CRCLEME
Cooperative Research Centre for Landscape Evolution & Mineral Exploration

CSIRO
EXPLORATION AND MINING

AMIRA
Australian Mineral Industries Research Association Limited ACN 004 448 266

OPEN FILE REPORT SERIES

CRC LEME OPEN FILE REPORTS 1-74 ABSTRACTS, INDEX AND DATABASE

COVERING CSIRO-AMIRA RESEARCH PROJECTS: 'LATERITE GEOCHEMISTRY (P240), 'YILGARN LATERITIC ENVIRONMENTS' (P240A), 'WEATHERING PROCESSES' (P241) AND 'DISPERSION PROCESSES' (P241A)

I.D.M. Robertson

CRC LEME OPEN FILE REPORT 75

June 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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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 75) is a first impression (first printing) and did not form part of the output of the above research projects, hovever it contains abstracts of reports from these research projects.

Copies of this publication can be obtained from:
The Publication Officer, c/- CRC LEME, CSIRO Exploration and Mining, PMB, Wembley, WA 6014, Australia. Information on other publications in this series may be obtained from the above or from http://leme.anu.edu.au/
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PREFACE

This report presents an index of the 74 reports written for the four CSIRO-AMIRA research projects 'Laterite geochemistry for detecting concealed mineral deposits' (P240), 'Geochemical exploration in complex lateritic environments of the Yilgarn Craton, Western Australia' (P240A), 'Gold and associated elements in the regolith - weathering processes and implications for explorations' (P241) and 'Gold and associated elements in the regolith - dispersion processes and implications for exploration' (P241A). The index and its contained database have been assembled to complement the re-issue of the reports in the LEME Open File Report series and to provide easy access to the large volume of information contained within them. It is hoped that this index will maximise the usefulness of these reports.

C.R.M. Butt
R.E. Smith
R.R. Anand

Project Leaders

May, 1999

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INTRODUCTION

This index covers 74 CRC LEME Open File Reports originally issued by the following CSIRO-AMIRA research projects :-

P240	*Laterite geochemistry* for detecting concealed mineral deposits.
P240A	Geochemical exploration in *Yilgarn lateritic environments* of the Yilgarn Craton, Western Australia.
P241	Gold and associated elements in the regolith - *Weathering processes* and implications for exploration.
P241A	Gold and associated elements in the regolith - *Dispersion processes* and implications for exploration.

Short titles of the research projects are given in italics.

This index volume provides a comprehensive searchable guide to these reports. In addition, the data supplied on magnetic disc with individual reports has been recompiled on CD because of the limited life of magnetic media.

HISTORY

Issues addressed

Most gold production in Western Australia had come from Archaean terrains and most initial discoveries were made by conventional means and by locating extensions to known mineralisation. As the reserves of known deposits became depleted, attention was directed to the extensive areas occupied by deep lateritic weathering and areas covered by continental sediments, where conventional prospecting methods (use of the geology, geochemistry and geophysics of the time) were much less successful. Rocks were difficult to identify where deeply weathered and lateritised, geochemical anomalies were subtle and confusing and the application of electrical geophysical methods was frustrated by saline or conductive regolith layers. An improved understanding of the regolith was clearly required.

The research

In January 1987, four research projects were proposed, through AMIRA (the Australian Minerals Industries Research Association to member companies in the minerals industry. These included 1) Laterite geochemistry, 2) Weathering processes, 3) Controls of primary gold mineralisation and 4) Remote sensing. Of these, 1 (as Project 240), 2 (as Project 241) and 4 (as Project 243) received industry support and funding and began in July 1987. Reports released by Project 243 are not included in this compilation, except where they relate to common study sites and were also issued by projects 240, 241 and their extensions.

The objectives

The overall aims of these research projects were to develop improved geological and geochemical methods for mineral exploration to facilitate the location of blind, concealed or deeply weathered gold deposits. Research concentrated on gold occurrences and host rocks of the Yilgarn Craton of Western Australia and each ran concurrently for an initial three years.

The research projects

The four research projects are detailed below:

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. It also involved mineralogical, fabric and geochemical characterisation of various lateritic materials. 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 in 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 CSIRO Floreat Park and North Ryde laboratories 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, each of two years duration, were developed and industry support successfully sought.

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.

Confidentiality and release of information
Final reports for P240A and P241A were issued in December and June 1993 respectively. Although the confidentiality periods of the research reports expired in December 1994, they have not been made public until recently. Publishing the reports through the CRC LEME Open File 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. Some of this research has been and is being released as papers in various scientific journals and at conferences (see list of papers).

The reports
Of the 74 reports, the most important for obtaining an overview of the research are the four final and summary reports, each of which was issued as the corresponding project was completed. Useful reference information may be obtained on regolith materials from two of the three atlases; a third deals with regolith mapping procedures. The remaining reports cover regional and site investigations and some general studies, which provide the scientific foundations of the atlases and final reports.

Some field guides, issued to sponsor representatives during well-attended field trips, assisted with technology transfer to industry. What cannot be represented here were the numerous technical presentations and workshops given to the sponsors in general and to individual sponsoring companies.

CSIRO divisional name changes and report numbering systems

During the life of these projects, the responsible CSIRO division underwent a number of re-organisations. It was named the Division of Minerals and Geochemistry up to 1st January 1988. From then to 1st July 1993, it was the Division of Exploration Geoscience (majority of the tenure of the projects). In 1993, it became the Division of Exploration and Mining and underwent a minor name change to Exploration and Mining on 13th March 1998.

The impact of this was three CSIRO report numbering systems (prefix MG for Minerals and Geochemistry; prefix E&M for exploration and Mining; no prefix for Exploration Geoscience). Some minor reports, including notes for field visits and discussion papers, many of which are valuable, were supplied to the sponsoring companies but were not entered into the CSIRO report numbering system. Where these have been obtained, they are included for completeness and to present the state of the science at the time.

All now have CRC LEME Open File Report numbers and it is this numbering system which is used throughout. The CRC LEME Open File Report series has been given a single series ISSN number (1329-4768). Individual ISBN numbers have been allocated to each report volume and another number has been allocated to sets of volumes for multi-volume reports.

Report preparation and replication

The format of these reports varies as the time span of the projects reflects the progressive change from manual typing and drafting to modern word processing, computer aided drafting and GIS systems. Also primitive colour photocopying systems, with visible scan lines, gave way to modern, almost photo-quality products. As much care as possible has been taken with this re-issue, using the best original material that could be obtained; however, in some instances, original material could not be located so copies were used as the masters.

INDEX

This index volume consists of maps showing the locations of the study sites. It also contains listings of the reports by LEME Report Number and by the various CSIRO report numbers, by project, by author and by report type.

Maps

Maps have been prepared to show the locations of the investigation sites, and the LEME Open File report numbers in which they referred, projected on Yilgarn bedrock geology (Figure 1) and rainfall information (Figure 3). The small study sites and district-scale investigations (Figure 1) are shown separately from the regional geochemical studies (Figure 2). The approximate position of the Menzies Line is also shown.

Listings

Listings have been prepared which are sorted by LEME Open File Report Number and by CSIRO Report Number, giving the report title, authors, report numbers, original issue date, LEME issue date, and the approximate latitude and longitude of the study site. Brief listings have also been prepared by report type, indicating atlases, final and summary reports, general studies, regional geochemical investigations, field guides, site studies, and specialist studies (gold morphology and hydrogeochemistry). The reports are also listed by author and by project.

Index

An index has been prepared from a document of combined titles, authorship and abstracts. This is not an ideal way of indexing - a better way would have been by using the full text of the reports themselves but this was all that could be achieved in the time available and serves as an introduction. This index lists selected subjects by LEME Open File Report numbers.

Compilation of abstracts

A listing of abstracts allows the suitability of the report to be investigated further. The majority of the reports have abstracts but, where reports did not contain abstracts, as for the field notes, the itinerary or a list of keywords has been used.

Databases and searchable files

During assembly and publication of the reports, a database was produced to control the publication process. Apart from authorship, titles, report numbers, dates of original and subsequent publication, library cataloguing information and geographic coordinates, this included an abstract of each report (where possible) or a list of keywords. The original reference is also supplied. Much more sophisticated searches may be achieved with the database than is possible by using the index and the output printed.

As software advances, old databases are left stranded and become useless. This database has been supplied as a 'runtime module' which can be used independently of the user's software and may be found on the CD at the back of the volume. It was compiled in *FileMaker Pro* for both the Windows and Macintosh platforms and can be launched as any normal application. All fields in the database have been secured. The reader is advised to read the licensing agreement carefully as breaking of the seal on the CD implies the reader's agreement to its terms.

Geochemical data

Geochemical data has been supplied with some reports on a 3.5" magnetic data disc. Data supplied in this way has a limited life of some 2-6 years. A more permanent storage method is the compact disc (CD). All the data supplied on 3.5" magnetic disc has been compiled here and stored on the same CD as the databases and searchable files. The disc is written in ISO format and the data files are in DOS format (some as ASCII files) filed in directories with the appropriate CRC LEME Open File Report Number. Some files are in fixed field format, others are in tab-delimited format. Many have ReadMe files, stating the content and format. For the regional geochemical studies, data are supplied with AMG map references but, for the site studies, much of the data refers to local (mine) grids.

ACKNOWLEDGEMENTS

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.

Finding the original material of the 74 reports, making the necessary corrections and alterations, document replication and finishing has not been a small task and would have been impossible without the co-operation of a substantial team, apart from the numerous authors. E.J. Owers, K.A. O'Connor and A. Isaac located and assembled the original material and prepared it for replication. Translation of digital files was by J. Porter. A.D. Vartesi and C.R. Steel assisted with artwork and report covers. A.E. Evans and B. Waugh assisted with keywording and the supply of ISSN and ISBN numbers. S.J. Game helped with the acknowledgements of air-photos. Report replication and binding of the majority of the reports was by K. Clatworthy.

For this particular volume, A Cox assisted with GIS skills and R.E. Smith, R.R. Anand and C.R.M. Butt critically reviewed this index volume. The Geological Survey of WA and the Western Australian Waters and Rivers Commission supplied GIS data for the maps at the end of this volume. Gordon Wilson-Cox compiled the databases into run-time modules. All this assistance is acknowledged with appreciation.

LIST OF REPORTS

Sorted by CRC LEME Open File Report Number

DATABASE OF CRC LEME OPEN FILE REPORTS - 1-74 © CRC LEME 1999

Title	Authors	CRC LEME O/FReptNo	LEME Publish Date	Original Report System	CSIRO Rept Number	Original Issue Date	Latitude and Longitude
Atlas of weathered rocks	Robertson, I.D.M. and Butt, C.R.M.	1	August 1997	CSIRO, Division of Exploration Geoscience	390R	1993/05	Yilgarn
Classification and atlas of regolith-landform mapping units - exploration perspectives for the Yilgarn Craton	Anand, R.R., Churchward, H.M., Smith, R.E., Smith, K., Gozzard, J.R., Craig, M.A., and Munday, T.J.	2	December 1998	CSIRO, Division of Exploration Geoscience	440R	1993/11	Yilgarn
Regolith-landform evolution and geochemical dispersion from the Boddington Gold Deposit, Western Australia	Anand, R.R.	3	November 1998	CSIRO, Division of Exploration and Mining	E&M24R	1994/04	32°45'08"S, 116°21'34"E
Morphology and geochemistry of gold in a laterite profile, Reedy Mine, Western Australia	Freyssinet, Ph. and Butt, C.R.M.	4	October 1998	CSIRO, Division of Minerals and Geochemistry	MG58R	1988/04	27°07'12"S, 118°16'11"E
Morphology and geochemistry of gold in a lateritic profile, Bardoc Mine, Western Australia	Freyssinet, Ph. and Butt, C.R.M.	5	November 1998	CSIRO, Division of Minerals and Geochemistry	MG59R	1988/04	30°20'S, 121°17'E
Morphology and geochemistry of gold in a laterite profile, Beasley Creek, Laverton, Western Australia	Freyssinet, Ph. and Butt, C.R.M.	6	November 1998	CSIRO, Division of Minerals and Geochemistry	MG60R	1988/04	28°34'S, 122°18'E

Title	Authors	CRC LEME O/FReptNo	LEME Publish Date	Original Report System	CSIRO Rept Number	Original Issue Date	Latitude and Longitude
A mineralogical, geochemical and petrographic study of the rocks of drillhole BCD1 from the Beasley Creek Gold mine - Laverton, Western Australia	Robertson, I.D.M. and Gall, S.F.	7	November 1998	CSIRO, Division of Minerals and Geochemistry	MG67R	1988/06	28°34'S, 122°18'E
Report on laterite geochemistry in the CSIRO-AGE Database for the Southern Murchison Region (Yalgoo, Kirkalocka, Perenjori, Ninghan sheets)	Grunsky, E.C., Innes, J., Smith, R.E. and Perdrix, J.L.	8	October 1998	CSIRO, Division of Exploration Geoscience	002R	1988/12	29°S, 119°E
The pre-mining geomorphology and surface geology of the Beasley Creek Gold Mine - Laverton, Western Australia	Robertson, I.D.M. and Churchward, H.M.	9	October 1998	CSIRO, Division of Exploration Geoscience	026R	1989/07	28°34'S, 122°18'E
Beasley Creek Orientation Study: Geochemistry, petrography and mineralogy of ferruginous lag overlying the Beasley Creek Gold Mine - Laverton Western Australia	Robertson, I.D.M.	10	September 1998	CSIRO, Division of Exploration Geoscience	027R	1989/11	28°34'S, 122°18'E
Mineralogy and geochemistry of weathered shale profiles at the Panglo Gold Deposit, Eastern Goldfields, Western Australia	Scott, K.M.	11	September 1998	CSIRO, Division of Exploration Geoscience	032R	1989/02	30°31'S, 121°23'E
Mineralogy and geochemistry of mineralised and barren weathered profiles, Parkinson Pit, Mt Magnet, Western Australia	Scott, K.M.	12	September 1998	CSIRO, Division of Exploration Geoscience	033R	1989/02	28°03'S, 117°49'E

Title	Authors	CRC LEME O/FReptNo	LEME Publish Date	Original Report System	CSIRO Rept Number	Original Issue Date	Latitude and Longitude
Mineralogical and geochemical studies of gossan and wall rocks, Bottle Creek, Western Australia	Taylor, G.F.	13	September 1998	CSIRO, Division of Exploration Geoscience	036R	1989/07	29°10'S, 120°27'E
Mineralogy and geochemistry of weathered mafic/ultramafic volcanics from section 4200N at Panglo, Eastern Goldfields, Western Australia	Scott, K.M.	14	September 1998	CSIRA, Division of Exploration Geoscience	042R	1989/04	30°30'S, 121°23'E
Mineralogy and geochemistry of some weathered rocks from Callion Gold Deposit, Yilgarn Block, Western Australia	Llorca, S.M.	15	September 1998	CSIRO, Division of Exploration Geoscience	043R	1989/04	30°07'S, 120°35'E
Mineralogy and geochemistry of the Glasson Gold Deposit, Callion, Yilgarn Block, Western Australia	Llorca, S.M.	16	September 1998	CSIRO, Division of Exploration Geoscience	058R	1989/08	30°07'S, 120°35'E
Mineralogy and geochemistry of mineralised and barren felsic volcanic profiles, Parkinson Pit, Mt Magnet, Western Australia	Scott, K.M.	17	September 1998	CSIRO, Division of Exploration Geoscience	073R	1989/09	28°04'S, 117°51'E
Report on laterite geochemistry in the CSIRO-AGE Database for the Northern Murchison Region (Cue, Belele, Glengarry, Sandstone sheets)	Grunsky, E.C., Smith, R.E. and Perdrix, J.L.	18	September 1998	CSIRO, Division of Exploration Geoscience	068R	1989/11	27°S,118°30'E

Listed by CRC LEME Open File Report Number

Title	Authors	CRC LEME O/FReptNo	LEME Publish Date	Original Report System	CSIRO Rept Number	Original Issue Date	Latitude and Longitude
The mineralogy and geochemistry of soils overlying the Beasley Creek Gold Mine - Laverton, Western Australia	Robertson, I.D.M.	19	December 1998	CSIRO, Division of Exploration Geoscience	105R	1990/09	28°34'S, 122°18'E
Gold morphology and composition at Panglo, Eastern Goldfields, Western Australia	Scott, K.M. and Davis, J.J.	20	September 1998	CSIRO, Division of Exploration Geoscience	110R	1990/04	30°30'S, 121°23'E
Hydrogeochemistry in the Mt. Gibson Gold District	Gray, D.J.	21	October 1998	CSIRO, Division of Exploration Geoscience	120R	1991/03	29°45'35"S, 117°09'45"E
Laterite geochemistry in the CSIRO-AGE Database for the Central Yilgarn Region (Barlee, Bencubbin, Corrigin, Hyden, Jackson, Kalgoorlie, Kellerberrin, Southern Cross sheets)	Grunsky, E.C.	22	September 1998	CSIRO, Division of Exploration Geoscience	121R	1990/07	31°S, 118°30'E
Morphology and geochemistry of particulate gold in the lateritic regolith, Mystery Zone, Mt Percy, Kalgoorlie, Western Australia	Gedeon, A.Z., and Butt, C.R.M.	23	October 1998	CSIRO, Division of Exploration Geoscience	124R	1990/10	30°43'48"S, 121°28'25"E
The mineralogical and geochemical effects of weathering on volcanics from the Panglo Deposit, Eastern Goldfields, Western Australia	Scott, K.M.	24	September 1998	CSIRO, Division of Exploration Geoscience	143R	1990/06	30°31'S, 121°23'E

Title	Authors	CRC LEME O/FReptNo	LEME Publish Date	Original Report System	CSIRO Rept Number	Original Issue Date	Latitude and Longitude
Electron microprobe studies of minerals from weathered profiles, Parkinson Pit and environs, Mt Magnet, Western Australia	Scott, K.M.	25	September 1998	CSIRO, Division of Exploration Geoscience	147R	1990/06	28°04'S, 117°51'E
Multi-element dispersion in the saprolite at the Beasley Creek Gold Mine - Laverton, Western Australia	Robertson, I.D.M.	26	October 1998	CSIRO, Division of Exploration Geoscience	152R	1991/04	28°34'S, 122°18'E
Laterite geochemistry in the CSIRO-AGE Database for the Wiluna Region (Duketon, Kingston, Sir Samuel, Wiluna sheets)	Grunsky, E.C.	27	December 1998	CSIRO, Division of Exploration Geoscience	154R	1990/12	27°S, 121°30'E
Laterite geochemistry in the CSIRO-AGE Database for the Albany-Fraser Region (Collie, Dumbleyung, Mt Barker, Pemberton sheets)	Grunsky, E.C.	28	December 1998	CSIRO, Division of Exploration Geoscience	161R	1991/03	34°S, 117°30'E
Gold and associated elements in the regolith - dispersion processes and implications for exploration. P241 Final Report	Butt, C.R.M., Gray, D.J., Lintern, M.J., Robertson, I.D.M., Taylor, G.F. and Scott, K.M.	29	November 1998	CSIRO, Division of Exploration Geoscience	167R	1991/09	Yilgarn
The mineralogical and geochemical effects of weathering in mafic and ultramafic profiles, Mt Magnet, Western Australia	Scott, K.M. and Martinez, A.	30	October 1998	CSIRO, Division of Exploration Geoscience	178R	1990/10	28°03'S, 117°49'E

Title	Authors	CRC LEME O/FReptNo	LEME Publish Date	Original Report System	CSIRO Rept Number	Original Issue Date	Latitude and Longitude
Petrography, mineralogy and geochemistry of soil and lag overlying the Lights of Israel Gold Mine, Davyhurst, Western Australia	Robertson, I.D.M. and Tenhaeff, M.F.J.	31	September 1998	CSIRO, Division of Exploration Geoscience	232R	1992/10	30°01'40"S, 120°39'45"E
Geochemical and hydrogeochemical investigations of alluvium at Mulgarrie, Western Australia	Gray, D.J.	32	September 1998	CSIRO, Division of Exploration Geoscience	339R	1992/12	30°22'S, 121°30'E
Investigation of hydrogeochemical dispersion of gold and other elements in the Wollubar Palaeodrainage, Western Australia	Gray, D.J.	33	September 1998	CSIRO, Division of Exploration Geoscience	387R	1993/05	31°S, 121°30'E
Further aspects of the chemistry of gold in some Western Australian soils	Gray, D.J. and Lintern, M.J.	34	September 1998	CSIRO, Division of Exploration Geoscience	391R	1993/06	Yilgarn
Exploration geochemistry about the Mt Gibson Gold Deposits, Western Australia. Progress to 31st March 1989	Anand, R.R., Smith, R.E., Innes, J. and Churchward, H.M.	35	October 1998	CSIRO, Division of Exploration Geoscience	020R	1989/03	29°45'35"S, 117°09'45"E
Occurrence of gold in hardpan, Youanmi Mine	Gedeon, A.Z. and Butt, C.R.M.	36	September 1998	CSIRO, Division of Exploration Geoscience	023R	1989/05	28°37'S, 118°50'E

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Lawlers orientation study - Contribution to Field Guide, Eastern Goldfields Trip. 1-2 November 1990	Anand, R.R., Smith, R.E., Churchward, H.M. and Perdrix, J.L.	37	February 1999	CSIRO, Division of Exploration Geoscience	Unnumbered	1990/11	Yilgarn
The aqueous chemistry of gold in the weathering environment	Gray, D.J.	38	September 1998	CSIRO, Division of Exploration Geoscience	004R	1988/12	-
The petrography, mineralogy and geochemistry of a felsic, mafic, ultramafic and metasedimentary weathered profile at Rand Pit, Reedy Mine - Cue, Western Australia	Robertson, I.D.M., Chaffee, M.A. and Taylor, G.F.	39	September 1998	CSIRO, Division of Exploration Geoscience	102R	1990/12	27°07'12"S, 118°16'11"E
Multi-element soil survey of the Mount Hope Area, Western Australia	Lintern, M.J., Churchward, H.M. and Butt, C.R.M.	40	October 1998	CSIRO, Division of Exploration Geoscience	109R	1990/05	32°07'S, 119°44'E
Hydrogeochemistry of the Panglo Gold Deposit	Gray, D.J.	41	October 1998	CSIRO, Division of Exploration Geoscience	125R	1990/10	30°30'S, 121°23'E
The sorption of gold and silver on soil minerals	Gray, D.J.	42	September 1998	CSIRO, Division of Exploration Geoscience	127R	1990/11	-

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Title	Authors	CRC LEME O/FReptNo	LEME Publish Date	Original Report System	CSIRO Rept Number	Original Issue Date	Latitude and Longitude
Chemistry of gold-humic interactions	Gray, D.J., Lintern, M.J. and Longman, G.D.	43	September 1998	CSIRO, Division of Exploration Geoscience	128R	1990/11	-
The distribution of gold and other elements in soils and vegetation at Panglo, Western Australia	Lintern, M.J. and Scott, K.M.	44	October 1998	CSIRO, Division of Exploration Geoscience	129R	1990/10	30°30'S, 121°23'E
Dispersion of gold and associated elements in the lateritic regolith, Mystery Zone, Mt Percy, Kalgoorlie, Western Australia	Butt, C.R.M.	45	October 1998	CSIRO, Division of Exploration Geoscience	156R	1991/01	30°43'48 "S, 121°28' 25"E
Reference geochemical data sets from the Mt Gibson orientation study, Western Australia	Smith, R.E., Wildman, J.E., Anand, R.R. and Perdrix, J.L.	46	November 1998	CSIRO, Division of Exploration Geoscience	157R	1992/03	29°45'35"S, 117°09'45"E
The distribution of gold and other elements in soils at Mulline, Western Australia	Lintern, M.J. and Butt, C.R.M.	47	November 1998	CSIRO, Division of Exploration Geoscience	159R	1991/02	29°44'S, 120°28'E
The mineralogical and geochemical effects of weathering on shales at the Panglo Deposit, Eastern Goldfields, Western Australia	Scott, K.M. and Dotter, L.E.	48	September 1998	CSIRO, Division of Exploration Geoscience	171R	1990/08	30°31'S, 121°23'E

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Laterite geochemistry for detecting concealed mineral deposits, Yilgarn Craton, Western Australia. P240 Summary Report	Smith, R.E., Anand, R.R., Churchward, H.M., Robertson, I.D.M., Grunsky, E.C., Gray, D.J., Wildman, J.E. and Perdrix, J.L.	50	November 1998	CSIRO, Division of Exploration Geoscience	236R	1992/11	Yilgarn
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The distribution of gold and other elements in soils and vegetation at Zuleika, Western Australia	Lintern, M.J. and Butt, C.R.M.	52	November 1998	CSIRO, Division of Exploration Geoscience	328R	1992/11	30°33'S, 121°04'E
The distribution of gold and other elements in soils at the Granny Smith Gold Deposit, Western Australia	Lintern, M.J. and Butt, C.R.M.	53	October 1998	CSIRO, Division of Exploration Geoscience	385R	1993/05	28°48'S, 122°25'E
Geochemical background, Mt. Percy, Kalgoorlie, Western Australia	Butt, C.R.M.	54	October 1998	CSIRO, Division of Exploration Geoscience	389R	1993/05	30°34'48"S, 121°28' 25"E

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Petrology and geochemistry of surface materials overlying the Bottle Creek Gold Mine, WA	Robertson, I.D.M. and Wills, R.	56	November 1998	CSIRO, Division of Exploration Geoscience	394R	1993/10	29°10'S, 120°27'E
Gold and associated elements in the regolith - dispersion processes and implications for exploration. P241A Final Report	Butt, C.R.M., Gray, D.J., Lintern, M.J. and Robertson, I.D.M.	57	November 1998	CSIRO, Division of Exploration Geoscience	396R	1993/06	Yilgarn
Geochemical exploration in complex lateritic environments of the Yilgarn Craton, Western Australia. P240A Final Report	Anand, R.R., Smith, R.E., Phang, C., Wildman, J.E., Robertson, I.D.M. and Munday, T.J.	58	November 1998	CSIRO, Division of Exploration Geoscience	442R	1993/12	Yilgarn
Strategies and methods for the interpretation of geochemical data.	Grunsky, E.C.	59	December 1998	CSIRO, Division of Exploration Geoscience	Unnumbered	1991/08	-
Introduction and Bottle Creek orientation study - Contribution to Field Guide, Eastern Goldfields Trip	Anand, R.R., Smith, R.E., Churchward, H.M. and Perdrix, J.L.	60	December 1998	CSIRO, Division of Exploration Geoscience	Unnumbered	1990/11	Yilgarn

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Regolith-landform development and consequences on the mineralogical and geochemical characteristics of regolith units, Lawlers District, Western Australia	Anand, R.R., Churchward, H.M., Smith, R.E. and Grunsky, E.C.	62	November 1998	CSIRO, Division of Exploration Geoscience	166R	1991/08	28°02'25"S, 120°33'10"E
Notes being incorporated into a report on laterite geochemistry for the Moora, Perth, Pinjarra, Collie and Pemberton 1:250000 sheets	Innes, J., Smith, R.E. and Perdrix, J.L.	63	November 1998	CSIRO, Division of Minerals and Geochemistry	Unnumbered	1988/04	-
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Study of the distribution of gold in soils at Mt Hope, Western Australia	Lintern, M.J.	65	February 1999	CSIRO, Division of Exploration Geoscience	024R	1989/05	32°07'S, 119°44'E
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Chemistry of gold in some Western Australian Soils	Gray, D.J., Lintern, M.J. and Longman, G.D.	68	February 1999	CSIRO, Division of Exploration Geoscience	126R	1990/11	Yilgarn
Spectral properties of soil and lag overlying the site of the Beasley Creek Gold Mine, Laverton Region, Western Australia	Cudahy, T.J., Robertson, I.D.M. and Gabell, A.R.	69	February 1999	CSIRO, Division of Exploration Geoscience	160R	1992/09	28°34'S, 122°18'E
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1) Leading zeros have been added to facilitate sorting - they are not normally referred to.
2) Numbers without a prefix are Division of Exploration Geoscience reports, numbers prefixed with MG were produced during the tenure of the Division of Minerals and Geochemistry and those prefixed with E&M are from CSIRO Exploration and Mining. Some reports were unnumbered.
3) All prefixed reports (Exploration and Mining and Minerals and Geochemistry) and unnumbered reports are at the end of the listing.

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Title	Authors	CRC LEME O/FReptNo	LEME Publish Date	Original Report System	CSIRO Rept Number	Original Issue Date	Latitude and Longitude
CRC LEME Open File Reports 1-74 - Abstracts, Index and Database	Robertson, I.D.M.	75	June 1999	CRC LEME Open File	-	not previously	Yilgarn
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Occurrence of gold in hardpan, Youanmi Mine	Gedeon, A.Z. and Butt, C.R.M.	36	September 1998	CSIRO, Division of Exploration Geoscience	023R	1989/05	28°37'S, 118°50'E
Study of the distribution of gold in soils at Mt Hope, Western Australia	Lintern, M.J.	65	February 1999	CSIRO, Division of Exploration Geoscience	024R	1989/05	32°07'S, 119°44'E

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Title	Authors	CRC LEME O/FReptNo	LEME Publish Date	Original Report System	CSIRO Rept Number	Original Issue Date	Latitude and Longitude
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Mineralogical and geochemical studies of gossan and wall rocks, Bottle Creek, Western Australia	Taylor, G.F.	13	September 1998	CSIRO, Division of Exploration Geoscience	036R	1989/07	29°10'S, 120°27'E
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The distribution of gold and other elements in soils at Mulline, Western Australia	Lintern, M.J. and Butt, C.R.M.	47	November 1998	CSIRO, Division of Exploration Geoscience	159R	1991/02	29°44'S, 120°28'E
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Gold and associated elements in the regolith - dispersion processes and implications for exploration. P241 Final Report	Butt, C.R.M., Gray, D.J., Lintern, M.J., Robertson, I.D.M., Taylor, G.F. and Scott, K.M.	29	November 1998	CSIRO, Division of Exploration Geoscience	167R	1991/09	Yilgarn
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The mineralogical and geochemical effects of weathering on shales at the Panglo Deposit, Eastern Goldfields, Western Australia	Scott, K.M. and Dotter, L.E.	48	September 1998	CSIRO, Division of Exploration Geoscience	171R	1990/08	30°31'S, 121°23'E
The mineralogical and geochemical effects of weathering in mafic and ultramafic profiles, Mt Magnet, Western Australia	Scott, K.M. and Martinez, A.	30	October 1998	CSIRO, Division of Exploration Geoscience	178R	1990/10	28°03'S, 117°49'E
Geochemistry of weathered rocks at the Telfer Gold Deposit, Paterson Province, Western Australia	Wilmshurst, J.R.	70	February 1999	CSIRO, Division of Exploration Geoscience	187R	1991/01	21°44'S, 122°12'E
Petrography, mineralogy and geochemistry of soil and lag overlying the Lights of Israel Gold Mine, Davyhurst, Western Australia	Robertson, I.D.M. and Tenhaeff, M.F.J.	31	September 1998	CSIRO, Division of Exploration Geoscience	232R	1992/10	30°01'40"S, 120°39'45"E

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Laterite geochemistry for detecting concealed mineral deposits, Yilgarn Craton, Western Australia. P240 Summary Report	Smith, R.E., Anand, R.R., Churchward, H.M., Robertson, I.D.M., Grunsky, E.C., Gray, D.J., Wildman, J.E. and Perdrix, J.L.	50	November 1998	CSIRO, Division of Exploration Geoscience	236R	1992/11	Yilgarn
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Regolith-landform mapping in the Yilgarn Craton, Western Australia: Towards a standardized approach	Craig, M.A., Anand, R.R., Churchward, H.M., Gozzard, J.R., Smith, R.E. and Smith, K.	72	February 1999	CSIRO, Division of Exploration Geoscience	338R	1993/01	Yilgarn

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The distribution of gold and other elements in soils at the Granny Smith Gold Deposit, Western Australia	Lintern, M.J. and Butt, C.R.M.	53	October 1998	CSIRO, Division of Exploration Geoscience	385R	1993/05	28°48'S, 122°25'E
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Geochemical background, Mt. Percy, Kalgoorlie, Western Australia	Butt, C.R.M.	54	October 1998	CSIRO, Division of Exploration Geoscience	389R	1993/05	30°34'48"S, 121°28' 25"E
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Geochemical exploration in complex lateritic environments of the Yilgarn Craton, Western Australia. P240A Final Report	Anand, R.R., Smith, R.E., Phang, C., Wildman, J.E., Robertson, I.D.M. and Munday, T.J.	58	November 1998	CSIRO, Division of Exploration Geoscience	442R	1993/12	Yilgarn
Regolith-landform evolution and geochemical dispersion from the Boddington Gold Deposit, Western Australia	Anand, R.R.	3	November 1998	CSIRO, Division of Exploration and Mining	E&M24R	1994/04	32°45'08"S, 116°21'34"E

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Morphology and geochemistry of gold in a lateritic profile, Bardoc Mine, Western Australia	Freyssinet, Ph. and Butt, C.R.M.	5	November 1998	CSIRO, Division of Minerals and Geochemistry	MG59R	1988/04	30°20'S, 121°17'E
Morphology and geochemistry of gold in a laterite profile, Beasley Creek, Laverton, Western Australia	Freyssinet, Ph. and Butt, C.R.M.	6	November 1998	CSIRO, Division of Minerals and Geochemistry	MG60R	1988/04	28°34'S, 122°18'E
A mineralogical, geochemical and petrographic study of the rocks of drillhole BCD1 from the Beasley Creek Gold mine - Laverton, Western Australia	Robertson, I.D.M. and Gall, S.F.	7	November 1998	CSIRO, Division of Minerals and Geochemistry	MG67R	1988/06	28°34'S, 122°18'E
Introduction and Bottle Creek orientation study - Contribution to Field Guide, Eastern Goldfields Trip	Anand, R.R., Smith, R.E., Churchward, H.M. and Perdrix, J.L.	60	December 1998	CSIRO, Division of Exploration Geoscience	Unnumbered	1990/11	Yilgarn
Lawlers orientation study - Contribution to Field Guide, Eastern Goldfields Trip. 1-2 November 1990	Anand, R.R., Smith, R.E., Churchward, H.M. and Perdrix, J.L.	37	February 1999	CSIRO, Division of Exploration Geoscience	Unnumbered	1990/11	Yilgarn

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ABSTRACTS

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N.B. These abstracts have been scanned and are not guaranteed free from error.

LEME Open File Report 1

Atlas of weathered rocks

Robertson, I.D.M. and Butt, C.R.M.

Determining bedrock type from its weathered counterpart is one of the chief problems encountered by exploration geologists, particularly newly qualified geologists, when working in intensely weathered terrain.

This report is an Atlas which makes use of some of the magnificent sectional exposures generated by open pit gold mining in the Yilgarn. It introduces regolith terminology, the principles of weathering and its attendant mineralogical changes. The main part of the Atlas illustrates the fabric and mineralogical changes that take place as rocks weather. The Atlas is presented in hard cover, loose-leaf format and contains 136 annotated colour photographs with detailed descriptions. Many of these are in pairs so as to relate petrographic detail to what can be seen with a hand lens.

It also records the changes in major and trace element contents which occur in the weathered profile, backed by tabulated geochemical data. The Atlas discusses the use of 'immobile' elements to identify rock types and introduces multivariate methods and discriminant analysis.

Improved identification of rock types in the weathered zone will assist interpretation of geochemical data. Being able to recognise the position in the weathered profile from weathering fabrics will lead to a better understanding and prediction of geochemical dispersion.

Keywords:
Lithogeochemistry, fabrics, petrography, immobile elements, multivariate statistics, bedrock identification, regolith terminology, regolith classification, posl lateritic modification, truncation, cementation, soil, lag, initiation of weathering, weathering reactions, mineral stability, colour, mineralogy, geochemistry, phyllite, Beasley Creek, granite, Trial Hill, Barr Smith Range, QAZ cement, Dam Bore, silcrete, aluminosilicate cement, Tammin, sandplain, Bottle Creek, Lights of Israel, Ora Banda, primary fabrics, secondary fabrics, voids, mica relics, palimpsest fabrics, accordion fabrics, void fill fabrics, duricrust fabrics, Reedy, foliation, saprock, saprolite, plasmic zone, kaolinite blasts, quartz segregation fabrics, porphyry, Mt Percy, ultramafic, mafic.

LEME Open File Report 2

Classification and atlas of regolith-landform mapping units - exploration perspectives for the Yilgarn Craton

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

For geochemical exploration, regolith units form the dominant sampling media in the initial stages of most programs. However, the regolith evolves in a complex fashion which results in a wide variety of regolith types at any particular site. Some of these are more appropriate for sampling than others. It is therefore important to have an understanding of the regolith in the region of interest in order to be able to devise effective sampling strategies and to interpret the geochemical data sensibly.

The *classification scheme and atlas* which is described in this report has been constructed with the explorationists in mind. The scheme and atlas should assist in the mapping of regolith-landform associations and subsequent selection of the sampling media. It also provides a standardized mode of description and classification of the diverse range of regolith-landform associations on the Yilgarn Craton. Such a standardized mode of description should allow mapping units from one region of the Yilgarn Craton to be compared with those from another region. These comparisons are particularly relevant when considering geochemical thresholds for different areas and in establishing the significance of geochemical anomalies.

The proposed classification and atlas is based on the examination of regolith-landform settings in a series of orientation districts across the Yilgarn Craton. The scheme is expandable, hierarchical and mnemonic. The results presented here form the basis of continuing work and are presented in a loose-leaf format so that findings from other areas can be incorporated.

The classification tables contain information on regolith-landform regimes, landforms and regolith materials. The latter are arranged vertically in order of regolith stratigraphy. Hierarchical mnemonic alpha-numeric codes are provided for all the designated regolith-landform mapping units. A system of map symbols for regolith-landform mapping units is proposed. Examples of coded maps from several orientation districts are presented.

Representative photographs of regolith materials and their positions in the landscape with accompanying descriptions (including geochemical data where available) are given in the atlas. The photos and data are arranged in the same order as those of classification tables. The codes provide link between the classification tables, and the photographs and their descriptions. The atlas should help exploration geologists, geochemists and geophysicists in recognising the nature of the regolith materials being mapped or sampled.

Future collaboration between Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australian Geological Survey Organisation (AGSO), Geological Survey of Western Australia (GSWA), and Curtin University will link this atlas and its incorporated concepts, with regolith-landform mapping units for other regions of Australia.

Mapping methods, regolith stratigraphy, genetic regolith maps, regolith-landform models, classification tables, atlas, Lawlers, Mt Gibson, Mt McClure, landform, lateritic family, lag, soil, weathering profile, substrate, transported overburden, Bottle Creek, Wombola, lateritic nodule, lateritic pisolith, Bardoc, Lady Evelyn, Madoonga, lateritic duricrust, ferruginous saprolite, mottled saprolite, Fe-rich duricrust, Cawse Find, iron segregation, ferruginous granule, pisolith, sandy clay, lateritic residuum, calcareous soil, alluvium, , Mt Hope, mega-mottle, Black Flag, saprolite, ferruginous bedrock, glossary, dune, erosional regime, ferruginous granule, hardened mottle. Mottled zone, pediment, colluvium, playa, regolith unit, residual regime, stripped slope,

LEME Open File Report 3

Regolith-landform evolution and geochemical dispersion from the Boddington Gold Deposit, Western Australia

Anand, R.R.

Regolith-Landform Relationships
A map of regolith-landform patterns was produced over an 11 km x 11 km area at Boddington. The regolith stratigraphy was established, the regolith units characterized, and a regolith-landform model established for the Boddington district. The model presents relationships in terms of preservation and erosion of the lateritic weathering profile and of local deposition.

The regolith of Boddington, as in other parts of the Yilgarn Craton, has developed over a long period, which is inferred to have taken place under a seasonally-humid climate during the Tertiary. The laterite profile is now undergoing degradation through physical and chemical processes.

A deep lateritic mantle occurs extensively over, much of the Boddington district. The profile comprises a gravelly, sandy soil containing loose lateritic pisoliths over a lateritic duricrust (Lateritic residuum), thence a bauxite zone, clay zone, saprolite, saprock, and bedrock. The thickness of the horizons varies considerably, depending upon the nature of the parent bedrock. Lateritic residuum forms a continuous blanket over some 30% of the landscape; however, the thickness and facies of lateritic residuum vary within the landscape. Lateritic residuum is either more developed or more preserved on mid-slopes than on crests or lower slopes. The mid-slope positions are dominated by pisolitic duricrust which is typically underlain by fragmental duricrust. By contrast, pisolitic duricrust is generally absent on crests and up-slope positions where fragmental duricrust is dominant. Lower slope positions are occupied by loosely-packed pisolitic gravels which can reach a thickness of 4 m.

The lateritic duricrust and associated loose lateritic pisoliths and nodules at Boddington are largely residual, but transported nodules and pisoliths are on lower slopes. Several types of nodules and pisoliths occur in the lateritic units and have been classified as lithic, non-lithic, and of mixed origin. Relict textures after andesite are visible through some of the profiles to the level of fragmental duricrust and these correlate with the bedrock relationships which have been established through drilling. Feldspars, in fabrics similar to those of bedrock have been pseudomorphed by gibbsite, showing that at least some of the lateritic duricrust is residual. Relict textures, derived from dolerite, are also present as residual ilmenite in the bauxite zone, as well as in the fragmental and pisolitic duricrusts. The dolerite results in a redder fragmental duricrust and bauxite zone than in those horizons derived from the felsic andesite.

Mineralogy

The saprock consists of smectite, kaolinite, and mixed-layer minerals with relict primary minerals from the bedrock. Kaolinite is the dominant mineral in the clay zone and saprolite. The bauxite zone is characterized by replacement of kaolinite by gibbsite, and by the presence of hematite. In the overlying duricrusts and the lateritic pisoliths and nodules, hematite becomes predominant over goethite. Maghemite and amorphous Al-oxide appear in the pisolitic duricrust and become major constituents of the loose lateritic pisoliths and nodules. Hematite and goethite are relatively more abundant in the weathering profiles formed from dolerite than in those derived from andesite. Anatase is an important secondary mineral over dolerite.

Aluminium substitution increases up the profile. In the bauxite and duricrust horizons, Al substitution in goethite ranges from 20-33 mole % whereas in saprolite it is only from 8-18 mole %.

Geochemistry

Chemical analyses of 284 samples of various regolith units, collected systematically from surface and from pit walls, document the multi-element characteristics of the lateritic Au deposits including dispersion during lateritic weathering of the protore and hosting lithologies.

Significantly anomalous concentrations of Au occur close to the surface within the lateritic residuum although the supergene Au ore occurs at greater depth (10 m to 30 m). The concentrations of Au generally decrease into the overlying laterite units, i.e. from the bauxite zone through the lateritic duricrust to loose pisoliths. Gold in pisolitic and nodular lag is variable and is generally much weaker than the underlying pisolitic duricrust.

The protore mineralization is depicted by a multi-element (W, Mo, As, Sn, Cu, Bi) geochemical halo in the lateritic residuum, both in the duricrust and in the lateritic pisoliths and nodules. The element association is As, Bi, Mo, Sn and W, with more erratic Cu and Au. Tungsten, Mo, As and, to some degree, Sn, show a more widespread and homogenous distribution than Cu and Bi.

Variations in the contents of As, W, Sn, Mo, and Au were observed between profiles that reflect variations in the parent rock and bedrock mineralization.

The trends in element behaviour in profiles formed from andesite and dolerite are very similar, with minor differences due to the contrasting chemistry and mineralogy of the host rock. The bauxite zone and duricrusts formed from dolerite are richer in Fe_2O_3, TiO_2, Mn, V, and Zn, than the same horizons from felsic andesite. The Ti and Zr contents of the laterite have been used to interpret the origin of the lateritic residuum following the method proposed by Hallberg (1984) for saprolite. Most of the samples appear to have been derived from felsic andesite rocks, the remainder from dolerite.

The Mn, Cu, Zn, Ni, and Co are relatively depleted in the upper horizons of the profile, while Fe, Al, Ti, V, Cr, As, Bi, Sn, Ga, W, Zr, Nb, Mo, and Pb are retained or enriched throughout the whole profile.

These elements have accumulated in the lateritic residuum and are either associated with Fe-oxides and gibbsite, or occur as resistant primary minerals such as zircon, cassiterite, and scheelite.

Gold, Cu, and Al are enriched in the non-magnetic pisoliths contrasting with Fe, and As that are relatively more abundant in magnetic pisoliths.

The Boddington Au deposit highlights some of the problems of Au exploration in lateritic terrains which are exemplified by the leaching of Au from surface and near-surface lateritic pisoliths and nodules. A large strong, consistent multi-element anomaly at surface, with or without Au, seems to be the best and most reliable indicator of Au deposits. For Au exploration in the Boddington area, samples of fragmental duricrust instead of loose lateritic pisoliths or pisolitic duricrust, should be collected.

Geomorphology, residual regime, erosional regime, depositional regime, regolith stratigraphy, andesite, bauxite zone, lateritic residuum, soil, pisolitic lag, nodular lag, dolerite, geochemistry, mineralogy, geochemical dispersion, magnetic nodule.

LEME Open File Report 4

Morphology and geochemistry of gold in a laterite profile, Reedy Mine, Western Australia

Freyssinet, P. and Butt, C.R.M.

The morphology and geochemistry of gold grains panned from bulk samples collected from various horizons of the weathering profile of gold mineralisation at the North Rand Pit at Reedy have been studied. The primary mineralization in the main lode is characterised by xenomorphic and euhedral grains containing 6-16% Ag and 300-1000ppm Cu. The gold in lateral veins is similar but coarser. In the saprolite, only a few residual, Ag-rich, primary grains remain, and these are strongly etched and rounded. The other grains are Ag- and Cu-free and appear to be secondary. In the ferruginous horizon, all the grains are secondary, being Ag- and Cu-free and having characteristic prismatic or flat pseudo-hexagonal morphologies; most are partly etched. Iron and As are present in many secondary grains, probably as micro-inclusions, suggesting that Fe plays an important role in the process of remobilisation and precipitation.

LEME Open File Report 5

Morphology and geochemistry of gold in a lateritic profile, Bardoc Mine, Western Australia

Freyssinet, P. and Butt, C.R.M.

The morphology and geochemistry of gold grains have been studied at different levels of the lateritic profile in the Zoroastrian Pit at Bardoc. At the bottom of the pit, 40% of the grains associated with the mineralised quartz veins were primary whereas, in the saprolite halo, only 17% were primary. The percentage decreases higher in the profile to only 4% in the mottled clay zone. However, in the ferruginous horizon, the proportion of residual, primary grains increases to 42%.

Several, different, secondary, gold morphologies have been observed, falling into four main categories: xenomorphic forms, euhedral crystals, flat pseudo-hexagonal crystals and irregular aggregates. Some grains are strongly corroded whereas others are quite well preserved and it can be assumed that there are several generations of secondary gold grains.

Electron microprobe analysis of polished sections indicates that primary gold contains 4-11% silver and that secondary gold is extremely pure. Secondary gold does, however, contain traces of iron, probably as micro-inclusions of iron oxide.

The observed gold distribution is probably the result of two mechanisms of chemical dispersion. Gold remobilisation first occurred during lateritization, principally in the ferruginous horizon, but dissolution was not complete. The second phase was during a later, arid period when gold was strongly dissolved by saline groundwaters and dispersed in the saprolite and mottled clay zone.

LEME Open File Report 6

Morphology and geochemistry of gold in a laterite profile, Beasley Creek, Laverton, Western Australia

Freyssinet, P. and Butt, C.R.M.

The morphology and geochemistry of gold grains was studied in panned concentrates from several depths in the weathering profile of gold mineralization at Beasley Creek, near Laverton. At 70-80 m depth, the mineralization is only partly weathered and both primary and secondary gold grains are present. The former are characterised by high Ag contents (maximum 48%), whereas the secondary gold is of high fineness. Above 60 m, only secondary grains were found, but with several morphological types, including flat polygonal forms, euhedral prismatic crystals and pseudohexagonal crystals. Most of the grains are etched and corroded. Above 20 m, a further generation of secondary gold appears, as irregular rounded grains that are only weakly corroded. No trace elements were detected in the primary gold, but Fe and As are present sporadically in the secondary grains, probably as micro-inclusions of Fe oxides.

LEME Open File Report 7

A mineralogical, geochemical and petrographic study of the rocks of drillhole BCD1 from the Beasley Creek Gold mine - Laverton, Western Australia

Robertson, I.D.M. and Gall, S.F.

The mineralogy, petrology and geochemistry of selected samples from DDH BCD1 were examined in detail to gain an overall understanding of the lithology, weathering characteristics and geochemistry of the Beasley Creek gold deposit (Laverton). Vertical drillhole BCD1 intersects the ore zone and footwall rocks to a depth of 100 m. The footwall consists of fresh, foliated basaltic amphibolites metamorphosed to the upper greenschist facies, consisting of a tremolite-albite-quartz assemblage. They contain at least one felsic unit and have been locally carbonated. There is a *suggestion* of hydrothermal alteration near the bottom of the hole where kaolinisation has taken place in the presence of fresh pyrite. Above this, pyrite is oxidised to goethite. Feldspars weather progressively to kaolinite and amphiboles to smectite. These rocks become upwardly friable and their foliation is cemented with clay, iron oxide and calcite.

The ore zone lies mainly within phyllitic rocks which are variably kaolinised and ferruginised. Garnet pseudomorphs indicate metamorphism to the quartz-albite-epidote-almandine subfacies. Progressive ferruginisation has replaced both minerals and fabrics, leaving only relict muscovite and shard-like quartz. Vesicles are lined with goethite, which becomes progressively poorer in Al, hematite and several Mn minerals including cryptomelane and lithiophorite. The upper part of the weathered profile has been subjected to calcrete formation where the rocks have been brecciated and set in a complex carbonate cement. Some of this has subsequently been dissolved leaving carbonate-lined vesicles.

The Ti/Zr ratio, together with Al and Cr are useful lithological indicators. Weathering has progressively depleted Mg, Ca and Sr and this is complete above 65 m. Mineralisation is marked by anomalous Pb, W, As and, to a lesser extent, by Be, Fe, Zn, Sb and Co.

Amphibolite, geomorphology, felsic schist, phyllite, mafic rock,

LEME Open File Report 8

Report on laterite geochemistry in the CSIRO-AGE Database for the Southern Murchison Region (Yalgoo, Kirkalocka, Perenjori, Ninghan Sheets)

Grunsky, E.C., Innes, J., Smith, R.E. and Perdrix, J.L.

A multi-element geochemical study, largely based upon laterite sampling, covering parts of the main greenstone belts of the Perenjori, Nyngan, Yalgoo, and Kirkalocka 1:250 000 map sheets has outlined the following geochemical features:

a) district-scale (30 to 50 km in length) patterns in the distribution of Cu + Zn + Ni + Co + Cr; V + Sn;, and Zr + Nb; each pattern appearing to relate to dominant characteristics of varying bedrock associations;

b) an As + Sb association in the Yalgoo-Singleton Greenstone Belt, most prominent in a central regional north-south trend (referred to as a chalcophile corridor, Smith, 1987) passing through Golden Grove and extending south to Mt Gibson;

c) isolated anomalies on the 2 to 5 km scale showing associations of Bi + Mo + W+ Ge + Sn;

d) several anomalies at the 1 km scale that require follow-up sampling in exploration in order to assess their continuity and significance;

The study also provides knowledge of the element abundance levels and variation of laterite geochemistry that complements information arising from orientation studies about mineral deposits.

Sporadic Au anomalies also occur. However, the general sample spacing of 3 km with fill-in sampling at 1 km is too wide for reliable interpretation of Au patterns in laterites. Laterite geochemistry at these low sample densities generally requires the use of intermediate zonal targets such as anomalous chalcophile envelopes which can occur about individual deposits.

The sampling arose as part of a combined research programme at CSIRO and an experimental exploration programme (the AGE Joint Venture Programme) during the period 1983 to 1986.

In the region covered by the present report a total of 721 samples were analyzed for 31 elements. Summary statistics, histograms, and maps of the percentile classes, are presented for selected elements in laterites and some very iron-rich materials from partly eroded profiles which have been referred to as ferricretes. A principal components analysis was also carried out with the resulting component scores plotted up for the first five components. The results of the analysis confirm the presence of some broad regional geochemical trends that are related to bedrock lithologies and regional alteration processes.

LEME Open File Report 9

The pre-mining geomorphology and surface geology of the Beasley Creek Gold Mine, Laverton, WA

Robertson, I.D.M. and Churchward, H.M.

The site of the Beasley Creek Gold mine lies on a small hill 3.5 m high, surrounded by wash plains which form a low tabular divide between broad drainage floors to the north and south. The hill is asymmetric, with a very gentle western slope, marked by calcrete and sparse, small, saprolite outcrops, a crest with sporadic ironstone outcrops and a steeper eastern slope protected by lateritic duricrust.

The whole area is mantled by red, friable clay soil and strewn with multi-component lag. The soils on the low-lying areas are deeper than on the hill, are relatively acid and are underlain by Wiluna hardpan but become alkaline and thin on the hill where they are underlain by saprolite and calcrete. Ironstone lag and a duricrust-related khaki lag show only slight dispersion from their sources. Coarse, black ferruginous lag has a wider distribution but seems associated with the subcrop of the black shale ore zone. Finer brown ferruginous lags have a wider distribution and their finest fractions seem to have been separated by down slope colluvial sedimentation. Quartz lag is dispersed around small quartz veins unrelated to ore.

Wanderrie country, geomorphology, surficial materials, lag, hardpan, calcrete, ironstone, lateritic duricrust, saproilite, permian glacials, regolith-landform, erosional regime, relict regime, depositional regime.

LEME Open File Report 10

Geochemistry, petrography and mineralogy of ferruginous lag overlying the Beasley Creek Gold Mine - Laverton WA

Robertson, I.D.M.

Two fractions (0.2 to 4.0 and 10 to 50 mm) of the black ferruginous lag that used to overlie the Beasley Creek gold mine have been studied physically, petrographically, mineralogically and geochemically. The fine lag was split into magnetic and non-magnetic components.

The coarse lag fraction consists of goethite and hematite with minor quantities of mica, kaolinite and quartz. It contains ferruginised lithorelics with remnant and pseudomorphed minerals and fabrics. These are related to both primary and authigenic features of the underlying saprolite. These relics occur as islands in several cycles of secondary goethite and hematite, which have obliterated much of the original fabric. In many instances, hematite can be shown to be a dehydration product of goethite. Later history of the coarse lag is shown by skins and nodules of ferruginous clay, which have undergone several cycles of solution, clay precipitation and permeation by iron-bearing solutions. Careful study of original fabrics could be used to aid the geological mapping of lag-covered areas.

In addition to black ferruginous nodules and red-brown and yellow-brown nodules, analogous to the coarse lag, the fine lag contains minor components of calcrete, quartz and a cellular ironstone, as well as very small quantities of silica-cemented red, aeolian sand and organic debris. The fine lag shows similar fabrics and components to the coarse lag but its finer and more fragmentory nature and wider dispersion make elucidation of the original rock type more difficult.

The orebody and its host, the weathered black phyllite, are depicted by positive anomalies in Au, As, Ba, Co, Cu, Mn, Mo (weak), Pb (possible), Sb, W and Zn in the lag. The cellular ironstone component is strongly anomalous in the target elements As, Au, Co, Cu, Mn, Sb, Se and Zn. Similar anomalies in Mg, Ca and Sr mark the occurrence of calcrete, which occurs near the hill crest and coincides with the orebody. Gold is the best indicator and shows strong anomalies (1000 ppb over a 10 ppb background) which are 600 - 900 m in width. Other elements show narrower dispersions. Superimposed on these broad gold anomalies are narrow, subsidiary peaks (10 000 ppb), specifically in the coarse lag, which accurately locate the ore. The wide dispersion of gold reflects chemical dispersion in the saprolite and lateritic duricrust, prior to mechanical dispersion of the lag on the surface. This is supported by the association of gold grains with vesicles and late goethite and even clay phases in the lag.

The fine lag is the most useful sampling medium and is best suited as a regional tool. The coarse lag, which is more tedious to collect, has use in follow-up work. No advantage is gained in analysis of the magnetic component, as it fails to give anomalies in Co, Cu, Se and Zn and the Au anomaly is not as distinct. This occurs because the important, non-magnetic, cellular ironstone or gossan component is excluded.

Geomorphology, petrography, maghemite, lag geochemistry, magnetic lag, mechanical dispersion, phyllite, duricrust, primary fabric, secondary fabric, Permian glacial, mica relic, accordion fabric, gold grain.

LEME Open File Report 11

Mineralogy and geochemistry of weathered shale profiles at the Panglo Gold Deposit, Eastern Goldfields, WA

Scott, K.M.

Profiles through weathered shale derived from reverse circulation drill holes at Panglo have been analyzed mineralogically by X-ray diffractometry. Quartz, muscovite, kaolinite, Fe oxides and halite are ubiquitous through such profiles but zones characterised by the presence of alunite or paragonite or the carbonates, siderite and dolomite, may be usefully employed during exploration. In weathered shale at Panglo, alunite appears to be developed to a greater depth above mineralization whereas paragonite occurs to higher levels in barren sequences. Carbonates occur between the mineralized intervals in one hole and may represent original hypogene wall-rock alteration

Molybdenum and Sb are the best pathfinders for Au with As, Tl and W also useful in specific cases. Elements like Ag, Cu, Pb, Sn and Zn are not consistently associated with the mineralization in the weathered shales at Panglo. The low Sr contents through the profile above mineralization may also be an indicator of mineralization.

LEME Open File Report 12

Mineralogy and geochemistry of mineralised and barren weathered profiles, Parkinson Pit, Mt Magnet, WA

Scott, K.M.

In both mineralised and barren profiles in the northern portion of the Parkinson Pit at Mt Magnet, progressive zonation occurs from a calcite (calcrete) zone through mica-rich and ferruginous assemblages into chlorite-dolomite assemblages before passing into unweathered pyrite-dolomite-siderite-bearing rocks. However, the barren profile shows the development of Na- and Ca-rich micas rather than muscovite. Ferruginization is more consistently present in the mineralised profile.

The elements Co, Cu, Ni, Sc, Ti, W and Zn are associated with Fe in highly ferruginous samples. The effect of discrete vertical zonation is reflected by surface enrichment of Ca, Mg, Ba, Sr, Ga and Zr and depletion in Co. However the most significant feature is the association of Ag, As, Mo and Sb with Au in the weathered profile. Readily mobilised elements like Co, Cu and Ni which occur within the pyrite are associated with Fe and are not good pathfinders for Au.

Weathering in the southern portion of the Parkinson Pit gives rise to essentially similar mineralogical zonation to that in the north except that a thick kaolinite blanket is developed in the top 20 m. Thus weathering conditions may have been more acidic in this portion of the pit.

LEME Open File Report 13

Mineralogical and geochemical studies of gossan and wall rocks, Bottle Creek, Western Australia

Taylor, G.F.

Samples of surface gossan from Emu, VB and Boags (VB South) prospects, and of subsurface gossan and mineralized weathered wall rocks from diamond drill core at Emu and VB prospects have been examined mineralogically and geochemically.

Mineralogy consists of quartz, muscovite, kaolinite, goethite, hematite in variable quantities with subordinate talc, rutile, tourmaline and manganese oxides. Secondary minerals of the jarosite and alunite supergroups are common in the gossans and wall rocks respectively. Pyrite is the predominant sulphide in protore with minor tetrahedrite, sphalerite, arsenopyrite, marcasite and magnetite.

Anomalous concentrations of Ag, As, Au, Cu, Pb, Sb and Zn in protore are reflected in gossan and mineralized wall rocks, although there is a marked depletion at the surface. These elements are therefore considered to be reliable pathfinder elements. Concentrations of Hg, Te and Tl are also considered anomalous, but because of low absolute values and difficulty of analysis, are not considered to be viable pathfinder elements. The nature of concentrations of Mn, Ti, B and Ba within the mineralized horizon is not yet established and analysis of both mineralized and unmineralized country rocks is necessary before they can be considered as pathfinder elements.

Lack of geochemical anomalies in soils supports previous observations (van der Heyde, 1988) that the regolith stratigraphy at VB is transported and represents colluvial-alluvial material on the floor of a drainage channel. Additional research relevant to present and longer-term exploration is indicated.

LEME Open File Report 14

Mineralogy and geochemistry of weathered mafic-ultramafic volcanics from section 4200N at Panglo, Eastern Goldfields, WA

Scott, K.M.

A total of 62 samples, derived from reverse circulation drilling through weathered volcanic sequences on the western edge of the Panglo gold deposit, have been analysed chemically and mineralogically. On the basis of their Cr contents, they have been classified as either mafic or ultramafic rocks. Higher Cr contents in the oxide phases, goethite, rutile and spinel, also appear to distinguish ultramafic from mafic rocks.

More extensive development of alunite and paragonite, which characterise mineralised and barren shale profiles respectively (Scott, 1989a), are not present in the weathered volcanic profiles. However, near-surface Au enrichment (>0.05 ppm) in the volcanics is associated with elevated As and sometimes Mo, Sn and W contents. These elements, plus Cu and Sb, are also associated with sub-economic mineralisation at depth. Thus, similar pathfinders are present in both shale and volcanic sequences at Panglo.

LEME Open File Report 15

Mineralogy and geochemistry of some weathered rocks from Callion Gold Deposit, Yilgarn Block, WA

Llorca, S.M.

Weathered profiles at Callion are the host of economic gold mineralization. This report starts the documentation of these profiles, which ultimately will enable us to understand the weathering processes and the distribution of gold and associated elements in the weathered profile. Data reported here concern the mineralogy and geochemistry of the upper weathered wall-rocks from the BC Pit at the northern end of the Callion mineralization.

Two geological formations were characterised, showing slightly different compositions.

The *in-situ* weathered rock is essentially composed of kaolinite and quartz gradually replaced by goethite. With the progressive decrease of Al and Si and the concentration of Fe, we observed a progressive dispersion of Ti, Mg, K, Na, Cl, Sr and Y and concentration of S and Cu.

An allochthonous formation at the northern end of the BC pit is composed mainly of hematite, goethite and alunite. In this formation, Si, Ba, Cu and Zn show a depletion whereas Ti, S, CO_2, As, Cr and Zr are concentrated. The presence of alunite indicates the presence, at some stage, of sulphate-rich groundwaters.

LEME Open File Report 16

Mineralogy and geochemistry of the Glasson Gold Deposit, Callion, Yilgarn Block, WA

Llorca, S.M.

This report describes a mineralogical and geochemical study of the weathered Glasson Au deposit and its country-rocks, in the Callion area, Yilgarn Block, Western Australia. The fresh country rocks are amphibole- and plagioclase-rich metabasalts. On weathering, the amphibole and plagioclase are initially replaced by smectites, opaline silica and kaolinite, and then, higher in the profile, by kaolinite, opaline silica and goethite. As the amphibole and plagioclase are weathered, Ca, Mg, Mn and some Si are leached; as, in turn, the smectites are consumed, the remaining Mg, Co and some more Si are leached away. This results in an increased relative concentration of elements such as Fe, Al, Ti, Cr, Cu, Zr, Ga and Sc. Nickel and Zn seem to accumulate in this part of the profile where smectites disappear.

The fresh mineralization consists of quartz veins within a shear zone containing additional amphibole, chlorite and mica, plus small amounts of sulphides. Gold is present both as free Au in the quartz and in the sulphides. In the overlying weathered zone, the sulphides are replaced by mixtures of goethite and rutile. Amphibole and chlorite are gradually replaced by smectites and kaolinite, passing upwards to kaolinite and goethite. Mica is residual, though it is altered to hydromica. Some halite has precipitated from groundwaters permeating the shear zone.

Lateritization occurred under humid conditions during the Cretaceous to mid Miocene. As the sulphides weathered, Cu, Zn, As, Au, Pb and W were mobilized. These elements precipitated with the goethite, both within the weathered sulphide zone and in the country-rock (as far as 10-20 m away for As, Pb, Au). Although the Au included in the sulphides was redistributed, Au in the quartz vein remained *in situ*. Some of this Au was still protected by the quartz and the Au located along the fractures which was attacked (its Ag leached), and the Au was re-cemented virtually in situ by the goethite precipitated in these fractures. Previously deposited secondary Au was also partially re-cemented in the fractures within goethite. Chloride-rich solutions that circulated along the quartz vein under the post-lateritisation arid conditions mobilized some of the Au that had been so far protected by the quartz. This Au was redeposited within the quartz vein and within 20 cm of it.

During the Cretaceous to mid Miocene humid period, Au close to the surface was remobilized and dispersed for up to 100 m from the quartz vein, probably by complexing with humic acids derived from soil organic matter. In the drier climates that followed, calcrete formed close to the surface and Au was fixed within it. Finally, mechanical dispersion at the surface caused As, Au, Pb and Cr enrichments in the pisolitic cover as far as 100 m away.

In a context such as the one of the Glasson deposit, the best indicators for Au mineralization are Au, As and, to a lesser extent, Pb and W. Chromium seems a good indicator of the shear zones.

LEME Open File Report 17

Mineralogy and geochemistry of mineralised and barren felsic volcanic profiles, Parkinson Pit, Mt Magnet, WA

Scott, K.M.

Study of profiles through felsic rocks below a thin soil in the southern portion of the Parkinson Pit at Mt Magnet shows zonation: goethite -> muscovite-kaolinite -> muscovite-kaolinite-goethite -> albite-goethite -> fresh rock. Calcrete may also be developed at the soil-rock interface. Bands of mafic rock within these profiles are similar mineralogically to adjacent felsic rocks but they do have greater Ti, Co, Cr. Ni, Sc and V contents than the felsic rocks.

The elements, Co, Cu, Ni, Sc, W and Zn which were found to be strongly associated with ferruginous rocks in mafic profiles are similarly associated in the felsic profiles. Of the pathfinders, Ag, As, Mo and Sb, associated with Au in mafic profiles, only As has been found useful in felsic rocks. However, in these rocks W and B also appear to be associated with Au.

LEME Open File Report 18

Report on laterite geochemistry in the CSIRO-AGE Database for the Northern Murchison Region (Cue, Belele, Glengarry, Sandstone sheets)

Grunsky, E.C., Smith, R.E. and Perdrix, J.L.

A multi-element geochemical study has been carried out upon laterite and ferricrete samples that cover parts of the main greenstone belts of the CUE, BELELE, GLENGARRY, and SANDSTONE 1:250,000 map sheets. This report presents a summary of the data, and a provisional interpretation of selected parts of the data. The data used in the study are contained in the accompanying diskette (in the back pocket).

The sampling arose as part of a combined research programme at CSIRO and an experimental exploration programme (the AGE Joint Venture Programme) during the period 1983 to 1986.

In the region covered by the present report a total of 1065 samples were analyzed for 30 elements. Summary statistics, histograms, and maps of the percentile classes, are presented for selected elements in laterites and some very Fe-rich materials from partly eroded profiles which have been referred to as ferricretes.

The database that was used for the study is dominated by two major sample types, laterites and ferricretes. The two sample media have different geochemical characteristics, and thus have been treated separately. Lateritic sample media are abundant in the southwestern parts of the area and ferricrete sample media are more abundant in the northern and eastern parts of the area. The study also provides knowledge of the element abundance levels and variation of laterite and ferricrete geochemistry that complement information arising from orientation studies about mineral deposits.

The geochemical characteristics of the area have been studied using four techniques.

a) Exploratory data analysis techniques were employed to rank the data for each element. Samples that rank in the upper percentiles for selected elements (chalcophile) have been considered as significant for further exploration follow-up.

b) Principal components analysis of the multi-element data was used for the purpose of isolating significant linear combinations of elements that are associated with dispersion haloes within potentially mineralized zones. The results of the analysis also confirm the presence of some broad regional geochemical trends that are related to bedrock lithologies and regional alteration processes.

c) Chalcophile and pegmatophile indices were computed for the purposes of isolating areas that are enriched in elements that are commonly associated with several types of mineral deposits. These indices are based on the cumulative concentrations of selected elements and outline regions where further exploration follow-up may be warranted.

d) χ^2 (Chi-square) plots provide a means of isolating multi-element outliers from the background population of samples. These outliers may be related to multi-element dispersion haloes that surround many types of mineral deposits and may warrant further exploration follow-up.

Application of the above methods of data analysis have outlined the following dominant geochemical features.

a) district-scale (10 to 30 km in length) patterns in the distribution of Cu + Zn + Ni + Co ± Cr; V + Sn; and Zr + Nb; each pattern appearing to relate to the dominant characteristics of varying bedrock associations;

b) an As + Sb + Mo + Sn + Be + W + Au association in the Weld Range - Meekatharra -Gnaweeda greenstone belts trending northeasterly which infers the presence of a chalcophile corridor;

c) an association of Au and W within selected laterite samples in the Dalgaranga greenstone area;

d) an association of Au and Sb within selected ferricrete sample in the Weld Range - Meekatharra - Gnaweeda greenstone areas;

e) several anomalies at the 1 km scale that require follow-up sampling in order to assess their continuity and significance. These anomalies have been determined by a variety of methods. The most anomalous samples tend to occur as outliers when these methods are applied.

Sporadic Au anomalies also occur. However, the general sample spacing of 3 km with fill-in sampling at 1 km is too wide for reliable interpretation of Au patterns in laterites. Laterite and ferricrete geochemistry at these low sample densities generally requires the use of intermediate zonal targets, such as anomalous chalcophile envelopes, which can occur about individual deposits.

LEME Open File Report 19

The mineralogy and geochemistry of soils overlying the Beasley Creek Gold Mine - Laverton, WA

Robertson, I.D.M.

Samples of the generally thin soil were collected along two traverses over the Beasley Creek Mine Site, prior to mining. The soil and its components have been examined petrographically, mineralogically and geochemically.

The coarse fraction (710 4000 m) consists of black, goethite and hematite rich nodules (some of which are magnetic), red to yellow ferruginous clay granules, quartz fragments and scarce fragments of calcrete, hardpan and cellular ironstone. The 710-4000 µm fraction is petrographically indistinguishable from the fine lag which was formed by deflation of the top layers of soil. The fragments of cellular ironstone, which are probably gossanous, are slightly more abundant near the subcrop of the ore.

The black, goethite- and hematite-rich fragments contain lithorelics which have microscopic remnants of muscovite and pseudomorphs after kaolinite, set in, and largely replaced by, massive, spongy or vesicular goethite. The clay-rich granules consist largely of hematite- or goethite-stained kaolinite and some include goethite-rich lithorelics. The soil also contains a significant, quartz-rich, wind-blown component, most abundant in the 75-710 µm fraction, which acts as a geochemical diluent. These subrounded, sand to silt-sized particles, which include a few grains of fresh microcline, are coated with red iron oxides. The silty fraction (<75 µm) contains less quartz but more iron oxides and day. The <4 µm fraction is very clay rich.

Sieving and clay sedimentation were used to separate the soil into the 710-4000, the <75 and the <4 µm fractions. The complete soil and its constituent size fractions were geochemically analysed to assess their value as sampling media. The 75-710 µm fraction has a significant component of aeolian sand and was discarded. The distributions of As, Au, Cd, Cu, Sb, Se, W and Zn are related to the occurrence of mineralisation, with anomalies centred over the subcrop of the shales hosting the ore. Maxima in Ca, Mg, P and Sr delineate the calcretes, the P peak being probably related to bone fragments from burrows under the calcrete. The phyllitic ore host rock is indicated by maxima in Ba and Mn and possibly by a decrease in Y. The explanation for a maximum in S over the ore and its host rock is problematical.

The complete soil has clearly been diluted by wind-blown sandy material and it is less effective than its fractions as a sampling medium. The most effective medium is the ferruginous 710-4000 µm fraction, followed by the <4 µm clays. The <75 µm silt fraction also contains a significant wind-blown component and is the least effective size fraction.

LEME Open File Report 20

Gold morphology and composition at Panglo, Eastern Goldfields, WA

Scott, K.M. and Davis, J.J.

Coarse >80 µm gold from the mineralised horizon in the weathered zone at 30 to 40 m below the surface at Panglo may be xenomorphic or euhedral. Xenomorphic forms are composed of pseudohexagonal platelets which are often severely pitted and may also have ?cryptocrystalline spherules within pits and voids. Euhedral gold occurs as aggregates or as single dodecahedral or elongate crystals. No Ag was detected in any of the grains studied. All the above features are consistent with the gold being supergene, possibly forming during lateritization and being corroded during the subsequent arid period.

LEME Open File Report 21

Hydrogeochemistry in the Mt Gibson Gold District

Gray, D.J.

Research was conducted into the hydrogeochemistry of groundwaters within the Mt Gibson mine area and in the surrounding district. This work involved determination of field parameters such as pH and Eh, laboratory analysis of water samples for major and trace elements, isotope determinations (D and O^{18}), computer speciation of analytical data, and statistical analysis of the water data.

The groundwater system is dominated by a northward saline drainage system. Groundwater flow along this drainage appears to be restrained by an underground sill about 7 km north of the mine area, resulting in highly saline groundwaters within the mine region. This saline groundwater appears to flow back, south into the mine area, at depth. Thus, the north section of the mine area has fresher waters (about 3% TDS) overlying hypersaline water (> 13% TDS).

Based on the major element and isotope analyses, the mine groundwaters were resolved into a number of hydrogeochemically distinct water masses. In particular, the waters from drill hole sample sites 600 m west of the major area of supergene Au mineralization at Midway were identified as probably originating from contact with granitic rocks. The other mine groundwaters appear to be associated with mafic or ultramafic systems.

Waters within the Midway area showed highly anomalous characteristics, being high in dissolved Au, Fe, Mn, Co, Cd, Ba and I, and having low HCO_3 concentrations. These observations are explained as being due to weathering of sulphide minerals. Down gradient of the Midway area, the groundwater becomes acidic, due to oxidation-hydrolysis of the dissolved Fe. This has led to major dissolution of many metals, particularly (in order from least to most enriched) Cd, Co, Ni, Zn, Cu, Cr, Al and Ag. This enrichment is related to the base affinity of the metals.

Soluble Au was only observed above the detection limit (0.05 µg/L) within the mineralized area. Two major anomalies were recognized: the first, within the Midway area, may represent dissolution of Au by thiosulphate; while a second, more localized anomaly, within the N2 pit area may represent dissolution by chloride.

On the basis of this work, soluble Au analyses could be used at this site to indicate areas of Au mineralization at both a district and a mine scale. Thus, measurements of dissolved Au may represent a useful adjunct to drilling during Au exploration, particularly with respect to buried mineralization.

LEME Open File Report 22

Laterite geochemistry in the CSIRO-AGE Database for the Central Yilgarn Region (Barlee, Bencubbin, Corrigin, Hyden, Jackson, Kalgoorlie, Kellerberrin, Southern Cross sheets)

Grunsky, E.C.

A multi-element geochemical study has been carried out based upon laterite samples that cover parts of the main greenstone belts and portions of the granitoid-gneiss terrain of the BARLEE, JACKSON, KALGOORLIE, BENCUBBIN, KELLERBERRIN, SOUTHERN CROSS, CORRIGIN, and HYDEN 1:250 000 map sheets. This report presents a summary of the data and a provisional interpretation of selected parts of the data. The data used in the study are contained in the accompanying diskette (in the back pocket).

The sampling arose as part of a combined research programme between CSIRO and an experimental exploration programme (the AGE Joint Venture Programme) during the period 1983 to 1986. The study provides geochemical knowledge of the element abundance levels and shows variations in the geochemistry of lateritic and associated ferruginous materials, geochemistry that complement more specific information arising from orientation studies about mineral deposits.

The database which was used for the study is dominated by two major lithological groups: greenstone and granitoid rocks. The two lithologies have different geochemical characteristics, and thus have been, for the most part, treated separately. The database consists of both regional and follow-up samples. Most of the investigation for this report has emphasized the results from the regional samples as this will provide information for additional regional sampling programmes for the sponsors.

Laterite is by far the dominant material sampled in the area. The ferricretes, which are second priority in sampling, are represented by 184 samples, while the laterites are represented by 1815 samples.

In the region covered by the present report, a total of 2102 samples were analyzed for 30 elements. Summary statistics, histograms, and maps of the percentile classes are presented for selected elements in laterites. Several numerically-based procedures were applied for the purposes of outlining regional trends and detecting areas of relatively-high abundances of selected elements (anomalies). Numerical techniques included the use of ranking of individual elements, principal components analysis, CHI-6*X, PEG-4, and NUMCHI indices, and multivariate ranking of the chalcophile elements χ^2 plots).

The resulting scores of these techniques have been ranked and plotted on maps and scatter plots. The most anomalous samples tend to occur as outliers when these methods are applied. The results of these applications confirm the presence of some broad regional geochemical trends that are related to bedrock lithologies and possible regional alteration processes.

The dominant geochemical features are:

Several multi-element associations occur with Au, primarily in the greenstone belts, and a few in the granitoid-gneiss terrain. The characteristic elements are, Sb, Se, Ag, W, As, and Sn.

Several Au anomalies occur in the Diemals, Marda, and Southern Cross greenstone belts.

Regional, geochemical features that are characteristic of the greenstone belts are defined by higher relative abundances of Cr, Mn, V, Zn, Ni, Co, and Fe_2O_3.

A chalcophile trend may be present striking parallel to the Southern Cross belt, parallel to the Johnston Range in the Diemals area, and parallel to the stratigraphy in the Marda complex.

Additional elevated abundances of Sn, W, Mo and P occur throughout the felsic and greenstone terrains and may be the result of mineralization, alteration, or fractionation. These anomalous areas should be followed up with several models in mind.

Broad, regional, geochemical features, characteristic of the granitoid-gneiss terrain, are defined by higher relative abundances of Nb, Ga, Mo, and Pb.

Elevated Au and chalcophile abundances occur within the gneiss terrain in the Kellerberrin area. These areas may be previously unrecognized greenstone enclaves and may warrant further investigation.

The use of ranked data, empirical indices, principal components, and chi-square plots is discussed as a means of determining anomalies as target sites for mineral exploration.

LEME Open File Report 23

Morphology and geochemistry of particulate gold in the lateritic regolith, Mystery Zone, Mt Percy, Kalgoorlie, WA

Gedeon, A.Z. and Butt, C.R.M.

The characteristics of grains of free gold in different horizons of the lateritic regolith have been studied at the Mystery Zone of the Mt Percy mine, Kalgoorlie. Primary mineralization consists of Ag-rich (to 50% Ag) free gold and Au and Ag tellurides in pyritic carbonate alteration zones and quartz veins. The gold distribution in the regolith is typical for the region, with minor enrichment and wide lateral dispersion in surficial lateritic gravels and duricrust, leaching and depletion in the underlying clay-rich horizons (5-15 m depth) and some secondary concentration and possible minor dispersion within the saprolite.

Gold grains have been mechanically panned and examined by scanning electron microscopy, observing particularly their size, shape, morphology, condition and composition. Primary gold grains persist only into the lower saprolite, where they are associated with Ag-poor secondary gold and Ag halide crystals. Secondary gold was recovered from all horizons of the regolith except from the depleted zone. Several different morphologies have been observed, namely subhedral to euhedral crystals, anhedral (including xenomorphic) forms and irregular, hackly aggregates having the form of three-dimensional dendritic growths. The majority of grains are less than 50 µm in diameter and most are nearly equant in shape. Most grains are corroded, some severely so, whereas others are pristine, and it is assumed that these represent several generations of gold mobilization and precipitation. Only very few gold grains were recovered from the lateritic duricrusts and gravels or soils and it is assumed that most of the gold in these horizons is present as very fine particles in secondary iron oxides or pedogenic carbonates.

The observed gold distribution is probably the result of two or three mechanisms of chemical dispersion. Firstly, mobilization occurred during lateritization, when most, if not all, primary gold in the duricrust was dissolved and presumably reprecipitated as very fine particles with iron oxides. The second phase has been during later arid periods, when primary gold remaining in the saprolite has been dissolved by saline groundwaters and, in particular, leached from the upper clay-rich horizons, and reprecipitated as Ag-poor grains, again in the saprolite. Finally, remobilization via vegetation has led to the accumulation of gold in the pedogenic carbonates.

LEME Open File Report 24

The mineralogical and geochemical effects of weathering on volcanics from the Panglo Deposit, Eastern Goldfields, WA

Scott, K.M.

Profiles above ultramafic and mafic volcanics at Panglo are characterized by the development of a surficial ferruginous calcrete zone which is not present above shales. This zone bears Au ~0.05 ppm and is generally characterized by elevated As, Ba, Cr, Mo, Sb, Sr, V and Zr contents relative to underlying rocks. Higher levels of Au and associated elements (As, Mo and Sb) are present directly above Au mineralization at depth.

Ultramafic rocks generally have high Mg, Cr and Ni contents reflecting the presence of chlorite-vermiculite and talc through the weathered profiles. Where weathering is particularly intense, these minerals may be destroyed and smectitic clays developed. Mafic volcanic profiles show greater development of micas and hematite than those above ultramafic rocks. Substantial paragonite is present in the barren profiles but not in the mineralized profiles.

Within both ultramafic and mafic rocks the mineralization is associated with elevated levels of S, Ag, As, Co, Mo, Sb, W and Zn. Sometimes these elements may be found for 5 m vertically above mineralization in ultramafic profiles. However mineralized mafic volcanic profiles may have very high levels of As and W for ~50 m above mineralization.

LEME Open File Report 25

Electron microprobe studies of minerals from weathered profiles, Parkinson Pit and environs, Mt Magnet, WA

Scott, K.M.

Major and trace element data for more than 100 minerals from 24 separate samples reveal the host minerals for specific elements during weathering processes at Mt Magnet.

Resistant minerals like rutile, spinel, tourmaline and mica retain their component elements through the weathering profile with a low Fe* (i.e. Fe/(Fe + Mg + Mn) ratio for muscovite and tourmaline indicating proximity to mineralisation. Gold and talc are not so resistant to weathering, with gold losing its Ag content during weathering processes at Mt Magnet. Sulphides, chlorite, feldspars and carbonates are readily destroyed during weathering with their component elements either incorporated into Fe and Mn oxides, kaolinite and smectitic clay or lost to the profile by dispersal by groundwaters. The Fe oxides are particularly important hosts for Au-pathfinder elements (e.g. As, Sb and W). Chlorite, carbonate and sulphide compositions may reflect proximity to mineralisation and be useful in deep profiles but because of their susceptibility to weathering they are not as versatile as mica or tourmaline.

The Cr contents of each of chlorite, muscovite, rutile and perhaps spinel, indicate the lithology of their host samples by showing decreasing Cr contents from ultramafic to mafic to felsic rocks.

LEME Open File Report 26

Multi-element dispersion in the saprolite at the Beasley Creek Gold Mine, Laverton, Western Australia

Robertson, I.D.M.

A fence of 11 inclined percussion drill holes, which crossed from the hangingwall to the footwall of the Beasley Creek Orebody, was selected for study of geochemical dispersion in the near surface materials and in the deep saprolite. Of these, four drillholes intersected the ore, its immediate foot- and hangingwall rocks and overlying calcretes, another four intersected amphibolitic saprolites and clay-rich materials proximal to the ore (40-160 m distant) and a further three cut amphibolites and amphibolitic saprolites distal to the ore (250-400 m distant). Samples were selected from these to maximise geochemical detail near the surface and to give adequate information to bedrock or to the limit of the drilling (60-100 m). They were analysed for eight major and 28 trace elements.

The zone around the orebody has been intensely weathered to below the depth of current diamond drilling (230 m) but amphibolites 400 m to the west are only weathered to a depth of 40 m. This locally intense weathering appears to be due to acid conditions generated by the weathering of sulphides in the orebody and its sulphidic host rock. The surficial materials immediately to the east of the ore host unit (to a distance of at least 75 m) contain calcrete and some gypcrete.

Some Rb- and muscovite-rich rocks in the footwall, enriched in Au, As, Cd, Cu and Pb and sporadically enriched in Ag, Bi, Mo, Sb, Sn and W, form an ill-defined zone about 100 m wide, 150 m to the west of the orebody, at a depth of 20-50 m. This zone, which straddles the saprolite-saprock boundary, appears to be a partly weathered phyllic alteration halo which apparently has not been fully investigated by drilling.

Apart from Au, the orebody is characterised by elevated concentrations of Ag, As, Cd, Cu, Pb, Sb, W and Zn. The lateritic duricrust and mottled zone are weakly enriched in Ag, Nb and W but are generally strongly enriched in As, Bi, In, Pb, Sb, W and Sn which enhances the value of these elements as pathfinders. Cobalt, Zn and Cu tend to be depleted near the surface, reducing their effectiveness as pathfinders but they show some enrichment below the mottled zone. Bismuth, Ge and In are at low abundances and have only sporadic anomalies so, despite some surficial enrichment, they are not very effective near the surface. Both Pb and Sb are also at low abundances but they tend to be strongly concentrated a little further below the surface, so their surficial anomalies are not readily interpreted. High concentrations of Al, Fe, Ba, Ce, Cr, Ga, Mn, Ni, Rb, V and Y reflect the composition of the host lithology.

LEME Open File Report 27

Laterite geochemistry in the CSIRO-AGE Database for the Wiluna Region (Duketon, Kingston, Sir Samuel, Wiluna sheets)

Grunsky, E.C.

A multi-element geochemical study has been carried out on laterite and ferricrete samples that cover parts of the greenstone belts and portions of the granitoid-gneiss terrain of the DUKETON, KINGSTON, SIR SAMUEL, and WILUNA 1:250 000 map sheets. The report presents a summary of the data and a provisional interpretation of selected parts of the data. The data used in this study are contained in the accompanying diskette (in the back pocket).

The sampling arose as part of a combined research programme between CSIRO and an experimental exploration programme (the AGE Joint Venture Programme) during the period 1983 to 1986. The database which was used for the study is composed of predominantly supracrustal metavolcanic and metasedimentary rocks over four supracrustal sequences; the Duketon, Dingo Range, Lake Violet-Milrose-Yandal, and Wiluna-Mt Keith-Perseverance-Agnew greenstone belts.

Laterite and ferricrete are both abundant materials in this area. The laterites are predominantly composed of loose nodules and mottled zone scree and number 272 samples. The ferricrete materials are mostly massive and fragments of ferricrete, numbering 174 samples. Fifty samples of lateritized rock are also included in the database but were not included in the interpretation.

A total of 496 samples were analyzed for 30 elements. Summary statistics, histograms, and maps of the percentile classes are presented for selected elements in laterites. Several numerically-based procedures were applied for the purposes of outlining regional trends and detecting areas of relatively-high abundances of selected elements (anomalies). Numerical techniques included the use of principal components analysis, ranking of individual elements, ranking of CHI-6*X, PEG-4, and NUMCHI indices, and multivariate ranking of selected chalcophile elements (χ^2 plots).

The resulting ranked scores of these techniques have been plotted on maps and scatter plots. The most anomalous samples tend to occur as outliers when these methods are applied. The results of these applications confirm the presence of some broad regional geochemical trends which are related to bedrock lithologies and possible regional alteration processes.

The dominant geochemical features are:

Several multi-element associations with Au have been noted in the Rose Hills, Milrose, and several localities in the Duketon greenstone belt.

Several Au anomalies occur in the Rose Hills, Milrose, southeast corner of the WILUNA sheet, and in the southern part of the Duketon greenstone belt on the DUKETON sheet.

Several individual elements (Bi, Mo, Sn, W, Ag, Nb, Se) indicate that the Rose Hills, Milrose, and Biddy Well areas are the most favourable areas for exploration on the WILUNA sheet and the Quongdong Well, Urarey Well, Christmas Well (Erlistoun), and Swanson Hill areas are the most favourable on the DUKETON sheet.

Regional, geochemical features that are characteristic of the greenstone belts are defined by higher relative abundances of Cr, Mn, V, Zn, Ni, Co, and Fe_2O_3. Geochemical features, characteristic of the marginal granitoid-gneiss terrain, are defined by higher relative abundances of Nb, Ga, Mo, and Pb.

The data and results presented in this report may provide sufficient information for a selective and cost efficient exploration programme.

LEME Open File Report 28

Laterite geochemistry in the CSIRO-AGE Database for the Albany-Fraser Region (Collie, Dumbleyung, Mt Barker, Pemberton sheets)

Grunsky, E.C.

A multi-element geochemical study has been carried out on laterite and associated ferruginous samples that cover parts of the granitoid-gneiss terrain of the COLLIE, DUMBLEYUNG, MOUNT BARKER, and PEMBERTON 1:250 000 map sheets. The report presents a summary of the data and a provisional interpretation of selected parts of the data. The data used in this study are contained in the accompanying diskette (in the back pocket).

The sampling arose as part of a combined research programme between CSIRO and an experimental exploration programme (the AGE Joint Venture Programme) during the period 1983 to 1986. The database which was used for the study is composed of laterite and associated ferruginous samples collected over predominantly gneissic and felsic intrusive rocks that span the Archaean Yilgarn Block and the Proterozoic Albany-Fraser Province. The data were split into two groups representing the distinctions between the two geological provinces. Laterite is the most abundant material. The laterites are predominantly composed of loose nodules and pisoliths and number 543 samples in the Yilgarn block, and 456 samples in the Proterozoic province.

A total of 1026 samples were analyzed for 30 elements. Summary statistics, histograms, and maps of the percentile classes are presented for selected elements in laterites. Several numerically based procedures were applied for the purposes of outlining regional trends and detecting areas of relatively-high abundances of selected elements (anomalies). Numerical techniques included the use of principal components analysis, and ranking of individual elements, ranking of CHI-6*X, PEG-4, and NUMCHI indices, and multivariate ranking of selected chalcophile elements (χ^2 plots).

The resulting ranked scores of these techniques have been plotted on maps and scatter plots. The most anomalous samples tend to occur as outliers when these methods are applied. The results of these applications confirm the presence of some broad regional geochemical trends that are most probably related to lithological variation within the granitoid-gneiss terrane.

There are significant geochemical distinctions between the laterites developed over the Archaean terrain (Yilgarn) and the laterites developed over the Albany-Fraser Orogenic belt based on the examination of histograms, order statistics, and a discriminant function analysis. Yilgarn laterite samples contain greater mean abundances for Ti, Mn, V, Zn, Sn, W, Ga, Nb, Zr, and Ba. Albany-Fraser laterite samples contain greater mean abundances for Cr, Ni, As, Sb, Bi, Mo, Se and Au.

The essential geochemical features of the area are:

Yilgarn Laterites
Gold occurs as individual Au anomalies as well as multi-element associations with Sb, W, Mo, Pb, and As in Whistlers, Darling Hill, Muradup, Boscabel, north of Trollup Hill, Peringillup, and Cranbrook areas.

Areas with the greatest Sn, W, Nb, Ta potential occur in the Whistlers, Darling Hill, Darkan, Quindanning, Boscabel, north of Trollup Hill and Peringillup areas.

Molybdenum occurs with Sn and As in the Whistlers, Darling Hill, Darkan, Boscabel and north of Trollup Hill areas.

Tungsten is associated with As, Mo, Sb, Pb, and Au and as isolated anomalies. Tungsten anomalies occur in the Whistlers, Darling Hill, Darkan, Quindanning, and Boscabel areas.

Silver appears to have a very limited multi-element association with the exception of a slight association with Pb and Ga. Elevated Ag occurs in the Whistlers, Darling Hill, Darkan, and Boscabel areas.

Albany-Fraser Laterites
Elevated multi-element abundances of Au occur with Sn, Sb, W, and Sn. The areas which contain these multi-element associations include the Carbarup Hill, Mt Barker, Denbarker, Lake Katherine, and Lake Muir areas.

Tin and Nb occur as single and multi-element associations southeast and southwest of Denbarker, north of Mt Barker, and the Lake Muir areas. Tin is also associated with Nb, Mn, Zr, Au, Mo, Sb, and Se in the Denbarker to Lake Katherine and Lake Muir areas.

Molybdenum occurs as single and multi-element associations with As, Rb, Pb; As, Ni, Zn, and Cr; Ni, Sb, and Co in the Carbarup Hill, Denbarker to Lake Katherine, north of Lake Muir, and Mt Barker areas.

Tungsten occurs with little or no multi-element signature. Elevated abundances of W occur in the Denbarker and Lake Muir areas.

Silver occurs with virtually no multi-element signature. Elevated abundances of Ag occur south of Denbarker, west of Lake Katherine, and the Lake Muir areas.

Other elements are difficult to assess individually. Since most economic commodities being sought have multi-element geochemical signatures, it makes sense to employ methods that make use of these multi-element characteristics. The results of the principal components analysis, the CHI-6*X, PEG-4, and NUMCHI indices, and Mahalanobis distance methods all show zones that have multi-element enrichment and indicate that the areas mentioned above may warrant additional follow-up investigation. Exploration for Au and associated precious metal deposits may be assisted by the use of several of these multi-element methods.

The data and results presented in this report, plus additional geophysical lithological, lithogeochemical, and structural data, may provide sufficient information for a selective and cost efficient exploration programme.

LEME Open File Report 29

Gold and associated elements in the regolith - dispersion processes and implications for exploration. P241 Final Report

Butt, C.R.M., Gray, D.J., Lintern, M.J., Robertson, I.D.M., Taylor, G.F. and Scott, K.M.

This report summarizes, integrates and discusses the results of over three years of research. The research had the objectives of (a) obtaining a better understanding of the nature and genesis of the regolith and the lateritic and saprolitic gold deposits contained within it, and (b) determining characteristics useful in exploration for further such deposits and for primary mineralization. These rather broad, strategic objectives have been met by some specific lines of research carried out at 16 different sites, mostly in the Yilgarn Block, and have been reported in about 40 Investigation Reports. Some of the highlights of the research include:

1. Data on multi-element dispersion in the regolith at nine mine sites, demonstrating the geochemical expression of gold mineralization.
2. Detailed mineralogical, petrographic and geochemical studies of a range of different lithologies as an aid to bedrock identification from weathered material.
3. Petrographic studies of rock weathering and (in collaboration with AMIRA Project 240), demonstration of the origins of the components of ferruginous lag.
4. A comparison of the morphologies and compositions of gold grains in semi-arid and humid tropical regions, and the implications for gold mobility and the genesis of supergene gold deposits.
5. Demonstration of the significance of soil carbonate horizons as sample media in gold exploration.
6. Demonstration of the existence and characteristics of groundwaters mobilizing gold under present conditions.
7. Further investigations of the chemistry of gold in the weathering environment and demonstration of the high solubility of gold in some soils.
8. Mineralogical and geochemical characteristics of a continuous section through primary gold mineralization (Mt Percy).
9. Data on the biogeochemical expression of gold mineralization.

LEME Open File Report 30

The mineralogical and geochemical effects of weathering in mafic and ultramafic profiles, Mt Magnet, WA

Scott, K.M. and Martinez, A.

Material from five drill holes located up to 300 m west of the Parkinson Pit have provided a suite of mafic volcanic rocks with which the effects of proximity to mineralization and alteration in the weathered zone can be determined. Fresh barren rocks consist of assemblages of calcite + dolomite + albite + chlorite ± minor mica and more proximal rocks, dolomite + chlorite + paragonite + muscovite whereas altered and mineralized assemblages consist of siderite + dolomite + chlorite + muscovite. With weathering, the carbonates, chlorite and albite break down to Fe oxides, kaolinite ± smectites but micas remain essentially unaffected. Thus, within weathered profiles, increasing proximity to mineralization is reflected by the progression minor mica -> abundant paragonite ± muscovite -> abundant muscovite i.e. increasing K contents. The relatively low abundances of other Au pathfinders (As, B, Mo, Sb and W) at Mt Magnet suggests that high muscovite (or K) contents are probably the best guide to mineralization in this area.

The absence of talc high in a weathered ultramafic profile suggests, by comparison with ultramafic profiles from the Eastern Goldfields, the presence of alteration. This is confirmed by the presence of some K-rich zones within the profile and elevated abundances of the Au pathfinders, As, Mo, Sb and Sn, in the surficial calcrete zone of the profile.

LEME Open File Report 31

Petrography, mineralogy and geochemistry of soil and lag overlying the Lights of Israel Gold Mine, Davyhurst, Western Australia

Robertson, I.D.M. and Tenhaeff, M.F.J.

The Lights of Israel Mine Site lies in an erosional regime, where the weathered profile has been truncated to within the mottled zone. This study area, south of the Menzies Line, in an area of eucalypt woodland, where soil carbonates are common, provides a useful contrast with the arid environment of Beasley Creek to the northeast.

Samples of the lag and the generally thin, colluvial soil were collected along one traverse over the Lights of Israel Mine Site, prior to mining. The lag, the soil and its components have been examined petrographically, mineralogically and geochemically. The coarse fraction (>600 µm) consists of black, goethite- and hematite-rich nodules (some of which are magnetic), red to yellow, ferruginous clay granules, quartz fragments and scarce crystals of tourmaline and gossan fragments. All the ferruginous fragments are petrographically indistinguishable from the fine lag, which was formed by deflation of the top layers of soil. Some of the upper soil layers are rich in carbonates, contain crystals of pedogenic gypsum and curly crystals of halite.

The iron-rich fragments contain lithorelics, containing microscopic relics of layer silicates (smectites and kaolinite), set in, and largely replaced by massive, spongy or vesicular goethite. The clay-rich granules consist largely of hematite- or goethite-stained kaolinite and some include goethite-rich lithorelics. Very close to the mineralisation, fragments of gossan, showing pseudomorphs after fine-grained pyrite, were identified in the lag. The soil contains a significant, quartz-rich, component which is largely angular and glassy and appears to be largely of local derivation. It is most abundant in the 75-710 µm fraction, where it acts as a geochemical diluent. There is a very minor aeolian component, which becomes progressively more abundant in the finer fractions. The silty fraction (<75 µm) contains less quartz but more iron oxides and clay. Its contained <4 µm fraction is very clay rich. The sandy and silty fractions contain a trace of sharp, fresh crystal fragments of tourmaline, which have a composition indistinguishable from that of local veinlet tourmaline.

The complete soil and the >600, the <75 and the <4 µm fractions were analysed to assess their value as sampling media. The quartz-rich 75-710 µm fraction was discarded. Gold in the fine soil fractions is the best guide to mineralisation by far. Very weak and equivocal anomalies in As, Sb, Cu and Cd are probably also ore related. Maxima in K and Rb seem to indicate a phyllic alteration halo around the mineralisation. The elevated S background above the mineralisation is problematical; its isotopic composition is slightly heavier than that which would be expected from meteoric S.

Gold anomalies are best developed in the calcareous soil fractions, are small and lack any extensive dispersion halo. Apart from Au, the multi-element signature is weak and subtle and is likely to be overlooked by exploration. These conclusions contrast with those reached at Beasley Creek, north of the Menzies Line, where there is a strong multi-element signature and the best geochemical medium is the lag and the coarse, ferruginous fraction of the soil.

LEME Open File Report 32

Geochemical and hydrogeochemical investigations of alluvium at Mulgarrie, Western Australia

Gray, D.J.

An integrated geochemical, chemical and hydrogeochemical survey of the Mulgarrie gold deposit was conducted by sampling RAB material, pit samples and groundwaters in the south-east margin of a palaeodrainage which overlies Au mineralization. The boundary between basement and alluvium is marked by decreased Mg, Zn, Ni and Au in the alluvium. Both basement and alluvium were identified as ultramafic by examining Ti/Zr and Cr/Fe ratios. Close to the surface, samples appeared to be depleted in Ti, relative to Zr, possibly due to organic acids dissolving Ti.

Elements associated with the surface carbonates are Au, which has been correlated with surface carbonates throughout the southern Yilgarn, and Th. These two metals are similar in that they are ordinarily highly insoluble but have enhanced mobilities in organic-rich horizons. Gold associated with carbonate is highly soluble and would be expected to have a high mobility in soil horizons. The soil enhancement could be caused by the metals been taken up by deeply rooting plants and then deposited on the soil surface.

There is a reduction in the magnitude of the surface Au anomaly from outcropping mineralization towards the middle of the drainage. This could be explained in terms of a lateral transport of Au, with dilution with distance, or by an upward movement of Au from the buried mineralization, with the magnitude of the soil Au anomaly being lesser with greater depth to mineralization. Iodide extraction has shown that surface Au close to the outcropping mineralization has a lower solubility than surface Au near the centre of the palaeodrainage (which has a similar extraction behaviour to Au in carbonate soils at other sites in the Yilgarn). Such distinctions may well be significant in understanding and utilizing exploration data.

Iron oxides control the geochemistry of a number of elements, particularly V, Cr, As and to a lesser extent, Sb, and Mn oxides have a critical role in the accumulation of Co, Ba and the REEs, and possibly Cu, Mg, Ca, Zn, Ni and S. In addition, Au in Mn-rich zones appears to be highly mobile, with only that Au which has been totally occluded by other phases being retained. Gold mobilized from such Mn-rich zones, either at Mulgarrie or at other sites, could be a source for secondary deposits.

Present-day groundwaters at this site are very unreactive, possibly because of low rates of sulphide oxidation. However, there are still several elements which have anomalous concentrations, due either to significant lithological enhancement (*e.g.*, Ni and Cr with ultramafics) or to enhancements related to mineralization (*e.g.*, Mn, Co, Ba, I and Ni), which are similar to groundwater enhancements observed at other sites. In addition, Mulgarrie groundwaters have specific depletions (K) or enrichments (Mg and SO_4^{2-}) of some of the major ions, which vary at a regional level, and may be useful in distinguishing different lithological regions. These data suggest the potential usefulness of groundwaters at a regional, lithological and exploration scale.

At this site (contrary to observations elsewhere) groundwater geochemistry did not "see through" the alluvium. This may be a consequence of the low activity of the groundwater and/or the presence of adsorptive phases such as Mn and Fe oxides. Additionally, groundwater at Mulgarrie has very low concentrations of Au, probably due to the lack of a means for Au mobilization, which at other sites involves either acid-oxidizing conditions (Au chloride) or neutral sulphide weathering (Au thiosulphate). The Au contents of Mulgarrie groundwater would be classified as background at these other sites.

LEME Open File Report 33

Investigation of hydrogeochemical dispersion of gold and other elements in the Wollubar Palaeodrainage, Western Australia

Gray, D.J.

The hydrogeochemistry, and the usefulness of groundwater as an exploration medium, was investigated for a 30 km length of the Wollubar palaeodrainage, an acid groundwater system that passes over mineralized Archaean rocks. Limited sampling was also conducted at the Golden Hope pit, about 1.5 km north of the palaeodrainage.

The Golden Hope groundwaters are very similar to deep waters from other mineralized sites, having neutral pH, low to moderate Eh and anomalous concentrations of Fe, SO_4 (from sulphides), Mg, Ca, Sr and HCO_3 (from carbonates). These data, and speciation results indicating groundwater equilibration with calcite, dolomite and magnesite, suggest that sulphides are dissolving at the weathering front, with the resultant acidity being neutralized by carbonate dissolution. Other minerals that appear to be in equilibrium with some or all of the Golden Hope groundwaters are gypsum ($CaSO_4.2H_2O$), barite ($BaSO_4$), amorphous alumina [$Al(OH)_3$] and ferrihydrite [$Fe(OH)_3.nH_2O$]. In addition, the groundwaters at Golden Hope are enriched in Ga, Mo, W, Ag, Hg, Tl, I, PO_4 and Cs. These elements (possibly with As, which was not determined) may also have value for exploration. Most of these elements appear to be sulphide associated, so they may not be directly related to Au. However, a system for easily pinpointing sulphide enrichments may still have exploration value.

The groundwaters at Golden Hope are different from other mineralized sites in that they are not Au rich. The reasons for this difference are not clear, because in all known respects these groundwaters should be just as effective in dissolving Au, as a thiosulphate complex, as other sites previously investigated. If dissolved Au is to be used as an exploration tool, it is critical to understand why strong groundwater enrichments are only occurring at some sites.

Total salinity, K and Br data indicate that groundwaters in the palaeochannel to the west and to the east of the main Boulder-Lefroy shear are hydrochemically distinct. This is consistent with the proposal that the two systems join near the shear and then flow south into Lake Lefroy. The palaeodrainage system is acid, with pH varying from near 6 at the northern part of the study area down to 3 in the western arm. In general, results for Wollubar closely matched observations at other sites with acid groundwaters, with the major difference that the Wollubar groundwaters were Fe-rich, and therefore tended to have lower Eh values. The mineral phases that appear to be equilibrating with some or all of the groundwaters, and the elements being controlled are:

(i) fluorite (F);

(ii) gypsum (Ca);

(iii) barite (Ba);

(iv) amorphous silica, for pH <4 (Si);

(v) jurbanite, for pH <5 (Al);

(vi) amorphous alumina, for pH >5 (Al);

(vii) ferrihydrite, for pH >4.5 (Fe);

With the exception of Au, for which speciation analysis works poorly, the minor elements were undersaturated with respect to their least soluble mineral phase, indicating that dissolution has occurred slowly and/or that concentration is being limited by other mechanisms such as sorption on, or co-precipitation with, iron oxides. Most metals, and particularly the base metals (other than the higher charge ions Al, Sc, Cr and U), showed no clear relationship with pH, possibly because their abundance was also affected by other hydrogeochemical or lithological factors. The concentration of REE is very high at Wollubar, both in the palaeodrainage and where acid waters are directly contacting Archaean rocks, being at least 5 times greater than for any other known surface water or groundwater in the world.

The palaeodrainage samples adjacent to the main Boulder-Lefroy shear showed particularly anomalous characteristics, being enriched in a similar "sulphide suite" as for the Golden Hope samples (Ga, Fe, Mo, W, Ag, Hg and Tl), in acid soluble elements (Sc, Y, REE and, relative to the observed pH, Al, Si and U) and also Au and Pb. This may represent acid weathering of a similar mineralized material to that at Golden Hope, and indicates that even high flow palaeochannel groundwaters can have solution characteristics relating to underlying mineralization.

LEME Open File Report 34

Further aspects of the chemistry of gold in some Western Australian soils

Gray, D.J. and Lintern, M.J.

Understanding of the soil chemistry of Au is important for the development and modification of sampling and analysis of soils for exploration. Gold chemistry in a range of soils and regolith materials from the southern Yilgarn, W.A., was investigated by selective extraction, primarily using an iodide reagent or de-ionised water. On the basis of these results, a number of different classes were delineated:

(i) unweathered rock and saprolite - low Au solubility;

(ii) laterite and other Fe oxide-dominated regolith - moderate Au solubility, with significant re-absorption of any dissolved Au;

(iii) Mn oxide-dominated regolith - very high Au solubility when pulverized;

(iv) carbonate - high Au solubility even without pulverizing;

(v) organic-rich - low Au solubility, possibly due to re-absorption of dissolved Au;

(vi) hardpan - high Au solubility when pulverized.

The very high solubility of Au in Mn-rich regolith suggests that Mn can act to mobilize Au, which is consistent with previous investigations indicating an important role for Mn in dissolution of Au in chloride-rich groundwaters.

Results for carbonate-rich soils from various sites across the southern Yilgarn craton indicate highly consistent Au behaviour. In general, about 30-50% of the total Au is dissolved in iodide reagent. Indeed, the inherent Au solubility is even higher (up to 100%), with the reduction in observed solubility being due to re-absorption of some of the dissolved Au by surfaces (such as Fe oxides) exposed by grinding. Commonly, Au solubility is as high, or higher, in coarsely ground material as compared with finely pulverized material. These results indicate that Au in these carbonate soils is highly soluble and commonly found on mineral surfaces or otherwise available to solution. Iodide-soluble Au is consistently found to be correlated with friable carbonate, even where other phases occur, such as Au associated with Fe oxides or contained in carbonate concretions. These results suggest that Au is behaving as a soluble element (like Ca or Mg) in soils and is precipitating in response to similar factors.

Pedogenic carbonate forms in soil as a result of evaporative processes, with the carbonate coating the surfaces of other minerals. Gold may be highly mobile in soil, as a result of biologically generated ligands and may be taken up by plants. As plant material is deposited on the ground surface, Au-organic complexes are formed that then percolate down the soil profile. Once these complexes reach the carbonate horizon, they will be immobilized, not necessarily by chemical means, but because these horizons are an evaporative zone. Therefore, the primary controls on Au distribution in soil with pedogenic carbonate may be biological and physical, rather than purely chemical, as first expected. Gold in such soils is in a highly dynamic state, which may explain why Au mobilization processes may give rise to enrichments, even in geologically recent overburden, that reflect underlying mineralization.

LEME Open File Report 35

Exploration geochemistry about the Mt Gibson Gold Deposits, Western Australia. Progress to 31st March 1989

Anand, R.R., Smith, R.E., Innes, J. and Churchward, H.M.

A regolith, landform, and geochemical orientation study about the S, C, and N lateritic Au deposits at Mt Gibson clarifies landscape evolution and geochemical dispersion in terms of the dynamics of formation, preservation, and dismantling of the undulating lateritic weathering mantle.

The relatively complex regolith and vegetation patterns are explained in terms of the distribution of (i) sub-areas of erosion of the lateritic mantle to the level of saprolite, (ii) sub-areas of essentially-complete lateritic mantle, and (iii) sub-areas characterized by depositional accumulation of detritus provided by the dismantling of the lateritic mantle up-slope, commonly burying the essentially complete laterite weathering profile in the local foot slopes and lowlands.

The regolith units were mapped over the central 3 km by 5 km area, the regolith stratigraphy established, and units of the upper regolith were characterized in field profiles petrographically, mineralogically, and chemically. An idealized regolith-landform facies model has been erected for use in predictions in appropriate terrain, and for planning and integrating follow-up research.

Geochemical analyses of samples of the loose pisolitic, nodular laterite unit collected systematically both from surface and from pit walls, where the unit occurred sub-surface, document the characteristics of the lateritic Au deposits. These and earlier results of the orientation study show that the lateritic Au ore, and the area peripheral to it, is a multi-element, chalcophile, geochemical anomaly, measuring 1-1.5 km across and greater than 4 km in length, with a Au, Ag, Pb, As, Bi, Sb, W association.

Within the loose lateritic unit, and in the underlying duricrust, coincident highs of several of these elements in centres within the overall anomaly suggested a close genetic link with bedrock sources, now verified by occurrences of gold-bearing quartz-hematite veining in saprolitic bedrock revealed by exploration and mining.

Geochemical results of 37 samples of the underlying lateritic duricrust show similar strengths and associations of elements as seen for the unit consisting of loose lateritic pisoliths and nodules. Close comparisons of the geometry of the dispersion patterns of these two closely related regolith units await the result of current research on more extensive sampling of the duricrust.

LEME Open File Report 36

Occurrence of gold in hardpan, Youanmi Mine

Gedeon, A.Z. and Butt, C.R.M.

Geochemical, mineralogical and petrological studies of the red-brown hardpan forming the surface horizon at the Youanmi gold mine were undertaken to determine the form and origin of the gold within it. The hardpan itself, apparently typical of the Wiluna Hardpan that occurs extensively in the Murchison District, is a silica-cemented unit across the transition from saprolite (in situ weathered bedrock) to colluvium (locally transported sheetwash deposit). Passing upwards, it consists of fractured saprolite, untransported saprolite blocks and poorly sorted colluvial debris cemented by a porous, red-brown matrix. The matrix contains apparently elastic clay, silt and sand-sized fragments and aggregates in a silica cement; translucent orange and clear silica (hyalite) forms a coating on the walls of fractures and voids. Despite the heterogeneity of the hardpan, the gold content appears to be fairly uniform within individual profiles. Four polished sections of hardpan were searched by scanning electron microscopy. Gold was found in only one section, in which four particles (1-3 microns) were located. These were all situated on open voids, which could be due to contamination during preparation or analysis of the samples, or to the late stage mobility of gold, either chemically or by physical illuviation. Gold probably also occurs throughout the hardpan matrix as very fine particles below the resolution of the scanning electron microscope.

LEME Open File Report 37

Lawlers orientation study - Contribution to Field Guide, Eastern Goldfields Trip. 1-2 November 1990

Anand, R.R., Smith, R.E., Churchward, H.M. and Perdrix, J.L.

LAWLERS FIELD STOPS 1 and 2 November 1990

10.00 AM

STOP 1 Brilliant area

An example of regolith in an erosional regime (Unit 2)

Low, stony hills

stripping of the lateritic profile

lag of ferruginous cobbles (iron segregations)

red, clay soil

pedogenic carbonate

pockets of saprolite-bedrock

The ferruginous cobbles occur largely on erosional areas in the Lawlers district and appear to have been derived from the breakdown of iron segregation bodies. The iron segregations, several metres across, commonly occur within the ferruginous saprolite-saprolite horizons in a weathering profile. Ferruginous cobbles are black, generally non-magnetic and many of them are dominated by low Al-substituted goethite and hematite. The internal surfaces of many of the ferruginous cobbles show the goethite pseudomorphs after pyrite. Ferruginous cobbles are high in Fe (71% Fe_2O_3), Mn (3000 ppm), Zn (380 ppm), Cu (157 ppm), and Co (91 ppm) - mean values of 33 samples.

STOP 2 Agnew-McCaffery area

Comparison of the regolith between erosional (Unit 2) and residual regimes (Unit 1) of the Agnew - McCaffery area. The location comprises two minor valleys.

Residual regime - broad crest, backslope, valley floor (Northern Valley).

- Gravelly sandy loam to sandy clay loam soil over lateritic residuum.

-Lateritic gravels with yellowish brown cutans on broad crest and become finer down slope.

- Down slope, the gravels with dark brown to brownish black surfaces become increasingly more common.

- Hematite and maghemite are more abundant in lateritic lag gravels on broad crest. This suite of minerals also dominates the backslope and valley floor.

- Fe_2O_3 is the most abundant constituent with values greater than 75% in lateritic gravels. The small amounts of Al_2O_3 and SiO_2 are mainly present as kaolinite.

- The trace elements V, Mn, Cr, As, Pb and Ga are more abundant in the lateritic gravels than in lag of ferruginous saprolite.

- Goethites are highly Al-substituted (up to 30 mole%).

Erosional regime - breakaway, pediment slope, valley floor (Southern Valley).

- Gravelly sandy clay loam soil over saprolite.

- Subcropping saprolite-ferruginous saprolite (Unit 2) on the breakaway and upper pediments and alluvium-colluvium dominating the valley floor.

- The pediments below the breakaway are mantled by a coarse lag containing yellowish brown ferruginous saprolite-mottled saprolite.

- These lags become finer down slope, they are a mixture of clasts with yellowish brown surfaces and others that are black. Cutans are generally not present.

- Goethite is the dominant mineral. Al-substitution in the goethite from the lags of the erosional regime is systematically lower (13-18 mole%) than goethites from the residual regime. Kaolinite is relatively more abundant in ferruginous saprolite than in lateritic gravels.

- Fe_2O_3 averages about 55% in lag of ferruginous saprolitic-mottled saprolite.

- Cu and Ni are more abundant in lag of ferruginous saprolite-mottled saprolite than in lateritic gravels.

LUNCH 12.45 PM

2.00 PM

STOP 3 Turrett Pit

Colluvial outwash plain (Unit 6), colluvium on lateritic residuum.

Laterite relationships and regolith stratigraphy from mine pit walls.

Units of the weathering profile (Southern half of the Western wall).

Top

- Gravelly colluvium (hardpanized and containing lateritic detritus).
- Lateritic residuum with iron segregations.
- Massive iron segregation bodies (note breakdown of iron segregations into small 5-10 mm nodules); many iron segregations and nodules show goethite pseudomorphs after pyrite).
- Ferruginous saprolite-collapsed ferruginous saprolite.
- Saprolite, saprock.

Bottom

Also (northern half)

- Colluvium on packed duricrust (black pisoliths in sandy matrix).

1. Colluvium on red clay (some hardpanized).

STOP 4 Agnew gravel pit

Residual regime - backslopes, crest

- Lateritic nodules, pisoliths.
- Nodular-pisolitic duricrust (some hardpanized).
- Pockets of Fe-rich pebbly duricrust.

Erosional regime - breakaway, pediment slopes.

- Lag of ferruginous saprolite-mottled saprolite, iron segregations.

Lateritic duricrust and lateritic gravels are dominated by hematite, goethite, and maghemite with small amounts of kaolinite, gibbsite, quartz and, anatase. By contrast, iron segregations are dominated by goethite, with small amounts of hematite.

5.00 PM

BARBECUE AT 5.45 PM

8.00 AM

STOP 5 Waroonga Pit

Colluvial outwash plain (Unit 6); thick colluvium on lateritic residuum.

Top

- Red colluvium.
- Hardpanized red colluvium containing lateritic detritus, with abundant partings (Si rich) and Mn staining.
- Red clay with some ferruginous granules (note the sharp contact between hardpanized colluvium and red clay).
- Nodular duricrust (hematite-rich red nodules in a kaolinite-rich matrix).

Bottom

STOP 6 Brilliant area

- Fe-rich nodular-oolitic duricrust on crest and breakaway face. - Ferruginous cobbles (iron segregations) on pediments. - Local pockets of pedogenic carbonates.

- Saprolite.

Iron-rich duricrusts are sporadically distributed throughout the Lawlers district and commonly occur on topographically elevated areas. The most characteristic features of Fe-rich duricrusts are:

- the boundaries between nodules-ooliths and matrix are not well developed in sliced surfaces, despite the pebbly appearance of weathered surfaces;
- the matrix and nodule compositions are not significantly different and both are Fe-rich;
- the volume of matrix between the nodules is small;
- nodules generally lack cutans;
- weathered ilmenite grains and slightly-ferruginized charcoal fragments occur within pisoliths;
- characterized by high concentration of Fe and very low concentration of Si and Al;
- dominated by hematite, goethite, and maghemite;
- large range in values on Mn, Cr, V, Zn, Ni, Co, As, and Ga.

11.00 AM DEPART LAWLERS FOR KALGOORLIE.

LUNCH AT LEONORA

LEME Open File Report 38

The aqueous chemistry of gold in the weathering environment

Gray, D.J.

Literature on the chemistry of gold in the weathering environment was critically examined. Additional thermodynamic data were calculated by the author to test and clarify conclusions drawn by other workers. New hypotheses on some of the mechanisms of gold mobility and alteration were also advanced.

Section 2 gives a brief summary of gold primary mineralisation and associated minerals. Section 3 gives relevant information on weathering processes and methods of analysis of thermodynamic data. The weathering environments under which the thermodynamically unstable thiosulphate and sulphite anions (which are effective ligands for gold) can be generated are discussed. An explanation of the importance of solution characteristics such as Eh, pH, and the presence of ligands such as thiosulphate or chloride for the mobilisation of gold is also given. It is demonstrated in Section 4 that gold can be mobile in particular environments: either ligated by inorganic anions such as chloride, thiosulphate or cyanide; as a colloid; or under biological influence. These mobilized forms of gold may be precipitated from solution by a number of mechanisms: changes in solution chemistry; reactions with metal ions in solution; adsorption onto the solid phase; or decomposition of ligand molecules. This is dealt with in Section 5.

The later sections of this report present a more general overview of gold chemistry in the weathering environment. Section 6 discusses the observed increases in gold fineness in the weathering zone and how this will be influenced by the form of the aqueous gold species: thus, for example, equilibration of gold and silver with a chloride rich solution will precipitate very high fineness gold; while the presence of thiosulphate in solution will result in electrum of lower fineness. Section 7 discusses alteration of primary gold grains: in particular a theory of galvanic silver loss whereby gold and silver are leached from electrum grains and gold is redeposited on the same grain, is suggested for the widespread occurrence of low silver rims in the weathering zone. Section 8 discusses the hypothesised environments of gold redistribution and the gold species that are considered to be important in each environment, as below:

Environment	Gold Species
Sulphide Weathering	$Au(HS)_2^-$
	$Au(S_2O_3)_2^{3-}$
Laterite and Soil	$Au(CN)_2^-$
	gold-organic matter
	gold colloids
Capillary Zone	$AuCl_4^-$ and $AuCl_2^-$
Arid-Acid Conditions	
Arid-Alkaline Conditions	$Au(OH)_2^-$

Further work on gold dissolution and re-precipitation, that may lead to a better understanding of the geochemistry of gold during weathering and in developing exploration strategies, is suggested in Section 9. Much of this work will be initiated by the author shortly.

LEME Open File Report 39

The petrography, mineralogy and geochemistry of a felsic, mafic, ultramafic and metasedimentary weathered profile at Rand Pit, Reedy Mine - Cue, WA

Robertson, I.D.M., Chaffee, M.A. and Taylor, G.F.

A near vertical sequence of variably-deformed, alternating, mafic and ultramafic metavolcanic rocks, interleaved with mica schists and black shales and intruded by porphyry pods, is exposed on the south face of the Rand Pit at Reedy to a depth of 75 m. The face has been mapped and each lithology sampled at approximately 20 m intervals from the base to the top. The samples have been studied mineralogically and petrographically to illustrate the mineral and fabric changes caused by weathering. Each sample has been analysed for 55 (major and trace) elements and the drying losses, ignition losses and densities were measured in order to understand further the geochemical changes due to weathering and to find ways of distinguishing the rock types on a geochemical basis, despite their weathering state.

Where fresh, the ultramafic rocks are talc-chlorite±tremolite schists and the mafic rocks are schists of granular quartz and albite with muscovite, chlorite and talc. Initially weathering solutions have penetrated the margins of quartz veins and some cleavage planes. Sulphides are among the first minerals to weather and, in the mafic rocks, these are closely followed by plagioclase which is almost completely altered at 70 m depth. At a depth of 50 m, needles of tremolite in the ultramafic rocks have largely dissolved, leaving voids, some of which have been filled by goethite. Chlorite in all rocks becomes progressively more turbid, Fe-stained and altered to smectite, and both sphene and ilmenite alter to anatase. Above 30 m depth, and particularly in the top 10 m, kaolinite becomes very abundant where it is an alteration product of talc, muscovite, feldspar, chlorite and smectite. It forms secondary fine-grained mats, coarser-grained stumpy stacks and accordion structures which progressively destroy the schistose saprolite fabric. The rocks become pockmarked with vesicles and solution channels which are, in part, filled with secondary clays. Muscovite and talc, in the mica schists and ultramafic rocks respectively, are relatively stable minerals which persist to close to the surface where both are partly altered to kaolinite.

The regolith exposed at Rand may be divided into a shallow zone (0-15 m), marked by rocks of low density (<2.0) in which there has been extensive leaching and element dispersion, and a more dense deep zone, extending to saprock and relatively fresh rock. In the deep zone, some elements (As, Au, Cu, Pb, Sb, Sn, W, Zn and, to a lesser extent, Ag, Mo, Se, Te and Tl) appear to be ore-related and many show an exponential relationship of their maximum concentrations to their distance from the main ore shoots. Of the remaining lithologically related elements, Cr differentiates the mafic from the ultramafic suite, Al and Ga separate the mafic rocks from the mica schists, low Fe concentrations mark the mica schists, black shales and porphyries, and abundant Ba characterises the mica schists and porphyries.

The number of useful pathfinder elements (As, Au, Cu, Se and W) is less in the low density shallow zone of the regolith where Al, B, Ba, Fe, Ga, Nb, Si, Sr, Ta, Th and V have been enriched but Ag, Al, Ca, Cd, Ce, Co, Eu, Fe, Ge, La, Li, Lu, Mg, Mn, Na, Ni, Sm, Y and Zn have been leached. Chromium, Ti, K, Cs, Rb, Zr and Hf are relatively unaffected by weathering; K, Rb and Cs are probably sited in residual micas and Zr and Hf in stable zircon.

Discriminant analysis has been used to separate the five lithologies at Rand. Effective discrimination (better than 94%) may be achieved by using power transformed Cr, Nb, Co, Sc, Lu, Hf, Ba, Eu and Zr data and using curved boundaries on canonical plots. Log transformed data is almost as successful. Discrimination may well be improved if samples below 10-15 m depth are used as, above this level, the geochemical and fabric changes are most severe.

LEME Open File Report 40

Multi-element soil survey of the Mount Hope Area, Western Australia

Lintern, M.J., Churchward, H.M. and Butt, C.R.M.

Composite soil auger samples from the top metre were analysed for elements and compared with similar existing information for Au. Regolith and geomorphological features were mapped from air photo and field studies and, in conjunction with existing geology maps, were used to interpret the observed distribution of the elements. Initially, simple distribution maps, selected binary plots, histograms and correlation matrices were used to describe the results. Further statistical treatment using R-Q mode principal component analysis and cluster analysis developed the interpretation. The results demonstrated strong associations between certain elements, soil type and underlying geology. Most notable were the associations between SiO_2 and sediments, transition metals and the laterites, and alkali and alkaline earth metals with the red earth soils. Whilst Au itself did not show any strong associations, certain areas have been identified from this integrated approach that warrant further investigation.

LEME Open File Report 41

Hydrogeochemistry of the Panglo Gold Deposit

Gray, D.J.

A hydrogeochemical survey of the Panglo Gold Deposit was conducted by sampling groundwaters in open drill holes, and from drainage holes in the Trial Pit. Waters were sampled from the three main geological environments of the area, namely shales in the south-east of the study area, mafic rocks, and ultramafic rocks.

The chemical characteristics of the water samples are closely correlated with the lithology in which the water was sampled. Waters derived from shales have relatively low concentrations in Au, the pathfinders, and most of the chalcophile elements analysed, whereas waters derived from mafic and ultramafic rocks have characteristic multi-element 'signatures'. Waters associated with mafic rocks are strongly enriched in Mn, Co, and Zn, and weakly enriched in Cu and Ni, whereas waters associated with ultramafic rocks are enriched in Ni, Cr, Bi, Sc and Ag. Using these data, water samples could be distinguished into geological groupings by using chemical compositions alone.

Chemical data also suggest major variations in the degree of weathering and leaching within the sample area. Waters in the northern part of the study area are highly acidic and oxidising, and have anomalously high concentrations of Au, Br, Fe, Mn, Co, Zn, Cu and Ni.

Dissolution of Au is primarily controlled by the redox status of the solution. Elevated Eh levels are caused by Mn oxidation, permitting the oxidative dissolution of native Au and its mobilisation by either the chloride or the iodide complexes. Dissolution of Au as the iodide complex occurs as a consequence of the relatively high concentrations of I at this site. Such a Au mobilisation mechanism has not, in the author's experience, been previously documented for groundwaters. The concentration of dissolved Au is high, and would represent a reasonable exploration method at this site.

LEME Open File Report 42

The sorption of gold and silver on soil minerals

Gray, D.J.

The sorption of Au and Ag was investigated by reacting synthesised Au and Ag complexes with a range of different soils. The systems used were Au and Ag in humic, thiosulphate, iodide and chloride solutions, and in a poorly complexed form.

Soils used were 4% Peat Moss - 96% Quartz, organic rich soil sample 1467, Fe oxide rich soil sample 1468, carbonate rich soil sample 1470, Fe oxide rich standard 7, Mn oxide rich Mount Keith Shaft, 44 m depth, and a Mn oxide rich segregation collected at Ora Banda.

The solutions and soils were equilibrated together and the Au and Ag concentrations in the soil solutions were measured at two weeks and again at three months.

Gold and Ag thiosulphates had a high initial solubility when contacting most of the soils, with the exception of the Mn rich soils, which quickly sorbed most of the Au and Ag. In general, both Au and Ag had similar solubilities in thiosulphate solution. When finally sorbed, Au did not redissolve.

In an acidic chloride-rich solution Au was more readily sorbed than Ag, only having an appreciable solubility when in contact with the most Mn rich material. This contrasts with the results for thiosulphate complexes, demonstrating the critical importance of the Au complex on the extent of sorption. Results were similar for Au iodide.

Humate complexes were found to maintain only small concentrations of Au in solution, suggesting a weak interaction between Au and humate. This is in contrast with work on Au humate interactions by other workers which has suggested that humate can be very effective at dissolving Au.

An important observation is the ability of the soils to redissolve Au. When the uncomplexed Au and Ag were mixed with the various soils they were quickly sorbed. After three months, however, a number of the mixtures contained significant quantities of dissolved Au (but not Ag). This is possibly due to soluble species with a high affinity for Au being produced by biological activity. Very similar effects were also observed for Au iodide. The humate mixtures also showed appreciable redissolution of Au, though in a different manner to the uncomplexed and the iodide mixtures, possibly due to the different types and concentrations of organic matter in the humate mixtures. These results suggest that Au is readily mobilized in soils, and this metal should be considered to be mobile under such environments.

LEME Open File Report 43

Chemistry of gold-humic interactions

Gray, D.J., Lintern, M.J. and Longman, G.D.

This report describes experiments on the interaction of ionic Au with various sources of soluble humic acid. The concentrations of soluble (<0.45 μm) Au in the presence of humic phases were dependent on a number of factors, including Au concentration, humic concentration, humic source, and the presence or absence of light. Such variations in solubility can readily explain the wide divergence of opinion on the effect of soluble humic phases on Au solubility, as detailed in the report.

Results obtained here indicated that the Au formed a very fine, highly coloured sol, in agreement with other work on the interaction of Au with humic phases (Ong and Swanson, 1969; Fedoseyeva *et al.*, 1986) and with other organic molecules (Fabrikanos *et al.*, 1963). Formation of the sol is activated by light, in agreement with previous work (Fabrikanos *et al.*, 1963).

The Au sol is effectively decolourised by the addition of ligands with strong (CN^-) or moderate (I^-, $S_2O_3^{2-}$, SCN^-) affinities for Au, or by ligands with weak (Cl^-) affinities for Au when in high concentration. This suggests that the Au sol will only be stable in the absence of such ligands. As the unpurified humate preparations readily converted Au to the sol, rather than complexing it, these preparations do not contain significant concentrations of such Au ligands.

It is postulated that the colour of the Au sol, rather than just indicating the size of the Au particle, may be due to specific chemical factors. Thus, a further understanding of the mechanism of the colour of this phase could give further important information on the chemistry of Au in the presence of humic material.

LEME Open File Report 44

The distribution of gold and other elements in soils and vegetation at Panglo, Western Australia

Lintern, M.J. and Scott, K.M.

Shallow auger, surface, profile, trench, grab and vegetation samples were taken along two traverses at the Panglo gold deposit about 30 kilometres NNW of Kalgoorlie, Western Australia. Landscape and soil features were photographed, described and used to interpret geochemical information. The relationship between the geochemistry of soils and vegetation was explored with particular reference to Au. Detailed examination of weathering surface material was performed using SEM (scanning electron microscopy) techniques.

The results establish a widespread and strong association between Au and pedogenic carbonate. The most significant result was the presence of Au (up to several hundred ppb) in pedogenic carbonate occurring in transported overburden above mineralisation. There was also a weak association between Au found in vegetation and that found in the soils. Other results indicated the strong association between landscape features, geochemistry and vegetation type. SEM studies revealed the importance of calcite in near-surface weathering processes.

The study demonstrates the importance of locating and sampling the pedogenic carbonate horizon if present. Augering and near-surface sampling appear to be the most successful exploration techniques whereas trench sampling may falsely locate or overlook the soil anomaly altogether. Vegetation sampling alone cannot be used to locate mineralisation.

LEME Open File Report 45

Dispersion of gold and associated elements in the lateritic regolith, Mystery Zone, Mt Percy, Kalgoorlie, Western Australia

Butt, C.R.M.

The dispersion of gold and over 40 other elements in the lateritic regolith has been studied at the Mt Percy gold mine, near Kalgoorlie. Primary Au mineralization in the Mystery Zone occurs in fuchsite-carbonate alteration zones at the contact with porphyries intruding the Hannan's Lake serpentinite. The mineralized sequence has been deeply weathered and is concealed beneath an almost complete lateritic regolith over 60 m thick. The regolith consists of saprolite (50 m), which is clay-rich in the top 10 m, plasmic and mottled clays, and surficial horizons of lateritic gravels, lateritic duricrusts and pisolitic soils. The surficial horizons contain pedogenic carbonates. Duplicates of grade-control composite samples from two sections across the Mystery Zone were collected at 1 or 2 m intervals at each 2.5 m level throughout the regolith as mining progressed. Samples of fresh rocks were obtained from diamond drill core. A selection of these samples, including a complete section through the primary mineralization, was analysed to illustrate element distributions in the fresh and weathered rocks. The elements associated with primary Au mineralization appear to be S, Ag, W, As, Sb, Te and, possibly, Ba, K and Pb, but except for Ag and Te, none has a very direct correlation with Au.

The Au distribution in the regolith is typical for the region, with minor enrichment and wide lateral dispersion in surficial gravels and duricrust (particularly associated with the presence of pedogenic carbonates), leaching and depletion in the underlying clay-rich horizons and some secondary concentration and minor dispersion in the saprolite. Primary and saprolitic Au mineralization is indicated by a broad superjacent Au anomaly (100->1000 ppb) in the soils and lateritic horizons, and by high concentrations of W (5->40 ppm), Sb (7->16 ppm) and As (10-200 ppm). High K contents, corresponding to resistant muscovite, give surface expression to the alteration zone. Although Au contents are <100 ppb in the underlying clay-rich horizons, Sb, W and, to a lesser extent, As remain anomalous; similarly, Ba and K contents remain high, indicating the porphyries and alteration zones respectively.

The porphyries and ultramafic rocks can be discriminated geochemically throughout much of the regolith by relative abundances and ratios of Ti, Zr, Ba and K. However, the lateritic horizons, particularly the duricrusts overlying the talc chlorite rocks of the Hannan's Lake serpentinite, have abnormal geochemical signatures. These duricrusts have low Cr contents (< 1000 ppm), because primary Cr is present in weatherable chlorite rather than resistant chromite, but are enriched in "immobile" elements derived from the porphyries. The distribution patterns of the elements are discussed in terms of landform evolution and their significance to exploration.

LEME Open File Report 46

Reference geochemical data sets from the Mt Gibson orientation study, Western Australia

Smith, R.E., Wildman, J.E., Anand, R.R. and Perdrix, J.L.

Data sets from the Mt Gibson geochemical orientation study have been organized into reference groups based upon the regolith stratigraphy for the area. The data sets (with the numbers of samples making up each set in brackets) consist of soils (17 or, with gravelly red earths included, 31), colluvium (58), lateritic gravel (55), lateritic duricrust (112), mottled zone (13), and saprolite (25). In addition, some data are presented for calcretes, iron segregations, mineralized veins, and lag. The total number of samples included in this report is 296.

The main information required to support the geochemical data is presented in concise and accessible form. This includes maps of the surface regolith relationships, bedrock geology, and sample sites for each sample set, together with a regolith-landform model and a schematic diagram of the regolith stratigraphy. Listings of chemical analyses for each sample, grouped according to sample type, are included, and summary statistics are presented. Box plots show the distribution of levels for each element, or oxide, for units of the regolith stratigraphy. Histograms for colluvium, lateritic gravel, and lateritic duricrust are presented for each element and oxide. Separate maps showing the geochemical dispersion patterns for Au, Pb, As, and Bi in colluvium, lateritic gravel, and lateritic duricrust allow the sampling to be seen in terms of the shape of the geochemical dispersion anomaly. Scales used for maps in this report are common to a previous report (20R) which comprehensively discussed the regolith relationships at Mt Gibson. Correlation webs highlight relationships between some elements for several of the sample media and a Si-Al-Fe triangular diagram shows the main characteristics of laterite samples.

The use of standardised formats for data presentation allow the characteristics of each data set to be appreciated, and comparisons to be made between the data sets. Furthermore, the Mt Gibson data can then be readily compared with data sets, as they arise, whether from other orientation studies, or from company exploration data. A floppy disk of the geochemical data together with sample type and location is included in standard format to enable users to have easy access and readily manipulate the data for their required purposes.

Data sets, such as those presented, which are controlled within a regolith-landform framework, are being generated from other orientation studies within the Laterite Geochemistry Project. Collectively, these reference data sets will form an essential part of a growing interpretational data system.

LEME Open File Report 47

The distribution of gold and other elements in soils at Mulline, Western Australia

Lintern, M.J. and Butt, C.R.M.

Soils, lateritic gravels, calcretes and saprolites were sampled at the Peach Tree and Lady Gladys gold prospects in the Mulline area, 50 km west of Menzies. Each of these sites has moderate reserves of gold as laterite-hosted deposits that are characterised by ferruginous gravels invaded by pedogenic carbonate.

Strong associations were found between gold and iron, and gold and the alkaline earth metals. In particular, gold distribution appears to be positively correlated with calcium and magnesium in the top 0.5 m of the soil profile and with iron in various zones beneath this. The alkaline earth metals are present as calcite and dolomite and iron as goethite or hematite. The association with Fe oxides is probably related to the formation of the deep lateritic regolith during the Tertiary, whereas the association with the pedogenic carbonates is of more recent origin, related to weathering under recently imposed semi-arid climates. The study has demonstrated the importance of selecting the correct soil horizon when sampling for gold and support similar data from elsewhere in the Yilgarn Block, Western Australia.

LEME Open File Report 48

The mineralogical and geochemical effects of weathering on shales at the Panglo Deposit, Eastern Goldfields, WA

Scott, K.M. and Dotter, L.E.

Examination of phyllosilicates, oxide phases, alunite and, where present, sulphides and carbonates in 10 samples of fresh and weathered shale from the Panglo area has helped elucidate how elements are retained during weathering. Chalcophile elements are strongly retained by Fe oxides and Sr and Ba (plus As and Cu) are retained by alunite. Micas, which are essentially unaffected by weathering, appear to have low Na and Fe contents in mineralized profiles and higher contents elsewhere.

By comparing mineralized and barren shale profiles, Fe and chalcophile elements (As, Mo, Sb and W) appear to be enriched and Na, Ba and Sr depleted in weathered shales above secondary gold mineralization at Panglo.

LEME Open File Report 49

Hydrogeochemistry of sulphide weathering at Boags Pit, Bottle Creek, Western Australia

Gray, D.J.

Hydrogeochemical sampling of the Boags Open Pit at Bottle Creek was conducted by collecting groundwaters thought to be in contact with zones where sulphide minerals were weathering in non-acid conditions. The near neutral pH and the chemical characteristics of the two water samples were consistent with this assumption. The elements that are anomalously high in these samples, and their possible source are:

i) Ca, Mg and HCO_3^-, derived from dissolution of carbonate minerals;

ii) SO_4^{2-}, As, Cd and Sb, released during oxidation of sulphide, arsenide and antimonide minerals;

iii) and (possibly) Br-, which have been observed to be extensively enriched in sulphide environments;

iv) Au, dissolved as the $S_2O_3^{2-}$ complex, as $S_2O_3^{2-}$ is released during neutral oxidation of sulphide.

Various mechanisms are postulated to dissipate these anomalies as groundwater disperses from the weathering sulphide body:

i) Ca, Mg, HCO_3^-, SO_4^{2-} and Br^- are already present in the saline groundwater and the anomalies will be dissipated via dilution, acidification, and precipitation of calcite, gypsum or Al sulphates. Thus, any enrichment of these ions in groundwaters in the surrounding strata tend to be subtle and not easily distinguished;

ii) As, Cd and Sb can be lost from solution via a variety of reactions such as precipitation or adsorption;

iii) I^- is highly soluble, with the major loss from solution being via oxidation to I^2 (Fuge, 1990). This reaction is expected to be slow and, given the low background of I^-; the I^- anomaly is expected to only be slowly diluted out and is commonly observed in mineralized areas (Gray, 1990, 1991);

iv) The extent of the Au anomaly is highly dependent on solution conditions. If conditions remain neutral or only weakly acidic then the $Au(S_2O_3)_2^{3-}$ complex may have a moderate mobility. However, if the waters are Fe-rich then oxidation in the upper part of the regolith can lead to waters with pH values down to 3. Under such conditions $Au(S_2O_3)_2^{3-}$ will be destabilized and Au precipitated. If conditions are sufficiently oxidizing, then Au may dissolve as the chloride complex. However, this is a secondary reaction, which is not directly related to the initial sulphide weathering reactions as observed at Boags.

LEME Open File Report 50

Laterite geochemistry for detecting concealed mineral deposits, Yilgarn Craton, Western Australia. P240 Summary Report

Smith, R.E., Anand, R.R., Churchward, H.M., Robertson, I.D.M., Grunsky, E.C., Gray, D.J., Wildman, J.E. and Perdrix, J.L.

The objective of this four-year AMIRA study was to develop new and improved methods for mineral exploration based upon the use of multi-element laterite geochemistry. The project focussed upon using the knowledge that geochemical dispersion haloes in laterite greatly enlarge the target size in the search for concealed ore deposits. Laterite geochemistry was known to be applicable to a wide range of commodity types, including precious-, base-, rare-, and strategic-metal deposits. A multidisciplinary team was established with skills in regolith geology, geomorphology, soil science, exploration geochemistry, bedrock geology, numerical geology, hydrogeochemistry, and, through collaboration, remote sensing.

Orientation studies
Considerable emphasis was placed on establishing a regolith-landform understanding of four carefully chosen orientation districts, within which geochemical dispersion from concealed Au deposits was studied. The orientation districts, Mt Gibson, Bottle Creek, Boddington, and Lawlers range from 120 km^2 to 500 km^2 in area, represent a range of regolith and geomorphic settings distributed across the present-day rainfall gradient of the Yilgarn Craton. The Beasley Creek Au deposit was the focus of a subsidiary orientation study.

Specific themes
Research was also directed at the following specific themes: establishing (a) a workable scheme for terminology and classification of laterites for the Yilgarn Craton, (b) the siting and bonding of ore-associated elements in laterites, (c) processes of geochemical dispersion, (d) anomaly recognition methods for use with multi-element laterite geochemistry, (e) knowledge of regional variations in laterite geochemistry, (f) geochemical dispersion models, and (g) participating in exploration feasibility tests based on the research findings.

Exploration applications
Study of the chosen orientation districts allowed a substantially-improved understanding of the distribution of regolith units, regolith stratigraphy, the characteristics of regolith units, regolith evolution, and of geochemical dispersion patterns in laterite. This understanding is fundamental to effective exploration and has progressively been transferred to industry users through field trips, sponsors' meetings, project reports, and workshops.

Laterite classification and sampling methods
The major findings of the project concern the characteristics, origin and use of the lateritic residuum as a sample medium in exploration. The project's volume *Laterite types and associated ferruginous materials - terminology classification and atlas* was an important practical outcome and is in widespread use amongst the sponsorship both in Australia and overseas.

Considerable attention was given to the question of where best to sample within the regolith stratigraphy. The spacing of samples and sampling patterns with regard to anomaly size have been integrated into general procedures. Knowledge of which parts of laterite blankets to sample is now well established from the results of this project. This knowledge has been extended, at pilot scale, to ferruginous material immediately underlying lateritic residuum, (materials such as mottled zone, ferruginous saprolite, and various iron segregations). Such media are important alternatives in areas where erosion has removed the lateritic residuum.

Data interpretation
The geochemical dispersion anomalies, studied within the orientation areas, have been comprehensively described. Sample type and geochemical characteristics are linked to the position within the regolith stratigraphy. These studies provide well-controlled reference geochemical data sets and thus provide important information on the geochemical characteristics for the settings and ore

types studied. When coupled with knowledge of the background variation and thresholds for the target pathfinder elements, as provided in the CSIRO-AGE database, these data sets provide the essential components of a powerful exploration system. A discussion document on anomaly recognition methods for multi-element laterite geochemistry, complete with worked-through examples from the project, was produced and distributed to sponsors.

Areas of sedimentary cover
The use of laterite geochemistry in areas of sedimentary cover, particularly for exploration of substantial colluvial and alluvial outwash plains, was developed during the project. Application of these techniques, in collaboration with sponsors, proved the feasibility of exploration in sediment-covered areas by drilling for geochemical haloes in buried laterite, capitalizing on their far larger size than the source ore deposits. An important outcome of this phase of the project has been the recognition that, in the semi-arid and arid parts of the Yilgarn Craton, buried laterite profiles are widespread, and can occur even in areas where lateritic residuum has been largely stripped from the uplands.

Overall, it is clear that the level of expertise in laterite geochemistry used by industry is now substantially greater than when the project commenced in mid-1987. In collaboration with other researchers, project staff have played a major role in improving this expertise, developing application capabilities, and transferring these skills to sponsors.

LEME Open File Report 51

Regolith-landform relationships in the Bottle Creek Orientation Study, Western Australia

Churchward, H.M., Butler, I.K. and Smith, R.E.

Regolith-landform Relationships
A framework of regolith stratigraphy and landforms was established for the area surrounding the Bottle Creek Au deposits, some 200 km north west of Kalgoorlie, as a basis for geochemical studies. An early phase of broad reconnaissance provided several sites at which the regolith was examined in detail and the landform-regolith relationships were defined. A regolith-landform map (1:10 000 scale) was produced for the upper Bottle Creek catchment. To test the findings of the detailed investigation, a study of the regolith was carried out over an area of approximately 450 km^2 surrounding the detailed study at a reconnaissance scale. A 1:25 000 map of this was produced.

Several well-defined regolith types were identified by these studies which relate, directly or indirectly, to a deeply weathered mantle and to its modification by landform processes. These regolith materials were either horizons of a deep profile developed by *in situ* weathering of basement rock or of transported debris, derived from this profile by erosion. Generally they form extensive surface and subsurface bodies so that the regolith, at any particular location, commonly comprises several strata.

The nature of the regolith stratigraphy is strongly related to the landforms with which they are associated so that a framework of landform regimes provides a useful concept for considering the regolith in this area. Thus, units of relatively stable, deeply weathered tracts were recognized as relics of a once more extensive landsurface that has been fragmented by fluvial action and replaced by erosional and depositional regimes.

At Bottle Creek, regolith types associated with the ancient, deeply weathered landsurface (the residual regimes) are mainly various expressions of the (upper) ferruginous horizon of the laterite profile, along with the mottled zone, the pallid saprolite and the saprock. Several transported regolith types, of colluvial and alluvial origin, were recognised in both erosional and depositional regimes.

Ferruginous Horizon(s)
The ferruginous horizon comprises various types of lateritic residuum but the more common are duricrusts having abundant lateritic pisoliths, generally with yellow-brown skins, set in a brown to red-brown clayey matrix. At depth, this material merges with the more ductile clays of the mottled zone. In addition, large irregular to lensoid bodies occur in the upper part of the regolith. The rock-

like nature of these masses contrasts with the surrounding brittle, pisolitic, lateritic residuum referred to above. Some of these masses are Fe-rich, having a dusky red matrix and dark brown to black nodules that can be magnetic. Such materials have been placed in the broad class of Fe-rich duricrusts. Another rock-like mass is diffusely mottled brown to pale brown and some have vermiform voids. These can be variously classified as ferruginous saprolite, vermiform duricrust or fragmentary duricrust. Other Fe-rich bodies in the upper regolith are goethite-rich pods which generally have box-work textures. At Bottle Creek, these gossan-like bodies occur close to a carbonaceous, previously pyritic shale in the underlying parent greenstone sequence.

Residual Regimes
The residual regimes at Bottle Creek form gently undulating tracts that are extensive on the divide between the Raeside and Ballard drainages. The principal type location for the regolith stratigraphy of this regime is at the Emu test pit, within this undulating tract. Most crests in this terrain are slightly stripped with consequent exposure of an array of ferruginous materials from the upper parts of the regolith. These are predominantly ferruginous saprolite but there are also some pisoliths and pieces of Fe-rich duricrust, as well as clay and sand released by weathering. Such materials contribute to the colluvial mantle that extend down-slope from the crest, covering the pisolitic, lateritic residuum; the latter forming the more extensive substratum of the residual regime. On the mid- and upper slopes, colluvium is less than 1 m thick; whilst beneath the lower slopes and local drainage floors, the colluvium is as much as 4 m thick. The lag composition also varies with topographic position; coarse fragments of ferruginous saprolite dominate the crests. Some yellow-brown cutan-coated pisoliths also occur here and are generally indicative of some subcropping pisolitic, lateritic residuum. On surfaces, down-slope from these crests, lags of dark brown to black granules are dominant; there is little quartz or lithic material. The soils are acid and have developed in a fine, sandy loam colluvium which has granules of similar composition to the lag. Hardpans appear at a depth of 1 m and continue for depths of from 3-8 m.

Erosional Regimes
The landforms and the regolith types in the erosional regimes present a more complex picture reflecting active geomorphic processes. Deeper units of the weathered mantle, as well as country rock, are exposed. This regolith is dominated by a shallow, generally calcareous soil, and a lag of lithic fragments; there are outcrops of vein quartz and goethitic Fe-segregations. Gentle slopes occur as pediments below low breakaways. These slopes are mantled by acid red earths, developed in a pedisediment, and have a lag dominated by coarse, ferruginous saprolite, lithic fragments and quartz. Erosion is active in such areas.

Depositional Regimes
The most extensive depositional tracts are mantled by a friable clay, being an alluvium of sheet flood origin; acid red earths have developed on this material. The lags are dark brown to black granules of mixed origin, with medium sized (2-4 cm) lithic and ferruginous saprolite fragments, and quartz clasts, as a minor, though characteristic component. This alluvium overlies pallid saprolite and saprock at a depth of 1-1.5 m but it may also be found mantling pockets of pisolitic lateritic residuum or coarse deposits in palaeochannels. Some of the depositional tracts are being further modified by erosion, resulting in land-surfaces having regolith types comparable with those in other erosional regimes.

Regolith Evolution and a Framework for Geochemical Dispersion
The topographic relationships and regolith stratigraphies revealed by this study indicate a polyphase, multi-process history. Many of the regolith types resulting from this complex array of processes, have a distinctive pattern. The residual regimes at Bottle Creek are dominated by a regolith that is the result of intense *in situ* weathering, some of the uppermost regolith has been deposited by local colluviation. These areas have had a relatively stable geomorphic history. In contrast, depositional regimes here represent areas that have received fluvial detritus from much further afield and this material varies from highly weathered to relatively fresh and is generally of diverse lithological origin. Prior to deposition, these areas can have been subjected to widespread, though incomplete, stripping of the more weathered regolith types. The regolith in erosional regimes is, in detail, complex with exposure of a variety of variably weathered lithologies. Understanding this general

geomorphic framework assists our appreciation of geochemical dispersion and thus it provides a basis for the developing sampling strategies for this weathered terrain.

LEME Open File Report 52

The distribution of gold and other elements in soils and vegetation at Zuleika, Western Australia

Lintern, M.J. and Butt, C.R.M.

This report describes an investigation of a possible surface expression of the Zuleika Sands Au deposits, south of Ora Banda. The deposits are situated within and beneath the sediments of a palaeochannel in a floodplain adjacent to a low rise and pediplain with residual soils. Gold mineralization occurs semi-continuously in the basal sands of the palaeochannel and the underlying saprolite. A variety of sample media were selected, including different soil horizons, surface lag, and vegetation, and analysed for Au and a range of other elements.

Anomalous Au concentrations (mean 28 ppb) were found in calcareous surficial horizons (0 - 1 m) directly overlying the buried mineralization, compared to a mean background of 13 ppb over barren sediments. However, much higher concentrations (mean 141 ppb) are present in equivalent horizons of residual soils associated with subcropping mineralisation on the low rise. Because of the proximity of the two areas, it is possible that the anomalies in the floodplain could be derived from down-slope dispersion from the residual areas, so that no unequivocal demonstration of the surface expression of the buried mineralization was possible. However, it is known that similar mineralization elsewhere, buried beneath over 20 m of barren sediments and leached saprolite, does give rise to soil anomalies. Gold distributions within topsoils and vegetation were similar to those shown by the calcareous horizon but that of lag was more erratic, with the highest values over the floodplain, suggesting a clastic derivation from the north.

LEME Open File Report 53

The distribution of gold and other elements in soils at the Granny Smith Gold Deposit, Western Australia

Lintern, M.J. and Butt, C.R.M.

The distribution of Au and other elements was examined at the Granny Smith Au deposit, south of Laverton. The area is extensively covered by hardpan, which is particularly common in the northern part of the Yilgarn Craton and inland Australia. Five profiles were studied, some to 10 m depth, for textural, geochemical and mineralogical characteristics pertaining to the distribution of Au and other elements. Laboratory studies were performed to examine the nature and behaviour of Au in the soil. Selected bedrock samples were analysed for trace elements in order to determine their potential as pathfinders for Au mineralization. This study was to complement work previously performed south of the Menzies Line where a strong association was found between pedogenic carbonate and Au.

The distribution of Au at Granny Smith appears to be primarily related to the contact between transported and residual components of the hardpan and is coincident with a trend towards increasingly alkaline conditions. South of the Menzies Line, such a change of pH has no significant effect on the distribution of Au. Segregations of hardpan material from contact between the transported and residual components indicates that the matrix does not necessarily contain all the Au because some is associated with lithorelic fragments cemented within the matrix. Furthermore, there does not appear to be any general mineralogical, geochemical or textural associations of Au with other components within the profiles, although these do exist within individual profiles. Laboratory experiments indicate that some Au is associated with specific extractable phases within the soil e.g., manganese oxides, organic material and soluble silica but, compared with Au that can be leached using water or iodide alone, they do not represent a highly significant fraction. Gold is generally found to be at least as soluble in water and iodide as in some soils south of the Menzies Line, but mobility in the surficial environment appears to be severely restricted due to encapsulation within the hardpan cement. Re-adsorption of dissolved Au by hardpan is possible, but is weaker than that occurring with ferruginous soils in the south.

Arsenic, W. Mo and, perhaps, Sb are associated with primary mineralization, but only As is retained at detectable concentrations in the upper regolith. Barium, Cu and Zn are weakly enriched in bedrock and are retained in the upper saprolite; however, Ba may also indicate the presence of felsic rocks, such as granodiorite, rather than mineralization. The generally low abundances of Bi, Cd, In, Pb, Se and Ag in primary mineralization eliminate them as potential pathfinder elements.

The work highlights the problems associated with exploration for Au in areas dominated by hardpan. Further studies and examples are required before any recommendations on specific sampling procedures can be made.

LEME Open File Report 54

Geochemical background, Mt Percy, Kalgoorlie, Western Australia

Butt, C.R.M.

In an earlier study, the distribution of gold and over 40 other elements in the regolith was determined over the mineralized Mystery Zone at Mt Percy. The site is typical of supergene Au deposits in the Kalgoorlie area. However, most of the samples were from the pit, so that only those from the western margin, including some drill cuttings, were in unaltered and unmineralized rocks or their weathered equivalent. None were distant from mineralization and could provide an adequate measure of the background. A further study has been undertaken to determine the geochemical background, using samples from diamond and percussion drilling approximately 1000 mN of the Mystery pit, across the same stratigraphy. The site was not ideal because, unlike the Mystery Zone, the regolith has been partly eroded and there is no lateritic duricrust or gravel horizon. Nevertheless, it provides useful comparative data for much of the regolith over barren or weakly mineralized equivalents of the rocks of the Mystery Zone.

The unweathered rocks in the background site consist of talc-chlorite-carbonate rocks of the Hannan's Lake Serpentinite, intruded by felsic porphyries. Unlike the Mystery Zone, there is no fuchsite-quartz-carbonate alteration and the rocks are essentially barren, with a maximum Au content of 8 ppb. The weathering front is at about 60 m but the full regolith profile could not be sampled as all percussion holes were terminated in saprolite at about 34 m vertical depth. The regolith consists of strongly leached saprolite that becomes softer and increasingly clay-rich towards the surface, merging with plasmic and mottled clays at about 10 m depth. These form a transitional zone, up to 4 m thick, between the saprolite and an almost uniform cover of non-calcareous and calcareous red clay soils. The regolith samples are from a traverse about 150 m south of the barren unweathered rocks of the diamond drill section and contain minor Au mineralization, associated with now-weathered fuchsite-altered ultramafic rocks.

For the *unweathered rocks* and *saprolites,* comparisons between the background site and mineralization in Mystery Zone indicate:

1. In both fresh and weathered ultramafic rocks, alteration is indicated by fuchsite (chromian muscovite) and by elevated concentrations of K, Ba and V. Altered porphyries can possibly be distinguished by their higher K contents.

2. Unmineralized talc chlorite ultramafic rocks in the Mystery Zone are relatively enriched in As and Sb compared to their equivalents in the background area. This may indicate widespread weak primary dispersion from mineralization into apparently barren wallrocks. The enrichment continues into the saprolite.

3. Unweathered mineralized porphyries have enhanced K, V, Au, As, W and Sb contents relative to unaltered background porphyries. However, although Au, As and W abundances are greater in the

saprolite in the Mystery Zone, there appears to be no significant difference in Sb content compared to the minor background mineralization.

4. Weathered fuchsitic ultramafic rocks of the Mystery Zone are enriched in Au, As, W and Sb relative to background.

5. Overall, in addition to Au, mineralized saprolite is indicated by As (contrast x10 compared to barren talc-chlorite ultramafic rocks), Sb and W (contrasts x2, but x6 in porphyries). Regional scale thresholds are 20 ppb Au, 10 ppm As, 4 ppm Sb and 3 ppm W; local thresholds are rather greater, *i.e.*, 90 ppb Au, 35 ppm As, 8 ppm Sb, 6 ppm W.

In the *clay-saprolite* and *mottled clay* horizons broadly similar conclusions apply, except that Au may be leached and that W and, particularly, Sb tend to be more strongly concentrated than in the saprolite, particularly over the porphyries. However, data from these horizons are too few to provide an adequate comparison. The *red clay soils* at the background site do not retain a clear indication of their parent lithologies, unlike immediately underlying horizons, and are, therefore, probably transported. The data indicate that Au becomes concentrated in the calcareous surface horizons, although it is not certain whether the anomaly represents a widespread enrichment (local threshold about 30 ppb) or is related directly to the concealed minor mineralization deeper in the regolith. The occurrence of Au anomaly in calcareous soils overlying buried mineralization is consistent with the findings of several other investigations in the southern Yilgarn Block.

LEME Open File Report 55

Mineralogy and geochemistry of the Lights of Israel Gold Mine, Davyhurst, Western Australia

Douglas, G.B., Robertson, I.D.M. and Butt, C.R.M.

The dispersion of gold and 32 other elements in the lateritic regolith has been studied at the Lights of Israel gold mine, Davyhurst. The Au mineralization occurs primarily within a westerly dipping biotite schist within tholeiitic metabasalts that have been metamorphosed to amphibolite facies. The mineralized sequence has been variably weathered and has been truncated to the upper saprolite, and is partially concealed beneath a thin (1 m) residual soil which has received minor input from surrounding granitoid terrain. Two hundred and sixty-one samples from near the surface, within the saprolite and from the fresh rock have been analyzed to examine the element distribution throughout the entire remaining weathering profile. The elements associated with Au mineralization appear to be S, W, As, Sb and Mo, but these have low mean concentrations i.e. S (0.3 %), W (2.9 ppm), As (5.5 ppm), Sb (0.6 ppm) and Mo (3.6 ppm) compared to other Au mineralization in the Yilgarn Block.

The Au distribution in the regolith is typical of the southern Yilgarn Block with a patchy dispersion within the regolith and a distinct geochemical anomaly associated within pedogenic carbonates. A zone of apparently secondary Au enrichment occurs approximately 30 m below the surface and is accompanied by minor enrichments in a number of other elements including rare earths (La, Ce, Y), and base and transition metals (Fe, Mn, Co, Cu, Zn, Ni). There is little evidence of the zone of leaching in the upper saprolite horizons that is commonly reported from other deposits. The unweathered metabasalts, saprolites, near surface samples, soils and, to a lesser extent, biotite schists can be discriminated geochemically using Zr-Ti-Cr plots.

There are several implications for exploration for Au and other commodities. In general, the data presented in this report support the contention that at local to subregional scales, Au is one of the best indicators of Au mineralization, despite (or perhaps because of) its chemical mobility during weathering. The principal proviso is that sampling must take into account the distribution of Au in the regolith, as exemplified by Lights of Israel and numerous other sites in the Yilgarn Block.

LEME Open File Report 56

Petrology and geochemistry of surface materials overlying the Bottle Creek Gold Mine, WA

Robertson, I.D.M. and Wills, R.

The tectonically-related mineralisation at Bottle Creek is a chalcophile, pathfinder-rich Au-Ag deposit. Gossans contain anomalous Ag, As, Au, Cu, Pb, Sb and Zn. The mineralised zone at Bottle Creek strikes for 5 km and traverses a complex geomorphic environment consisting of residual lateritic duricrust, partly covered by colluvium, parts where the duricrust has been partly or wholly stripped to saprolite, areas where laterite and stripped profiles are buried beneath sheet-flood colluvium-alluvium and numerous, more recent drainage channels, now filled with fluvial gravels. Most profiles have been hardpanised to a varying extent. The study area lies in an arid area of mulga scrub, very close to, but north of, the Menzies Line.

Within the broad catchments, regolith-landform relationships have been integrated with both the original exploration data and with CSIRO orientation geochemistry to test the effectiveness of surficial sampling in residual, erosional and depositional areas. The two study areas, Emu and VB Boags, lie in contrasting residual-erosional and depositional regimes respectively. In the former area, geochemical sampling of laterite and lag gives broad indications of mineralisation typical of lateritic areas. Indications from the latter are very dependent on localised thinning of the cover, on mechanical dispersion and on bioturbation carrying ferruginised saprolite and hardened, ferruginous mottles to the surface.

The best indicator elements are As > Sb > Au > Pb. The width of the As anomaly is 1200 m, that of Pb is 400 m. A phyllic halo surrounds the Emu mineralisation and this is detectable mineralogically as remnant muscovite in the lag by both XRD and petrography and geochemically as a K halo with minor Na and Ba. At VB-Boags, the phyllic halo is very much reduced in size and patchy, as are halos in As, Sb, Au and Pb. A sediment-filled fluvial channel, between VB and Boags, has truncated all geochemical anomalies.

A very brief investigation indicated that the coarse soil fraction would be as effective as the lag; the choice between these sampling media would be one of cost and convenience.

Regolith-landform mapping provides an essential basis for planning geochemical prospecting. In the residual-erosional lateritic terrain, surrounding the Emu Pit, wide-spaced (up to 1 km) lag sampling on a triangular grid, using As, Sb, Au and Pb as indicator elements will delineate the mineralised zone. In thinly-covered depositional regimes (for example VB-Boags), lag may be used at a much reduced sample spacing (e.g., 50-100 m) but there are significant attendant risks, in that success is very dependent on the cover being thin. Thin cover may, in part, be due to induration of the weathered mineralisation which tends to form positive features in the palaeotopography.

LEME Open File Report 57

Gold and associated elements in the regolith - dispersion processes and implications for exploration. P241A Final Report

Butt, C.R.M., Gray, D.J., Lintern, M.J. and Robertson, I.D.M.

This report summarises the results of the two-year continuation of the CSIRO-AMIRA Project P241 *"Gold and associated elements in the regolith - dispersion processes and implications for exploration."* The continuation had the principal objective of extending the research into some important topics identified during the original project. The data complement and expand those obtained previously and the discussion of each topic draws on the results and conclusions of each phase of the Project. The principal fields of research and the outcomes are as follows:

1. Elemental dispersion in deep regoliths was investigated at Lights of Israel, Davyhurst and a background site at Mt Percy, Kalgoorlie, with a minor study at Mulgarrie. The data confirm that, at local to sub-regional scales, Au is the best indicator of Au mineralization. However, sampling and

interpretation must account for the distribution of Au in the regolith, in particular, its accumulation in ferruginous and calcareous surface horizons, its depletion for 5 to 20 m below them, and further sub-horizontal enrichment at depth. The most suitable pathfinders suite is As, Sb, W, +/- Bi, Mo, Pb; Ba, K and Rb give expression to some alteration zones. These elements provide confirmatory evidence for mineralization where Au has been depleted or where the distribution is patchy or has little focus.

2. The determination of bedrock lithology from its weathered counterpart is a major problem in regolith dominated terrain. The processes of rock weathering and procedures for geochemical, mineralogical and petrographic identification of different lithologies have been summarized in an *"Atlas of Weathered Rocks"* produced specifically for this Project. The Atlas illustrates the changes in fabric, mineralogy and composition that take place during weathering. It is far from an exhaustive catalogue of all lithologies, but demonstrates the amount of lithological information that can be obtained from chemical analysis and by careful observation, even at the hand lens scale.

3. The close relationship between the distributions of Au and pedogenic carbonate in areas south of the Menzies Line was further confirmed by detailed orientation studies at Lights of Israel and Zuleika (Ore Banda), with a minor study at Mulgarrie. Zuleika and Mulgarrie represent sites where soil Au anomalies directly overlie mineralization concealed beneath barren palaeochannel sediments. Unfortunately, due to natural contamination from nearby outcropping mineralization, no unequivocal evidence could be obtained to relate the anomalies and the concealed deposits, although such a relationship has been demonstrated during routine exploration programs elsewhere. Further soil investigations were conducted north of the Menzies Line, where Au tends to be associated dominantly with ferruginous materials in residual soils. However, in hardpan at Granny Smith, Au is associated with lithorelics and the siliceous cement. There is no obvious association with Mn oxides. Gold enrichment occurs towards the base of the hardpan, overlying leached and possibly depleted saprolite. Secondary carbonate is present in the lower hardpan and upper saprolite; this has much less Au than pedogenic carbonates, although much of it is highly soluble.

4. Laboratory investigations of the chemistry of Au in soil have led to an improved understanding of its associations with other constituents and the mechanisms of the formation of Au anomalies. Gold in carbonates is highly soluble and can be distinguished from that associated with Fe oxides by partial extraction. Gold and Ca are probably brought to the surface biochemically, being cycled via vegetation, but the Au carbonate association in soil is probably largely physical in origin, arising from precipitation via evaporative processes. Gold in soil is highly labile and, at least in part, as water-soluble complexes, so that under wet conditions can readily be redistributed.

5. Hydrogeochemical data show that the clearest indication of Au mineralization is given by Au itself. Data interpretation depends upon knowledge of the dominant dispersion mechanism. Where Au is dissolved as a thiosulphate complex (Boags, Bottle Creek; Hornet, Mt Gibson), Au distribution matches that of mineralization. Where dispersion is by halide complexation (Panglo, Wollubar and parts of Mt Gibson), the distribution of dissolved Au is controlled by physico-chemical parameters unrelated to the presence of mineralization, in particular where a high Eh is maintained by Mn oxidation in acid groundwaters. Additionally, there is a strong antipathetic relationship between dissolved Au and Fe, due to Fe^{2+} acting as a reductant. The presence of other elements, such as As and Sb, may indicate sulphides associated with Au mineralization. However, groundwaters in some drainages have very high concentrations of base metals and REE unrelated to the presence of such mineralization, probably having been leached from country rock and concentrated by evaporation.

6. The spectral characteristics of Fe oxides and clays in the 0.4 to 2.5 μm wavelengths may have use in distinguishing different minerals not always apparent by routine XRD analysis and, in field logging or remote sensing, for mapping regolith materials such as lateritic horizons, lag and exposed saprolite. Spectral identification and semi quantitative estimation of micas has potential for identifying alteration zones and micaceous lithologies, but practical application is limited to materials having over 20% mica. Similarly, poor discrimination of soil carbonates means that the presence of this important sample medium cannot be recognized.

LEME Open File Report 58

Geochemical exploration in complex lateritic environments of the Yilgarn Craton, Western Australia. Final Report

Anand, R.R., Smith, R.E., Phang, C., Wildman, J.E., Robertson, I.D.M. and Munday, T.J.

The objectives of this two-year extension project were to develop and improve methods of finding mineral deposits (particularly gold and base metals) in lateritic environments of the Yilgarn Craton, using geochemistry within a sound regolith-landform framework. The project focussed on more complex lateritic environments than its precursor, by including a study of the Kalgoorlie region and areas of transported cover overlying variably truncated laterite profiles elsewhere. The multidisciplinary project team augmented its skills in remote sensing and regolith mapping through collaboration with the newly formed Co-operative Research Centre in Australian Mineral Exploration Technologies.

The Kalgoorlie region
A regolith-landform framework for the Kalgoorlie region was established over an area of 10 000 km^2. Landscapes were shown to be characterised by extensive stripping of upland areas, very shallow to deep weathering, patchy development of lateritic residuum and extensive occurrence of calcareous and acid, red clays, which commonly contain ferruginous granules. Erosional stripping of the upper, more weathered, parts of the regolith appear to be important factors, coupled with the distribution of mafic and ultramafic rocks, influencing the gross distribution of carbonates in the regolith. Results were then compared and contrasted with other parts of the Yilgarn Craton.

Orientation studies
Eight additional geochemical orientation studies were completed and set within their district-scale regolith-landform setting. In the Kalgoorlie region these were: Ora Banda (Matt Dam), Kanowna Belle and Wombola; and elsewhere: Boddington, Mt McClure, Lawlers (Waroonga and Genesis), Bottle Creek, Golden Grove, Beasley Creek and Lights of Israel. All are Au deposits except Golden Grove, a Cu-Zn-Au volcanic-hosted massive sulphide deposit.

Systematising regolith-landform mapping units
A framework for classification of regolith-landform mapping units was established which links landform with regolith stratigraphy. Most regolith-landform mapping units so far encountered in the Yilgarn are accommodated and can be compared with each other. An accompanying atlas aids recognition of regolith units being mapped or sampled.

Developments in new sample media
Several new sample media were demonstrated to have application in exploration, particularly where lateritic residuum is missing. These include ferruginous saprolite, iron segregations, ferruginous mottles in upper saprolite, ferruginous granules in soils (including soils on transported overburden) and ferruginous mottles in cover sequences.

Ferruginous granules in soil. It was shown at Kanowna Belle, that near-surface ferruginous granules hold trace element indicators (As, Sb, Au) of the Au deposit forming a broad (>400 m wide) anomaly in the thin, transported cover overlying the deeply leached, partly truncated profile. These granules are a distinctive sample medium, quite separate from lateritic nodules. Their use holds considerable promise in exploration for Au and base metals in areas of deeply leached, partly truncated profiles, with or without the presence of transported cover, situations which are common in the Kalgoorlie region.

Ferruginous saprolite. At Matt Dam, ferruginous saprolite gave a strong multi-element anomaly (Au, As, W) over the deeply leached, partly truncated profile and the concealed Au mineralisation are similar to Lawlers. Ferruginous saprolite is common, in both the Kalgoorlie and Leonora-Wiluna regions, and forms a useful sampling medium for reconnaissance. It is a useful medium for target definition by sampling at surface or by drilling through sedimentary cover.

Ferruginous mottles in cover sediments. It was shown by the research at the Kanowna deep leads and the Matt Darn prospect that such ferruginous mottles in the vicinity of concealed Au deposits can carry anomalous As, Sb, W, and Au, apparently generated through hydromorphic dispersion (As, Sb, and Au) during weathering after sediment deposition.

Dispersion models and exploration procedures
Regolith and geochemical dispersion findings have been integrated into new exploration models for the following settings: (i) full lateritic profile, high seasonal rainfall, no surficial cover (based on Boddington); (ii) full lateritic profile, semi-arid to arid climate, little or no cover (based on Golden Grove, VHMS Cu-Zn; Mt Gibson, Bottle Creek and Beasley Creek). Updated models were generated for: (iii) buried, complete profile, arid terrain (based on Mt McClure and Waroonga), (iv) buried, partly truncated profile, arid terrain (based on Kanowna Belle, Matt Dam, Kanowna deep leads, Bottle Creek, Boags, Mt McClure, Waroonga and Genesis).

Systematic differences in the distribution of Au between the high and low rainfall areas were revealed by the Boddington orientation study, in comparison with the Mt McClure and Lawlers Au orientations. The surface depletion of Au in the upper ferruginous part of the profile at Boddington is opposite to that found at Mt McClure and Lawlers. However, despite surface depletion of Au at Boddington, Sn, W, Mo, and As are strongly anomalous throughout the profile.

Research findings were transferred to sponsors through production of research reports, review meetings, workshops and a field trip. Research projects for nine Bachelors Degree Honours students, in regolith geology, geochemistry or geophysics, were an integral part of project strategy, providing an additional, effective mechanism of experience transfer to industry.

LEME Open File Report 59

Strategies and methods for the interpretation of geochemical data. Discussion paper applied to laterite geochemistry

Grunsky, E.C.

This paper summarizes a systematic approach to analyzing the geochemical data collected over lateritic terrains in the Yilgarn Block of Western Australia.

Critical steps in the sequence of data analysis are:

1) preliminary data analysis,
2) exploratory multivariate data analysis, and
3) specific multivariate data analysis and modeled multivariate analysis.

For the evaluation of geochemical data in laterites of the Yilgarn Block the following sequence of investigation is recommended:

1) Preliminary Data Analysis

- The use of histograms, box & whisker plots, Q-Q plots, scatter plot matrix, data ranking;
- Preparation of summary statistical tables;
- Maps of elements with each sample ranked into percentile ranges;
- Elimination of gross outliers
- Investigate outliers for each element: analytical error or atypical abundance;
- Adjust data for censored values;
- Transformation of data based upon samples below the 95th-98th percentile;
- Scatterplot matrix for transformed data
- Threshold selection after transformation

2) Exploratory Multivariate Data Analysis

- Robust estimates to compute means and covariances to enhance the detection of outliers;
- Application of dimension reducing techniques such as principal components analysis;
- The use of methods to delineate structure in the data (cluster analysis, multi-dimensional scaling, non-linear mapping, and projection pursuit);
- The use of χ^2 plots applied to transformed data to isolate outliers based upon all of the elements of interest; maps of large Mahalanobis distances (>95th percentile) may identify anomalous areas.

3) Specific Multivariate Data Analysis and Modeled Multivariate Analysis

- Calculation of empirical indices specifically tailored to areas in which multi-element associations are understood.
- Multiple regression applied to areas where a linear model of the multi-element association can be computed with good results (i.e. high R^2 coefficients). Residuals can be examined for the potential of being associated with mineral deposits.
- The establishment of background and target groups that characterized the geochemical variation of the regional geochemistry and the mineral deposits.
- Analysis of variance and canonical variate analysis to test the statistical uniqueness of the groups.
- The use of all possible subsets to compare reference groups with each other and determine which group of elements enhance the group separations.
- The application of allocation-typicality procedures to test unknown samples from a regional exploration; programme. Each sample is assigned a probability of belonging to one of the reference groups. Maps of typicality or posterior probability can be made to indicate group membership.

This approach of systematically analyzing the laterite geochemistry forms the basis of an effective exploration programme strategy in geochemistry.

LEME Open File Report 60

Introduction and Bottle Creek orientation study - Contribution to Field Guide, Eastern Goldfields Trip

Anand, R.R., Smith, R.E., Churchward, H.M. and Perdrix, J.L.

Schedule of stops

8.00 a.m.

STOP 1 Erosional regime - walk from mine road to line 14 800 mN, turn west towards breakaway. Note variability in topography, outcrops, and lags on erosional surfaces. Lags of quartz, saprock, ferruginous lithic fragments, iron segregations, ferruginous saprolite and calcrete. Elements of the regolith-landform mapping units 3, 5, and 6 should be present.

STOP 2 Stable regime from crest (above a low breakaway) down a long, gentle backslope Continue the walk along line 14 800 mN. Stop on crest, midslope and lower slope positions. On crest, note coarse fragments of duricrust of various types, also some nodules and pisoliths with yellow-brown cutans (skins). Midslope; note finer lag which is dark brown to black also few if any pisoliths and little, if any, quartz. Lower slope fine lag. Note contrast with silts of the narrow alluvial track (mapping unit 9a nearby). Move on to next stop along 14 800 mN.

STOP 3 Stable regime EMU location. Exposure of deep nodular and pisolitic lateritic residuum in EMU test pit.

(i) Note deep hardpanization of lateritic residuum

(ii) trends downwards from lateritic residuum to mottled zone

(iii) types of iron segregations

(a) pisolitic and nodular, Fe-rich, magnetic

(b) yellow brown to red brown mottled to incipiently pisolitic

(c) gossanous types

Commentary by G. F. Taylor on gossans and lithogeochemistry. If sufficient time, continue along exposures of regolith north of EMU test pit, noting lateritic residuum, lens-shaped iron segregations, "fragmentary duricrusts", gossanous materials and trends in depth to weathered rock.

STOP 4 Towards north end of VB pit - Gossan and lithogeochemistry - G. F. Taylor

12.30 p.m.

Lunch

1.30 p.m.

STOP 5 BOAGS mine pit

Greenstone sequence well exposed.

Channel deposit, at north end of decline.

Fine nodular, very gravelly lateritic residuum mid-way along eastern face of decline.

Pisolitic and nodular lateritic residuum at south end of entrance to the main pit.

Iron segregations will be noted in the face.

Gossans will be discussed - G. F. Taylor.

3.00-3.30 p.m.

Depart Bottle Creek by bus

LEME Open File Report 61

Regolith-landform development and siting and bonding of elements in regolith units, Mt Gibson District, Western Australia

Anand, R.R., Churchward, H.M. and Smith, R.E.

Regolith-Landform Relationships

The complex regolith of the Mt Gibson district is explained in terms of the distribution of: (a) regimes where the essentially complete laterite profile is preserved, commonly forming broad crests and upper gentle slopes, (b) regimes of erosion of the laterite profile to the level of saprolite, saprock, bedrock resulting in terrain characterized by low to medium hills, and (c) regimes characterized by depositional accumulations of detritus provided by the erosion of the laterite profile, commonly burying the complete and partly-truncated lateritic weathering profile in the lower slopes and valley floors. In the latter, sediments reach 30 m in thickness and residual laterite up to 6 m thick was observed to occur under the sediments.

The regolith units were mapped over a 17 km x 10 km area, the regolith stratigraphy established, and the regolith units were characterized. A regolith-landform model for the Mt Gibson district describes relationships in terms of erosion and burial of complete and partly truncated profiles. Lateritization and post-lateritization processes responsible for the formation of a variety of regolith types are discussed.

Midway North Area

The pattern of regolith at Midway North which characterizes the district relates closely to the erosional and depositional modification of the deeply-weathered mantle. A total of 25 samples representing various regolith units were characterized petrologically, mineralogically, and geochemically. Systematic mineralogical and geochemical differences occur between transported and residual regolith units. For example, the colluvial units (soils and hardpanized colluvium) contain higher amounts of kaolinite and quartz relative to the underlying residual regolith units. Hematite increases upwards in the residual weathering profile. The Al content in goethite also tends to increase towards the top of the residual profile.

Lateritic residuum is enriched in Cu, Pb, Zn, As, W, Ag, and Au which are associated with hematite and goethite. The calcareous clays overlying acid, plastic clays largely consist of dolomite, kaolinite with small amounts of hematite, calcite, halite, and palygorskite. These clays have low contents of chalcophile elements, but contain significant amounts of Au. However, the amounts of Au are very low in clays relative to the lateritic residuum. The upper saprolite is depleted compared to the lower saprolite in Au and chalcophile elements. Acid, red plastic clays, developed from the weathering of underlying saprolite, are also low in Au.

Carbonates

Scanning electron microscopic studies of calcareous soils and nodular calcretes from the Mt Gibson Au deposits reveal a fossilized community of soil micro-organisms dominated by filamentous structures preserved in fine detail by calcite. The calcite forming the filaments has a variety of crystal habits. Calcified filaments observed in samples of nodular calcrete suggest that biological activity could have played a significant role in the formation of the carbonates in the regolith.

Siting and Bonding of Elements and Dispersion Processes

The bulk samples of soils, lateritic residuum, hardpanized colluvium (red-brown hardpan), and calcareous soils were separated into various morphological groups, such as magnetic vs., non magnetic nodules-clasts, matrix vs., clasts, calcareous fragments vs., ferruginous clasts, and cores vs., cutans. The petrological, mineralogical, and geochemical characteristics of these materials were established. Non-magnetic lateritic nodules and clasts are the dominant fraction of both soils and lateritic residuum. The magnetic and non-magnetic nodules and clasts have different internal fabrics. The cores of magnetic nodules and clasts are black and massive, whereas those of nonmagnetic nodules and clasts are yellowish brown and porous. Hematite is a dominant mineral in both magnetic and non-magnetic lateritic nodules and clasts. The non-magnetic lateritic nodules and clasts contain higher amounts of goethite and kaolinite relative to the magnetic lateritic nodules and clasts, while maghemite is present in the magnetic nodules and clasts. The cutans of nodules and pisoliths are dominated by goethite. Goethite in the lateritic residuum is highly Al-substituted (17 mole%).

Iron, Cr, V, Pb, As, W, Sb, Bi, and Zn are enriched in magnetic lateritic nodules and clasts relative to the non-magnetic lateritic nodules and casts. By contrast, Al, Si, Cu, Ag, Au, and Ni are relatively more abundant in non-magnetic lateritic nodules and clasts. Cores of both groups of nodules and clasts contain higher amounts of Au than cutans.

The matrix of hardpanized colluvium (red-brown hardpan) consists of kaolinite, quartz, and amorphous silica. The mean values of Au and Ag for the matrix of hardpan are higher than, or very similar to, those for lateritic nodules.

Carbonate fractions separated from nodular calcrete are anomalous in Au. The magnitude of the anomaly is, however, smaller than that of lateritic nodules and pisoliths.

The possible associations of Au, Pb, Zn, As, Cu, Ni, Cr, and V with various secondary mineral species are discussed. Chromium, V, Ga, Pb, As, and Sb are strongly associated with hematite. Goethite and kaolinite appear to have strong affinities for Cu, Ni, Ag, and Au. Hydromorphic dispersion appears to be the major dispersion process that extended the geochemical halo in the upper part of the regolith.

LEME Open File Report 62

Regolith-landform development and consequences on the mineralogical and geochemical characteristics of regolith units, Lawlers District, Western Australia

Anand, R.R., Churchward, H.M., Smith, R.E. and Grunsky, E.C.

Regolith-Landform Relationships

The regolith patterns observed in the Lawlers district are explained in terms of the distribution of (a) regimes of erosion of the laterite profile to the level of saprolite, saprock, bedrock resulting in terrain characterized by low hills, (b) regimes where the essentially-complete laterite profile is preserved. commonly forming gentle ridge crests and backslopes, and (c) regimes characterized by depositional accumulations of detritus derived by erosion of the laterite profile, burying the partly-truncated, and in places complete, laterite profile in the lower slopes of colluvial-alluvial outwash plains. In the depositional areas, the sediments reach up to 30 m in thickness. It is now well established that buried residual laterite profiles are widespread beneath the colluvium and alluvium.

Studies in three type areas (the Agnew-McCaffery, Meatoa, and Brilliant areas) provide an understanding of regolith relationships, regolith stratigraphy, and the origin of regolith units. Criteria are established for distinguishing residual regolith from transported regolith applicable to drill hole logging. A regolith-landform model for the Lawlers district presents relationships in terms of erosion and burial of complete and partly truncated lateritic profiles.

Soils

The soils occurring within those truncated regimes which have mafic or ultramafic bedrock lithologies are predominantly red-coloured light clays and red sandy clay loams. They are often acidic and commonly are underlain by a red-brown hardpan. The red clays often contain pseudomorphic grains after amphiboles, further evidence of their mafic origin. The occurrence of pedogenic calcrete at shallow depths in the erosional regimes generally relates to a mafic lithology. Soils on felsic lithologies are acidic, yellowish-brown, sandy loams. Residual regimes are dominated by acidic, brown gravelly sandy loams and sandy clay loams and generally red-brown hardpan is not developed. The soils within the depositional regimes are developed in colluvium-alluvium and are acidic, gravelly sandy clay loams and light clays.

Lags

The distribution and characteristics of lag gravels have been placed within the regolith-landform framework established during this study. Black, ferruginous cobbles of iron segregations, fragments of ferruginous saprolite, and vein quartz occur largely on erosional areas (Units 2a, 2b). Lag of lateritic pisoliths and nodules occurs on residual areas (Units 1a, 1b) overlying complete or nearly complete laterite profiles. The lag of mixed origin, comprising lithic fragments, quartz, lateritic pisoliths and nodules, and fragments of ferruginous saprolite, is abundant on colluvial-alluvial outwash plains.

Lateritic residuum

The top of the residual laterite profile is composed of a layer of lateritic residuum averaging some 3-8 m in thickness comprising a sub-unit of loose pisoliths and nodules which may be underlain by a sub-unit of nodular duricrust. A zone of ferruginous saprolite characterized by bodies of iron segregations generally underlies the lateritic residuum. It is established that ferruginous saprolite forms a blanket deposit up to several metres thick in many areas in the Lawlers district and is preferentially developed over mafic and ultramafic lithologies. In turn, ferruginous saprolite grades into a thick saprolite zone, which extends to vertical depths of 50 to 70 m.

Development of many nodules and pisoliths in lateritic residuum is associated with fragmentation of ferruginous saprolite. Fragmentation of bodies of iron segregations can also yield nodules and pisoliths which become incorporated within the lateritic residuum.

Investigation suggests that the Fe-rich duricrusts are probably formed by absolute accumulation of Fe. One possible explanation is that Fe originally impregnated the soils and sediments in local valleys which now occur as ridge crests in the present landscape because of inversion of relief.

Hardpan
At Lawlers, hardpan has developed within *in situ* regolith and detritus resulting from the erosional modification of the old surface. Cementation of these materials by Si and Fe to form the hardpan is a relatively recent process.

Discrimination between sample types
The 181 samples collected from the McCaffery-North Pit area were separated into four broad groups based mainly upon their morphological characteristics and regolith-landform framework. These include materials from both surface and subsurface units of the weathering profiles. The four groups recognized are: colluvium, lateritic residuum, ferruginous saprolite, and iron segregations. These four groups are shown to have different morphological, mineralogical, and geochemical characteristics. Iron segregations can be recognized by their irregular, black, non-magnetic pitted surfaces. Internal surfaces of iron segregations may show goethite and hematite pseudomorphs after sulphides. Lateritic pisoliths and nodules of lateritic residuum typically have 1 to 2 mm thick yellowish-brown to greenish cutans around black to red nuclei. The presence of cutans may be used to recognize nodules and pisoliths derived from the breakdown of lateritic residuum.

Mineralogy has been shown to give valuable information concerning which part of the weathering profile is exposed at the surface. Iron segregations differ from lateritic residuum by having abundant goethite and less hematite and kaolinite. Maghemite is typically absent in iron segregations. Lateritic residuum can be distinguished from ferruginous saprolite by having abundant hematite and less kaolinite. Colluvium differs from the other groups in having abundant quartz, kaolinite, and some heavy minerals.

The four sample media also show differences in the degree of Al substitution in goethite which appears to be related to the maturity of the regolith, level of truncation, and may also reflect the environments in which the particular regolith unit has formed. Evaluation and identification of various sample media by the degree of Al substitution in goethite looks to be very promising.

Iron segregations are dominated by Fe_2O_3, Mn, Zn, Co, Ba, and goethite and these elements can be used to discriminate iron segregations from lateritic residuum, ferruginous saprolite, and colluvium. Many of the chalcophile elements and Au exhibit lower levels of abundances to those in lateritic residuum and ferruginous saprolite. However, the prominent regional distribution of iron segregations, often as scree on pediment surfaces in partly-stripped profiles, offers potential for use as a geochemical sampling medium.

Whilst the Fe_2O_3 contents of the ferruginous saprolite are comparable with those of the lateritic residuum, there are strong geochemical distinctions between the two types. Lateritic residuum has relatively higher levels of Cr, V, Ni, As, and Pb. Conversely, ferruginous saprolite carries significantly higher levels of Cu, Sb, Bi, and Au. The concentrations of SiO_2, MgO, TiO_2, Zr, and Nb are higher in colluvium than in lateritic residuum and ferruginous saprolite. These differences may be due to the degree of weathering, mineralization, mechanism of accumulation of the secondary weathering products, and origin.

The group separation using canonical variate analysis and all possible subset calculations has indicated that effective separation of the four sampling media exists. A combination of 14 elements (Fe, Mn, Cr, V, Pb, Zn, Ni, Co, As, Sb, Bi, W, Zr, Nb) would seem to be the most useful for separation of the groups.

Siting and bonding of elements
Gold in lateritic nodules from the North Pit location occurs as (i) grains up to 15 µm in diameter, occurring in cracks, and (ii) relatively large dendritic Au grains, which reach 70 µm in diameter, attached to the surface of goethite. Both occurrences of Au appear to be secondary and are almost free from Ag (<1% Ag). In the lateritic nodules, As and Mn are strongly associated with Fe oxides, while Cu is associated with kaolinite.

LEME Open File Report 63

Notes being incorporated into a report on laterite geochemistry for the Moora, Perth, Pinjarra, Collie and Pemberton 1:250 000 sheets

Innes, J., Smith, R.E. and Perdrix, J.L.

These notes support the presentation of regional laterite geochemical coverage in part of the SW of the Yilgarn Block of Western Australia to sponsors of Project P240, on 11 April, 1988.

The geochemical results of some 2000 samples of lateritic duricrust materials are discussed. These represent: (a) all of the sampling within the five 1:250 000 sheets, Moora, Perth, Pinjarra, Collie and Pemberton, arising from research into laterite geochemistry sponsored by Greenbushes Ltd. from 1980 to 1983, Fig. 1; (b) with the addition of some sampling within these sheets arising from a second phase of research sponsored by Greenbushes in conjunction with St. Joe Minerals during 1983 and 1984, Fig. 2.

Accompanying these notes is a plot of the distribution of As in laterite at 1:1 M scale, and a floppy disk of the data.

LEME Open File Report 64

Weathering Processes - P241 Eastern Goldfields Field Trip

Butt, C.R.M., Churchward, H.M., Lintern, M.J. and Scott, K.M.

Bounty Mine, Mt Percy, Panglo

ITINERARY

Sunday 28th October

1.00 pm Assemble at CSIRO Floreat Park

6.00 pm Briefing: Mt Hope - Soils and Landforms

Dinner and overnight accommodation

Monday 29th October

8.00 am Departure for the Bounty Gold Mine after breakfast. Guides: Max Churchward and Melvyn Lintern

1.00 pm Departure for Kalgoorlie after lunch

7.00 pm Arrival Overland Motor Inn, Kalgoorlie for dinner and overnight accommodation

Tuesday 30 October

8.00 am Briefing: Mt Percy - geology, geomorphology and geochemistry

Panglo - geology, geomorphology, soils and groundwaters

9.30 am Depart for Mt Percy.

9.45 am Mystery Pit, Mt Percy. Guides: Charles Butt, Paul Sauter (KCGM) and Ravi Anand. Traverse along west and north walls on bench at RL 400 to NE corner

11.00 am Depart for Panglo.

11.30 am Panglo. Guides: Melvyn Lintern, David Gray, Ian G. Robertson (Pancon). Demonstration of water sampling techniques. Soil geochemistry and biogeochemistry.

12.30 am Lunch.

1.00 pm Depart for Bottle Creek.

Wednesday 31st October

8.00 am	Field visits around Bottle Creek
4.00 pm	P241 only Sponsors return to Kalgoorlie by coach - end of trip
P240	Sponsors depart for Leonora for P240 Field Trip

LEME Open File Report 65

Study of the distribution of gold in soils at Mt Hope, Western Australia

Lintern, M.J.

The principal objective of the study at Mt Hope was to determine the location of gold in the surface environment and to determine the mechanism of its emplacement. Mt Hope provided a near ideal exploration case study area where sampling of soils and vegetation could take place in a relatively undisturbed site.

After an initial orientation survey where a traverse of RAB and RC drilled material was sampled, several small pits (3 x 10 x 2 m deep) were dug. These were situated over, adjacent to and away from mineralisation in order to expose various soil profiles. Following photography and description, the profiles were comprehensively sampled. The mineralogical and chemical composition of the samples show strong and highly significant associations especially between gold and the alkaline earth metals, the latter present as carbonates. The associations are widespread and therefore might be used as an exploration tool when looking for gold in areas similar to Mt Hope. The chemical analysis of samples of vegetation and organic litter indicate the occurrence of gold. Gold values in the vegetation and litter generally reflect those found within the soil profiles. Experimental work is being undertaken to examine these associations in further detail.

LEME Open File Report 66

Spectral properties of muscovite- and paragonite-bearing rocks and soils from the Panglo Gold Deposit, Ora Banda Region, Western Australia

Cudahy, T.J., Scott, K.M. and Gabell, A.R.

Gold exploration in the Yilgarn Craton would be greatly assisted if minerals, diagnostic of gold-related alteration, were developed at the surface and detectable using spectral remote sensing methods. One group of minerals that may satisfy this need are the potassic micas which are often found in weathered surface materials overlying zones of potassic, gold-related, hydrothermal alteration. These minerals exhibit characteristic adsorptions in the 0.4 to 2.5 µm wavelength region, though it was not clear whether the natural abundances of these minerals are sufficient to produce these adsorptions. An answer to this problem was the first objective of this study. The second objective of the study was to determine whether different species of mica could be discriminated.

These problems were investigated using a suite of surface and subsurface samples of weathered mafic rock, shale and soil collected from the Panglo gold deposit, Western Australia. The Panglo deposit was interesting as the alteration comprised muscovite (K-bearing mica), associated with mineralisation, and paragonite (Na-bearing mica), in areas peripheral to mineralisation. Therefore, spectral discrimination of these two mica minerals could theoretically better define the limits of gold mineralisation.

The spectral investigation concentrated on the wavelengths of the 1.4 and 2.2 µm adsorptions (hypothetically provide information on the composition of micas related to the size and composition of the mica unit-cell), and the depth of the 2.35 µm absorption (provides information about the abundance of mica). The geometry of the 1.4 and 2.2 µm adsorptions were not considered as these are strongly affected by other clays, such as kaolinite and smectite. Some consideration was given to the associated spectral mineralogy (nature of other clays, sulphates, water) and possible relationships to the character of the regolith.

The results showed the wavelengths of the OH-related absorption at 1.4 µm and the A1-OH 2.2 µm absorption are approximately 10 nm longer than expected for either muscovite or paragonite. There is also no pattern between these parameters from paragonite-rich to muscovite-rich. These negative results can be caused by mixing with other 2.2 µm absorbing, A1-OH minerals, such as kaolinite. The spectrum of a kaolinite-poor, muscovite-rich shale sample showed wavelengths expected for muscovite.

The concentration of K_2O was used as a quantitative measure for the abundance of muscovite and was compared with the depth of the 2.35 µm absorption. The results showed significant correlation, though a threshold muscovite concentration of approximately 3% K_2O is required, below which the 2.35 µm absorption is no longer distinguishable in the reflectance spectra. This threshold abundance equates to approximately 20% muscovite (by weight). The only exceptions to this relationship were exhibited by the spectra of quartz-rich shales (>60% SiO_2) which showed the threshold abundance can be as little as 1% K_2O. This lower threshold is probably related to the relatively transparent nature of quartz.

The natural K_2O abundances of the weathered mafic subcrop were sufficient to produce recognisable absorption at 2.35 µm. Therefore, mica-bearing, mafic outcrop or float (if present), can be detected using spectral techniques. However, the soils did not show this absorption apparently because these contained <1% K_2O (by weight). Therefore, spectral sensing of soils derived from mica-rich, mafic rocks is unlikely to show mica-related absorption at 2.35 µm.

A relationship, analogous to that between the K_2O content and the depth of the 2.35 µm absorption, could not be established for the Na_2O and paragonite abundances. This is because the samples contained halite.

The reflectance data show different spectral properties for the mafic subcrop, soils and sedimentary subcrop. The mafic subcrop are characterised by strong absorption at 1.395, 1.411, 2.165, 2.318 and 2.386 µm, producing absorption doublets at 1.4 and 2.2 µm. These properties are typical of well-crystalline kaolinite. The soils are characterised by weaker adsorptions at these wavelengths, producing poor absorption doublets, indicating more poorly crystalline kaolinite. The soil spectra also show small adsorptions at 1.46 and 2.25 µm, possibly caused by water, Fe- or Si-cations in the kaolinite structure (typical of more poorly crystalline clay). The shale subcrop show weak to non-existent development of the kaolinite absorption doublets.

The results from this study have limited application to gold exploration strategies. The most important result is the requirement for 3% K2O in a material (contained in potassic mica) before the mica-related absorption at 2.35 µm becomes apparent in the reflectance spectra. If soils dominate the surface materials over mica-bearing gold mineralisation, as is the case at Panglo, then remote sensing techniques (at these wavelengths) are not practical, unless the soils are quartz-rich (quartz-rich soils are not likely to be associated with mafic-ultramafic rocks). The most appropriate application of these results is in the field where a spectrometer could be used to log the presence and abundance of mica in subcrop and drill core. Further work is required to establish whether mica-bearing, mafic saprock is spectrally characterised by well-crystalline kaolinite and K-bearing mica.

LEME Open File Report 67

Spectral properties of soil overlying the sites of the Bounty and North Bounty gold mines, Forrestania Region, Western Australia

Cudahy, T.J., Lintern, M.J. and Gabell, A.R.

Gold exploration in the Yilgarn Craton using spectral remote sensing is difficult for at least two reasons. Firstly, very deep weathering has changed the complex, fresh rock mineralogy to a surface mantle largely consisting of ferric oxides, clays and quartz. Secondly, there is little detailed knowledge of the spectral properties of these weathered surface materials, of very variable crystallinity, overlying gold mineralisation and background areas. To address these problems, some of the studies in the P243 project have concentrated on the measurement and analysis of the 0.4 to 2.5 μm spectra of a large range of regolith materials overlying gold deposits (reports 160R, 169R and 234R) and background areas (reports 235R and 240R). This study of the spectral properties of weathered materials overlying gold mineralisation at the Bounty and North Bounty deposits, Forrestania region, was conducted in association with P241 mineralogical and geochemical studies on the same samples which meant that spectral information could be directly compared with other physicochemical data.

The exposed regolith units of the study area comprise saprolite, lateritic duricrust and alluvium-colluvium which have developed over mafic, ultramafic and sedimentary parent rocks. Primary gold mineralisation is hosted by shales and cherts. The collection of samples preceded major disturbance of the surface materials by mining. Approximately 100 samples were measured, including 57 near-surface samples from three east-west profiles spanning primary gold mineralisation and background areas, and 25 samples from drill core and costeans, which provided information from deeper down the regolith profile. Only 6 samples were taken from areas overlying primary gold mineralisation and approximately 12 from areas associated with secondary gold.

The spectral results show no evidence for alteration minerals associated with primary gold mineralisation. Only one spectrum from weathered surface materials showed spectral properties related to primary minerals, including absorptions at 1.1 (ferrous iron), 2.306 and 2.384 μm (Mg-trioctahedral silicate). All the other surface samples were characterised by spectral properties related to the products of weathering, namely the ferric oxides (hematite and goethite) and clays (kaolinite and smectite). The spectral variations associated with these weathering products show poor relationships with primary gold mineralisation, though there is information related to the character of the regolith, and possibly secondary gold.

The associated studies found secondary gold, is in places, associated with pedogenic carbonate in the top metre of the soil profile. However, the spectra of even the most carbonate-rich samples showed no evidence for the CO_3^{2-} absorptions in the 2.3 μm wavelength region. This lack of carbonate absorption was found to be caused by insufficient abundance of carbonate, as a laboratory experiment showed 40% by weight of carbonate is required in a given mineral mixture (less than 75 μm particle size) before the absorption at 2.33 μm is recognisable. The soils from the study area contained less than 30% carbonate by weight

The reflectance data provide other evidence, albeit indirectly, for the presence of pedogenic carbonate. This includes increased albedo, particularly in the visible wavelengths. Also, an intimate relationship between carbonate and smectite was discovered. The smectite is recognised by characteristic adsorptions at 1.4, 1.46, 1.9 and 2.2 μm. The associated XRD analyses confirmed the presence of smectite only after XRD was performed on clay-rich concentrates. Kaolinite is evident in the spectra of carbonate-poor samples and is recognised by absorption doublets at 1.4 and 2.2 μm.

The spectral data show information related to the hematite-goethite ratio. This information is indicated by shifts in the wavelength of the ferric iron charge transfer shoulder, near 0.6 μm, and the crystal field absorption, near 0.9 μm. As with the smectites, XRD did not provide much information on the iron oxide mineralogy. The reflectance data show the carbonate-poor soils are related to hematite whereas the carbonate-rich soils are related to goethite. The reasons for these changes in the iron oxide mineralogy are not clear but may be related to the effects of Ca and Mg on pH.

The depth of the 0.9 μm absorption was found to correlate with the Fe_2O_3 content. A few soils from primary gold mineralisation show relatively deep 0.9 μm absorption, though further work is required to establish the wider significance of this result as regolith-related variations appear to be more important.

The depth of the 2.2 μm absorption was examined because it can provide information on the relative clay abundances important for discriminating regolith units and possibly gold mineralisation. The 2.2 μm absorption depth was found to correlate with the Al_2O_3 content but a correction factor had to be applied before the 2.2 μm absorption depth could be related to the total clay abundance. This correction is related to the different proportions of Al^{3+} in the smectite and kaolinite structures. The corrected results show the "clay abundances" in the soils over exposed saprolite and lateritic duricrust are similar and that there are no variations spatially related to primary or secondary gold.

The reflectance data provide information consistent with a model for regolith development (report 243R). Important for the interpretation of the Mt Hope regolith is the recognition that pedogenic carbonate (associated with smectite and hematite) overprinted the earlier-formed laterite mineralogy. According to the regolith model, saprolite is characterised by well-crystalline kaolinite and goethite. However, this mineralogy was overprinted by the enrichment of Ca and Mg and the development of smectite, hematite and carbonate.

Regional geochemical sampling and analysis could be assisted using spectral sensing (remote or proximal) by mapping both the surface distribution of pedogenic carbonate and laterite units. Further work is required to establish the significance of more subtle spectral information to gold mineralisation. This subtle information may have to be interpreted in the context of a quantitative regolith model. If for example, gold mineralisation was found to be related to a small increase in the iron oxide content, then larger iron oxide variations, related to regolith development, would first have to be removed (by normalisation with a predicted regolith model) so that more subtle information can be enhanced.

LEME Open File Report 68

Chemistry of gold in some Western Australian Soils

Gray, D.J., Lintern, M.J. and Longman, G.D.

The chemistry of Au in sample soils from the southern Yilgarn, W.A. was investigated by a variety of experiments. Soil solution and incubation studies implied that in carbonate-rich soils dolomite was forming as a result of evaporative processes, with the soil solution in the carbonate horizon being more saline than elsewhere, and containing high concentrations of Na and Mg. The dolomite appears to be coating the surfaces of other minerals, and will therefore dominate the chemistry of this zone.

Shaking $AuCl_4$ solutions with various soil samples showed that the samples least likely to adsorb $AuCl_4^-$ over one day are those enriched in carbonates and low in organic matter. This may reflect poor adsorption of anionic Au complexes at the higher pH of the carbonate dominated materials.

Selective extraction data suggested that various forms of Au exist in the soils tested. In the upper part of the profile, where organic matter is high, Au appears to be associated with this phase. Lower in the profile, Au associated with the Fe oxides or other non-carbonate materials generally has a moderate extractability, which is considerably lower for samples that are merely crushed to <10 mm, relative to those pulverised to <75 μm, suggesting that the Au occurs within solid phases or is otherwise not available to solution. Gold associated with carbonates is very soluble, even in crushed samples, suggesting that a substantial part of the Au associated with carbonate is on surfaces or in environments that are readily accessible to the solution.

Soil incubation experiments were performed on three samples from various depths down a carbonate-rich soil profile. Shaking the samples with deionized water resulted in significant dissolution of about 10 μg/L Au over one week for all three samples. This dissolution was suppressed by CO_2 bubbling. The dissolved Au then reprecipitated in the mixtures with the two samples that occurred closer to the soil surface. Reprecipitation was prevented by irradiation of the mixtures, indicated it to be a result of biological activity. The deeper, carbonate-rich sample differed in that Au dissolution increased with time and was not suppressed by CO_2 bubbling.

When the soil samples were shaken with a solution containing $AuCl_4^-$ the Au precipitated from solution. After several weeks exposure, there was major redissolution of the Au (up to 2.3 mg/L) in the mixtures with the two samples closer to the surface. This redissolution was completely repressed by CO_2 bubbling and strongly reduced by irradiation. The redissolution carbonate-rich sample showed a sustained redissolution, that was less strongly affected by CO_2 bubbling or irradiation.

Thus, the incubation experiments indicated that the soil samples tested had the capacity to dissolve major concentrations of Au. Results suggested that Au dissolved more readily from the carbonate-rich sample than from samples further up in the profile.

Results to date suggest that, contrary to expectations, Au is less strongly adsorbed by, and more soluble from, carbonate-rich horizons than other soil zones. The mechanism for Au concentration in this zone is suggested to be evaporative concentration, rather than through chemical factors. This hypothesis may have important applications for the use of soil as an exploration tool north of the Menzies line.

LEME Open File Report 69

Spectral properties of soil and lag overlying the site of the Beasley Creek Gold Mine, Laverton Region, Western Australia

Cudahy, T.J., Robertson, I.D.M. and Gabell, A.R.

Gold exploration, using spectral remote sensing in the Yilgarn Craton, is difficult for at least two reasons. Firstly, very deep weathering has changed the complex fresh rock mineralogy to a surface mantle, largely consisting of ferric oxides, clays and quartz. Secondly, there is little detailed knowledge of the reflectance properties of these weathered surface materials, of very variable crystallinity, overlying gold mineralisation and in background areas. To address these problems, some of the studies in the P243 project have concentrated on the measurement and analysis of 0.4 to 2.5 μm reflectance spectra of a large range of regolith materials overlying gold deposits at Beasley Creek (this study), Bounty (in the Forrestania region, report 169R) and Panglo (in the Ora Banda region, report 234R). Background areas have included studies at Laverton (report 235R), Lawlers (report 240R) and Ora Banda.

The Beasley Creek gold mine is located in the Laverton area, north-eastern Yilgarn Craton. Before disturbance of the ground by open-pit mining, the Beasley Creek gold deposit was situated under the crest of a small, 3.5 m high rise. Gold mineralisation was related to deeply weathered carbonaceous shale and chert rocks, within an Archaean greenstone sequence. Laboratory reflectance spectra were measured of surface samples collected from two east-west traverses across gold mineralisation and extending into background areas. The samples comprised soil and ferruginous lag overlying subcropping lateritic duricrust, exposed saprolite and mottled zone.

The spectral results show no evidence for sericite or other primary minerals related to the original fresh rock. Instead, the spectra show information related to the products of weathering, namely, ferric oxides (hematite and goethite) and kaolinite.

The spectra of the coarser, ferruginous lag (10-50 mm diameter) show variations in the wavelengths of the ligand-metal charge transfer shoulder, near 0.6 μm, and the iron crystal field absorption minima, near 0.9 μm, indicating hematite or goethite. The relative changes in the wavelength of these parameters are invariant over broad zones (>500 m wide), consistent with hematite-goethite relationships measured by XRD and spatially related to particular, exposed, lateritic units. The goethitic lag is located over saprolite and mottled zone and is interpreted to be the residual product of deflation of the upper, lateritic horizons. The hematitic lag is located over lateritic duricrust.

The soil shows a relatively consistent spectral mineralogy comprising hematite and poorly crystalline kaolinite. The poor kaolinite crystallinity is indicated by the weakly developed absorption doublets at 1.4 and 2.2 μm. Within a 100 m wide zone, over gold mineralisation, there is an 8 nm shift to shorter wavelengths of the charge transfer shoulder, indicating slightly more goethite-rich soil. This shift in wavelength is much less than that shown by the coarse lag.

The soil and lag data indicate a weak relationship between gold and the wavelength of the charge transfer shoulder. This relationship shows that the weathered materials, with more gold, are relatively goethite-rich though, there are too few data to consider this result as significant.

The associated P240 and P241 investigations noted an increase in the overall abundance of iron-rich lag in the vicinity of gold mineralisation. The increase in the total ferric iron content of the soil and lag was examined, using the depth of the crystal field absorption near 0.9 μm. This spectral parameter showed weak correlation with the Fe_2O_3 content but no relationship to areas of gold mineralisation. However, this does not preclude gold being associated with higher ferric iron content at the surface. An increased amount of ferruginous lag at the surface will increase the total iron content, especially in the context of remote sensing applications.

According to a regolith model (report 243R), passage from saprolite and mottled zone to lateritic duricrust is hypothetically associated with a decrease in the abundance of clays. This relationship was tested for the soil developed over these particular units, using the depth of the AlOH-related 2.2 μm absorption. The depth of the 2.2 μm absorption was found to correlate with the Al_2O_3 content of the soil but there was poor correlation with the position in the regolith. The results showed soil mantling saprolite and mottled zone has relatively shallow 2.2 μm adsorptions (lower clay abundances) compared to the soil covering lateritic duricrust. It is suggested that this anomaly is caused by increased winnowing of the soils, overlying saprolite and mottled zone on the western-side of the low rise, by the prevailing winds.

The associated P240 and P241 studies found that powdery carbonates occur as patches within the soil. However, spectral examination of carbonate-rich soil showed no evidence of the diagnostic carbonate absorption at 2.33 μm, even though scanning electron microscope examinations showed calcium-rich particles were well exposed at the surface of the soil minerals. A related P243 study (report 169R) discovered more than 40% by weight of sub-75 μm carbonate powder was required in a soil before carbonates were spectrally recognisable. This is much greater than the maximum carbonate content of the Beasley Creek soil. The only indication of carbonate in the spectra was an increase in the albedo, particularly the visible brightness.

Spectral analysis of the depth, width and wavelength of the 1.9 μm, water-related absorption, can provide information about the content and site (free, adsorbed, trapped) of water molecules. The soil shows two distinct populations of 1.9 μm adsorptions, one associated with free water (driven off after heating to 100°C), and the other associated with water trapped in quartz as fluid inclusions (unrelated to gold mineralisation).

The coarse, ferruginous lag commonly shows an upward ramp in reflectance from 0.9 and 1.3 μm which can dominate spectral properties in this region and will influence the geometry of the ferric iron absorption at 0.9 μm. Another P243 study (report 244R) found the intensity of this feature is correlated with the depth and width of the 1.9 μm absorption and suggested this water is either adsorbed on the surfaces of the iron oxide crystals, by hydrogen bonding, or is intimately associated with silica and iron oxide and formed after lateritisation (report 243R). This spectral property may be associated with the affects of desert varnish, though the underlying rock mineralogy is clearly evident in the spectra (for example, the hematite-goethite ratio).

The spectral results show that the soil and ferruginous lag overlying the Beasley Creek gold mineralisation are not mineralogically distinct from the background materials. An increased development of goethite (shorter wavelength charge transfer shoulder) appears to be associated with gold at Beasley Creek but goethite is pervasively developed in varying abundances throughout the regolith. Therefore, the significance of ferric oxide development to gold mineralisation needs to be further evaluated, especially in the context of the regolith. The spectral results appear to be useful for the regolith characterisation of the soil and lag and so could be used to help classify regolith materials to assist geochemical gold exploration.

LEME Open File Report 70

Geochemistry of weathered rocks at the Telfer Gold Deposit, Paterson Province, WA

Wilmshurst, J.R.

A study has been made of a suite of surface rocks and sub-surface profile samples from the Telfer Gold Deposit, Paterson Province, W.A.

The surface rocks are weathered material, generally gossanous, from the East and West limbs of the Middle Vale Reef (MVR) and from the West Dome, together with three from the Fallows Field prospect; color illustrations are available for definition and reference. Profile samples are from the East and West limbs of the MVR, and from the overlying E-1 Reef.

Chemical analysis was performed by icp-oes, icp-ms, inaa and XRF methods, with data being obtained for the following elements:

Ag Al, As, Au, Ba, Bi, Br, Ca, Cd, Ce, Co, Cr, Cs, Cu, Eu, Fe, Hf, Ir, K, La, Lu, Mg, Mn, Mo, Na, Ni, P, Pb, Rb, S, Sb, Sc, Se, Si, Sm, Sr, Ta, Ti, Th, TI, U, V, W, Y, Yb, Zn, Zr.

In general, the subordinate elements can be divided into those with an affinity for the iron-oxides, residual phases (primary and secondary), secondary oxidate minerals and secondary silicates.

While the affinity of the several elements for the iron-oxides is a function of pH during the formation of the oxides, and hence the absolute concentrations may vary in a carbonate bearing system, cobalt, copper, nickel, zinc, arsenic and molybdenum vary with iron as expected. Tungsten, phosphorus and sulphur also associate with iron-oxides but each is bimodal in its associations as are bismuth and lead. Uranium, also, has an apparent affinity for the iron-rich rocks. It is notable that zinc is present in only very low concentration.

Residual phosphate minerals, monazite and xenotime, probably account for a high proportion of the lanthanide and phosphorus content; the titanium-thorium association, as found in this study, might be accounted for by 'residual' anatase, and zirconium by zircon. The high degree of correlation between thorium and titanium was unexpected, but is not unique. In the surface rocks, and in the upper part of the profile, gold is resistate.

Secondary oxidate minerals are rare in the surface rocks and hence are of minor importance except in that silver, antimony, bismuth and lead are, in varying degree, hosted by such minerals which are subject to leaching, thus accounting for variation in concentration of these elements. In spite of the moderately high content of copper, and of arsenic, secondary minerals are little in evidence in hand specimen or at the macro-scale.

Although thorium is not so evident in the high-iron gossans, the concentrations of both thorium and uranium are exceptionally high in the surface and profile rocks and, while this may be a function of the weathering history of the total sedimentary sequence, it warrants further consideration.

The clay mineral, illite, might be expected to host boron but there is no evidence for associations with other clays, although there is evident distinction between potassic and magnesian zones. The latter implies a higher local pH and buffer capacity.

The gossans are very largely directly derived from the sulphidic precursor with general indication of a sulphide content in the form of boxworks or pseudomorphs; some, however, are evidently deposited from solution more or less remotely from the site of oxidation, and the Fallows Field material shows indication of ferruginisation well in excess of the initial sulphide content. Pyrite of larger scale was common in the Telfer rocks, as evidenced by pseudomorphs of both cubic and pyritohedral forms, and a number of the West Limb gossans are derived from rock carrying well crystallised carbonate, probably at the centimetre scale. Many of the West Limb gossans carry visible gold, but it is not so visually evident in the East Limb material, despite a high analytical content.

The profile samples, in their intersections of the MVR, show many of the associations noted for the surface rocks, but since there is a lower proportion of iron, and a higher clay content, the absolute concentrations of the several iron-associated elements is usually much lower; however, the association between titanium and thorium is more clearly evident.

The peak concentration of the lanthanides is found at the upper contact of the MVR, in association with phosphorus; this is, therefore, possibly a primary feature. The data also suggest that there has been mobilisation of the lanthanides since there is some separation of the light and heavy members, although this could well be explained by the presence of a second lanthanide phase with a much higher proportion of the heavy elements.

If the epithermal model of Goellnicht et al., (1989) is correct, the data, as given here, might be used with little modification; however, it is likely that there would be lateral and vertical haloes of the more mobile elements around the mineralisation channelways, and, hence, variation in relative abundances. The present study suggests that the elements can be prioritised for likely effectiveness in further exploration in the Province, thus:

High - Au, As, Cu, Co, W, Bi, Sb, ?Mo, ?Ag, Zn

Probable - Lanthanides

Possible - Th, Ti, U, Zr

Informative - Fe, Si, Al, Ca, Mg, S, Mn, P

[both Sn and B have a high potential priority, but further data are needed].

However, if gold itself was not introduced largely by epithermal activity in association with the above elements, and the mineralisation has a more complex and perhaps multi-episodic origin, the relationship of this suite of elements to gold, as seen in the Main Dome data, might not hold on a more regional scale. (The relative intensity of the several phases of mineralisation might vary from one locality to another.) It is important to note, however, that the above suite of elements would not necessarily be 'absent' in the case of a non-epithermal genesis since their occurrence is not restricted to epithermal style mineralisation. Nonetheless, it would seem prudent to regard each member of the above suite as very significant in reinforcement or confirmation, but not as an essential factor in a multi-element strategy.

LEME Open File Report 71

Radioelements in weathered shales and mafic volcanics, Panglo Gold Deposit, Eastern Goldfields, WA

Scott, K.M. and Dickson, B.L.

The K, eU and eTh contents of 111 samples of shales, mafic volcanics and dolerites from the Panglo gold deposit have been determined radiometrically. Shales have consistently higher K, eU and eTh contents than the mafic volcanics and dolerites. However, within shale profiles above the Au mineralization, eTh and eU contents are low relative to equivalent barren profiles. This feature is similar to the behaviour of Sr in the same shale profiles (Scott, 1989a) and, with the additional constraints imposed by the geochemistry of Th, an hypothesis to account for the mineralogical and geochemical features in the shale is presented. Under the acid sulphate conditions resulting from the weathering of sulphides, Th (and U) are envisaged as having migrated from more acid areas to what is now the periphery of the deposit where they are adsorbed onto and/or incorporated into Fe oxides. Strontium in hanging wall rocks at the edge of the deposit is contained largely in Na-rich phyllosilicates which formed during the interaction of later saline groundwaters with the original mica. This saline ground water is probably responsible for the formation of the Ag-free supergene gold deposit at Panglo.

Twenty-seven soil samples from over the deposit have similar concentrations of K, eU and eTh. Because they show no variations which can be related to the underlying geology, a major transported component within the soils is suggested. The eU and eTh contents of pisoliths within the soils indicate that eU and eTh are specifically related to the iron oxide components.

LEME Open File Report 72

Regolith-landform mapping in the Yilgarn Craton, Western Australia: Towards a standardized approach

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

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, characterising 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 recognised. 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 recognised 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 recognised 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.

LEME Open File Report 73

Laterite types and associated ferruginous materials, Yilgarn Block, WA: terminology, classification and atlas

Anand, R.R., Smith, R.E., Innes, J., Churchward, H.M., Perdrix, J.L., and Grunsky, E.C.

Terminology, classification and atlas of laterites.

Keywords:
Ferruginous materials, lateritic duricrust, lateritic nodules, lateritic pisolith, lateritic gravel, ferricrete, laterite, nodular duricrust, pisolitic duricrust, vermiform duricrust, vesicular duricrust, slabby duricrust, massive duricrust, fragmental duricrust, fabrics, mineralogy, geochemistry, microstructures, classification, origin, Yilgarn Craton, North Queensland, Victoria, India, Zambia, Brazil.

LEME Open File Report 74

Regolith-landform relationships and the petrological, mineralogical and geochemical characteristics of lags, Lawlers District, Western Australia

Anand, R.R., Churchward, H.M. and Smith, R.E.

This study of the regolith in the Lawlers district is focussed upon the Meatoa, Brilliant, and Agnew-McCaffery areas. The regolith units were mapped using 1:25 000 colour air photographs and three times enlargements (1:8333) of selected air photographs as the base. The regolith stratigraphy has been established for each of these areas and some selected surface units characterised petrologically, mineralogically and geochemically. The regolith patterns observed in these areas are explained in terms of the distribution of (a) regimes of erosion of the laterite profile to the level of saprolite and bedrock resulting in terrain characterised by low hills, (b) regimes where the essentially complete laterite profile is preserved, commonly forming gentle ridge crests and backslopes, and (c) regimes characterised by depositional accumulations of detritus derived by the erosion of the laterite profile, burying the partly truncated, and in places complete laterite profile in the lower slopes of colluvial-alluvial outwash plains. Idealized regolith-landform models for these areas have been established for the purpose of predicting regolith relationships in comparable terrain elsewhere.

The soils occurring within those truncational regimes which have mafic or ultramafic bedrock lithologies are predominantly red-coloured light clays and red sandy clay loams. They are often acidic and commonly are underlain by a red-brown hardpan. The red clays often contain pseudomorphic grains after amphiboles, further evidence of their mafic origin. The occurrence of pedogenic calcrete at shallow depths in the erosional regimes generally relates to a mafic lithology. Soils on felsic lithologies are acidic, yellowish brown, sandy loams. Residual regimes are dominated by acidic, brown gravelly sandy loams and sandy clay loams and generally red-brown hardpan is not developed. The soils within the depositional regimes are developed in colluvium-alluvium and are acidic, gravelly sandy clay loams and light clays.

The distribution and characteristics of lag gravels have been placed within the regolith-landform framework established during this study. At Meatoa, four classes of lag have been recognized: black, coarse cobbles after ferruginized saprolite, yellow to reddish-brown lateritic lithic fragments, lateritic lag, and fine lag of mixed origin. The fine lag of mixed origin, which is widespread in the Meatoa area, comprises a variety of clasts derived from the breakdown of large lateritic lithic fragments and lateritic duricrust, both of which occur in the local uplands. These four lag types differ in their morphological, chemical, and mineralogical characteristics and include systematic variations in the Al substitution within the Fe-oxides. Some lateritic lithic fragments preserve the original rock fabric. Lateritic lithic lag is relatively richer in kaolinite while lags of ferruginized saprolite and lateritic lag are poorer in kaolinite. Petrographic examination of the lag gravels has shown that kaolinite is progressively replaced by hematite and goethite. Goethites of ferruginized saprolite contain lowest Al substitution (<5 mole%), whereas those of lateritic lag contain highest Al substitution (19-26 mole%). The low Al substitution in goethites of ferruginized saprolite suggests that these have formed by absolute accumulation of Fe in an environment almost free of available Al. The data on Al substitution of various regolith materials from this study have shown that the degree of Al substitution in goethite can be used to predict the weathering status of regolith materials and the environments within which they have formed.

The lags of lateritic lithic fragments and lateritic lag show relatively high levels of As, Pb, and Ga, Sn, W, and Bi occur in low concentrations and did not show any variations between the lag types. The lags of ferruginized saprolite have significantly higher levels of Mn, Zn, and Co than the other lag types. The differences in the geochemistry of various types of lags are related to the nature of bedrock, degree of weathering, and mechanism of accumulation of weathering products. The concentrations of Cr and Ni were found to be useful in discriminating the origin (mafic vs ultramafic) of lag gravels. The levels of Au are low in the range of 0-0.034 ppm.

Investigation suggests that the Fe-rich duricrusts are probably formed by absolute accumulation of Fe. One possible explanation is that Fe originally impregnated the soils and sediments in local valleys which now occur as ridge crests in the present landscape because of inversion of relief.

Gold in lateritic nodules from the North Pit location occurs in two forms (i) grains up to 15 µm in diameter, occurring in cracks, and (ii) large, dendritic Au grains which reach 70 µm in diameter and are attached to the surface of goethite. Both occurrences of Au appear to be secondary and are almost free from Ag (<1% Ag). In the lateritic nodules, As and Mn are strongly associated with Fe oxides, while Cu is associated with kaolinite.

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FileMaker Pro Tutorial

This brief tutorial will allow you to use the basics of the run-time 'FileMaker Pro' Database, which is stored on the CD in the back of this volume. For more elaborate operation of a FileMaker Pro database, see Hester (1998)[1].

There are two database versions; *S240_241.FP3* for those using the MS Windows platform and *S240_241.MAC* for the Macintosh platform. These databases are runtime modules and contain all the software you require. Ownership of FileMakerPro software is unnecessary. First, read the license agreement on the last page of this volume. Provided you accept this agreement, you may copy the appropriate file to your hard disc and launch it as you would any normal application. A splash screen with the license agreement appears. On accepting the terms of the license, the data may be accessed. All the data in these databases has been secured. However, in the extremely unlikely event of file corruption, reload the file from the CD.

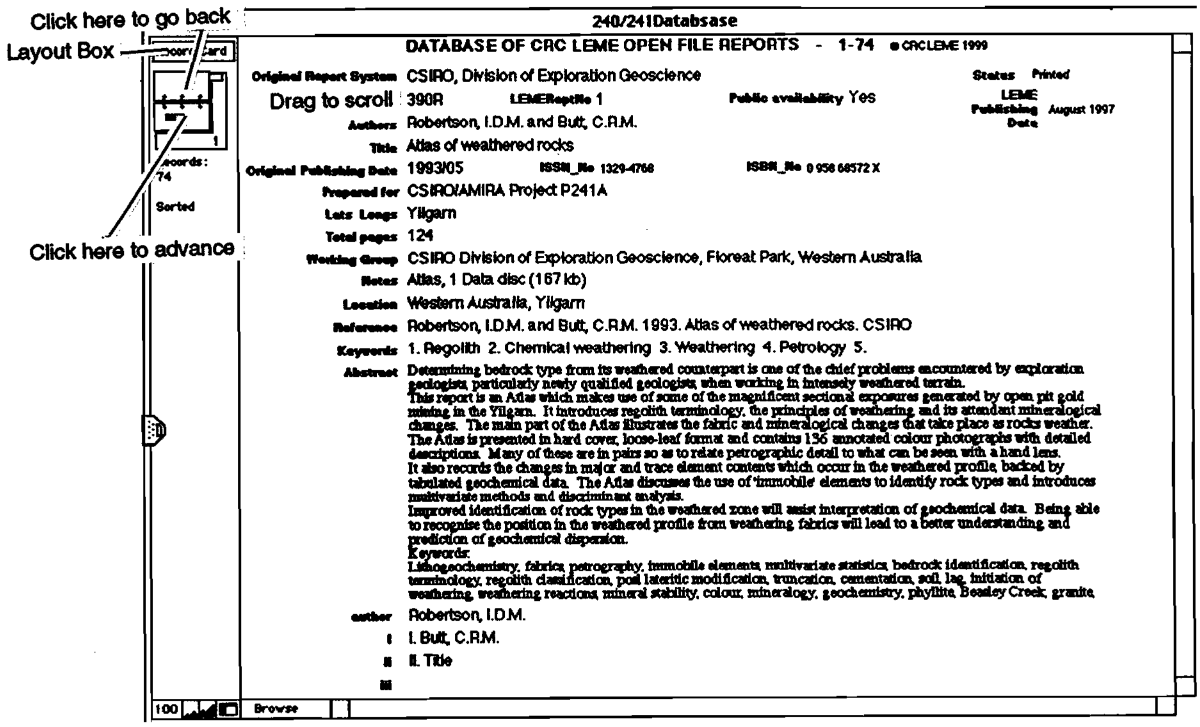

Figure 1. The appearance of the Record Card layout. Stepping through the database is achieved with the booklet icon and scroll bar in the top left.

Layouts and getting around

The first layout is the Record Card layout as in Figure 1. In the top left is a booklet icon on edge with a mini-scroll bar. The number of records is stated (74 in this database) and the database is sorted according to LEME Open File Report Numbers. You may scroll up and down the database, report by report, by clicking on the upper or lower pages of the booklet icon or by dragging the scroll bar for gross changes.

Three other layouts may be accessed by selecting from a menu activated by clicking on the Layout box. These other layouts are Bibliographic, Index Listing and Reference. The Index

[1] Hester, N. 1998. FileMaker Pro for Windows and Macintosh. Peachpit Press. Website http://www.peachpit.com. This quickstart guide gives details of the full implimentation of FileMaker Pro.

Listing is a similar layout to the listings given elsewhere in this volume. The Reference layout is used for a list of the *original* references; this will require editing to suit the required format. The Bibliographic layout contains information that might be required by librarians.

Note that, in the Record Card layout, some fields contain more information than their field initially shows. Click on the field to read all its contained information. Click and drag in the Abstract field to read large abstracts.

Searching
Select **Find** from the **Mode** menu. Click in the Abstract box, type the word 'calcrete' and click the **Find** button. This will search all abstracts for the word 'calcrete'. There are 16 reports with this specification. Step through them with the book icon.

A more complex search can be achieved by typing different criteria into different boxes before initiating the **Find**. In this case, the search will find only those records that match all these criteria. To include an extra search criterion (where *either* one *or* the other (or both) will be met) select **New Request** from the **Mode** menu for the second or subsequent criterion before starting the **Find**. A * may be used as a wild-card for zero or more unknown characters. In numeric fields (only the number of pages and the Open File Report Number are numeric fields) <, or > etc may be used to set criteria. See Hester (1998) for details of more sophisticated searches.

To return to *all* the records, select **Find All** from the **Select** menu.

Sorting
The **Sort** command is found in the **Mode** menu. Select the required sort fields and **>>Move>>** them from the LH menu to the RH menu and click **Sort**.

Printing
Print from your chosen layout using the **Print** command in the **File** menu. It may be necessary to scale the size of the printed output, using the **Page Setup or Printer Setup**, to suit your printer and paper size.

Exporting
Exporting of selected records is achieved by selecting **Import/Export** from the **File** menu and selecting **Export Records** *but read and ensure compliance with the license agreement before doing this*. Give the export file a name and, under **Type**, select the export file format required. Be aware of the severe limitations in field sizes imposed by Excel and MS Access if the abstracts are to be exported. ASCII text is selected as comma-delimited text or tab-delimited text. Output to Excel may be achieved with SYLK. Select the fields to be exported from the LH Menu and **>>Move>>** these to the RH menu. Click **Export** to write the file in the chosen format.

In general, basic operation of this secure database is easy and intuitive but more complex use will require a little reading.

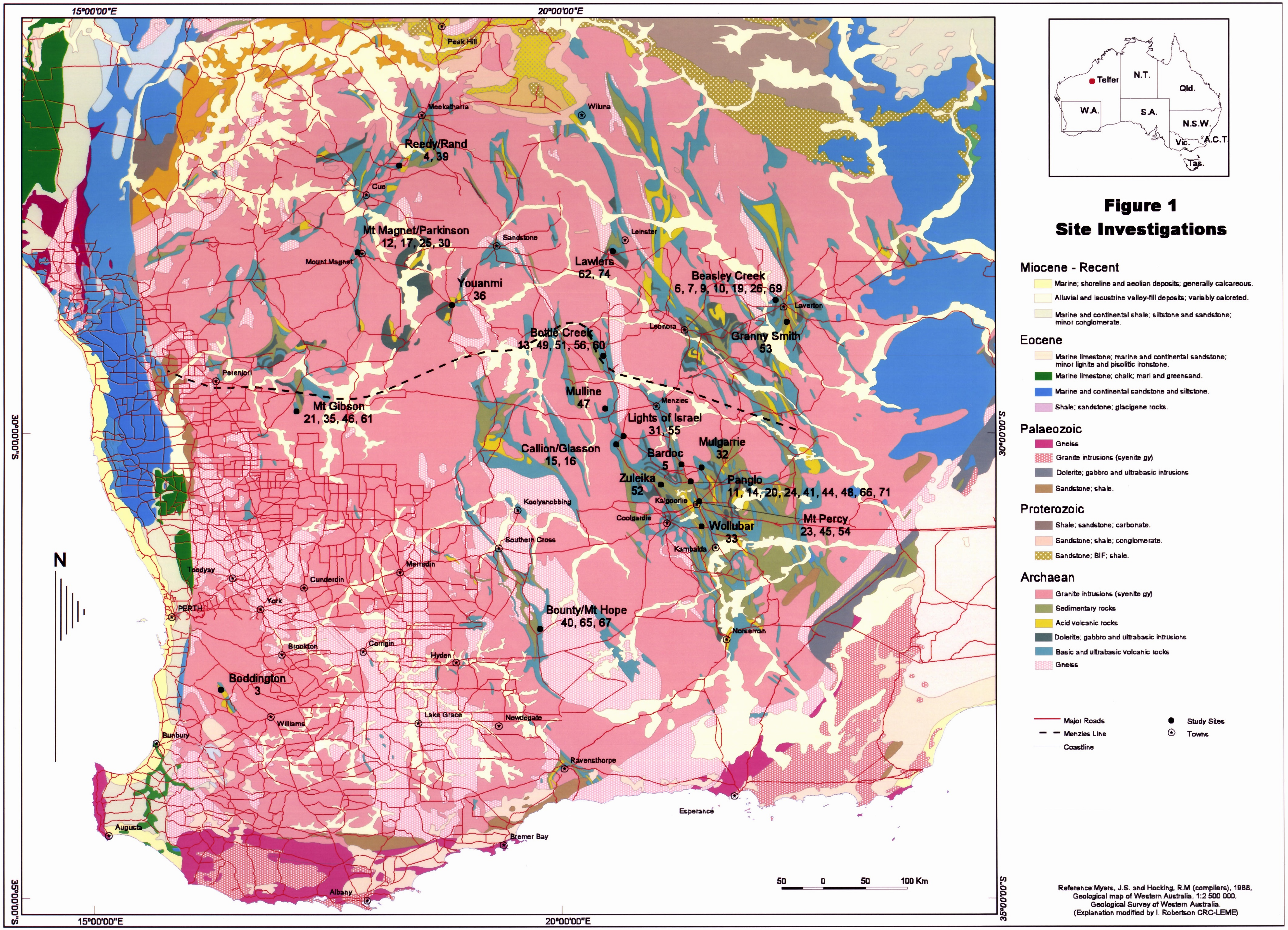

Figure 1
Site Investigations

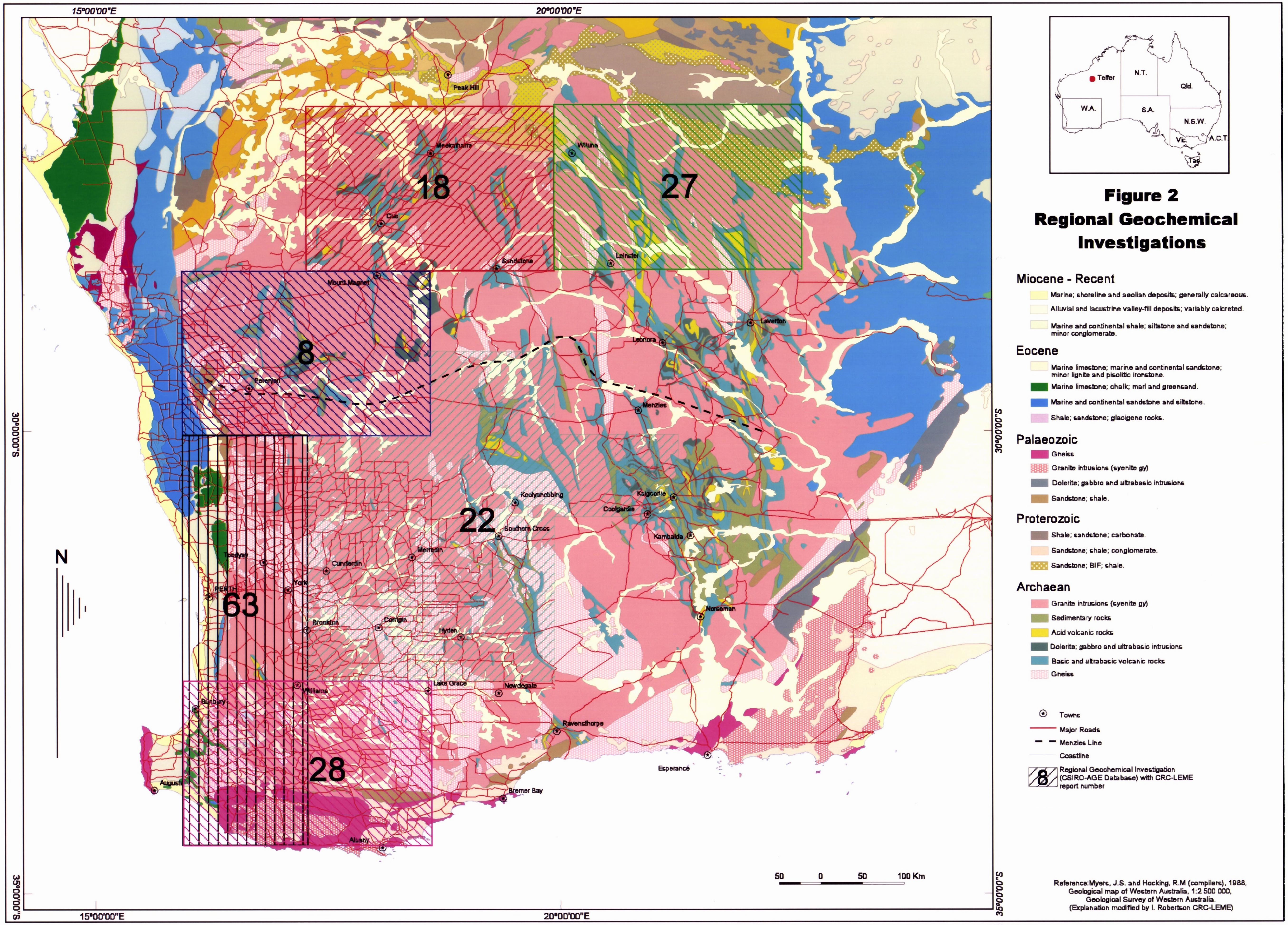

Figure 2 Regional Geochemical Investigations

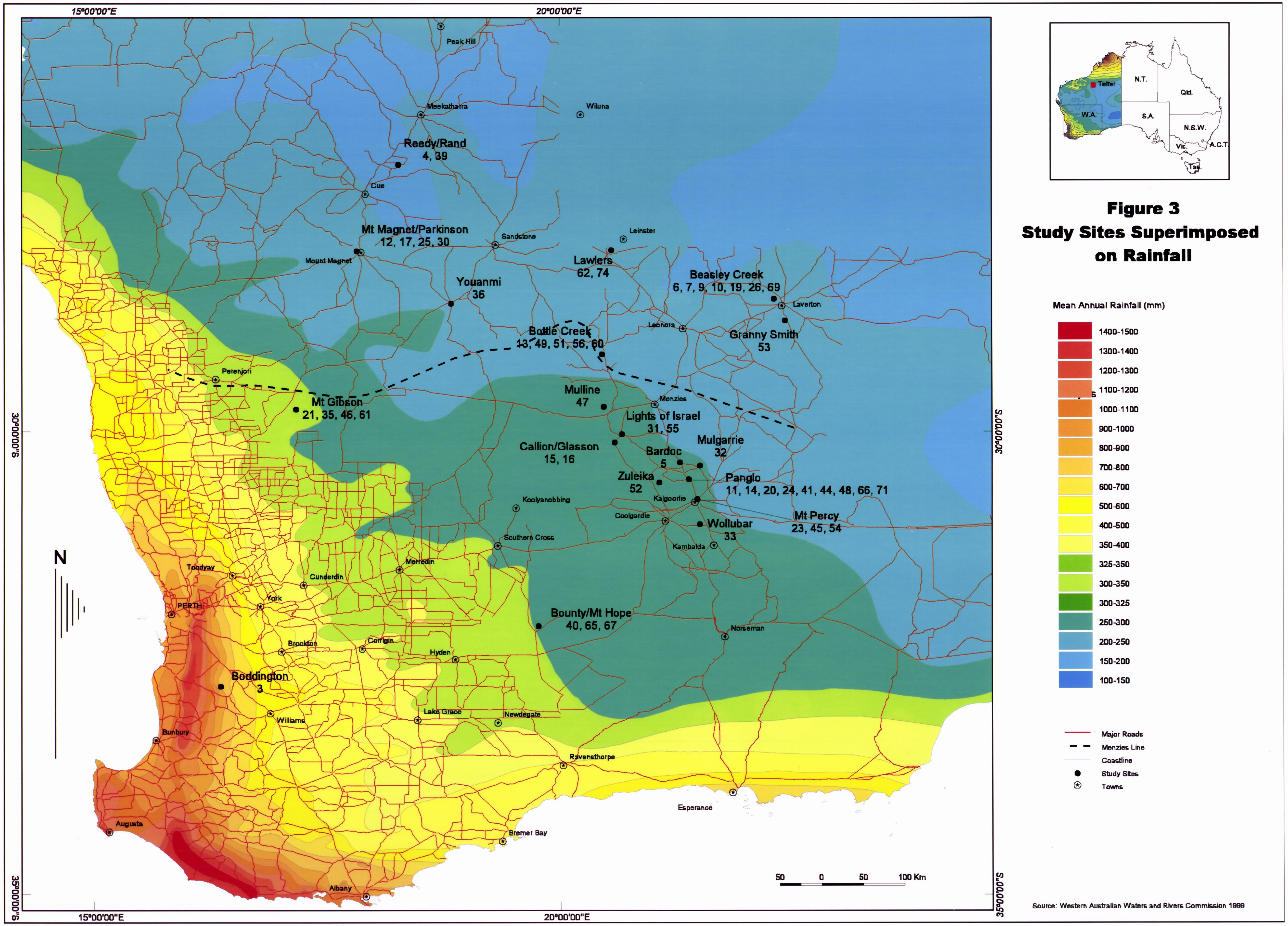

Figure 3
Study Sites Superimposed on Rainfall

CONTENTS OF COMPACT DISC

This is a multi-session disc with a Macintosh part (MAC.VOL) and a Windows part (WIN_VOL). Macintosh computers will be able to see both parts; Windows machines will only be able to see the WIN_VOL part. Each contains an identical license agreement (see next page). The contents of the disc are as follows: -

WIN_VOL - for Windows computers

Copy the contents of this volume to a directory of your choice. Its contents are given below.

DATABASE This contains the Filemaker Pro runtime module with supporting files (ten in all). Launch the executable file in the usual way and the database will run.

FMPTUTOR This contains a brief HTML FileMaker Pro tutorial, which will be readable with your web browser. There is also a JPG file with an image to support the tutorial.

GEOCHEM This contains a number of directories (by CRC LEME Report Number) each of which contain a compilation of all the geochemistry in the relevant Open File report. Individual Readme files are provided to give content and format.

LICAGREE.HTM The License Agreement in HTML format, accessible by your Web Browser.

ABSTRACT This contains the Abstracts in Word, HTML and text format.

MAC.VOL - for Apple Macintosh Computers

Copy the contents of this volume to a folder of your choice. Its contents are given below.

LICAGREE.htm The License Agreement in HTML format, accessible by your web browser.

Database.fldr This contains the Filemaker Pro runtime module with supporting files and directories. Read the installation instructions and complete the installation.

Abstracts This contains the Abstracts in Word, HTML and text format.

Geochem Data This contains a number of directories (by CRC LEME Report Number) each of which contain a compilation of all the geochemistry in the relevant Open File report. Individual Readme files are provided to give content and format. These files are in DOS format and may need a minor translation into the Mac format.

FileMaker Tutorial This contains a brief HTML FileMaker Pro tutorial, which will be readable with your web browser. There is also a JPG file with an image to support the tutorial.

CRC LEME is an unincorporated joint venture between the Australian National University, University of Canberra, Australian Geological Survey Organisation and CSIRO Exploration and Mining. CRC LEME's mission is to aid the discovery of concealed world-class ore deposits through knowledge of Australian landscape evolution. Established and supported under the Australian Government's Cooperative Research Centres Program.