reef	Continuously active or relict landform pattern built up to the sea level of the present day or 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.
		marine plain	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 eustasy, and little modified by subaerial agents such as stream flow or wind.
		tidal flat	Level landform pattern with extremely low relief and slowly migrating deep alluvial stream channels which form dendritic tributary patterns; it is aggraded by frequently active tides.
		coastal dunes	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.
		coastal plain	Level landform pattern with extremely low relief either with or without stream channels, built up by coastal, usually tidal, processes.
		beach	Short, low, very wide slope, gently or moderately inclined, built up or eroded by waves, forming the shore of a lake or sea.
		delta	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.
aeolian deposition	wind	aeolian landforms	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.
		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.
		longitudinal	Dune field characterised by long narrow sand dunes and wide flat swales. The dunes are oriented parallel with the

		dunefield	direction of the prevailing wind, and in cross section one slope is typically steeper than the other is.
		transverse dunefield	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.
		irregular dunefield	Dune field with a mixture of longitudinal and transverse dunes, as well as other more complicated forms.
		source bordering dune	A dune formed adjacent to the source of the wind blown material. Most commonly the source is a river or floodplain which supplies aeolian sediment during periods of low or no flow.
		lunette	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.
		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 coarse sand grains, such as alluvial plains, or weathering of coarse-grained granite, as in the Yilgarn of Western Australia.
		climbing sheet	
erosion	water, gravity	erosional landforms	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.
		erosional plain	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.
		pediment	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.
		pediplain	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.
		peneplain	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.
		etchplain	Level to undulating or, rarely, rolling landform pattern of extremely low relief, 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).
		rises	Landform pattern of very low relief (9 - 30 m) and very gentle to steep slopes. The 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.
		residual rise	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.

		low hills	Landform pattern of low relief (30 - 90 m) and gentle to very steep slopes, typically with fixed erosional stream channels, closely to very widely spaced, which form a dendritic or convergent integrated tributary pattern. There is continuously active sheet flow, creep, and channelled stream flow.
		residual low hill	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.
		hills	Landform pattern of high relief (90 - 300 m) with gently sloping to precipitous slopes. Fixed, shallow erosional stream channels, closely to very widely spaced, 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.
		mountains	Landform pattern of very high relief (> 300 m) with moderate to precipitous slopes and fixed erosional stream channels which 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.
		escarpment	Steep to precipitous landform pattern forming a linearly extensive, straight or sinuous inclined surface which 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.
		badlands	Landform pattern of low to extremely low relief (< 90 m) and steep to precipitous slopes, typically with numerous fixed erosional stream channels which form a dendritic to parallel integrated tributary network. There is continuously active erosion by collapse, landslide, sheetflow, creep and channelled stream flow.
		drainage depression	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).
mainly depositional	water flow, gravity	fan	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.
		alluvial fan	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.
		colluvial fan	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.
		sheet-flood fan	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.

glacial activity	ice	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).
		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).
		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).
solution	water	karst	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, the products being removed through underground channels.
erosion, deposition	humans	made land	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.
rapid excavation	meteor impact	meteor crater	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.
erosional and depositional	water, wind	plain	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.
		depositional plain	Level landform pattern with extremely low relief formed by unspecified depositional processes.
		lacustrine plain	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.
		playa plain	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.
		sand plain	Level landform pattern with extremely low relief, typically without stream channels, aggraded by active wind deposition and rarely active sheet flow.
		plateau	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.

		plateau edge	The cliff, scarp or escarpment that extends around a large part of the perimeter of a plateau.
		plateau surface	The low relief surface of a plateau.
		unknown	
volcanic	volcanic eruption	volcano	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.
		caldera	Rare landform pattern typically of very high relief and steep to precipitous slopes. It is without 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.
		cone (volcanic)	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.
		lava plain	Level to undulating landform pattern of very low to extremely low relief typically with widely spaced fixed stream channels which 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.
		ash plain	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.
		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.
		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.

APPENDIX 5: GEOMORPHIC PROCESSES

The contents of this section are taken from "RTMAP" (Pain *et al.* 2003)

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 a textbook on geomorphology, such as Chorley *et al.* (1984). Other suitable references are given at various points.

Geomorphic Process	**Definition**
Gravity	Any geomorphic process that acts mainly as a result of gravity. For more details see Selby (1982).
Vertical collapse	Collapse of large fragments of rock and/or soil, commonly from cliff faces. The collapsed materials accumulate where they fall, and may be acted on by other processes.
Particle fall	More-or-less free fall of small particles of rock and/or soil from or near vertical faces.
Creep	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 down slope movement of material.
Landslide	Translational movement of material along a shear plane 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.
Mudflow	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.
Water	The movement and deposition of material through the agency of water. For more details see Morisawa (1985).
Channelled stream flow	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).
Over-bank stream flow	Erosion, transport and deposition of material on flood plains and other areas adjacent to rivers by water which has flowed out of a confined channel (over-bank deposits).
Sheet flow, sheet wash, surface wash	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.
Waves	Erosion, transport and deposition of material by wave action either on the seacoast or along lake edges. For more details on coastal processes see Davies (1980).
Tides	Erosion, transport and deposition of material by movement of tidal currents.
Detrital deposition in still water	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.
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.

Ice	Erosion, transport and deposition of material by moving ice. For more details see Davies (1969).
Frost	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.
Glacial erosion	Erosion and transport of material by glacial ice, giving rise to distinctive landforms such as U-shaped valleys and cirques.
Glacial deposition	Deposition of material from melting ice. The general term moraine refers to the deposits.
Wind	Erosion, transport and deposition of material by wind. For more details see Mabbutt (1977).
Wind erosion (deflation)	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 corrosion to produce ventifacts.
Sand deposition (wind)	Deposition of sand by wind to form various landform types including dunes and sand sheets.
Dust deposition (wind)	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.
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.
Volcanism	Volcanism refers to the group of processes generated by volcanic activity on the land surface (see Ollier 1988).
Lava flow	The flow of molten rock across the land surface.
Ash flow	The flow of volcanic ash material across the land surface. This includes nuée ardentes. The resulting deposits are sometimes called ignimbrites.
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.
Biological agents	Formation or changes in the shape of landforms by animals or plants, for example, the development of coral reefs.
Human agents	Formation or changes in the shape of landforms by human activity.
Impact by meteors	Formation or changes in the shape of landforms by meteorite impact, typically to produce craters.

APPENDIX 6: LANDUSE LOOKUP DESCRIPTIONS

The descriptions below pertain to the land use lookup. They were modified from the Bureau of Rural Sciences (2007).

Class 1 - Conservation and Natural Environments

1.1.0 Nature conservation

Tertiary classes 1.1.1 - 1.1.6 are based on the Collaborative Australian Protected Areas Database (CAPAD) classification (Cresswell and Thomas 1997). Includes nature conservation areas (nature reserves, wilderness areas, nature parks), areas of managed resource protection (catchment areas, traditional indigenous lands) and areas of minimal land use (defence lands, stock routes, areas under rehabilitation or unused due to land degradation).

Class 2 - Production from Relatively Natural Environments

2.1.0 Grazing natural vegetation

Land uses based on grazing by domestic stock on native vegetation where there has been limited or no deliberate attempt at pasture modification. Some change in species composition may have occurred.

2.2.0 Production forestry

Commercial production from native forests and related activities on public and private land. **NB:** Environmental and indirect production uses associated with retained native forest (eg prevention of land degradation, wind-breaks, shade and shelter) are included in an appropriate class under 1. Conservation and natural environments.

Class 3 - Production from Dryland Agriculture and Plantations

3.1.0 Plantation forestry

Land on which plantations of trees or shrubs (native or exotic species) have been established for production or environmental and resource protection purposes. This includes farm forestry. Where planted trees are grown in conjunction with pasture, fodder or crop production, class allocation should be made on the basis of either prime use or multiple class attribution.

3.2.0 Grazing modified pastures

Pasture and forage production, both annual and perennial, based on significant active modification or replacement of the initial native vegetation. Land under pasture at the time of mapping may be in a rotation system so that at another time the same area may be, for example, under cropping. Land in a rotation system should be classified according to the land use at the time of mapping. Suggested tertiary classes for legume and grass pasture types can be fitted to the pasture attributes collected through the Australian Bureau of Statistics (ABS) Agricultural Census.

3.3.0 Cropping

Land under cropping at the time of mapping may be in a rotation system so that at another time the same area may be, for example, under pasture. Land in a rotation system should be classified according to the land use at the time of mapping. Cropping can vary markedly over relatively short distances in response to change in the nature of the land and the preferences of the land manager. It may also change over time in response to market conditions. Fodder production, such as lucerne hay, is treated as a crop as there is no harvesting by stock. At the tertiary level it is suggested that classes be based on commodities / commodity groups that relate to ABS level 2 agricultural commodity categories. Crops categories are: Cereals, beverage and spice crops, hay and silage, oil seeds, sugar, cotton, tobacco and legumes. **NB:** These are classified further using the Landuse_Subtype category in Appendix 3.

3.4.0 Perennial horticulture

Crop plants living for more than two years that are intensively cultivated, usually involving a relatively high degree of nutrient, weed and moisture control. Suggested tertiary classes are based on the ABS commodities Level 2 categories that relate to horticulture. They are: tree fruits, oleaginous (oil) fruits, tree nuts, vine fruits, shrub nuts, fruits and berries, flowers and bulbs, and vegetables and herbs.

3.5.0 Seasonal horticulture

Crop plants living for less than two years that are intensively cultivated, usually involving a relatively high degree of nutrient, weed and moisture control. Suggested tertiary classes are based on the ABS commodities Level 2 agricultural commodity categories that relate to horticulture. They are: fruits, nuts, flowers and bulbs, and vegetables and herbs.

3.6.0 Land in transition

Areas where the land use is unknown and cannot reasonably be inferred from the surrounding land use. For example: degraded land (severely degraded land not undergoing active rehabilitation), abandoned land, land under rehabilitation, and land of no defined use.

Class 4 - Production from Irrigated Agriculture and Plantations

4.1.0 Irrigated plantation forestry

Land on which irrigated plantations of trees or shrubs have been established for production or environmental and resource protection purposes. This includes farm forestry e.g., hardwood production, softwood production.

4.2.0 Irrigated modified pastures

Irrigated pasture production, both annual and perennial, based on a significant degree of modification or replacement of the native vegetation. This class may include land in a rotation system that at other times may be under cropping. Land in a rotation system should be classified according to the land use at the time of mapping. Cropping/pasture rotation regimes are treated as land management practices. Pastures include: woody fodder plants, legumes, and sown grasses.

4.3.0 Irrigated cropping

Land under irrigated cropping. This class may include land in a rotation system that at other times may be under pasture. Land in a rotation system should be classified according to the land use at the time of mapping. Cropping/pasture rotation regimes are treated as land management practice. Crop types as per dryland cropping. NB: These are classified further using the Landuse_Subtype category in Appendix 3.

4.4.0 Irrigated perennial horticulture

Irrigated crop plants living for more than two years that are intensively cultivated, usually involving a relatively high degree of nutrient, weed and moisture control. They are: tree fruits, oleaginous (oil) fruits, tree nuts, vine fruits, shrub nuts, fruits and berries, flowers and bulbs, and vegetables and herbs.

4.5.0 Irrigated seasonal horticulture

Irrigated crop plants living for less than two years that are intensively cultivated, usually involving a relatively high degree of nutrient, weed and moisture control. They are: fruits, nuts, flowers and bulbs, and vegetables and herbs.

4.6.0 Irrigated land in transition

Areas where irrigated production may have been carried out but land use is unknown and cannot reasonably be inferred from the surrounding land use. **NB:** Evidence or knowledge of irrigation use, or irrigation infrastructure, should be present. Land can be degraded, abandoned, under rehabilitation or have no defined use (irrigation).

Class 5 - Intensive uses

5.1.0 Intensive horticulture

Intensive forms of plant production e.g., glasshouses and shade houses.

5.2.0 Intensive animal production

Intensive forms of animal production (excludes associated grazing/pasture). Agricultural production facilities such as feedlots, piggeries etc may be included as tertiary classes. Production types are: dairy, cattle, sheep, poultry, pigs, aquaculture. **NB:** These are classified further using the Landuse_Subtype category in Appendix 3.

5.3.0 Manufacturing and industrial

Factories, workshops, foundries, construction sites etc. This includes the processing of primary produce eg sawmills, pulp mills, abattoirs etc.

5.4.0 Residential

Residential includes urban (houses, flats, hotels etc), rural residential (peri-urban where agriculture is not primary source of income) and rural (areas with substantial amount of native vegetation with no agricultural development)

5.5.0 Services

Land allocated to the provision of commercial or public services resulting in substantial interference to the natural environment. Where services are provided on land that retains natural cover, an appropriate classification under (i) Conservation and Natural Environments should be applied (eg 1.1.7; 1.3). Services include: commercial (shops, markets etc), public (education and community services), recreation and cultural (parks, camping grounds, pools, museums, places of worship etc), defence facilities (unless significant natural cover is retained) and research facilities.

5.6.0 Utilities

Utilities such as electricity generation/transmission and gas treatment, storage and transmission.

5.7.0 Transport and communication

Includes airports/aerodromes, roads, railways, ports and navigation and communication uses (like radar stations).

5.8.0 Mining

Mines, quarries and tailings.

5.9.0 Waste treatment and disposal

Waste material and disposal facilities associated with industrial, urban and agricultural activities e.g., stormwater, landfill, incinerators and sewage.

Class 6 - Water

6.1.0 Lake

Feature relates to uses in 1. Conservation and Natural Environments, 2. Production from Relatively Natural Environments, and 5. Intensive Uses.

6.2.0 Reservoir/dam

Includes water storages, evaporation basins and effluent ponds.

6.3.0 River

Feature relates to uses in 1. Conservation and Natural Environments, 2. Production from Relatively Natural Environments, and 5. Intensive Uses.

6.4.0 Channel/aqueduct

Includes supply and drainage channel/aqueducts.

6.5.0 Marsh/wetland

Feature relates to uses in 1. Conservation and Natural Environments, 2. Production from Relatively Natural Environments, and 5. Intensive Uses.

6.6.0 Estuary/coastal waters

Feature relates to uses in 1. Conservation and Natural Environments, 2. Production from Relatively Natural Environments, and 5. Intensive Uses.