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REGOLITH-LANDFORM MAPPING IN THE YILGARN CRATON, WESTERN AUSTRALIA: TOWARDS A STANDARDIZED APPROACH

M.A. Craig, R.R. Anand, H.M. Churchward, J.R. Gozzard, R.E. Smith and K. Smith

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February 1999

(CSIRO Division of Exploration Geoscience Report 338R, 1993. Second impression 1999)

CRC LEME is an unincorporated joint venture between The Australian National University, University of Canberra, Australian Geological Survey Organisation and CSIRO Exploration and Mining, established and supported under the Australian Government's Cooperative Research Centres Program.

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Headquarters: CRC LEME c/o CSIRO Exploration and Mining, Private Bag, PO Wembley, Western Australia, 6014

RESEARCH ARISING FROM CSIRO/AMIRA REGOLITH GEOCHEMISTRY PROJECTS 1987-1993

In 1987, CSIRO commenced a series of multi-client research projects in regolith geology and geochemistry which were sponsored by companies in the Australian mining industry, through the Australian Mineral Industries Research Association Limited (AMIRA). The initial research program, "Exploration for concealed gold deposits, Yilgarn Block, Western Australia" (1987-1993) had the aim of developing improved geological, geochemical and geophysical methods for mineral exploration that would facilitate the location of blind, buried or deeply weathered gold deposits. The program included the following projects:

P240: Laterite geochemistry for detecting concealed mineral deposits (1987-1991). Leader: Dr R.E. Smith.
Its scope was development of methods for sampling and interpretation of multi-element laterite geochemistry data and application of multi-element techniques to gold and polymetallic mineral exploration in weathered terrain. The project emphasised viewing laterite geochemical dispersion patterns in their regolith-landform context at local and district scales. It was supported by 30 companies.

P241: Gold and associated elements in the regolith - dispersion processes and implications for exploration (1987-1991). Leader: Dr C.R.M. Butt.
The project investigated the distribution of ore and indicator elements in the regolith. It included studies of the mineralogical and geochemical characteristics of weathered ore deposits and wall rocks, and the chemical controls on element dispersion and concentration during regolith evolution. This was to increase the effectiveness of geochemical exploration in weathered terrain through improved understanding of weathering processes. It was supported by 26 companies.

These projects represented "an opportunity for the mineral industry to participate in a multi-disciplinary program of geoscience research aimed at developing new geological, geochemical and geophysical methods for exploration in deeply weathered Archaean terrains". This initiative recognised the unique opportunities, created by exploration and open-cut mining, to conduct detailed studies of the weathered zone, with particular emphasis on the near-surface expression of gold mineralisation. The skills of existing and specially recruited research staff from the Floreat Park and North Ryde laboratories (of the then Divisions of Minerals and Geochemistry, and Mineral Physics and Mineralogy, subsequently Exploration Geoscience and later Exploration and Mining) were integrated to form a task force with expertise in geology, mineralogy, geochemistry and geophysics. Several staff participated in more than one project. Following completion of the original projects, two continuation projects were developed.

P240A: Geochemical exploration in complex lateritic environments of the Yilgarn Craton, Western Australia (1991-1993). Leaders: Drs R.E. Smith and R.R. Anand.
The approach of viewing geochemical dispersion within a well-controlled and well-understood regolith-landform and bedrock framework at detailed and district scales continued. In this extension, focus was particularly on areas of transported cover and on more complex lateritic environments typified by the Kalgoorlie regional study. This was supported by 17 companies.

P241A: Gold and associated elements in the regolith - dispersion processes and implications for exploration. Leader: Dr. C.R.M. Butt.
The significance of gold mobilisation under present-day conditions, particularly the important relationship with pedogenic carbonate, was investigated further. In addition, attention was focussed on the recognition of primary lithologies from their weathered equivalents. This project was supported by 14 companies.

Although the confidentiality periods of the research reports have expired, the last in December 1994, they have not been made public until now. Publishing the reports through the CRC LEME Report Series is seen as an appropriate means of doing this. By making available the results of the research and the authors' interpretations, it is hoped that the reports will provide source data for future research and be useful for teaching. CRC LEME acknowledges the Australian Mineral Industries Research Association and CSIRO Division of Exploration and Mining for authorisation to publish these reports. It is intended that publication of the reports will be a substantial additional factor in transferring technology to aid the Australian Mineral Industry.

This report (CRC LEME Open File Report 72) is a Second impression (second printing) of CSIRO, Division of Exploration Geoscience Restricted Report 338R, first issued in 1993, which formed part of the CSIRO/AMIRA Project P241.

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PREFACE

In the Yilgarn Lateritic Environments Project (AMIRA P240A) and its precursor, regolith-landform mapping methods and the terminology and classification of regolith materials have been undergoing development, particularly from the perspective of exploration geochemistry.

This discussion paper has been produced for sponsors of the project to facilitate an understanding of the co-operative process taking place between the various government and geoscience agencies involved in mapping regolith in the Yilgarn and to put forward the major issues involved in moving towards an integrated regolith-landform mapping, nomenclature and map presentation strategy.

The Working Group

14 January 1993

SUMMARY

Knowledge of regolith relationships is essential for control of most forms of geochemical exploration and many forms of geophysical exploration. This is particularly true for exploration in the Yilgarn Craton because of the extent of deep lateritic weathering and the complexities caused by variable degrees of dismantling and modification of the lateritic weathering profiles. It is important that the principles and approaches used or being developed for regolith mapping, establishing regolith stratigraphy, characterizing regolith units, interpretation, and synthesis be understood – firstly by those engaged in development of the methods and secondly by users.

Three major geoscience agencies (AGSO, CSIRO, and GSWA) are involved in mapping regolith in the Yilgarn Craton of Western Australia both collaboratively and separately. Each group has been working at a different scale as a result of their original charter, national role, or specific client needs. Each has developed techniques to suit its own purpose. There is much common ground in the way each group has mapped the regolith, although until the present initiative, this was not clearly recognized. There are still differences between the groups because of the scale of the work they undertake.

Each group is using landform as a surrogate method of defining variations in regolith types across mapping areas. The mapping methods are loosely based on CSIRO Land Systems mapping which varied with toposequence and included catena concepts used by soil scientists. Landform-based mapping schemes are internationally recognized as successful approaches to a variety of problems associated with earth resources. In Australia, AGSO has adapted the techniques to regolith mapping at a variety of scales. Those agencies mapping regolith in the Yilgarn have recognized that landform is the common element in their approach.

Several scientists from AGSO, CSIRO, GSWA, and Curtin University have been involved in a working party to clarify the individual mapping processes, classification of materials, and presentation of data in map and database form. A summary of mapping techniques, regolith and landform types, and induration categories shows the common ground. Perceived similarities and differences between working methods and definitions are defined. Proposals are suggested for the development of fully-integrated mapping methods and for regolith and landform terminology. The approaches also take into account the need to maintain differences in order to account for purpose and scale variations in the work.

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1.0 INTRODUCTION

1.1 Background

Interest in the regolith in Australia comes from a wide range of disciplines. The minerals exploration industry has a particular interest in mapping and understanding the Australian regolith because of the way in which regolith obscures a large proportion of the so-far-unexplored bedrock and because of the dispersion patterns which have been generated as an integral part of regolith evolution. In an attempt to co-ordinate approaches to regolith mapping in the Yilgarn, representatives of the major geoscience agencies active there (AGSO, CSIRO, GSWA, and Curtin University) formed a working group to look at ways of integrating individual mapping approaches to maximize the benefits to all concerned with regolith data. In this regard, collaborative participation of these parties in the CSIRO-AMIRA Project P240, *Laterite Geochemistry*, and its successor P240A, *Yilgarn Lateritic Environments*, became the catalyst. Here, the focus is on providing an understanding of the regolith-landform relationships for control of exploration geochemistry. Some comments about the ensuing deliberations, various approaches, and co-operative efforts are now timely.

In this report, CSIRO, unless otherwise qualified, refers to current activities within the Division of Exploration Geoscience, AGSO refers to the Australian Geological Survey Organisation (formerly the Bureau of Mineral Resources, Geology and Geophysics), and GSWA refers to the Geological Survey of Western Australia.

The techniques used in Australia to map the regolith can be viewed against a backdrop provided by the early work of Christian and Stewart (1953) in which landform essentially provides the basis of defining areas with similar characteristics. The Land System is essentially an area, or group of areas, throughout which a recurring pattern of topography, soils, and vegetation can be recognized. A polygon boundary is drawn to indicate the area in which similar characteristics could be expected to occur. Beyond the polygon boundary a different set of characteristics would prevail. So, in general, a boundary should be placed on a regolith-landform map where the rate of change is greatest. A unit so delineated may also contain geomorphic sub-divisions. The subdivisions are: areas of little erosion, areas of active erosion, and areas essentially depositional in character. This could also be thought of in terms of (i) areas where deep weathering is dominant, (ii) areas where bedrock dominates, and (iii) areas where sediment dominates.

AGSO has been involved in regional approaches to mapping the Australian regolith for some years and the approach used is similar in philosophy to that used earlier by the CSIRO Land Systems mapping programme (Christian and Stewart, 1953). GSWA produces regolith maps of the Yilgarn which are intermediate in scale and method between AGSO and CSIRO. The fundamental mapping unit of AGSO appears on a map as a polygon defined principally by landform. The mapping unit represents an area characterized by similar landform and regolith attributes or a pattern of landforms and regolith attributes. The size of the mapping units is in no way predefined and, like the CSIRO Land System, each unit is dependent upon what can be isolated at the scale of mapping. The important issue is that the mapping technique does not need to be scale dependent, even though Christian and Stewart's original work was at the 1:250 000 scale.

The CSIRO Laterite Geochemistry Group (through projects P240 and P240A) uses a definition for a regolith mapping unit which is fundamentally the same as that of AGSO. Differences largely arise as a result of its application at a more detailed scale. A regolith-landform mapping unit is a map polygon or an area of land characterized by a landform unit, or combination of a small number of units, which usually encloses a surface or subsurface-substrate combination of regolith elements. Most often the level of detail shown on a large scale map (a detailed map) cannot be shown on a regional map, therefore the within-polygon detail resides within a database linked to the structure of the Geographic Information System (GIS) rather than being crowded onto the regional map face. So, as we should expect, scale affects map face presentation.

It is important to recognize that each of the above-mentioned agencies mapping the Yilgarn regolith is actually using scale independent mapping concepts and each is presenting a level of detail appropriate to the scale of investigation.

LANDFORM BASED MAPPING SCHEMES

CSIRO AUSTRALIA	SOIL CONSERVATION AUTHORITY, VIC, AUS	OXFORD, MEXE UK	USSR	JAPAN	GERMANY	AGSO	CSIRO/AMIRA	GSWA
-	LAND ZONE	-	MESTNOST	PROVINCE	MACROCHORES			
LAND SYSTEM	LAND SYSTEM	LAND SYSTEM	UROCHISCHE	SECTION	MESOCHORES	REGOLITH-LANDFORM UNITS		
LAND UNIT	LAND UNIT	LAND FACET	SUB-UROCHISCHE	ASSOCIATION	MICROCHORES			
LAND FACET	LAND COMPONENT	LAND ELEMENTS (not mapped)	ZVENO	SERIES	ECOTYPE COMPLEX			REGOLITH-LANDFORM UNITS
LAND ELEMENTS (not mapped)	-	-	FACIA	LANDFORM TYPE	-		REGOLITH-LANDFORM UNITS	
1	1	1	1	1	1	2	2	2

Fig.1. Landform based mapping schemes showing hierarchical relationships between basic mapping units and subunits. Broad units at the top, subdivisions at the bottom.

Notes: 1, mostly extracted from Christian and Stewart (1953)

2, from the present study, vertical bars show the range of scales.

It is also worth noting that the mapping concepts adopted for continental-, regional-, district- and prospect-scale regolith mapping, and particularly regolith mapping efforts in the Yilgarn by AGSO, GSWA and CSIRO, are consistent with landscape-based mapping systems developed elsewhere in Australia and in other parts of the world. Figure 1 shows the simple hierarchical relationships between landscape-based mapping schemes. This is not intended to be a review of the topic, but is a selection which provides some insight, and a contextual setting, for what is taking place in Australia and in particular in the Yilgarn.

1.2 Objectives of the research

The objectives of the research are to establish a sound working approach to (a) regolith-landform mapping and (b) the classification of regolith materials, for use in geochemical exploration. A further objective is (c) to have such schemes developed for use in the Yilgarn fit congruently as subsets within a broader national framework which is concurrently under development.

Clearly, for explorationists to adopt recommended procedures, it is important that they have confidence that the main research authorities have come to a common understanding. Furthermore, it is important that the methods and proposed classification schemes have been tested amongst the researchers before being proposed for widespread use in exploration and that the methods would not, thereafter, be rapidly changing.

1.3 Purpose of this document

The purpose of this discussion document is to present the common ground in the approaches and philosophies being used in regolith-landform mapping, by the three government agencies involved in the Yilgarn Craton. It is intended that the ensuing discussion will facilitate continued advancement of the concepts involved and continued development of practical methods for regolith mapping and modelling for control in exploration geochemistry and geophysics.

2.0 MAJOR ISSUES

2.1 The effect of scale on map presentation

One major task of the working group was to define the common ground in the mapping approaches used by the major geoscience agencies. Whilst initial focus is on the Yilgarn Craton, there is a very real need to follow a national strategy which will be robust enough to permit the integration of the various approaches currently in use. The working group has spent some considerable time both in committee and its members separately exploring these issues. There is substantial common ground when the mapping concepts are examined closely. This common ground allows integration of the various schemes thereby providing a robust national scheme. There will be no need to learn new mapping philosophies each time data are taken from a different agency nor will there be a need to learn a new system each time the scales of maps change. However the map face, even with a common mapping system, will and must inevitably look different as the scale of presentation changes. Figure 2 shows, as an example, how map presentation changes from regional scale to prospect scale even though both use the same landscape-based mapping technique.

An important point which must be stressed here is the difference between a **regolith-landform mapping unit** and an **ideal regolith classification unit.** In the context of this document, **ideal regolith classification units** consist of regolith units which are defined in terms of various regolith-landform characteristics. They are ideal units because they can be defined precisely. They are used as a medium for the transfer of knowledge and can be grouped in various ways for particular purposes. Only at very detailed mapping scales is it likely that a classification unit could be used as a **regolith-landform mapping unit**. This is because as the mapping area becomes more detailed, it is easier to represent a single pure regolith regolith-landform unit (Section 3.2) on the map. At smaller scales (i.e., more regional) the polygons must be more general and therefore less pure because they contain variations. This variation within a polygon usually means that a regolith-landform mapping unit is rarely the same as a regolith classification unit.

2.2 Map information

Of concern also, is the nature of information presented on a regolith map. Obviously, information would be in the form of polygons which would be identified by symbols and/or colours. The ideal situation would be when, at prospect and more detailed scales, the map symbol refers to a polygon containing only one regolith type. This may be the case in some instances at prospect scale, but as the area represented on the map gets larger, the likelihood of a polygon being a simple regolith type is very much reduced. Ultimately, a symbol can only indicate the dominant regolith type or a characteristic assemblage of regolith types inside the polygon. The minor regolith types cannot be shown at these smaller (regional) scales. The detail must be extracted from an accompanying database. We all recognize that there is a limit to the detail that can be shown on any map face, otherwise the map becomes impossible to use effectively. Regolith maps are no exception to this rule. As the areas dealt with become smaller it becomes easier to show more detail. In some cases a map could show all the detail of the regolith in an area.

The symbols used to indicate the major regolith types in a map polygon should be chosen from the list of theoretical regolith classification units. If there is not a dominant regolith type in a defined polygon then the polygon should probably be subdivided further.

2.3 Map symbols and legends

Of equal concern is what legend goes in the margin of a regolith map and just how can each unit or polygon be coded on the map face. Figure 3 shows a simple map with the symbol style being tested by AGSO. In the scheme, each polygon is labelled by a fractional representation, for example:

$$\frac{\text{REGOLITH TYPE} + \text{INDURATION}}{\text{LANDFORM TYPE} + \text{BEDROCK LITHOLOGY}}$$

It is possible that the first major surface regolith type may be followed by the immediately underlying regolith unit where small areas are being mapped. At reconnaissance scales this may not be a successful approach because the distribution of a second polygon layer or pseudo-stratigraphy may not have the same boundaries as the topmost layer. Obvious cartographic problems would arise as a result.

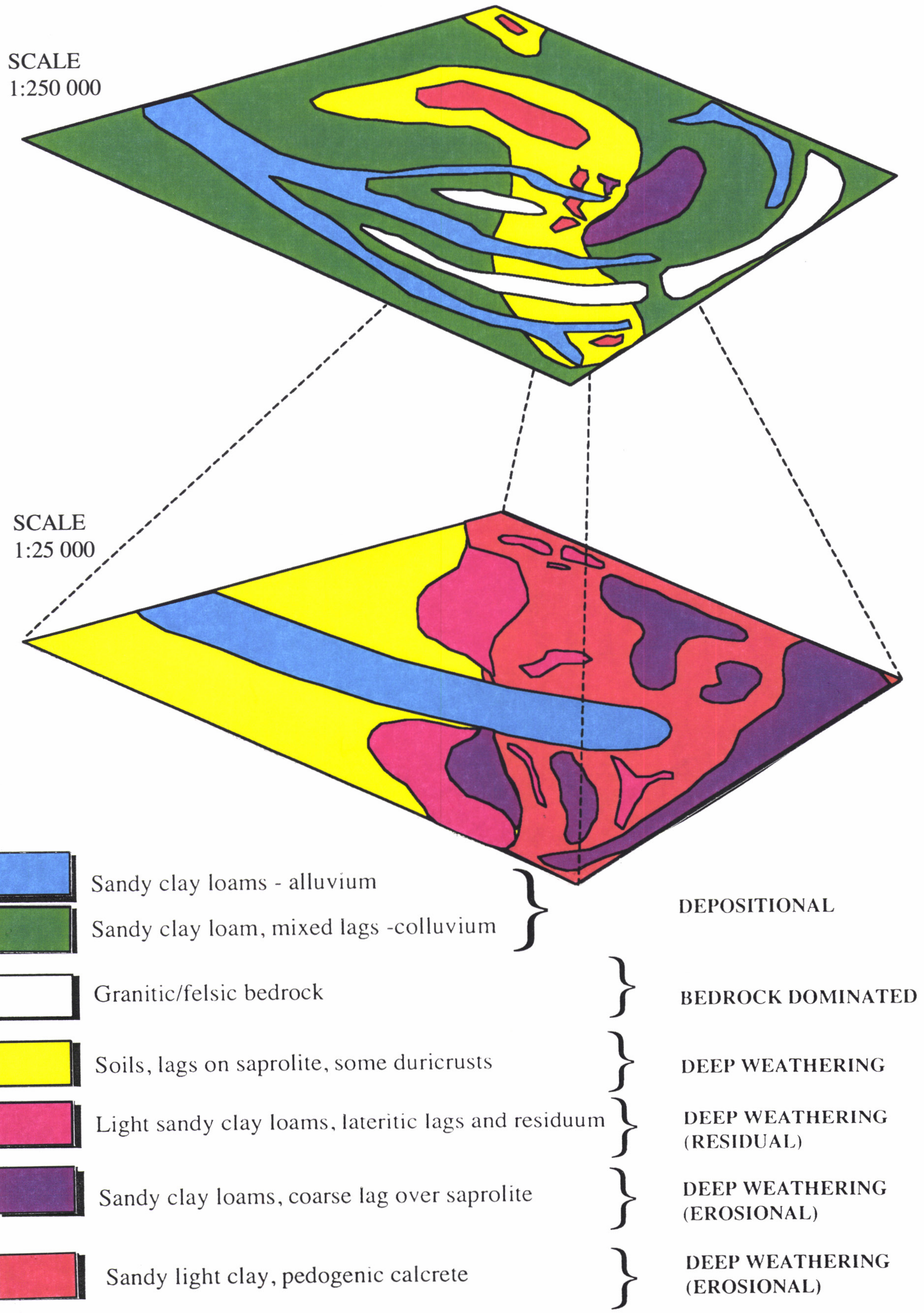


Figure 2. Prospect scale (1:25 000) regolith map dissolved to regional scale (1:250 000) representation. Prospect scale polygons show the extent of unit purity whereas the regionalized polygons show the inherent inhomogeneity required for that scale of representation. The detail for regional polygons resides within the linked database rather than on the map face.

$$\frac{\text{REGOLITH TYPE 1/ REGOLITH TYPE 2} \;+\; \text{INDURATION}}{\text{LANDFORM TYPE} \;+\; \text{BEDROCK LITHOLOGY}}$$

These fractional representations are much smaller than the word examples suggest. For example, using database notation from the AGSO field handbook for regolith mapping the fraction would appear as:

$$\frac{\text{WIR22 / WIR12} \;+\; \text{IDS42}}{\text{PLO4} \;+\; \text{INFGRN}}$$

WIR22	= Residual sand*
WIR12	= Structured saprolite*
IDS42	= Nodular ferricrete*
PLO4	= Sand plain
INFGRN	= Intrusive felsic-granite

* Cautionary note: The terms marked with an asterisk are not accepted terms in the current terminology for this AMIRA Project.

There are a number of options for providing an interpretative element in regolith maps. Wherever possible the map ought to reflect the facts. Whilst it is recognized that with surface materials this can become a difficult undertaking, we also recognized that to "colour" a map too strongly with an interpretative veil may reduce its value considerably. Instead, the map should have boxes in its margins where interpretative summaries can be added as appropriate to the area. Clearly, there is still some difficulty here because it is not possible to include every interpretative view of the data. Where further interpretation of the basic data is needed, the digital data sets consisting of at least the site descriptions/location (as an electronic version of the field notebook), primary polygons, and polygon attribute data will be needed.

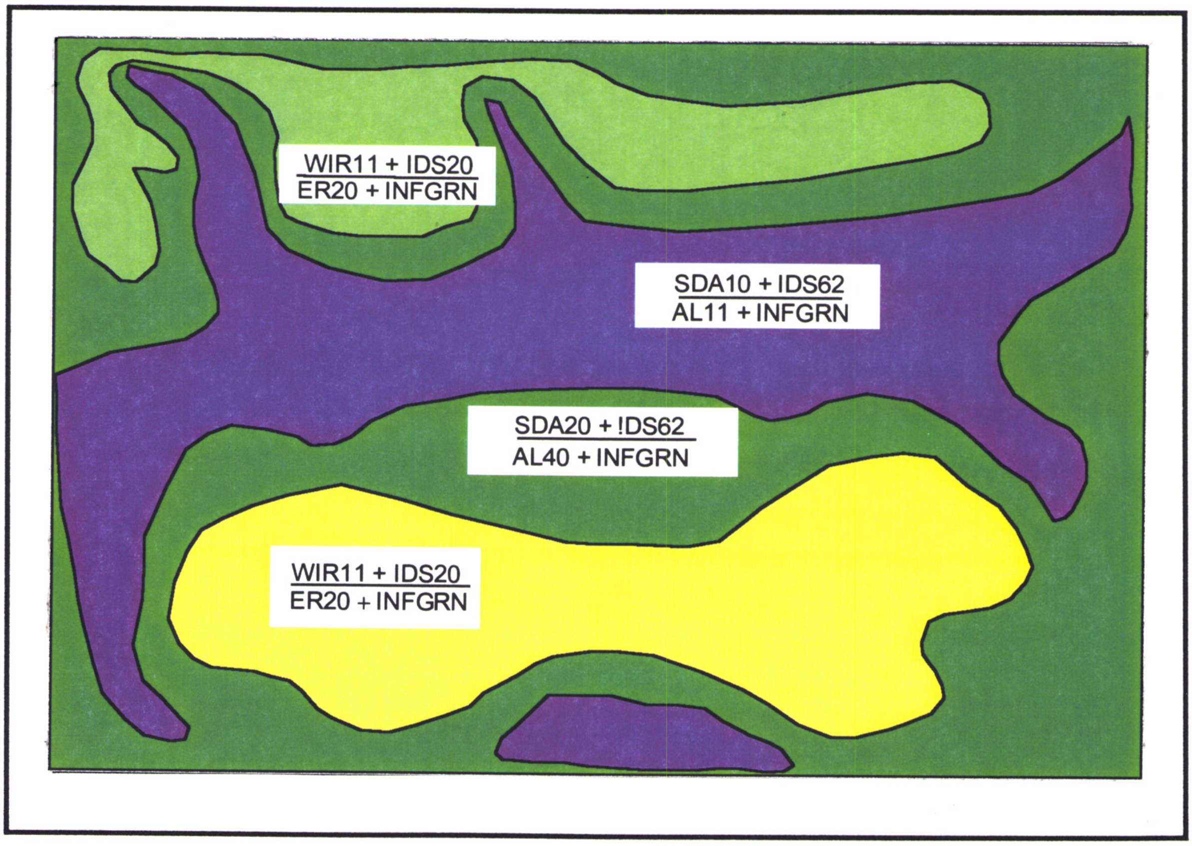


Figure 3. An AGSO style map face layout with polygon labelling option.

2.4 Current status within government agencies

The common aspects of the three agencies involved in regolith mapping in the Yilgarn are:

1. Each agency is using a surrogate system to map the regolith and, to varying extents, each relies on landforms (in some cases modified by vegetation patterns) as the surrogate to provide basic regolith landform unit boundaries and so,

   a) AGSO employs a greater surrogacy for regional scale mapping (1:250 000) and less surrogacy at compilation scale (1:100 000);
   b) GSWA employs even less surrogacy because it works at 1: 50 000 to 1:100 000 scale;
   c) CSIRO, because it tends to do detailed to semi-detailed mapping at scales of around 1:10 000 to 1:50 000, employs the least degree of surrogacy.

2. The Regolith-Landform Mapping Units (RLUs) defined by each agency differ in terms of their internal complexity and this is **principally a function of the scale, not concept,** at which each agency is working. Therefore,

   a) AGSO's regolith landform units are more internally complex, that is, have greater heterogeneity;
   b) GSWA is able to define RLUs which are less internally complex; and
   c) CSIRO can work with even less internal complexity, that is, greater homogeneity because of the more detailed working scales.

3. Each agency defines landform-based polygons called regolith-landform units which contain different degrees of surrogacy and internal purity, all of which are driven by the scale factor. Regardless, RLUs contain a spatially-related package of regolith components.

From this it is clear that the approaches have a common theme which allows integration of data sets and there is a common mapping approach which needs to be clear to users.

The realization and acceptance that each agency is making regolith-landform map polygons in fundamentally the same way is a substantial step forward. The next most important step of integrating the codes and data from different scales becomes a clearer need. Integration into a national database and GIS is required to make as much information available as possible. We each agree that a change of scale should not justify a totally new mapping system, but instead we need to fine-tune a robust, scale-independent system. We already have the major elements of such a mapping approach in the regolith-landform mapping approach. Users will benefit from such clarification. They should be able to move from scale to scale, up or down as their needs dictate, yet still be able to follow the one mapping system and move through an integrated classification code. The number of site observations residing within any accompanying database will be influenced because each agency or company collects data based upon its major charter. So the observation density increases as the survey changes from regional to prospect scale. Provided these limitations are borne in mind, it is unlikely that the digital data will be stretched beyond reasonable limits.

3.0 DEFINITIONS

3.1 Introduction

This section focuses on the definitions of some of the main terms used, particularly those by Project P240A team members in the regolith-landform mapping process. The definitions used by AGSO are listed at length in its publication, BMR Record 1991/29: *RTMAP BMR Regolith Database Field Handbook*. Sponsors should be aware of the information within that publication as it addresses a wide range of definitions focussed particularly towards regional application. Many of the definitions used in Project P240 are presented in the Summary Report 236R, Section 2 (Smith *et al*., 1992).

3.2 Regolith stratigraphy

Regolith stratigraphy
This term refers, collectively, to units of weathering profiles as well as to those of the Cainozoic sedimentary succession. The use of the term stratigraphy, when dealing with regolith materials, is compatible with the International Stratigraphic Guide (Hedberg, 1976). A lithostratigraphic approach is used, namely systematic organization of rocks (in this case weathered rocks) and sediments based upon certain unifying characteristics, or attributes that distinguish each from the other layers. (Discussed further in Section 4.2.2.)

Regolith Unit
Regolith units are subdivisions of regolith stratigraphy as used in P240 and P240A reports. They include zones or horizons of weathering profiles such as soil, lateritic duricrust, lateritic gravel, mottled zone, saprolite, etc., as well as the subdivisions of the associated sedimentary sequences. These are units of the regolith stratigraphy. Each regolith unit can vary spatially and changes can be gradual or sharp. Some example descriptions of regolith units are now given:

Lateritic Residuum
Lateritic residuum is a collective term for certain ferruginous units of the laterite profile. It is formed by weathering, precipitation of minerals, and residual accumulation in the upper part of a lateritic weathering profile. Lateritic residuum includes units consisting of loose lateritic pisoliths and nodules (forming lateritic gravel) as well as lateritic duricrust. The colour of this regolith unit varies from yellowish-brown, through dark reddish-brown to very dark brown. The mineralogy is mainly kaolinite, hematite, goethite, with or without subordinate and variable amounts of gibbsite, quartz, maghemite, muscovite, zircon, ilmenite, and anatase. Lateritic residuum may occur at surface or subsurface when the weathering profile has been buried.

Mottled Zone
The mottled zone represents the lower part of the ferruginous zone of the weathering profile and differs from the lateritic residuum above by lesser accumulation of Fe-oxides and lacks induration. The mottled zone has contrasting kaolinite-rich bleached domains and Fe-mottles, which may be distinguished easily in outcrops and in samples on a centimetre scale.

Ferruginous Saprolite
Ferruginous saprolite is formed by the infusion of clay-rich saprolite with goethite, and is firm to hard, massive to mottled, and is dominated by goethite and kaolinite. Fragments of ferruginous saprolite are yellowish-brown to reddish-brown, non-magnetic, and may have an incipient nodular structure. Ferruginous saprolite may form a continuous blanket and is generally overlain by collapsed ferruginous saprolite where soft, soluble, less ferruginized material has been removed by leaching, causing the whole structure to collapse.

Saprolite
Saprolite is weathered rock that retains much of the fabric and structure of the parent bedrock. Saprolite can be firm (rather than hard), soft, or friable. Isovolumetric weathering is commonly envisaged. Saprolite may become more massive upwards as the proportion of clay increases and cementation by secondary silica, carbonates, and especially Fe-oxides is common. Saprolite is lighter in colour than the overlying mottled zone and lateritic residuum. Its mineralogy is variable, depending upon the nature of the parent bedrock.

Saprock
Saprock is a compact, slightly-weathered rock of low porosity, with less than 20% of the weatherable minerals altered. The boundary between bedrock and saprock is not generally a plane, but is very irregular and corestones of fresh rock may occur in the saprock and saprolite.

3.3 Regolith-landform (mapping) units – RLUs

Regolith-landform units
These are areas delineated on a map, within which a particular association of regolith materials and landforms. (Discussed further in Section 4.2.1.)

3.4 Regolith-landform regimes

These are broad genetic groupings of the landform and associated regoliths which appear on a second stage interpretative map. They often form the basis of regolith-landform models, particularly for weathered terrain. In these models, the development of an extensive deeply-weathered mantle is proposed as the first stage, and this is subsequently modified by erosion and deposition. In broad terms, three major regimes are perceived as being widely applicable in lateritic terrain, namely, residual, erosional, and depositional (referred to in this document as the RED scheme), which are defined as follows:

Residual Regimes
Residual regimes are mappable areas characterized by widespread preservation of lateritic residuum. Conceptually, they are relics of an ancient weathered land surface.

Erosional Regimes
Erosional regimes are characterized by erosion and removal of the lateritic residuum to a level where the mottled zone, clay zone, saprolite, or fresh bedrock are either exposed, concealed beneath soil, or beneath thin locally-derived, associated sediments.

Depositional Regimes
These regimes are characterized by widespread sediments which can be many metres thick. The boundary between residual and depositional regimes can be gradational or sharp. The substrate can range from stripped surfaces to complete weathering profiles.

4.0 THE IMPORTANCE OF REGOLITH-LANDFORM CONTROL IN EXPLORATION GEOCHEMISTRY

4.1 Introduction

On the Yilgarn Craton, it is interpreted that the combined effects of prolonged deep lateritic weathering under warm, humid conditions followed by differential erosion and chemical modification, particularly under arid or semi-arid conditions, have led to a great variety of materials being exposed on the land surface and to intricate regolith-landform relationships (Fig. 4). For an exploration programme, it is important to understand the regolith-landform relationships in the wide variety of terrain types which have resulted from this complex and geomorphic setting and regolith evolution for two reasons: (i) to design and execute the sampling programme properly; (ii) to present and interpret the data properly. Both of these tasks need to include a knowledge of regolith and landscape evolution, weathering, and dispersion processes.

Different geochemical thresholds usually apply to different sampling media and hence to different regolith-landform mapping units. One purpose of producing a regolith-landform map is to delineate areas or units within which data may be treated uniformly. If the variation in sample characteristics is too great, geochemical dispersion anomalies arising from ore deposits will be lost among the natural variation in sample characteristics, related to changes in regolith-landform situations. Regolith-landform maps also identify and delineate areas characterized by complex surficial relationships which may require specialized exploration approaches in contrast with areas which require, for example, straightforward soil sampling.

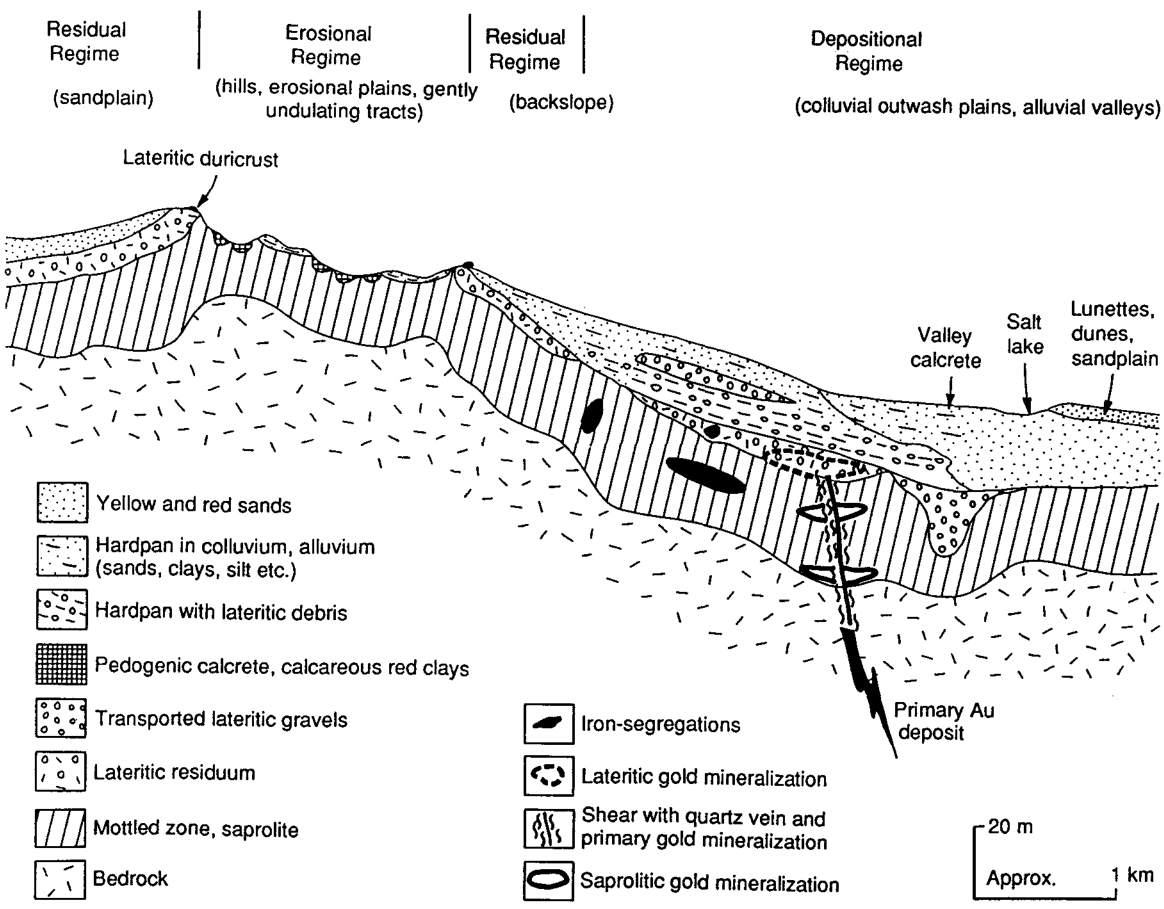


Figure 4. Generalized cross section showing regolith-landform relationships and regolith stratigraphy in the Yilgarn.

Linking sample type to regolith stratigraphy is fundamental because it firstly indicates what is actually being sampled. Secondly, the position within the regolith stratigraphy for an area leads to an estimation of the size, shape, element associations, and threshold values of useful geochemical anomalies. Linking regolith stratigraphy to regolith-landform models likewise allows better design of sampling and better interpretation of geochemical dispersion patterns.

Fundamental to exploration in lateritic terrain is whether lateritic residuum is still present, has been removed by erosion, or was never present. The boundaries which marks the base of lateritic residuum and that which outlines areas having substantial sedimentary cover are both very important and these also need to be clearly defined. Commonly, it may be very useful to consider regolith-landform relationships in the interpretative terms already defined, that is, residual, erosional, and depositional regimes.

If the broad *regolith-landform regimes* are mapped in an area, it usually becomes clear which is the preferred geochemical sampling media. For example, in erosional regimes, soil geochemistry – either conventional soil geochemistry or bulk-leach cyanide-extractable gold (BLEG) – is commonly very effective. However, in residual regimes laterite geochemistry is generally superior to soil geochemistry, because geochemical anomalies in laterite are relatively large and consistent. Moreover, soil sampling on a lateritic substrate may result in weaker contrast anomalies, erratic gold patterns, and imposes an extra weathering process to be understood. Much, however, depends upon the size fraction used.

4.2 Mapping procedures

A general flow chart for carrying out detailed regolith mapping is shown in Figure 5. A full understanding of the regolith is provided by regolith-landform mapping, establishing the regolith stratigraphy within these mapped units, and synthesizing a regolith-landform model. Once the regolith-landform relationships for an exploration area or district are defined and regolith cross sections, facies models, and three-dimensional regolith-landform models are interpreted, appropriate geochemical dispersion models can be sought from orientation studies, the research literature, or from a company's past experience. Such models can be used predictively, obviating some of the need for repeating comprehensive orientation studies.

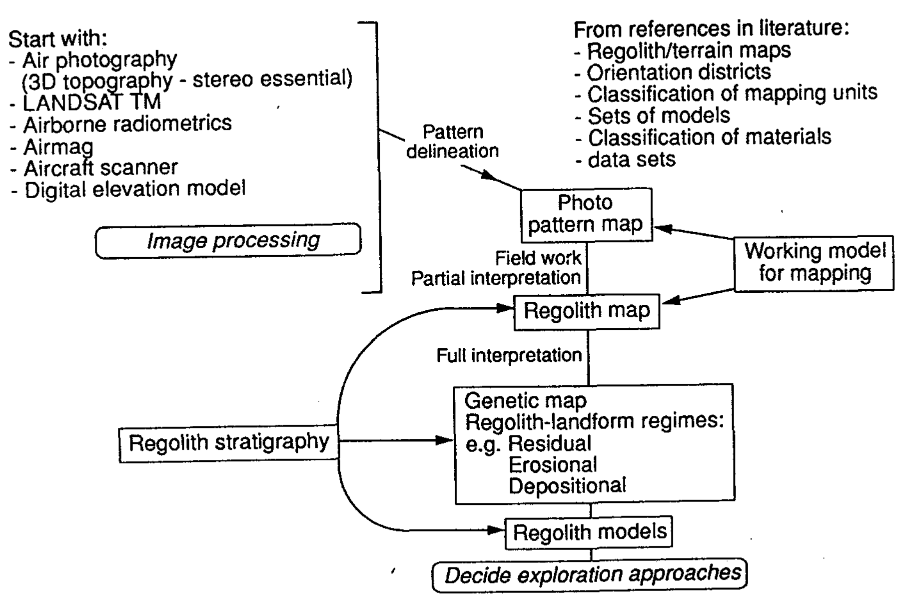


Figure 5. General flow chart for detailed regolith mapping.

4.2.1 *Regolith-landform mapping*

Regolith-landform mapping is essentially an integrated approach to mapping whereby the terrain as a whole is studied. This approach enables identification of mapping units based upon discrete associations of landform, geology, regolith materials, and vegetation. It places more emphasis on the landforms and regolith materials together with the relationships between the two than on vegetation and bedrock geology.

The basic mapping unit is one where there is a recurring pattern of landform, bedrock, regolith materials, and vegetation. The recurring pattern is used as a basis for extrapolating site data since commonly only isolated occurrences of any one regolith landform unit will be sampled.

Such integrated surveys assume that many land characteristics are inter-dependent and tend to occur in associations, and that attributes observable on air-photos, such as landform and vegetation, can be used to predict the distribution of regolith material attributes which are observed at selected sites and traverses in the field.

An area may be mapped by delineating regolith-landform units based upon field traverses and inspection and interpretation of aerial photographs. This media can be supplemented by scanner imagery, airborne radiometric surveys (where available), and satellite imagery such as LANDSAT TM. An essential feature of regolith-landform mapping is the concurrent development of three-dimensional regolith-landform models. These models reflect the current understanding of the distribution of regolith materials, and through their predictive qualities can lead to an efficient mapping programme.

Air-photo image patterns generally form the basis of regolith-landform mapping. They are largely related to the interactions of landform, bedrock, surficial geology, soil, and vegetation. *Regolith-landform mapping units* may consist of multiples or subdivisions of airphoto patterns. The interpretation of these patterns leads to establishing regolith landform mapping units. A specific array of regolith materials can be related to particular landforms so that the recognition of the landforms is an essential part of regolith-landform mapping. This process is very similar to the toposequence concept used in soils mapping. The scale of airphotos or other imagery will influence the choice and definitions of regolith-landform units because of the practicalities of representing heterogeneous assemblages at those scales. The more detailed the scale becomes, the more the mapping units become regolith material rather than landform-based.

4.2.2 Establishing regolith stratigraphy

Air-photo patterns alone are generally insufficient to provide adequate knowledge of the regolith stratigraphy of an area. This must be established by detailed studies at strategically chosen sites from drilling, road cuttings, costeans, or mine pits. This information enables an understanding of local regolith stratigraphy, evolution of weathering profile, and regolith facies relationships to be established which can be presented as a series of regolith cross sections. Such presentations must be geomorphically valid.

4.2.3 Genetic regolith maps

As discussed above, it can be useful for geochemical purposes to interpret lateritic landscapes in terms of residual, erosional, and depositional regimes where the focus is on evidence of preservation versus truncation of the lateritic residuum (Fig. 6). These interpretative regimes are broader terms than regolith-landform units described earlier. In the weathered terrains of the Yilgarn, regolith-landform units can be grouped together into three major geomorphic regimes, but this is not always appropriate.

4.2.4 Regolith-landform models

Regolith-landform models are conceptual devices developed to represent regolith-landform relationships. They seek to have a predictive capability and often point to clear genetic interpretations. Regolith-landform models are commonly presented as cross sections and block diagrams. These diagrams show (a) the main regolith-landform regimes (sometimes subdivided into regolith-landform mapping units), (b) the main units of the regolith stratigraphy, and (c) bedrock lithologies where known. The vertical scale is

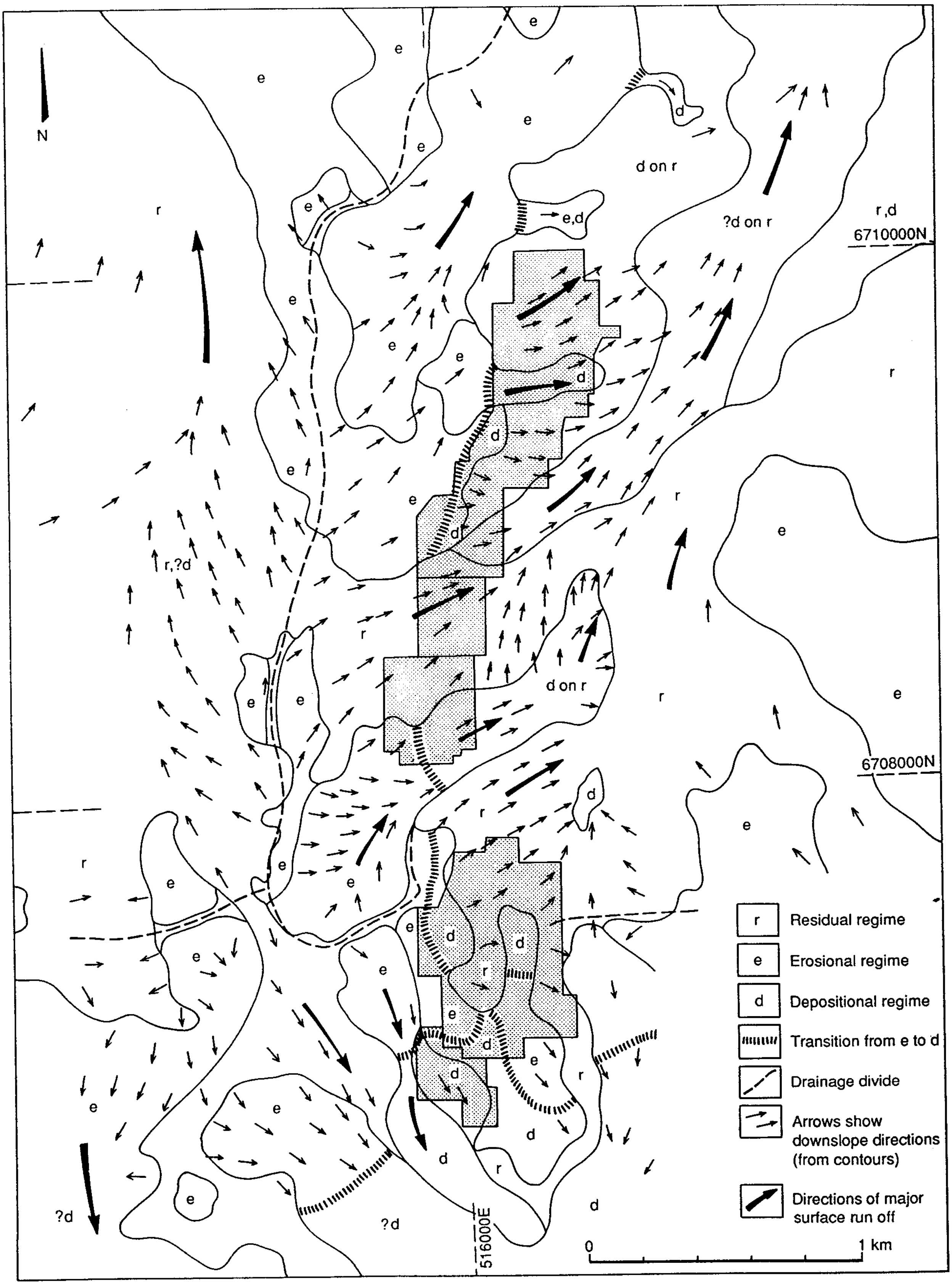


Figure 6. Genetic map of the Mt. Gibson detailed orientation area showing regolith-landform regimes and a synthesis of regolith-landform dynamics (after Anand *et al.*, March 1989).

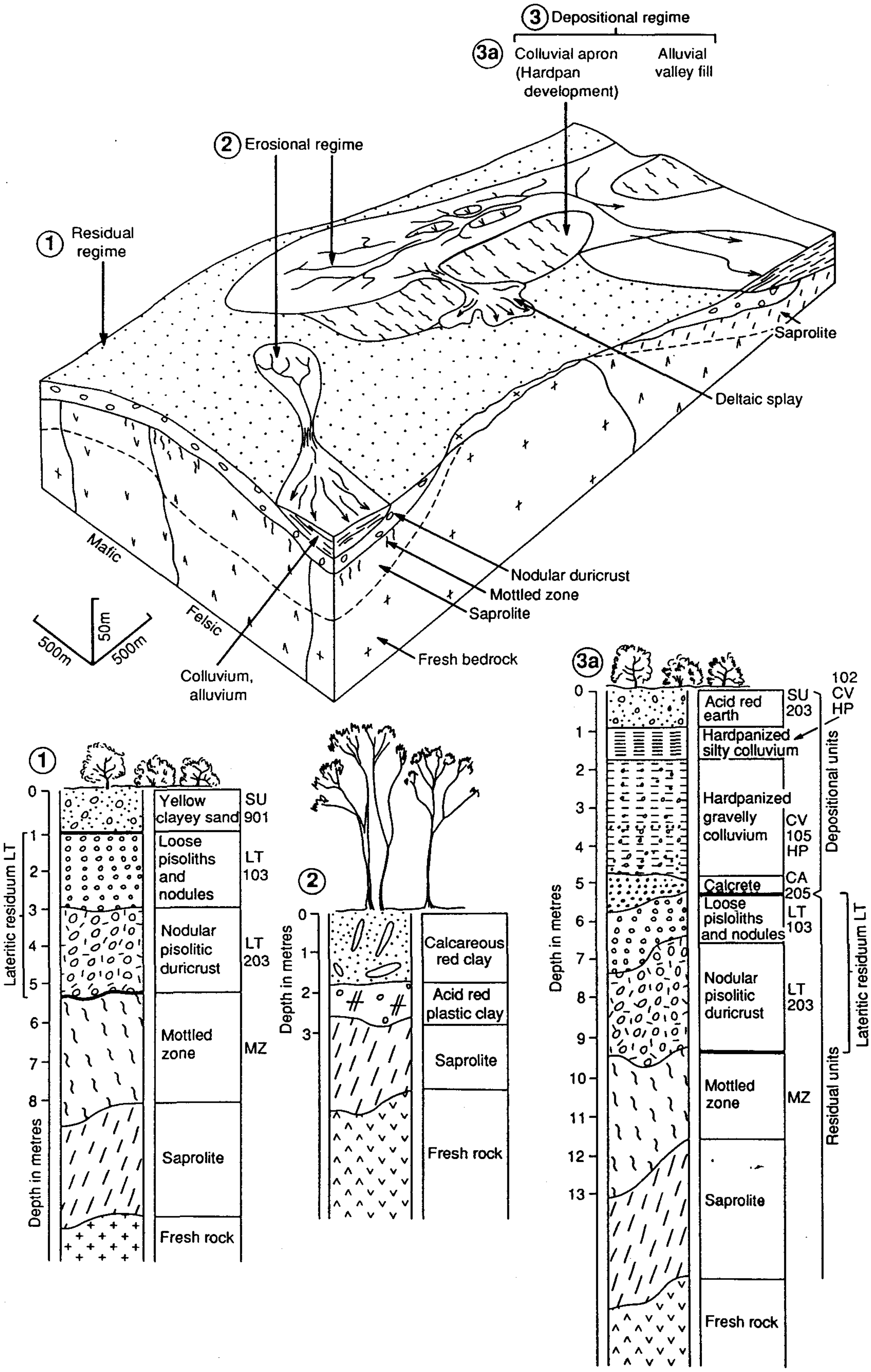


Figure 7. Regolith-landform model for the Mt. Gibson orientation area, columns show units of the regolith stratigraphy with classification codes for selected regolith materials (modified from Anand *et al.*, March 1989).

usually exaggerated to show units of the regolith stratigraphy. It is useful to show individual regolith profiles linked with different regolith-landform interpretative regimes on a diagram, in effect expanding the vertical scale to show details of the regolith stratigraphy (Fig. 7). By adding information about geochemical dispersion processes and patterns, regolith-landform diagrams become conceptual geochemical dispersion models.

5.0 THE FIRST STEPS TOWARDS INTEGRATING REGOLITH NOMENCLATURE

5.1 Introduction

At an in-house meeting held at the Geological Survey of Western Australia on 13 December, 1991 part of the discussions centred on the need to develop a scale-independent classification and terminology scheme for regolith landform mapping units to facilitate correlation, comparison, and contrasts across the Yilgarn Craton. The following text is based upon an internal draft document (Gozzard, 1992) which resulted from the distillation of various comment documents exchanged between members of the working group.

Two related points were discussed:

1. The need for an integrated hierarchy of codes to be used for map symbology, regolith types, materials, and landform classification; and

2. The need to compare and contrast the current AGSO, GSWA, and CSIRO systems for both mapping units and regolith materials, and to recommend improvements to those systems.

The establishment of an agreed classification scheme for types of regolith materials, landform types, and induration underpins the whole approach to regolith-landform mapping.

5.2 Rationale of any scheme

In order to study a complex and variable entity, such as terrain, some form of classification, rather than separate descriptions of each terrain component, is essential. Such an approach allows a measure of generalization about the terrain characteristics. That is, those properties which are directly observable and measurable can be identified and described, and similarities can be grouped according to common attributes.

In establishing any scheme for regolith-landform mapping in areas of lateritic terrain, it is important to consider, among others, the following points:

1. preservation versus removal of lateritic residuum;
2. preservation versus removal of the saprolite profile and the degree of truncation;
3. domination by fresh bedrock, that is, completely stripped areas; and
4. presence of substantial depositional units such as transported overburden and chemically-precipitated sediments.

It is thus important to be able to consider the ease with which the following boundaries could be shown and maintained at different scales of mapping:

5. the base of the lateritic residuum (where present);
6. the boundary between the fresh and weathered bedrock; and
7. the base of substantial sheets of depositional material.

5.3 Inconsistencies between approaches

At present there are various inconsistencies between AGSO, GSWA, and CSIRO mapping programmes which slow the effective synthesis and interchange of regolith landform mapping information. In summary these are:

1. contentious terminology;
2. collection of field data to different levels of detail, sometimes in an *ad hoc* manner;
3. computer database storage of information about regolith materials and landform data, if available, are in different formats;
4. different amounts and types of data collection; and
5. regolith-landform units are named often in an inconsistent manner.

5.4 Regolith materials

Each of the following schemes was created independently and focused on different levels of classification. The task now of integration is more one of joining the schemes together and removing any duplication rather than simply accepting one scheme over another.

5.4.1 AGSO terminology

Appendix I lists the types of regolith materials currently recognized by AGSO (Pain *et al.*, 1991). An hierarchical approach was adopted when constructing the list of regolith terms. A five character alpha-numeric code is used. The list, while extensive, is not exhaustive and has merit at the regional scale to which it is applied, namely compilation at 1:100 000 with presentation at 1:250 000.

5.4.2 GSWA terminology

Appendix II lists the lithology/material terminology currently used by the GSWA. In this system, an attempt has been made to describe the loose, unconsolidated deposits, which rarely comprise one grain size, by using, where appropriate, compound terms, for example, clayey sand, sandy gravel, silty sandy clay. This is in addition to the description of the more consolidated materials. Each lithology/material is then qualified by reference to Appendix III. This system also has merit at its scale of application (1:50 000 to 1:100 000) in all areas studied to date.

5.4.3 CSIRO terminology

The classification scheme for regolith materials used by CSIRO (Anand *et al.*, August 1989) is an hierarchical approach using three levels. The broad-terms (Level 1) refer to the main zones or units of the regolith stratigraphy. Each broad term is subdivided, commonly with intermediate terms (Level 2), and detail terms (Level 3) being provided at the mesoscopic scale (hand specimen to outcrop scale). The detail terms have been designed to apply to the working level of field sampling. Hierarchical mnemonic alpha-numeric codes are provided for the designated terms. Amongst the prime purposes of the coding are data storage and manipulation. Units of the regolith stratigraphy can be grouped using the interpretative categories of residual, erosional, and depositional regimes (Section 3.4, referred to as the RED scheme in this paper).

This system works at the tested local and district scales. However, the scheme has not been extended to include all regolith units nor all types of regolith materials encountered in the Yilgarn.

5.4.4 Discussions and conclusions on integrated nomenclature

It is apparent that none of the currently-used schemes alone can adequately be used to cover all types of regolith materials encountered in the Yilgarn or address all the scales which may be required. Certainly, there is considerable overlap of terms. It can be expected that between the three organizations a viable alternative scheme, which suits the needs of all can be established. However, the CSIRO scheme is of particular value to the exploration industry, especially in relation to exploration geochemistry, and is worthy of consideration as the basis for extension and modification from the detailed materials end of the spectrum.

It would appear that loose, unconsolidated sedimentary, or individual weathered materials have not been the area of focus by AGSO. In terms of Yilgarn-related regolith, the categories of coastal, lacustrine, marine and volcanic materials so far have not been considered in the proposal herein, but AGSO rightly must address the wider context, certainly beyond the Yilgarn.

Both the GSWA and CSIRO schemes attempt to describe the regolith materials. This undoubtedly is a function of the larger scale (more detailed) mapping methods of these two organizations and their user needs.

5.4.5 Proposal

One proposal is that the current CSIRO scheme (Anand *et al.*, August 1989) be modified and extended to cover the range of materials encountered in the Yilgarn in such a way that it may be integrated, in the future, with a revised AGSO regional scheme. Tables 1A to K show this proposal. As presented, the CSIRO scheme is not exhaustive, but allows for extension as further materials are encountered.

The interpretative 'RED regime' approach of CSIRO has significant practical benefits for exploration when used in lateritic environments of the Yilgarn. It is therefore proposed that the regime approach of CSIRO be adopted as a useful interpretative option which may appear on detailed material-level interpretative regolith maps of the Yilgarn.

5.5 Landform types

5.5.1 AGSO classification and terminology

Appendix IV lists the landform types currently in use by AGSO (Pain *et al.*, 1991). Landforms are generally grouped hierarchically on the basis of genesis. The original source document is the *Australian Soil and Land Survey Field Handbook* (McDonald *et al.*, 1990). Some additions have been made to the list of landform patterns and they have been arranged in an hierarchical fashion.

5.5.2 GSWA classification and terminology

The landform types currently in use by the GSWA comprise two levels: landform, and landform element. Landform elements are components of landforms. Certain kinds of landform elements are typical of a given type of landform. Other elements are found commonly and others occasionally in a given landform type. These two levels are equated with the landform pattern and landform element of McDonald *et al.* (1990) with a number of additions to both categories based upon field experience.

5.5.3 CSIRO classification and terminology

For the Yilgarn regolith research, CSIRO currently do not have a structured terminology for landform type in use. However, discussions (R Anand) indicated that, *de facto*, they tend to use the landform pattern and landform element terminology of McDonald *et al.* (1990) with additions based on field experience. These are then grouped according to the RED regime approach.

5.5.4 Discussion and conclusions on landform types

All three organizations are using the terminology of McDonald *et al.* (1990) to describe landform types as part of their regular mapping projects. However, in all cases it has been found that this system has needed extension and modification in the light of field experience.

In some instances, this also has meant that some landform types are only used by AGSO, for example, since the GSWA and CSIRO (for this research activity) have, to date, worked only in Yilgarn environments. Coastal, karstic, meteoritic, and volcanic landform terms have been omitted from their schemes because such landforms have not been identified in these environments.

AGSO did not need to go to a lower, second level of terms (landform element), because of the regional-scale nature of their mapping responsibilities. In contrast, because the GSWA and CSIRO are mapping at detailed scales, they have a need to identify constituent elements of landforms, hence the use of the two level approach at the more detailed materials end of the mapping spectrum.

The interpretative terrain units (below) shown on the AGSO Kalgoorlie 1:1 Million Regolith Terrain Map (Chan, 1992) and the interpretative RED regimes of CSIRO attempt to fulfil the requirements of Section 5.2. However, the two schemes are not fully equivalent. In brief:

Bedrock dominated (BD) is equivalent to Erosional (E);
Sediment dominated (SD) is equivalent to Depositional (D); but
Deep weathering dominated (DW) is equivalent to Residual (R) plus some Erosional (E).

This may not be a contentious issue as both are interpretative, not compulsory, so there is no need to decide one above the other. AGSO is moving to the view that terrain units may be better used as interpretative regolith super-groups on 1:1 million scale regional summary maps.

5.5.5 *Proposal*

In an attempt to fulfil the requirements of all three organizations, one proposal is that a two level system of landform terms be adopted. Level 1 terms are broadly similar to the landform pattern terms of McDonald *et al.* (1990) being used by all three organizations, with modifications and extensions. Level 2 terms are broadly those of the landform element terms of McDonald *et al.* (1990) being used by the GSWA and CSIRO, with modifications and extensions.

Table 2 lists the proposed Level 1 landform pattern terms. Table 3 lists the proposed Level 2 landform element terms.

An earlier proposal, in Section 5.4.5, is that the interpretative RED regime approach to landform and materials classification be adopted. A consequence would be that the landform patterns listed in Table 2 would necessarily show some duplication. This is unavoidable if continued use of the interpretative RED regime approach at a high (broad) level of classification is maintained.

5.6 Induration

Discussions are underway to examine the characteristics of each agency's approach to induration and its application to regolith materials.

6.0 OUTLOOK - A PROCESS OF INTEGRATION

The process of integration, discussed above, requires some care. Peer review will be a vital part of attempting to create a set of nationally-accepted guidelines for regolith mapping, classification, and terminology of both regolith-landform mapping units and regolith materials. The systems from which each group originally developed its own mapping and classification ideas took many years to develop. Despite our desire to reduce that time, an integrated scheme will continue to evolve once initiated. There will be resistance to using a scheme that is cumbersome, poorly thought out, or one that has not undergone general critical comment.

Steps have already been made towards defining how the schemes discussed above can be integrated. The critical *major steps* now undertaken are:

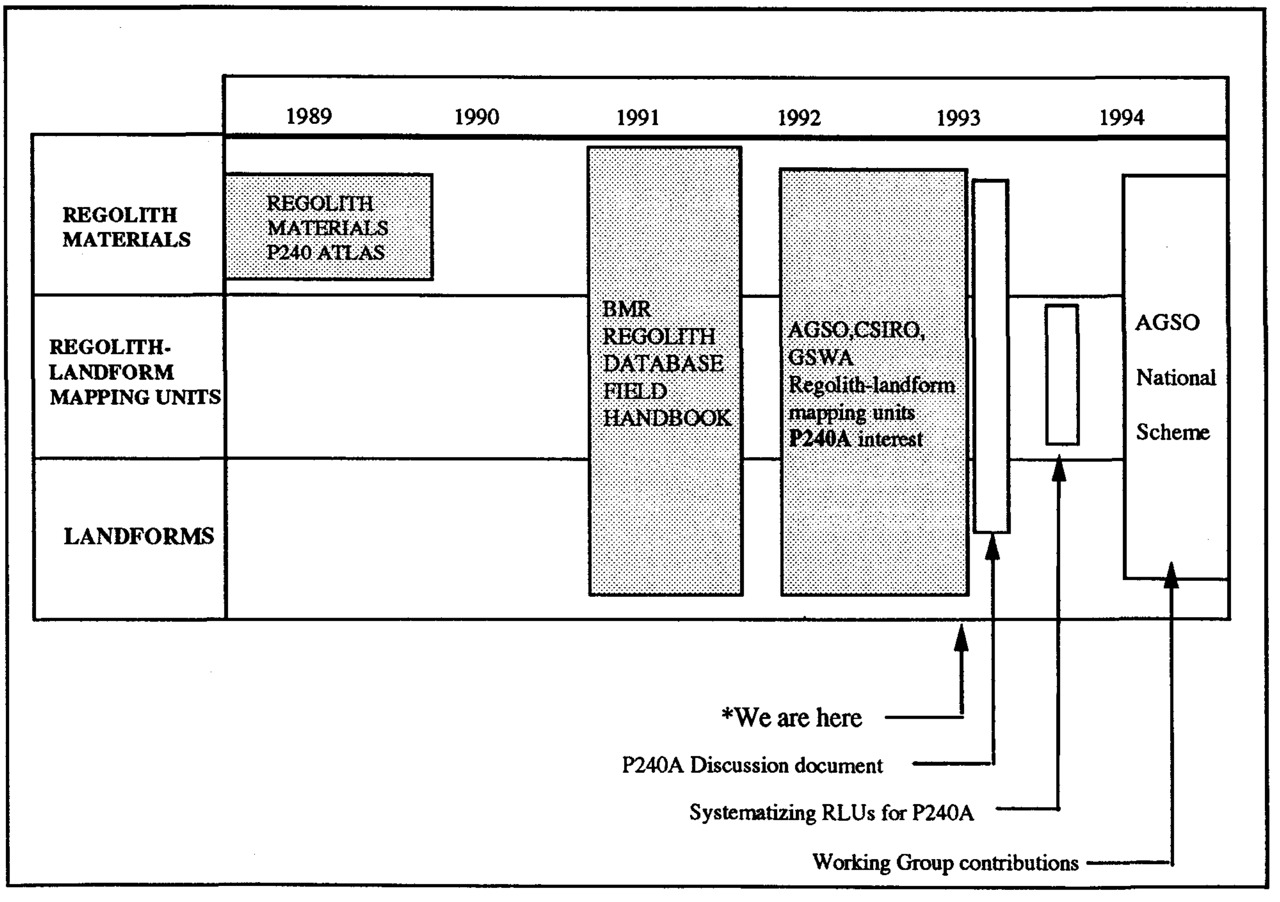
1. a statement of what these schemes are all about has been prepared;

2. a set of hierarchical charts which clearly demonstrate the internal relationships within each group's regolith materials and landform types terminology have been drafted.

The third step, about to be taken, is the cut and paste of the schemes.

Members of the working group have set an internal target of June 1993 to have a workable first draft of integrated terminology for both landforms and regolith terminology prepared for P240A. Thereafter, wider peer review and evaluation of the first draft would be appropriate. Of relevance to P240A is the focus of an internationally co-ordinated group concerned with the classification of laterites. The integration of Yilgarn-focused classification schemes into a regional framework will be of concern to that group. The group is known as **CORLAT**. CORLAT is a mnemonic derived from **co**llection of **r**eference **lat**erite profiles.

An overview of the early development of the agency schemes and the timetable of the envisaged steps towards integration may be summarized by the following time chart:



7.0 CONCLUSIONS

1. Regolith Materials

- A national scheme can and should be set up, but its time frame will extend beyond the requirements of this current AMIRA project P240A.
- The precise integration mechanisms are the next step to be decided in such a process.
- Integration requires that we acknowledge that each of the present schemes has been directed towards specific scale requirements.
- Each scheme needs to be modified and/or extended in some way to allow the integration. The CSIRO scheme can provide the most suitable basis for integration from the detailed end of the materials spectrum, the AGSO scheme better addresses the regional overview at the other end and the GSWA suitably addresses the middle ground. The integration process needs to proceed using the strengths of these existing schemes.
- Peer review will be required as the scheme moves beyond the specific needs of P240A.

2. Regolith-Landform Mapping

- The three agency are using the same philosophy.
- Individual presentation varies with scale.
- Classification, encoding, and symbology require further work, but the needs of P240A can be addressed by the release of a working document by the end of June 1993.

3. Landform terminology

- Published guides have formed the basis of terminology already used by AGSO and to some extent by GSWA and CSIRO.
- Hierarchical organization and coding needs to be assessed and modified where appropriate.

4. General

- The longer term aim is to link schemes for 1, 2, and 3 (above) in order to provide a fully-integrated approach to regolith studies which would be applicable not only for the Yilgarn Craton, but also for Australia in general. This requires a time frame beyond project P240A, and additionally, a period of open peer review.

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CLASSIFICATION TABLES

AS	*AEOLIAN SEDIMENTS*
AV	ALLUVIUM
CA	CALCRETE, CARBONATES
-CF	suffix, CALCIFICATION
CV	COLLUVIUM
EV	*EVAPORITES*
-HP	suffix, HARDPANIZATION
IS	IRON SEGREGATIONS
LG	LAGS
LT	LATERITIC RESIDUUM
MC	MISCELLANEOUS
MZ	MOTTLED ZONE
SD	SOILS, DIFFERENTIATED
-SF	suffix, SILICIFICATION
SP	*SAPROLITE*
SR	*SAPROCK*
SU	SOILS, UNDIFFERENTIATED

Explanation

The pages of classification tables flow alphabetically based upon the code at the top right hand side of each major classification entry.

For each entry, the hierarchy goes from the broadest term on the left to the narrowest terms on the right. For many major classification entries, intermediate levels of hierarchy are used. The top of each intermediate term is aligned with the top of the list of its narrower terms.

Table 1A. A proposed regolith materials terminology. Proposed new terms are shown in italics, terms and codes from the existing CSIRO P240 scheme (Anand *et al.*, August 1989) are in Roman.

AS

AEOLIAN SEDIMENTS

AS AEOLIAN SEDIMENTS	*Aeolian sand*	*Alpha-numeric codes not given*
	Loess	
	Parna	

AV

ALLUVIUM

AV ALLUVIUM	AV100 Alluvial clays	AV101 alluvial clay AV102 alluvial silty clay AV103 alluvial sandy clay
	AV200 Alluvial sands	AV201 alluvial clayey sand AV202 alluvial silty sand AV203 alluvial sand AV204 alluvial gravelly sand
	AV300 Alluvial gravels	AV303 alluvial sandy gravel AV304 alluvial oligomictic gravel AV305 alluvial polymictic gravel AV306 alluvial boulder beds
		AV333 alluvial pisolitic/nodular lateritic gravel AV334 alluvial lateritic gravel (general)

Table 1B. A proposed regolith materials terminology. Proposed new terms are shown in italics, terms and codes from the existing CSIRO P240 scheme (Anand *et al.*, August 1989) are in Roman.

CA

CALCRETE, CARBONATES

	CA100 Soft carbonates	CA101 powdery carbonates
CA CALCRETE, CARBONATES	CA200 Calcretes	CA202 pisolitic calcrete
		CA204 nodular calcrete
		CA205 calcrete pods
		CA207 calcrete sheets in hardpan
		CA241 laminated calcrete

-CF

suffix
CALCIFICATION

Calcification is an authigenic process which can act upon colluvium, soils, and lateritic gravels in particular.

Please refer to codes for each material which is being calcified and add CF as a suffix.

Examples:
LT102CF is a calcified loose pisolitic lateritic gravel.

Table 1C. A proposed regolith materials terminology. Proposed new terms are shown in italics, terms and codes from the existing CSIRO P240 scheme (Anand *et al.*, August 1989) are in Roman.

CV

COLLUVIUM

CV COLLUVIUM	CV100 Colluvial clays	CV101	colluvial clay
		CV102	colluvial silty clay
		CV103	colluvial sandy clay
		CV104	colluvial gravelly clay
		CV105	colluvial gravelly silty clay
		CV106	colluvial gravelly sandy clay
	CV200 Colluvial sands	CV201	colluvial clayey sand
		CV203	colluvial sand
		CV204	colluvial gravelly sand
	CV300 Colluvial gravels	CV303	colluvial sandy gravel
		CV304	colluvial oligomictic gravel
		CV305	colluvial polymictic gravel
		CV306	colluvial boulder beds
		CV333	colluvial pisolitic/nodular lateritic gravel
		CV334	colluvial lateritic gravel (general)
		CV335	colluvial lateritic rubble

EV

EVAPORITES

EV EVAPORITES	*Soft evaporites*	*anhydrite*	*Alpha-numeric codes not given*
		halite	
		gypsum	
	Indurated evaporites	*gypcrete*	

Table 1D. A proposed regolith materials terminology. Proposed new terms are shown in italics, terms and codes from the existing CSIRO P240 scheme (Anand *et al.*, August 1989) are in Roman.

-HP

suffix
HARDPANIZATION

Hardpanization is an authigenic process that affects most categories of regolith materials.

Please refer to codes for each material and add HP as a suffix.

Examples:

LT202HP is a hardpanized pisolitic duricrust.
CV106HP is a hardpanized colluvial gravelly sandy clay.
CV333HP is a hardpanized colluvial pisolitic/nodular lateritic gravel.
or, in shortened form, hardpanized colluvial lateritic gravel.

IS

OTHER FORMS OF IRON SEGREGATIONS

IS IRON SEGREGATIONS	IS101	vesicular goethite pods
	IS102	discordant goethite bodies
	IS103	stratabound goethite bodies
	IS111	goethite selvages to quartz veins
	IS201	stratabound hematite layers
	IS301	pervasively hematized saprolite

Table 1E. A proposed regolith materials terminology. Proposed new terms are shown in italics, terms and codes from the existing CSIRO P240 scheme (Anand *et al.*, August 1989) are in Roman.

LG

LAGS
(at surface)

LG LAGS	LG100 Lateritic lag	LG101	ooliths*
		LG102	pisoliths*
		LG103	pisoliths and nodules*
		LG104	nodules*
		LG105	hardened mottles
	LG200 Lag, other	LG201	ferruginous granules
		LG203	ferruginous pebbles
		LG206	ferruginous cobbles
		LG207	ferruginous boulders
		LG221	lithic fragments
		LG222	ferruginized rock fragments
		LG261	gossan fragments

* If abundant, use Lateritic gravels LT101 to LT104.

Table 1F. A proposed regolith materials terminology. Proposed new terms are shown in italics, terms and codes from the existing CSIRO P240 scheme (Anand *et al.*, August 1989) are in Roman.

LT

LATERITIC RESIDUUM

LT LATERITIC RESIDUUM	LT100 Lateritic gravel	LT101	loose ooliths
		LT102	loose pisoliths
		LT103	loose pisoliths and nodules
		LT104	loose nodules
	LT200 Lateritic duricrust	LT201	oolitic duricrust
		LT202	pisolitic duricrust
		LT203	pisolitic-nodular duricrust
		LT204	nodular duricrust
		LT205	fragmental duricrust
		LT211	packed oolitic duricrust
		LT212	packed pisolitic duricrust
		LT213	packed pisolitic-nodular duricrust
		LT214	packed nodular duricrust
		LT228	Fe-rich pebbly duricrust
		LT229	Fe-rich massive duricrust
		LT231	vermiform duricrust
		LT232	cellular duricrust
		LT241	mottled duricrust
		LT242	massive duricrust

Table 1G. A proposed regolith materials terminology. Proposed new terms are shown in italics, terms and codes from the existing CSIRO P240 scheme (Anand *et al.*, August 1989) are in Roman.

MC

MISCELLANEOUS

MC MISCELLANEOUS		MC101 ferruginous granules in soil
		MC201 bog iron

MZ

MOTTLED ZONE

MZ MOTTLED ZONE	MZ100 Fe-rich mottles	MZ102 pisolitic mottles
		MZ104 nodular mottles
		MZ105 fragmental mottles
		MZ142 Fe-rich septa

Table 1H. A proposed regolith materials terminology. Proposed new terms are shown in italics, terms and codes from the existing CSIRO P240 scheme (Anand *et al.*, August 1989) are in Roman.

SD

SOILS, DIFFERENTIATED
(see also SU SOILS UNDIFFERENTIATED)

SD SOILS, DIFFERENTIATED	SD100 Lateritic podzolic soils	SD101	yellow podzolic soil
		SD102	red podzolic soil
	SD200 Podzolic soils	SD203	grey sands
		SD202	non-calcic brown soils
		SD203	red-brown earths

-SF

suffix
SILICIFICATION

Silicification is an authigenic process that affects several categories of materials. Please refer to the codes for the material that has been silicified and add SF as a suffix.

Example:
LT204SF is a silicified nodular duricrust

Table 1I. A proposed regolith materials terminology. Proposed new terms are shown in italics, terms and codes from the existing CSIRO P240 scheme (Anand *et al.*, August 1989) are in Roman.

SP

SAPROLITE

Subdivisions not established

SR

SAPROCK

Subdivisions not established

Table 1J. A proposed regolith materials terminology. Proposed new terms are shown in italics, terms and codes from the existing CSIRO P240 scheme (Anand *et al.*, August 1989) are in Roman.

SU

SOILS, UNDIFFERENTIATED

(see also SD SOILS DIFFERENTIATED)

SU SOILS, UNDIFFERENTIATED	SU100 Ironstone gravel soils	SU101 gravelly yellow sands SU102 yellow-brown sandy gravel
	SU200 Sesquioxide soils	SU201 yellow earth SU202 orange earth SU203 red earth
	SU300 Calcareous soils	SU301 grey-brown calcareous soil SU302 red calcareous soil
	SU400 Saline soils	SU401 sodic brown soil SU402 saline calcareous earth
	SU500 Cracking clays	SU501 black earth
	SU600 Stony soils	SU601 lithosol
	SU900 Other soils	SU901 yellow clayey sands

Table 1K. A proposed regolith materials terminology. Proposed new terms are shown in italics, terms and codes from the existing CSIRO P240 scheme (Anand *et al.*, August 1989) are in Roman.

ALLUVIAL

- Alluvial plain
  - floodplain
  - anastomotic plain
  - bar plain
  - covered plain
  - meander bar
  - stagnant alluvial plain
- Fan
- Delta
- Alluvial terrace
  - terraced land
  - terrace

COLLUVIAL

- Outwash plain
  - valley side colluvium
  - valley floor colluvium
- Fan
- Sheet flood fan

DUNAL

- Dunefield
- Sand sheet
- Parabolic dune
- Longitudinal dune
- Nested parabolic dune
- Seif dune

EROSIONAL

- Erosional plain
  - pediment
  - pediplain
  - peneplain
  - etchplain
- Plateau
- Rises
- Low hills
- Hills
- Mountains
- Badlands
- Escarpment
- Breakaway
- Drainage depression (sump)

RESIDUAL/STABLE

- Rises
- Low hills
- Hills
- Escarpment
- Breakaway
- Pediplain

PLAIN

- Depositional plain
- Pediplain
- Lacustrine plain
- Playa plain
  - Sand plain

MISCELLANEOUS

- Made ground

Table 2. Proposed landform pattern terminology

Table 3. Proposed landform element terminology.

LANDFORM

Karst	KAR
Badlands	BAD
Mountains	MOU
Hills	HIL
Escarpment	ESC
Low hills	LOW
Plateau	PLT
Rises	RIS
Plain	PLA
Peneplain	PNP
Pediplain	PEP
Sandplain	SAN
Sheet-flood plain	SHF
Alluvial fan	ALF
Alluvial plain	ALP
Terrace	TER
Stagnant alluvial plain	STA
Floodplain	FLO
Anastomotic plain	ANA
Covered plain	COV
Meander bar	MEA
Bar plain	BAR
Delta	DEL
Dunefield	DUN
Playa plain	PLY
Parabolic dunefield	PAR
Londitudinal dunefield	LON
Beachridge plain	BEA
Chenier plain	CHE
Coral reef	COR
Marine plain	MAR
Tidal flat	TID
Colluvial fan	COV
Etchplain	ETP
Terraced land	TEL
Made ground	MAD

LANDFORM ELEMENT

Crest

Hillcrest	HCR
Summit surface	SUS
Dunecrest	DUC
Mesa surface	MES

Slope

Hillslope	HSL
Simple slope	SSL
Upper slope	USL
Mid-slope	MSL
Lower slpoe	LSL
Bench	BEN
Berm	BER
Scarp	SCA
Scarp foot slope	SFS
Landslide	LDS
Talus	TAL
Footslope	FOO
Bank	BAN
Cliff	CLI
Cliff-foot slope	CFS
Beach	BEA
Cutface	CUT
Embankment	EMB
Breakaway	BRE

Flat

Pediment	PED
Fan	FAN
Valley flat	VLF
Flood-out	FLO
Rock flat	RFL
Fill-top	FIL
Rock platform	RPL
Plain	PLA
Backplain	BKP
Channel bench	CBE
Cut-over surface	COS
Tidal flat	TDF
Supratidal flat	STF
Intertidal flat	ITF
Reef flat	REF
Fill-top	FIL
Rock platform	RPL
Scald	SCD
Sandsheet	SDS

Open depression

Alcove	ALC
Drainage depression	DDE
Stream channel	STC
Estuary	EST
Swale	SWL
Gully	GUL
Stream bed	STB
Tidal creek	TDC
Trench	TRE
Swamp	SWP
Tidal creek	EST
Gilgai	GIL

Closed depression

Lake	LAK
Playa	PLY
Swamp	SWP
Pit	PIT
Playa edge	PLE
Clay pan	CLP
Doline	DOL
Oxbow	OXB
Blowout	BOU
Lagoon	LAG

Hillock

Tor	TOR
Dune	DUN
Mound	MOU

Ridge

Levee	LEV
Scroll	SCR
Bar	BAR
Prior stream	PST
Dune	DUN
Embankment	EMB
Dam	DAM
Ridge	RID
Lunette	LUN
Playa border dune	PLB
Kopi dune	KOP
Sand sheet	SDS
Beachridge	BRI

Appendix I Description of AGSO regolith type codes (including induration codes)

WMU00	weathered material (unknown origin)
WIR00	in situ weathered rocks
WIR10	deep weathered regolith
WIR11	saprolite
WIR12	structured saprolite
WIR13	mottled zone
WIR14	pallid zone
WIR20	residual material
WIR21	lag
WIR22	residual sand
WIR23	residual clay
WIR24	soil on bedrock
WIS00	shallow soil on fresh bedrock
UOS00	sand (unknown origin)
UOC00	clay (unknown origin)
SDT00	terrestrial sediments
SDA00	alluvial sediments
SDA10	channel deposits
SDA20	overbank deposits
SDC00	colluvial sediments
SDC01	scree
SDC02	landslide deposit
SDC03	mudflow deposit
SDC04	creep deposit
SDC05	sheet flow deposit
SDE00	aeolian sediment
SDE01	aeolian sand
SDE02	loess
SDE03	parna
SDS00	coastal sediments
SDS01	beach sediments
SDS02	estuarine sediments
SDL00	lacustrine sediments
SDM00	marine sediment
SDG00	glacial sediments
SDF00	fill
VOL00	volcanic material
VOL01	lava flow
VOL02	ash
EVA00	evaporite
EVA01	halite
EVA02	gypsum

IND00	indurated material
IND10	bauxitic induration
IND20	calcareous induration
IND30	clay induration
IND40	ferruginous induration
IND50	gypsiferous induration
IND60	siliceous induration
IND70	humic induration

Appendix I (cont.) Description of AGSO regolith type codes (including induration codes)

IDU00	duricrust
IDS00	completely cemented duricrust (crete)
IDS10	alcrete (bauxite)
IDS20	calcrete
IDS40	ferricrete
IDS41	massive ferricrete
IDS42	nodular ferricrete
IDS50	gypcrete
IDS60	silcrete
IDM00	moderately cemented duricrust
IDM20	calcareous duricrust
IDM40	ferruginous duricrust
IDM60	siliceous duricrust
IDP00	partially cemented duricrust (hardpan)
IDP10	bauxitic hardpan
IDP30	clay hardpan
IDP40	ferruginous hardpan
IDP60	siliceous hardpan
IDP70	humic hardpan
INO00	nodules
INO10	bauxitic nodules
INO20	calcareous nodules
INO30	clay nodules
INO40	ferruginous nodules
INO60	siliceous nodules

Appendix II GSWA lithology/material terminology

LITHOLOGY/MATERIAL

Soil

Clay	C
Silt	M
Sand	S
Gravel	G
Cobbles	K
Boulders	B
Rock rubble	R
Organic material	P

Regolith

Saprock	SR
Saprolite	SA
Structures saprolite	SS
Collapsed saprolite	CS
Grus	GS
Mottled zone	MO
Massive lateritic duricrust	ML
Nodular lateritic duricrust	ND
Pisolitic lateritic duricrust	PD
Oolitic lateritic duricrust	OD
Vermiform duricrust	VD
Cellular duricrust	CD
Nodular lateritic gravel	FN
with cutans	FNC
Pisolitic lateritic gravel	FP
with cutans	FPC
Ferruginized bedrock	FB
Laterite	LA
Ferricrete	FC
Ironstone	FS
Iron segregations	IS
Kankar	KA
Calcrete	KC
Powder calcrete	PC
Nodular calcrete	NC
Honeycomb calcrete	HC
Calcareous duricrust	KD
Massive calcrete	MC
Calcareous nodule	KN
Siliceous nodule	SN
Bauxitic nodule	BN
Clay nodule	CN
Ferruginous nodule	IN
Silcrete	SI
Gypcrete	GC
Hardpan	HP
Pallid zone	PL
Alcrete (bauxite)	AC

Chemical deposits

Anhydrite	AN
Banded Iron Formation	BF
Barite	BA
Chert	CH
Evaporite	EV
Halite	HA
Gypsum	GY
Phosphate	PH
Potash	PO
Sulphur	SU

Appendix III GSWA lithology/material qualifier

QUALIFIER

Acidic	AC	Hematitic	HM
Alkaline	AL	Humic	HU
Amorphous	AM	Kaolinitic	KA
Andesitic	AD	Labile	LA
Arenaceous	AR	Lateritic	LT
Argillaceous	AG	Leucocratic	LU
Anhydritic	AN	Lignitic	LI
Anthracitic	AT	Limonitic	LM
Arkosic	AK	Limy	LY
Asphaltic	AS	Lithic	LH
Basaltic	BS	Mafic	MA
Basic	BC	Mesocratic	MS
Bauxitic	BA	Micritic	MC
Bentonitic	BN	Manganiferous	MN
Biohermal	BH	Marly	MY
Biostromal	BI	Melanocratic	ML
Bituminous	BT	Metamorphosed	ME
Calcareous	CC	Micaceous	MI
Cannel	CN	Montmorillonitic	MO
Carbonate	CT	Muddy	MD
Carbonaceous	CB	Oolitic	OO
Chalcedonic	CD	Organic	OR
Chalky	CK	Pebbly	PB
Cherty	CR	Pegmatitic	PG
Chloritic	CL	Phosphatic	PH
Clayey	CY	Phyllitic	PY
Cindered	CI	Pisolithic	PS
Coaly	CA	Porcellaneous	PR
Conglomeratic	CG	Polymictic	PO
Coralline	CO	Pyritic	PY
Crinoidal	CI	Quartzitic	QZ
Crystalline	CX	Quartzose	QT
Dacitic	DA	Rhyolitic	RH
Dolomitic	DM	Rudaceous	RU
Evaporitic	EV	Sandy	SD
Feldspathic	FD	Schistose	SC
Felsic	FS	Shaly	SH
Ferruginous	FE	Shelly	SY
Fossiliferous	FO	Sideritic	SD
Glassy	GS	Siliceous	SI
Glauconitic	GL	Silty	SY
Gneissic	GN	Slaty	SL
Graphitic	GP	Stromatolitic	SR
Gravelly	GR	Stylolitic	ST
Gritty	GT	Sub-labile	SL
Gypsiferous	GY	Torbanitic	TO
Haliferous	HL	Tuffaceous	TF
Hardpanized	HP	Ultramafic	UM

Appendix IV AGSO landform terminology.

DATABASE FIELDS

Landform unit data
There may be many landform units within one Regolith Terrain Unit.
The following fields are completed for each landform unit .

AL00	alluvial landforms
AL10	alluvial plain
AL11	flood plain
AL12	anastomotic plain
AL13	bar plain
AL14	covered plain
AL15	meander plain
AL20	alluvial terrace
AL30	stagnant alluvial plain
AL40	terraced land
AL50	alluvial swamp
CO00	coastal lands
C001	beach ridges
C002	chenier plain
C003	coral reef
C004	marine plain
C005	tidal flat
C006	coastal dunes
DE00	delta
DU00	dune field
DU01	longitudinal dune field
ER00	erosional landforms
ER10	erosional plain(<9m relief)
ER11	pediment
ER12	pediplain
ER13	peneplain
ER14	etchplain
ER20	rises(9-30m relief)
ER30	low hills(30-90m relief)
ER40	hills(90-300m relief)
ER50	mountains(>300m relief)
ER60	escarpment
ER70	badlands
ER80	drainage depression
FA00	fan
FA01	alluvial fan
FA02	colluvial fan/footslope
FA03	sheet-flood fan
KA00	karst
MA00	made land
ME00	meteor crater
PL00	plain
PL01	depositional plain
PL02	lacustrine plain
PL03	playa plain
PL04	sand plain
PT00	plateau
VO00	volcano
VO01	caldera
VO02	cone(volcanic)
VO03	lava plain
VO04	ash plain