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NORTHERN TERRITORY GEOLOGICAL SURVEY

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Stream Sediment Survey
of
Western MacDonnell Ranges -

GIS-based Interpretation

John N. Dunster and Andrew E. Mügge

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Darwin, October 2001

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Part 1: Main text and tables

Stream Sediment Survey of Western MacDonnell Ranges - Statistical and GIS-based Interpretation

John N Dunster and Andrew E Mügge

Darwin, October 2001

NORTHERN TERRITORY DEPARTMENT OF MINES AND ENERGY

MINISTER: Hon Paul Henderson MLA

SECRETARY: Peter Blake

NORTHERN TERRITORY GEOLOGICAL SURVEY

DIRECTOR: Dr R Dennis Gee

JN Dunster and AE Mügge
Stream sediment survey of western MacDonnell Ranges – statistical and GIS-based interpretation

SUMMARY

The Northern Territory Geological Survey has undertaken a stream sediment survey of the western MacDonnell Ranges covering 6700 km^2. Most samples come from the metamorphic Palaeo- and Mesoproterozoic Arunta Province, which includes rocks of the same age as host sequences to the Broken Hill, Mount Isa, McArthur River and Century ore bodies. Other samples are sourced from unmetamorphosed northern Amadeus Basin (Neoproterozoic to Devonian) and Tertiary sedimentary rocks.

Samples comprise:

- 1193 samples with an average spacing of one sample per 5.6 km^2. These were sieved to <6.5 mm and analysed for 35 elements (n = 41 755) using four-acid digest and combined ICPMS/OES. Au was also analysed to 0.01 ppb detection level by cyanide leach and ICPMS;

- 75 wet pan concentrates analysed for Ag, Au, Cr, Cu, Ni, Pb, Sn and Zn by four-acid digest and ICPMS/OES. Zn was also analysed using peroxide fusion and ICPOES; and

- 29 magnetic fractions analysed by four-acid digest and ICPOES for Cu, Fe, Ni, Pb, Sn, Ti and Zn.

Data have been censored, log-transformed and reduced to the standard normal distribution (LNSND) to enable meaningful comparisons between different units of concentration and analytical methods. Box Cox power transform is used as an alternative where LNSND is inappropriate.

Univariate statistics, including robust measures of central tendency, box and whisker plots and histograms compared to the normal curve are presented for all elements. Crossplots and principal component analyses highlight relationships between elements that are interpreted geologically. Thresholds are picked from inflection points on n-score plots and by using either 95th percentile or +2 LNSND cutoffs. Additive indices, based on target and pathfinder elements for numerous ore body models, are calculated from LNSND data. GIS-based presentations include maps of elemental concentrations using LNSND and Box Cox data, and additive indices.

A rigorous statistical and spatial approach to geochemistry enables mapping of both regional trends related to lithological units and individual anomalies that would be prospective for follow-up work.

The uraniferous Teapot Granite and overlying younger rocks have regionally elevated, possibly partly radiogenic Pb but relatively less Cu or Zn. The highest sieved sample Pb comes from near Round Hill in HAAST BLUFF and is probably sourced from the 1620-1600 Ma Ikuntji Metamorphics. It is constrained to a catchment of less than 1 km^2 and although it is in the same area as base metal occurrences at Nickel Hill and Haast Bluff II, it is probably not directly related to them. Mount Chapple Metamorphics and Mount Hay Granulite have relatively high levels of Cu and Zn and some individual streams contain long dispersion trails. The highest Zn recorded in sieved samples comes from Mount Chapple Metamorphics. Several samples sourced from Mount Hay Granulite are also anomalous in Co, Ti and V. Mount Hay Granulite and Mount Chapple Metamorphics are gradational with one another. They contain 1850 Ma mafic and felsic rocks and locally significant amounts of varied metasediments including calcsilicates. These are regarded as potential hosts for epigenetic base metal mineralisation associated with their long history of tectonism.

Other geological units with base metal prospectivity defined by various additive indices include Speares Metamorphics and rocks near the contact of the newly named 1640-1600 Ma Putardi Granite Suite and Peculiar Volcanics in MOUNT LIEBIG.

One sample from Talyi-Talyi Hills in LIEBIG, with a catchment of just over 1 km^2, is anomalous in Nb, Sn, Ti and W based on n-scores. It is also anomalous in Zn using other criteria. This sample is sourced from charnockite or overlying younger rocks and has high additive indices for Jervois- and Oonagalabi-type base metals, U, VHMS and kimberlite.

Unconformity uranium-gold indices are highest in Narwietooma Metamorphics and Neoproterozoic Amadeus Basin sedimentary rocks.

Point source Au anomalies probably reflect placer concentrations. Of various sampling and analytical techniques tried for Au, wet pan concentrates are probably the most reliable, but significant anomalies in the sieved samples also warrant further investigation (cyanide leach of 5251-031 is 174 times the geometric mean). The Gold Index is generally higher in the Amadeus Basin than the Arunta Province but the highest value is sourced from the Arunta Putardi Granite Suite and rocks overlying it.

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INTRODUCTION

This report presents the results of a stream sediment survey of the western MacDonnell Ranges conducted by the Northern Territory Geological Survey (NTGS) during 2000. A comprehensive statistical analysis is complemented by a GIS-based presentation to identify anomalous samples of interest in exploration for ore bodies.

Tables and figures and their source files are cross-referenced in the List of Figures and Tables. They can be accessed from within this document by clicking on the ➢ icon. Located assays are presented in .CSV ASCII, Excel 97 and Explorer 3 file formats. Over 150 GIS layers can be accessed in MapInfo. Other graphics are in .pdf or .tif formats. This digital information package is not accompanied by hardcopy. Prints of figures, maps and plans can be requested from the Reference Geologist at NTGS. A key to abbreviations is appended.

Rationale

This study is part of the Northern Territory Exploration Initiative. The initiative includes compilation of data in open and closed file statutory exploration company reports as well as NTGS projects that generate lithogeochemical and exploration geochemical analyses (see http://www.dme.nt.gov.au/ntgs). This study is an example of the latter.

The southwestern Arunta Province contains metavolcanics and metasedimentary rocks equivalent in age to the Mount Isa, Century, McArthur River and Broken Hill host sequences. By virtue of its high metamorphic grade, the Arunta Province has escaped the largely gold focussed exploration of the last two decades. Consequently, this study was designed to:

- establish a multi-element baseline stream sediment geochemical database in the southern Arunta Province;

- highlight anomalous areas of potential economic interest; and

- refine techniques of stream sediment sampling and analysis used in exploration for potential ore bodies in this province.

Geochemical data generated from this study will be integrated with existing company data as part of a larger study of the Arunta Province.

Study Area

The study area extends west from Alice Springs to Mount Udor, covering ten 1:100 000 map sheets, mostly in HERMANNSBURG[1] and MOUNT LIEBIG 1:250 000 sheets (➢ **Figure 1**). Although it was originally planned to extend the survey to the West Australian border, access to certain Aboriginal lands in MOUNT RENNIE and western MOUNT LIEBIG had not been granted at the time of fieldwork.

Physiographic Setting

Major topographic features are the east-west trending MacDonnell, Heavitree and Chewings Ranges that form rugged ridges with dissected drainage near Alice Springs. There is up to 1000 m of topographic relief including Mount Zeil (1531 m amsl), which is the highest point in the Northern Territory. Isolated massifs such as Mount Chapple and Mount Hay occur in the north. Ranges become more subdued to the west, and only isolated hills and mountains to 400 m amsl occur in the far west. Dendritic drainage flows south into the Finke River system. Shallow creeks and sheet-wash streams dissipate into sand and claypan country in the north. Stabilised seif dunes occur north and south of the western study area.

A landscape-regolith province map of the study area was prepared under a consultative arrangement by CRC LEME as part of an orientation study (Skwarnecki *et al* 2000).

The climate is semi-arid with less than 300 mm of annual rainfall. Evaporation exceeds precipitation by an order of magnitude. None of the creeks in the area are perennial. However, this study was undertaken after an atypically wet summer and waterholes remained in normally dry creeks.

Average daily maximum temperatures range from 38°C in summer to 18°C in winter. Winter minima are commonly below 5°C and frost occurs on an average of 60 mornings each year.

Vegetation consists of patchy spinifex grassland and sparse shrubs. Isolated bloodwood, bean tree and desert oak are the only large trees in the open plains. *Eucalyptus* occurs along stream channels.

Geological Setting

This study focuses on the metamorphic Palaeo- and Mesoproterozoic Arunta Province (➢ **Figure 1c**), but also includes samples sourced from the northern Amadeus Basin (Neoproterozoic to Devonian) and Tertiary sedimentary rocks. Warren and Shaw (1995) described the geology and whole-rock geochemistry of HERMANNSBURG. Ranford (1969) described first edition

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[1] Names of 1:250 000 map sheets are shown in upper case, eg MT LEIBIG; 1:100 000 sheets are in small capitals, eg HAAST BLUFF

mapping in MOUNT LIEBIG. NTGS are currently remapping this area and some new subdivisions of the Arunta Province (as defined by Scrimgeour, Close and Edgoose pers comm 2001) are used in this study (➢ **Figure 2**[2]).

Mineralisation

Mineral occurrences and prospects listed below (**Table 1**) are from the MODAT database (NTGS 2000) and Barraclough (1975).

The most significant occurrence is the Stokes Yard Prospect in which base metals are associated with a pegmatite in a shear zone in Glen Helen Metamorphics (Fruzzetti 1972). Host rocks at the surface are calcareous metasediments, para-amphibolite and gneissic granite. Mineralised outcrop extends over an area of 20 m x 70 m and the best assay is 7.5% Pb, 26% Zn, 7.5% Cu and 43g/t Ag. Surface samples average 2.83% Pb, 2.81% Zn, 0.27% Cu and 40g/t Ag. The prospect was tested in 1972 with five inclined diamond drill holes. These led Fruzzetti to conclude that mineralisation does not persist at depth. About 1 tonne of rhodonite was mined for ornamental stone and the prospect is now abandoned.

Surface indications of Cu mineralisation near Haast Bluff were described by Barraclough (1975, 76).

Table 1 Prospects and mineral occurrences in the study area. Locations in italics are approximate.

Occurrence/ Prospect	Commodity	Host Geology	GDA94 mE	GDA94 mN	1:100 000 Sheet
Nickel Hill (Haast Bluff 1, Ulpuruta)	Cu-Zn	schist	53 804523	7405939	HAAST BLUFF
Mount Larrie	Cu	metapelite and veins at contact of mafic intrusive and pegmatite	53 787834	7422498	HAAST BLUFF
Haast Bluff II	Cu-Pb-Zn	amphibolite in Arunta Complex	53 802502	7406496	HAAST BLUFF
Glen Helen II	Cu-Pb-Zn-Ag	veins in Glen Helen Metamorphics	*52 220230*	*7407170*	GLEN HELEN
Glen Helen III	Cu-Pb-Zn-Ag	veins in shear zone, Glen Helen Metamorphics	*52 226530*	*7407170*	GLEN HELEN
Jay Creek	Cu	Burst Bluff Gneiss	*52 345530*	*7369170*	MACDONNELL RANGES
Stokes Yard	Zn-Pb	shear in Glen Helen Metamorphics	52 203592	7406291	GLEN HELEN

Previous Stream Sediment Surveys

During the early 1970s, CRA conducted stream sediment sampling in the Mount Chapple and Mount Hay areas as part of a search for nickel and uranium. Regional sampling was undertaken at about one per six km[2]. The <80 >10 mesh fraction was analysed for Ag, Co, Cr, Cu, Ni, Pb, W, U and Zn (Tham 1971a, b, Tham and O'Sullivan 1972). More detailed work was undertaken over magnetic anomalies in Chewings Range where nominal 100 m spaced stream sediment samples were analysed for Co, Cr, Cu, Ni and W (O'Sullivan *et al* 1972). Relatively high levels of Cr were recorded where chromite was shed from ultramafics (O'Sullivan *et al* 1972). Although minor scheelite was observed in about 20 locations, tungsten was not elevated in adjacent stream sediments.

Barraclough and Glasson (1988) described a 41 sample stream sediment program in the vicinity of Stokes Yard Prospect. The <2.5 mm fraction was analysed for Au and <80 mesh analysed for Ag, As, Cu, Pb and Zn. Pb anomalism (max 460 ppm) was traced to the contact between an Arunta gneiss and the Heavitree Quartzite. A second potential target defined by anomalous Pb (max 135 ppm) and Zn (max 70 ppm) was not geologically explained. Barraclough and Glasson concluded that neither area justified retention of the exploration license.

Several stream sediment surveys have been conducted over the northern Amadeus Basin and some of these areas (eg Stewart 1992) adjoin this study.

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[2] Note that this a preliminary map and not accurately registered.

CRC LEME Orientation Survey

CRC LEME was contracted to undertake an orientation stream sediment survey and regolith study during 1999. This work, reported by Skwarnecki *et al* (2000) and Skwarnecki (2001), has been released publicly to accompany this record. Orientation sites at Winnecke and Oonagalabi are, respectively, minor gold and base metal prospects northwest of Alice Springs. Both lie outside the present survey area but are in a similar geological and climatic environment within the Arunta Province. They serve to determine the appropriate analytical suite, optimum stream survey parameters and possible threshold values. A comprehensive set of samples was collected at increasing distances from the source. These were sieved to <6 mm in the field, split in the laboratory to five size fractions and analysed by XRF or ICPMS for Au, As, Ba, Bi, Cd, Ce, Cu, Cr, Fe, Mn, Mo, Ni, Pb, Rb, Sb, Se, Sn, Sr, Ti, U, W, Zn and Zr.

Mineralisation was difficult to detect downstream of Winnecke because of dilution by sand derived from Heavitree Quartzite. Significant dispersion of Au was detected only in the creek draining old Coronation workings, in which there is no quartz dilution. Other isolated anomalous values may be related to local alluvial concentrations. Bi, Sb and W in the fine fraction were considered to be pathfinders for Winnecke style mineralisation, but Au shows no significant statistical correlation with these or any other elements in the orientation survey (Skwarnecki *et al* 2000).

Oonagalabi base metal prospect has a distinct Au-Bi-Cd-Cu-Pb-Sn-W-Zn signature in all size fractions. The dispersion trail is about 1 km long. Pb, Zn and Bi are widely dispersed, whereas Cd, Sn and W are restricted to the immediate vicinity of the prospect. Oonagalabi is also noteworthy because calcsilicate and marble host rocks contain gahnite. This zinc spinel may indicate BHT mineralisation.

The orientation study recommended collecting and analysing the <6 mm size fraction in first and second order streams.

Selection of Sample Sites

With the exception of ALICE SPRINGS, the only available topographic maps are 1:250 000 scale. These have variable coverage of drainage and were inadequate for selection of sample sites. This study utilised:

- digital terrane data obtained by NTGS as part of geophysical surveys[†];
- 1:250 000 digital AUSLIG drainage and cultural data;
- partial coverage of 1:50 000 and 1:25 000 colour aerial photographs;
- merged mosaics of false-colour Landsat TM images[†]; and
- published geological maps in MapInfo[†].

These were re-scaled to 1:100 000 and overlaid.

Sample sites were then selected with the focus on areas draining relict or erosional regimes. Sampling concentrated on well-defined first and second order streams greater than 1 km in length. Streams choked with silt on sheetwash plains and bedloads likely to be dominated by boulders and cobbles were avoided.

Sample spacing is a compromise between establishing meaningful regional coverage and the practical advantage of sampling each of two or more sites upstream of stream junctions. The latter results in samples in close proximity that can make spatial image processing more complicated.

Over 1300 potential sample sites were selected and their locations digitised as AMG66 coordinates.

METHODOLOGY AND FIELD TECHNIQUES

Access and Helicopter Support

The study, conducted during August and September 2000, covers large areas of National Park and aboriginal land that have very few tracks. Consequently, the majority of samples were collected using a Bell 206 Jet Ranger helicopter (VH-FHX) from Jayrow Helicopters. During this phase, each of four samplers was dropped at landing sites from which one or more sample locations were accessible. Samplers were then leap-frogged in sequence. Two man teams using four wheel drive vehicles collected samples that were easily accessible from existing tracks and roads.

Sample Site Location

The survey covers Universal Grid Zones 52 and 53. Digitised AMGs of pre-selected sample points were used as a navigational guide to sample locations. Actual locations were recorded in AMG AGD66 by samplers using handheld GPSs with a stated accuracy of 10 m (selective availability turned off). In practice, sample sites could be relocated to within a metre. These locations have been honoured for all subsequent data processing (see discussion on image processing).

Sample locations have been corrected to GDA94. Data files contain both co-ordinate systems and maps have been scaled to GDA94 unless otherwise stated.

[†] These data accompany this study as GIS layers in MapInfo.

Field Sample Number Terminology

The identification number of the 1:100 000 sheet prefixes field sample numbers. Not every pre-selected site could be effectively sampled and, in some cases, access was denied, so field numbers are a discontinuous set.

Field duplicates are prefixed by 1000. Magnetic fractions have the suffix M and sample numbers for wet pan concentrates are followed by B.

Field Data and Sample Collection

Details of topography, stream data and bedload composition were recorded on a field form and this information has been integrated into the database (➢ **Table 2**). Sampling equipment consisted of an aluminium sieve, plastic prospector's pan, plastic scoop, calico sample bags and a geology pick that had been sandblasted to remove any paint. Samplers also removed any jewellery that may have caused contamination. Annotated aluminium tags and small lengths of flagging tape were stapled to trees as semi-permanent markers on freehold land (not on Aboriginal land or National Parks).

Several types of samples were collected, as described below.

Sieved Reference Samples and Field Duplicates

Routine samples were collected by removing any surface contamination (eg leaves) and trenching the full width of the active channel to a depth of about 10 cm, or by taking amalgamated spot samples across wider streams. Normally, trap sites were avoided. However, in areas sourced predominantly by quartzite or where contamination by aeolian sand was a potential problem, gravel-sized material from depressions in the surface of the active channel or from the foreset of crossbeds from the most recent flood were preferentially sampled. These "semi-trap" sites meant that, where possible, at least some material coarser than sand-sized was included in the sample.

A nominal 5 kg <6.5 mm sample was sieved at each site. These are herein referred to as sieved reference samples. A suite of 1193 samples was collected. In addition, duplicate field samples were collected every 30 samples and randomly entered into the analytical stream.

Wet Panned Concentrates

Samples of 30-40 kg from 75 trap sites were wet panned in the field. Heavy mineral residues of >100 g to 1000 g were retained for Au analyses and detection of gahnite.

Other significant minerals that would report to this fraction include cassiterite, chromite, diamond, galena, platinum, rutile, tourmaline, scheelite, sillimanite, tantalite, spinel, wolframite and zircon.

Magnetic Fractions

Magnetic fractions were collected by sifting a horseshoe magnet through sediment in the active channel at 29 sites. Collection of a minimum of 20 g from each site often took up to an hour and such sampling was not included in the helicopter phase.

It was expected that magnetite, maghemite and ilmenite would report to this fraction. Substitutions for both Fe^{3+} and Fe^{2+} and inclusions within these minerals are known to produce geochemical signatures capable of indicating their source even where mobile cations are weakly absorbed onto clays or where the clay fraction is greatly diluted (Joyce 1984, McQueen and Cross 1996).

NTGS Check Samples

Several sieved samples (5851 series) were taken to check the methodology of the current survey by deliberately including base metals and garnet. These samples also provide a direct comparison with the orientation study. Samples were collected from creeks near Oonagalabi and a tributary of Aturga Creek. One sample from Oonagalabi included visible malachite (5851-004) and one sample from Aturga Creek (5851-001) targeted garnet sands. Assays of these samples, given at the bottom of ➢ **Table 3**, have been excluded from statistical treatment of the survey.

CHEMICAL ANALYSES

Laboratories Used

Genalysis Laboratory Services in Perth carried out analyses. Sieved reference samples were milled in an ultra-low contamination facility in Adelaide prior to shipment to their Perth laboratory. Heavy liquid separation was performed by Independent Diamond Laboratory in Perth.

Preparation and Analysis of Sieved Reference Samples and Field Duplicates

Sieved reference samples were split to 100 g using a plastic riffle. Sub-samples were pulverised using ultra-low contamination zirconia mills. Mills were cleaned using a barren quartz wash and ethanol wipe between samples.

A four-acid (HF-$HClO_4$-HNO_3-HCl) digest in Teflon beakers was used prior to combined ICPOES and ICPMS analysis for 35 elements. Even this "near total attack" digestion has limitations (eg incomplete dissolution of cassiterite) that need to be kept in mind during interpretation. The ICPOES suite and detection limits are: Ba (2 ppm), Ca (10 ppm), Cr (2 ppm), Cu (1 ppm), Fe (0.01%), K (20 ppm), Mg (20 ppm), Mn (1 ppm), Na (20 ppm), Ni (1 ppm), P (20 ppm), Ti (5 ppm), V (2 ppm) and Zn (1 ppm). The ICPMS suite and detection limits consists of: Au (0.05 ppm), As (1.0 ppm), Be (0.1 ppm), Bi (0.01 ppm), Cd (0.1 ppm), Ce (0.01 ppm), Co (0.1 ppm), Li (0.1 ppm), Mo (0.1 ppm), Nb (0.05 ppm), Pb (2 ppm), Rb (0.05 ppm), Sb (0.05 ppm), Se (2 ppm), Sn (0.1 ppm), Sr (0.05 ppm), Te (0.1 ppm), Th (0.01 ppm), U (0.01 ppm), W (0.1 ppm) and Y (0.05 ppm). S was excluded because low values found in previous geochemical studies in the area would have necessitated additional analytical techniques. Al and Zr were excluded because of potential contamination from sieves and mills respectively. Samples were analysed in batches of 200 and any values considered atypically high by the analyst were double-checked. Analytical and gravimetric factors used to convert to oxides were taken from Németh (1975).

A 24 hour cyanide leach was used on a 100 g split prior to ICPMS for Au. This gave a 0.01 ppb lower detection limit (LDL). These data are labelled Au_2_ppb in accompanying statistical analysis.

Raw results are presented as a series of files corresponding to individual 1:100 000 sheets as listed below (**Table 4**).

Table 4 Key to tables of assays sorted by 1:100 000 sheet

Laboratory Duplicates and Standards

Splitting of the sieved reference sample to the required small aliquot prior to pulverisation can introduce a nugget affect. Au is typically susceptible to this. Mn and Fe rich gravel, which can scavenge metals, also produce problems. As a quality control, the laboratory ran a second riffle of every 25th sample and these were carried through all preparation and analyses to provide a measure of precision of the overall technique.

In addition, Genalysis ran an internal set of standards consisting of control blanks and known standards Bleg2, Bleg3, SY-4, TKC1 and WGB-1. Results are given in ➢ **Table 12**.

CSIRO Standards

The same CSIRO standards (6 and 8) that were used in orientation were included in this study. One standard, CSIRO6 or CSIRO8, was run alternately at the end of each batch of about 50 to monitor precision and detect any shifts between batches. Results are given in ➢ **Table 12**.

Preparation and Analysis of Wet Pan Concentrates

Quartz and feldspar remaining in wet pan concentrates were removed using tetrabromoethane (SG 2.97) static heavy liquid separation. Some micas have a specific gravity similar to the liquid, but they rarely sank because of their flaky habit. The sink fraction was dried and weighed and, where necessary, split to 100 g using a plastic riffle. Float was discarded. After pulverising in a zirconia mill, a four-acid digest was used prior to ICPMS/OES for Ag (0.1 ppm), Au (0.05 ppm), Cr (2 ppm), Cu (1 ppm), Ni (1 ppm), Pb (2 ppm), Sn (0.1 ppm) and Zn (1 ppm). Sodium peroxide fusion in zirconia cubicles, HCl acid dissolution and ICPOES were used to give a measure of "total" Zn to compare with "acid soluble" Zn. Samples with elevated "total" Zn compared to ICPMS values potentially contain gahnite. Results are given in ➢ **Table 13**.

Preparation and Analysis of Magnetic Fractions

Magnetic fractions were pulverised in a zirconia mill with quartz washes between samples. A four-acid digest was followed by ICPOES analysis for Cu (1 ppm), Fe (0.01%), Ni (1 ppm), Pb (5 ppm), Sn (10 ppm), Ti (5 ppm) and Zn (1 ppm). Results are given in ➢ **Table 14**.

Storage and Access to Library Samples

The remainder of sieved reference samples, their pulps and pulps of wet pan concentrates are stored in the Department of Mines and Energy Alice Springs Core Library and are available to the public for further analysis.

Presentation of Merged Analytical Results

Merged data are presented in .CSV ASCII, Excel 97 (➢ **Table 15**) and Explorer 3 formats (➢ **Table 16**). The significance of the displayed decimal places can be judged from the LDL shown in the header.

DATA ANALYSIS

This study follows most aspects of methodology advocated by Eggo (1991) and Grunsky (1998), and follows an approach similar to that used by AGSO in north Queensland (Cruikshank 1994).

Sampling Density

Large regional stream sediment surveys typically have one sample per 2-10 km^2 and more detailed reconnaissance work requires one sample per 0.5-2 km^2 (Reedman 1979). Follow-up exploration work commonly has up to 5 samples per km^2.

Regional stream sediment surveys by government agencies over broadly similar geological provinces include a BMR study of the Seigal and Hedleys Creek 1:100 000 sheets (Rossiter and Scott 1980) and an AGSO study of the Coen Inlier in Queensland (Cruikshank 1994, 1997; Cruikshank and Brugman 1997). These had one sample per 2-3 km^2 and 10-15 km^2, respectively. Regolith-materials studies in Western Australia have integrated stream sediment, soil and lake samples designed to give a combined average of one sample per 16 km^2 (Bradley *et al* 1995, Kojan and Faulkner 1994, Pye *et al* 1999).

With an overall average of one sample per 5.6 km^2, this study achieved coverage similar to, or better than other government surveys. **Table 17** shows sample coverage in each 1:100 000 map area.

Table 17 Sieved reference sample coverage excluding field duplicates and check samples taken in orientation area

1:250 000 Map Sheet	1:100 000 Map Sheet		Samples
MOUNT LIEBIG	5151	LIEBIG	113
MOUNT LIEBIG	5250	IDIRRIKI	2
MOUNT LIEBIG	5251	HAAST BLUFF	216
HERMANNSBURG	5350	GOSSES BLUFF	84
HERMANNSBURG	5351	GLEN HELEN	155
HERMANNSBURG	5450	HERMANNSBURG	204
HERMANNSBURG	5451	NARWIETOOMA	115
HERMANNSBURG	5550	MACDONNELL RANGES	245
HERMANNSBURG	5551	ANBURLA	47
ALICE SPRINGS	5650	ALICE SPRINGS	12

The orientation study (Skwarnecki *et al* 2000) recommended a 500 m spacing to detect base metal mineralisation at Oonagalabi and noted that, depending on the size fraction, between 150 m and 500 m spacing would be needed to detect Au mineralisation at Winnecke.

It is also possible to mathematically estimate the maximum viable catchment size for various sampling procedures using a geochemical balance equation (Hawkes 1976, Moon 1999). The Hawkes' equation, used here, is a simplification of a wider range of equations used by Russian workers for several decades (Moon 1999). Application of the best case scenario from the Winnecke orientation data is shown below:

Mea = Au content of anomalous sediment at mouth of catchment = 0.17 ppm (highest recorded in <6 mm fraction)
Aa = theoretical maximum area of catchment to be calculated
Mem = Au content of eroding surface expression of the mineralised target = 20 ppm (estimate of average)
Am = area of surface expression of mineralised target (assume dimensions of Golden Goose) = 20 m x 90 m = 1800 m^2
Meb = Au content of eroding background materials in catchment = 0.001 ppm.
Substituting in the equation:

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$$\textit{Mea Aa = Mem Am + Meb (Aa - Am)}$$

gives 0.21 km^2 as the maximum viable catchment size for a survey using these parameters. If this catchment is assumed to be a quadrant, the equivalent radius (and hence maximum linear sample spacing) is 520 m.

Drainage of Oonagalabi base metal prospect was also analysed using the equation and the following assumptions:

Mea = Cu content of anomalous sediment at mouth of catchment = 700 ppm
Aa = theoretical maximum area of catchment to be calculated
Mem = Cu content of eroding surface expression of the mineralised target = 30 000 ppm
Am = area of surface expression of mineralised target = 500 m^2
Meb = Cu content of eroding background materials in catchment = 100 ppm.
The maximum catchment determined is 0.025 km^2. If assumed to be a quadrant, then required linear sample spacing is less than 180 m.

Thus, the sample spacing of the present study should be regarded as reconnaissance rather than rigorous exploration.

Possible Contaminants

During the survey, car bodies, sheets of galvanised iron, fencing wire, star pickets, cans and lead fishing sinkers were noted in creek beds. Wherever possible, such obvious metal contamination was avoided.

When dealing with low concentrations of major and minor elements, biological contamination is also a potential problem. Animal faecal matter was noted at most sites near surface water and in many cases contamination was unavoidable. Algae are known to be a sink in several metals, especially Zn, and dried algae were reported in some samples. Carbonate fresh water mollusc shells constitute a minor fraction of the bed load at some sample sites. The extent of any biological concentration of elements is unknown. All possible contaminants were recorded on field forms and are included in the database ➢ **Table 2**.

Treatment of Assays below the Detection Limit – Censored Data

In accordance with usual practice, assays below the LDL of the method used are shown in the raw datafiles as the negative of the DL value. However, data have been censored for statistical calculations and a value of half the DL has been substituted. For example, Sb by ICPMS has a LDL of 0.05 ppm and a value of -0.05 in the datafile indicates that no Sb is detectable. It is treated as 0.025 ppm in calculations and referred to as the censored value. In many cases, this necessitates the inclusion of extra decimal places that are not statistically significant.

Interpretation of Internal Laboratory Standards

Repeated-measures ANOVA and Tukey-Kramer tests were used to compare assays of Genalysis standards run with each batch. Use of uncensored data leads to apparent significant differences where a sample is close to the LDL. For example, Na may appear as –20 or +20 but the assays may not really be significantly different. This is particularly true for the control blank. GraphPad was used to selectively ignore these data and model corresponding variation in statistical parameters. A full printout of tests is appended for each standard [➢ **Table 18** (WGB-1), ➢ **Table 19** (TKC1), ➢ **Table 20** (SY-4), ➢ **Table 21** (Control Blank)]. Matrices of XLSTAT Similarity Indices for TKC1 and WGB-1 show all possible comparisons for the multiple runs of these standards. Repeat assays of TKC1 (9 assays) and WGB-1 (23 assays) have no significant difference at 95% confidence level and the vast majority of other batch comparisons can also be accepted at the same confidence level.

Interpretation of Analyses of CSIRO Standard Samples

Full descriptive statistics for censored replicate data for CSIRO standards 6 and 8 are given in ➢ **Table 22** and ➢ **Table 23**, respectively. Greatest coefficients of variance are 0.67 for Au (acid digest - ICPMS) in CSIRO6 and 0.39 for Cd in CSIRO8.

These tables also compare means of assays of CSIRO standards run during this survey and orientation. Mo and Zn are apparently relatively lower in the current survey. However, there are no statistical differences at 95% degree of confidence level between the orientation and the current study for those elements assayed using identical techniques.

Comparisons with "accepted" INAA and XRF CSIRO values are also given in ➢ **Table 22** and ➢ **Table 23**, respectively. These should not be compared directly with acid digest ICPMS data, but do allow differences between analytical techniques to be extrapolated to clients' own datasets.

Precision may be expressed as a percentage derived from the ratio of standard deviation to mean. In exploration geochemistry, it is commonly expressed as the ratio of a robust estimate of the mean to censored lower detection limit (CDL). Precision is considered reliable where the CDL has been exceeded by a factor of 5 or more (Skwarnecki *et al* 2000). Thus, ➢ **Table 22** shows that CSIRO6 will not provide useful measures of precision of Au (A/MS), As, Cd, P, Se and Te. However, precision for Zn, for example, can be judged from the standard deviation of 2.376 and geometric mean of 6.384, giving 63% precision. CSIRO8 has higher absolute values for many key elements and consequently gives useful estimates of precision for all but Cd and Se. For example, Zn in the hundred ppm range has a precision of 98% (➢ **Table 23**).

Degree of precision was also compared on a batch by batch basis using Similarity Indices generated by XLSTAT and ANOVA. Tukey-Kramer tests on both raw and censored data were undertaken with GraphPad (➢ **Table 22** and

➢ Table 23). The 8 assays of CSIRO 8 are not significantly different at 99% confidence level. Cyanide leach MS data for CSIRO6 indicate either inhomogeneity at 5 gram level or that Au in this sample is only partly cyanide soluble. Other than this, there is no significant difference between any pairings at 95% confidence level.

Interpretation of Analyses of Laboratory Duplicate Splits

Comparative statistics for raw data of 55 laboratory duplicates are given in ➢ Table 24. These consist of paired t-test (Koch and Link 1970), r-squared regression, Pearson Correlation (assuming a normal population) that is calculated using Excel add-ins, and Spearman Rank Correlation (rho, z- and p-value) that is calculated with StatView. The latter method is independent of the distribution of the data. The degree of correlation is higher as r-squared, Pearson Correlation and Spearman rho approach one and p-value approaches zero.

Paired t-tests indicate that there is no significant difference at 2% level of significance (df = 5) and that 31 duplicates (53%) are not significantly different at 20% confidence level. The t-test for 5550-087 and its duplicate indicates that they have almost identical means. R-squared and Pearson Correlation for 5151-116 indicate a very high degree of reproducibility. Six of the samples have a Spearman rho of >0.999. All data have a Spearman p-value <0.0001.

On average, there is less variation between laboratory duplicates than field duplicates (discussed below), indicating that overall, laboratory splits were reliable.

Interpretation of Analyses of Field Duplicates

On average, every 30th sieved reference site was sampled in duplicate to test overall reproducibility of sampling and analytical procedures. This resulted in 39 pairs of duplicates, in which blind samples were given the field prefix 1000.

➢ Table 25 gives comparative summary statistics for field duplicates. The paired t-test indicates no significant difference at 2% confidence level and 26 pairs (67%) have no significant difference at 20% confidence level. The paired t-test for 5451-060 and 1000-013 (t-value = -0.002) indicates a very high statistical correlation. In all cases, r-squared, Pearson Correlation and Spearman rho are close to one. Spearman Rank p-values are all <0.0001. This precision is comparable to field duplicates in similar stream sediment studies (Cruikshank 1994).

Assays of duplicate samples with original map-based sample numbers have been used for all statistical analysis and imagery.

UNIVARIATE STATISTICS

Univariate statistical methods deal with data for which a single observation has only one variable. In this section, frequency distributions and their geochemical significance are discussed on an element by element basis. Fundamental manipulations include reducing data to a standard normal distribution or employing Box Cox transformation.

Summary Univariate Statistics

Summary univariate statistics derived using Statview, DataDesk and GraphPad are given in ➢ Table 26. Where distributions are highly skewed, robust estimates of central tendency such as the 10% trimmed mean, geometric mean and median of absolute deviation are more meaningful than the traditional arithmetic mean. Univariate statistics of selected elements are discussed in the context of histograms (see Distribution Histograms).

Box and Whisker Plots

Box and whisker plots showing the statistical distribution of censored assays for each element are given in ➢ Figure 3. Horizontal lines represent 10th, 25th, 50th, 75th and 90th percentiles. The shaded box represents the 95% confidence interval around the median.

Reduction to Log-normalised Standard Normal Distribution (LNSND)

Transforming data to log$_{10}$ reduces the effect of extremely high and low values and enables comparison of elemental data that differ by several quanta (cf majors at percent level and Au at ppb level) by reducing them to unitless form. Transformed data have then been converted to a standard normal distribution by subtracting the overall mean value from each assay and dividing by standard deviation. Thus, in a similar way to a z-score, each raw value is replaced by the number of standard deviations that the value is away from the mean. For example a value of +2 indicates an assay two standard deviations above the mean. Assays in excess of this are within the top 2.3% of the population if it is normally distributed. This enables a statistically meaningful determination of anomalism irrespective of analytical method or relative units. These data are herein referred to as LNSND values and presented in ➢ Table 27.

Box Cox Transformation

As pointed out by Link and Koch (1975) and Grunsky (1998), simple LNSND transform may not always be the best to apply to stream sediment geochemistry. Indeed, in some cases it may distort distribution parameters even more than untransformed data. The Box Cox generalised power transform[3] is recommended as an alternative where the LNSND data still do not fit the normal curve (see following section on histograms). This was undertaken using StatView and, by compacting the lower end of the distribution, highlights positive outliers that may constitute anomalies. These transformed data are given in ➢ **Table 28**.

Distribution Histograms

Histograms, which are standardised on 20 intervals with the normal curve superimposed, were prepared for censored assays, LNSND and Box Cox transformed data for each element using StatView software. Results are given in ➢ **Figure 4**. Finite LDLs and the need to censor data places limitations on interpretations of histograms. However, the appropriateness of each transformation can be readily assessed. For example, LNSND transformation of Au_2 (cyanide leach - mass spectrometer) fits the normal curve reasonably well; whereas Na remains heavily skewed after the same transformation. Outliers are readily evident on Box Cox histograms (Rb, Sr, Zn). More abundant elements either tend towards a normal distribution (Ba) or indicate mixed populations (K, Na). Sr is bimodal. Pb and Rb appear to be normally distributed. In general, minor elements (Co, Cu, Ni, U, Y, Zn) follow an approximately log-normal distribution. Fe and Mn are also log-normal.

Discussion of Selected Elements and their Descriptive Statistics

Geochemical explanations given below are based on Boyle (1974) and Levinson (1980). The geological distribution of target and pathfinder elements within the study area is discussed later in the context of exploration indices.

Copper

Cu is one of the most widely used elements in exploration geochemistry and is generally a good pathfinder to all deposits in which it occurs. Cu concentrations are significantly above "background" (as defined by CRC LEME) in stream sediments around Oonagalabi base metal prospect. Under oxidising surface conditions, much of the copper is present in streams as malachite, azurite and sulfates. Aside from its ore minerals, Cu can also substitute in pyroxene, amphiboles, magnetite and biotite and is relatively readily absorbed by clays, Fe-Mn oxides, other metal sulfates and silicates.

Maximum readings are tabulated below (**Table 29**).

Table 29 Cu maxima in different sample types

Sample Type	Maximum	Geometric Mean	Sample
Sieved	61 ppm	7 ppm	5551-047
Wet Pan Concentrate	138 ppm	33 ppm	5450-117B
Magnetic Fraction	86 ppm	23 ppm	5450-257M

Lead

Aside from galena, anglesite and cerussite, Pb can also occur by substitution in feldspar, mica, zircon and magnetite. Pb has low mobility in high Eh (oxidising) environments and is immobile in low Eh sulfide environments. Pb carbonate, sulfate and phosphate minerals are insoluble in most geological settings. There may have been incomplete dissolution or some reprecipitation during four-acid digest. Pb occurring as galena, anglesite and cerussite would report to the heavy mineral fraction of wet pan concentrates.

The orientation study confirmed a strong correlation between Pb and mineralisation across all size fractions at Oonagalabi.

Maximum values for the three sample types are shown below in **Table 30**. The highest value in the sieved samples constitutes a gross outlier and would normally be removed in statistical treatment. The next highest value is 55 ppm in 5251-027. Pb assays are normally distributed.

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[3] Second order Box Cox transformation, used here, is $(x^2-1)/2$.

Table 30 Pb maxima in different sample types

Sample Type	Maximum	Geometric Mean	Sample
Sieved	91 ppm	16 ppm	5251-046
Wet Pan Concentrate	483 ppm	nd	5550-042B
Magnetic Fraction	320 ppm	54 ppm	5350-252M

Zinc

Zinc is highly mobile in high Eh and neutral conditions but is less so in carbonate provinces. Its concentration can be greatly affected by adsorption or co-precipitation on clays or Fe-Mn oxides and by adsorption on organic matter, particularly algae. Acid soluble Zn was found to be significantly elevated (716 ppm in sample 5851-004) for up to 1 km downstream of Oonagalabi. As explained previously, Zn also occurs in an acid-insoluble form in gahnite.

Censored Zn assays from sieved samples in the present study are log-normally distributed. There are several outliers including a maximum of 144 ppm in sample 5551-014. Three sample types are compared below (**Table 31**). The magnetic fraction maximum is a gross outlier; the next highest value is 691 ppm in 5350-252M.

Table 31 Zn maxima in different sample types

Sample Type	Maximum	Geometric Mean	Sample
Sieved	144 ppm	24 ppm	5551-014
Wet Pan Concentrate	463 ppm	150 ppm	5450-117B
Magnetic Fraction	762 ppm	226 ppm	5450-129M

Nickel

Ni is a good indicator element in almost all geochemical surveys, including stream sediments. It is both a siderophile and a chalcophile. Substitution in olivine can produce up to 5000 ppm and Ni also substitutes in Mg-pyroxenes, amphiboles, mica and sulfides. Ni is less mobile in high pH environments but is subject to scavenging by organic matter over a wide range of pH. It was not found to be a pathfinder element at the Oonagalabi or Winnecke prospects.

Summary statistics are shown in **Table 32**. The maximum in the sieved samples from the current study is 113 ppm and the LNSND transform is satisfactory. The highest Ni in wet pan concentrates is four times the geometric mean. Sample 5450-129M is a gross outlier; the next highest is 151 ppm in 5350-239M.

Table 32 Ni maxima in different sample types

Sample Type	Maximum	Geometric Mean	Sample
Sieved	113 ppm	8 ppm	5251-112
Wet Pan Concentrate	186 ppm	45 ppm	5251-036B
Magnetic Fraction	182 ppm	62 ppm	5450-129M

Cobalt

Co forms many primary and secondary minerals. Ores are known from both categories. It follows Ni closely and there is commonly some substitution of Co for Ni. Co is relatively mobile under most weathering conditions and is regarded as a good indicator of deposits, even those in which it is only a minor constituent. However, Co is readily scavenged by Mn oxide. Co was not considered to be a pathfinder at Oonagalabi or Winnecke.

There are no gross outliers in the population and censored assays have a geometric mean of 5 ppm and a maximum of 71.6 ppm in sample 5551-014.

Selenium

Se and S have a strong affinity and Se is commonly used as a proxy for S (which was not analysed during this study). Se is less mobile. The orientation survey at Oonagalabi, using a mixed acid digest/ICPMS method directly comparable with this study, had a "background" of 3 ppm, a threshold of 5 ppm and a maximum of 7 ppm Se. NTGS check sample 5851-002 from the same general area returned 2 ppm. In contrast, none of the samples from the current study area exceeded the MS LDL of 2 ppm and this probably indicates a lower background for both Se and S.

Chromium

Cr is widely diffused in most rocks and is particularly common in ultrabasic rocks. Chromite, the only commercial ore of Cr, is effectively insoluble except under low pH, high Eh conditions and so commonly occurs as a mechanical concentrate in the heavy fraction. Cr is a siderophile element. It also occurs in limonite, micas and garnets and can substitute in pyroxene and magnetite in basic rocks. The four-acid digest used in this study would not liberate much Cr from these minerals. Cr was not found to be associated with mineralisation at Oonagalabi or Winnecke.

There are no gross outliers in the population and the maximum of 430 ppm (sample 5251-112) compares with a geometric mean of 19 ppm.

Tin

Sn is effectively immobile in solution and would normally be found in high concentrations as detrital cassiterite, which may form placers. The acid digest employed during this study would not extract all Sn from cassiterite. Sn also occurs as a substitution in mica, titanite, rutile, tourmaline, magnetite and amphiboles.

The Oonagalabi orientation survey found a correlation with Cu, Pb and Zn in some size fractions.

In the current study, Sn in sieved samples shows a skewed normal distribution. An outlier of 6.8 ppm (sample 5151-126) compares to a geometric mean of 1.3 ppm. Only one magnetic fraction contained measurable Sn at a 10 ppm LDL (11 ppm in 5251-036M). The significantly higher maximum of 25 ppm in wet pan concentrate 5550-217B is four times the mean and probably reflects a higher concentration of cassiterite.

Titanium

Ti is widely diffused in most rock types and is present in largest amounts in basic rocks. Numerous Ti minerals are known, but those of most commercial importance are rutile, anatase, leucoxene, brookite and ilmenite. Titaniferous magnetite and titanite are common, but not considered to be ore minerals. Ti is a good indicator of its deposits in stream sediment surveys, particularly those using the heavy mineral fraction. Ti is not a pathfinder to either Oonagalabi-style or Winnecke-style mineralisation.

Censored Ti data are log-normally distributed and even LNSND data remain skewed. The maximum is 3.0% compared to a geometric mean of 1460 ppm. This should be compared to the magnetic fractions that have a maximum of 2.3% and a geometric mean of 4485 ppm.

Tungsten

W is widely dispersed in most rocks in tens or parts per million ranges. Many primary minerals of tungsten are known and there is a suite of secondary (supergene) forms. W is normally an excellent indicator of its deposits (Boyle 1974) and its transport is dominantly mechanical as scheelite or wolframite. W is elevated around both the Oonagalabi and Winnecke prospects. However, stream sediments from a watershed within the current study area, which were reported to contain scheelite (O'Sullivan *et al* 1972), did not have elevated W.

Sample 5151-126 contains the maximum of 7.6 ppm compared to a geometric mean of 0.4 ppm.

Cadmium

The geochemistry of Cd is essentially identical to that of Zn. Cd may become enriched relative to Zn in areas of hydrothermal zonation and the orientation study at Oonagalabi showed Cd to be a good proximal indicator of base metal mineralisation. This was confirmed by NTGS check samples including 5851-004 with 1.5 ppm. In the present study area, only 3% of sieved samples exceeded the MS 0.1 ppm LDL, precluding rigorous statistical treatment. The maximum is 0.2 ppm in sample 5251-155.

Gold

For all practical purposes, Au is only mechanically mobile in stream sediments. It is subject to localised concentration as placer deposits and sieved reference samples are potentially prone to a nugget affect. It was not found to correlate with any other elements at Winnecke prospect (Skwarnecki *et al* 2000). In the present study, Au was assayed in sieved reference samples using both acid digest or cyanide leach prior to MS. The former technique yielded very few assays above the 0.05 ppm LDL. Even with the lower DL of 0.01 ppb, 4% of samples were below the DL and the majority of assays are barely above the DL, resulting in a highly skewed distribution. Nevertheless, cyanide leach Au_2 data do contain several significant outliers. The maximum of 12.17 ppb (sample 5251-032) is 174 times the geometric mean of 0.07 ppb and sample 5151-019 contains 6.82 ppb. The former is a gross outlier and would normally be removed in statistical analysis (see section

on treatment of outliers). Very few anomalous samples appear to be part of any recognisable dispersion trail and so the majority probably represent isolated detrital concentrations.

Wet pan concentrates from trap sites should be more reliable than the much smaller sieved samples from active bedload. However, most wet pan assays are below the LDL of 0.05 ppm. The maximum of 1.82 ppm from sample 5550-217B warrants further investigation.

Uranium

U is widely diffused in igneous, sedimentary and metamorphic rocks, and is especially enriched in more acidic igneous and metamorphic rocks, in carbonaceous shale and in phosphorite. U is normally very mobile in the supergene environment (especially high Eh, high pH) and is readily adsorbed by organic matter, clays, or various oxides and hydroxides. However, appreciable amounts of U can be held in resistate minerals such as monazite, zircon or xenotime.

The orientation study found no relationship between U concentration and mineralisation at Oonagalabi or Winnecke and previous stream sediment surveys near Mount Chapple and Mount Hay failed to identify any significant U anomalies (Tham 1971a, b; O'Sullivan *et al* 1972, Tham and O'Sullivan 1972).

LNSND transformation of U data closely approximates the normal curve. The maximum of 7.42 ppm (sample 5550-051) is over 6 times the geometric mean but is not a gross outlier.

Manganese

Magmatic concentrations of Mn are rare and elevated Mn is usually attributed to carbonates, their metamorphic equivalents and/or surface processes. During weathering, Mn is released from its host minerals as Mn^{+2} bicarbonate, chloride and sulfate and readily re-precipitated as Mn oxides and hydroxides. These scavenge metal cations and can cause false anomalies in target elements.

The highest Mn recorded is 3726 ppm in sample 5450-264.

Treatment of Outliers

Samples with concentrations of one or more elements significantly different from the rest of the population constitute outliers. In a survey of this type, outliers below the mean are rare because of the distribution forced by the LDL. Outliers greater than the rest of the population could constitute an anomaly (see section on determination of threshold values).

Other studies (eg Grunsky 1998) recommended removal of gross outliers before further statistical analysis. In this study, arithmetic means have been compared to robust estimates of central tendency (see **Table 26**) and population distributions have been examined in detail (➣ **Figure 4**) where differences are significant. Given these caveats, all data have been honoured and outliers have not been removed.

MULTIVARIATE STATISTICS

Multivariate statistics deals with statistical correlation between pairs of elements.

Crossplots

Crossplots are a first pass bivariate analysis and can confirm relationships suggested by principal component analysis (PCA; see next section). Since some elemental ratios are constant across a variety of geological materials, crossplotting analyses on X-Y scatter diagrams will highlight any anomalies. Other elemental correlations readily evident on crossplots may indicate metal scavenging.

DataDesk was used to generate scatterplot matrices of all elemental pairings using both censored and log transformed data. Using these displays interactively, it is possible to track labelled samples or groups of samples across all 1260 plots simultaneously. The more meaningful relationships are described below and selected StatView crossplots of log transformed data are included in ➣ **Figure 5**. The r-squared correlation coefficient has been calculated for all plots.

The Zn-Cd crossplot is commonly used in base metal exploration. This ratio remains constant at about 500 in most geological situations, so any anomalously high Zn seen on the crossplot should be investigated. Unfortunately in this study, there are insufficient Cd data above the DL to validate such a test.

Zn shows no overall relationship to Pb (r-squared = 0.005), whereas they do correlate in the orientation survey. At Oonagalabi, especially, there is a strong relationship between Pb and Zn across all size fractions.

In many Australian weathering regimes, a strong correlation between Zn and Fe is interpreted as scavenging of Zn by Fe. Such a relationship exists at Winnecke but not at Oonagalabi. The current study returned an r-squared value of 0.769 and, as at Oonagalabi, many elevated Zn assays are not accompanied by high Fe. These would be considered prospective.

There is a very strong correlation between Fe and V (r-squared = 0.954). This relationship is less well defined at either end of the range of Fe assays. Fe and Co have an r-squared value of 0.865. The relationship between V and Fe may indicate substitution in magnetite. However, at least some Co is independent of Fe and therefore not associated with magnetite. Winnecke data show a correlation between Ce, Pb, Rb, Ti, U, W, Sn, Sr and Zr and Fe oxides. This is interpreted as scavenging and occurrences in detrital heavy minerals.

Scavenging by Mn would be revealed by a strong correlation evident on its crossplots. The r-squared values of Cu 0.620, Co 0.824, Pb 0.001 and Zn 0.803 indicate that only Co and Zn are likely to be involved, although it can also be argued that these relationships may indicate that Co, Zn and Mn may substitute for each other in detrital ferromagnesian minerals. Several of the highest Zn assays are not accompanied by elevated Mn and should be considered prospective. There is no relationship between Zn and Mn on crossplots of Oonagalabi orientation data. However, Cu, Ni, Ba, and Pb are believed to be associated with Mn oxides at Winnecke (Skwarnecki 2001).

The relationship between Co and Ni (r-squared = 0.812) is consistent with Co substituting for Ni as it does in a wide variety of minerals. Similar relationships exist between Cr and Ni (r-squared = 0.820) and Co and Zn (r-squared = 0.817). Crossplots of orientation data also show a strong correlation between Cr and Ni.

A linear relationship between Pb and U is usually interpreted to indicate a direct radiogenic source for Pb. Any anomalous Pb is of potential economic interest. In this study, there is a broad spread of both Pb and U and the low r-squared value (0.383) indicates that much of the elevated U occurs independently of Pb and that some Pb is not directly of radiogenic origin. The U/Th crossplot (r-squared = 0.640) shows that highest Th values are not accompanied by proportionately high U. There does not appear to be a significant relationship between Ce and Th (r-squared = 0.604) as might be expected if uraniferous resistate minerals such as monazite were common. Significant U that is not accompanied by Ce+Th is unlikely to be in such minerals and is therefore of interest. Contrary to the PCA (see later discussion), the low r-squared value (0.511) shows no significant relationship and the only elevated U relative to Ce+Th is in the mid range of U assays. The relationship between Ce and U is stronger at Winnecke than Oonagalabi and this study.

The K-Rb ratio remains constant at about 230 in a wide variety of geological materials and very strong fractionation processes are required to produce an enrichment of Rb relative to K. There is no evidence of this in this study. Despite different statistical distributions of K and Rb (see ➢ **Figure 4**), the r-squared value for censored raw data is 0.869. The r-squared value for log transformed data is 0.937.

Ca and Mg show a relationship typical of limestone and dolomite where some elevated Ca occurs without correspondingly high Mg, but not vice versa. Co and Mg are even more closely affiliated (r-squared = 0.812).

Statistical Principal Component Analysis (PCA)

Principal component factor analysis uses a matrix of Pearson product-moment correlation coefficients to group elements into associations based on their mutual linear correlations. For example, chalcophile (Ag, As, Cd, Cu, Zn) and lithophile (Al, Fe, O, Si) elements typically form such associations.

Since distributions of elements in this study have a combination of both normal and log-normal affinities, correlation coefficients have been computed from both raw censored and logarithmically transformed data. StatView was used to undertake comprehensive analyses using both orthogonal (uncorrelated varimax) and oblique (correlated promax) methods. The greatest absolute factor loading for each element has been termed a major contributor and is shown in bold (red) in summary tables discussed below. In accordance with Dillion and Goldstein (1984) and Cruikshank (1994), an arbitrary cutoff of ±0.30 has been used to determine minor contributors and these are shown in italics (blue).

Results are discussed separately below and then compared and interpreted in a geological context. A spatial PCA has also been undertaken and is discussed on

PCA of Censored Raw Data

Tabulated results and factor analysis plots are given in ➢ **Figure 6.** As summarised in ➢ **Table 33**, there are 7 factors, each with an eigenvalue greater than one, and these collectively account for 76% of variance.

Factor 1 accounts for 32% of total variance and is defined by major contributions from Ca, Cd, Co, Cr, Cu, Fe, Mg, Mn, Nb, Ni, P, Ti, V, Y and Zn. Cd should be discounted because of the dearth of assays above the DL and its low communality. As, Ce, Li and Sn are minor positive contributors. Factor loadings for both orthogonal and log data approach a bimodal distribution (➢ **Figure 7**), indicating that two processes are involved.

Major contributors to **Factor 2** are Ba, Be, K, Na, Pb, Rb, Sn, Sr and U. Most of their communalities exceed 0.8, exceptions being Pb (0.669) and Sn (0.730). Minor positive contributors are Ce, Nb and Th. As is a minor negative contributor. Factor 2 accounts for 17% of total variance. Statistical distribution of loadings (➢ **Figure 7**) is complex and indicates that more than one process governs the association.

Factor 3 accounts for 12% of total variance and consists of major loadings for As, Bi, Li, Mo, Sb and W. Be, Pb, Sn and U are minor contributors. Ba, Na, and Sr are minor negative loadings in the orthogonal matrix and are insignificant after rotation.

Factor 4 includes major contributors Ce and Th in orthogonal data. Rotation elevates U from minor to major positive loading and so its inclusion is less certain than other elements. Communalities of all three elements are relatively high but the factor accounts for only 5% of total variance.

Factor 5 is a nebulous association of Nb, Sn and W that emerges only after rotation.

Factor 6 is a tenuous association of Te, Ba and Sr that relies on rotated data. Te has only 14 assays above the DL, a relatively low communality, and should be disregarded.

Factor 7 groups Bi, Au_2 and Te, but low communalities of the last two invalidate this association.

PCA of Log Transformed Data

Tabulated PCA results and factor analysis plots for log transformed data are given in ➢ **Table 33** and ➢ **Figure 8**. As summarised in **Table 33** (**sheet 3**), there are 5 factors, each with an eigenvalue greater than one, which collectively account for 77.8% of variance. Histograms of distributions of factor loadings show that, in every case, more than one process is involved in determining elemental associations.

Factor 1 accounts for 37% of total variance. It principally comprises Ca, Co, Cr, Cu, Fe, Mg, Mn, Nb, Ni, P, Ti, V, Y and Zn. These elements are major positive contributors in both orthogonal and oblique pattern matrices. Their communalities all exceed 0.85, indicating that most variance due to these elements is accounted for by the extracted factors. Other associated elements are Be, Ce, Li, Sn, Sr and Th.

Principal components of **Factor 2** are Ba, Be, K, Na, Pb, Rb and Sr. There are minor positive contributions from Nb, Sn, Th and U. Au_2, As, Cr, Cu, Fe, Ni, Sb and V are negative contributors. Au_2 has a relatively low communality and should be rejected on this basis. Factor 2 accounts for 21% of total variance.

Factor 3 principally comprises Bi, Li, Mo, U and W. Relatively low communality of Mo makes its inclusion questionable. Minor positive contributors are As, Be, Ce, Pb, Sb and Th. Sr is a minor negative contributor. Factor 3 accounts for just under 5% of total variance.

Factor 4 is fairly nebulous and accounts for less than 4% of total variance. The orthogonal matrix has no major positive contributor but oblique patterns highlight Ce, Sn, Th and U. There are minor positive contributions from Au_2, Bi, Pb and W.

Au_2 and Te are major positive contributions to **Factor 5** in log transformed data. This matches Factor 7 in raw censored data, but low communalities invalidate this association.

Interpretation of PCA

In order to obtain the most robust factors, PCAs of raw censored and log data have been compared. Rossiter (1975) recommended that a correlation is not considered meaningful unless the coefficient loading is statistically significant for both raw and logarithmic values. In this study, robust associations are based on final communalities above 0.5 that contain major contributors in both orthogonal and oblique analyses for both raw censored and log data. Thus, PCA factors are reduced to those shown in **Table 34**.

Table 34 Results of principal component factor analysis

Factor 1	Ca, Co, Cr, Cu, Fe, Mg, Mn, Ni, P, Ti, V, Y, Zn
Factor 2	Be, K, Na, Pb, Rb
Factor 3	Bi, Li, Mo
Factor 4	Ce, Th, ?U

To facilitate a geological interpretation of these factors, their LNSND data have been summed (➢ **Table 35**) and plotted on a geological base map.

Factor 1- Ca, Co, Cr, Cu, Fe, Mg, Mn, Ni, P, Ti, V, Y, Zn

As confirmed by crossplots, there is a clear relationship between V and Fe, possibly indicating some substitution in iron minerals. The crossplot of Ni and Co confirms that these elements follow each other closely, presumably where Co substitutes for Ni. Strong r-squared values for relationships between Mn and Co and Mn and Zn indicate scavenging. This may also explain similar groupings with Fe. A general correlation between Cr, Fe, Mn, Ni and Ti could also reflect mafic rocks or an association of these elements in magnetite and/or spinel. A relationship between Ni and Mg could be explained by substitution of Ni in Mg-pyroxenes, amphiboles and mica.

Highest Factor 1 sums plot in the Narwietooma Metamorphic Complex, particularly Mount Chapple Metamorphics and Mount Hay Granulite. This is consistent with mafic rock geochemistry. The affects of scavenging are probably a more widespread secondary phenomenon.

Factor 2 - Be, K, Na, Pb, Rb

A strong association between Rb and K is to be expected and has been previously substantiated by crossplotting. Similarly, Na and K are commonly closely allied in a wide variety of rock types and both are enriched in granites and metamorphics. Be is a typical component of pegmatites, granites and high-grade metamorphics.

Highest Factor 2 sums are sourced from Mesoproterozoic Teapot Granite and Tertiary fanglomerate that overlies it.

Factor 3 - Bi, Li, Mo

Greatest Factor 3 sums occur in Neoproterozoic Amadeus Basin sedimentary rocks. Traditionally, Bi and Mo are most commonly associated in metamorphic rocks, whereas Li is highest in pegmatites and granites. However, levels of Bi and Mo from sedimentary rocks are also consistent with organic shales. Li-bearing clays and shales are not common (Boyle 1974) and the abundance of Li may indicate an evaporite association.

Factor 4 - Ce, Th, ?U

REE elements such as Ce are commonly associated with Th and U in a wide variety of detrital heavy minerals, particularly monazite. Although PCA has highlighted this possible relationship, it is difficult to justify given the low r-squared for U vs Ce+Th.

Compared to previous factors, summed Factor 4 elemental scores do not correlate convincingly with mapped geology. Isolated highs occur in the Mount Hay Granulite, Mount Chapple Metamorphics, Teapot Granite Complex, Illyabba Metamorphics and Redbank High Strain Zone.

Comparison with Orientation Study

Table 36 lists principal factors from PCA of Winnecke and Oonagalabi data. There is little in common between the two areas and less in common with the main survey. This is because the current study includes a wide variety of rock types whereas suites hosting mineralisation at the orientation sites are much more limited. The closest match of any factors is between Factor 2 at Winnecke and Factor 1 of the current study, which have Cu, Fe, Mn, Ni and Zn in common. This is more likely to be related to widespread surface processes rather than to intrinsic similarity of geology.

Table 36 Factors determined from orthogonal varimax PCA of <6 mm orientation data. Elements shown in italics are less significant

	Winnecke	Oonagalabi
Factor 1	*Ce*, *U*, Zr	Au, Bi, Cd, Cu, Pb, Sn, Zn
Factor 2	Ba, *Cd*, Cu, Fe, Mn, Ni, Pb, *Sn*, Zn	Ce, Fe, Mn, Se, U, W, *Zr*
Factor 3	Bi, *Zn*	*Cr*, *Fe*, Ni
Factor 4	Au, As	Cr, Sr, TiO$_2$, Zr
Factor 5	Ce, Cr, Fe, Rb, *Sb*, Sr, TiO$_2$, U, W	As, Sb, *Sn*

Determination of Thresholds

As tabulated below (**Table 37**), the orientation study estimated "background" and threshold values from points of inflection on normal probability plots.

Table 37 Background and threshold values determined during the orientation survey (Skwarnecki *et al* 2000). Less reliable values are shown are in italics; calculation was hampered by very low variance and/or many values below LDL. Units: ppm, except Au (ppb), and Fe and Ti (%)

Element	Oonagalabi		Winnecke	
	Background	Threshold	Background	Threshold
As	1.5	3	3	6
Au	1.5	3	21	71
Ba	380	427	508	722
Bi	1.8	5	0.6	3
Cd	1	3	-	-
Ce	105	164	58	92
Cr	82	92	39	63
Cu	78	355	17	22
Fe	9.2	11	5.4	6
Mn	2769	3580	980	2241
Mo	1.4	1.8	*0.8*	*1.2*
Ni	40	52	15	26
Pb	31	130	17	27
Rb	44	56	144	175
Sb	*0.2*	*0.3*	0.6	1.4
Se	*3*	*5*	-	-
Sn	5	5.5	*4*	*5*
Sn_XRF	*6*	*8*	*5*	*9*
Sr	54	67	33	121
Ti	0.69	0.88	0.42	0.62
U	2.55	3.6	2.1	3
W	4.5	8	1.8	3.5
Zn	164	1270	57	70
Zr	246	288	194	224

In the current study, anomalism has been defined in three ways. Firstly, thresholds were determined by picking points of inflection or breakpoints on n-score plots generated using DataDesk[4]. Anomalous samples are listed in **Table 38**. Most thresholds are substantially different from the orientation study. It was impossible to reliably pick thresholds for Cd, K, Se, Sr, Te and U.

A more objective determination of anomalism is based on a threshold of the 95th percentile. These have been calculated (**Table 39**) for censored raw data, log, LNSND and Box Cox transformed data.

A generally less conservative definition of anomalism would be to use LNSND values above +2 (ie two standard deviations above the mean). Assays in excess of this are within the top 2.3% of a normal population. In the cases of As, Ti and V, which have skewed populations, the 95th percentile cutoff exceeds +2 LNSND threshold.

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[4] To overcome the inherent skewness of the sampling distributions, DataDesk calculates n-scores using *medians* approximated by $Gau^{-1}(i-1/3)/(n+1/3)$.

Table 38 Anomalous samples based on visual picks of breakpoints and points of inflection on z-score plots

Element										
Au_2_ppb	Sample	5251-032	5151-019	5550-067	5550-130	5550-208	5450-018			
	ppb	12.17	6.82	3.77	2.82	2.73	2.09			
As	Sample	5350-100	5151-099	5450-120	5251-066					
	ppm	32	16	16	14					
Ba	Sample	5451-063	5451-067	5451-068	5451-065	5451-066				
	ppm	2061	1881	1840	1638	1572				
Be	Sample	5650-018	5450-112	5450-109	5450-106	5450-105	5450-104			
	ppm	6.2	4.0	3.4	3.2	3.2	3.2			
Bi	Sample	5251-022	5550-216	5550-021	5451-094	5450-096				
	ppm	1.99	1.24	1.20	1.13	1.08				
Ca	Sample	5450-268	5450-267	5450-146	5550-403	5550-385	5450-200			
	ppm	229394	171068	138130	123643	113886	109486			
Ce	Sample	5451-012	5451-046	5451-114	5351-007	5550-051	5451-041			
	ppm	608.49	316.95	316.73	310.19	302.10	292.00			
Co	Sample	5551-014	5551-012	5551-009	5551-010	5551-013				
	ppm	71.6	71.2	64.6	62.1	56.1				
Cr	Sample	5251-112	5451-041	5551-009	5551-018	5551-038	5451-026	5251-115	5551-014	
	ppm	430	426	390	389	386	372	366	365	
Cu	Sample	5551-047	5450-251	5551-018	5550-408	5551-043	5551-041	5551-037	5551-013	5551-005
	ppm	61	50	47	44	40	40	40	40	40
Fe%	Sample	5551-009								
	percent	18.42								
Li	Sample	5650-018	5450-261	5450-144						
	ppm	49.2	44.0	42.0						
Mg	Sample	5551-014	5551-012	5551-011	5551-038	5551-008	5551-009	5551-013		
	ppm	68509	65542	52234	47690	47601	47487	47169		
Mn	Sample	5450-264	5551-014	5551-012						
	ppm	3726	2352	2342						
Mo	Sample	5450-116	5351-048	5350-100						
	ppm	2.3	2.2	2.0						
Na	Sample	5450-252	5151-019	5351-038						
	ppm	19360	19352	19268						
Nb	Sample	5151-126	5451-065	5451-003	5451-066	5351-126				
	ppm	73.05	27.98	25.09	23.90	23.18				
Ni	Sample	5251-112	5551-011	5551-014	5451-046	5551-008				
	ppm	113	106	101	100	99				
P	Sample	5451-003	5450-137							
	ppm	1449	1056							
Pb	Sample	5251-046	5251-027							
	ppm	91	55							
Rb	Sample	5450-105	5450-106	5450-118	5450-105	5450-113	5450-112	5450-107	5450-109	5450-220
	ppm	474.92	464.07	446.00	433.23	406.56	405.39	405.32	402.95	402.83
Sb	Sample	5450-120	5450-274	5251-066	5450-261	5450-251	5350-100	5151-099		
	ppm	1.10	0.92	0.85	0.83	0.81	0.81	0.81		
Sn	Sample	5151-126								
	ppm	6.8								
Th	Sample	5551-044								
	ppm	260.69								
Ti	Sample	5551-009	5151-126	5551-010	5451-003					
	ppm	30080	27694	24464	21853					
V	Sample	5551-009	5551-010							
	ppm	1004	705							
W	Sample	5151-126	5550-067	5550-018						
	ppm	7.6	5.2	5.1						
Y	Sample	5451-045	5451-003	5451-101						
	ppm	61.19	55.52	55.30						
Zn	Sample	5551-014	5350-100	5551-012	5451-003	5551-009				
	ppm	144	140	137	123	121				

Table 39 Thresholds based on the 95th percentile. Censored units: ppm, except Au (ppb), and Fe (%)

Element	Censored	Log₁₀	LNSND	Box Cox
Au_2_ppb	0.32	-0.49	1.60	-0.4478
As	5	0.70	2.14	12
Ba	1 085	3.04	1.18	5.88×10^6
Be	1.8	0.26	1.31	1.12
Bi	0.41	-0.38	1.60	-0.41
Ca	38 046	4.58	1.47	723×10^6
Cd	0.05	-1.30	-0.16	-0.50
Ce	78.90	1.90	1.66	3 112
Co	28.36	1.45	1.88	402
Cr	184	2.27	1.98	17 001
Cu	28	1.45	1.87	392
Fe%	8.57	0.93	1.95	36.24
K	47 548	4.68	1.16	$1\ 130 \times 10^6$
Li	18.1	1.26	1.82	163
Mg	22 462	4.35	1.85	252×10^6
Mn	1294	3.11	1.64	837 735
Mo	0.4	-0.40	1.45	-0.42
Na	13 700	4.14	0.87	94×10^6
Nb	10.83	1.03	1.55	58
Ni	55	1.74	1.89	1 534
P	460	2.66	1.75	105 803
Pb	32	1.51	1.57	512
Rb	253.74	2.40	1.38	32 192
Sb	0.354	-0.45	1.81	-0.44
Sn	2.7	0.43	1.50	3.15
Sr	208.89	2.32	1.27	21 817
Te	0.05	-1.30	-0.106	-0.50
Th	21.87	1.34	1.74	239
Ti	6 940	3.84	2.01	24×10^6
U	2.78	0.44	1.57	3.364
V	217	2.34	2.11	23 631
W	1.3	0.11	1.40	0.35
Y	31.18	1.49	1.75	486
Zn	73	1.87	1.74	2 693

➢ **Table 40** shows values above the 95th percentile in bold red and those >2 LNSND in bold mauve.

IMAGE PROCESSING

MapInfo Professional and Discover software were used to create maps of target and pathfinder elements, LNSND and Box Cox transformed data. 1:100 000 scale maps are colour scaled, dot proportional, single element, point-source images in which highest values are shown in red and lowest in dark blue. Ten data ranges correspond to ten-percentiles. On LNSND data, stars indicate values above 2. Stars on other maps indicate values above the 95th percentile.

Use of a grid size greater than sample separation in spatial imaging causes averaging and subdues high values. This is a potential problem where stream sediment sample points are closely clustered upstream of a junction (Eggo 1991). However, Eggo demonstrated that, in practice, there was little difference between gridding using a judicious search radius on original locations and relocating sample points to an approximate centroid of their drainage polygon. In this study, original locations have been honoured and 1:250 000 and larger scale inserts have been gridded and contoured using the Inverse Distance Weighting algorithm in Discover with an elliptical search radius of 4000 m E-W and 3000 m N-S. No filters have been applied unless explicitly stated.

ADDITIVE INDICES

LNSND values have been used to calculate several exploration indices in which a number of target and/or pathfinder elements have been added together. These indices are based on information in Beus and Grigorian (1975), Boyle (1974), Chaffee (1983), Cox and Singer (1986) and Levinson (1974), and have been modified from those employed by Cruikshank (1994, 1997). A similar approach has been used in GSWA geochemical studies (eg Pye *et al* 1999). LNSND-based indices are tabulated in ➢ **Table 41** and presented as a series of continuous tone maps. Histograms of most indices are given in ➢ **Figure 9**.

Gold Index

The most commonly used elements in an Au index are: Au+As+Bi+Cu+Mo+Sb+Sn. In addition, Ag, Te and W can be particularly useful pathfinders in stream sediment surveys (Boyle 1974). All of these elements except Ag (which was not analysed in sieved reference samples) were combined to give the Gold Index, $Au\_2+As+Bi+Cu+Mo+Sb+Sn+Te+W$, in ➢ **Figure 10**. This list includes Au-Bi-Sb-W as displayed by Winnecke (Skwarnecki *et al* 2000). However in the current survey, Au has little statistical affinity with other elements in sieved reference samples and a generalised multi-element index may be misleading.

Amadeus Basin sedimentary rocks generally have higher Gold Indices than rocks of the Arunta Province. Anomalies occur in Ormiston Pound. Glen Helen Metamorphics and Teapot Granite Complex have consistently low Gold Indices. The most significant outlier above the 95th percentile threshold of 9.1 is sourced from the Putardi Granite Suite and Tertiary conglomerate overlying it. Other anomalies for which Cu is a major contributor appear to be sourced from Tertiary conglomerate or duricrust.

Sediment-hosted and Broken Hill-type Base Metal Index

The Base Metal Index (Ba+Cu+Pb+Zn) of Levinson (1974) is applicable to many sediment-hosted and Broken Hill-type deposits. Cd is less mobile than Zn and is known to be an additional pathfinder to base metal mineralisation in the Mount Isa Basin. Its inclusion in the index, Ba+Cd+Cu+Pb+Zn, shown in ➢ **Figure 11**, has little affect because few values are above the DL. The distribution has one significant outlier. Mount Chapple Metamorphics and rocks associated with the Redbank Thrust Zone have elevated Base Metal Indices. The most prospective values above the 95th percentile of 3.5 report to several formations in the Arunta Province including Speares Metamorphics. Other anomalies appear to be sourced by the Neoproterozoic portion of the Amadeus Basin and possibly by Tertiary conglomerate.

Jervois Base Metal Index

The Jervois base metal deposit is typified by Ag-Bi-Cu-F-Mn-Mo-Pb-W-Zn, similar to some BHTs. These elements, with the exceptions of Ag and F (not analysed in this study), are shown as an additive index Bi+Cu+Mn+Mo+Pb+W+Zn with a threshold of 6.9 (➢ **Figure 12**). Anomalies in Arunta Province rocks occur in the Talyi-Talyi Hills, near the contact between the Putardi Granite Suite and Peculiar Volcanics and in the Ikuntji Metamorphics near Round Hill (for which Pb is a major contributor). The latter is near, but probably not directly related to a documented Cu, Zn occurrence at Nickel Hill. There are also significant anomalies, many of which are in common with the generalised Base Metal Index, in Neoproterozoic sedimentary rocks of the Amadeus Basin.

Oonagalabi Base Metal Index

The Oonagalabi base metal prospect has a distinct Au_2-Bi-Cd-Cu-Pb-Sn-W-Zn signature and this was used to construct an additive index for this style of mineralisation (➢ **Figure 13**). It has many elements in common with the Jervois Index and the two maps are broadly similar, but statistically the Oonagalabi Index has one positive outlier not present in the Jervois Index. Regionally elevated values occur in Mount Chapple Metamorphics, Illilli Granite and the Amadeus Basin. Anomalous values above the threshold of 6.8 are scattered throughout the survey area. One sample in the Talyi-Talyi Hills is again prominent.

Granite-Related Base Metal Index

Base metals associated with Sn-W granites, like on the west coast of Tasmania, have a zonation of W→Sn→Cu→Pb/Zn/Ag outwards from the granite. An additive index based on this, Cu+Pb+Sn+W+Zn (threshold 5.2), is shown in ➢ **Figure 14**. The map is similar to the Jervois Base Metal Index, with which it shares most elements. The Granite Index fits the normal curve. The Narwietooma Metamorphic Complex (particularly the Mount Chapple Metamorphics and Illilli Granite) generally has higher Granite-Related Base Metal Indices than the younger (Mesoproterozoic) Teapot Granite. Other isolated high values sourced from the Bitter Springs Formation (Amadeus Basin) are probably reflecting relatively higher backgrounds in Cu and W.

VHMS Base Metal Index

Cox and Singer (1987) identified the following elements as pathfinders to VHMS mineralisation: Ag, As, Au, Ba, Bi, Cu, Fe, Mg, Pb, S, Sb, Se, Sn, Zn. Those analysed are shown as an additive index, Au_2+As+Ba+Bi+Cu+Fe+Mg+Pb+Sb+Sn+Zn, in ➤ **Figure 15**. Se was omitted because all assays are below the DL. The threshold for this index is 9.2. The statistical distribution is negatively skewed in the mid range but retains a long positive tail. Interpretation needs to be filtered by geology since only appropriate volcanic facies and their metamorphic equivalents will be prospective. In a purely statistical sense, the Narwietooma Metamorphic Complex including Illilli Granite has elevated VHMS indices, as do parts of the Neoproterozoic Amadeus Basin. Anomalies at Talyi-Talyi Hills and possibly associated with a shear zone in Mount Chapple Metamorphics should be considered prospective. There are too few samples from the Peculiar Volcanics to ascertain their prospectivity for VHMS.

Ishikawa/Date VHMS Alteration Index

VHMS ore bodies are typified by a well defined zonation of Fe→Cu/Au→Cu→Pb, Zn→Au/Ag→Ba from footwall to hanging wall. This is accompanied by an alteration halo and Ishikawa *et al* (1976) developed the index $(MgO+K_2O)/(Na_2O+CaO+MgO+K_2O)$ x 100 to vector on this alteration. The z-scores for this index (➤ **Figure 16**) highlight an anomalously low value of –13 088. The map shown in ➤ **Figure 17** has used a low cut filter of zero and retained the threshold of 113.8. It should be interpreted in conjunction with the VHMS Base Metal Index and restricted to suitable host geology.

Magmatic Nickel Index

The Co+Cu+Ni+Pd+Pt+Te index is commonly used for magmatic nickel. Cr could also be added (Levinson 1980). An index of those elements analysed in this study, Co+Cr+Cu+Ni+Te, is shown in ➤ **Figure 18**. The statistical distribution shows three distinct positive outliers well in excess of the 7.6 threshold. Isolated anomalous samples occur in Tertiary conglomerate (also anomalous in Au) west of Mount Palmer, in the Cumming Leucogabbro and in the Cambrian sequence of the Amadeus Basin. Individual roles of Cu, Ni and Co in this index can be ascertained from their ternary image (see ➤ later discussion). The Narwietooma Metamorphics also has elevated indices.

Kupferschiefer Copper Index

An index based on ore and pathfinder elements for Kupferschiefer Cu consists of Ag+Co+Cu+Mo+Pb+Zn. Boyle (1974) also considered As, Cd, Mn, Re, Sb, Se and V as pathfinders. An index of those elements analysed in this study, As+Cd+Co+Cu+Mn+Mo+Pb+Sb+V+Zn, is shown in ➤ **Figure 19**. Se has been deliberately omitted. The statistical distribution is skewed away from the normal curve. The Narwietooma Metamorphics has elevated indices, as does the Neoproterozoic portion of the Amadeus Basin. Values above the 95th percentile threshold of 10.8 occur sporadically throughout the area from Talyi-Talyi Hills in the west to east of Mount Hay. One or more of the other indices highlighted all the anomalous samples.

Porphyry Copper Index

Porphyry Cu ore bodies are zoned Mo→Cu/Au→Pb, Zn→Au, Ag outward from core to margin of the system. Most geochemical exploration relies only on a strong association of Cu+Mo, as seen in all of these ore bodies including the Cu-Au type such as OK Tedi and Alumbrera. The Brenda, British Columbia, porphyry Cu-Mo deposit has an ore zone containing Cu, Mo, Ag, W, B, Sr and a halo of Pb, Zn, Au, As, Sb, Se, Te, Mn, Co, Ba, Rb, Bi, Sn. An additive index of Au_2+Cu+Mo+Sr+W (threshold 4.4) is shown in ➤ **Figure 20**. The Illilli Granite, Ellery Granitic Complex and Mount Chapple Metamorphics have relatively high indices, as do some Tertiary conglomerates. Numerous isolated anomalies, many more than twice the threshold, warrant further investigation.

Platinum Index

Pt and the pathfinder Pd were not included in this study. Cr+Ni+V, shown in ➤ **Figure 21**, defines areas likely to contain mafic/ultramafic rocks that have potential for platinum group elements. The histogram shows a bimodal distribution and many of the second population are in excess of the overall 95th percentile threshold of 5.8. The Platinum Index shows the strongest correlation to geology of all additive indices. The Narwietooma Metamorphics has the highest indices. Almost all samples sourced by the Mount Chapple Metamorphics and Mount Hay Granulite, which mostly constitute a discrete population, are above the 95th percentile threshold but there are no gross outliers from those sources. The elevated Ni in one sample from the Cumming Leucogranite makes it anomalous. The Bunghara Metamorphics and its intrusives also source isolated anomalies.

Rare Earth Index

This study was not specifically targeted on REE and so a generalised index is necessary. REE-bearing phosphate minerals (monazite and xenotime) and other elements associated with carbonatites would be targeted by Ce+La+Nb+Nd+P+Th+V+Y. Of these, La and Nd were not analysed during this study. Cox and Singer (1987) considered the additional following elements as vectors to carbonatites: B, Ba, Be, Ca, Cu, F, Li, Mn, Mo, Pb, Sr, Ta, Ti, U, W, Zr. A compromise rare earth index based on Nolans Bore, Ca+Ce+Nb+P+Sr+Th+Ti+U+V+Y (threshold 11.5), is shown in ➢ **Figure 22**. It fits the normal curve reasonably well. The Narwietooma Metamorphics and rocks along the Redbank Thrust Zone have relatively high indices. An isolated anomalous sample with an index of 19 in Talyi-Talyi Hills has been highlighted by several other indices. Other isolated anomalies of 22 and 18 are sourced from Madderns Yard Metamorphic Complex and Teapot Granite Complex, respectively.

Kimberlite Index

Based on the Merlin diamond pipes, Ba+Cr+Nb+P would be a useful kimberlite index. It is shown in ➢ **Figure 23**. Most samples above the threshold of 4.8 are sourced from the Mount Chapple and Bunghara Metamorphics. High Nb in the sample from Talyi-Talyi Hills makes it anomalous.

Pegmatite Index

Pye *et al* (1999) advocated Be+Li+Nb+Sn+Ta+W as an index for pegmatite mineralisation. Of these, Ta was not analysed in this study, but the sum of other elements is shown in ➢ **Figure 24**. The Pegmatite Index is moderately high throughout the Mount Chapple Metamorphics. Prospective samples above the threshold of 5.6 include isolated samples in Talyi-Talyi Hills, Teapot Granite and Iwupataka Metamorphic Complex in ALICE SPRINGS.

Tin/Tungsten Index

Tin/tungsten mineralisation that is associated with contact metamorphic deposits would be targeted by Be+Bi+Mo+Sn+W. This index is shown in ➢ **Figure 25**. It has Be, Sn and W in common with the previous index and so is broadly similar in the Arunta Province. Isolated anomalies in the Arunta Province include Talyi-Talyi Hills and the Iwupataka Metamorphic Complex. However, many samples above the threshold of 5.4 are sourced from the Neoproterozoic Amadeus Basin.

Redox/Calcrete Uranium Index

Mo+U+V is based on the geochemistry of Beverley and Honeymoon in South Australia and Yeelirrie in Western Australia. This index is also applicable to some sandstone-type uranium deposits (Cox and Singer 1987). Se would normally be included but all assays from this survey were below the DL. This index has a threshold of 3.2 and is shown in ➢ **Figure 26**. The statistical distribution is negatively skewed. The Mount Chapple Metamorphics, Illilli Granite and Neoproterozoic Amadeus Basin sedimentary rocks have above average indices. Isolated anomalies occur in Talyi-Talyi Hills, Speares Metamorphics, in rocks along the Redbank Thrust Zone and in Tertiary conglomerates.

Unconformity Uranium-Gold Index

Alligator River and Rum Jungle uranium would be targeted by Au_2+As+Co+Mg+Ni+P+U and this index is used in this study (➢ **Figure 27**). However, Cox and Singer (1987) also considered Ag, Cu, Hg, Mo, PGE, Rb, REE, Te and Zn as indicative of unconformity U-Au elsewhere in the world. The Narwietooma Metamorphics and Neoproterozoic Amadeus Basin sedimentary rocks have a high background for this index and most of the anomalous samples (above 7.5) also come from these units.

Volcanogenic Uranium Index

Volcanogenic uranium such as Ben Lomond, Queensland, would be targeted by As+F+Li+Mo+U. This style of mineralisation also has high REE, W, Sb and distal Hg. An index of As+Li+Mo+Sb+U+W has been used in this study and is shown in ➢ **Figure 28**. This index reports strongly to the Amadeus Basin sedimentary rocks and many samples above the threshold of 7.8 are in this group. However, these rocks would not be considered prospective for volcanogenic uranium so the index would have to be filtered by geology.

TERNARY RATIO RGB COLOUR COMPOSITE IMAGES

LNSND transformed data were used to create ternary Red-Green-Blue colour maps. White indicates relative enrichment in all three elements.

Lead-Copper-Zinc

The ternary image of Pb-Cu-Zn (➢ **Figure 29**) shows the Teapot Granite and overlying rocks as relatively high in Pb. The Mount Chapple Metamorphics and Mount Hay Granulite have elevated Zn. Isolated samples enriched in all three elements occur in several places in the Arunta Province including along the Redbank Thrust Zone. Most of the western Amadeus Basin sedimentary rocks are high in Cu. Some samples from the east are relatively high in all three elements.

Copper-Nickel-Cobalt

These elements have similar geographic distributions and the combined ternary image (➢ **Figure 30**) shows that the Narwietooma Metamorphics, particularly Mount Chapple Metamorphics and Mount Hay Granulite, are relatively high in all three elements.

Potassium-Thorium-Uranium

The K-Th-U ternary images from stream sediment data (➢ **Figure 31**) can be compared to airborne radiometrics (➢ **Figure 32**). In both images, Mount Chapple and Mount Hay are prominent as relatively high in U, whereas the Teapot Granite is anomalous in all three elements.

SPATIAL PCA

ER Mapper was used to generate spatial images of principal components for censored data. The spatially-interpolated diagonal PCA used by this approach produced different principal components to purely statistical methods which do not take geographic proximity into account. ➢ **Table 42** shows the table of eigenvalues and summary statistics for the merged data. RGB ternary plots for factors 1-3 and 4-6 are included as ➢ **Figure 33** and ➢ **Figure 34.** The greatest PC1 values correspond to Mount Chapple Metamorphics and Mount Hay Granulite.

COMPARISON OF SIEVED REFERENCE SAMPLES, WET PAN CONCENTRATES AND MAGNETIC FRACTIONS

Maximum concentrations for wet pan concentrates (➢ **Table 13;** catchments for selected target elements are also included in the GIS) and magnetic fractions (➢ **Table 14**) can be compared to sieved samples (➢ **Table 26**). In absolute terms, wet pan concentrates and magnetic fractions are higher in pathfinder and target elements in almost all cases. Zn is more likely to be highest (and so have the greatest range) in the magnetic fraction, whereas Cu, Pb and Au are most likely to be highest in wet pan concentrates. Ranges for Cu and Pb in wet pan concentrates and magnetic fractions are approximately 60% greater than in sieved samples.

➢ **Table 43** summarises the comparison of wet pan concentrates that record the maximum of each element and corresponding sieved reference samples. Comparison of LNSND values shows that there is little similarity between the two data sets. For example, 5550-217B has the highest Au, Sn and Ag of all wet pan concentrates but the corresponding sieved sample is not anomalous. In absolute terms, Cr is also striking; 5251-036B has 988 ppm (LNSND 2.127) whereas the sieved sample has only 7 ppm (LNSND –0.666).

Comparing anomalous sieved samples (based on n-scores) to their wet pan counterparts is also revealing. Sample 5251-032 has highest Au (12.17 ppb) of sieved samples, but there is no detectable Au at 0.05 ppm in the wet pan concentrate. This may be attributed to the small sink fraction (5.7 g) being non-representative or, more likely, a nugget affect in the sieved sample. Anomalous Cu in sieved sample 5551-047 was not replicated in the wet pan concentrate despite a sink weight of 377.6 g indicating a large heavy-mineral tail.

Concentrates usually indicate different geochemical parameters to sieved samples. A comparative study in Canada by Bellehumeur *et al* (1994) showed that fine sieved fractions and heavy mineral concentrates have different background values and different multiple-element associations (as determined by PCA). This led them to conclude that the fine fraction was strongly influenced by surficial processes, whereas the heavy fraction reflects principal lithological characteristics.

None of the wet pan concentrates returned sufficient difference between acid soluble and insoluble Zn to indicate the presence of significant gahnite.

Maxima for all elements assayed in magnetic fractions are compared to sieved reference samples in ➢ **Table 43.** All but one of the anomalous magnetic fractions correspond to sieved samples >1 standard deviation above the mean. The exception of Fe is only to be expected when dealing with a deliberate concentration of magnetic minerals.

Sieved sample 5350-100 is anomalous in As, Zn (LNSND 2.735), Mo and Sb. Of these, only Zn was analysed in the magnetic fraction. It has a LNSND value of 1.332.

In summary, sieved samples, wet pan concentrates and magnetic fractions are all valid complementary sampling methods in these geological provinces. They indicate prospectivity in different ways for different target and pathfinder elements and could gainfully be used in parallel. Magnetic fractions are best for Zn and wet pan concentrates from trap sites are best for Au, Cu and Pb.

CONCLUSIONS

Helicopter-borne sampling proved expeditious in the rugged terrain of the western MacDonnell Ranges and enabled collection of over 1200 samples with an average density of one sample per 5.6 km^2. Sampling of the <6.5 mm fraction of active bedload in first and second order creeks, wet pan concentrates from trap sites and magnetic fractions are all viable sampling methods, but indicate prospectivity in different ways.

Rigorous procedures of sample duplication and multiple runs of internal and external standards enable precision to be quantified.

Statistical distributions of elements include normal (Ba, Pb, Rb), log-normal (Co, Cu, Fe, Mn, Ni, U, Y, Zn) and mixed populations (K, Na, Sr). Robust measures of central tendency are used in preference to traditional arithmetic means.

Assays have been censored, log-transformed and reduced to the standard normal distribution (LNSND) to enable meaningful comparison. Data have also been transformed using Box Cox power transform.

Statistical PCAs indicate four factors that account for over 75% of total variance. The principal factor of Ca, Co, Cr, Cu, Fe, Mg, Mn, Ni, P, Ti, V and Zn is highest in the Narwietooma Metamorphics, particularly Mount Chapple Metamorphics and Mount Hay Granulite. This factor is probably a combination of mafic rock geochemistry and the affects of metal scavenging in the weathering profile. Spatial PCA generated different factors, many of which can be related to the source geology.

Anomalism has been determined by three alternative criteria (inflection on n-score plots, >95th percentile and >2 LNSND). The last two are portrayed by stars on dot and colour proportional single point-source images at 1:100 000 scale. Images at 1:250 000 are gridded and contoured to show regional trends. Pb-Cu-Zn, Cu-Ni-Co and K-Th-U red-green-blue ternary images are included. Exploration indices based on numerous ore body models are also provided as colour image maps. Other included raster GIS layers are cadastral data, drainage, NTGS digital terrain data, Landsat TM images and published geological maps.

A rigorous statistical and spatial approach to geochemistry enables mapping of both regional trends related to lithological units and individual anomalies that would be prospective for follow-up work.

The uraniferous Mesoproterozoic Teapot Granite and overlying younger rocks have regionally elevated Pb (at least some of which may be of direct radiogenic origin) and relatively less Cu and Zn. In contrast, Mount Chapple Metamorphics and its gradational equivalent, Mount Hay Granulite, have relatively high levels of Cu and Zn and some individual streams contain long dispersion trails. The highest Zn recorded in sieved samples (5551-014) comes from the 1820 Ma Mount Chapple Metamorphics and can be constrained to a 1.52 km^2 catchment. Several samples sourced from the Mount Hay Granulite are also anomalous in Co, Ti and V.

The highest sieved sample Pb (5251-027) comes from near Round Hill on HAAST BLUFF and is probably sourced from the 1620-1600 Ma Ikuntji Metamorphics. It is constrained to a catchment of less than 0.4 km^2 and, although in the same area as base metal occurrences at Nickel Hill and Haast Bluff II, it is probably not directly related to them.

Various base metal indices targeted the Speares Metamorphics and near the contact of the 1640-1600 Ma Putardi Granite Suite and Peculiar Volcanics.

One sample in Talyi-Talyi Hills (5151-126) in LIEBIG, with a catchment of less than 0.7 km^2, is anomalous in Nb, Sn, Ti and W based on n-scores. It is also anomalous in Zn using other criteria. This sample has high additive indices for Jervois- and Oonagalabi-type base metals, U, VHMS and kimberlite. It is sourced from 1640-1600 Ma charnockite or overlying younger rocks.

Other high kimberlite indices come from the 1820 Ma Mount Chapple and Bunghara Metamorphics.

Unconformity uranium-gold indices are highest in the Narwietooma Metamorphics and Neoproterozoic Amadeus Basin sedimentary rocks.

Au anomalies are point source with no discernible dispersion trails and probably reflect placer concentrations. Of various sampling and analytical techniques tried for Au, wet pan concentrates are probably the most reliable, but significant anomalies in sieved samples (cyanide leach of 5251-31 is 174 times the geometric mean) warrant further investigation. The Gold Index is generally higher in the Amadeus Basin than the Arunta Province but the highest index is sourced from the Arunta Province Putardi Granite Suite and rocks overlying it.

RECOMMENDATIONS FOR FURTHER WORK

Extension of this study west to the Western Australia border and access to small areas around Jay Creek in MACDONNELL RANGES and ALICE SPRINGS that are prospective for Cu have been the subject of on-going negotiations with Traditional Landholders.

This study has highlighted lithological units with elevated target and pathfinder elements in their stream sediment geochemistry and this can be used in project generation for metals exploration. Anomalies need to be ground-truthed, particularly where Tertiary sediments and/or duricrust are possibly involved. Additional samples may be required from the newly recognised, and potentially prospective, Peculiar Volcanics.

Further work would include levelling the dataset by geology to make indices such as VHMS, Ishikawa alteration and volcanogenic uranium more meaningful. Such work would be best undertaken after completion of remapping in MOUNT LIEBIG by NTGS.

Isolated anomalies for which catchments have been delineated represent potential targets for direct follow-up work by explorers.

Stream sediment geochemistry from this survey will be integrated into an overall study of the Arunta Province by NTGS.

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APPENDIX - KEY TO ABBREVIATIONS

AMG – Australian metric grid

Amsl – above mean sea level

ANOVA – analysis of variance

AUSLIG – Australian Surveying and Land Information Group

BHT – Broken Hill-type

CDL – censored (lower) detection limit

CI – confidence interval

CRC LEME – Cooperative Research Centre for Landscape Evolution and Mineral Exploration

DEM – digital elevation model

DF – degrees of freedom

DL – detection limit

GDA – geocentric datum of Australia 1994

GPS – global positioning system

ICPMS – inductively coupled plasma mass spectroscopy

ICPOES – inductively coupled plasma optical (atomic) emission spectroscopy

INAA – instrumental neutron activation analysis

LDL – lower limit of detection

LNSND – log-normalised standard normal distribution

MAD – median absolute deviation

MODAT – mineral occurrence database

MS – mean of squares

na – not applicable

nd – not determined

nr – not recorded

PCA – principal component analysis

PGE – platinum group elements

REE – rare earth elements

SMC – squared multiple correlation

SND – standard normal distribution

SS – sum of squares

XRF – x-ray fluorescence

NORTHERN TERRITORY GEOLOGICAL SURVEY

Digital Information Package
DIP 002

Part 2: GIS-based Interpretation

Stream Sediment Survey of Western MacDonnell Ranges - Statistical and GIS-based Interpretation

John N Dunster and Andrew E Mugge

Darwin, October 2001

INTRODUCTION

This GIS-based interpretation has utilised the following software packages:

- MapInfo Professional 6.0 (the underlying GIS component for interpretation and chosen platform);
- ER Mapper 6.0 (geophysical and image processing, digital terrain model creation);
- Discover 3.097 (geochemical analysis and geological mapping functions); and
- ER Viewer 2.0 and MapImagery 6.513 (links between MapInfo and ER Mapper for specific data formats).

To run the GIS interpretation will require MapInfo Professional (version 5.5 or higher recommended). ER Viewer and MapImagery are provided on this CD. ER Viewer can be used to view ER Mapper files. MapImagery can be used to view ER Mapper files within MapInfo. The remaining packages are not essential.

MapInfo Workspaces

There are five MapInfo workspaces in the MapInfo GIS folder, these are:

- Add_indices.WOR Contains dot proportional ranged maps of each exploration index. Values greater than 95th percentile are highlighted. Images of gridded indices included. Suitable for most recent releases of MapInfo;
- Dot_Add_indices.WOR As above, but images of gridded indices not included. Suitable for older versions of MapInfo;
- Dot_BoxCox_g95th.WOR Contains dot proportional ranged maps of individual elements, Box Cox transformed. Values greater than 95th percentile are highlighted;
- Dot_Censored_Raw.WOR Contains dot proportional ranged maps of individual elements; negative values are substituted by values of half detection limit. Values greater than 95th percentile are highlighted;
- Dot_LNSND_g2.WOR Contains dot proportional ranged maps of individual elements, transformed to log normalised values and reduced to standard normal distribution. Values greater than 2 standard deviations are highlighted;
- Selected_Catchments.WOR Contains drainage polygons, with parameters that exceed threshold values as defined in Determination of Thresholds.
- Cadastre.WOR Contains the NT cadastre, sample locations, and ALRA land and National Park boundaries.

MapInfo tables (TAB files)

In the MapInfo GIS folder, there are a number of subfolders containing the individual TAB files for each layer. These subfolders are:

- Ages (these are the element layers that were used at AGES 2001 for map display)
- BoxCox_g95th (BoxCox transformed data, the samples per element that have a value greater than their sets 95th percentile)
- Catchments and Drainage (contains the drainage pattern for the project area, catchments of specified elements, and the digital terrain model used for catchment analysis)
- Censored_raw (raw data, with sample values greater than the 95th percentile per element)
- Index_Images (additive exploration indices, some used at AGES 2001). Also available as .ecw files.
- Indices_g95th (additive exploration index sample points with values greater than the 95th percentile)
- LNSND_g2 (Log normalised standard normal distribution data, with sample values per element greater than two standard deviations)
- Geological_maps (the set of 1:250 000 geological maps covered by the project area, maps have been cubic polynomial rectified). Landsat TM imagery is also included.
- Pca (principal component analysis of factors 1–4)
- Sample_loc (location of the sample points taken)
- Cadastre (cadastral, ALRA land and National Park data)

Metadata

Contains ANZLIC A0 metadata (Metadata_A0.xls) and metadata for individual layers (Metadata_layer.xls).

SOFTWARE CREDITS

Specialist statistical software

DataDesk 6.1
Data Description Inc
PO Box 4555
Ithaca NY 1485-4555
USA
www.datadesk.com

GraphPad Prism 3.02
Graphpad Software Inc
5755 Oberlin Drive #110
San Diego CA 92121
USA
www.graphpad.com

StatView 5.0.1
SAS Institute Inc
SAS Campus Driev
Cary NC 27513
USA
www.statview.com

XLSTAT 4.4
Thierry Fahmy
6 rue de Varize
75016 Paris
France
www.xlstat.com

Specialist GIS software

MapInfo Professional 6.0
MapInfo Corporation
One Global View
Troy NY 12180-8399
USA
www.mapinfo.com

ER Mapper 6.0
ER Viewer 2.0
Earth Resource Mapping
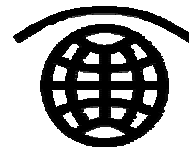Level 2
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