

**EXPLANATORY  
NOTES**



# **GEOCHEMICAL MAPPING OF THE MOUNT PHILLIPS 1:250 000 SHEET**

by **A. J. Sanders, P. A. Morris,  
A. G. Subramanya, and J. A. Faulkner**



**GEOLOGICAL SURVEY OF WESTERN AUSTRALIA  
DEPARTMENT OF MINERALS AND ENERGY**



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17. Ba
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19. Bi
20. Cd
21. Ce
22. Cl
23. Co
24. Cr
25. Cu
26. F
27. Ga
28. In
29. La
30. Li
31. Mo
32. Nb
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# Geochemical mapping of the Mount Phillips 1:250 000 sheet

by

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## Abstract

Regolith and geochemical mapping of MOUNT PHILLIPS at 1:250 000 scale is based on regolith characteristics and sampling of regolith at 1038 sites, comprising 57 sheetwash, 933 stream sediments and 48 soil samples. The nominal sampling density was one sample per 16 km<sup>2</sup>. Each sample has been analysed for 49 elements, pH and conductivity. The distribution of 48 elements (excluding SiO<sub>2</sub>) are shown as spot-concentration maps, whereas acidity-alkalinity and conductivity data are shown as contour maps. Some trace-element data have been statistically treated to produce three additive index maps to highlight areas of possible mineralization.

A map showing the distribution of regolith has been produced, using regolith characteristics recorded at each sample site, Landsat imagery, and aerial photography. Open-file company data dealing with surface geochemistry have been tabulated.

Granitoids of different age and composition are clearly distinguished by their regolith chemistry. The Bangemall Group rocks differ from other geological units in terms of their dominantly mafic regolith signature, whereas regolith over the Morrissey Metamorphic Suite is characterized by its chemical diversity and areas of high pegmatite-element concentrations. Statistical treatment of regolith data has examined downslope effects and lithological control on regolith composition. Potential areas of mineralization include the central and southwestern areas of the Morrissey Metamorphic Suite, the Bangemall Group, and parts of the early- and late-stage granitoids.

**KEYWORDS:** Mount Phillips, Bangemall Basin, Gascoyne Complex, regolith, geochemistry, mineralization, regolith mapping

## Introduction

Regolith and geochemical mapping of the MOUNT PHILLIPS\* 1:250 000 map sheet has been completed as part of the regional regolith and geochemical mapping program of the Geological Survey of Western Australia (GSWA). The aim of this program is to provide information about the distribution and chemistry of regolith to the mineral exploration industry, pastoralists and environmental agencies. Three maps and accompanying explanatory notes have been completed covering parts of the Yilgarn Craton (MENZIES: Kojan and Faulkner, 1994; LEONORA: Bradley et al., 1995; SIR SAMUEL: Kojan et al., 1996b), together with four that cover the Yilgarn Craton and/or parts of the adjoining Capricorn Orogen (PEAK HILL: Subramanya et al., 1995; GLENGARRY: Crawford et al., 1996; ROBINSON RANGE: Bradley et al., 1997; NABBERU: Morris et al., 1997).

The move away from map sheets covering the Archaean Yilgarn Craton (whose mineralization potential is well established) to those over Proterozoic sequences reflects the perceived, but as yet undemonstrated, potential for large-scale mineralization (Tyler et al., in press).

Regolith is unconsolidated or indurated weathered rock, and includes residual and transported material that can cover and obscure underlying bedrock. In areas of extensive regolith cover, an understanding of the distribution of regolith types and their formation processes can offer significant insight into the nature of the bedrock, including the presence and extent of mineralization.

## Location and access

The MOUNT PHILLIPS 1:250 000 sheet (SG 50-2) is bounded by latitudes 24°00'S and 25°00'S and longitudes 115°30'E and 117°00'E (Fig. 1). The few permanent residents are

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\* Capitalized names refer to standard map sheets.

mainly involved with the pastoral industry, but there are small tourist operations based at Mount Augustus and Cobra Stations (Plate 1). There are no towns on MOUNT PHILLIPS. Stations partly or wholly on MOUNT PHILLIPS include Bidgemia, Cobra, Dalgety Downs, Dooley Downs, Eudamullah, Gifford Creek, Landor, Lyons River, Mangaroon, Minnie Creek, Mooloo Downs, Mount Augustus, Mount Phillips, Waldburg, Wanna and Yinnetharra. The Burringurrah aboriginal community is located at what was once Mount James Station.

Although there are no sealed roads in the area, graded roads provide access to Gascoyne Junction (110 km to the southwest), Carnarvon (250 km to the west), Meekatharra (330 km to the southeast), and Mullewa (450 km to the south). Station tracks allow access to most of the map sheet, although some hilly terrain is inaccessible even to four-wheel-drive vehicles (e.g. Lockier Range). During wet weather, graded roads become impassable due to flooding. Most stations have airstrips suitable for light planes.

## Climate and vegetation

MOUNT PHILLIPS lies in the Eremaean Botanical Province of Beard (1981). Most of the map sheet has a true desert climate in which precipitation is irregular and low with no assured growing season. The summers are hot and winters are mild. Average annual rainfall over most of MOUNT PHILLIPS does not exceed 200 mm and takes place in late summer to early winter, often associated with thunderstorm and cyclonic events. This pattern of rainfall favours low woodlands of mulga (*Acacia aneura*) with an understorey of *Cassia*, *Eremophila*, annual herbs and other species of *Acacia*. On river plains, such as the catchment areas of the Lyons and Gascoyne rivers, mulga is mixed with *A. victoriae* and *A. xiphophylla*, other acacias and *Hakea preissii*. Granitic areas have a low scrub cover of *Eremophila*.

## Physiography

Williams et al. (1983) described the MOUNT PHILLIPS area as a well-dissected plateau capped by Tertiary duricrust relicts. The map sheet is drained by the Gascoyne River system which includes the Lyons and Thomas rivers. Many prominent topographic features, such as Mount Augustus (1106 m), Mount Gascoyne (789 m), Mount Phillips (780 m) and Mount James (602 m), constitute Proterozoic sandstone erosional relicts of Jutson's (1934) 'old plateau'. The plains vary in height from about 350 m in the east to 260 m in the west. Much of the remaining terrain is hilly except around the main drainages. Proterozoic sedimentary rocks of the Bangemall Group form prominent strike ridges in the northeastern part of the map sheet.

Large granitic areas usually form undulating plains with scattered low hills, whereas areas of metamorphic rock give rise to a rugged hilly terrain that is strongly dissected. This terrain, which is found on the PINK HILLS 1:100 000 map sheet in the southeastern corner of MOUNT PHILLIPS, proved to be the most inaccessible area encountered during

the sampling program. Permian sedimentary rocks in the west of MOUNT PHILLIPS form undulating plains with shallow drainages and sandstone ridges.

## Landform and regolith development

Major landforms on MOUNT PHILLIPS are:

- prominent hills and ridges of sandstone, chert, granite and gneiss with a coarse lag of freshly weathered bedrock on slopes,
- low hills and rises of granitoid and sedimentary rocks,
- undulating plains developed over granitoids, metamorphic and sedimentary rocks (in the Carnarvon Basin), with debris of weathered rock overlying bedrock,
- upland colluvial plains interrupted by areas of outcrop,
- dissected plateau with lateritic remnants and abundant ferruginous lag,
- alluvial and sheetwash fans,
- alluvial plains,
- sandplains,
- major drainage floors containing active streams and extensive floodplains,
- major drainages deeply incised in consolidated colluvium.

## Soils

Soils on MOUNT PHILLIPS have been classified by Bettenay et al. (1967). They are predominantly soils with contrasting (duplex) texture profiles, mainly pedal subsoils with sporadically bleached A<sub>2</sub> horizons and an alkaline-reaction trend. Soils over most of the Lyons and Gascoyne river drainages are termed BD1, which correspond to non-calcareous loamy soils with weak pedologic development. Other major soil types are AA 9 (brown and red sandy soils with weak pedologic development), Fa 8 (shallow coherent and porous loamy soils), BE 6 and BE 9 (shallow earth loams with red-brown consolidated colluvium), and small patches of Mz 23 (mainly red earths, with gradational texture profiles and an acid-reaction trend).

## Topographic and remote-sensing datasets

The topographic information used in construction of the accompanying maps was obtained from the Department of Land Administration (DOLA) and Australian Land Information Group (AUSLIG). Landsat Thematic Mapper and MSS scenes were obtained from the Remote Sensing Services (DOLA). Airborne radiometric and magnetic data were acquired from the Australian

Geological Survey Organisation (AGSO) and World Geoscience Corporation. Other remote sensing datasets used in the interpretation of MOUNT PHILLIPS included 1:50 000-scale black and white aerial photographs (1993) also obtained from DOLA.

## Geology

Three tectonic units outcrop on MOUNT PHILLIPS: the Palaeoproterozoic Gascoyne Complex, the Mesoproterozoic Bangemall Basin, and the Phanerozoic Carnarvon Basin.

The geology of MOUNT PHILLIPS was described briefly by Maitland (1909) and Talbot (1926), with Johnson (1950) carrying out more extensive mapping in the southern central part, and in the Eudamullah area. Permian sedimentary rocks in the western part of the map sheet were first studied by the Bureau of Mineral Resources (now Australian Geological Survey Organisation) (Condon, 1967). The first major account of the geology, based on aerial photograph interpretation and several traverses, was published by Daniels (1975). Systematic regional mapping by GSWA resulted in the production of a 1:250 000-scale geological map and explanatory notes (Williams et al., 1979), which were later revised and updated following further mapping of the Gascoyne Province (Williams et al., 1983). A regional overview of the geology of the Gascoyne Province (Williams, 1986) and its geochronology (Libby et al., 1986) included large parts of MOUNT PHILLIPS. Myers (1990) summarized new and existing information on the geology of the Gascoyne Complex, including MOUNT PHILLIPS. Although Gee (1979a) argued that the Capricorn Orogen represented deformed geosynclinal sediments deposited between the Pilbara and Yilgarn Cratons, Tyler and Thorne (1990) have suggested that these rocks result from events associated with the oblique collision of the two cratons.

A simplified geological interpretation has been compiled from the mapping (Fig. 2) of Williams et al. (1983), and forms the basis for the regolith classification (Plate 1) and the assignment of geological codes in the accompanying datafile PHILCHEM.CSV.

## Gascoyne Complex

The Gascoyne Complex is the deformed and high-grade metamorphic core of the Palaeoproterozoic (2.0–1.6 Ga) Capricorn Orogen (Gee, 1979a; Myers, 1990), and occupies the largest area on MOUNT PHILLIPS (Plate 1). The complex is composed of high-grade metasedimentary rocks, gneiss and granitoid that are unconformably overlain by Mesoproterozoic rocks of the intracratonic Bangemall Basin, and Permo-Carboniferous sedimentary rocks of the Carnarvon Basin.

Daniels (1975) first used the term 'Gascoyne Province' for metamorphic and igneous rocks bounded by the Yilgarn Craton, and the Bangemall and Carnarvon Basins. Following the mapping of Williams et al. (1979, 1983) and the more detailed study of Williams (1986), this was

renamed the Gascoyne Complex by Myers (1990), who divided it into five major zones based on structure and lithologic distribution (Myers, 1990, fig. 3.2). At the southern margin (zone A) is a series of complexly deformed and multiply metamorphosed 3.7–3.3 Ga gneissic rocks of the Narryer Gneiss Complex, which are abruptly truncated by the Errabiddy shear zone. North of this shear zone, rocks in zone B consist of reworked Archaean basement, together with Palaeoproterozoic gneissic granitoids, metasedimentary rocks, and post-tectonic granite. Nutman and Kinny (1994) have reported Sensitive High Resolution Ion Microprobe (SHRIMP) U–Pb zircon ages of c. 2.0 Ga from granitoid rocks in zone B. The metasedimentary rocks form part of the Morrissey Metamorphic Suite (Williams et al., 1983), which outcrops extensively on MOUNT PHILLIPS.

North of the Chalba Shear Zone, which is the northern boundary of zone B, rocks of zone C are mostly multiply deformed metasedimentary lithologies of the Morrissey Metamorphic Suite overlying gneissic granitoid rocks, the main body of which is the Yinnetharra Gneiss Dome (Williams, 1986). Maximum and minimum ages for gneisses within the dome are given by a Sm–Nd model age of 2240 Ma (Fletcher et al., 1983) and a whole-rock Rb–Sr age of  $1626 \pm 99$  Ma (Libby et al., 1986). In the northern part of MOUNT PHILLIPS, the Minnie Creek Batholith, which forms Zone D and has been emplaced into gneissic granitoid rocks and metasedimentary rocks of Zone C, has given a Sm–Nd model age of 2060 Ma (Fletcher et al., 1983) and a Rb–Sr whole-rock age of about 1600 Ma (Libby et al., 1986). Nelson (1995) has reported a SHRIMP U–Pb zircon age of c. 1800 Ma from a granitoid underlying the Bangemall Group, to the east of MOUNT PHILLIPS.

Zone E lies to the north of MOUNT PHILLIPS and consists of repeatedly deformed metasedimentary rocks intruded by numerous plutons of both I- and S-type granitoid. The metasedimentary rocks pass northwards, with decreasing metamorphic grade, into the Wyloo Group of the Ashburton Basin. Alkaline granitoid rocks in the Gifford Creek area have given SHRIMP U–Pb zircon ages of c. 1680 Ma (Pearson et al., 1996).

## Archaean gneiss

Archaean banded gneisses are mainly of syenogranite or monzogranite composition with some tonalitic or granodioritic bands. Associated with the banded gneisses are migmatites, which contain foliated medium- to coarse-grained biotite granite or adamellite and pegmatoid that were considered products of anatexis (Williams et al., 1983).

## Morrissey Metamorphic Suite

The Morrissey Metamorphic Suite (Williams et al., 1979) consists of metamorphosed and deformed sedimentary rocks that were originally deposited as shelf and trough sediments, and less common volcanic rocks (Williams, 1986). They are intruded by Palaeoproterozoic granitoids,

and unconformably overlain by late-orogenic sedimentary rocks of the Mount James Formation and Mesoproterozoic, post-orogenic sedimentary rocks of the Bangemall Group.

The Morrissey Metamorphic Suite is lithologically diverse, and includes prograde and retrograde pelitic and semi-pelitic schists, phyllite, quartzite, micaceous quartzite, and thick sequences of fine-grained quartzofeldspathic paragneiss, and paragneiss with pelitic schist intercalations. There are local occurrences of metamorphosed conglomerate. Migmatites are extensively developed and calc-silicate gneisses and marble form small but prominent units. In addition, there are minor occurrences of mafic and intermediate volcanics, and narrow bodies of amphibolite after dolerite dykes and sills.

Gee (1979b) argued that the Morrissey Metamorphic Suite represented metamorphosed Glengarry Group sedimentary rocks, whereas Williams (1986) suggested that it may correlate with the Peak Hill Metamorphic Suite. Age determinations on intrusive granitoids (Compston and Arriens, 1968; de Laeter, 1976; Williams et al., 1978; Nelson, 1995), basement gneiss, and from the metamorphosed suite itself (Williams et al., 1978) restrict the age of the Morrissey Metamorphic Suite to between 2470 and 1800 Ma.

Polyphase prograde and retrograde metamorphism of these pelitic lithologies has resulted in a wide range of mineral assemblages (Williams, 1986) including coarse quartz, chlorite, chloritoid, muscovite, biotite, garnet, staurolite, sillimanite, cordierite, magnetite, and andalusite. The second metamorphic event recognized in the rocks was accompanied by large-scale boron and sodium metasomatism, resulting in alteration of biotite to muscovite and phlogopite, calcic plagioclase and potash feldspar to albite, and extensive formation of tourmaline. Throughout the zone of metasomatism, which extends from Morrissey Hill to the northern side of Mortimer Hills, pegmatites are developed, which may contain coarse books of muscovite, together with tourmaline, beryl and less common bismutite, euxenite and pitchblende. Coarse crystals of dravite can be found in augen adamellite with minor occurrences of fluorite, garnet, lepidolite and green tourmaline.

## Early-stage gneissic granitoids

The Morrissey Metamorphic Suite was intruded by gneissic granitoids prior to or during the first phase of metamorphism recognized in the rocks (Williams et al., 1983). These granitoids developed an elongate granoblastic fabric during this event. Compositions range from granite to granodiorite, with subordinate alkaline anorthosite gneiss, calc-silicate gneiss and metadolomites. Discrete plutons of even-grained, pink gneissic granitoid with syenogranite to adamellite (monzogranite) compositions form another distinct part of the early-stage granitoids. This suite has undergone partial melting, and migmatitic phases are common (Williams et al., 1983).

## Late-stage granitoids

The late-stage granitoids are concentrated in the northern and southeastern parts of MOUNT PHILLIPS (Williams et al., 1983; Williams, 1986), where they form part of the 230 km-long by 35 km-wide Minnie Creek Batholith. Their emplacement caused widespread deformation in the Morrissey Metamorphic Suite. Foliated coarse-grained porphyritic biotite granodiorite and adamellite (monzogranite) at the margin of the batholith is intruded by coarse-grained, mostly unfoliated granitoid. Compston and Arriens (1968) dated the Minnie Creek Batholith at 1690 Ma using Rb–Sr isochrons, whereas de Laeter (1976) quoted a Rb–Sr isochron age of  $1672 \pm 18$  Ma.

## Mount James Formation

Deformed and metamorphosed sedimentary rocks of the Mount James Formation form disconnected belts and isolated outcrops in the central and southeastern parts of MOUNT PHILLIPS. These rocks unconformably overlie the Morrissey Metamorphic Suite, and are in turn unconformably overlain by sedimentary rocks of the Bangemall Group. Barnett (1975) correlated this formation with parts of the Padbury Group. Lithologically, the Mount James Formation consists of a polymictic boulder conglomerate at the base (marking the unconformity with the Morrissey Metamorphic Suite) followed by well-bedded metasandstone, meta-arkose and massive quartz sandstone with interbeds of metasiltstone and metasandstone. The total thickness is in excess of 2000 m. These rocks have undergone low-grade metamorphism, indicated by the presence of sericite and muscovite, followed locally by moderate-grade metamorphism that produced porphyroblasts of biotite, garnet, andalusite and grunerite. This metamorphism is thought to be equivalent to the fourth metamorphic event recognized in the Morrissey Metamorphic Suite (Williams et al., 1983).

## Bangemall Group

Sedimentary rocks and intrusive dolerite of the Bangemall Group are found in the northeastern part of MOUNT PHILLIPS, where they unconformably overlie rocks of the Gascoyne Complex. These sedimentary rocks form elongate, doubly plunging folds that trend in a north-westerly direction, and are part of the Edmund Subgroup of Williams (1990). Nelson (1995) has recently dated the base of the Bangemall Group at 1640 Ma. The lower part of the Bangemall Group succession consists of terrestrial alluvial-fan deposits that include such units as the Mount Augustus Sandstone, a coarse-grained quartz arenite with subordinate amounts of conglomerate. The overlying units represent lagoonal to shallow marine facies, and include laminated dolomite and black shale of the Irregully Formation, siliceous quartz arenite of the Kiangi Creek Formation, variably coloured siliceous and pyritic shales of the Jillawarra Formation, and the prominent black and grey laminated pyritic chert making up the Discovery Chert. Laminated dolomite and

subordinate siltstone and sandstone of the overlying Devil Creek Formation represent a return to marine-shelf and basinal conditions of sedimentation, which continued through to the deposition of the sandstone and shale of the Fords Creek Shale. Outliers of the Bangemall Group are found in the southeastern and central part of MOUNT PHILLIPS.

## Carnarvon Basin

The geology of the Carnarvon Basin has been discussed in detail by Hocking et al. (1987) and summarized by Hocking (1990). The most extensively developed unit on MOUNT PHILLIPS is the Late Carboniferous Lyons Group (Lyons Formation of Williams et al., 1983), which unconformably overlies rocks of the Gascoyne Complex and was deposited in the Bidgemia Sub-basin. Although this unit is poorly exposed, it is lithologically diverse (conglomerate, calcareous sandstone, sandstone) with its glaciogene origin being a unifying feature. The Austin Member (included in the Harris Sandstone by Hocking (1985)) is locally developed, and consists of quartzofeldspathic sandstone. In the southwest of MOUNT PHILLIPS, near Tallangatta Outcamp, are areally restricted occurrences of the overlying Callytharra Formation, Moogooloo Sandstone and Billidee Formations (Williams et al., 1983), which could represent half-graben infillings (Hocking, 1990). The Callytharra Formation conformably overlies the Lyons Group, and consists of carbonate-bearing siltstones, sandstones and mudstones. The Moogooloo Sandstone, part of the overlying Wooramel Group, comprises quartz wacke with less common conglomerate and siltstone. Conformable on this unit are siliciclastic sandstones of the Billidee Formation.

## Cainozoic

The Cainozoic geology consists largely of alluvium, colluvium and eolian units of Quaternary age with older, semi-consolidated colluvium, lacustrine deposits, calcrete and some laterite and silcrete of probable Tertiary age. Most of these units are treated in more detail in a later section focusing on regolith mapping. The Nadarra Formation has been mapped by Williams et al. (1983) as a lacustrine limestone deposit in the southwestern part of MOUNT PHILLIPS. They consider it to be a Miocene-Pleistocene valley-fill deposit.

## Mineralization

MOUNT PHILLIPS lies in the Gascoyne Mineral Field, an area also well known for its gemstones, which include varieties of tourmaline, garnet, staurolite, cordierite, amethyst, quartz and beryl. Gold, bismuth, beryllium, copper, tantalum, columbite, and semi-precious stones have been intermittently mined from various parts of MOUNT PHILLIPS, and there are several occurrences of lead, copper, barite, tungsten, uranium, rare earths and molybdenum. Current exploration interests in the area focuses on base metals, uranium and gold.

Details of mineral production for MOUNT PHILLIPS between 1897 and 1995 are tabulated in Appendix 1 and include 40 individual and group mineral prospects (column 3, Appendix 1). For group-mineral prospects, the amounts of the mineral mined have been summed and the total attributed to the largest producer. The coordinates identify the centre of the region or site, determined from survey diagrams, mining registers, tenement applications, public plans and TENGGRAPH (Department of Minerals and Energy (DME) digital graphical mining-tenure database). Appendix 1 is a collation of all available data from published and unpublished sources, as reported to the DME Royalties Branch. Only post-1897 gold-production figures are reported, as earlier production was not systematically recorded. Sundry claims refer to prospects and small deposits that were permitted to treat a maximum of 50 tonnes of ore per year.

## Gold

Gold production figures have been recorded only from the Bangemall Mining Centre (discovered in 1896), 1 km southwest of Cobra Homestead. The total recorded production of 393.4 kg of ore yielded 20.20 kg of gold, at an average grade of 25 g/t. Small amounts of gold have also been reported from McCarthys Find, 14 km northwest of the Bangemall Mining Centre, but there are no official production figures.

At both the Bangemall Mining Centre and McCarthys Find, mineralization is confined to quartz saddle reefs, axial-plane reefs and quartz stringers within shale of the Jilawarra Formation of the Bangemall Group. Gold is associated with sphalerite, pyrite and carbonate (Williams et al., 1983).

## Beryl

Beryl has been mined intermittently from 1943 to 1970 at four centres (Bidgemia, Eudamullah, Upper Gascoyne and Yinnetharra), but most production has been from the Yinnetharra Mining Centre. The four centres have produced a total of 59.144 tonnes of beryl from 494.58 tonnes of ore.

## Bismuth

The Yinnetharra area has been a major bismuth producer in Western Australia. During the period 1939 to 1970, production totalled 7.34 tonnes of ore and concentrate, yielding 4601.58 kg of metal, mainly from the Morrissey Hill and Yinnetharra Mining Centres. The bismutite ore was worked mainly from eluvial deposits adjacent to muscovite- and beryl-bearing pegmatites of the Morrissey Metamorphic Suite (Ellis, 1940, 1941a). A rare bismuth mineral (clinobisvanite) has been reported from MOUNT PHILLIPS in pegmatites associated with beryl, spessartine and bismutite (Bridge and Pryce, 1974).

## Copper

Williams et al. (1983) provided a brief discussion of copper occurrences on MOUNT PHILLIPS. They have been reported from granitoid bodies, various parts of the Bangemall Group, and in schists, paragneisses and pegmatites of the Morrissey Metamorphic Suite. In general, copper mineralization is associated with areas of intense deformation. Total reported copper production on MOUNT PHILLIPS amounts to 10.14 tonnes of ore yielding 1556.20 kg of copper. Production was confined to the mid-1960s.

## Tantalite and columbite

A total of 5.68 tonnes of tantalite and columbite has been mined at the Yinnetharra Mining Centre, yielding 302 kg and 390 kg of metal oxide respectively. The material was recovered entirely from eluvial deposits adjacent to muscovite- and beryl-bearing pegmatites.

## Mica

Reports on the mica deposits of MOUNT PHILLIPS can be found in Maitland (1909), Wilson (1923, 1927), Ellis (1941b) and Matheson (1944, 1945). The total mica production on MOUNT PHILLIPS of 11 239.45 kg has been recorded from the Yinnetharra Mining Centre, which includes the Morrissey Hill and Cairn mines. Last known production was in 1949. Most economic mica deposits were found in proterozoic pegmatites. These pegmatites consist of a zoned association of quartz, feldspar, tourmaline and beryl, with minor amounts of bismutites, biotite, tantalite-columbite and uranium and rare-earth bearing minerals. Most of these pegmatites were also sources of beryl production

## Semi-precious stones

The Yinnetharra district is well known for its semi-precious gemstones and other specimen-quality minerals. A total of 343 048 kg of gem-quality amethyst was produced between 1971 and 1995 from quartz segregation in zoned pegmatite bodies, and from pegmatites in calc-silicate and marble palaeosomes of Proterozoic migmatite. In excess of 8600 kg of dravite (a brown, magnesium-rich tourmaline) and 1035 kg of schorl (black tourmaline) have been recovered from the same area. Other semi-precious gemstones associated with tourmaline and amethyst deposits include garnet, staurolite, cordierite, and rose and smoky quartz.

## Lead

Although there is no recorded production of lead from MOUNT PHILLIPS, lead mineralization has been recorded from two localities in the Bangemall Group and from four localities in Proterozoic granitoids. These are discussed in Simpson (1951), Blockley (1971) and Williams et al. (1983). Some of these occurrences are associated with

argentiferous galena and cerussite, whereas others are found with fluorite and barite.

## Uranium

More than 45 separate occurrences of uranium have been described on MOUNT PHILLIPS (Williams et al., 1983), but none has been economically viable. Uranium is found mainly as secondary, yellow or olive-green carnotite in calcrete and weathered bedrock. Such occurrences are near-surface deposits and are erratic in their distribution and grade. Primary uranium and rare-earth bearing minerals are found in some zoned pegmatites, and include euxenite, pitchblende, beta-uranophane and gummite. Many of the gneisses and metamorphosed clastic rocks from the Morrissey Metamorphic Suite have above-average background radioactivity.

## Geochemical surveys in open-file company reports

To comply with the Mining Act of 1978, mineral exploration companies must lodge reports, detailing exploration activity. These are listed in the GSWA WAMEX database, as either open-file or confidential reports. Details of open-file company reports that contain surface or near-surface geochemical data on MOUNT PHILLIPS are summarized in Appendix 2. For each project, surface geochemical exploration data (including costean and shallow-drilling information) are captured to maximum depths of four metres. Projects with fewer than 30 samples have been omitted.

Each project has been assigned an identification number (ID No. of Appendix 2), which is shown, with project boundaries, on Plates 3 and 4. Most projects cover a single area, although some projects cover two or more distinct areas.

The projects in Appendix 2 are tabulated in order of increasing M number for the period 1968 to 1994. When reports are released to open-file, the M number is replaced by an Item number, with the highest Item number denoting the most recent release. Gaps in reporting result from either the failure of some tenement holders to lodge reports, or on account of mineral-claim holders not being obliged to report all of their exploration results prior to 1978.

A total of 16 538 samples contained within the 55 projects listed in Appendix 2 have been analysed for an average of four elements. The projects are classified according to the targeted mineralization as follows:

Uranium	24%
Gold	18%
Copper + lead	11%
Base metals	9%
Gold + base metals	9%

The remaining 29% of projects targeted mainly rare-earth elements, tungsten, and tantalum.

## Hydrogeology

Although the rivers on MOUNT PHILLIPS flow for short periods each year, they contain many semi-permanent pools which are a valuable source of water. Rock pools and springs are scattered over the map sheet. The main supply of water on MOUNT PHILLIPS comes from widely distributed wells and bores, most of which have been sunk in or adjacent to drainage lines in consolidated alluvium or colluvium (Williams et al., 1983), or in valley calcrete in major drainages. Permian sandstones also serve as a source of stock and domestic water. Williams et al. (1983) reported that water quality ranges from 100 to 15 000 mg/L total dissolved solids (TDS), with 82% of wells and bores returning less than 5000 mg/L. This is confirmed by borehole data held by the Water and Rivers Commission (Fig. 53).

## Geochemical mapping

### Sampling and sample density

Mapping and regolith sampling on MOUNT PHILLIPS, which commenced in July 1995, was undertaken by A. G. Subramanya (GSWA) with assistance from P. Penna, B. McCrow, S. Keeling and E. Mead of Geochemex Australia. The aim of the GSWA regional regolith geochemical sampling program is to collect regolith samples at a nominal density of one sample per 16 km<sup>2</sup> over a 1:250 000 map sheet, resulting in approximately 1030 samples. The sampling program fulfils two objectives. Firstly, it provides a sample for subsequent multi-element chemical analysis, and secondly, the characteristics of the regolith and surrounding geology recorded at each site are used in construction of the regolith-materials map (Plate 1).

### Site selection

Sample sites were chosen using a 4 × 4 km grid superimposed on 1:100 000-scale topographic maps. Within each grid square, the site was chosen with regard to bedrock geology, satellite imagery, topographic data and access. Site locations were digitized and allocated a unique site-location number, which also served as a reference number for subsequent database storage of site information. Vehicle-mounted GARMIN 75 GPS (Global Positioning System) units set to the Ausgeo 84 datum, and accurate to ± 100 m on the ground, were used to locate the sample sites in the field. The geologist was given the discretion to relocate the site to avoid (for example) areas of standing water or sites of human activity. The location of each sample point is listed in AMG coordinates in the accompanying datafile PHILCHEM.CSV and in Plate 2.

Whenever possible, stream sediments were the preferred sampling medium and an effort was made to collect samples from first- to third-order streams, as these have been shown to be the ideal medium for regional geochemical surveys (Fordyce et al., 1993; Darnley, 1993). This accounts for the high proportion of depositional

samples collected (refer to section on **Regolith-materials mapping**). In areas where drainage was lacking or ill-defined, sheetwash or soil samples were taken. Areas extensively disturbed by human activity, such as near homesteads, cattle yards, roads, airstrips and old mining areas, were avoided.

### Sample-site form

At each site, characteristics of the sample, surrounding regolith and bedrock geology were recorded on a standard form (Appendix 3), along with locational data. This information was used in construction of the regolith-materials map (Plate 1), and in interpretation of regolith chemistry. Mandatory data for all sample sites includes the sample's AMG co-ordinates read from the GPS, the sample site code (e.g. EUD 177 — for sample site 177 on the Eudamullah 1:100 000 sheet), unique GSWA number (e.g. 138475), sampling date, sampler's initials and nature of sample (e.g. stream or sheetwash; channel or pit). The position of the sample in a typical landform profile is indicated on the idealized cross section, and components of the regolith sample in terms of grain size and lithologic/mineralogic components (i.e. iron-rich, non-lithic, lithic) are recorded as Abundant (>30%), Common (5–30%), Rare (1–5%), and Trace (<1%). Identifiable fresh rock fragments are also recorded in the same fashion (Clast lithology). The surrounding regolith, using regolith descriptors (Table 1) and free-form entry, is also described. Fields also exist for recording any secondary coatings, the nature of fine-grained material, the presence of nearby rock outcrops and secondary units, and the nature of the stream-sampling site.

### Sampling methods

Two samples were collected from each site, one for geochemical analysis and the other as an archive sample. A second (duplicate) geochemical sample was collected at every fiftieth site and used for quality control. Analytical samples comprised approximately 1.5 kg of the <2 mm to >0.45 mm fraction. An estimate of the proportion of material >2 mm and <0.45 mm was recorded at each site as a guide to the degree of sorting. The rationale for choosing the <2 mm to >0.45 mm fraction followed an orientation study carried out in the Glengarry Basin by R. Davy (1995, pers. comm.). The chosen size fraction aims to minimize both the nugget effects of coarse-grained material, and the dilution effects of fine-grained, wind-blown sand. The second sample is a 3–4 kg archive of the <2 mm fraction. All sieving and labelling was done at the site, apart from wet or damp samples which were collected in bulk, and dried, sieved and labelled at the base camp.

Surface debris, such as vegetation, coarse rubble and loose windblown sand, were removed prior to collecting the sample. Stream-sediment samples were collected from a pit or channel excavated to depths of between 10 and 40 cm. Well-defined streams were sampled by trenching across the channel and including both active sediment and some material from the stream banks. In the case of braided streams, all main channels were sampled and

composited. Soil and sheetwash samples were composited from samples taken from three pits spaced about 50 m apart. In areas with a discernible slope, the three subsamples were collected in a line normal to the slope direction, whereas in flat areas the three pits formed the apices of an equilateral triangle.

A separate GSWA number was allocated to each sample, including the quality-control duplicate samples taken at every fiftieth site. The samples were labelled externally with the GSWA numbers and a numbered paper tag was placed in the sample bags. Numbered aluminium tags were included with the archive samples. In order to facilitate relocation for quality control or follow-up work, sample sites were marked with a metal stake to which the GSWA number was attached.

Approximately thirty sample sites were checked by an independent geologist on completion of the sampling program. At each site, a second sample-site recording form was completed, and the locations at which the sample was taken were inspected in terms of such aspects as trench orientation, pit depth, and pit spacing. Assessment was also made of any potential contamination. At the majority of sample sites, GSWA sampling policy was adhered to.

### Acidity-alkalinity and conductivity determinations

Acidity-alkalinity (pH) and conductivity measurements were made by thoroughly mixing approximately 20 g of archive material with 90 mL of de-ionized water and allowing it to stand for at least 30 minutes. The pH and conductivity of the solution was then determined and the results included in the digital datafile (PHILCHEM.CSV). Acidity-alkalinity measurements were made using a 3050 Portable Jenway pH meter, following calibration using three buffer solutions with pH values of 4, 7 and 10. The electrode was rinsed with de-ionized water before measurement of the first test suspension, and between measurements of unknown samples.

Conductivity measurements were made using a TD SCAN4 conductivity meter. The meter was calibrated against a buffer solution with a conductivity value of 12.9 millisiemens/cm. The electrodes were rinsed with de-ionized water before measurement of the first test suspension, and between measurements of unknown samples. Sample number, conductivity and temperature were recorded for each test suspension and the conductivity values in millisiemens/metre, adjusted to equivalent readings at 20°C, are recorded in the datafile (PHILCHEM.CSV). These equivalent readings have been calculated from the formula:

$$k_{20} = k \times 100 / (1 + 0.022 (T - 20))$$

where  $k$  is the measured conductivity in millisiemens/cm recorded at temperature  $T^{\circ}\text{C}$ .

TDS in mg/L is calculated from the formula:

$$\text{TDS} = 4.437 \times (k_{20})^{1.066}$$

Both formulas are similar to those Kevi (1988) used for calculation of TDS values from resistivity measurements.

### Regolith-materials mapping

A regolith-materials map (Plate 1) has been produced for MOUNT PHILLIPS using Landsat Thematic Mapper imagery, aerial photography, magnetic and radiometric data and field observations recorded at each sample site. Occasionally the scale difference between field-recorded data and remotely sensed mapping causes discrepancies between the regolith code assigned by the sampling geologist and the unit shown on the interpreted regolith-materials map. This may affect the expected chemistry of a sample, particularly if two quite different regolith units are in contact (e.g. calcrete next to an erosional breakaway). A simplified geological map (Fig. 2) has also been produced, largely from a combination of airborne magnetic data and the 1:250 000 geological mapping of Williams et al. (1983). Scale difference may also occur between the simplified geological map and the more detailed regolith map, and may result in different geological codes in the same area (e.g. metamorphic-derived regolith overlying primarily granitoid basement). The assigned regolith codes for each sample are listed in the accompanying datafile (PHILCHEM.CSV). A simplified version of the regolith map appears as Figure 3.

The GSWA has adopted the regolith-landform approach to regolith mapping (Craig and Anand, 1993; Anand et al., 1993; Anand and Smith, 1994; Hocking et al., in prep.), where regolith is classified according to its nature and position in an idealized landform profile. The regolith-landform approach involves classification of regolith into one of three regimes (residual, erosional and depositional). In the GSWA scheme, the term 'relict' is preferred over 'residual' to avoid any genetic connotations. The regolith codes and descriptions used on MOUNT PHILLIPS are listed in Table 1.

*Relict* regimes are predominantly upland surfaces, and include lateritic and siliceous duricrusts developed prior to the more recent and continuing period of downcutting and erosion. *Erosional* regimes are characterized by active erosion and a net loss of material as a result of weathering and downslope transport. The remaining landform types are assigned to the *depositional* regimes which have a net gain of detritus and are characterized by widespread sedimentation. The MOUNT PHILLIPS sheet contains extensive areas of consolidated colluvium, most of which are being actively eroded by streams. They have been assigned to the depositional regime, as they represent earlier deposits of colluvium and alluvium.

Regolith cover over most of the map sheet is thin and the erosional regime is predominant.

### Relict regime

The relict regime regolith on MOUNT PHILLIPS, occupies just over 1% by area and contributes less than 0.5% of the geochemical samples. Relict regime units consist

Table 1. Regolith codes and description

Regolith code	Description
<b>RELICT REGIME</b>	
R1	Ferruginous pisolites, granules and nodules
R2	Iron-rich duricrust forming remnant land surfaces
R3	Silcrete, often weakly ferruginized; includes areas of silicified calcrete and kankar
R4	Quartz-rich sand and silts overlying R1–R3 material; may be locally reworked
<b>EROSIONAL REGIME</b>	
E1	Mottled zone and saprolite; generally poorly exposed except in upland areas with incised drainage
E2g	Granitoid rock: outcrop of saprock and bedrock, and areas of subcrop with locally derived sands and sandy clays. Coarse (bouldery) lag may be present adjacent to prominent ranges
E2v	Mafic rock: outcrop of saprock and bedrock, and areas of subcrop with locally derived sands and sandy clays. Coarse (bouldery) lag may be present adjacent to prominent ranges
E2s	Sedimentary rock: outcrop of saprock and bedrock, and areas of subcrop with locally derived sands and sandy clays. Coarse (bouldery) lag may be present adjacent to prominent ranges
E2m	Metamorphic rock: outcrop of saprock and bedrock, and areas of subcrop with locally derived sands and sandy clays. Coarse (bouldery) lag may be present adjacent to prominent ranges
E2q	Prominent ridges, possibly quartz-filled shear zones
E4g	Granitoid rock: Lag of locally derived ferruginous and/or lithic fragments in a sandy clay to sand-rich matrix, associated with actively eroding outcrop/subcrop
E4v	Mafic rock: Lag of locally derived ferruginous and/or lithic fragments in a sandy clay to sand-rich matrix, associated with actively eroding outcrop/subcrop
E4s	Sedimentary rock: Lag of locally derived ferruginous and/or lithic fragments in a sandy clay to sand-rich matrix, associated with actively eroding outcrop/subcrop
E4m	Metamorphic rock: Lag of locally derived ferruginous and/or lithic fragments in a sandy clay to sand-rich matrix, associated with actively eroding outcrop/subcrop
<b>DEPOSITIONAL REGIME</b>	
<b>Dominantly colluvial</b>	
DC1	Medium- to coarse-grained rock detritus, in sandy clay-rich colluvial matrix; generally in upland areas
DC1g	As for DC1 derived mainly from granitoid rock
DC1s	As for DC1 derived mainly from sedimentary rock
DC1m	As for DC1 derived mainly from metamorphic rock
DC1f	As for DC1 derived from various sources; strongly ferruginized clasts of variable composition
DC1h	Consolidated colluvium; reddish brown and poorly bedded; proximal to outcrop/subcrop
DC2	Fine- to medium-grained detritus (clasts 4–25 mm) mainly of lithic origin, in sandy clay colluvial matrix; generally topographically lower than DC1
DC2g	As for DC2 derived mainly from granitoid rock
DC2s	As for DC2 derived mainly from sedimentary rock
DC2m	As for DC2 derived mainly from metamorphic rock
DC2f	As for DC2 derived from various sources; strongly ferruginized clasts of variable composition
DC2h	Consolidated colluvium; reddish brown and poorly bedded; moderately distal to outcrop/subcrop
DC3	Sand/clay dominated colluvium or sheetwash; merges into alluvial plains (DA5)
DC3f	Non-lithic ferruginous detritus (mostly <10mm), possibly magnetic, in red sandy clay. May include buckshot gravel; position comparable with DC3
DC3h	Consolidated colluvium (hardpan); reddish brown and poorly bedded; distal to outcrop/subcrop
<b>Dominantly alluvial</b>	
DA4	Gravelly sand and sandy clay of active alluvial channels with mixtures of ferruginous and variably altered lithic fragments
DA5	Sand- or clay-rich alluvium and colluvium on broad drainage floors, including overbank deposits and terraces. Includes non-saline claypans and calcrete fragments
DA8	Calcrete; includes kankar and silicified calcrete
D9	Sand; eolian in origin. May form dunes to thin sheets overlying sheetwash, soil or bedrock

predominantly of ferruginous and siliceous duricrust. The R1 unit is poorly developed on the sheet and contains upland unconsolidated ferruginous pisolites, granules and nodules. The R2 unit comprises iron-rich duricrust forming remnant land surfaces and R3 consists of silcrete, commonly weakly ferruginized, and found along remnant drainages as silicified calcrete and kankar (Plate 1). This includes silicified calcrete north of the Gascoyne River (Plate 1: 435000 mE, 7290000 mN) which now forms a remnant land surface (R3). The R4 unit comprises

relatively stable sand and silt (overlying inferred R1–R3 material) and is formed on relict backslopes with low gradient.

### Erosional regime

Regolith units prefixed with the code letter 'E' (Plate 1) comprise approximately 47% by area, and account for 36% of regolith samples collected on MOUNT PHILLIPS.

Extensive areas of granitoid outcrop and subcrop (E2g and E4g) characterize early- and late-stage granitoids, with lesser mottled zone and saprolite (E1), exposed largely in the southeast near Coondoondoo Hills. The erosional volcanic units (E2v and E4v) are restricted to mafic dykes and sills of the Bangemall Group, and are commonly found with interbedded erosional sedimentary units (E2s and E4s). The Carnarvon Basin and Mount James Formation also contain significant areas of erosional sedimentary units. The Morrissey Metamorphic Suite is overlain largely by erosional metamorphic material (E2m and E4m), particularly in areas of prominent relief between Mount Steere and Chalby Chalby. A number of narrow prominent ridges, (possibly representing quartz-filled shear zones) have been classed as E2q.

## Depositional regime

This regime is divided into a colluvium regime and an alluvium regime. Colluvial regolith units are widespread on MOUNT PHILLIPS, occupying 39% of the sheet and accounting for 48% of regolith samples.

In upland areas with reasonably steep gradient adjacent to outcrop or subcrop, the depositional regolith is typically medium- to coarse-grained with a sandy clay-rich colluvial matrix (DC1). Further downslope in areas of lower gradient, the detritus is generally finer grained and this material is labelled DC2. Where a particular source can be inferred for the DC1 and DC2 regimes a geological qualifier is attached (e.g. DC1g — derived mainly from granitoid rock). At still greater distance from the outcrop or subcrop, in the lowest energy environment, the DC2 unit gives way to sand- and clay-rich colluvium, labelled DC3. The DC3 unit often grades into broad drainage floors. Transportation of material, in this relatively stable environment, is largely by sheetwash. The DC3 unit is too distal from its source to justify use of a geological qualifier.

Two special regolith qualifiers (f, h) have been used to further describe the DC1, DC2 and DC3 regimes. The 'f' units (e.g. DC1f) often contain highly ferruginized clasts of variable composition, whereas the 'h' units are dominated by consolidated colluvium. Significant areas of MOUNT PHILLIPS contain consolidated colluvium, including upland areas such as the Clever Mary Hills (Plate 1). The upland units (DC1h, DC2h) are commonly incised, giving the appearance of an erosional terrain. In these notes, consolidated colluvium developed in low-energy environments is referred to as hardpan (e.g. DC3h). The largest area of hardpan (DC3h) is between the Lyons River and Koorabooka Creek, northwest of Mount Augustus Station, and possibly represents an ancient lake system.

Depositional alluvial regolith units (DA4, DA5, DA8) comprise almost 11% by area of MOUNT PHILLIPS and account for 14% of regolith samples. The regolith is variably sorted, mainly unconsolidated gravels, sands and clays with altered lithic fragments. Active stream channels are termed DA4, whereas areas of overbank deposits and non-saline claypans in broad drainage floors are labelled DA5. Sediment over calcrete (DA8) is often developed in conjunction with DA5, and extensive areas of DA8 are

found along the Lyons and Gascoyne rivers (Plate 1). In these notes, the term 'calcrete' is used to include also sediment overlying pedogenic calcrete.

Eolian sandplain (unit D9) is poorly developed on MOUNT PHILLIPS, comprising only 2% of the map sheet (Plate 1), and accounting for just over 1% of samples. The main area of sandplain is 20 km southwest of Mount Augustus Station, where it interfingers with colluvium derived from Bangemall Group rocks.

## Chemical analysis

One thousand and eighty-one regolith samples were analysed in five separate batches by Amdel Laboratories Ltd, Wangara, Perth. These batches consisted of 57 sheetwash samples, 933 stream sediments and 48 soil samples (total 1038) plus 23 duplicates and 20 GSWA standards. Wet samples were oven dried, and then approximately 1 kg of each sample was pulverized to <75 mm in a chrome-free bowl pulverizer. Contamination imparted by the pulverizer has been estimated by the manufacturer at approximately 50 ppm Mn and 5000 ppm Fe, with no detectable contamination for Cu, Pb, Zn, Ni, Mo, Co, and V.

Forty-nine components were measured for each sample, comprising ten elements as oxides in percent (SiO<sub>2</sub>, TiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>, MnO, MgO, CaO, Na<sub>2</sub>O, K<sub>2</sub>O, P<sub>2</sub>O<sub>5</sub>), thirty-two trace elements as parts per million or ppm (Ag, As, Ba, Be, Bi, Cd, Ce, Co, Cr, Cu, Ga, In, La, Li, Mo, Nb, Ni, Pb, Rb, Sb, Sc, Se, Sn, Sr, Ta, Th, U, V, W, Y, Zn, Zr), three ultra-trace elements as parts per billion or ppb (Au, Pd, Pt), three anions (Cl and F as ppm, and S as percent), and loss on ignition (LOI) reported as percent. These data are contained on the accompanying floppy disk as a comma-separated file PHILCHEM.CSV.

## Analytical methods

Eight analytical methods were used by Amdel Laboratories:

- SiO<sub>2</sub>, TiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>, MnO, MgO, CaO, Na<sub>2</sub>O, K<sub>2</sub>O, P<sub>2</sub>O<sub>5</sub>, Ba, Be, and Ta, were analysed by inductively coupled plasma optical emission spectrometry (ICP-OES) following an alkaline (lithium metaborate) fusion and dilute hydrochloric acid digestion (Amdel code IC4).
- Analysis of Ag, As, Bi, Cd, Ce, Ga, In, La, Mo, Nb, Pb, Rb, Sb, Se, Sn, Sr, Th, U, and W involved digestion of samples in a hydrofluoric + perchloric + nitric + hydrochloric acid mixture for 24 hours, then evaporation to fume dryness and dissolution in dilute hydrochloric acid. This solution was analysed by inductively coupled plasma mass spectrometry (ICP-MS) (Amdel code IC3M).
- Co, Cr, Cu, Li, Ni, Sc, V, Y, Zn and Zr were analysed by inductively coupled plasma optical emission spectrometry (Amdel code IC3E). Each sample was digested in a hydrofluoric + perchloric

+ nitric + hydrochloric acid mixture for 24 hours, then evaporated to fume dryness and dissolved in dilute hydrochloric acid.

- Au, Pt and Pd were analysed by inductively coupled plasma mass spectrometry. Precious metals for each sample were collected in a lead collection fire assay fusion. Following cupellation, the prill was dissolved in aqua regia, then analysed (Amdel code FA3).
- S was determined by infra-red spectrometry, following release of gas by ignition in a LECO furnace (Amdel code VOL2).
- Loss on ignition (LOI) was determined by gravimetric means (Amdel code GRAV7).
- F was determined by selective ion electrode, following a sodium peroxide fusion and dissolution in water (Amdel code SIE2).
- Cl was determined by leaching each sample with nitric acid, then titrating with AgNO<sub>3</sub> (Amdel code SIE1).

Detection limits and the number of samples with values below detection are shown in Table 3. In this study, the 'theoretical detection level' (as displayed on the element concentration plots) is taken as three times the standard deviation of the signal at or near the blank level. This is further documented in Morris et al. (1997).

## XRD mineralogy

Thirteen samples, spanning a wide range of bedrock types, have been analysed by X-ray diffractometry (XRD) at CSIRO. The X-ray peak position and height have been combined with results of the chemical analysis to calculate theoretical mineral abundances. Results are shown in Table 2.

The thirteen samples include three early-stage granitoids, one late-stage granitoid, five samples from regolith overlying the Morrissey Metamorphic Suite, three samples of regolith sources from the Bangemall Group, and one from the Carnarvon Basin succession. Seven of the samples are from the erosional regime, five from the depositional colluvial regime, and one from sandplain.

All three early-stage granitoid samples are dominated by quartz (64–68%), regardless of regolith division, and they all have roughly equal amounts of K-feldspar (6–9%). Plagioclase and kaolinite show an antithetic relationship, suggesting that the breakdown of feldspar results in formation of clay. There are minor amounts of goethite and/or hematite. There is no clear separation of erosional versus depositional colluvial material in terms of XRD mineralogy. The late-stage granitoid sample (GSWA No.138475) has lower quartz (46%) than the early-stage granitoids, and higher plagioclase (30%), with broadly similar kaolinite and K-feldspar contents. The sample contains 5% muscovite. The higher plagioclase/quartz ratio and presence of muscovite is consistent with known compositional differences between early- and late-stage granitoids.

All five samples from the Morrissey Metamorphic Suite are stream sediments, covering both the erosional and depositional colluvial regimes. Two of the three erosional regime samples have similar K-feldspar contents to depositional colluvial regime samples, and all samples have similar goethite concentrations. There is an antithetic relationship between quartz and plagioclase contents for the erosional versus depositional colluvial regime samples; the latter have higher quartz and lower feldspar than the former, suggesting that downslope weathering may result in the breakdown of feldspar, with a concomitant increase in quartz.

Bangemall Group sandplain sample (138120) is dominated by quartz (76%) which is consistent with eolian input. Two other Bangemall Group samples, DC1 (138145) and E4s (138427), are similar in terms of quartz, plagioclase, kaolinite, K-feldspar, and goethite contents, but the effects of downslope weathering are seen in the higher hematite and calcite contents of the depositional colluvial regime sample. Sheetwash sample 138427 has K<sub>2</sub>O, Na<sub>2</sub>O, and CaO contents indicative of feldspar, but no feldspar was detected by XRD. One possibility is that these components are incorporated in the clay mineral palygorskite ((Mg,Al)<sub>2</sub>Si<sub>4</sub>O<sub>10</sub>(OH).4H<sub>2</sub>O).

Stream sediment 138881 from regolith overlying the Carnarvon Basin is quite different from other samples analysed by XRD in that it contains little feldspar or the breakdown products of feldspar (i.e. clays), or Fe-rich weathering products, and has a high proportion of calcite (26%).

## Quality control

Quality control is the mechanism to monitor variability in sampling and geochemical analysis, to ensure that results reflect genuine geochemical variation. Within set limits, reproducible results should normally be obtainable from the same sample site and repeat analysis of the same sample, except that variability will inevitably increase close to the detection limit. Four main quality-control procedures were used in the analysis of the MOUNT PHILLIPS regolith samples:

- Analysis of duplicate samples from the same site
- Analysis of GSWA reference standards
- Analysis of international and laboratory reference standards
- Repeat analysis at a second and third laboratory for samples with anomalously high concentrations.

## Analysis of duplicate samples from the same sample site

Duplicate analytical samples were collected at 23 sites, corresponding to about one duplicate for every 50 samples collected. These samples were used to assess within-site variability. Each duplicate was assigned a GSWA number and submitted separately. Duplicate

Table 2. XRD mineralogy of regolith samples from MOUNT PHILLIPS

GSWA No.	Unit	Medium	Regolith– Landform	Quartz	Plagioclase	Kaolinite	K-feldspar	Goethite	Hematite	Calcite	Anatase	Palygorskite	Muscovite	Total
138088	Early granite	Stream	DC2g	65	19	8	7	1	–	–	–	–	–	100
138160	Early granite	Stream	DC3h	68	3	10	9	–	6	–	–	–	–	96
138733	Early granite	Stream	E4g	64	8	15	6	5	–	–	–	–	–	98
138475	Late granite	Stream	E4g	46	30	6	10	–	2	–	–	–	5	99
138540	Morrissey MS	Stream	DC1	72	4	3	18	1	–	–	–	–	–	98
138633	Morrissey MS	Stream	DC2h	73	3	5	8	5	–	3	–	–	–	97
138724	Morrissey MS	Stream	E2m	41	24	5	27	2	–	–	–	–	–	99
138727	Morrissey MS	Stream	E2m	62	9	4	22	2	–	–	–	–	–	99
138848	Morrissey MS	Stream	E4m	49	28	3	17	2	–	–	–	–	2	101
138120	Bangemall	Soil	D9	76	1	9	8	–	3	0	–	–	–	97
138145	Bangemall	Stream	DC1	26	1	19	3	20	16	13	1	–	–	99
138427	Bangemall	Sheetwash	E4s	21	3	17	6	29	–	–	1	23	–	100
138881	Carnarvon	Stream	E2s	62	–	4	2	5	–	26	–	–	–	99

**Table 3. Detection limits and number of samples below detection**

Element	Detection <sup>(a)</sup>	n <DL
SiO <sub>2</sub>	0.01	0
TiO <sub>2</sub>	0.01	0
Al <sub>2</sub> O <sub>3</sub>	0.01	0
Fe <sub>2</sub> O <sub>3</sub>	0.01	0
MnO	0.01	17
MgO	0.01	121
CaO	0.01	26
Na <sub>2</sub> O	0.01	24
K <sub>2</sub> O	0.01	1
P <sub>2</sub> O <sub>5</sub>	0.01	130
LOI	0.01	4
Ag	0.05	774
As	0.5	71
Au	1	919
Ba	5	0
Be	0.2	386
Bi	0.1	253
Cd	0.1	384
Ce	0.05	0
Cl	50	676
Co	2	443
Cr	2	122
Cu	2	114
F	100	371
Ga	0.05	0
In	0.05	842
La	0.05	0
Li	0.5	7
Mo	0.2	5
Nb	0.5	0
Ni	2	120
Pb	0.2	0
Pd	1	971
Pt	5	1 035
Rb	0.02	0
S	0.01	891
Sb	0.5	859
Sc	0.5	14
Se	0.5	706
Sn	0.1	0
Sr	0.1	0
Ta	2	996
Th	0.02	0
U	0.02	0
V	2	0
W	0.1	1
Y	2	20
Zn	2	26
Zr	5	0

NOTE:

(a) Oxides, LOI and S as %

Elements as ppm (except Au, Pd and Pt as ppb)

element concentrations greater than ten times detection level were compared using percent relative difference (i.e.  $(1 - (\text{lower duplicate} / \text{higher duplicate})) \times 100$ ). Duplicates with percent relative differences  $\geq 30\%$  are detailed in Table 4.

Elements that show significant differences in most batches include Ba, Ce and La, which are probably held in resistate phases that are resistant to dissolution. Overall,

**Table 4. Significant differences in sample-site duplicates**

Batch	GSWA	Element	Sample value <sup>(a)</sup>	Duplicate value <sup>(a)</sup>	% relative difference
Batch 1	138109	Mo	4.1	7.8	47
		Ce	77	45	42
		Cl	100	2 600	96
	138440	La	39	27	31
		Th	18	12	33
		Sr	55	38	31
Batch 2	138160	Zn	78	123	37
		Ce	35	12	66
		Ga	39	20	48
		La	14	6	57
		Rb	64	33	48
		Sr	26	13	50
	138240	Th	5.6	2.5	55
		Ag	0	1.51	100
		Ce	53	30	43
		Li	21	14	33
		Rb	52	35	33
		Sc	9.2	5	46
		Th	11	6.6	40
		U	3	1.85	38
		no significant difference in duplicates			
Batch 4	137974 138646	La	9.6	3.9	59
		Ce	71	141	50
		Th	22	42	48
Batch 5	127751	TiO <sub>2</sub> (%)	0.22	0.40	45
		Fe <sub>2</sub> O <sub>3</sub> (%)	2.86	4.26	33
		CaO (%)	0.94	1.38	32
		Ba	651	1 190	45
		Ga	19	27	30
		Nb	3.4	11	69
	138540 128846	Sr	63	102	38
		Ce	18	12	33
		Ce	16	31	48
		Ga	16	26	38
		La	12	20	40

NOTE: (a) values in ppm except where noted otherwise

the field duplicate pairs were geochemically consistent, supporting the reproducibility of the sampling process.

## Analysis of GSWA reference standards

To monitor analytical precision and accuracy, twenty GSWA reference standards were submitted as unknowns (average 4 standards spread throughout batch) in conjunction with the regolith samples. These include, IQC-47 (Laterite), GRA-2 (Granite 2), IQC-45 (Gossan) and IQC-41 (vein quartz). Accuracy cannot be properly determined, as there are no certified values for these standards, although data for MOUNT PHILLIPS have been compared to values obtained from previous GSWA geochemical mapping projects for elements found at greater than ten times detection level. A number of GSWA standards showed variation for certain elements. Standards with percent relative differences  $\geq 30\%$  are detailed in Table 5.

Elements that are commonly found in insoluble phases or near detection level tend to show the greatest relative differences, although consensus values may

Table 5. Significant differences between GSWA standards and consensus values

Batch	Standard	Element	Consensus value <sup>(a)</sup>	Standard 1 <sup>(a)</sup> <sup>(b)</sup>	% relative difference	Standard 2 <sup>(a)</sup> <sup>(b)</sup>	% relative difference	Standard 3 <sup>(a)</sup> <sup>(b)</sup>	% relative difference
Batch 1	IQC-47	Ga	1.6	9.3	83	8.2	80	–	–
		Cu	19	8	58	7	63	–	–
	GRA-2	As	1	21	95	–	–	–	–
		Ce	150	56	63	–	–	–	–
		La	70	123	43	–	–	–	–
		Sr	90	54	40	–	–	–	–
	IQC-41	Sb	215	319	33	–	–	–	–
Batch 2	GRA-2	Ce	150	28	81	–	–	–	–
		La	70	19	73	–	–	–	–
		Li	9	1.7	81	–	–	–	–
		Pb	37	19	49	–	–	–	–
		Rb	220	106	52	–	–	–	–
		Sr	90	46	49	–	–	–	–
		Th	60	8.6	86	–	–	–	–
		U	10	2.3	77	–	–	–	–
		Zr	183	74	60	–	–	–	–
	IQC-41	Au (ppb)	550	828	34	–	–	–	–
		Sb	215	310	31	–	–	–	–
		Cr	490	186	62	–	–	–	–
		Cu	35	8	77	–	–	–	–
		Rb	32	11	66	–	–	–	–
	IQC-45	Au (ppb)	33	23	30	58	43	–	–
Batch 3	GRA-2	Ga	17	31	45	30	43	–	–
		Rb	220	108	51	128	42	–	–
Batch 4	IQC-47	MgO (%)	0.32	0.14	56	–	–	–	–
		Cr	1 298	1 990	35	–	–	–	–
		Cu	19	8	58	–	–	–	–
	IQC-45	MgO (%)	0.12	0.05	58	0	100	0	100
		K <sub>2</sub> O (%)	0.31	0.08	74	0.07	77	0.27	13
		Co	17	9	47	9	47	9	47
		Rb	16	9.4	41	7.9	51	8.3	51
Batch 5	IQC-47	Cr	1 298	2 009	35	–	–	–	–
	GRA-2	Ce	150	89	41	–	–	–	–
		Rb	220	115	48	–	–	–	–
	IQC-41	Sn	3.5	0.8	77	–	–	–	–

## NOTES:

(a) values in ppm except where noted otherwise

(b) separate standards (of the same type) may have been submitted up to 3 times in a batch (Standard 1, Standard 2, Standard 3)

(–) denotes no analysis

need revision. This has been addressed in Bradley et al. (1997, appendix 5), which includes revised average values for GSWA standards.

## Inclusion of Amdel reference standards and repeat analysis

Amdel reported analytical data for in-house reference standards, blanks and repeat analyses which were regularly spaced throughout each of the five batches submitted, and on average make up 10% of samples analysed. Furthermore, repeat analysis was carried out on all samples with elevated Au, Pd, and Pt.

The reference standards used in the analysis of major elements include an Amdel standard (600) and three international reference materials (SY3, SARM-1, and MRG-1). During analysis of a variety of trace elements, three Amdel in-house standards were analysed (IC7A, AMD1B, and BM21). Standards and repeat analyses

(>10 × D.L.) were compared with their consensus values using a measure of percent relative difference.

Some variation within batches was identified and is outlined below:

**Batch 1.** Beryllium values were low, but consistent, in both the 600 and SARM-1 standards. Tin, W and Zr were slightly low in BM21, and W was lower in IC7A. Spurious results for one analysis of BM21 resulted in re-analysis of one group of samples (138441–138451). Vanadium tended to be consistently high in the AMD1B standard. The most significant differences in the repeat analyses were Na<sub>2</sub>O in sample 138326 (0.36% vs 0.06%) and Mo in sample 138110 (7.8 ppm vs 16 ppm).

**Batch 2.** For a number of elements there were significant differences between consensus values and those reported for the analysed standards. For this reason, reanalysis of the entire batch was undertaken, resulting in an improved level of accuracy. The most significant percentage difference in the new batch of data was in

the Rb concentration for sample 138456 (66 ppm vs 118 ppm).

*Batch 3.* Beryllium values were marginally low in both the 600 and SARM-1 standards and MgO was higher in SARM-1. There was poor duplication for sample 138754 in terms of Ba (537 ppm vs 1106 ppm). Chromium was marginally low in the IC7A standard and AMD1B had elevated U compared with consensus values.

*Batch 4.* Beryllium values were marginally low in both the 600 and SARM-1 standards and MgO was higher in SARM-1. Furthermore, Na<sub>2</sub>O and Ba tended to be slightly low in the MRG-1 analysis. The repeat analysis of sample 138859 showed some differences in TiO<sub>2</sub> (0.08% vs 0.18%), Fe<sub>2</sub>O<sub>3</sub> (1.62% vs 5.07%), CaO (0.52% vs 0.12%), Na<sub>2</sub>O (0.94% vs 0.34%), K<sub>2</sub>O (3.04% vs 1.46%) and Ba (685 ppm vs 255 ppm). The repeat of sample 138033 displayed differences between K<sub>2</sub>O (4.6% vs 1.82%) and Ba (1124 ppm vs 205 ppm) and sample 138863 also displayed some differences, particularly Al<sub>2</sub>O<sub>3</sub> (9.08% vs 4.32%).

*Batch 5.* Beryllium was generally low in both the 600 and SARM-1 standards, and Nb and W were lower in standard BM21. Tungsten was also low in IC7A along with Rb, Cr and Zr, but V was higher than usual in AMD1B. The repeat of sample 128769 showed some difference in Ba (1289 ppm vs 536 ppm) and 138784 was significantly different in Al<sub>2</sub>O<sub>3</sub> (2.66% vs 10.68%), Na<sub>2</sub>O (0.38% vs 1.82%) and K<sub>2</sub>O (0.75% vs 1.96%).

### Repeat analysis of selected samples at other laboratories

Thirty-five samples were submitted to Genalysis Laboratory Services, Maddington, Perth, for reanalysis of the same components, excluding F and Cl. Most of the thirty-five samples selected contained anomalous element concentrations as determined by Amdel Laboratories Ltd. Comparisons were made between analytical results of the two laboratories, using percent relative difference.

Fourteen samples that showed significant inter-laboratory variation were submitted to Ultra Trace Pty Ltd, Canning Vale, for further checking. In addition some additional samples and a GSWA standard were also analysed. Eight other anomalous samples were also submitted to Genalysis for cross checking of Au, Pt, Pd, Cl and F concentrations. From this analytical series, values were chosen for incorporation in the digital datafile (PHILCHEM.CSV), selecting either the more conservative value or that with consensus between two or more laboratories.

### Groupings of chemical components

For the purpose of discussion, the 49 major-element oxides and trace elements (plus LOI) have been divided into seven groups, based on the scheme of Evans (1993):

1. Major-element oxides  
SiO<sub>2</sub>, TiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>, MnO, MgO, CaO, Na<sub>2</sub>O, K<sub>2</sub>O, P<sub>2</sub>O<sub>5</sub>, LOI.
2. Anions  
Cl, F, S.
3. Precious metals  
Au, Ag, Pt, Pd.
4. Base metals  
Cu, Pb, Zn, Sn.
5. Ferroalloy metals  
Ni, Cr, Mo, W, V, Co.
6. Fissionable metals  
U, Th
7. Minor metals and non-metals  
As, Ba, Be, Bi, Cd, Ce, Ga, In, La, Li, Nb, Rb, Sb, Sc, Se, Sr, Ta, Y, Zr.

## Element-distribution maps

The concentration of various components is shown as a series of spot-concentration maps (Figs 4–51). These maps are ordered in terms of major-element oxides (including LOI), then trace elements in alphabetical order, although elements are discussed in terms of their groupings outlined above. Silica is not presented as values are consistently high and yield little information. On these maps, star symbols are used when the element concentration is greater than 2.5 standard deviations above the mean. Thus, stars correspond to values that lie either at the end of, or off, a normal distribution curve.

Elements are also discussed in terms of their respective simplified geological unit (Fig. 2) and regolith unit (Plate 1).

### Major-element oxides

Two of the highest titanium oxide values are in samples 138417 (5.45%) and 138418 (4.49%), from hardpan (DC3h) adjacent to Koorabooka Creek, 35 km northeast of Cobra Station, overlying the Bangemall Group (Fig. 4). High TiO<sub>2</sub> values are also found in regolith along the Bangemall Anticline, in particular sample 138435 (4.56%) from 8 km east of Cobra Station. Regolith over outliers of the Bangemall Group, the Ti Tree Syncline and Bore Paddock Hills, also contains slightly higher TiO<sub>2</sub> concentrations. The lowest values in the Bangemall Group are recorded in an area of sandplain 15 km southwest of Mount Augustus Station. Elsewhere, TiO<sub>2</sub> values are generally low over Proterozoic granitoids and metamorphic rocks, and Phanerozoic sedimentary rocks of the Carnarvon Basin.

The aluminium oxide content of regolith is generally consistent over the whole map sheet. (Fig. 5). Lower values are associated with sandplain southwest of Mount Augustus Station and colluvium derived from the

sedimentary rocks of the Carnarvon Basin, southwest of Eudamullah Station. The maximum  $\text{Al}_2\text{O}_3$  value is in an alluvial sample (DA5, 138315: 16.43%) located 14 km northwest of Mount Augustus Station. In this area, other samples with high  $\text{Al}_2\text{O}_3$  include two hardpan samples 138311 (14.4%) and sample 138335 (15.81%). Slightly higher  $\text{Al}_2\text{O}_3$  values are found in regolith over late-stage granitoids, particularly the Minnie Creek Batholith, which extends from the northwest corner of the map sheet through to the vicinity of Pink Hills. Erosional granitoid sample 138279 (E4g), 3 km northwest of Morrissey Hill, also contains high  $\text{Al}_2\text{O}_3$  (14.49%), possibly due to the abundance of micaceous fragments at the locality.

The Bangemall Group is well defined by ferric oxide in regolith (Fig. 6). The maximum value is in sample 138142 (51.22%) from 20 km north-northeast of Cobra Station. Areas of particularly high  $\text{Fe}_2\text{O}_3$  follow the trend of the Bangemall Anticline; the elevated values are consistent with an extensive area of mafic sills. As with  $\text{TiO}_2$ ,  $\text{Fe}_2\text{O}_3$  is also relatively high in regolith proximal to the outliers of the Bangemall Group. Elsewhere,  $\text{Fe}_2\text{O}_3$  values are generally low in regolith over the early- and late-stage granitoids, Morrissey Metamorphic Suite and Carnarvon Basin.

A group of high manganese oxide values is found in regolith over the Bangemall Group (Fig. 7). The highest MnO value of 1.14% is in alluvial sample 138130 (DA5) 20 km northwest of Mount Augustus Station. Colluvium derived from dolomite, shale, chert and dolerite sills, in the northeast corner of the map sheet, also carry relatively high MnO. Low values, approaching the level of detection (0.01%), are found in several areas throughout the sheet, including the large area of sandplain southwest of Mount Augustus Station, and in regolith over sedimentary rocks of the Carnarvon Basin south-southeast of the Coondoo Outcamp.

The highest value for magnesium oxide in regolith is recorded in calcrete sample 138337 (DA8 : 4.19%), 5 km northwest of Mount Augustus Station (Fig. 8). This sample also has high CaO and LOI, consistent with the occurrence of calcrete. Other elevated MgO values are found in regolith over the Bangemall Group, in both broad alluvial channels and hardpan. Values close to detection (0.01%) are recorded in a number of areas, including the broad alluvial channels north of Yinnetharra Station, regolith overlying the Carnarvon Basin, and over early-stage granitoids northeast of Eudamullah Station. The distal colluvium and hardpan units overlying late-stage granitoid, immediately north of Pink Hills, also have relatively low MgO.

Sample 138337, from calcrete 5 km northwest of Mount Augustus Station, has the highest calcium oxide content in regolith (34.17%). Other calcrete samples north of the Bangemall Anticline, along the Lyons River, also contain elevated CaO. Sample 138449 (7.98%, CaO), 4 km southeast of Cobra Station, is in a narrow active drainage in a high-relief area of the Bangemall anticline. This sample, although clearly calcrete (DA8) from its chemistry and field description, has been represented as erosional mafic regolith (E2v) in the datafile (PHILCHEM.CSV). This discrepancy is an example of

scale difference as described in the **Regolith materials mapping** section, where field observations are sometimes more meaningful than map-derived regolith classifications. Within the Carnarvon Basin, in the vicinity of Coondoo and Tallangatta outcamps, a number of high CaO values are recorded in the erosional and proximal colluvial units of the calcareous Callytharra Formation.

Samples with high sodium oxide (Fig. 10) are found in a number of areas. Values over the late-stage granitoids are consistently high, whereas a variety of concentrations are found in regolith over the Morrissey Metamorphic Suite. Within the Morrissey Metamorphic Suite, higher values are found adjacent to a series of northwesterly trending faults and shears between the Arthur River Outcamp and Mount Steere, with the highest value of 3.70% found 25 km southeast of Chalby Chalby (138574). Regolith overlying the Carnarvon Basin, particularly south of Coondoo Outcamp, also has higher  $\text{Na}_2\text{O}$ , whereas values are low over the Bangemall Group and, to a lesser degree, over early-stage granitoids.

Potassium oxide values are relatively high in regolith over early-stage granitoids (Fig. 11). High values are also found in late-stage granitoids adjacent to a series of converging shear zones, 13 km south of Seventeen Mile Outstation, and the area includes the maximum  $\text{K}_2\text{O}$  value (138048: 6.94%)(Fig. 57). Values are generally low in regolith over the Bangemall Group rocks, and slightly higher over the Carnarvon Basin and Morrissey Metamorphic Suite.

The Bangemall Group is highlighted by elevated phosphorus pentoxide values in regolith, including the highest value of 0.31% in alluvial sample 138424 (DA5). Phosphorus pentoxide shows a similar distribution to  $\text{Fe}_2\text{O}_3$  and  $\text{TiO}_2$ , exceptions being lower levels (largely below detection) over parts of the late-stage granitoid and Morrissey Metamorphic Suite (Fig. 12).

The maximum loss on ignition (LOI) value of 31.00% is found in a calcrete sample (138337), 5 km northwest of Mount Augustus Station (Fig. 13), in the Bangemall Group. The majority of elevated LOI values are found in calcretes (DA8) and wide alluvial plains (DA5), with some other high values associated with calcarenites of the Carnarvon Basin.

## Anions

Regolith sample 138536, north of Yinnetharra Station, has the highest chlorine content (3900 ppm). This sample comprises mixed granitic colluvium and alluvial overbank material of the Gascoyne River (Fig. 22). Other elevated Cl values are found in broad alluvial channels (DA5) and hardpan (DC3h) such as 25 km northeast of Cobra Station (138431: 3400 ppm, DC3h), and along the Lyons River 25 km north of Eudamullah Station (137954: 3400 ppm, DA5). Other non-alluvial samples with high Cl content include sample 138007 (12 km south of Eudamullah Station) and a group of samples with high Cl and  $\text{K}_2\text{O}$ , southwest of Seventeen Mile Outstation. This latter group is coincident with an area of converging shear zones.

Elevated fluorine values are scattered throughout MOUNT PHILLIPS, principally in alluvial and hardpan units overlying the Bangemall Group, and in regolith over early-stage granitoids between Yinnetharra Station and Arthur River Outcamp (Fig. 26). The highest F value of 2700 ppm is found in a calcrete sample (138337), 5 km northwest of Mount Augustus Station, which also has high MgO, CaO and LOI. Values are generally low in regolith over late-stage granitoids, the Morrissey Metamorphic Suite, and in particular the Carnarvon Basin.

The maximum sulfur value of 0.49% is found in sample 138150, from calcrete 10 km north-northwest of Cobra Station (Fig. 38). Most other high S samples are confined to alluvial and hardpan samples overlying the Bangemall Group; however, colluvial sample 138207 overlies late-stage granitoid 22 km southwest of Mount Isabella.

## Precious metals

There are few regolith samples with elevated gold concentrations on MOUNT PHILLIPS (Fig. 16). The maximum value of 6 ppb is in colluvial sample 138173 (DC1f), 10 km southwest of Cobra Station, which contains highly magnetic ferruginous granules, granitic saprolite and sandstone fragments, representing a mixed granitoid/Bangemall Group provenance. Several other regolith samples have Au concentrations up to 5 ppb, such as in the wide area of alluvium (DA5) and hardpan (DC3h) overlying the Bangemall Group north-northwest of Mount Augustus Station. In the vicinity of the Bangemall Anticline, a number of colluvial samples (DC1) have Au values of 3 and 4 ppb. Sample 138472 from the Bassit Belt (Williams et al., 1983), 25 km southwest of Cobra Station, has 4 ppb Au, and is in mixed Bangemall Group, Mount James Formation and late-stage granitoid colluvium (DC1). Other scattered values between 1 and 3 ppb occur in regolith overlying the Morrissey Metamorphic Suite, early-stage granitoids, and Carnarvon Basin.

Silver values on MOUNT PHILLIPS are generally low (Fig. 14). A group of higher values in the northwest part of the Bangemall Anticline, contains the maximum value of 0.81 ppm (138362; 16 km southeast of Gifford Creek Station). Some elevated values are also found in regolith overlying other parts of the Bangemall Group, early- and late-stage granitoids, the Morrissey Metamorphic Suite, and Carnarvon Basin.

Palladium values up to 5 ppb are found in scattered regolith samples on MOUNT PHILLIPS (Fig. 35); in particular, over the Morrissey Metamorphic Suite southeast of Eudamullah Station, and over early- and late-stage granitoids between Eudamullah Station and Seventeen Mile Outstation. A number of values up to 3 ppb occur within the wide alluvial plain and hardpan overlying the Bangemall Group.

Platinum concentrations in regolith are generally low, with most samples less than the 5 ppb detection level. Alluvial sample 138130 (DA5), 20 km northwest of Mount Augustus Station, contains the maximum Pt concentration of 6 ppb (Fig. 36).

## Base metals

The Bangemall Group is well defined by elevated copper concentrations in regolith, including the highest value of 134 ppm in a hardpan sample (138415) adjacent to Koorabooka Creek, 22 km northwest of Peedawarra Bluff. Samples are generally high in both the erosional and depositional units along the Bangemall Anticline, and over Bangemall Group rocks south of Mount Isabella (Fig. 25). Moderately high Cu values are also found in regolith near outcrops of interbedded mafic and sedimentary rocks, north and south of Peedawarra Bluff and north of Koorabooka Creek. Copper values are generally low across the remainder of the sheet, exceptions being slightly higher values over the Mount James Formation.

Lead values are evenly distributed in regolith over most geological units, except where they are noticeably lower over late-stage granitoids (Fig. 34). The highest value, 86 ppm, is in sample 138620 from 12 km northeast of Spring Camp Outstation. It is one of a number of high Pb samples scattered throughout the Morrissey Metamorphic Suite. Other elevated samples include 127731 and 138698, from 15 km east-southeast of Coondoo Outcamp; the latter sample also contains high levels of Ce, La, Th, U and Y. Sample 138325, from an area of broad alluvium and calcrete overlying the Bangemall Group 4 km southeast of Mount Augustus Station, has high Pb and Sn concentrations.

Rocks of the Bangemall Group generally contain elevated regolith zinc concentrations, in erosional, colluvial, alluvial and hardpan units. The highest Zn value of 380 ppm is in sample 138318 from an outcrop of mixed shale, chert and dolerite, 10 km north of Mount Augustus Station (Fig. 50). Other samples with elevated Zn levels were taken from colluvium derived from outcropping Bangemall Group rocks. Alluvial sample 138234 (Koorabooka Creek, 20 km northeast of Cobra Station) has high Zn, TiO<sub>2</sub>, P<sub>2</sub>O<sub>5</sub>, Cd, Cu, Ni and U. Zinc levels are generally low over other geological units, although erosional late-stage granitoid sample 138729 (E4g), 10 km north of Mount James Station, is marginally higher in Zn and Sn.

Tin is evenly distributed at low levels over MOUNT PHILLIPS (Fig. 42), but with slightly lower concentrations in regolith over the Carnarvon Basin south of Coondoo Outcamp. The highest Sn value is found in regolith over late-stage granitoids 30 km east-southeast of Eudamullah Station (128800: 7.3 ppm). This sample also has higher levels of Ce and Th. Sample 138285, also over late-stage granitoid, 6 km northeast of Morrissey Hill, has elevated Sn, W and Rb concentrations. The highest Sn value in regolith over the Bangemall Group is in calcrete sample 138325, 4 km southeast of Mount Augustus Station, which also contains elevated levels of Pb.

## Ferroalloy metals

High nickel values are most apparent in regolith overlying the Bangemall Group (Fig. 33), particularly along Koorabooka Creek, in a series of broad alluvium and

hardpan samples. The maximum value is in hardpan sample 138415 (101 ppm: DC3h), 22 km northwest of Peedawarra Bluff, near an outcrop of mixed dolerite, chert and dolomitic shale. This sample also contains elevated Cu. Other high Ni samples along Koorabooka Creek also contain raised concentrations of  $\text{TiO}_2$ ,  $\text{P}_2\text{O}_5$ , Cd, Cu, U and Zn. High Ni values in regolith also follow the trend of the Bangemall Anticline, and the outliers of the Bangemall Group. Over the remainder of the map sheet Ni concentrations are low.

Low chromium values are found in regolith overlying early- and late-stage granitoids (Fig. 24). Higher Cr values are observed in regolith over the Morrissey Metamorphic Suite and Carnarvon Basin, but in general these are still an order of magnitude less than Cr recorded in regolith overlying the Bangemall Group. The highest value on the map sheet (546 ppm: 138109) is from 13 km south of Mount Isabella, in colluvium derived from the Bangemall Group. This sample also has high levels of  $\text{Fe}_2\text{O}_3$ , As, In, Sb, Sc and V. Similarly, colluvial sample 138142 (538 ppm Cr), derived from the Bangemall Group rocks 20 km north-northeast of Cobra Station, also contains the same elevated element association.

Molybdenum values are highest over the Bangemall Group, with a maximum value of 16 ppm from sample 138318 (13 km southwest of Peedawarra Bluff) and 138422 (32 km northeast of Cobra Station; Fig. 31). Both samples are adjacent to outcrops of interbedded dolerite, chert, shale and dolomitic shale, and carry raised levels of As, Cd, Sb and Zn. High Mo values are also found in areas of broad alluvium and hardpan. Molybdenum values are low over all other units.

Higher tungsten values are found in regolith in a zone extending from Thirty-One River to Mount James Station, adjacent to the Ti Tree Syncline (outlier of the Bangemall Group). The highest value of 12 ppm, in sample 138529, is found in an erosional unit of the Morrissey Metamorphic Suite, 13 km northeast of Camel Hill (Fig. 48). To the southeast of Camel Hill, samples 127775 and 138533 have high W; the former sample also contains high Bi and U, and 138533 has high Be and Ta. Sample 138285, in late-stage granitoids 6 km northeast of Morrissey Hill, has elevated W, Rb and Sn.

The Bangemall Group generally contains elevated levels of vanadium in regolith (Fig. 47). Many samples with high V follow the trend of the Bangemall Anticline and other outcrops of Bangemall Group rocks, and have correspondingly raised levels of  $\text{Fe}_2\text{O}_3$ , As, Cr, Nb and Sc. The highest V value on the map sheet is in sample 138142 (1213 ppm), 20 km north-northeast of Cobra Station. Vanadium concentrations are also high in the alluvium and hardpan overlying the Bangemall Group, but V concentrations are low in areas of sandplain southwest of Mount Augustus Station. Over other geological units V levels are low, an exception being regolith over the Morrissey Metamorphic Suite 4 km east-southeast of Camel Hill, which is receiving Bangemall Group detritus from the Ti Tree Syncline (samples 138841 and 138842).

There is a broad range of cobalt values on MOUNT PHILLIPS (Fig. 23). Values are generally low in regolith over

early-stage granitoids and the Carnarvon Basin and marginally higher over the Morrissey Metamorphic Suite and late-stage granitoids. The outliers of the Bangemall Group are well defined by elevated Co values, however the areas of hardpan and sandplain northwest and southwest of Mount Augustus have Co values close to the detection level (2 ppm). Alluvium sample 138130 (DA5), 20 km northwest of Mount Augustus Station, has the highest Co value on the sheet (77 ppm) as well as high MnO, Ba, Pt, S and Y. A number of DA5 and DC1 samples north of the Bangemall Anticline also have high Co values with mixtures of elevated  $\text{TiO}_2$ , LOI and Sc.

## Fissionable metals

Uranium levels are similar over most of MOUNT PHILLIPS, except that background values tend to be marginally lower in regolith over late-stage granitoids and the Carnarvon Basin and marginally higher in the Bangemall Group (Fig. 46). The maximum value of 13 ppm is from sample 127731, 15 km east-southeast of Coondoo Outcamp, and nearby samples 138698 and 138879 also contain elevated U. These samples are close to the lacustrine limestone of the Nadarra Formation (Williams et al., 1983), in valley fill of the Morrissey Metamorphic Suite, and together contain elevated levels of Ce, La, Pb, Th and Y. Other high U samples are found along the margin of the Morrissey Metamorphic Suite and Carnarvon Basin.

Thorium values in the south of the sheet, particularly in the southeast and southwest corners, tend to be higher than values farther to the north (Fig. 45). The highest value of 111 ppm (138698), 15 km east-southeast of Coondoo Outcamp, is in a group of high Th samples close to the Nadarra Formation limestone which overlies the Morrissey Metamorphic Suite. Some of these samples also contain elevated Ce, La, Pb, U, Y and Zr. Alluvial sample 138805 (93 ppm), 15 km southeast of Mount James Station, has elevated Ce and La. Other samples in the area, overlying mixed rocks of the Bangemall Group, late-stage granitoid and Morrissey Metamorphic Suite, contain high Th. The northernmost elevated Th value is in sample 128800, from 30 km east-southeast of Eudamullah Station on the boundary between early-stage granitoids and the Morrissey Metamorphic Suite (refer also to Fig. 57). This sample also has high concentrations of Ce and Sn.

## Minor metals and non-metals

High arsenic values are found mainly in regolith over the Bangemall Group (Fig. 15). The maximum value of 87 ppm is in sample 138142, from 20 km north-northeast of Cobra Station. The highest values are found in colluvium (DC1) close to outcrop of Bangemall Group rocks, and are in all cases associated with high concentrations of other components including  $\text{Fe}_2\text{O}_3$ , Cr, In, Mo, Sb, Sc, Se, V and Zn. Elsewhere on the sheet As values are low, except in regolith over the Carnarvon Basin where a number of samples with higher As are found, particularly west of a line between the Coondoo and Tallangatta Outcamps.

Barium values are lower over most of the Bangemall Group and Morrissey Metamorphic Suite, and higher in regolith over granitoids and the Carnarvon Basin (Fig. 17). South and west of Yinnetharra Station is a zone of high Ba samples over early-stage granitoid, many of which have elevated Ga and Sr contents. The maximum Ba value on the sheet is associated with late-stage granitoid 13 km south of Mount James Station (138803: 2091 ppm), in a sample that also has high levels of F, Ga and Zr. The highest value in the Carnarvon Basin (sample 138894: 1836 ppm) also contains elevated Li. Alluvial sample 138130, 20 km northwest of Mount Augustus Station, has high MnO, Ba, Co, Pt, S and Y.

Beryllium concentrations are highly variable (Fig. 18). Noticeable areas of low Be include regolith over the early-stage granitoids centred on Yinnetharra Station, sandplain southwest of Mount Augustus, the Bangemall Anticline between Gifford Creek Station and Cobra Station and late-stage granitoids south of Minnie Creek Station. Hardpan, consolidated colluvium and alluvial units over the Bangemall Group have modest levels of Be, as does regolith overlying the Mount James Formation and Morrissey Metamorphic Suite. In particular, there is a group of higher Be samples around Camel Hill (an area of known beryl occurrence), which includes the highest regolith value of 6.0 ppm (138840). This area also includes samples with higher Ta and W.

Bismuth reaches a maximum 6.0 ppm in sample 138535, over early-stage granitoid 10 km southeast of Camel Hill (Fig. 19). This is one of a number of higher Bi, Nb and Ta samples, in a zone south of the Ti Tree Syncline between Thirty-One River and Mount James Station. High Bi sample 127775, in consolidated colluvium (DC2h) 18 km southeast of Camel Hill, also contains elevated U and W. The Bangemall Group is characterized by moderate Bi values in regolith, whereas over late-stage granitoid, concentrations are largely below detection.

Cadmium is highest in regolith over the Bangemall Group and reaches a maximum of 2.0 ppm in sample 138318, an erosional unit 10 km north of Mount Augustus Station (Fig. 20). Other samples with high Cd include hardpan northwest of Mount Augustus Station and a line of alluvial samples (DA5) along Koorabooka Creek northeast of Cobra Station. The Bangemall Anticline is defined by moderate Cd values as is the area of Bangemall Group rocks south of Mount Isabella. In the Bangemall Group, samples with high Cd also have elevated  $\text{TiO}_2$ ,  $\text{P}_2\text{O}_5$ , As, Cu, In, Mo, Se, U and Zn. The Mount James Formation is also characterized by moderate Cd values, but elsewhere values are generally low.

Cerium and lanthanum are highly correlated on MOUNT PHILLIPS (Spearman's  $R = 0.91$ ) and show a very similar spatial distribution (Figs 21 and 29). Higher values are usually found in regolith over the Bangemall Group, whereas lower values are found over late-stage granitoids. The highest La content of 333 ppm (127735) and the highest Ce concentration of 532 ppm (138698) are found close together in a group of high Ce and La samples overlying the Morrissey Metamorphic Suite and Nadarra Formation limestone, 15 km east-southeast of Coondoo Outcamp.

The maximum gallium value of 90 ppm is from sample 138803, adjacent to an outcrop of late-stage granitoid 14 km south of Mount James Station (Fig. 27). There are a number of high Ga samples overlying early-stage granitoid south and west of Yinnetharra Station, although the highest average concentration of gallium in regolith is overlying late-stage granitoids, particularly between Minnie Creek Station and Mount Phillips Station. Many samples also contain high Ba and Sr.

Although values are low, the Bangemall Group is clearly defined by indium in regolith (Fig. 28). Apart from the Bangemall Group most other values are below detection level, exceptions being samples 138855 and 138856 near the margin between the early-stage granitoids and the Morrissey Metamorphic Suite, 15 km east of Yinnetharra Station.

In the Carnarvon Basin, west of a line between Tallangatta and Coondoo Outcamps, lithium concentrations in regolith are relatively high (Fig. 30). Lithium reaches a maximum 38 ppm in sample 138894, 15 km northwest of Coondoo Outcamp. Average concentrations of Li are highest over the Bangemall Group and in particular the hardpan units, whereas sandplain southwest of Mount Augustus is relatively depleted. As for Bi, there is a northwesterly trending zone with elevated Li values north of Yinnetharra Station, between Thirty-One River and Mount James Station. This area includes sample 138279, 3 km northwest of Morrissey Hill, with high Li and  $\text{Al}_2\text{O}_3$  and which was collected in an area of conspicuous micaceous fragments (possibly lepidolite).

Niobium values are generally higher over the Bangemall Group, particularly along the Bangemall Anticline around Gifford Creek Station and Cobra Station (Fig. 32). Many samples with elevated Nb over the Bangemall Group have increased concentrations of other elements including  $\text{Fe}_2\text{O}_3$ ,  $\text{TiO}_2$ , Sc, Sr, V and Y. The highest Nb value on MOUNT PHILLIPS is from early-stage granitoid sample 138535 (55 ppm), 9 km southeast of Camel Hill, which also has high Bi and Ta concentrations. In the early-stage granitoids Nb values are generally higher southwest of Yinnetharra Station, similar to the pattern shown by Ba, F, Ga and Y.

Rubidium values are greater in regolith over granitoids (particularly early-stage granitoid), compared with other units (Fig. 37). However, the highest value on the sheet is from ferruginous colluvium derived from the Bangemall Group, 8 km north of Morrissey Hill (sample 138276: 251 ppm). Nearby, erosional regolith overlying late-stage granitoid (138285) has elevated concentrations of Rb, Sn and W. Regolith over late-stage granitoids south of Minnie Creek Station and rocks of the Bangemall Anticline have relatively lower concentrations of Rb.

Scandium concentrations are highest in regolith over the Bangemall Group and in particular around Gifford Creek Station and Cobra Station (Fig. 40). The highest value of 30 ppm is found in samples 138109 and 138373, which are both from proximal colluvial regolith (DC1) developed over Bangemall Group rocks 13 km southwest of Mount Isabella and 20 km southeast of Gifford Creek Station respectively. Many samples with elevated Sc also

have higher concentrations of Fe<sub>2</sub>O<sub>3</sub>, Ag, As, Co, Cr, In, Nb, Sb, Sc and V. Elsewhere on MOUNT PHILLIPS, Sc values are low.

Selenium (Fig. 41) and antimony (Fig. 39) concentrations on MOUNT PHILLIPS show a very similar spatial distribution. In the Bangemall Group, excluding the area of sandplain southwest of Mount Augustus, Se and Sb values are moderately high. The highest Se value of 5.7 ppm is from sample 138318, 13 km southwest of Peedawarra Bluff, whereas the highest Sb value is 12 ppm in sample 138422, 32 km northeast of Cobra Station. Both these samples are from colluvium (DC1) close to outcrops of interbedded dolomite, shale, chert and dolerite. Many samples with elevated Se and Sb have higher concentrations of P<sub>2</sub>O<sub>5</sub>, As, Cd, Cu, In, Mo and Zn. Elsewhere, Se and Sb values are largely below detection.

Strontium values show a pattern similar to that of Rb, particularly overlying early-stage granitoid west and south of Yinnetharra Station. This area includes the maximum value in regolith of 277 ppm (138760) (Fig. 43). Strontium values are also high in regolith over the late-stage granitoids between Minnie Creek Station and Mount Phillips Station, and over Bangemall Group rocks, between Gifford Creek Station and Cobra Station. Sample 138435, 9 km east-southeast of Cobra Station, has high Rb (257 ppm), TiO<sub>2</sub> and Nb. Strontium is noticeably depleted over the Mount James Formation and in the area of sandplain southwest of Mount Augustus Station.

Tantalum values are generally low (Fig. 44). The maximum value in regolith is in erosional sample 138862 (58 ppm), from 30 km south of Yinnetharra Station in the Morrissey Metamorphic Suite. A group of three anomalous (star) values occurs around Camel Hill, over early-stage granitoid. Bismuth, Be, Nb and W are also high in these samples. Isolated values above detection level include sample 127756 25 km southeast of Eudamullah Station, which is in the vicinity of a known Ta, Li and Sn prospect.

Yttrium concentrations are lowest over late-stage granitoids and highest over Bangemall Group rocks (Fig. 49). The highest value of 33 ppm is found in alluvium (138130: DA5) and hardpan (138417: DC3h), 20 km northwest of Mount Augustus Station and 35 km northeast of Cobra Station respectively. Other elevated Y samples include 138631, 10 km east-northeast of Spring Camp Outstation (in an outlier of the Bangemall Group) and sample 138698, 16 km east-southeast of Coondoo Outcamp. The latter sample is from lacustrine limestone overlying the Morrissey Metamorphic Suite and also contains higher concentrations of Ce, La, Pb, Th and U. Yttrium concentrations are moderately high in early-stage granitoid south and west of Yinnetharra Station.

The highest value for zirconium is 330 ppm from sample 138688, 25 km east of Coondoo Outcamp, collected near the boundary of the Archaean gneiss and the Morrissey Metamorphic Suite (Fig. 51). This sample also contains high Ce, La and Th. A group of high Zr samples is found between Yinnetharra Station and the Spring Camp Outstation, near the boundary of early-stage granitoid and the Morrissey Metamorphic Suite. Sample 138803, 14 km south of Mount James Station and close

to an outcrop of late-stage granitoid, has elevated Zr, Ba, F and Ga. Regolith over the Bangemall Group is characterized by moderate to high Zr concentrations.

## Discussion of element-concentration maps

Variation in element concentration in regolith on MOUNT PHILLIPS is controlled by the combined effects of bedrock composition, structure, erosion and chemical weathering. Interpretation of the element-distribution maps (Figs 4–51) has been made in conjunction with the regolith map (Plate 1), the simplified geology (Fig. 2) and the geological map (Williams et al., 1983).

The geology on MOUNT PHILLIPS can be simplified into seven units for the purpose of discussing variations in regional-scale regolith geochemistry. These are: Archaean rocks, Morrissey Metamorphic Suite, early- and late-stage granitoids, Mount James Formation, Bangemall Group and Carnarvon Basin. Archaean rocks and the Mount James Formation are of limited extent on MOUNT PHILLIPS and there are correspondingly few regolith samples. Of the remaining five units, each contains examples of bedrock, structural, weathering and transportational control on regolith composition.

The Morrissey Metamorphic Suite is lithologically diverse, and has undergone several metamorphic and metasomatic events which are reflected in the regolith geochemistry. For example, between Chalby Chalby and Mount Steere there is an area dominated by migmatite and quartz–muscovite–biotite schist with elevated Na<sub>2</sub>O in regolith. This may be related either to a higher proportion of feldspar-bearing rocks, or to the introduction of sodium along a series of northwesterly trending faults and shears. North of Yinnetharra Station, between Thirty-One River and Mount James Station, there is narrow zone of elevated Be, Bi, Li and W with scattered high values of Nb, Sn, Ta and U. This is highlighted in Figure 55, a log standard score pegmatite index, normalized to geological unit (further discussed below in **Element-index maps**). Williams et al. (1983) identified a belt of boron and sodium metasomatism, extending from an area 10 km south of Camel Hill to Morrissey Hill, containing pegmatite with muscovite, tourmaline and beryl and less common bismutite, euxenite and pitchblende. Regolith geochemistry, in particular elevated Bi and W, suggests this pegmatite zone extends in a southeasterly direction towards Mount James Station and northwest towards Thirty-One River. Some elevated Bi concentrations in the area may also indicate the mafic influence of the Ti Tree Syncline. An extensive area of consolidated colluvium, following the Thomas and Gascoyne rivers between Mount James and Yinnetharra stations, conceals large areas of the Morrissey Metamorphic Suite (Plate 1). However, the elevated suite of elements in the area (e.g. DC2h sample 127775, 18 km southeast of Camel Hill) suggests the pegmatite zone may continue beneath or adjacent to this cover of consolidated colluvium.

In the Morrissey Metamorphic Suite, 15 km southeast of Coondoo Outcamp and near the boundary between

Archaean gneiss and the Carnarvon Basin, there is a group of samples with elevated concentrations of Ce, La, Th, U and Y (Fig. 56). In addition, some samples have high Pb and Zr. These high values may indicate the presence of rare-earth elements in the Morrissey Metamorphic Suite, combined with a concentrating effect of carbonates in the Nadarra Formation. Unlike other areas of suggested mineralization in the Morrissey Metamorphic Suite, this southwest corner has very few known mineral occurrences.

The composition of the early-stage granitoids is quite varied and this is expressed in their regolith geochemistry. For example, Be concentrations around Yinnetharra Station are near detection level, whereas regolith over early-stage granitoid near Camel Hill, west of Morrissey Hill and north of Arthur River Outcamp, carry the highest Be values on the map sheet. Augen gneiss (*Pgla*) is the most abundant granitoid in the suite, with a series of plutons centred on Yinnetharra Station and Eudamullah Station. Compared with other areas of *Pgla* the regolith over granitoid southwest of Yinnetharra Station has significantly higher concentrations of Ba, F, Ga, Nb, Sr and Y, possibly resulting from some variation in magma composition. Like the Morrissey Metamorphic Suite, early-stage granitoid contains a number of pegmatite associations (particularly southeast of Camel Hill) shown by high Be, Bi, Ta and W in regolith. Northwest of Morrissey Hill, anomalous Li in regolith is associated with abundant micaceous fragments including lepidolite, which occurs almost exclusively in granite pegmatites. Sample 128800, overlying early-stage granitoid 30 km east-southeast of Eudamullah Station, is in colluvium largely derived from the Morrissey Metamorphic Suite (particularly Lockier Range). This sample has high concentrations of Ce, Sn and Th with slightly lower La, Nb, Ta and Y, suggesting a pegmatite and/or rare-earth element influence and/or enhancement of resistate phases in regolith (Figs 56 and 57).

Late-stage granitoid is also compositionally diverse, particularly in the broad area of shear zones between Mount Phillips Station and Seventeen Mile Outstation. Regolith over these late-stage granitoids has higher Na<sub>2</sub>O, Ba, F, Ga, Nb, Rb and Sr, than other late-stage granitoids. Furthermore, 10 km southwest of Seventeen Mile Outstation, in an area of converging faults and shears, is a series of samples with elevated K<sub>2</sub>O and Cl. Figure 57, a combination plot between airborne radiometric data, Landsat TM, simplified geology and regolith geochemistry, highlights these areas of high K<sub>2</sub>O (see **Speciality maps — combination plot**). These are possibly late-stage plutons that are poorly expressed on the Landsat TM imagery and aerial photography, and have not been mapped by Williams et al. (1983). Field observation in the area notes highly sheared granite (sample 138048). The elevated K<sub>2</sub>O and Cl values may be related to the original composition of these late intrusive bodies and/or shear-related alteration. The regolith geochemistry and radiometric data suggest further bedrock mapping in this area may be warranted.

The Bangemall Group has the most diverse assemblage of regolith–landform types including erosional colluvial, alluvial, hardpan, calcrete and sandplain. Nevertheless,

compared with the other geological units, regolith derived from the Bangemall Group rocks is uniquely defined by its largely mafic content. Due to the wide variety of regolith units, the Bangemall Group is a good example of how regolith type may influence the geochemistry. For instance, the sandplain southwest of Mount Augustus comprises eolian and residual sand and is dominantly SiO<sub>2</sub>. This unit is noticeably depleted in most other elements, although some elements (e.g. K<sub>2</sub>O and Th) are at low levels throughout the entire Bangemall Group. Other regolith control on chemistry is well illustrated in the northeast corner of the Bangemall Group, which is dominated by large areas of alluvium (DA5), calcrete (DA8) and hardpan (DC3h). Many samples over calcrete have elevated CaO, MgO and LOI values, consistent with a high carbonate content in regolith. A number of calcrete samples, particularly north of the Bangemall Anticline, have relatively high Sr concentrations, possibly related to the substitution of Sr for Ca. Many high F values are also found along drainage and may indicate the presence of fluorite (CaF<sub>2</sub>) as well as carbonate. These alluvial and calcrete units are traps for many major and trace elements. For example, calcrete sample 138325, southwest of Mount Augustus Station, contains elevated Pb and Sn, possibly transported from the nearby Jillawarra Formation or by drainage in a northerly direction from late-stage granitoid. Other soluble elements (such as Co and U) are in high concentration in alluvial and calcrete samples, east of Gifford Creek Station and north of Cobra Station respectively. High Ba, Cu, S and P<sub>2</sub>O<sub>5</sub> concentrations in a number of drainages may indicate complexing to form sulfates and phosphates (Wedepohl, 1978). High concentrations of other components such as TiO<sub>2</sub>, Cd, Ni, Y and Zr indicate the presence of resistate phases (e.g. anatase and zircon), and a few alluvial samples also contain higher Au and Pt.

The broad hardpan unit northwest of Mount Augustus Station is noticeably different from other units of the Bangemall Group. High Al<sub>2</sub>O<sub>3</sub> in regolith suggests that this unit is dominated by clay. In comparison with other areas of MOUNT PHILLIPS, average MgO concentrations are very high, suggesting the clay is derived from the weathering of mafic rocks. In the Bangemall Group, surface hardpan pH varies from acidic (averaging 6.0–6.5 north of Mount Augustus Station) to alkaline (averaging 7.0–8.0 northeast of Cobra Station) (Fig. 52). There is field and laboratory evidence for a variety of clay types in the area including montmorillonite, kaolinite and palygorskite (see **XRD mineralogy**). In the hardpan unit, the elements U, Li and Ni, which are known to precipitate in clays, are also in higher average concentration. Elevated LOI, Cl and S values suggest that chlorides and sulfates are also being precipitated in the hardpan. The average Sn concentration is also generally higher in the hardpan.

Bangemall Group colluvium (DC1, DC2) is derived from interbedded shale, chert, dolomite and mafic rock and has produced a variety of elemental associations. For instance, south of Peedawarra Bluff, colluvium derived from outcrops of the Jillawarra Formation and Discovery Chert have high As, Cd, Cr, In, Mo, Se, Sb and Zn, suggesting derivation from sulfidic shales. Other common associations include TiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>, Cr, Nb, Sc and V,

suggesting the colluvium is derived from mixed mafic igneous rocks and probably contains common detrital minerals, such as rutile, ilmenite and chromite. Scandium is generally in high concentration along the trend of the Bangemall Anticline, supporting the influence of the dolerite sills in the formation of the surrounding colluvium. Around Peedawarra Bluff, elevated MnO values in regolith are consistent with secondary Mn coating on lithic fragments recorded at the sample locations.

The erosional units of the Bangemall Group contain a number of areas with elevated As, Cd, Mo, Sb and Zn (e.g. Bangemall Group outcrops south of Peedawarra Bluff). Following the Bangemall Anticline, erosional units also contain modest levels of TiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>, MgO, CaO, Cr, Cu, Se, Sc, Sr and Y, indicative of mafic parent rock.

The most noticeable difference in the element distributions over the Carnarvon Basin is the relative depletion in a number of elements including CaO, LOI, As, Li, Sr, Y and Zr, north of a line extending west of the Arthur River Outcamp. The northern area is dominated by subcrop of the Lyons Formation, whereas the southern area includes distinctive ridges and colluvium of the Callytharra Formation, Moogooloo Sandstone and Billidee Formation. The elevated CaO and LOI concentrations in regolith near Coondoo and Tallangatta outcamps are probably controlled by the calcarenites of the underlying Callytharra Formation. The relatively high Sr content of the regolith is also consistent with a carbonate parent. In colluvium derived from the Lyons Formation, 25 km west of Arthur River Outcamp, sample 138894 contains high Li and Ba. Although concentrations at these levels are not unexpected in sandstones, they may here relate to granitoids beneath the Carnarvon Basin. Granitic fragments in the float and recent (1996) World Geoscience Corporation aeromagnetic surveying suggest the Carnarvon Basin shallows markedly in this area.

## Statistical treatment of regolith chemical data

Element-concentration maps (Figs 4–51) permit visual comparison of regolith chemistry with regolith unit and bedrock geology. However, in order to better determine any significant differences in regolith composition (e.g. between geological units or between regolith units), it is necessary to compare groups of data statistically.

Numerous statistical tests are available for comparing groups of data, provided these data are normally distributed. Unfortunately, many geological datasets (including regolith chemistry on MOUNT PHILLIPS) follow a non-normal distribution, in that the majority of element concentrations are low, and only a few are high giving a positive skew to the distribution (Koch and Link, 1970). Transformation of the non-normally distributed data must be carried out so that parametric tests of population difference can be applied (e.g. Student's t-test). The most common transformation involves adding a constant to each value and taking the log, thus:  $y = \log(x + C)$ , where  $x$  is

the original element concentration and  $C$  is a constant (e.g. 10) (Rock, 1988).

On MOUNT PHILLIPS two significance tests of population-mean difference have been employed; Student's t-test for comparing two populations and Tukey's  $w$  (or Honestly Significant Difference-HSD) for comparing multiple populations (Miller and Kahn, 1962; Rock, 1988). Several geological units and regolith types have been tested, as follows:

- comparison between element concentrations from regolith overlying early- and late-stage granitoids (t-test)
- comparison between element concentrations from erosional regolith overlying the Carnarvon Basin, Morrissey Metamorphic Suite, early- and late-stage granitoids and the Bangemall Group (Tukey's HSD)
- comparison between element concentrations from regolith (simplified) overlying the Bangemall Group (Tukey's HSD)
- comparison between element concentrations from erosional and depositional regolith overlying the Morrissey Metamorphic Suite (t-test).

All statistical tests of the geochemistry on MOUNT PHILLIPS (Student's t-test and Tukey's HSD) were carried out at the 95% confidence level. Components at low levels (average composition  $<10 \times$  detection level) are not discussed statistically, due to complications introduced at low levels.

- **comparison between element concentrations from regolith overlying early- and late-stage granitoids (t-test)**

Areas of granitoid are found throughout MOUNT PHILLIPS, although the most extensive area is the late-stage Minnie Creek Batholith extending from the northwest corner of the sheet to Pink Hills in the east (Fig. 2). A large area of early-stage granitoid is found between Yinnetharra Station and Arthur River Outcamp, and from Morrissey Hill northwest towards the map sheet boundary. Mapping by Williams et al. (1983) identified several rock types in each group, including granite, granodiorite, adamellite (monzogranite), anorthosite and pegmatite. For the purpose of regional-scale regolith mapping, with a sampling density of one sample per 16 sq km, these sub-units have been combined into early- and late-stage granitoid, which permits the statistical comparison of the regolith for each group.

The Student's t-test on all regolith samples overlying the early- and late-stage granitoids reveals a number of differences and these are highlighted in Table 6, which details the arithmetic mean and standard deviation for the two groups.

Regolith over early-stage granitoid has statistically significant higher average concentrations of SiO<sub>2</sub>, K<sub>2</sub>O, Ba, Ce, La, Nb, Pb, Rb, Sn, Th and U. The higher K<sub>2</sub>O content in early-stage granitoid may reflect the abundant microcline augens in the dominant *Pgla* unit (Williams et

**Table 6. Arithmetic mean and standard deviation for regolith over early- and late-stage granitoids**

Element	Late-stage granitoid n=198		Early-stage granitoid n=206	
	Mean	Std. Dev.	Mean	Std. Dev.
<b>Percent</b>				
SiO <sub>2</sub>	79.92	4.37	81.34	3.68
TiO <sub>2</sub>	0.18	0.19	0.19	0.13
Al <sub>2</sub> O <sub>3</sub>	9.53	2.33	8.65	1.91
Fe <sub>2</sub> O <sub>3</sub>	2.69	2.99	2.55	1.49
MnO	0.03	0.02	0.04	0.04
MgO	0.12	0.13	0.13	0.14
CaO	0.81	0.62	0.77	0.57
Na <sub>2</sub> O	1.83	0.88	1.25	0.59
K <sub>2</sub> O	2.77	1.16	3.34	1.27
P <sub>2</sub> O <sub>5</sub>	0.03	0.02	0.04	0.03
<b>Parts per million <sup>(a)</sup></b>				
Ag	0.02	0.05	0.03	0.08
As	1.9	2.6	1.4	1.6
Au (ppb)	0	1	0	0
Ba	634	254	754	372
Be	0.6	0.7	0.9	1.0
Bi	0.1	0.2	0.2	0.5
Cd	0.1	0.1	0.1	0.1
Ce	26	22	34	25
Cl	82	242	69	316
Co	4	3	2	3
Cr	17	42	12	15
Cu	9	7	6	5
F	104	116	127	144
Ga	29	11	27	13
In	0.00	0.02	0.00	0.03
La	18	14	23	14
Li	5.4	2.6	4.6	3.3
Mo	0.9	0.7	0.9	0.4
Nb	5.7	3.0	7.0	5.3
Ni	6	4	5	4
Pb	11	5.4	22	8.2
Pd (ppb)	0	0	0	0
Pt (ppb)	0	0	0	0
Rb	65	38	79	33
S (%)	0.00	0.03	0.00	0.01
Sb	0.0	0.3	0.0	0.0
Sc	2.7	2.0	2.3	1.3
Se	0.1	0.3	0.1	0.3
Sn	1.6	0.6	1.9	0.7
Sr	89	48	92	51
Ta	0	1	0	3
Th	5.83	5.20	8.16	6.92
U	1.10	0.55	1.57	0.73
V	37	62	30	20
W	0.9	1.0	1.0	0.8
Y	5	2	7	4
Zn	13	12	12	10
Zr	38	28	42	33

NOTE: (a) except where noted otherwise

al., 1983). Statistically, the greatest discriminator between the early- and late-stage granitoids is the Pb concentration in regolith (Fig. 34).

Compared with early-stage granitoid, late-stage granitoid is relatively enriched in Al<sub>2</sub>O<sub>3</sub>, Na<sub>2</sub>O and Li. The Minnie Creek Batholith, is clearly defined by its Na<sub>2</sub>O concentration, which probably reflects the type and

proportion of plagioclase in the rock. In addition, between Mount Phillips Station and Seventeen Mile Outstation, regolith contains the maximum Na<sub>2</sub>O values found over granitoid, which coincides with a broad series of northwesterly trending shear zones in the area. A metasomatic influence cannot, therefore, be ruled out.

Even though concentrations are low, Co in regolith over late-stage granitoid is noticeably higher than that over early-stage granitoid (Fig. 23). The higher Co could reflect the abundance of dolerite, metadolerite, metagabbro, and ultramafic dykes and sills that are scattered throughout the late-stage granitoid (Williams et al., 1983).

- comparison between element concentrations from erosional regolith overlying the Carnarvon Basin, Morrissey Metamorphic Suite, early- and late-stage granitoids and the Bangemall Group (Tukey's HSD)

Statistical comparison of geological units using only samples of erosional regolith (E2 and E4) minimizes the compositional variations due to weathering and transportation. Where the element concentrations are well above the level of detection (i.e. those  $\geq 10 \times \text{D.L.}$ ), the geological units have been compared using Tukey's HSD (at the 95% confidence level).

The arithmetic mean and standard deviation of erosional units from the Carnarvon Basin, Bangemall Group, early- and late-stage granitoid and the Morrissey Metamorphic Suite, are presented in Table 7. The Mount James Formation and Archaean gneiss are limited in outcrop and between them account for less than 1.5% of the regolith samples, and are therefore not considered for statistical comparison.

Erosional regime regolith overlying the Bangemall Group is statistically significantly different from that derived from the other geological units. In particular the Bangemall Group regolith has higher average concentrations of TiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>, MgO, CaO, Ce, Cr, La, Li, Ni, Nb, V, Zn and Zr and lower average concentrations of SiO<sub>2</sub> and K<sub>2</sub>O. This is consistent with the mixed sedimentary and mafic units characterizing the Bangemall Group on MOUNT PHILLIPS.

The Carnarvon Basin has statistically significant higher levels of SiO<sub>2</sub> and lower levels of Al<sub>2</sub>O<sub>3</sub>, F, Ga, Nb, Sn and Sr in the erosional regime regolith compared with the other units. On MOUNT PHILLIPS, the majority of the erosional samples from the Carnarvon Basin are in the Lyons Formation, a glaciogene sandstone, siltstone and tillite (Williams et al., 1983). Silica tends to dilute other elements, and the low Al<sub>2</sub>O<sub>3</sub> concentration of regolith suggests a minimal clay content in the Lyons Formation (see XRD mineralogy).

The erosional regime regolith over late-stage granitoid is uniquely defined by its relatively high Al<sub>2</sub>O<sub>3</sub> and Na<sub>2</sub>O, and low Pb concentrations.

There is no single element or group of elements that uniquely defines the regolith over the Morrissey Metamorphic Suite or early-stage granitoid. This is consistent with the lithological diversity of these units, and

Table 7. Arithmetic mean and standard deviation for erosional regolith over selected geological units

Element	Carnarvon Basin n=38		Bangemall Group n=28		Late-stage granitoid n=82		Early-stage granitoid n=73		Morrissey Metamorphic Suite n=152	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Percent										
SiO <sub>2</sub>	84.42	5.71	62.18	15.04	78.30	3.21	79.72	3.53	80.77	4.74
TiO <sub>2</sub>	0.14	0.06	1.47	0.96	0.18	0.21	0.20	0.13	0.21	0.15
Al <sub>2</sub> O <sub>3</sub>	5.96	2.17	9.48	2.69	10.77	1.71	9.65	1.75	8.83	2.00
Fe <sub>2</sub> O <sub>3</sub>	2.80	1.29	16.37	9.77	2.24	1.62	2.68	1.54	3.42	3.18
MnO	0.04	0.03	0.19	0.18	0.03	0.02	0.04	0.04	0.05	0.05
MgO	0.14	0.24	1.07	0.91	0.14	0.12	0.19	0.16	0.24	0.24
CaO	0.82	2.46	1.65	1.91	0.89	0.56	0.94	0.56	0.72	0.47
Na <sub>2</sub> O	1.00	0.73	0.58	0.56	2.20	0.67	1.57	0.55	1.40	0.78
K <sub>2</sub> O	2.16	0.94	1.34	0.68	3.20	1.09	3.35	1.23	2.51	1.12
P <sub>2</sub> O <sub>5</sub>	0.05	0.02	0.11	0.06	0.02	0.02	0.04	0.03	0.04	0.02
Parts per million <sup>(a)</sup>										
Ag	0.04	0.10	0.07	0.14	0.02	0.04	0.02	0.05	0.04	0.08
As	4.8	2.9	15	13	1.6	2.6	1.5	2.4	2.4	3.2
Au (ppb)	0	0	0	1	0	0	0	0	0	0
Ba	559	167	417	183	694	242	750	396	508	255
Be	1.1	0.8	1.5	0.6	0.6	0.7	1.2	1.2	1.1	1.1
Bi	0.2	0.1	0.4	0.2	0.1	0.2	0.2	0.3	0.2	0.3
Cd	0.1	0.1	0.5	0.4	0.1	0.1	0.1	0.1	0.1	0.1
Ce	26	15	70	32	25	20	39	22	46	41
Cl	16	37	61	69	72	131	52	137	64	228
Co	2	2	6	9	4	3	3	4	4	5
Cr	21	25	120	78	8	13	11	10	24	22
Cu	4	4	62	34	9	8	7	5	11	11
F	29	69	246	188	132	97	173	157	125	147
Ga	16	5.0	25	9.6	32	10	29	14	20	8.5
In	0.00	0.00	0.09	0.05	0.00	0.01	0.01	0.04	0.00	0.02
La	22	11	43	20	17	11	25	15	31	27
Li	5.5	3.8	11	6.2	6.1	3.1	5.1	4.2	5.3	3.9
Mo	1.0	0.5	4.2	3.2	0.9	0.8	1.0	0.4	1.2	0.9
Nb	3.5	1.6	13	6.0	6.5	2.8	7.7	4.5	5.6	2.9
Ni	7	5	39	21	5	4	6	5	10	9
Pb	18	7.2	22	7.1	12	5.6	23	7.8	22	9.2
Pd (ppb)	0	0	0	0	0	0	0	0	0	1
Pt (ppb)	0	0	0	0	0	0	0	0	0	0
Rb	51	24	55	31	75	43	79	29	62	32
S (%)	0.00	0.01	0.02	0.04	0.01	0.03	0.00	0.00	0.00	0.00
Sb	0.0	0.1	1.8	1.7	0.0	0.3	0.0	0.0	0.1	0.3
Sc	1.7	1.1	12	8.0	2.4	1.1	2.6	1.3	3.3	2.2
Se	0.1	0.2	1.7	1.3	0.1	0.2	0.1	0.2	0.1	0.3
Sn	1.1	0.4	2.1	0.4	1.8	0.7	2.1	0.6	2.0	0.7
Sr	54	29	92	59	96	45	103	55	79	43
Ta	0	1	0	1	0	1	0	3	1	5
Th	7.16	3.97	11	5.39	5.01	3.45	8.99	6.39	12	11
U	1.07	0.42	2.18	0.75	1.09	0.51	1.80	0.79	2.04	0.92
V	38	21	320	195	29	51	31	19	42	49
W	0.6	0.3	1.4	0.4	1.2	1.4	1.2	1.1	1.2	1.3
Y	6	3	15	8	5	2	7	4	6	3
Zn	14	9	90	69	15	16	14	10	19	17
Zr	55	20	99	43	35	22	44	24	66	36

NOTE: (a) except where noted otherwise

for this reason they will be compared on a pairwise basis with each of the other geological units as follows;

- Carnarvon Basin,
- late-stage granitoid,
- Bangemall Group, and
- with each other.

Compared with the Carnarvon Basin, regolith over early-stage granitoid has statistically significant higher

concentrations of Al<sub>2</sub>O<sub>3</sub>, Na<sub>2</sub>O, K<sub>2</sub>O, F, Ga, Nb, Pb, Rb, Sn, Sr and U, whereas the Morrissey Metamorphic Suite has higher Al<sub>2</sub>O<sub>3</sub>, Na<sub>2</sub>O, F, Ga, Nb, Pb, Sn, Sr, Th, U and W.

Erosional regolith over early-stage granitoid has greater Pb, Sn, Th and U and the Morrissey Metamorphic Suite has greater SiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>, Ce, La, Pb, Th, U and Zr compared with the late-stage granitoid. This confirms that

the early-stage granitoid and Morrissey Metamorphic Suite carry higher proportions of pegmatite (REE)-type assemblages. Furthermore, compared with the late-stage granitoid, the average Morrissey Metamorphic Suite is significantly lacking in the typically granitic association of  $\text{Al}_2\text{O}_3$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ , Ba, Ga, Rb and Sr.

The Bangemall Group is higher in mafic-element assemblages than either the early-stage granitoid or the Morrissey Metamorphic Suite. In addition, regolith over the Bangemall Group has significantly higher concentrations of F and Ga compared with that over the Morrissey Metamorphic Suite. Both units have significantly higher  $\text{SiO}_2$ ,  $\text{Na}_2\text{O}$  and  $\text{K}_2\text{O}$ , and regolith over the early-stage granitoid also has higher Ba and Rb.

Comparison of the Morrissey Metamorphic Suite and early-stage granitoid shows the latter to have significantly higher concentrations of granitic suite elements such as  $\text{Al}_2\text{O}_3$ ,  $\text{K}_2\text{O}$ , Ba, F, Ga, Nb and Rb. The Morrissey Metamorphic Suite contains significantly higher concentrations of Cr, Th and Zr.

- **comparison between element concentrations from regolith (simplified) overlying the Bangemall Group (Tukey's HSD)**

To measure the change in chemical concentrations related to weathering and erosion, independent of bedrock variations, Tukey's HSD has been applied to simplified regolith units over the Bangemall Group. The simplified groups are: E (combined erosional E2 and E4), DC (combined colluvium DC1, DC2 and DC3), DCH (all consolidated colluvium DC2h and hardpan DC3h), D9 (sandplain), DA5 (alluvium) and DA8 (calcrete). The average concentration and standard deviations of these simplified groups are shown in Table 8.

Sandplain (D9), overlying the Bangemall Group, is geochemically distinct from all other units in that it has statistically higher  $\text{SiO}_2$  and lower  $\text{Al}_2\text{O}_3$ ,  $\text{P}_2\text{O}_5$ , Ba, Cu, F, Li, Nb, Ni, Pb, Sc, Sn, Sr, V, Zn and Zr. Calcrete (DA8) and erosional regime regolith (E) are distinguishable from all other units by their respectively elevated CaO and  $\text{Na}_2\text{O}$  concentrations. Progressive depletion in  $\text{Na}_2\text{O}$  downslope from colluvium to hardpan to alluvium probably represents the mechanical and chemical breakdown of plagioclase. The areas of colluvium (DC), hardpan (DCH), and alluvium (DA5) cannot be uniquely identified by any particular element concentration. However, alluvium can be separated from sandplain, erosional and colluvial units by its statistically higher U content. The similar U concentration in alluvium, hardpan and calcrete suggests that U precipitates uniformly in the alluvial environment (DA5, DCH, DA8). Clay-dominated hardpan differs from other regolith units (excluding calcrete) in terms of its higher average Sn concentration. Colluvium is best discriminated by its statistically lower concentrations of MgO and Ba. Magnesium is rapidly depleted downslope, due to the breakdown of primary silicate minerals, and redeposited in the most stable regolith regimes (DA8, DCH). This is confirmed in elevated levels of MgO and Ba in a number of hardpan and alluvial samples overlying the Bangemall Group. This trend was also noted by Subramanya and

Sanders (1996), in discrete areas of the Narracoota Formation in the southwest of PEAK HILL.

- **comparison between element concentrations from erosional and depositional regolith overlying the Morrissey Metamorphic Suite (t-test)**

To measure the change in chemical concentrations between erosional and colluvial units, Student's t-test has been applied to the simplified regolith units over the Morrissey Metamorphic Suite. The simplified groups are E (combined erosional E2 and E4) and DC (combined colluvium DC1, DC2 and DC3). The variations in concentration are highlighted in Table 9, which details the arithmetic mean and standard deviation for each group.

Significant differences include slightly higher concentrations of  $\text{Al}_2\text{O}_3$ , MgO, CaO and  $\text{Na}_2\text{O}$  in the erosional regime compared with those in the colluvium. This is probably related to the breakdown of feldspars and amphiboles with progressive movement downslope. Elevated trace elements in the erosional units include Sn and Sr, whereas  $\text{SiO}_2$  is the only component that is significantly enriched in colluvium. Most elements, particularly Ba, Cr, Cu, Ga, Rb, Th and U, show very little difference in concentration between the erosional and depositional areas.

## Speciality maps

### Acidity–alkalinity and conductivity

Contoured maps of regolith pH and conductivity are presented as Figures 52 and 53. Figure 53 also includes borehole TDS data, supplied by the Water and Rivers Commission.

Areas of more acidic regolith (pH <7) on MOUNT PHILLIPS include the sandplain southwest of Mount Augustus Station and the contact between the Carnarvon Basin and the Morrissey Metamorphic Suite (Fig. 52) from Coondoo Outcamp to Eudamullah Station. Both regions tend to be dominated by  $\text{SiO}_2$  in regolith. The lowest pH (4.4) is recorded in sandplain samples 138220 and 138228, 19 km southwest and 13 km west of Mount Augustus Station respectively. Areas of more alkaline regolith (pH >7) are mostly found in areas dominated by calcrete and hardpan. Elevated values north of Cobra Station coincide with a wide expanse of calcrete. West of Mount James Station the alkaline regolith — including the maximum pH (9.3: 138633) for the map sheet — is largely associated with consolidated colluvium following the Gascoyne and Thomas rivers (Plate 1). Other alkaline areas include the Bangemall Anticline and north and south of Coondoo Outcamp, in regolith derived largely from calcarenites of the Callytharra Formation.

Contoured regolith TDS (Fig. 53) highlights the hardpan northeast of Cobra Station and the Gascoyne River and its tributaries around Yinnetharra Station. The highest TDS value on MOUNT PHILLIPS (1665 mg/L) is in DC3h sample 138431, from 24 km northeast of Cobra

Table 8. Arithmetic mean and standard deviation for simplified regolith units over the Bangemall Group

Element	<i>Erosional</i> (E) n=28		<i>Colluvium</i> (DC) n=94		<i>Consolidated colluvium</i> (DCH) n=46		<i>Alluvium</i> (DA5) n=31		<i>Calcrete</i> (DA8) n=12		<i>Sandplain</i> (D9) n=13	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
<b>Percent</b>												
SiO <sub>2</sub>	62.18	15.04	67.99	16.38	60.97	9.96	62.29	14.79	56.63	13.09	87.63	2.26
TiO <sub>2</sub>	1.47	0.96	1.19	0.92	1.37	0.98	1.27	0.88	1.06	0.44	0.31	0.12
Al <sub>2</sub> O <sub>3</sub>	9.48	2.69	8.05	2.84	10.23	2.73	8.70	2.80	8.72	3.69	4.38	1.07
Fe <sub>2</sub> O <sub>3</sub>	16.37	9.77	14.65	11.96	16.69	6.87	17.21	11.29	13.26	7.95	2.84	0.57
MnO	0.19	0.18	0.19	0.23	0.16	0.10	0.23	0.22	0.17	0.14	0.01	0.01
MgO	1.07	0.91	0.55	0.66	1.02	1.00	0.85	0.71	1.60	1.08	0.09	0.03
CaO	1.65	1.91	0.93	1.49	0.52	0.81	1.34	2.03	5.69	10.59	0.01	0.01
Na <sub>2</sub> O	0.58	0.56	0.27	0.34	0.20	0.13	0.23	0.22	0.21	0.12	0.05	0.02
K <sub>2</sub> O	1.34	0.68	1.29	0.79	1.47	0.56	1.28	0.58	1.36	0.49	1.20	0.37
P <sub>2</sub> O <sub>5</sub>	0.11	0.06	0.11	0.07	0.13	0.05	0.14	0.07	0.12	0.04	0.03	0.02
<b>Parts per million <sup>(a)</sup></b>												
Ag	0.07	0.14	0.09	0.17	0.03	0.13	0.09	0.14	0.07	0.09	0.08	0.09
As	15	13	17	14	16	7.2	19	14	14	6.8	2.3	1.0
Au (ppb)	0	1	1	1	1	1	0	1	1	1	0	0
Ba	417	183	348	143	457	177	499	324	427	238	174	47
Be	1.5	0.6	1.3	1.0	1.6	0.9	1.4	1.0	1.0	0.9	0.0	0.0
Bi	0.4	0.2	0.4	0.2	0.4	0.1	0.4	0.1	0.3	0.1	0.1	0.0
Cd	0.5	0.4	0.4	0.3	0.6	0.3	0.6	0.4	0.5	0.4	0.1	0.1
Ce	70	32	66	36	58	27	79	57	58	25	42	20
Cl	61	69	56	80	300	689	23	43	50	80	146	113
Co	6	9	4	9	2	3	11	18	9	13	0	1
Cr	120	78	155	126	160	74	153	100	107	46	49	20
Cu	62	34	52	35	58	27	62	35	51	23	7	3
F	246	188	227	213	293	299	252	222	500	717	31	63
Ga	25	9.6	22	11	27	8.2	29	14	28	14	13	2.5
In	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.0
La	43	20	43	28	36	14	49	36	36	13	28	10
Li	11	6.2	9.7	5.2	16	6.4	13	6.3	14	7.3	4.7	1.2
Mo	4.2	3.2	4.8	3.8	4.5	2.0	4.3	2.7	3.6	2.2	0.8	0.2
Nb	13	6.0	13	7.7	15	6.8	14	7.3	14	4.2	5.1	1.6
Ni	39	21	32	21	44	23	43	25	39	22	7	3
Pb	22	7.1	22	7.8	26	4.3	24	8.7	26	19	13	2.4
Pd (ppb)	0	0	0	1	0	1	0	1	0	1	0	0
Pt (ppb)	0	0	0	1	0	0	0	1	0	0	0	0
Rb	55	31	48	31	53	17	50	19	45	16	38	8
S (%)	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.0	0.0
Sb	1.8	1.7	2.2	2.5	1.7	1.0	1.9	1.5	0.8	0.8	0.0	0.0
Sc	12	8.0	10	7.7	9.7	4.0	11	5.6	9.5	4.2	2.9	0.8
Se	1.7	1.3	1.8	1.5	1.4	0.5	1.6	1.2	1.3	0.6	0.1	0.2
Sn	2.1	0.4	2.1	0.6	2.6	0.5	2.2	0.5	2.2	1.0	1.5	0.3
Sr	92	59	63	49	59	28	67	40	82	65	24	7
Ta	0	1	0	1	0	0	0	0	0	0	0	0
Th	11	5.4	11	6.2	13	3.6	14	15	10	3.7	11	4.5
U	2.2	0.7	2.5	1.0	2.9	0.8	3.0	1.3	2.7	0.9	1.7	0.6
V	320	195	301	268	338	163	341	237	267	161	38	10
W	1.4	0.4	1.6	0.9	1.6	0.7	1.6	0.7	2.0	1.2	0.9	1.3
Y	15	8	12	7	13	6	16	8	15	6	5	1
Zn	90	69	81	62	90	46	85	50	70	41	14	4
Zr	99	43	94	35	120	41	108	38	105	32	49	9

NOTE: (a) except where noted otherwise

Station, and coincides with elevated concentrations of MgO and Cl. Large areas of the remainder of the sheet have TDS values less than 1 mg/L.

Of the 271 borehole readings for conductivity the maximum value obtained was 16 000 mg/L in drainage

10 km north of Cobra Station. Other high values of conductivity in boreholes are associated with drainage west of Seventeen Mile Outstation, around Yinnetharra Station, and east of Eudamullah Station. The patchy distribution of borehole data means that few comparisons can be made between regolith conductivity and borehole TDS.

**Table 9. Arithmetic mean and standard deviation of erosional and colluvial regolith units over the Morrissey Metamorphic Suite**

Element	Erosional (E) n=152		Colluvium (DC) n=102	
	Mean	Std. Dev.	Mean	Std. Dev.
<b>Percent</b>				
SiO <sub>2</sub>	80.77	4.74	82.79	4.62
TiO <sub>2</sub>	0.21	0.15	0.23	0.21
Al <sub>2</sub> O <sub>3</sub>	8.83	2.00	7.57	2.13
Fe <sub>2</sub> O <sub>3</sub>	3.42	3.18	3.19	2.69
MnO	0.05	0.05	0.05	0.04
MgO	0.24	0.24	0.15	0.13
CaO	0.72	0.47	0.54	0.45
Na <sub>2</sub> O	1.40	0.78	0.98	0.64
K <sub>2</sub> O	2.51	1.12	2.38	1.20
P <sub>2</sub> O <sub>5</sub>	0.04	0.02	0.04	0.03
<b>Parts per million <sup>(a)</sup></b>				
Ag	0.04	0.08	0.06	0.11
As	2.4	3.2	2.4	2.8
Au (ppb)	0	0	0	0
Ba	508	255	500	254
Be	1.1	1.1	0.9	1.0
Bi	0.2	0.3	0.2	0.2
Cd	0.1	0.1	0.1	0.1
Ce	46	41	53	71
Cl	64	228	45	70
Co	4	5	3	3
Cr	24	22	25	21
Cu	11	11	10	9
F	125	147	95	113
Ga	20	8.3	20	8.9
In	0.00	0.02	0.01	0.03
La	31	27	35	49
Li	5.3	3.9	4.4	2.7
Mo	1.2	0.9	1.1	0.5
Nb	5.6	2.9	6.7	6.7
Ni	10	9	8	6
Pb	22	9.2	22	13
Pd (ppb)	0	1	0	1
Pt (ppb)	0	0	0	0
Rb	62	32	60	33
S (%)	0.00	0.00	0.00	0.01
Sb	0.1	0.3	0.0	0.1
Sc	3.3	2.2	2.9	2.2
Se	0.1	0.3	0.1	0.3
Sn	2.0	0.7	1.6	0.7
Sr	79	43	60	37
Ta	1	5	0	1
Th	12	11	13	17
U	2.04	0.92	2.12	1.69
V	42	49	40	42
W	1.2	1.3	1.1	0.8
Y	6	3	6	4
Zn	19	17	15	13
Zr	66	36	64	42

NOTE: (a) except where noted otherwise

## Element-index maps

Smith and Perdrix (1983) and Smith et al. (1989) have shown how pathfinder elements and additive indices can be used to highlight areas of mineralization in arid terrains of the Yilgarn Craton. Although they have concentrated

on a limited type of sample media (predominantly ferruginized duricrust, or laterite), the use of additive indices has been adapted and extended to include all media types sampled in the GSWA regional regolith and geochemical mapping program. For example, Kojan et al. (1996a,b) have shown how a greenstone chalcophile index can be used to identify areas of known and potential gold mineralization on Sir Samuel. Indices are usually additive (e.g. element a + element b + element c etc.), but account must be taken of the relative concentration and concentration range of each element. The first step is to log-transform the data, which reduces the effect of extremely high or low values. The transformed data are then standardized, which involves expressing each value as a standard normal deviate, thus allowing direct comparison of elements regardless of concentration (Rock, 1988). The geologically standardized scores are then summed to create an elemental association suite.

Three element-index plots have been compiled for MOUNT PHILLIPS. These comprise a base-metals index (summed standard scores of Cu, Pb, Zn, Sb, As and Sn; Fig. 54); a pegmatite index (summed standard scores for Be, Bi, Nb, Sn, Ta and W; Fig. 55); and a REE (association) index (summed standard scores of Ce, La, Th, U, Y and Zr; Fig. 56). Owing to the wide variation in regolith chemistry associated with the various lithologies, each element in the pegmatite and REE index has been standardized to the geological unit in which they are contained, in the following manner. The arithmetic mean and standard deviation are calculated for each of the seven geological units. Element concentrations are then compared to the average for their respective geological unit; this prevents 'swamping' by any particular geological group (e.g. the high background levels for many elements in the Bangemall Group tend to dominate the more subdued concentrations for other geological units). An index score of zero in any geological unit represents a theoretical average score for that unit.

The base-metals index plot highlights the Bangemall Group (Fig. 54). The area of sandplain, southwest of Mount Augustus, is depleted in elements of the base-metal association, but the hardpan, northwest of Mount Augustus Station, contains relatively high index scores and may be acting as a 'sink' particularly for Cu, Pb and Sn. The highest values, shown as stars, lie along the northern and eastern boundaries, typically in the colluvium of the Jilawarra Formation, Discovery Chert, Kiangi Creek Formation, Devil Creek Formation and interbedded dolerite sills. Each of these samples has elevated base-metal concentrations, particularly As, Sb, Zn and Cu, the highest being 20 km north-northeast of Cobra Station (sample 138142: DC1). The Bangemall Group outliers along the Ti Tree Syncline and the northwest extent of the Bore Paddock Hills (Plate 1) are also characterized by higher base-metals index values. Moderately high values, from 23 km north-northwest of Yinnetharra Station (sample 138609) and 10 km north of Mount James Station (sample 138729) in the Morrissey Metamorphic Suite and late-stage granitoid respectively, may reflect elevated Sn concentrations associated with pegmatites (Fig. 55). Other values in the Morrissey Metamorphic Suite (sample 138842, 25 km east of Yinnetharra Station), probably

relate to mafic detritus derived from the Ti Tree Syncline. A number of moderate scores 15 km southeast of Coondoo Outcamp reflect elevated Pb concentrations and are also associated with high REE index values (Fig. 56).

Elevated pegmatite index scores, normalized to geological unit, highlight regolith samples overlying granitoids and Morrissey Metamorphic Suite rocks from north of Mount James Station to north of Yinnetharra Station (Fig. 55). The highest index score is in early-stage granitoid sample 138535, from 27 km east of Yinnetharra Station. Sample 138729, from 10 km north of Mount James Station, is moderately elevated in all the pegmatite associated elements, particularly Sn. High scores recorded for regolith 20 km north of Yinnetharra Station are largely due to elevated Be, Sn and W. Other high scores between Eudamullah Station and Yinnetharra Station include sample 128800 (see also Figs 56 and 57) and sample 127756, the latter being near a Sn, Ta and Li prospect.

Areas with elevated REE scores, normalized to geological unit, are scattered throughout the map sheet (Fig. 56). Zones with high scores include the mixed granitoid areas in the southeastern corner of the map sheet and the contact between the Archaean gneiss, Morrissey Metamorphic Suite and Carnarvon Basin, southeast of Coondoo Outcamp (some values in the area are probably enhanced by carbonate of the Nadarra Formation limestone). This latter area also includes elevated Pb concentrations as expressed in the base metals index (Fig. 54). The maximum REE score is from sample 128800, taken between Eudamullah Station and Yinnetharra Station (see also Fig. 57). Other samples with elevated REE scores include groups of colluvial samples from 25 km south and 10 km north of Mount Augustus Station, and from 10 km south and 18 km west-northwest of Cobra Station.

## Combination remote-sensing and geochemical plot

Figure 57, which covers a northwestern portion of MOUNT PHILLIPS near Seventeen Mile Outstation, comprises band 5 Landsat Thematic Mapper (path-114, row-77, 10/10/86), three-channel airborne radiometric data (World Geoscience Corporation, 1996), simplified geology (Williams et al., 1983) and regolith  $K_2O$  geochemistry. Only high radiometric values ( $\geq 2.5$  standard deviations above mean response) are displayed in the plot. The size of on-ground circles is representative of regolith  $K_2O$  concentration, with the highest values presented as stars.

Biotite–tourmaline–muscovite late-stage granitoid plutons (*Eg*) intruding the Morrissey Metamorphic Suite (*Es*) are clearly defined in the southeast corner by their elevated radiometric potassium levels (bright red) with correspondingly high on-ground  $K_2O$  concentrations. Fifteen kilometres south of Seventeen Mile Outstation between converging shear zones, two potassic rich areas (red/yellow elongate ovals) suggest later stage intrusions into the late-stage granitoid (*Eg*). This area contains the highest  $K_2O$  concentrations in regolith as well as elevated Cl values. There is strong correlation between on-ground

geochemistry and airborne radiometric data in more potassic areas of early-stage granitoid (*Em*) 32 km south-southwest of Seventeen Mile Outstation.

High radiometric thorium concentration in regolith (green) in the southwest of Figure 57 corresponds with partially consolidated colluvium (largely DC1m from the Lockier Range, Plate 1) overlying early-stage granitoid (*Em*). This area includes one of the highest Th concentrations in regolith (sample 128800), with elevated Ce and Sn and lesser La, Nb, Ta and Y. These elements are usually found in resistate minerals.

The small area of enhanced radiometric uranium (blue), 22 km south-southwest of Seventeen Mile Outstation in an area overlying the Morrissey Metamorphic Suite (*Es*) and early-stage granitoid (*Em*), coincides with a silicified remnant surface (R3).

## Mineralization potential

The concentrations of precious metals Au, Ag, Pt and Pd are generally low in analysed regolith from MOUNT PHILLIPS (Figs 16, 14, 36, 35). Most of the elevated Au and Ag values were recorded in samples from colluvium adjacent to the Bangemall Anticline, which is consistent with the known Au occurrences around the Bangemall Mining Centre (Plate 1). The extension of the folded Bangemall Group rocks, south of Mount Isabella, also contains low-level Au and Ag. Even at low concentration, Figure 16 shows that the hardpan east-northeast of Cobra Station may be a 'trap' for detrital Au. The geologically diverse area 25 km southwest of Cobra Station (the Bassit Belt of Williams et al., 1983) may also include areas of Au mineralization. The remaining elevated Au and Ag values are scattered and show no apparent preference for any particular regolith type or bedrock.

Higher Pd values are found in several areas, including the west of the map sheet around Eudamullah Station. These values may reflect regolith derived from dolerite, metadolerite and metagabbro dykes and sills in this area. A number of other Pd values, including one sample with 6 ppb Pt, were recorded within the wide alluvial plain and hardpan overlying the Bangemall Group.

The northeastern part of MOUNT PHILLIPS contains areas with elevated base-metal and ferroalloy-metal contents in regolith, including high Cu, Cr, Mo, Ni, V and Zn. Most of these are from samples of colluvium, derived from mixed shale, chert, dolomite and dolerite of the Bangemall Group. Resistate minerals tend to be concentrated in colluvium, whereas the more soluble phases have been broken down and re-precipitated in drainage channels and hardpan. In addition, there are several other elements of importance, such as As and Sb, which may be pathfinder elements for mineralization. The numerous Cu occurrences recorded in the southern Morrissey Metamorphic Suite (Plate 1) are generally not supported by the regional-scale regolith Cu concentrations (Fig. 25). Copper concentrations in the Morrissey Metamorphic Suite indicative of mineralization may have been 'swamped' by regolith values from the Bangemall

Group, where average Cu concentrations are significantly higher.

The highest levels of U in regolith are in drainage, consolidated colluvium and hardpan. The maximum value of 13 ppm is from regolith in the southwest of the map sheet that also contains elevated concentrations of other elements such as La and Pb. The numerous U occurrences, as recorded by Williams et al. (1983) throughout the Morrissey Metamorphic Suite and early-stage granitoid, do not coincide with notably high U concentrations in regolith. Uranium in drainage is supported by airborne radiometric uranium data, particularly in consolidated colluvium and tributaries of the Gascoyne and Thomas rivers.

Pegmatite-type minerals of interest on MOUNT PHILLIPS include the Bi- and Sn-bearing minerals and beryl, tantalite-columbite, dravite and scheelite. Regolith geochemistry supports pegmatite mineralization, particularly between Thirty-One River and Mount James Station. Southeast of Eudamullah Station, Mount James Station and Coondoo Outcamp are regolith samples with elevated pegmatite and REE concentrations, possibly enhanced by the accumulation of resitite phases in colluvium. The area southeast of Coondoo Outcamp also contains the highest Pb concentrations in regolith for the map sheet.

In summary areas of potential mineralization include:

- gold mineralization associated with the Bangemall Anticline (Jillawarra Formation), the extension of the folded Bangemall Group rocks south of Mount Isabella, and possibly the Bassit Belt southwest of Cobra Station
- base metals and ferroalloy metals associated with the Jillawarra Formation, Kiangi Creek Formation, Devil Creek Formation, Discovery Chert and interbedded dolerite sills
- pegmatite- and REE-associated minerals in the Morrissey Metamorphic Suite and early- and late-stage granitoids, mainly between Thirty-One River and Mount James Station, southeast of Eudamullah Station and Coondoo Outcamp, and the southeastern corner of the map sheet
- potential lead-bearing veins southeast of Coondoo Outcamp
- gemstones (tourmaline, garnet, staurolite, cordierite, amethyst, quartz and beryl), mostly in the Yinnetharra district.

## Summary and conclusions

Regional-scale regolith and geochemical mapping on MOUNT PHILLIPS involved the collection of 1038 regolith samples (57 sheetwash, 933 stream sediment and 48 soil), representing a nominal sample density of one sample per 16 km<sup>2</sup>. Each sample has been analysed for 49 components, comprising major-element oxides and trace elements, acidity-alkalinity (pH) and conductivity. These data are presented as either spot-concentration maps or contour maps. A regolith map has been compiled using

Landsat imagery, aerial photography, radiometric data and sample-site descriptions. The regolith scheme comprises three broad subdivisions; relict, erosional and depositional. Each broad subdivision can be further subdivided based on regolith composition, texture and slope; thirty-three such regolith units have been defined. The erosional regime is the dominant regolith type on MOUNT PHILLIPS and constitutes 47% of the sheet area. The colluvial units constitute 39% and the broad areas of drainage 11%. The relict regime and depositional eolian units are poorly developed on MOUNT PHILLIPS and together account for less than 3% of the map sheet area.

Differences in regolith chemistry are evident over the early- and late-stage granitoids. Samples over early-stage granitoid have higher SiO<sub>2</sub>, K<sub>2</sub>O, Ba, Ce, La, Nb, Pb, Rb, Sn, Th and U compared with regolith over the late-stage granitoid. The latter is clearly defined by elevated Al<sub>2</sub>O<sub>3</sub> and Na<sub>2</sub>O and particularly low Pb concentrations. The early-stage granitoid is variable in its regolith chemistry, which includes high Ba, F, Ga, Nb, Sr and Y south of Yinnetharra Station and elevated Be, Bi, Ta, W and Li around Camel and Morrissey hills. A broad area of shear zones between Mount Phillips Station and Seventeen Mile Outstation (overlying late-stage granitoid) contains elevated concentrations of K<sub>2</sub>O, Na<sub>2</sub>O, Ba, Cl, F, Ga, Nb, Rb and Sr in regolith.

Although the Bangemall Group has the most diverse range of regolith types compared with other units on MOUNT PHILLIPS, it is uniquely defined by its largely mafic signature. This is characterized by higher average concentrations for TiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>, MgO, CaO, Ce, Cr, La, Li, Ni, Nb, V, Zn and Zr in regolith. High As, Cd, In, Mo, Se and Sb (sulfidic shale indicators) are recorded adjacent to outcrops of the Jillawarra Formation, Discovery Chert, Devil Creek Formation and dolerite sills. Areas of calcrete, hardpan and alluvium, northwest of Mount Augustus Station, also carry elevated concentrations of Al<sub>2</sub>O<sub>3</sub>, CaO, MgO, LOI, Ba, Cl, Cu, Li, Ni, Pb, S, Sn, Sr and U. Some drainage samples also carry detectable Au and Pt, indicating that these depositional regolith regimes may be worthy of investigation.

The compositional diversity of the Morrissey Metamorphic Suite is reflected in its regolith geochemistry. This includes an area of northwesterly trending shear zones between Chalby Chalby and Mount Steere with the highest Na<sub>2</sub>O contents for the map sheet. Like early-stage granitoid, the Morrissey Metamorphic Suite contains a pegmatite zone of elevated Be, Bi, Li and W values north of Yinnetharra Station. Regolith geochemistry suggests this zone extends in a northwesterly direction towards Thirty-One River and in a southeasterly direction towards Mount James Station. Southeast of Coondoo Outcamp, near the boundary between the Carnarvon Basin and Archaean gneiss, the Morrissey Metamorphic Suite contains elevated Ce, La, Pb, Th, U, Y and Zr. Some of these elevated components are from samples within the lacustrine valley fill of the Nadarra Formation, which overlies the Morrissey Metamorphic Suite, and may represent a concentrating effect by carbonates.

Compared with other units, the Carnarvon Basin erosional regolith is characterized by high SiO<sub>2</sub> content and

low  $\text{Al}_2\text{O}_3$ , F, Ga, Nb, Sn and Sr. North of a line extending west of the Arthur River Outcamp, CaO, LOI, As, Li, Sr, Y and Zr values are noticeably lower than in the southern regions of the Carnarvon Basin. Higher CaO and LOI values in the south are probably due to the calcarenites of the dominant Callytharra Formation. Elevated Li and Ba concentrations, 25 km west of Arthur River Outcamp, may be related to near-surface granitoid beneath the Carnarvon Basin rocks.

Regolith chemistry has been used to construct three additive element-index maps, which highlight the potential for base-metal, pegmatite and REE mineralization. The base-metals index highlights areas in the northeast of the map sheet overlying Bangemall Group rocks. Moderate scores are also recorded southeast of Coondoo Outcamp and are related to elevated Pb values in regolith. The pegmatite index highlights an area between Thirty-One River and Mount James Station, and between Yinnetharra and Eudamullah stations. REE-index scores are high in the same area, as well as southeast of Coondoo Outcamp and in the southeastern corner of the map sheet.

A plot combining Landsat, airborne radiometric data, simplified geology and on-ground geochemistry has confirmed the utility of multi-datasets in geological and regolith mapping, geochemical surveys and the interpretation of geochemical anomalies. The combination of regional-scale geochemistry and remote sensing has suggested areas, particularly in the northwest of MOUNT PHILLIPS, where further bedrock mapping may be fruitful. It also lends support to the future approach of digitally integrating data (GIS) for mapping, map products and mineralization studies.

Regolith pH is low in areas of high  $\text{SiO}_2$ , such as the sandplain southwest of Mount Augustus Station and Carnarvon Basin regolith east of Coondoo Outcamp. The more alkaline areas tend to coincide with drainage, hardpan and calcrete. Elevated regolith TDS values highlight the hardpan northeast of Cobra Station, as well as the Gascoyne River and its tributaries around Yinnetharra Station.

The results of the regional regolith and geochemical mapping program on MOUNT PHILLIPS, combined with information from previous exploration activity and bedrock geology, indicate several areas worthy of further investigation in terms of mineral potential. However, some mineral occurrences (e.g. Cu and U in the Morrissey Metamorphic Suite) noted by Williams et al. (1983) are not fully supported by the results of the regional-scale regolith geochemistry. However, the sampling density of this program may be unsuitable in detecting localized mineralization where there is a limited dispersion halo.

Areas of mineral potential, identified in this study include:

- gold, base-metal and ferroalloy-metal mineralization, particularly associated with Bangemall Group rocks.
- pegmatite- and REE-associated minerals in the Morrissey Metamorphic Suite, and early- and late-stage granitoids.
- lead-bearing veins in the Morrissey Metamorphic Suite.
- semi-precious stones, largely in the Yinnetharra district.

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## Appendix 1

## Mines and prospects in MOUNT PHILLIPS prior to 31 December 1995

Mining centre	Years	Mine/prospect/ owner/name	Tenements	Location (AMG)		Production	
				Easting	Northing	Ore (t)	Metal (kg)
1. METALS							
BERYLLIUM							
Bidgemia	1960	Lee, E.	PA 9/35	391900	7264400	1.02	10.47
Eudamullah	1958–59	Sundry claims				7.47	895.00
Upper Gascoyne	1970	Kempton Bros	MC 9/186	388100	7262700	6.15	711.20
Yinnetharra	1943–44	Burt, G. H.	PA 70/815	415600	7287900	22.32	2 881.20
	1943–44	Moss, F. A. <sup>(a)</sup>	MC 70/291	405500	7288500	43.82	5 545.40
	1944	Commonwealth	Project 58	403900	7288900	2.54	299.10
	1949	NW Metals & Minerals	MC 70/413	<sup>(b)</sup> 415000	7283000	6.77	754.20
	1949–50	Symonds, H. H.	PA 70/891	410300	7287400	5.01	601.70
	1950	Western Rare Metals	MC 70/414–15	402600	7289100	7.38	752.40
	1950	Woodman, S. J.	PA 70/895	<sup>(b)</sup> 416500	Morrissey Creek	5.01	551.00
	1952–53	Brazzle, P. J.	MC 70/444	416500	7285300	1.54	190.20
	1959	Kempton Bros	PA 9/39	424600	7246800	6.56	791.00
	1959–60	Poland, W. C.	PA 9/36	429300	7246800	16.38	1 946.20
	1960	Kempton, T. L.	PA 9/40	<sup>(b)</sup> 429000	7249000	0.35	41.00
	1960	Williams, R.	PA 9/38	442000	7274800	0.34	45.00
	1960–61	Kempton Bros	PA 9/41	416800	7274900	45.28	5 503.20
	1961	Poland, W. C.	PA 9/43	406400	7292100	1.53	177.60
	1961	Starr, J.	PA 9/51	419300	7294200	4.22	491.80
	1943–68	Sundry claims				310.89	36 956.40
	Total					494.58	<sup>(c)</sup> 59 144.07
BISMUTH							
Morrissey Hill	1958	Kempton Bros	MC 9/17	398800	7298600	0.98	713.41
	1958	Wilhelm & Pederick	PA 9/32	406400	7289300	0.52	342.60
Upper Gascoyne	1970	Kempton & Kempton	MC 9/186	388100	7262700	0.91	261.27
Yinnetharra	1939–45	Thompson, A. B. <sup>(a)</sup>	MC 70/173	405700	7288300	3.04	2 033.45
	1940	Roe & Hassell	MC 70/195	416900	7284900	0.16	80.01
	1970	Hazlett, J. E.	MC 9/51	405500	7288400	0.81	542.57
	1943–62	Sundry claims				0.92	628.27
	Total					<sup>(d)</sup> 7.34	4 601.58
COPPER							
Yinnetharra	1963	Hester, M. P.	PA 9/62	<sup>(b)</sup> 421000	7249000	5.80	1 078.80
	1964–67	Sundry claims				4.34	477.40
	Total					10.14	1 556.20
GOLD							
Bangemall	1897–1916	Carnarvon Gem <sup>(a)</sup>	GML 9/1	445200	7323000	295.07	<sup>(e)</sup> 7.89
	1899	Boss	GML 9/4	445800	7322700	19.66	0.77
	1899	Eldorado	GML 9/6	446600	7322200	41.67	1.29
	1991–95	Sundry claims				37.00	<sup>(e)</sup> 10.25
	Total					393.40	<sup>(e)</sup> 20.20
TANTALITE							
Upper Gascoyne	1970	Kempton Bros	MC 9/186	388100	7262700	0.08	20.50
Yinnetharra	1980–81	Jays Exploration	MC 9/2651–2	406000	7288100	4.38	815.00
	1962–64	Sundry claims				0.41	194.60
	Total					4.87	1 030.10
TANTALITE/COLUMBITE							
Yinnetharra	1953	New Metals Australia	MC 70/458	405700	7288300	0.81	<sup>(f)</sup> 662.00
2. MINERALS							
MICA							
Yinnetharra	1939	Allsopp, C. H.	PA 70/699	<sup>(b)</sup> 439000	7255000		59.87
	1939	Martin, J. G.	PA 70/698	416100	7284600		27.22
	1940	Spargo & Martin	MC 70/180	416500	7285300		317.51
	1942	Thompson, A. B.	MC 70/173	405700	7288300		176.45
	1943–44	Commonwealth	Project 58	403900	7288900		10 103.88
	1949	Miller, D. F.	PA 70/893	<sup>(b)</sup> 417000	7286000		172.37
	1949	Woodman, S. J.	PA 70/895	<sup>(b)</sup> 417000	Morrissey Creek		382.15
	Total						11 239.45

## Appendix 1 (cont.)

Mining centre	Years	Mine/prospect/ owner/name	Tenements	Location (AMG)		Production	
				Easting	Northing	Ore (t)	Metal (kg)
TOURMALINE Gascoyne	1969–70	Soklich, A.	MC 9/82	414600	7280700		(g) 8 640
	1972–73	Soklich, D.	MC 9/346	409900	7287000		1 035
	<b>Total</b>						<b>9 675</b>
AMETHYST Gascoyne	1971–93	Soklich, F.	PL 9/66	416500	7285300		<b>343 048</b>

SOURCE: Department of Minerals and Energy (DME), unpublished records; Department of Mines, 1954

NOTES:

- (a) Group site
- (b) Tenement not map-located; position derived from written description
- (c) Beryl
- (d) Ore and concentrate
- (e) Includes alluvial/dollied
- (f) Includes 390 kg of columbite
- (g) Dravite specifically

## Appendix 2

## Open-file geochemical surveys

KEY	
<b>ID No.</b>	Project reference number — allocated for these notes
<b>Map sheet</b>	1:100 000 sheet number(s) to aid in project location (Plates 3 and 4)
<b>Area (sq km)</b>	Project area. When the project extends outside MOUNT PHILLIPS the area is not stated
<b>Company</b>	The company that carried out the geochemical exploration
	Expl: Exploration
	Consol: Consolidated
<b>M No.</b>	GSWA project reference number
<b>Item No.</b>	DME library reference number for a group of related open-file reports on microfiche; the Item number replaces the M number for project identification
<b>A No.</b>	GSWA report reference number
<b>Year</b>	The year that the report was written
<b>Medium</b>	How the sample was obtained
	RAB: Rotary air blast drilling
	RC: Reverse circulation drilling
<b>No/Ag to Zn</b>	The number of samples from the medium indicated, and each element determined marked 'X' or 'x'. The 'x' means that this element was not determined for the entire number of samples listed. If more than one analytical method is used for a group of samples from a particular medium, a new line is taken to identify the elements relevant to each method
<b>Method/Analyst</b>	Blanks occur in these columns if the information is not given in the company report
	AAS: Atomic absorption spectroscopy
	AR: Aqua regia
	BLEG: Bulk leach extractable gold
	ETA: Electrothermal absorption
	FA: Fire assay
	Hydride: Hydride generation
	ICP: Inductively coupled plasma
	Neuton: Neutron activation
	OES: Optical emission spectroscopy
	XRF: X-ray fluorescence
	AAL: Australian Assay Labs
	ALS: Australian Laboratory Services
	ARA: Assay Research Australia
	AS: Analytical Services
	CC: Classic Comlabs
	PL: Pilbara Labs
	PML: Perth Metallurgical Labs
	RDG: Resources Development
	RW: Rapley Wilkinson
<b>DD</b>	'Y' marked in this column indicates deep drilling activity
<b>Comments</b>	Further sample details with regards to collection and analysis
	D: Depth
	DL: Detection limit — only relates to gold analyses

NOTES: For public use all open-file company reports are provided on microfiche in the Department of Minerals and Energy (DME) library at Mineral House. To locate a particular report on microfiche, the relevant Item number and A number are required

## Appendix 2

## Open-file surface geochemistry

ID No.	Map Sheet	Area sqkm	Company	M No.	Item No.	A No.(s)	Year	Medium	No.	Ag	As	Au	Ba	Bi	Co
1	2249		Westfield Minerals	62	3227	573 980	1968	RAB Rock Soil Stream	3 35 54 153						
2	2149	9	Union Miniere Ltd	1094	172	3322	1972	Diamond Percussion Rock	1 7 51						
3	2148	2	Carpentaria Exploration Co	1164	2060	3588	1972	Auger Rock Soil Stream	34 12 60 16						
4	2148	70	Aust Anglo American Services	1238/2	153/B	3780	1972	Auger	78						
5	2049 2149	150	Esso Mineral Enterprise Aust	1414	32	4523	1974	Rock Stream	140 524	X X				X X	X X
6	2148		Frio Mining & Expl / Samedan Oil	1464	143	5373	1974	Grab	86						
7	2148 2149		Esso Mineral Enterprises Aust	1489	84	4525	1974	Rock Stream	104 308	X X		X X		X X	X X
8	2248		Noranda Aust	1624	607	5278	1973	Auger Soil	8 107						
9	2149	25	Newmont / Samin	1716/1	929	5825	1975	Gossan	120	X			X		
10	2149	35	Newmont	1716/1	928	5720	1975	Gossan RC Rock	19 355 101			X X X			
11	2148 2248	200	Agip Nucleare Aust	1732/1	601	7570	1978	Rock Vacuum	24 23						
12	2248	110	Agip Nucleare Aust	1732/2	602	6829	1977	Costean Rock Soil Vacuum	72 5 1 26						
13	2148 2248	125	Agip Nucleare Aust	1732/4	725	7598	1978	Rock Vacuum	26 35						

## survey for MOUNT PHILLIPS as at 20 December 1995

Cu	Mn	Mo	Nb	Ni	Pb	Sb	Ta	Th	U	W	Zn	Method	Analyst	DD	Comment on Samples
X											X			Y	D:0-6ft, poor sample location
X											X				5 traverses, 100-200ft intervals
X															5 traverses
X											X				
X					X						X			Y	
X					X						X				Results as profiles
X					X						X				
X											X				
X					X						X				Channel
X					X						X				
									X						U3O8 only, 17 traverses
X				X	X				X		X				500m intervals
X				X	X				X		X				
									X	X	X				Also V, some outside project area
X				X					X		X	AAS, XRF			
X				X					X		X	AAS, XRF			
									X						
									X			XRF			
X	X				X						X	AAS		Y	
														Y	
X	X				X						X	FA/AAS AAS			
									X	X					
									X	X					D:0-1m
									X	X				Y	
									X	X					
									X	X					
									X	X				Y	Grab
									X	X					D:0-1m

## Appendix 2

ID No.	Map Sheet	Area sqkm	Company	M No.	Item No.	A No.(s)	Yr	Medium	No.	Ag	As	Au	Ba	Bi	Co
14	2248	1	Agip Nucleare Aust	1732/6	604	6881	1977	Costean Vacuum	44 27						
15	2248	2	Agip Nucleare Aust	1732/7	605	6883	1977	Costean Vacuum	23 16						
16	2148	20	Uranerz	1833	329	6349	1976	Costean Percussion Rock	3 27 13						
17	2149	200	Occidental Minerals	2382	1104	8598	1979	Rock Rock Rock	80 3 5	X	x	X		X	
18	2248 2249		Intl Nicklet Aust Ltd	2487	1111	8716	1979	Auger Rock Soil Stream	77 134 174 267	X					
19A	2248	200	Urangesellschaft Aust	2567/1	2008	9797	1981	Percussion Rock Stream	81 21 38				X		
			Urangesellschaft Aust	2567/1	2008	10405	1981	Percussion Stream	81 38		X		X		
19B	2248	370	Urangesellschaft Aust	2567/1	2008	9788	1981	Rock Stream	97 17						
			Urangesellschaft Aust	2567/1	2008	11545	1981	Stream	146						
			Urangesellschaft Aust	2567/1	2008	16273	1981	Rock Stream	28 17						
20	2248		Urangesellschaft Aust	2567/2	2009	10897	1982	Costean Costean Grab Percussion Rock Stream	12 8 29 6 15 15		X	X			
										X					
											X	X			
21	2048 2148		Urangesellschaft Aust	2567/4	2011	13128	1983	Grab Rock Rock Rock	15 10 120 2						
											X	x			X
22	2248	2	Esperance Minerals NL	2579	2698	8817	1979	Drill	45						

(continued)

Cu	Mn	Mo	Nb	Ni	Pb	Sb	Ta	Th	U	W	Zn	Method	Analyst	DD	Comment on Samples
								X	X					Y	
								X	X						
								X	X						
								X	X						D:0-1m
								X	X				Labtech		D:0-1.5m
X					X			X	X		X				
								X	X						
								X	X						
X	X	X			X			x			X				Also for U3O8, V
								X	X			XRF	ACS Lab		
					X			X	X				Amdel		
X	X				X						X			Y	D:0-1m
X	X				X						X	AAS			
X	X				X						X	AAS	SGS		
X					X						X	AAS			Mesh:-20#
X					X			X	X		X		PL		D:0-1m
X					X			X	X		X				Also for P2O5
X					X			X	X		X		PL		Also for Se
X					X			X	X		X				
X					X				X		X				Also for Se
X			X		X		X	X	X		X	XRF, AAS	PL		Also for Mg
			X				X	X	X	X		XRF, ICP			
							X			X			Amdel		
								X	X				PL		Also for Mg
X		X	X		X		X	X	X	X	X		*		
				X				X	X			XRF	Analabs/CMS	Y	Also for Cr, V
								X	X				PL/CMS		
								X	X				PL		Channel
								X	X				*		D:0-1m
								X	X				*		
X					x		x		x	x	X		*		Also Se & some Sn
										X			Amdel		
										X		XRF	PL		Channel
x		X			x	X					x	ICP	*		Also some Sn, channel
			X				X	X	X	X			PL/CMS		Also Ce, Eu, La, Nd, Sm, Tb, Y
									X			XRF	Analabs	Y	Also Rb, Sr; 200x100m grid, D:1.5m

## Appendix 2

ID No.	Map Sheet	Area sqkm	Company	M No.	Item No.	A No.(s)	Yr	Medium	No.	Ag	As	Au	Ba	Bi	Co
23	2148 2149 2248	126	Aust Anglo Amer Prosp	2640	2235	9809	1981	Rock Stream Stream Stream	46 141 311 107	x   	x   	   	x   	   	x   
24A	2149	10	Whim Creek Consolidated NL	2689/01	2166	9617	1980	Rock Soil Soil Stream	63 195 71 25	X   	X  X	X   	X   	X   	X   
			Whim Creek Consolidated NL	2689/01	2166	10728, 30	1981	Percussion	112						
24B	2148 2149	110	Whim Creek Consolidated NL	2689/01	2166	10371	1981	Rock Soil Soil	12 71 194	   	x X x	X   	   	   	   
			Whim Creek Consolidated NL	2689/01	2166	10374	1981	Rock Rock Stream	18 33 69	   	  x	 x x	 x x	   	   
			Whim Creek Consolidated NL	2689/01	2166	11431-33	1982	Percussion	53						
24C	2148 2149		Whim Creek Consolidated NL	2689/01	2166	10731 10733	1981	Percussion Rock	21 4	 X	  	  X	   	   	   
25	2148 2149		Whim Creek Consolidated NL	2689/02	2063	10651	1982	Rock Stream	2 65						
26	2148	380	Kalgoorlie Southern Gold Mines NL	2793	1824	10001	1980	Stream	105	x	x		X		
27	2248 2249		Alcoa of Australia Ltd	2882/00	2049	12208	1982	Rock	40	x			x	x	x
28	2149	30	AMAX Australia Ltd	3052/1	2257	11710-11	1982	Rock Rock Soil Soil Soil "	524 105 30 11 7	X X X X X	    X	    	    	X X X	X X X
29	2049 2149		Alcoa of Australia	3052/2	2258	12356	1982	Ironstone Rock	3 76	X X	  	X X	  	X X	  
30	2149	2	Esmeralda Expl/Tanderra Investments	3087	5665	12045	1983	Rock	45		x	x			
			Tanderra Investments	3087	5665	13663	1983	Rock	22	X		X			
			Esmeralda Exploration Ltd	3087	5665	23223	1987	Soil "	13						
			Esmeralda Exploration Ltd	3087	5665	28241	1989	Rock	14		X	X			

(continued)

<i>Cu</i>	<i>Mn</i>	<i>Mo</i>	<i>Nb</i>	<i>Ni</i>	<i>Pb</i>	<i>Sb</i>	<i>Ta</i>	<i>Th</i>	<i>U</i>	<i>W</i>	<i>Zn</i>	<i>Method</i>	<i>Analyst</i>	<i>DD</i>	<i>Comment on Samples</i>
x	x	x	X	x		x	x			x		AAS, XRF			Also some Cd, F
x		x	x	x	x		x				x	XRF			Also Sr & some Li, mesh:-12#
X				X	X						X	AAS			6 samples / sqkm
		X								X		AAS, XRF			Also for Li, Sn
X		x			X	x	x				X		Genalysis	Y	Also Sn & some F
X										X			"		Mesh: -80#
										X			"		Mesh:-8mm
		X											"		Mesh: -8mm , -1/4"
										X			Genalysis/SGS	Y	D:0-2m
X		X			x	x				X				Y	Also for F, Sn
X										X					Mesh: -8mm
x										x					Mesh:-80#
X										X			Genalysis		
x		x					x			x					Also some F, Sn
x		x		x	x					X	x		Genalysis		Also for Sn, mesh: -1/4"
										X		FA/AAS	Genalysis	Y	D:0-2m-angled.
										X		FA/AAS	Genalysis	Y	D:0-2m
X					X						X		"		Also for Sn
										X			Genalysis		Wt:10kg, mesh:-5mm, along skams
										X					
x		X	X		x		X	X		X	x		Genalysis		Also Be, Li, Rb, Sn, U3O8
x	x			x	x						x			Y	Also Cd & some Fe,TiO ; outcrop
X		X			X						X	AAS	Analabs		100mx50m grid
X		X			X						X	AAS	"		
X		X			X						X	AAS	"		Mesh: -20#
													"		
X	X	X	X	X	X	X	X	X		X	X		"		Also Be,Ca,Cd,Cr,Fe,K,La,Li,Mg,Na,P, S,ScSi,Sn,Ti,V.
X					X						X		Genalysis		Also for Fe,Mg; overlying siltstone
X					X						X		"		Also for Fe,Mg; 6 traverses
	x				x			x							Also Li & some U3O8, Y2O3
X	X	X			X				X		X		Genalysis		
								X	X	X			Nagram		Also Ce,Dy,La,Nb2O5,Nd,Ta2O5,WO3, Y,Yb; alluvial bulk, D:1.1m
			X												Also for Y2O3

## Appendix 2

ID No.	Map Sheet	Area sqkm	Company	M No.	Item No.	A No.(s)	Yr	Medium	No.	Ag	As	Au	Ba	Bi	Co
31A	2149		BHP Minerals	3805	4401	15620	1985	Percussion	11	X	X				
	2249							Rock	20	X					
31B	2149		BHP Minerals	3805/01	4401	19281	1986	Soil	357	X	X				
	2249							Stream	57	X	X				
32	2048		BHP Exploration	3857	3106	16401	1985	Stream	35		X		X		X
	2049							"							
33	2149	510	Broken Hill Pty Co Ltd	3910	3161	15960	1984	Auger	15			X			
	2248							Costean	11			X			
	2249							Drilling	13	X	X				
								"				X			
								Rock	164		X	X			
								Soil	82			X			
								Soil	1 299		X	X	X		
								Stream	30	X	X				
								"					X		
								"				X			
								Stream	30		X				
								"				X			
								Stream	30			X			
			Broken Hill Pty Co Ltd	3910	3161	15961	1985	Stream	88			X			
34	2148		CRA Exploration	3924	2139	16077	1985	Rock	10		X	X	X	X	X
								Stream	18	X	X	X	X		X
35	2148	70	Greenvale Mining NL	3970/01	3703	16096	1985	Auger	22						
								Stream	112						
36	2148	40	Greenvale Mining /Esperance Minerals	3970/02	3704	19682	1986	Stream	32						
37	2148	70	CRA Exploration	4117	3015	17512	1985	Rock	47		X	X			
	2149							"							
								Rock	5	X	X	X	X		X
38	2149		Esmeralda Exploration / Lubbok	4136	3586	17445	1985	Soil	489		X	X		X	
								Soil	8			X			
			Esmeralda Exploration	4136	3586	24746	1988	Rock	145			X			
39	2149	65	Indian Ocean Gold	4551	4793	20530	1987	Rock	228			X			
	2249														
40	2149	1	Inca Gold NL	5246	4710	23986	1988	Rock	83			X			

(continued)

Cu	Mn	Mo	Nb	Ni	Pb	Sb	Ta	Th	U	W	Zn	Method	Analyst	DD	Comment on Samples
X					X						X		Amdel	Y	D:0-2m
X					X						X	Mixed acid /AAS	PL		
X					X						X	AAS	RDG		50m intervals
X					X						X	AAS	"		Mesh:-20# & +40#
X			X	X	X						X		Analabs		Also Cr,La & some Ce; gravel, Wt:20kg, mesh:-4mm
												FA	PL	Y	
												FA	"		Vert. channel samples @ 10cm intervals
X	X				X						X	AAS	"		D:0-2m, 2m intervals.
												FA	"		
x					x						x	AAS	"		Mesh:+2mm, -2mm; 25m intervals,
												FA	"		Mesh:+2mm, -2mm
x	x				x						x	AAS	Comlabs		25m intervals traverses
X	X				X						X	AAS	PL		Wt:10kg(panned to 0.2kg), mesh:-4mm
												ICP	"		
												FA	"		
X	X				X						X	AAS	"		Mesh:-4mm, fractional analysis
												FA	"		
												Cyanide	Analabs		Mesh:-2mm
												Cyanide/AR	PML/Amdel		Wt:7kg, mesh:-4mm
X	X	X		X	X					X	X	AAS	Genalysis		Also for Cr, Ga, P, Sn, U205
X	X	X		X	X						X	AAS	"		Also Cr,Fe,U3O8; mesh: -80#
			X				X					XRF			D:0.4m
			X				X					AAS, XRF			For some Nb2O5,Sn,Ta2O5; Wt:3kg
			X				X					ICP,XRF,AAS			Wt: 3kg, D:blw 0.15m
X	X				X						X	AAS	Genalysis		Also Al2O3,CrO,K2O,Na2O; 5m intervals, 2 trenches 890m apart.
X	X	X		X	X						X		Minlab		Also for Cd, Cr
X					X						X		PL		Wt:15kg, mesh:-20# Bulk, Vol:0.5m3, D:2m
				X						X	X		AS		
													RDG		7 samples taken outside tenement

## Appendix 2

ID No.	Map Sheet	Area sqkm	Company	M No.	Item No.	A No.(s)	Yr	Medium	No.	Ag	As	Au	Ba	Bi	Co		
41	2248	300	Battle Mountain (Aust) Inc	5396	4174	24587-90	1988	Percussion	98			X					
								Rock	266	X	X	X					
								Soil	771			X					
								Stream	725			X					
								Stream	15			X					
			Battle Mountain (Aust) Inc	5396	4174	27536-38 27540	1989	Percussion	236			X					
								Rock	152			X					
								Soil	289			X					
								Stream	488			X					
42	2049	420	BHP-Utah Minerals Intl.	5620	3610	23903	1987	Rock	93	X							
	2148							Soil	2 546	X							
	2149																
	2248																
43	2048	180	Aust Consolidated Minerals	5854	3734	25293	88	Rock	45			X					
	2148							Stream	80	X		X					
44	2248		Baracus Pty Ltd/Kingsgate Consol	5877	4346	25317	88	Percussion	12			X					
			Baracus Pty Ltd	5877	4346	26245	1989	Percussion	14			X					
			Kingsgate Consolidated NL	5877	4346	29810	1989	Rock	14			X					
45	2149	6	Sons of Gwalia	6202	7002	35602	1989	RC	12			X					
								Rock	21		x	X					
								Rock	17			X					
								"		X							
								Rock	12		X						
								Rock	5		X						
								Soil	97			X					
46	2148	110	BW Menzel & Quicksilver	6268	5403	28109	88	Rock	37			X					
	2149							Soil	9			X					
47	2148	185	Helix Resources NL	6518	4361	29892	1989	Grab	17			X					
	2248							Rock	36			x					
								Soil	10			X					
								Stream	28			X					
48	2048	790	Kookynie Resources NL	6752	4455	31555	90	Stream	40	X		X		X			
	2049																
	2149																
	2148																

(continued)

Cu	Mn	Mo	Nb	Ni	Pb	Sb	Ta	Th	Sn	Y	Zn	Method	Analyst	DD	Comment on Samples
X					X							FA /AAS	Genalysis	Y	Also Pd,Pt; channel & grab
												FA	"		Also Pt, D:0.2m,Wt:6kg
												FA	"		1 sample/sqkm, Wt:12kg
												BLEG	"		Wt:3kg
															D:0-1m
															Heavy mineral concentration
X	X				X						X	AAS	Analabs		Grab
X	X				X						X	AAS	"		Intervals 5-10m, D:0.3m
X					X						X		Comlabs		
X												BLEG	Classic		Wt:5kg
												FA	AAL	Y	Wt:2kg, D:0-1m
												FA	AAL		Wt:2kg, D:0-1m
												FA	Analabs		Wt:5kg, outcrop
x	x				x	x					x	AR/AAS	Genalysis		Wt:1kg, D: 0-1m
												FA/AAS	"	Y	Also for Fe. Grab
X					X							AAS	RW		
										X		XRF	RW		
												Hydride	"		
												AR/ETA	Genalysis		Mesh:-2mm, 100x25m grid
X												AR/AAS	"		
X													Genalysis		
												BLEG	Analabs		Mesh:-1.2mm, 20mx150m grid
X				X	X						X		Amtel		Also for Pd, Pt
x			x	x	x		x			x	x		"		Also some La, Pt, Y
X				X	X						X		"		Also for Pd, Pt; mesh:-3mm
													"		Wt:25kg, mesh: 2mm
			X				X	X		X	X		Analabs		Also Be,Ce,Fe,Gd,La,Ti, Y; mesh:-2mm

## Appendix 2

ID No.	Map Sheet	Area sqkm	Company	M No.	Item No.	A No.(s)	Yr	Medium	No.	Ag	As	Au	Ba	Bi	Co
49	2149 2249		Newmont Australia Ltd	6783	6438	32886-88	90	RAB	26		x	x	x		
								Rock	55	X	X	X	X		X
								Soil	24	X			X	X	
								Stream	78	X	X	x	X	X	X
			Newcrest Mining Ltd	6783	6438	35093	1991	Auger	85		X	X		X	
								RAB	88	X	X	X	X	X	X
								"							
								"							
50	2149 2249	349	Newcrest Mining Ltd	6783/02	6069	34699	1991	RAB	48			X			
								"		X	X	X	X	X	X
								"							
			Newcrest Mining Ltd	6783/02	6069	34982	1991	Lag	5		X	X	X		X
								Rock	21			X			
								"		X					
								"		X	X	X	X	X	X
								"							
								Soil	13		X		X		X
								Stream	6					x	X
								"							
51	2249		Newcrest Mining NL	7180	5865	34702	1991	Lag	12	X	X		X	X	X
								"							
								Rock	27	X	X		X		X
								"		X					
								"				X			
								Stream	17	X	X		X	X	X
								Stream	2			X			
52	2148	200	Poseidon Exploration Ltd	8026/2	7302	38467	1993	Rock	74			X			
								"		X	X		X	X	X
								Soil	124	X	X	X	X		
								Stream	150		X	X	X	X	
53	2248	210	International Resource Services	8139	7047	38755	1992	Rock	42	X		X	x	x	
54	2049 2149		Newcrest Mining Ltd	8242/00	6926	39271	1993	Rock	83	x	X	X	x		
								Stream	88						
								"				X			

(continued)

<i>Cu</i>	<i>Mn</i>	<i>Mo</i>	<i>Nb</i>	<i>Ni</i>	<i>Pb</i>	<i>Sb</i>	<i>Ta</i>	<i>Th</i>	<i>U</i>	<i>W</i>	<i>Zn</i>	<i>Method</i>	<i>Analyst</i>	<i>DD</i>	<i>Comment on Samples</i>
x						x			x				Analabs	Y	Also Pt,Rb & some Eu,La,Se,W; D:0-1m
X	X	X	X	X	X	X	X	X	X	X	X		"		Also Cr,Cs,Eu,Fe,Hf,Ir,K,La,Lu,Na,P,Sc,Sm,Ti,Yb,Zr.
		x	x			x				x	x		Analabs		Also for Ce,Cs,Eu,La,Rb,Se,Sm,Yb, Wt:2kg, mesh:-80#.
		X				X	X	x	x	X	X		Analabs		Also Ce,Cr,Cs,Eu,Fe,Hf,Ir,La,Lu,Rb,Sc,Se,Sm,Yb; Wt:4kg, mesh:-80#.
X		X		X	X						X		Genalysis	Y	Also for Fe, Se
X	X	X		X	X	X	X	X	X	X	X		Analabs		Also Br,Ce,Cr,Cs,Eu,Fe,Hf,Ir,K,La,Lu,P,Rb,Sc,Se,Sm,Ti,Yb; D:0-1m.
												ETA	Analabs	Y	
X	X			X	X						X	ICP	"		Also for Ti
X	X	X		X	X	X	X	X		X	X	Neutron act.	"		Also Ce,Cr,Cs,Eu,Fe,Hf,I,La,Lu,Rb,Sc,Se,Sm,Ti,Yb; D:0-1m.
X	X	X	X	X	X	X		X	X	X	X	Neutron act.	Analabs		Also Br,Ce,Cr,Cs,Eu,Fe,Hf,Ir,K,La,Lu,Na,P,Rb,Sc,Se,Sm,Te,Ti,Yb.
X	X		X	X	X				X		X	AR/ETA	Analabs		
		X							X		X	ICP-OES	"		Also for K, P, Ti
						X		X	X	X	X	Neutron act.	"		Also for Ce, Cr, Cs, Eu, Fe, Hf, Ir, La, Lu, Rb, Sc, Se, Sm, Ta, Yb
X	X	X			x	X	X	X		x	X	Neutron act.	Analabs		Also Ce,Cr,Cs,Eu,Hf,K,La,Na,Rb,Sc,Sn,Yb.
X	X											Neutron act.	Analabs		Also for Cr, Fe, I, K, Na, Rb, Sc
X	X	X	X	X	X	X	X	X	X	X	X	Neutron act.	Bequerel		Also Ce,Cr,Cs,Fe,Hf,Ir,K,La,Lu,P,Rb,Sc,Se,Sn,Ti,Y,Yb.
		X				X	X	X	X	X	X	Neutron act.	Bequerel		Also Br,Ce,Cr,Cs,Eu,Fe,Hf,Ir,La,Lu,Rb,Sc,Se,Sn,Yb.
X	X	X	X	X	X						X	ICP	Analabs		Also for K,P,Ti,Yb
X	X	X	X	X	X	X	X	X	X	X	X	AR	"		
X	X	X	X	X	X	X	X	X	X	X	X	Neutron act.	Bequerel		Also Ce,Cr,Cs,Fe,Hf,Ir,K,La,Lu,P,Rb,Sc,Se,Sn,Ti,Y,Yb.
												AR	Analabs		
X	X			X	X						X	AR/AAS	ALS		
X	X				X						X	ICP	"		Also for Cd,Fe,P
X	X	X		X	X	X					X		"		Also Fe; Wt:2kg, D:blw 0.2m,100m intervals
													"		Also Cd,Fe; Wt:2kg, mesh:-2+0.5mm
X		x			X	x			x	x	X				Also Ir & some Cd,Ga,Ge,Hg,Sn,; surface
X		X			X	X				X	X		Genalysis		Wt:4kg, mesh:-2mm
X		X			X	X					X		ARA		Wt:2kg, mesh:-2mm.
												BLEG	"		

## Appendix 2

<i>ID</i> <i>No.</i>	<i>Map</i> <i>Sheet</i>	<i>Area</i> <i>sqkm</i>	<i>Company</i>	<i>M No.</i>	<i>Item</i> <i>No.</i>	<i>A No.(s)</i>	<i>Yr</i>	<i>Medium</i>	<i>No.</i>	<i>Ag</i>	<i>As</i>	<i>Au</i>	<i>Ba</i>	<i>Bi</i>	<i>Co</i>
55	2048	210	Helix Resources NL	9026	7745	42509	1994	Rock	105	X	x	X	x	x	x
	2148							Stream	108			X			

**Source:** Department of Minerals and Energy, WAMEX database, 20 December 1995

(continued)

<i>Cu</i>	<i>Mn</i>	<i>Mo</i>	<i>Nb</i>	<i>Ni</i>	<i>Pb</i>	<i>Sb</i>	<i>Ta</i>	<i>Th</i>	<i>U</i>	<i>W</i>	<i>Zn</i>	<i>Method</i>	<i>Analyst</i>	<i>DD</i>	<i>Comment on Samples</i>
X	x	x			X	x				x			Analabs		Also some Ga, Ge, Sn, Tl
X					X						X	BLEG	"		Wt: 5k; 200g. Mesh; -80

## Appendix 3

## Regolith sample-recording form

Mt. Phillips

Sheet <u>SG 50-2</u> Zone <u>50 I</u>		Loc/n No _____	GSWA No _____	Date _____
Site Ref _____		_____ E	_____ N	Sampler _____
Photo Y/N (Describe) _____				
Channel <input type="checkbox"/> Pit/Hole <input type="checkbox"/> Single point <input type="checkbox"/> Multipoint <input type="checkbox"/> Shtwash <input type="checkbox"/> Creek <input type="checkbox"/> Soil <input type="checkbox"/> Lake <input type="checkbox"/>				
<b>CLASTS</b> Gravel (2-5mm) <input type="checkbox"/> Stones (5-64mm) <input type="checkbox"/> Cobbles (64-256mm) <input type="checkbox"/> Boulders(>256mm) <input type="checkbox"/>		Surrounding Regolith Code: Left _____ Right _____		
Abundnt : >30%    Commn : 5-30%    Rare : 1-5%    Trace : <1%		Regolith Description:		
Iron-rich Abnt/Comn/Rare/Tr <input type="checkbox"/> Lithic Abnt/ Comn / Rare/ Tr <input type="checkbox"/>				
<input type="checkbox"/> Pisoliths		<input type="checkbox"/> Saprolite fragments		
<input type="checkbox"/> Nodules <input type="checkbox"/> Ferrug. granules		<input type="checkbox"/> Ferruginous Saprolite frag's		
<input type="checkbox"/> Ferrug. duricrust		<input type="checkbox"/> Saprock Fragments		
<input type="checkbox"/> Gossan fragments		<input type="checkbox"/> Fresh B'rock frag's (below)		
<input type="checkbox"/> Ferrug lithic fragments		<input type="checkbox"/> Quartz <input type="checkbox"/> Other Silica		
Non-Lith Abnt/Comn/Rare/Tr <input type="checkbox"/>		<b>Clast Lithology</b>		
<input type="checkbox"/> Feldspar		<input type="checkbox"/> Mafic	<input type="checkbox"/> BIF	<input type="checkbox"/> Carbonate
<input type="checkbox"/> Calcrete		<input type="checkbox"/> Ultramafic	<input type="checkbox"/> Sandstone	<input type="checkbox"/> Pyroclastics
<input type="checkbox"/> Hardpan		<input type="checkbox"/> Felsic	<input type="checkbox"/> Ark / Gwk	<input type="checkbox"/> Other
<input type="checkbox"/> MnO <sub>2</sub>		<input type="checkbox"/> Granite	<input type="checkbox"/> Shale/Siltstone	
<input type="checkbox"/> Silcrete <input type="checkbox"/> Other :		<input type="checkbox"/> Quartzite	<input type="checkbox"/> Chert	
Secondary coating <input type="checkbox"/> Fe / Mn <input type="checkbox"/> Siliceous <input type="checkbox"/> Calcareous <input type="checkbox"/> Clay				
- 2 mm Material <input type="checkbox"/> Sand (0.1 - 2mm) <input type="checkbox"/> Clay <input type="checkbox"/> Other _____ Colour _____				

Rock O/c	Dist.	Dir.	Secondary Units Nearby	Heading _____ Width: _____ m
1. _____ m _____			Hardpan <input type="checkbox"/> Consolidated Collvm <input type="checkbox"/>	<input type="checkbox"/> Single <input type="checkbox"/> Braided <input type="checkbox"/> Incised
2. _____ m _____			Calcrete <input type="checkbox"/> Duricrust <input type="checkbox"/>	Seived to Size Y/N    Depth- _____
3. _____ m _____			Mot Zone <input type="checkbox"/> Saprolite <input type="checkbox"/> Saprock <input type="checkbox"/>	Osize - _____ %    Usize - _____ %
4. _____ m _____			Gyps Dune <input type="checkbox"/> Sand Dune <input type="checkbox"/> Salt <input type="checkbox"/>	

REMARKS

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## Figures

1. Locality plan
2. Geological interpretation
3. Generalized regolith

### Element-distribution maps

4.  $\text{TiO}_2$
5.  $\text{Al}_2\text{O}_3$
6.  $\text{Fe}_2\text{O}_3$
7. MnO
8. MgO
9. CaO
10.  $\text{Na}_2\text{O}$
11.  $\text{K}_2\text{O}$
12.  $\text{P}_2\text{O}_5$
13. LOI
14. Ag
15. As
16. Au
17. Ba
18. Be
19. Bi
20. Cd
21. Ce
22. Cl
23. Co
24. Cr
25. Cu
26. F
27. Ga
28. In
29. La
30. Li
31. Mo
32. Nb
33. Ni
34. Pb
35. Pd
36. Pt
37. Rb
38. S
39. Sb
40. Sc
41. Se
42. Sn
43. Sr
44. Ta
45. Th
46. U
47. V
48. W
49. Y
50. Zn
51. Zr
52. Contoured regolith pH
53. Contoured regolith TDS (mg/L) and borehole TDS (mg/L) data
54. Base-metals index (Cu + Pb + Zn + Sn + As + Sb)
55. Pegmatite index (Be + Bi + Nb + Sn + Ta + W)
56. REE index (Ce + La + Th + U + Y + Zr)
57. Combination plot of Landsat (shaded grey), radiometric data, geology and regolith geochemistry ( $\text{K}_2\text{O}$ ) of part of MOUNT PHILLIPS



Figure 1.

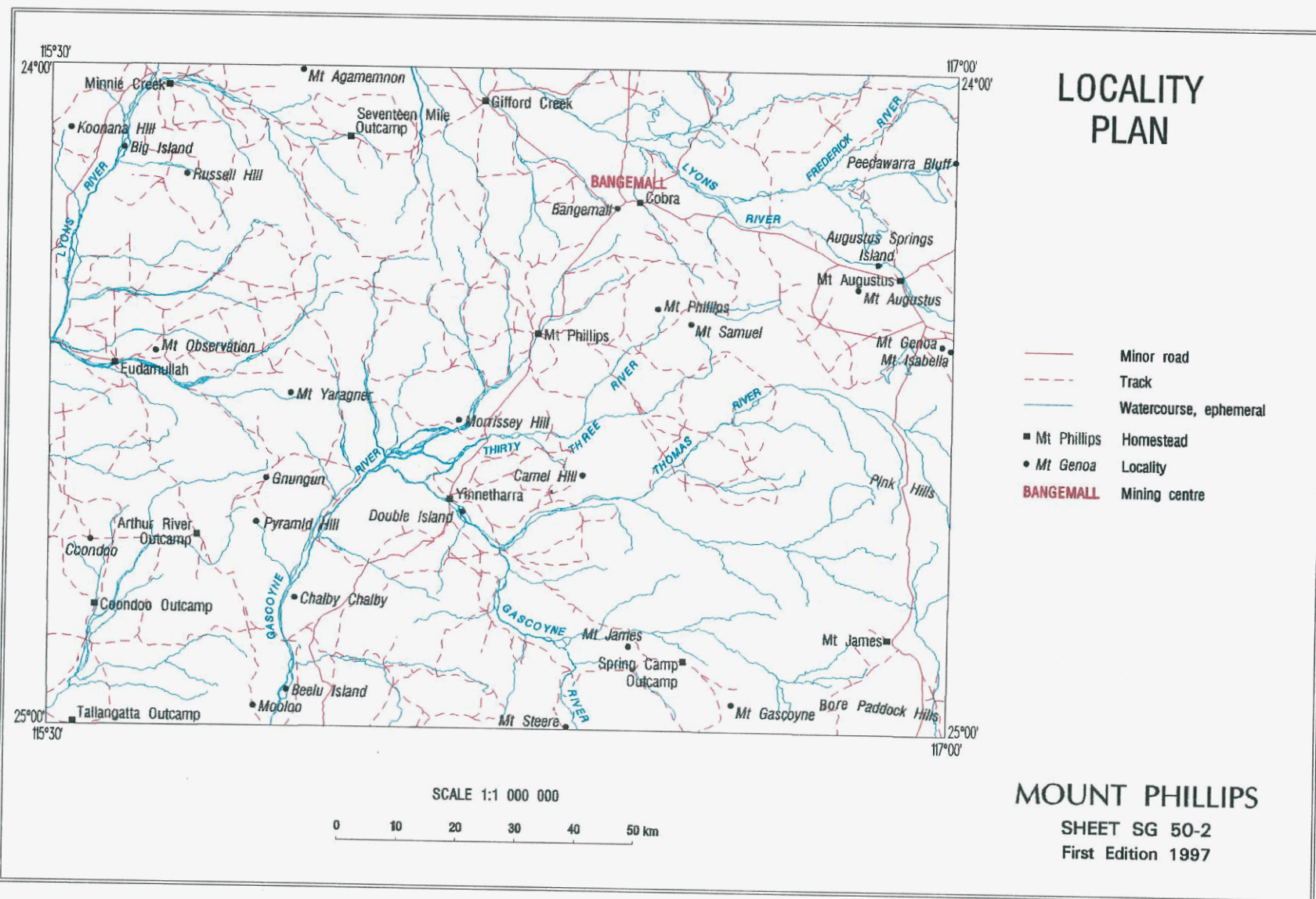
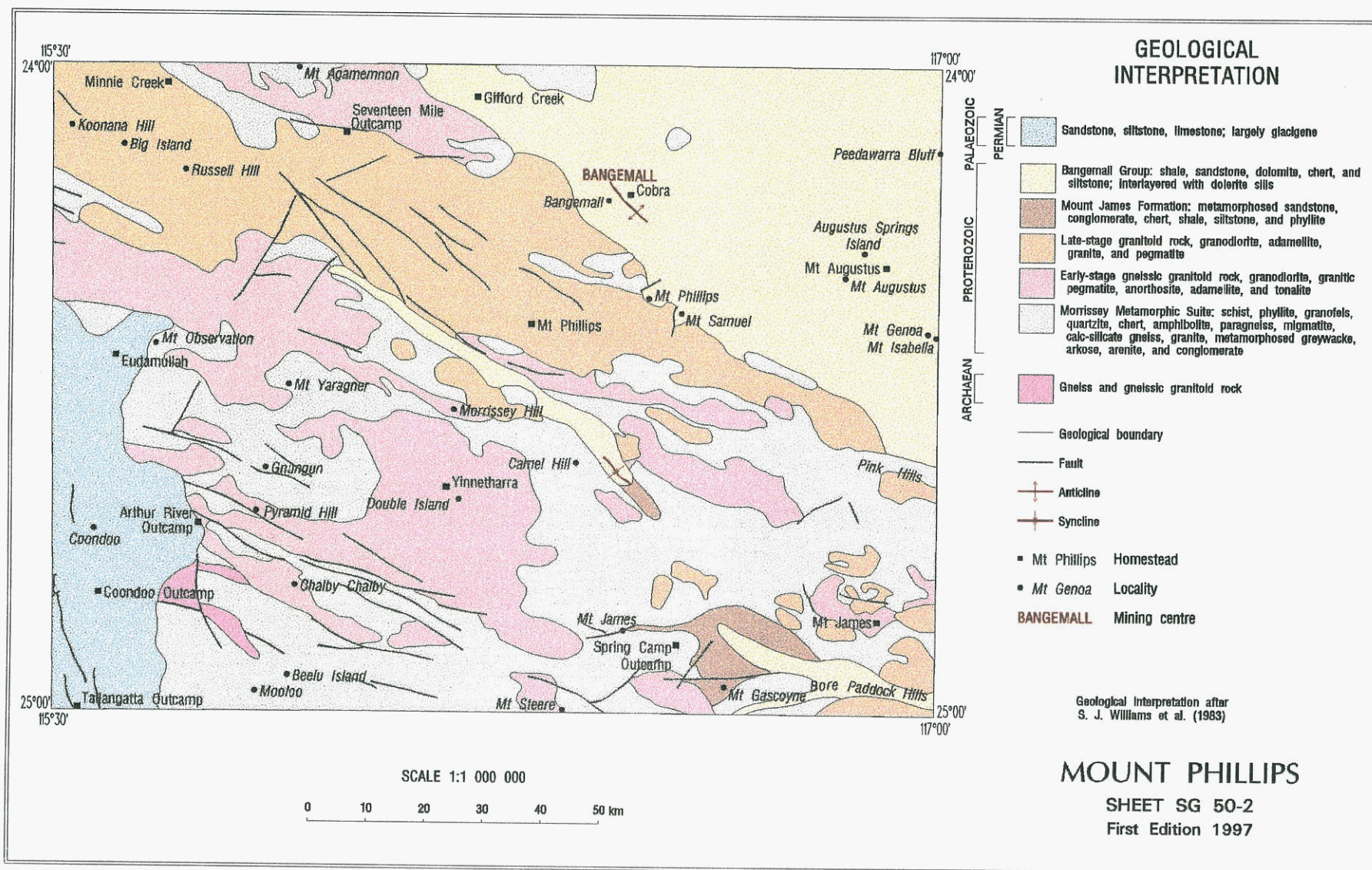


Figure 2.



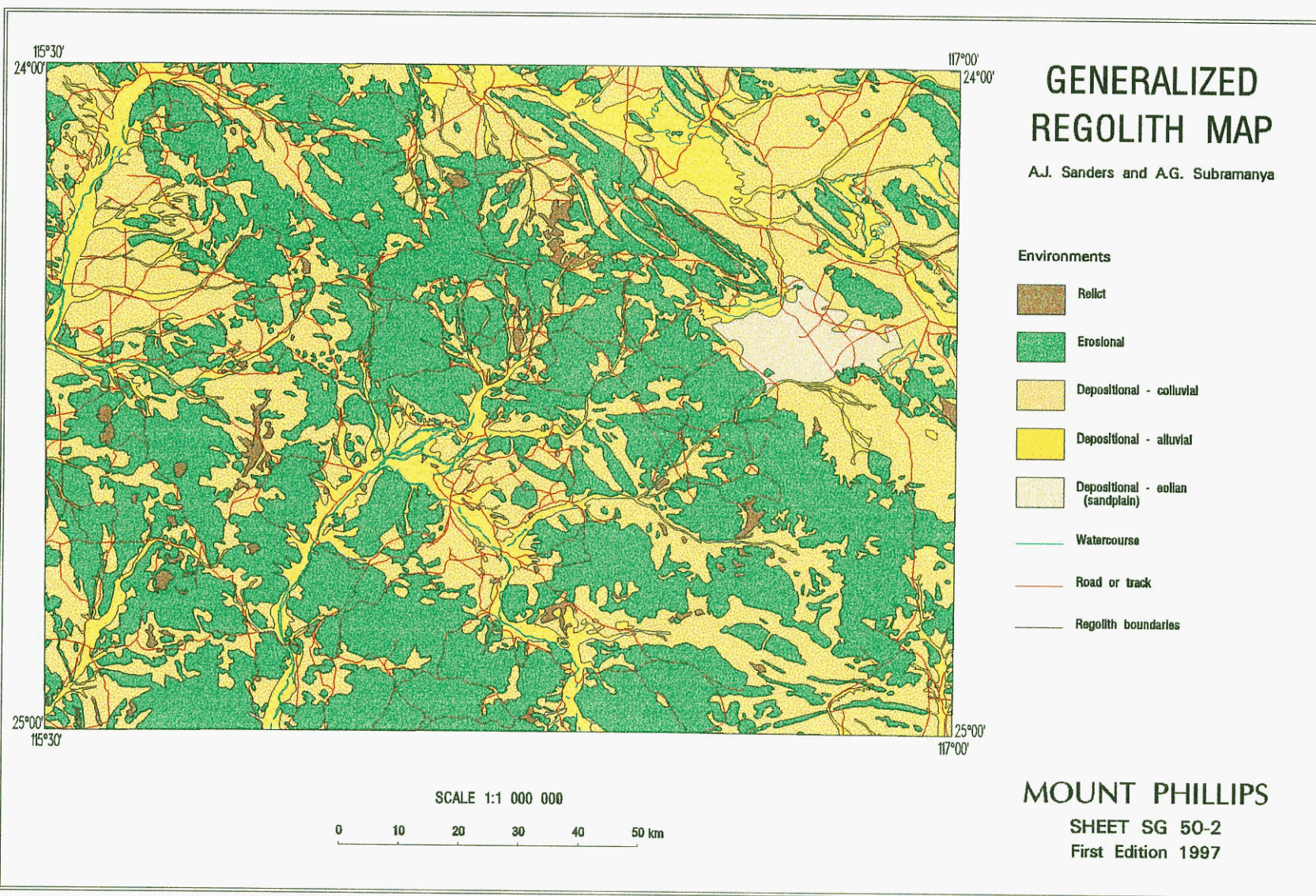
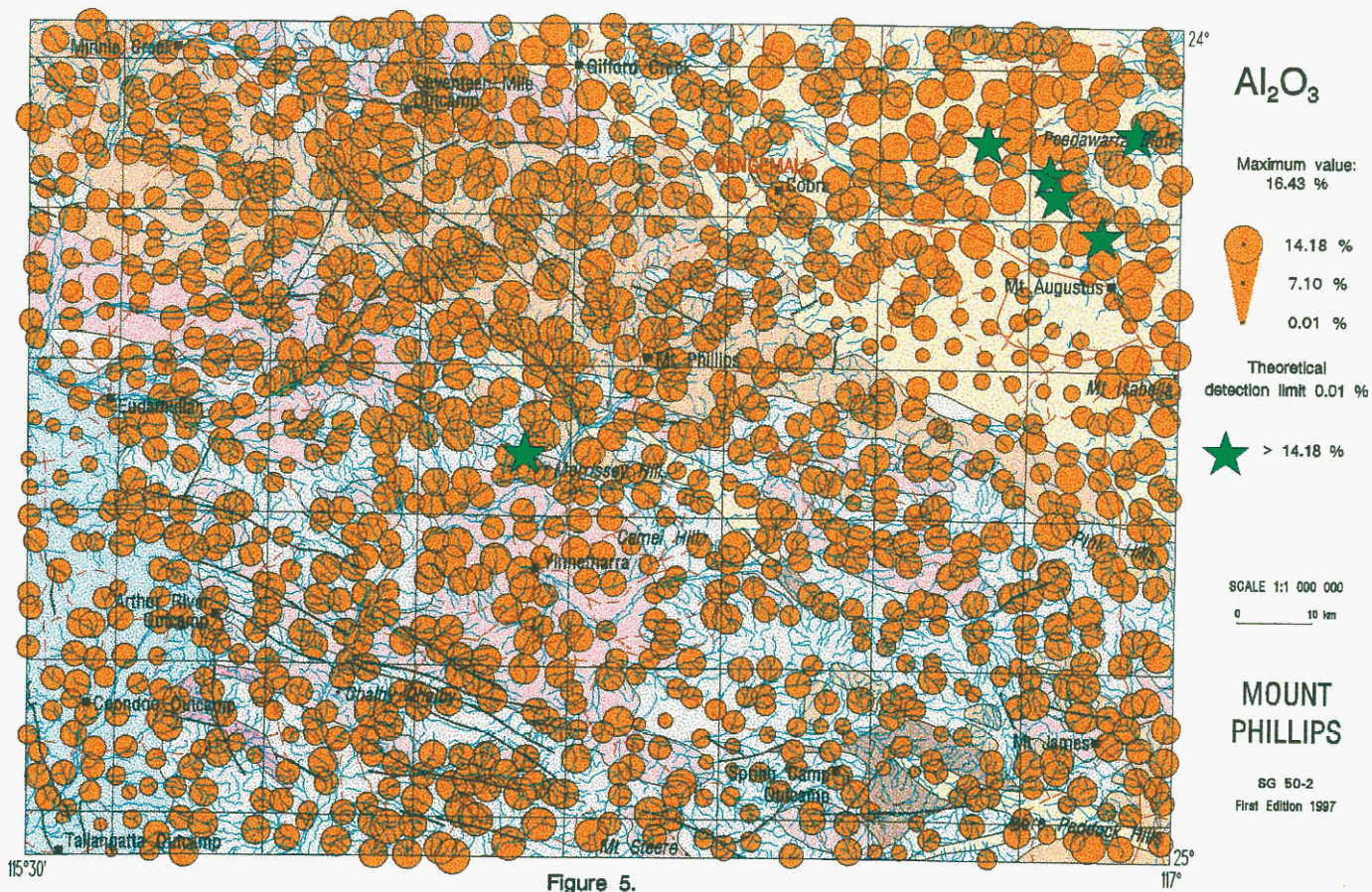
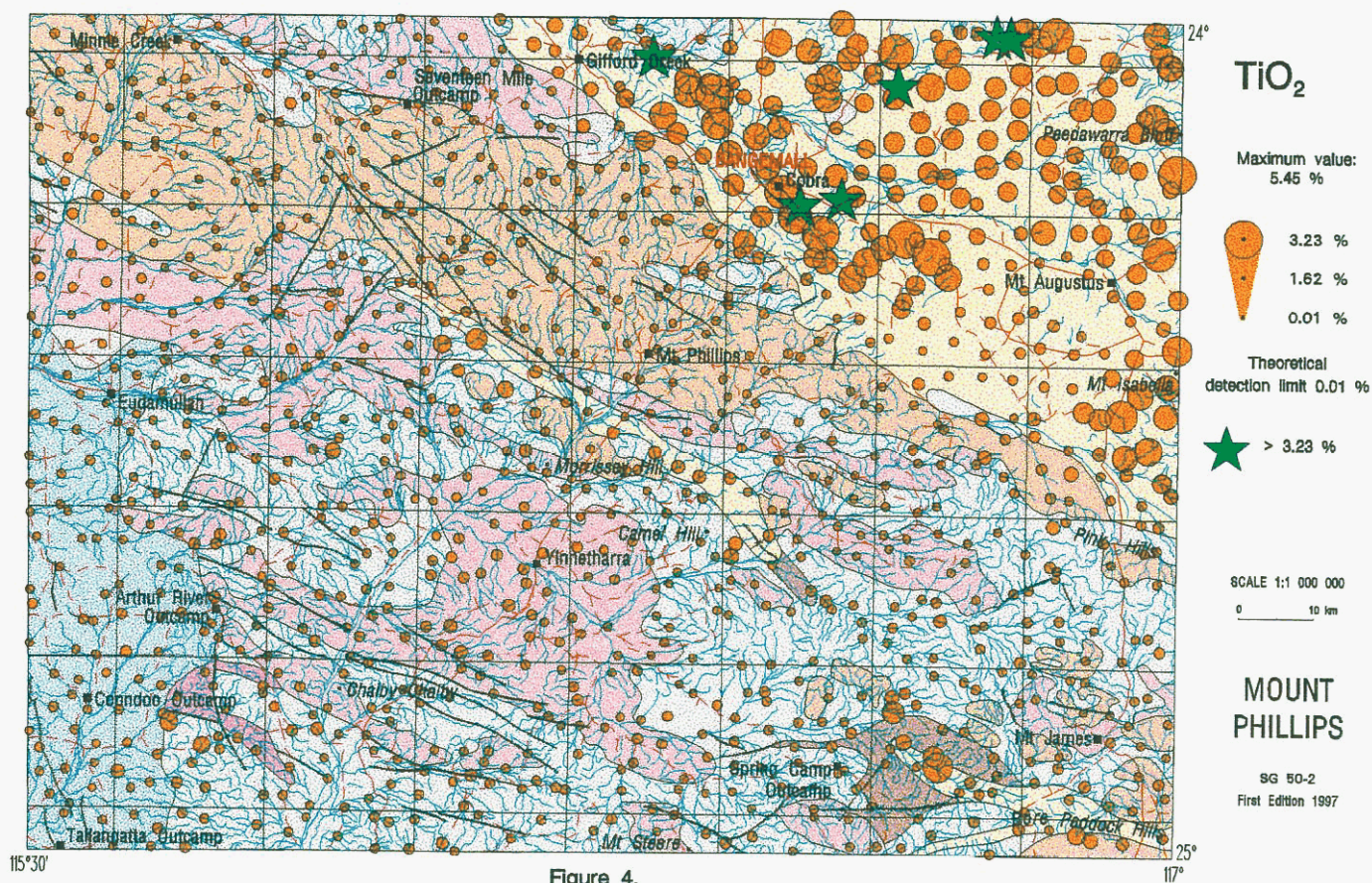


Figure 3.



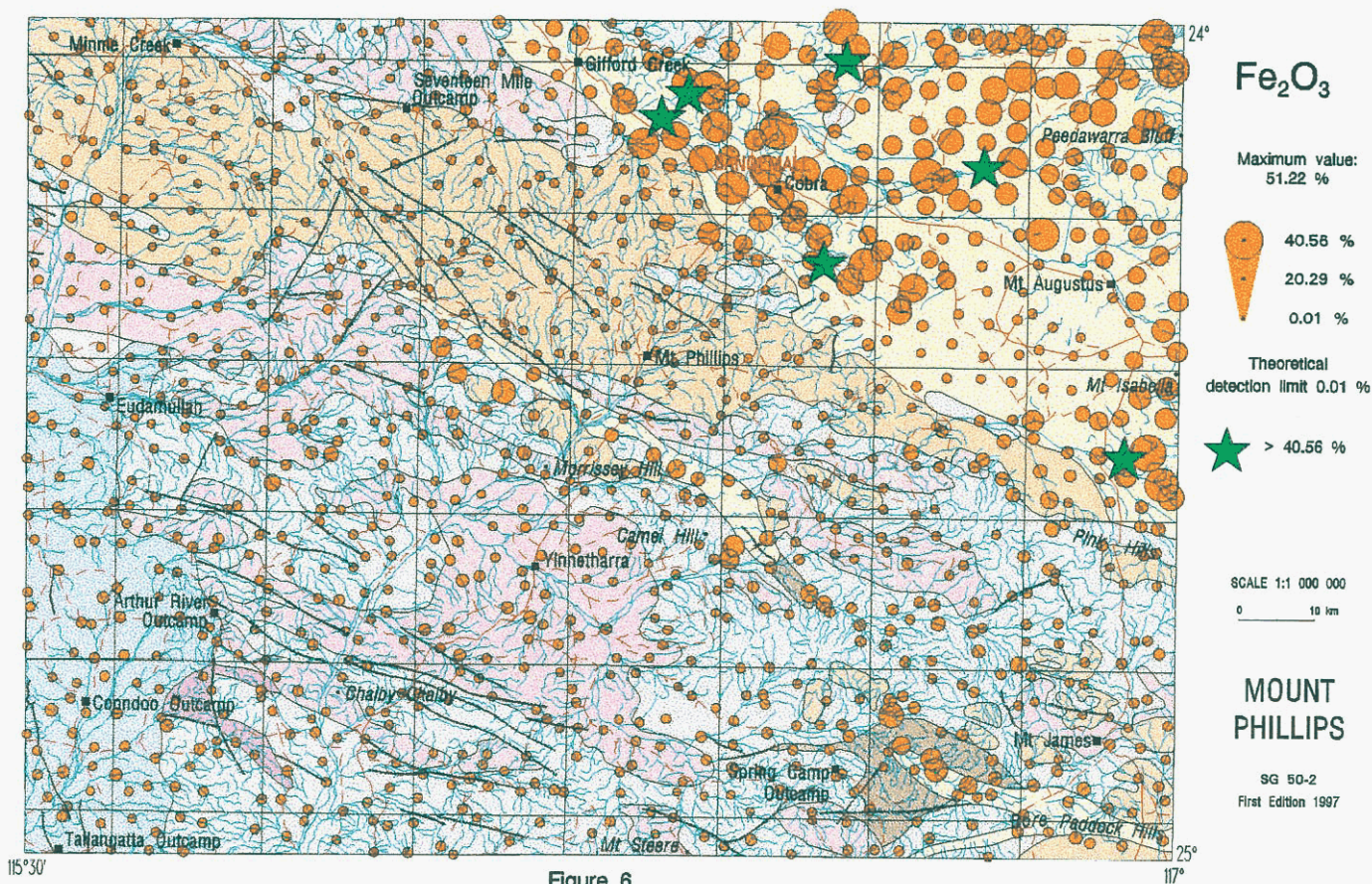


Figure 6.

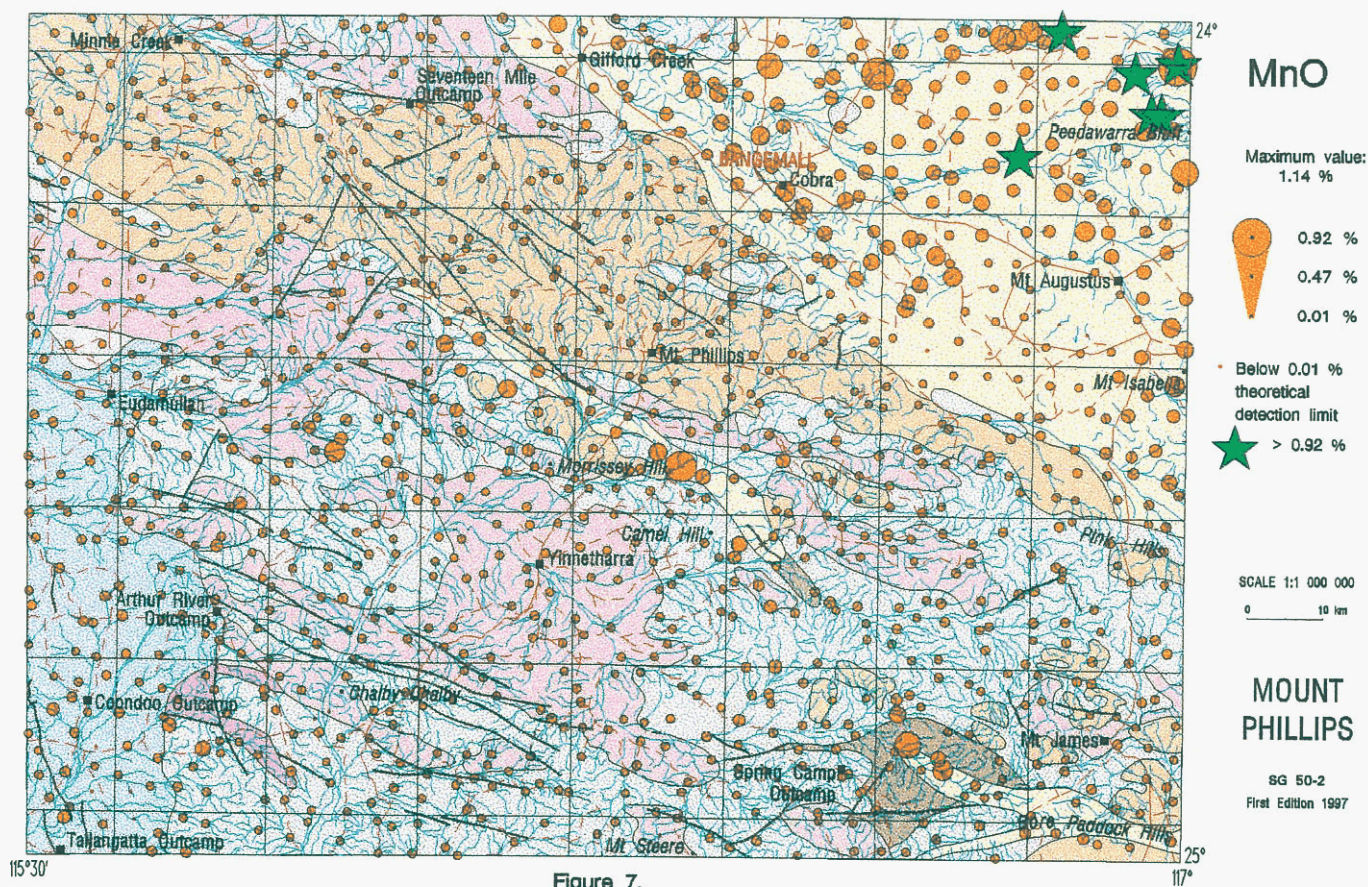
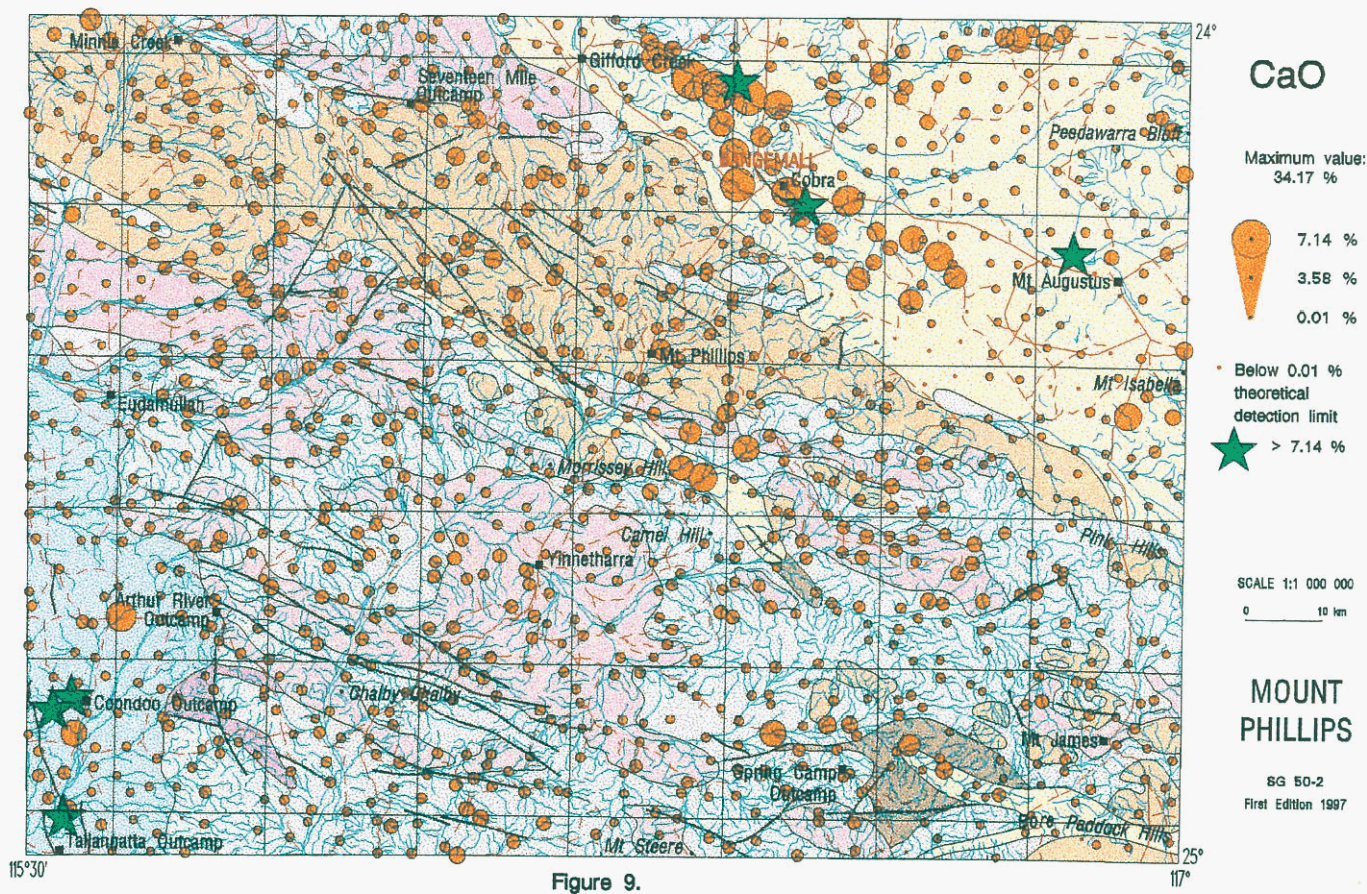
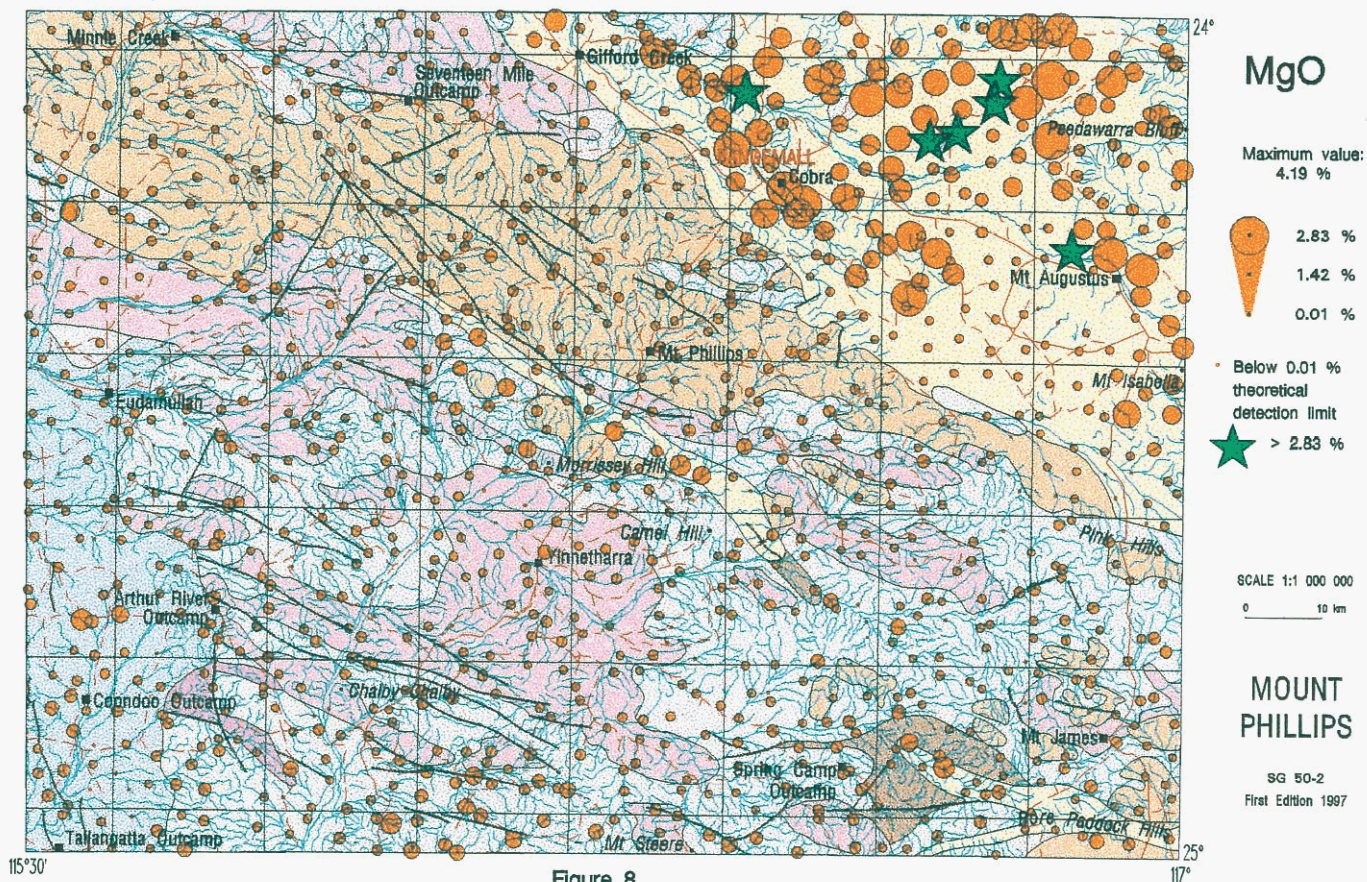


Figure 7.



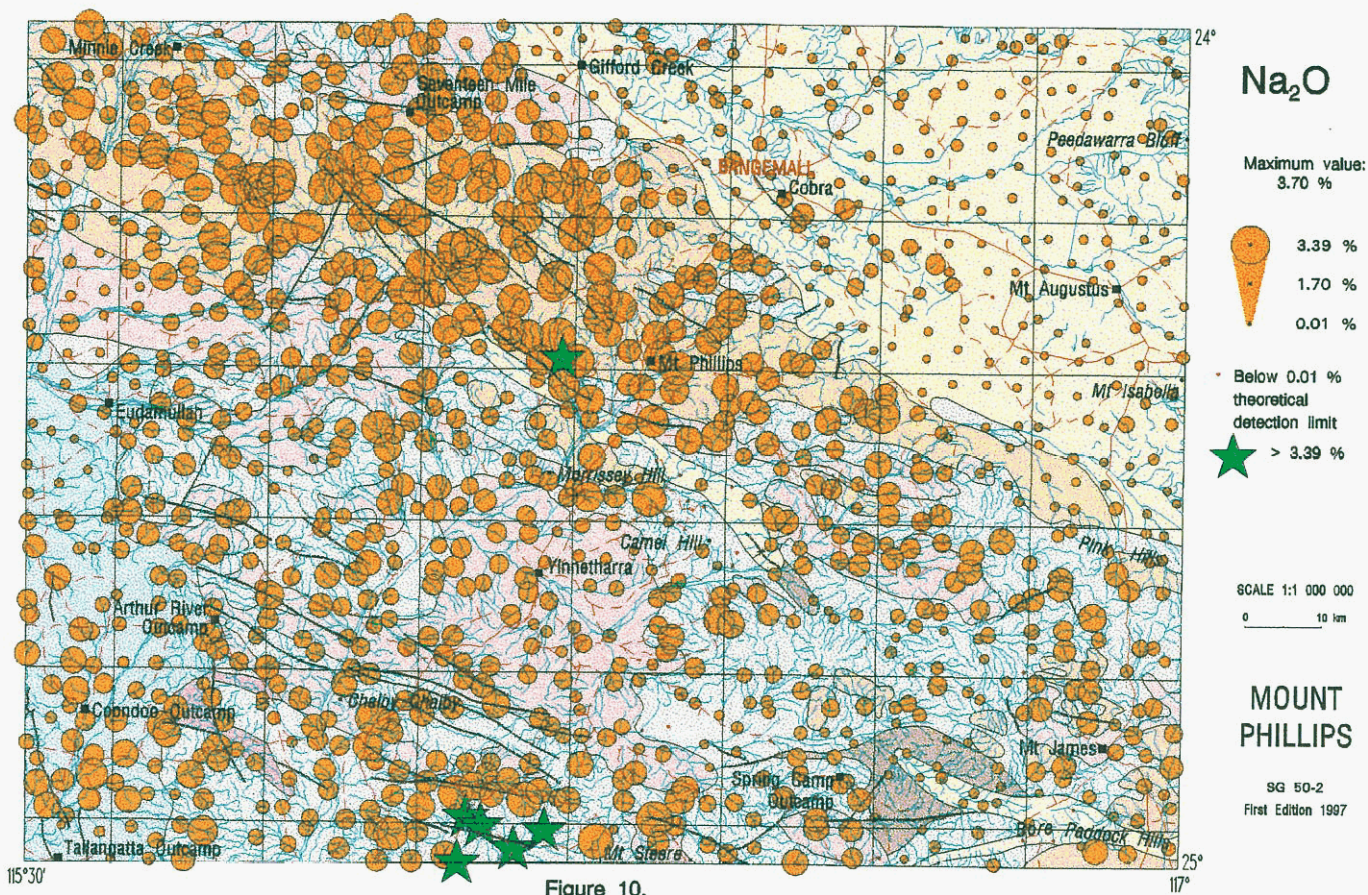


Figure 10.

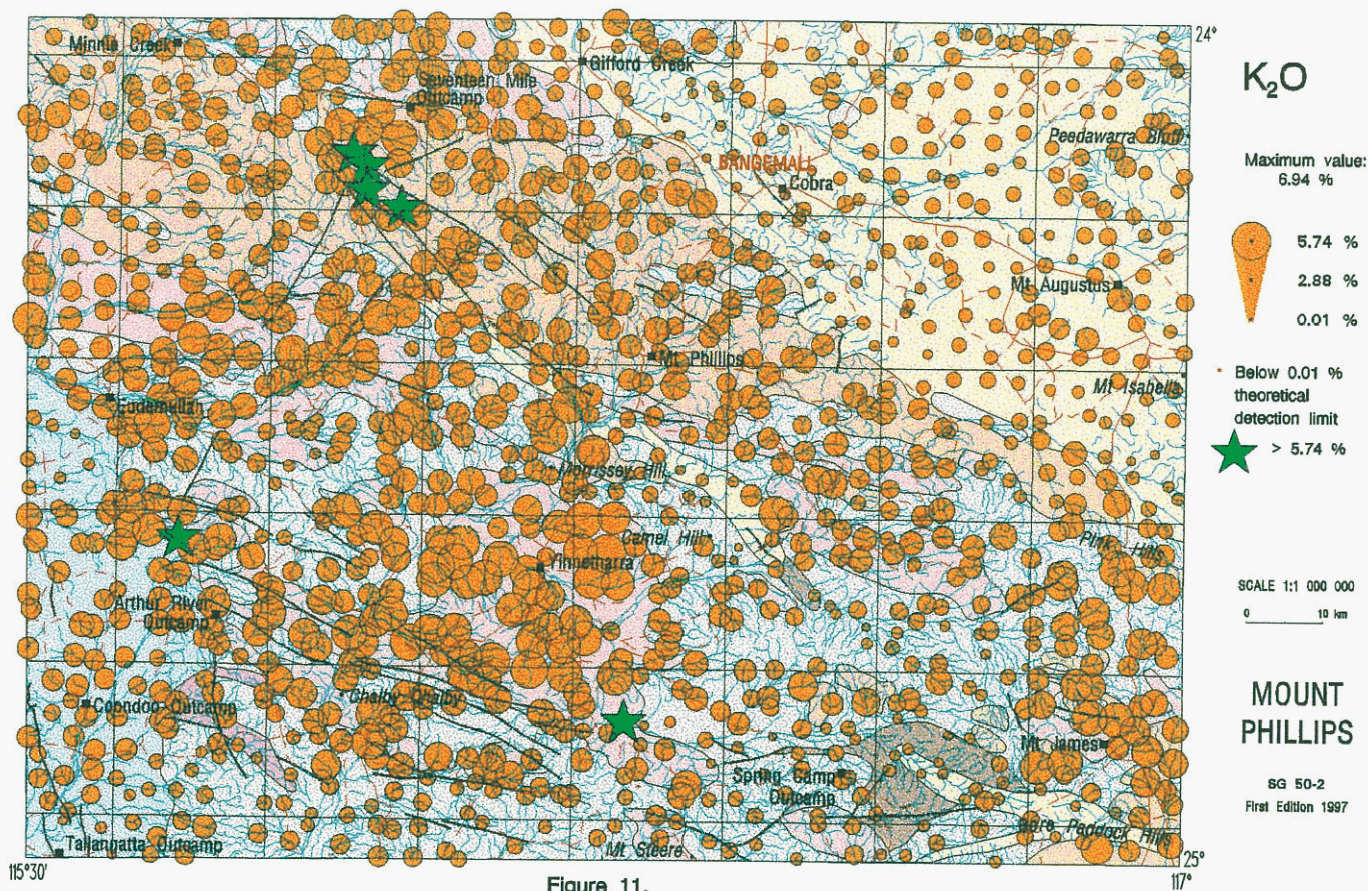
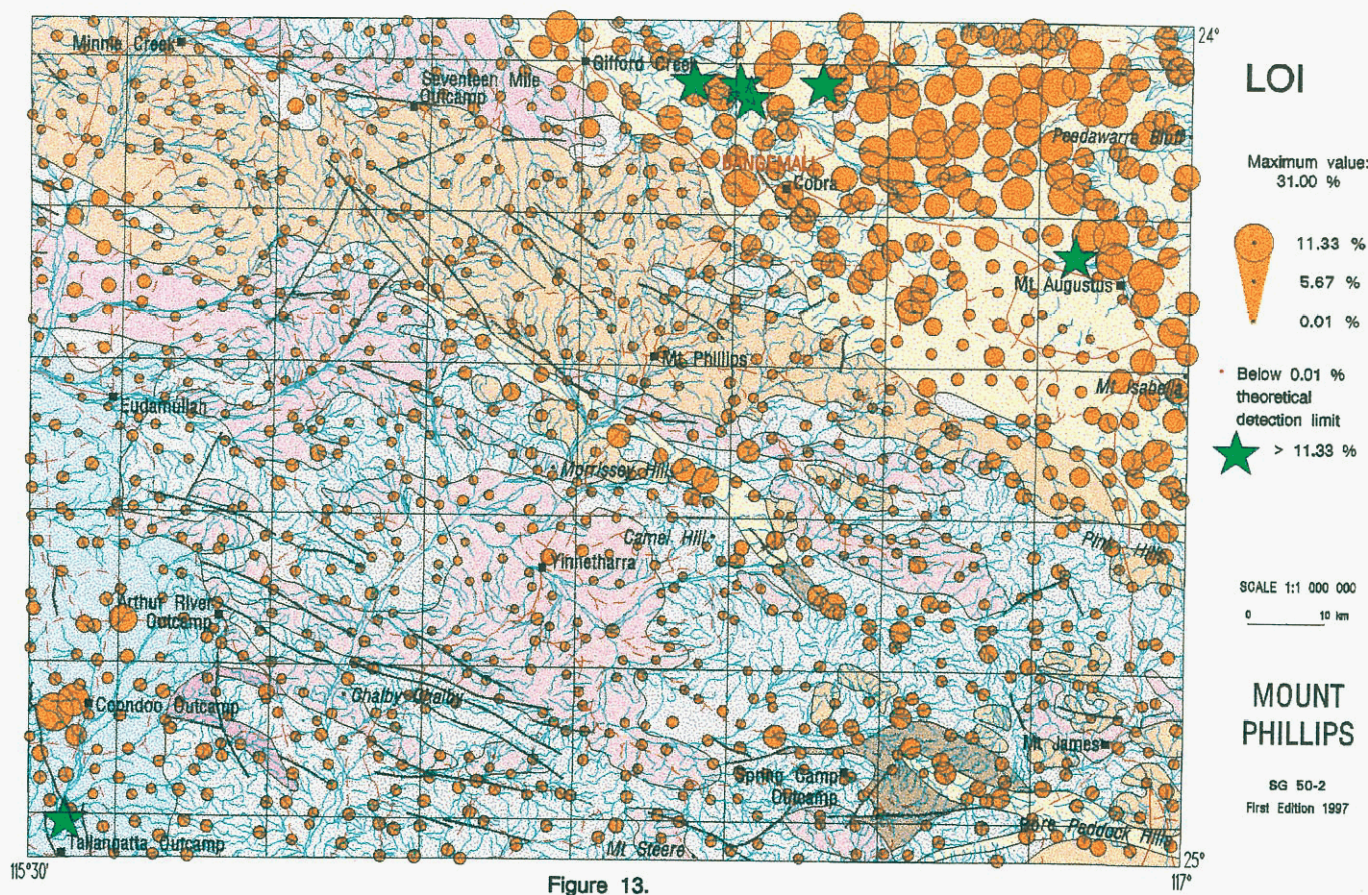
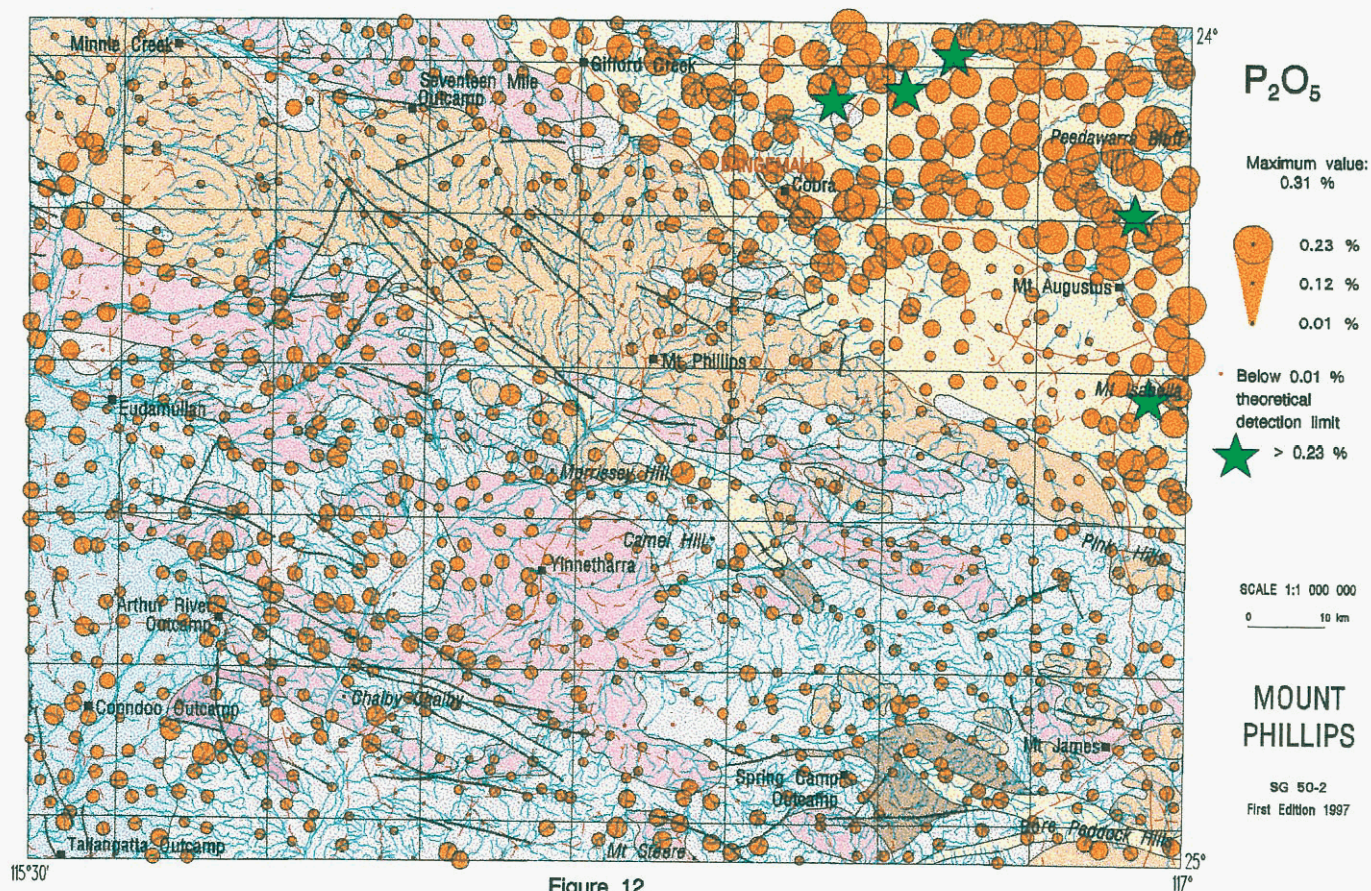


Figure 11.



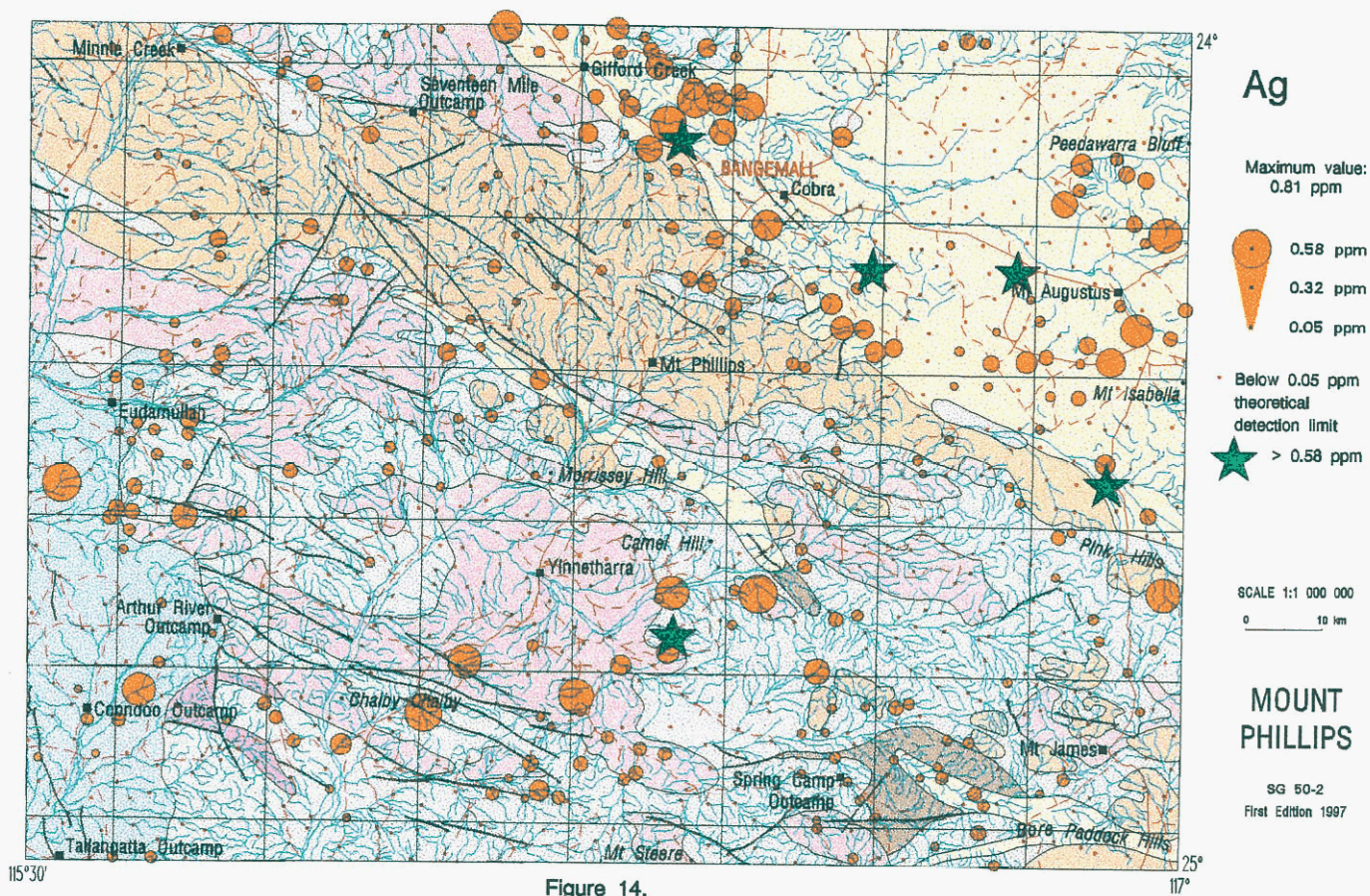


Figure 14.

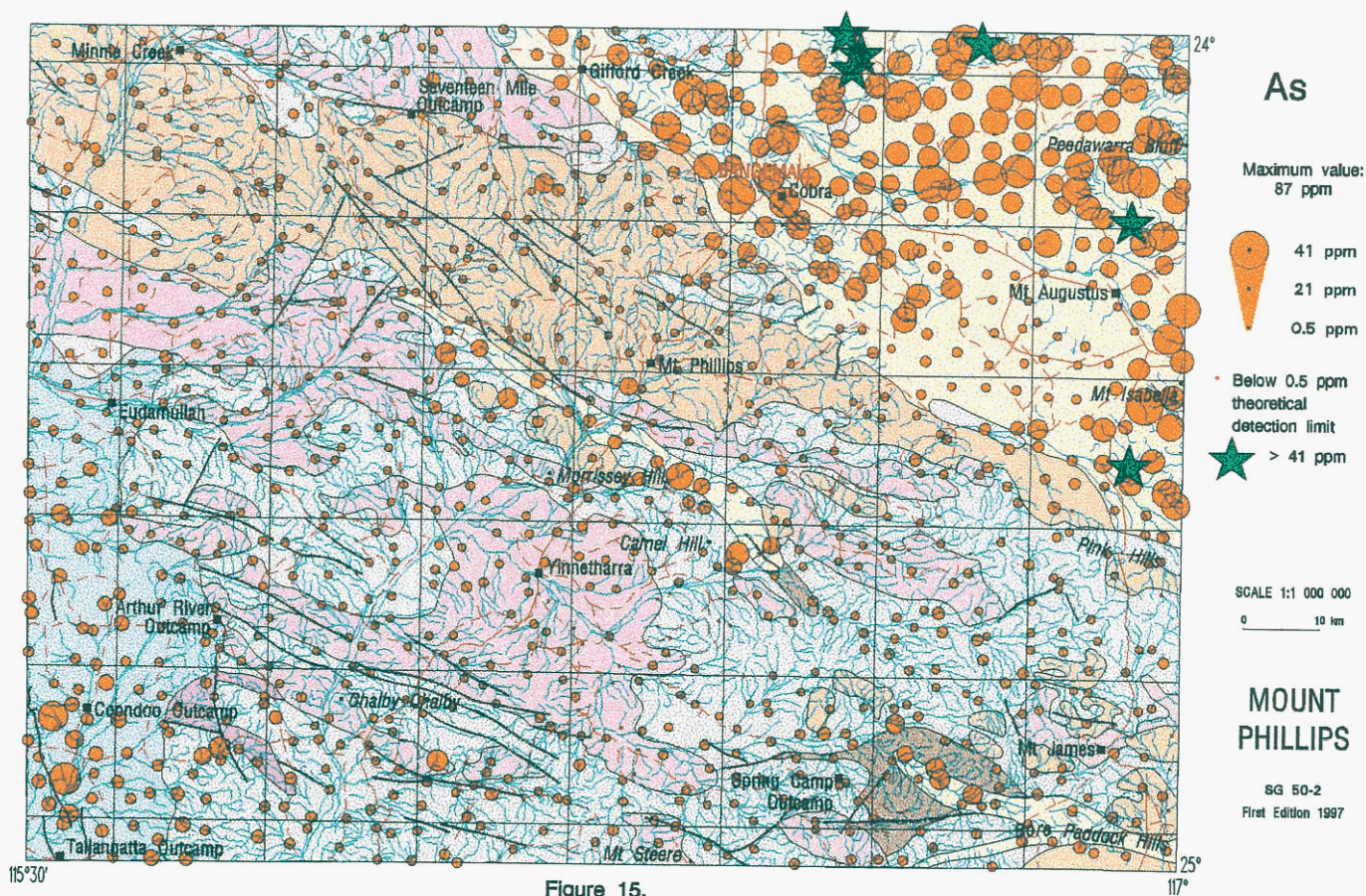


Figure 15.

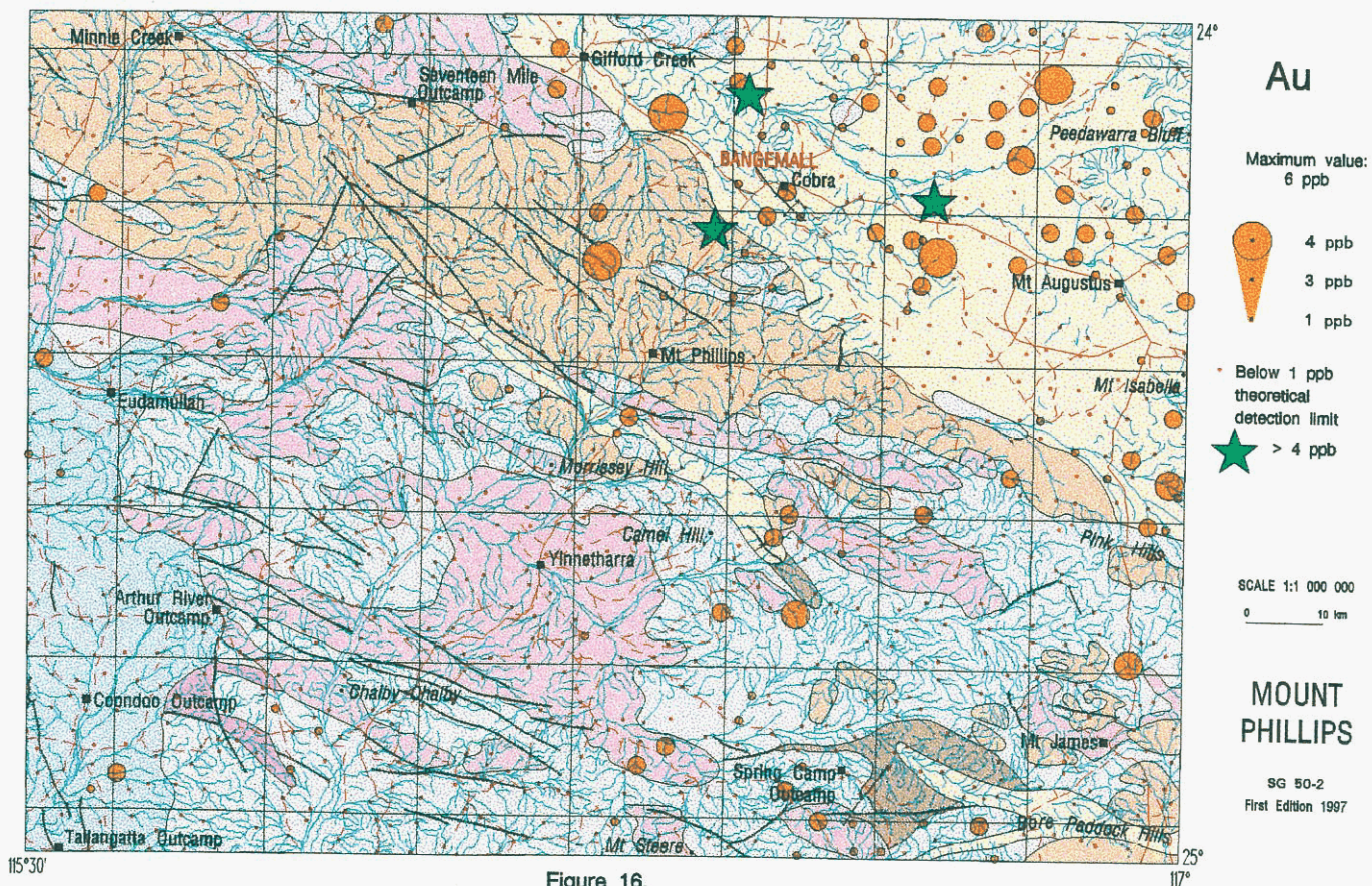


Figure 16.

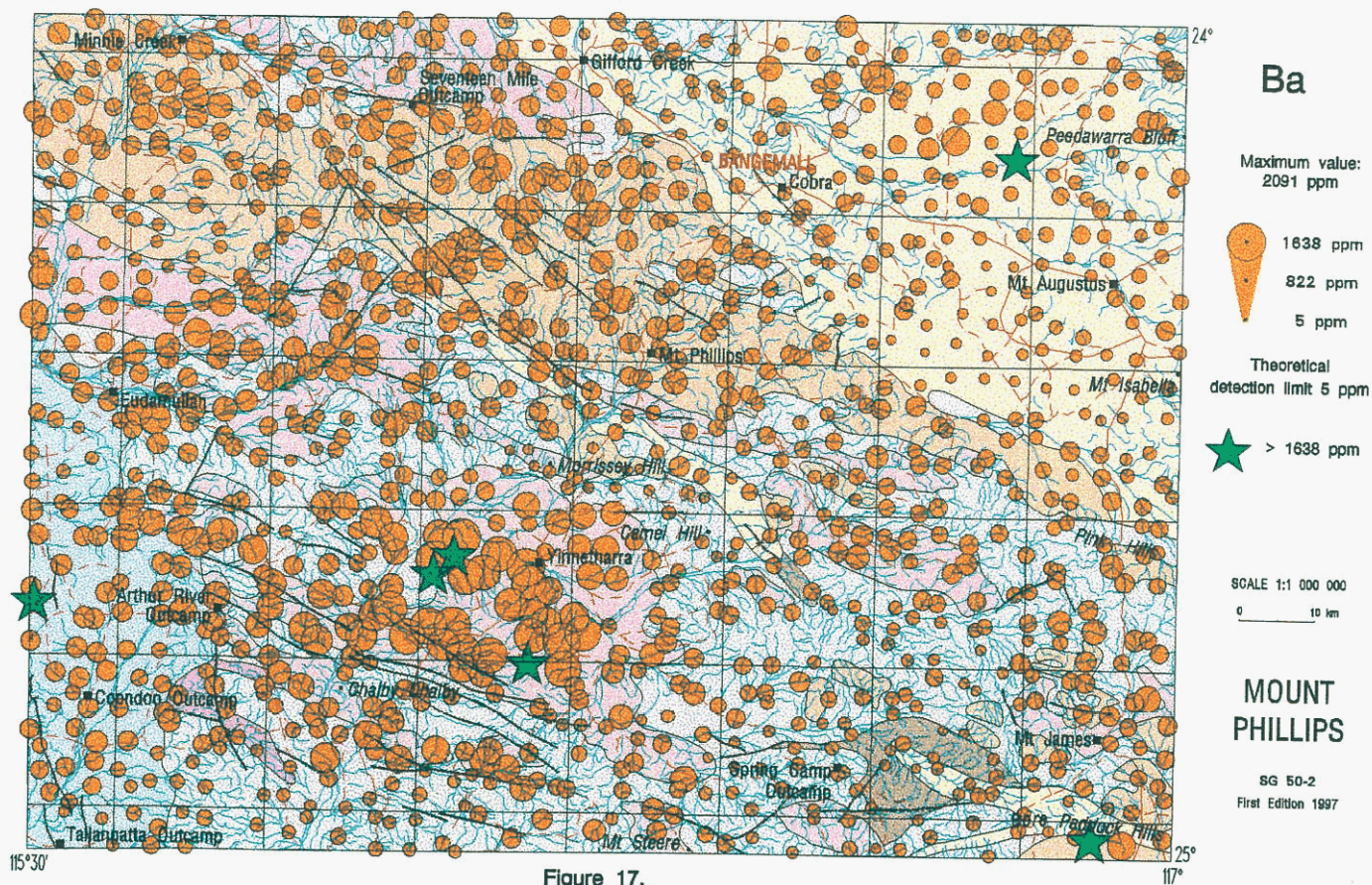


Figure 17.

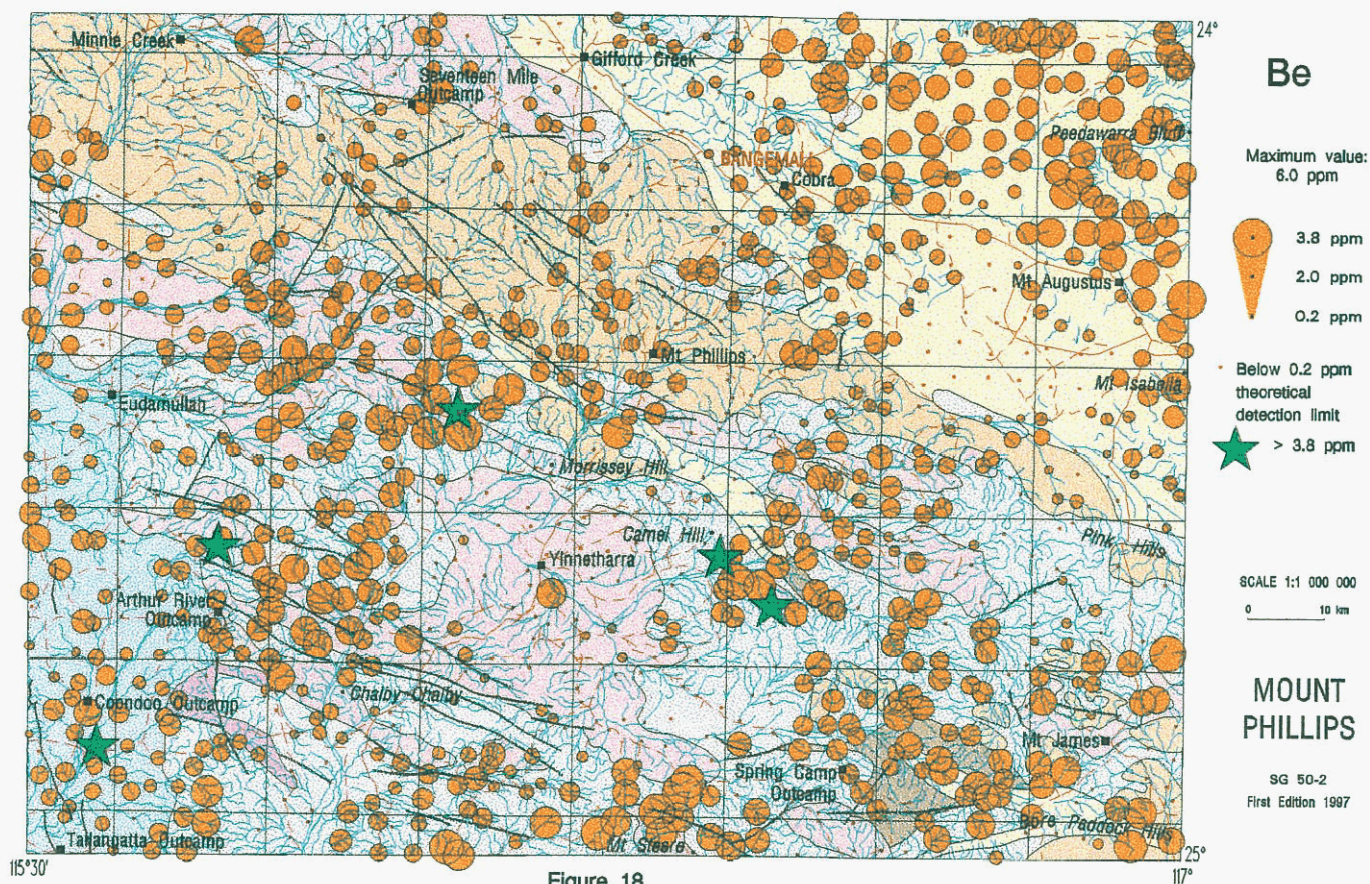


Figure 18.

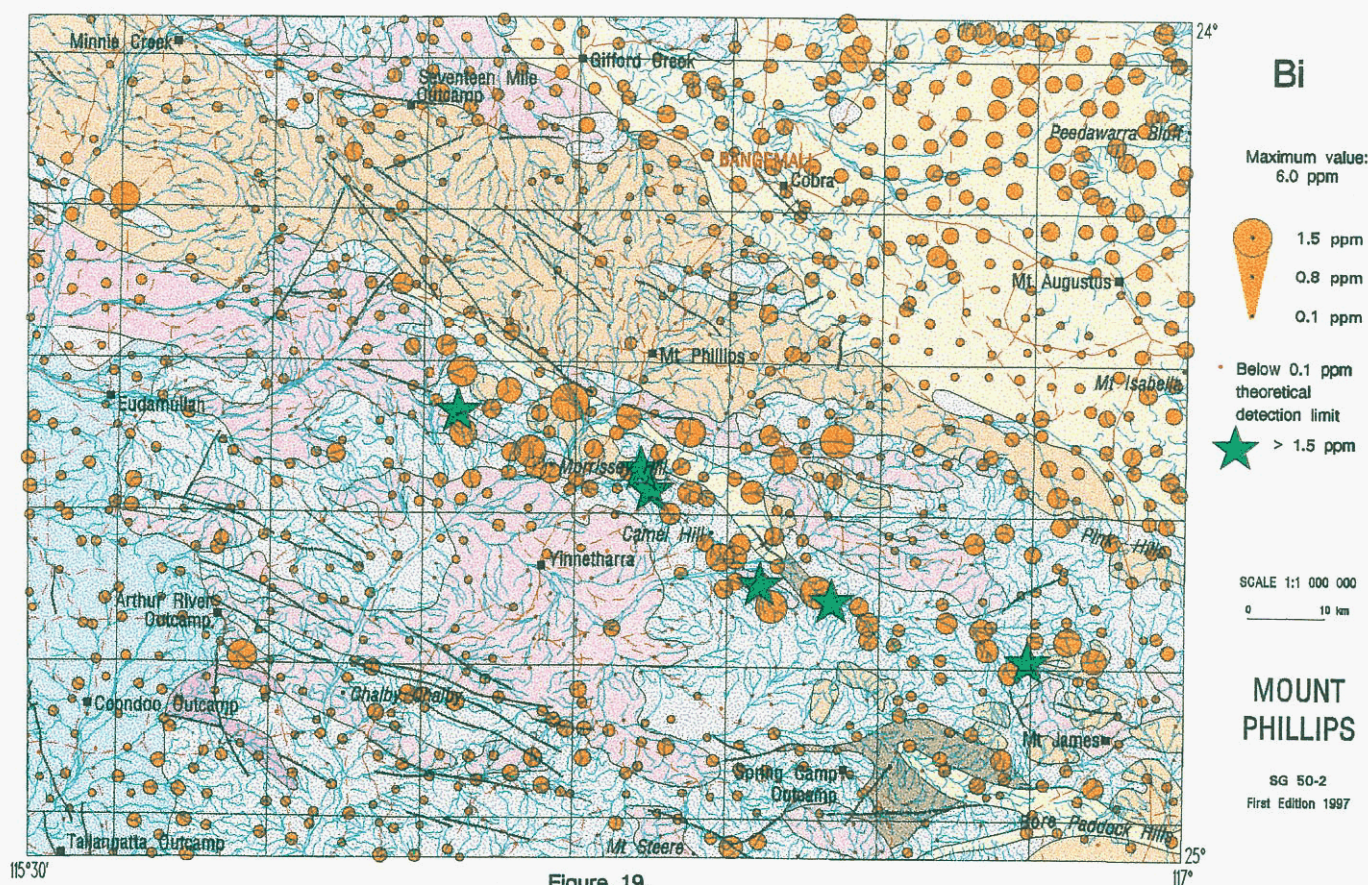
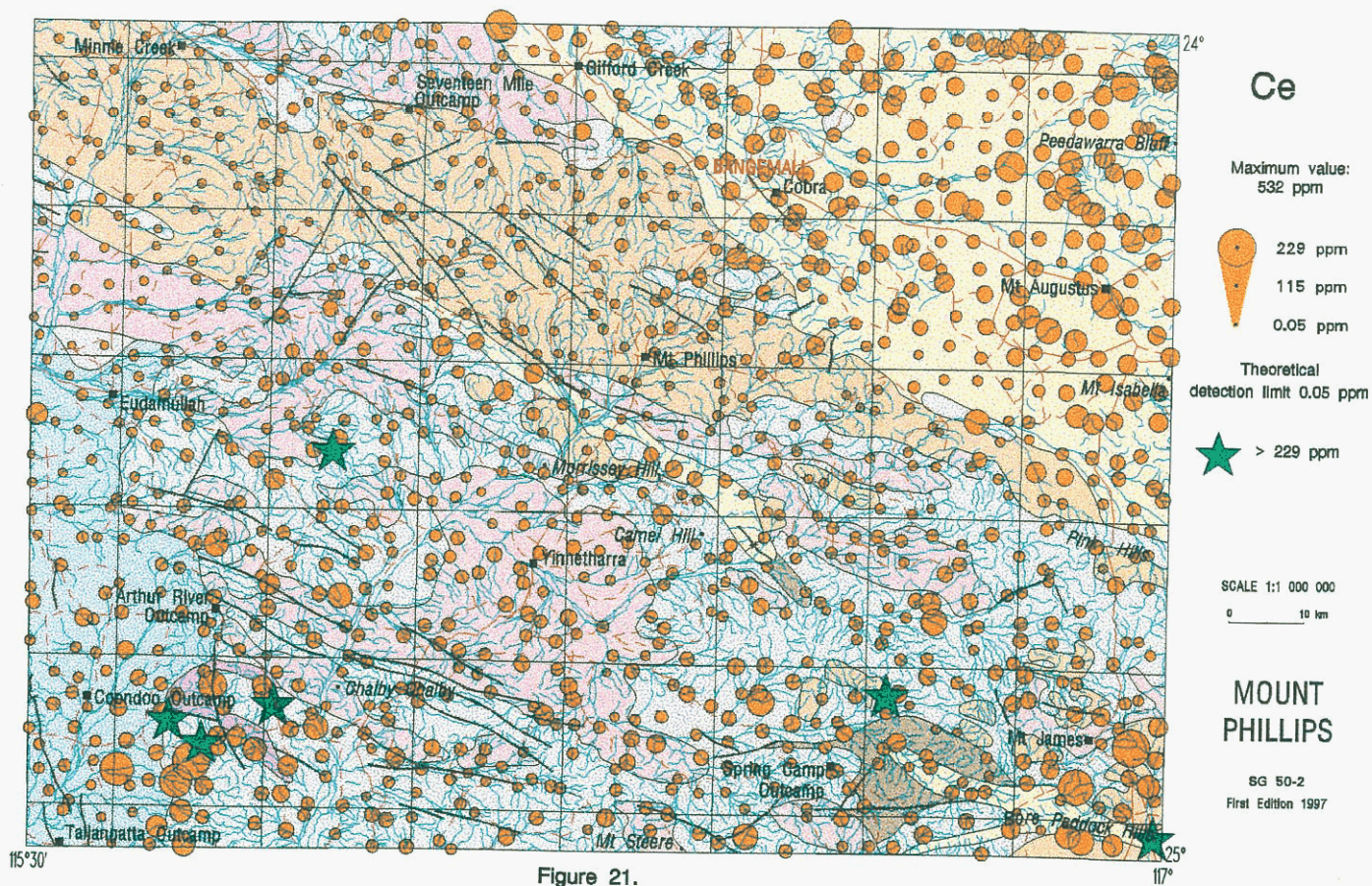
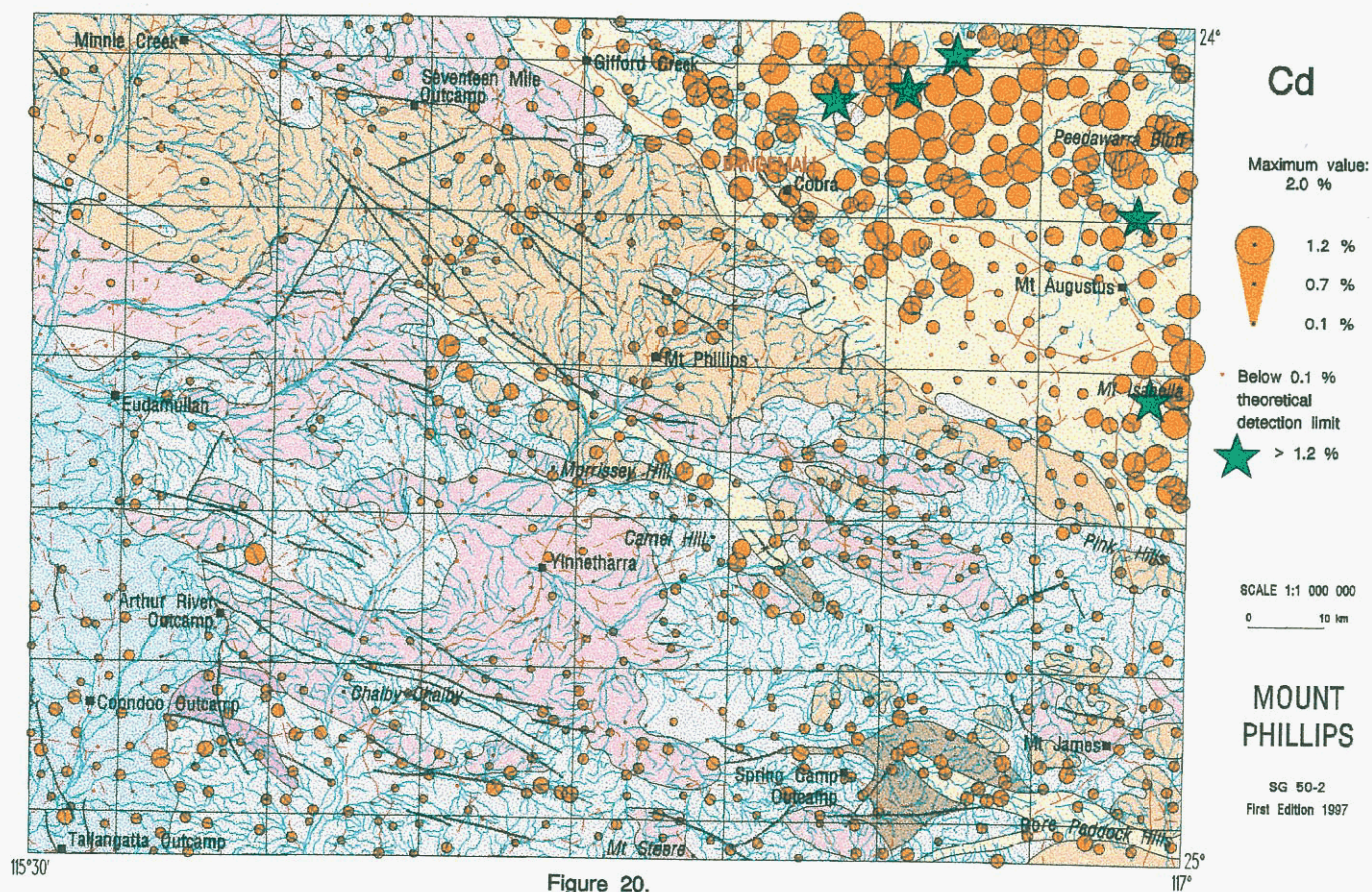


Figure 19.



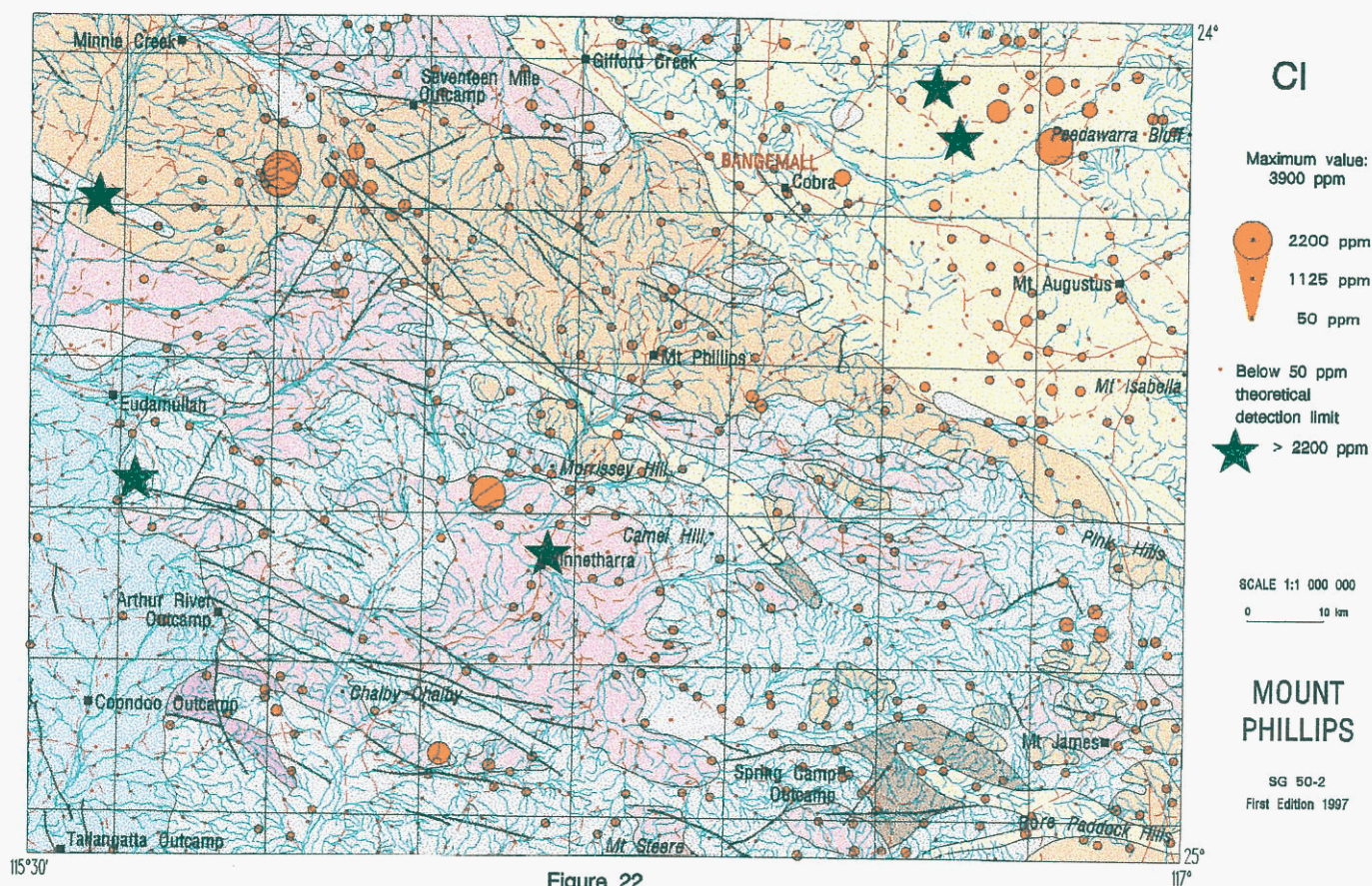


Figure 22.

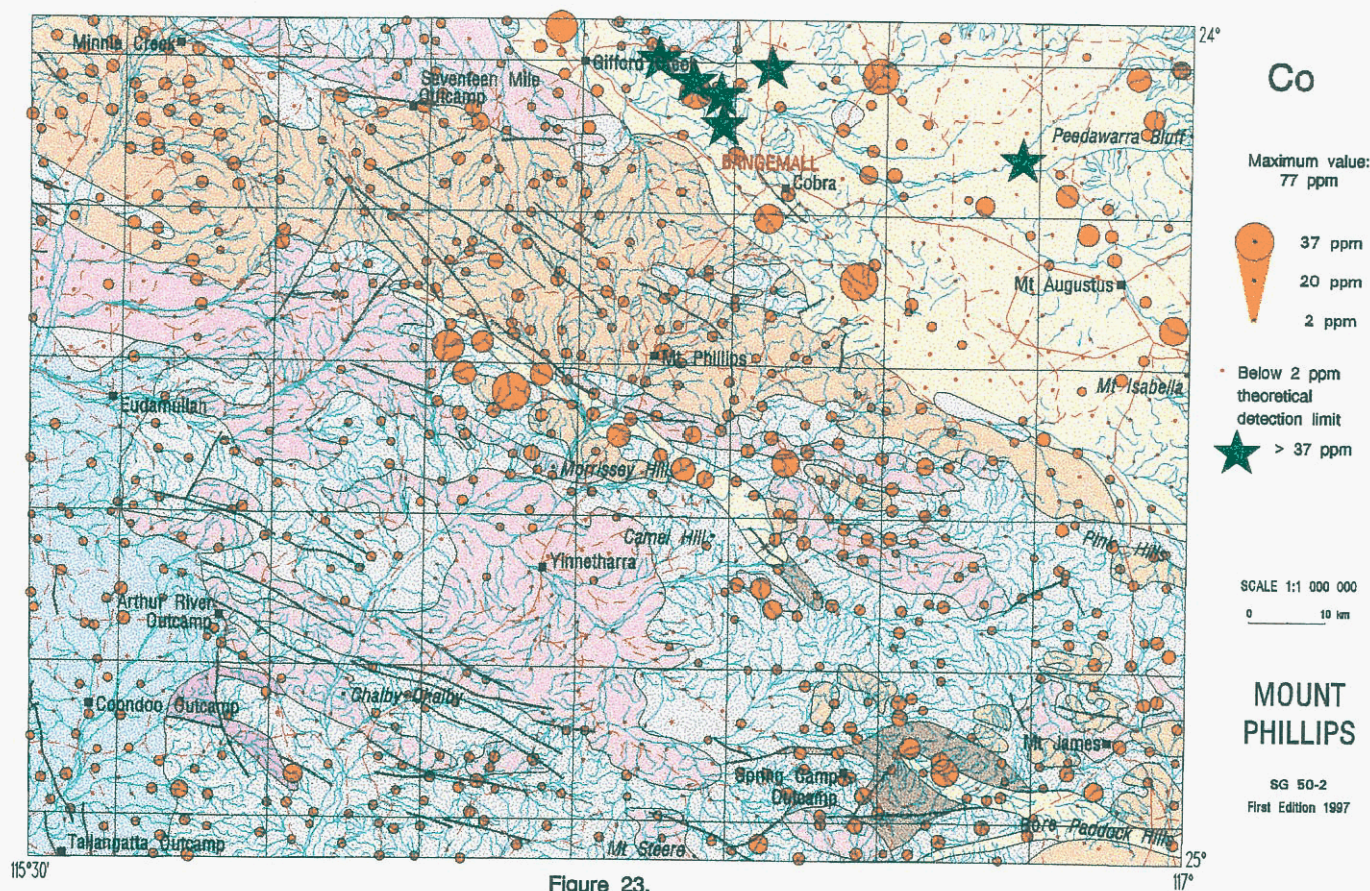


Figure 23.

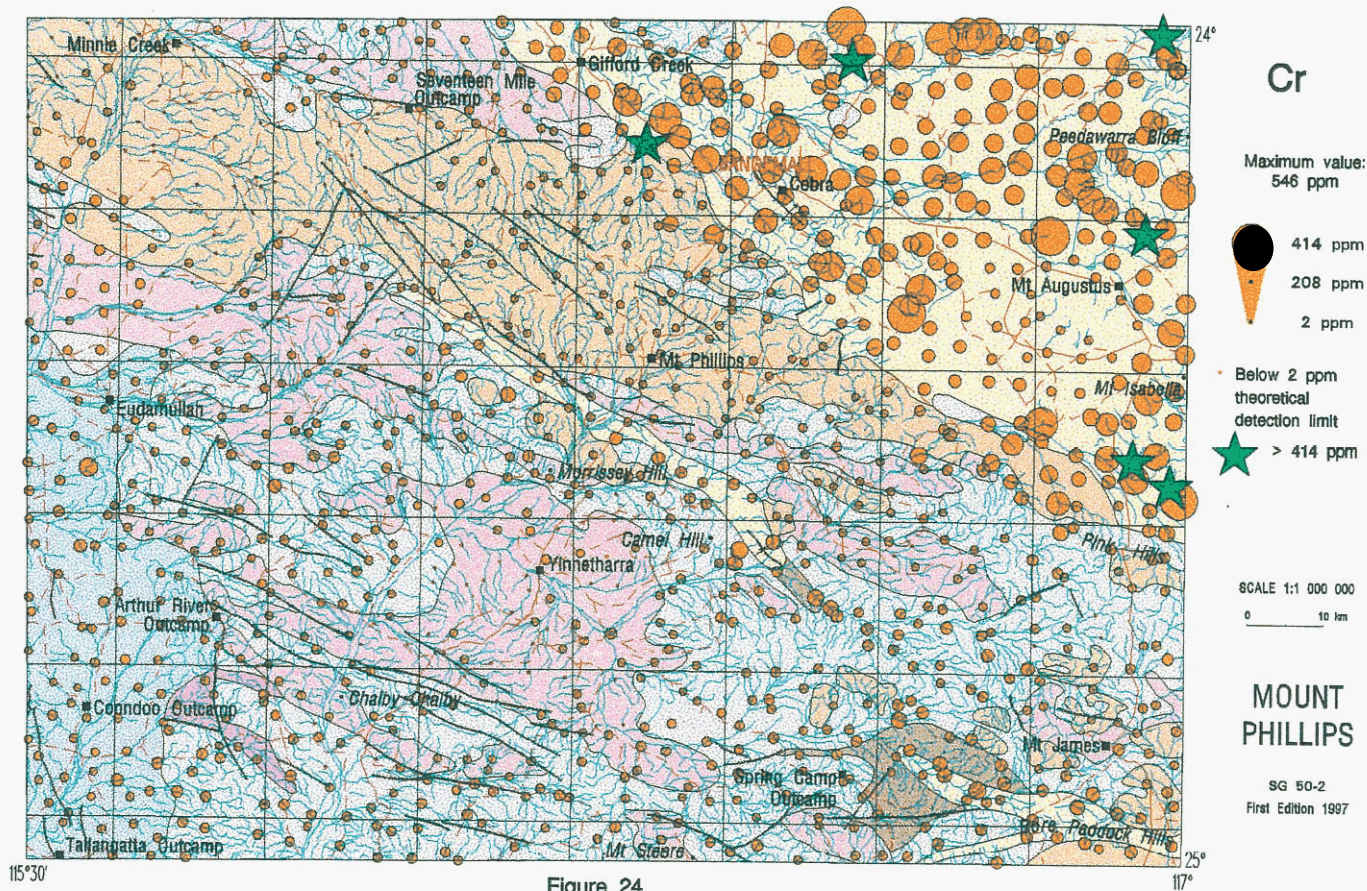


Figure 24.

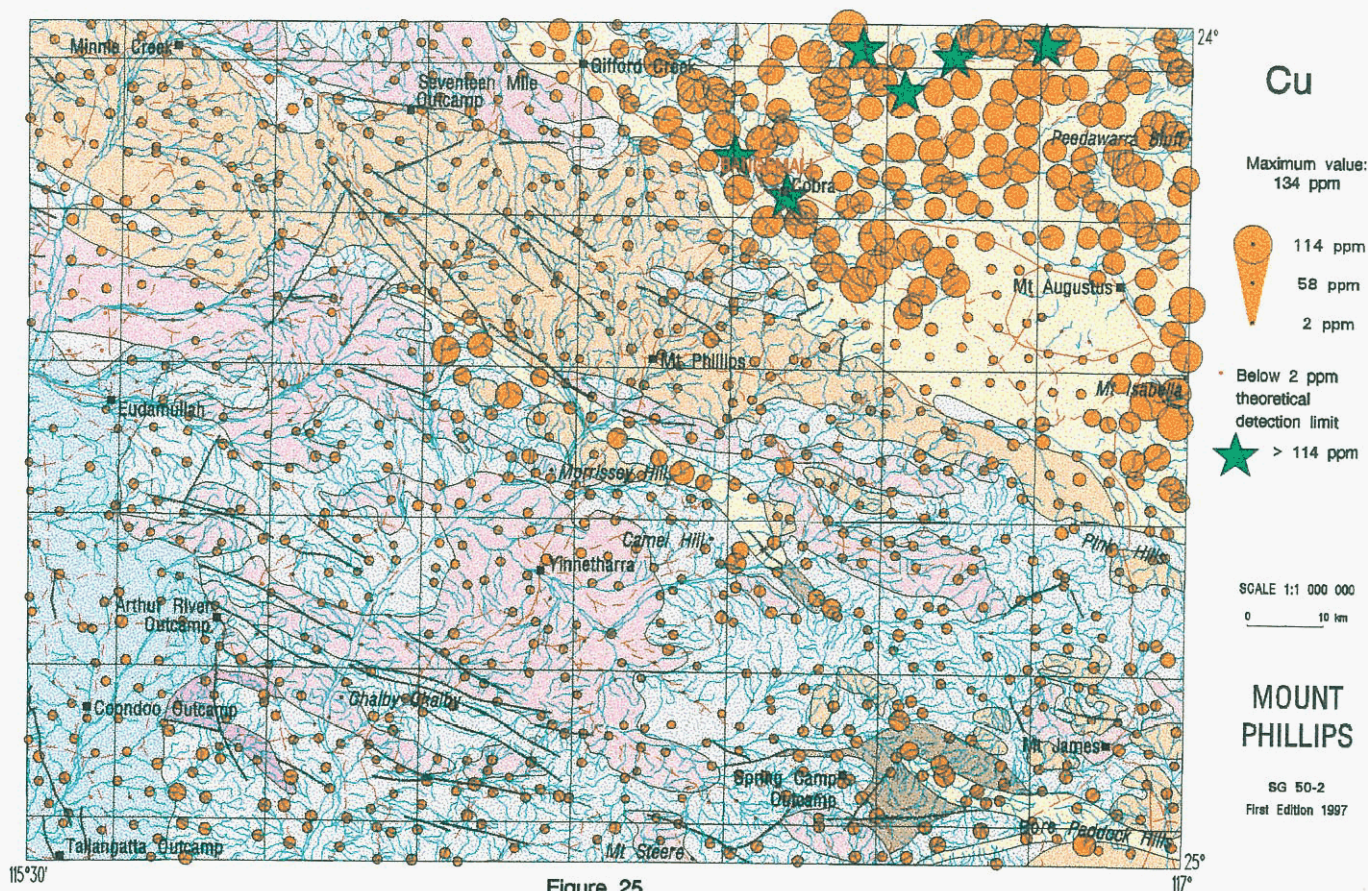
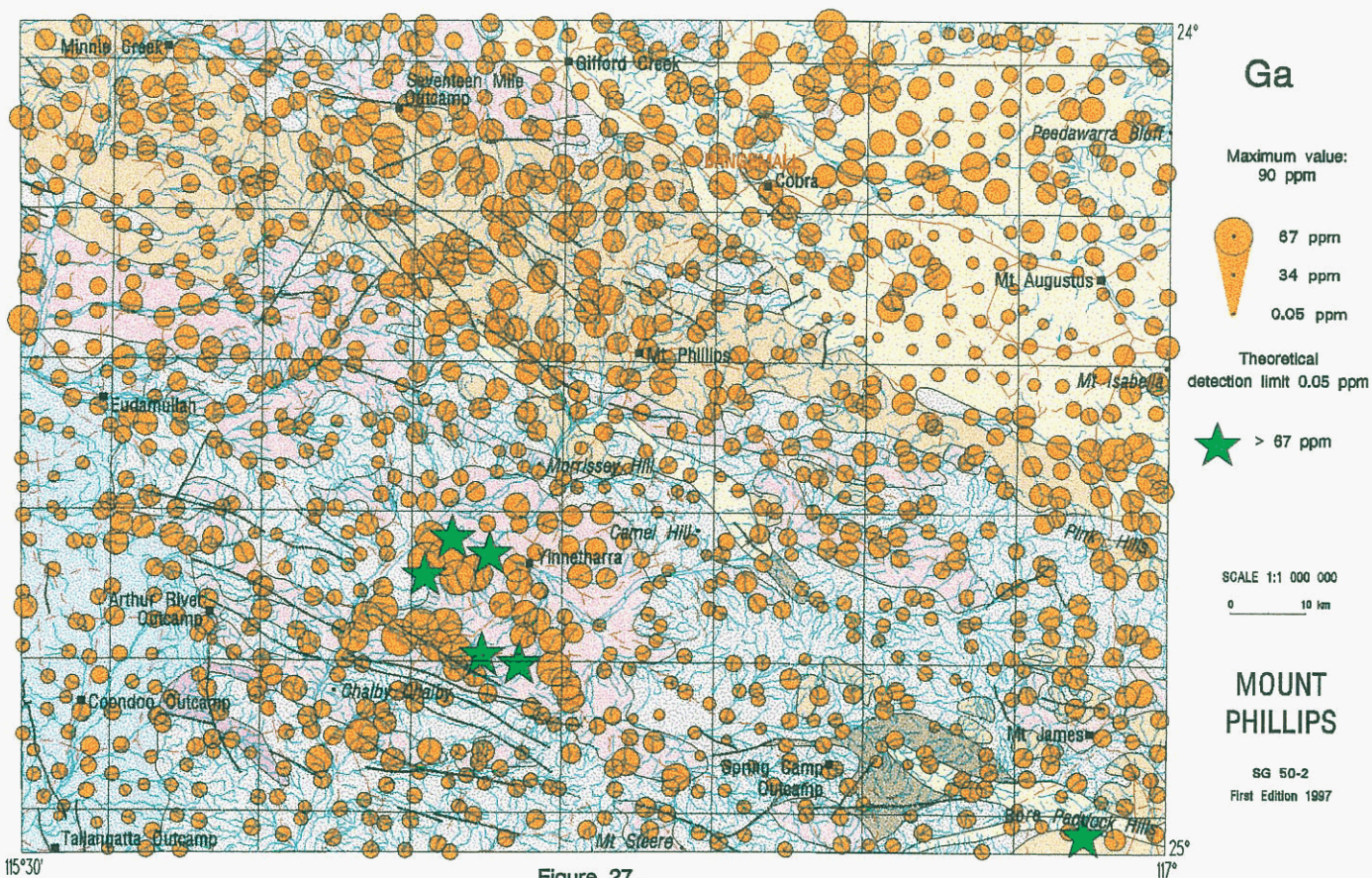
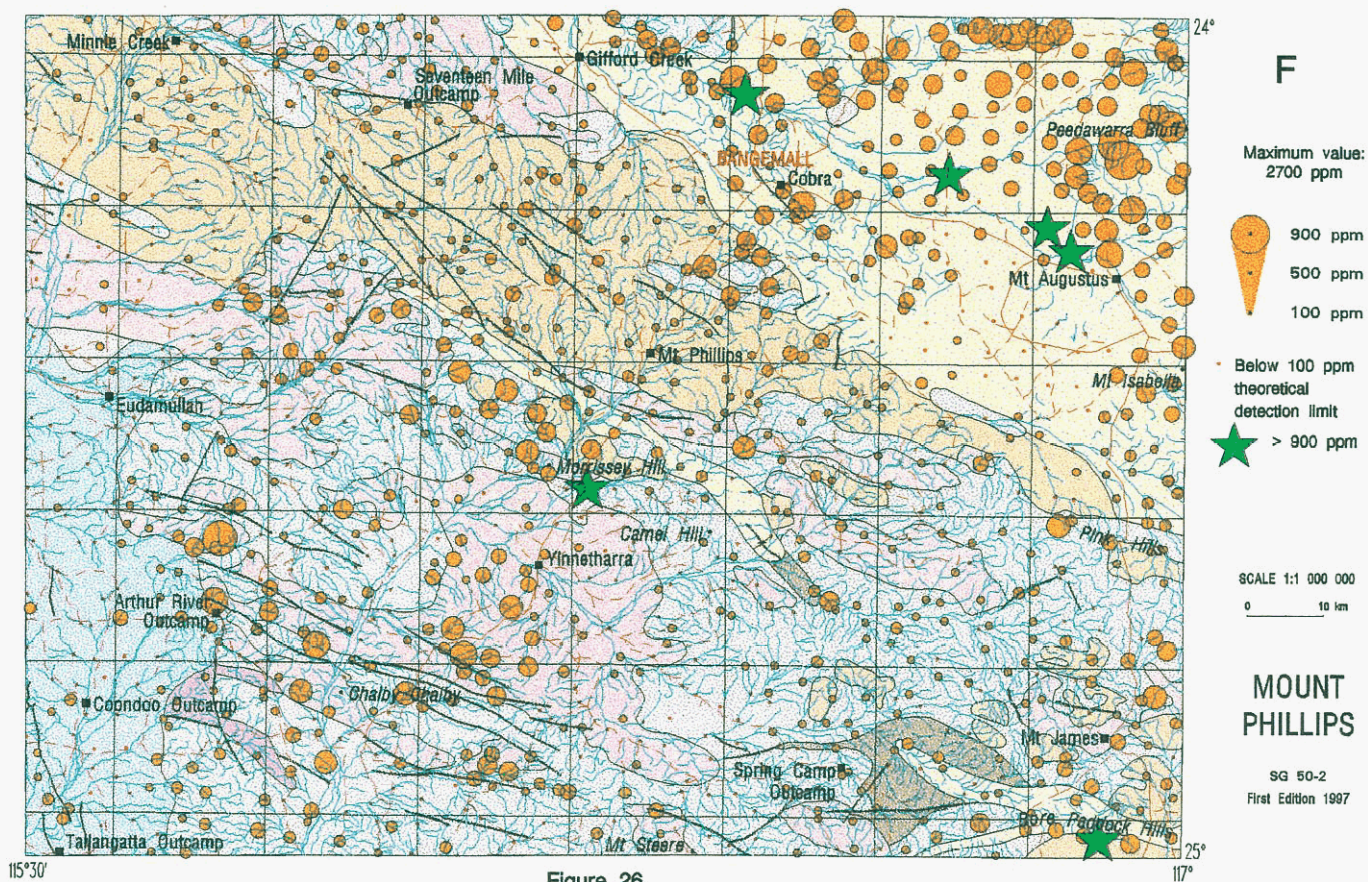
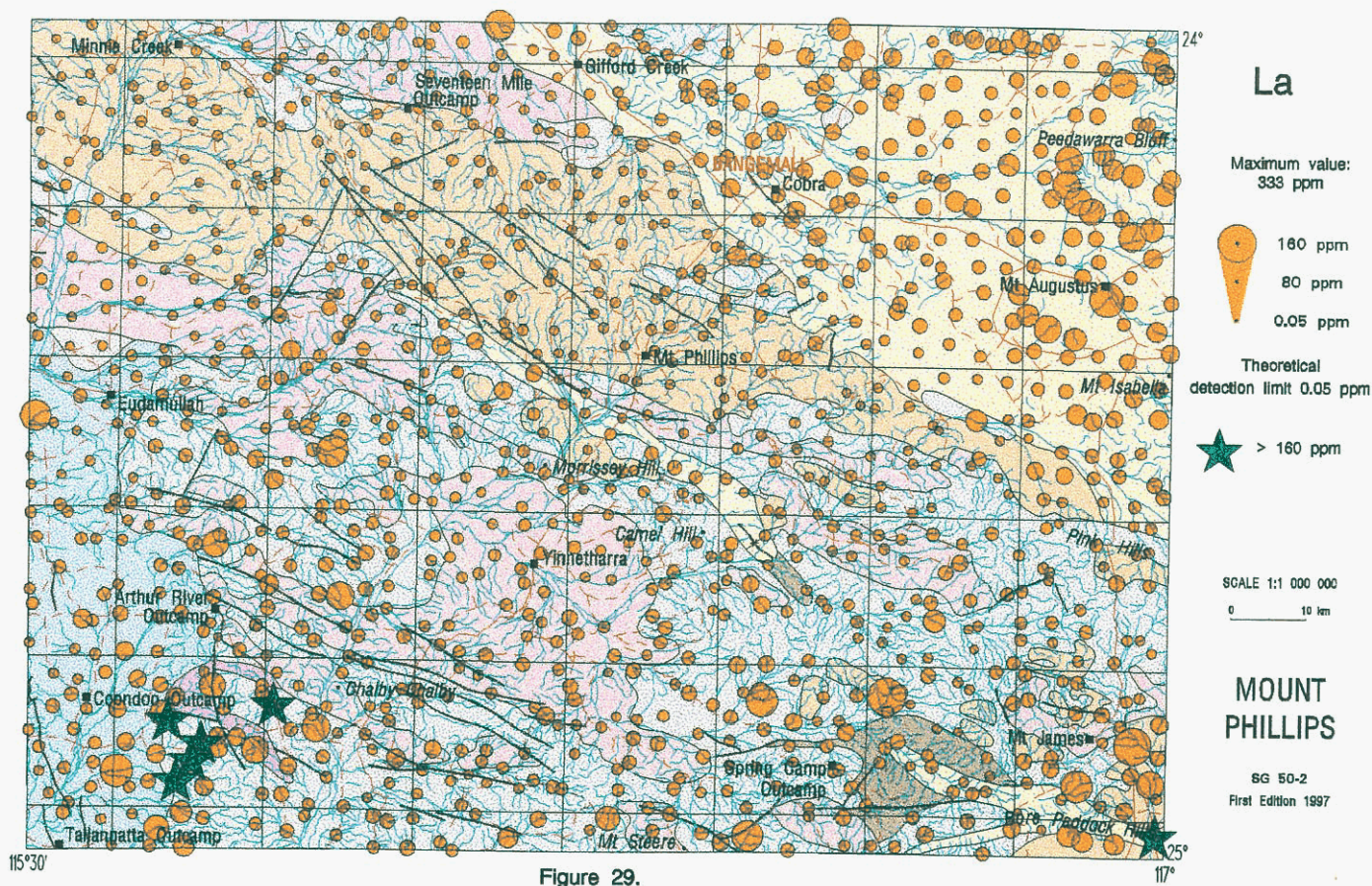
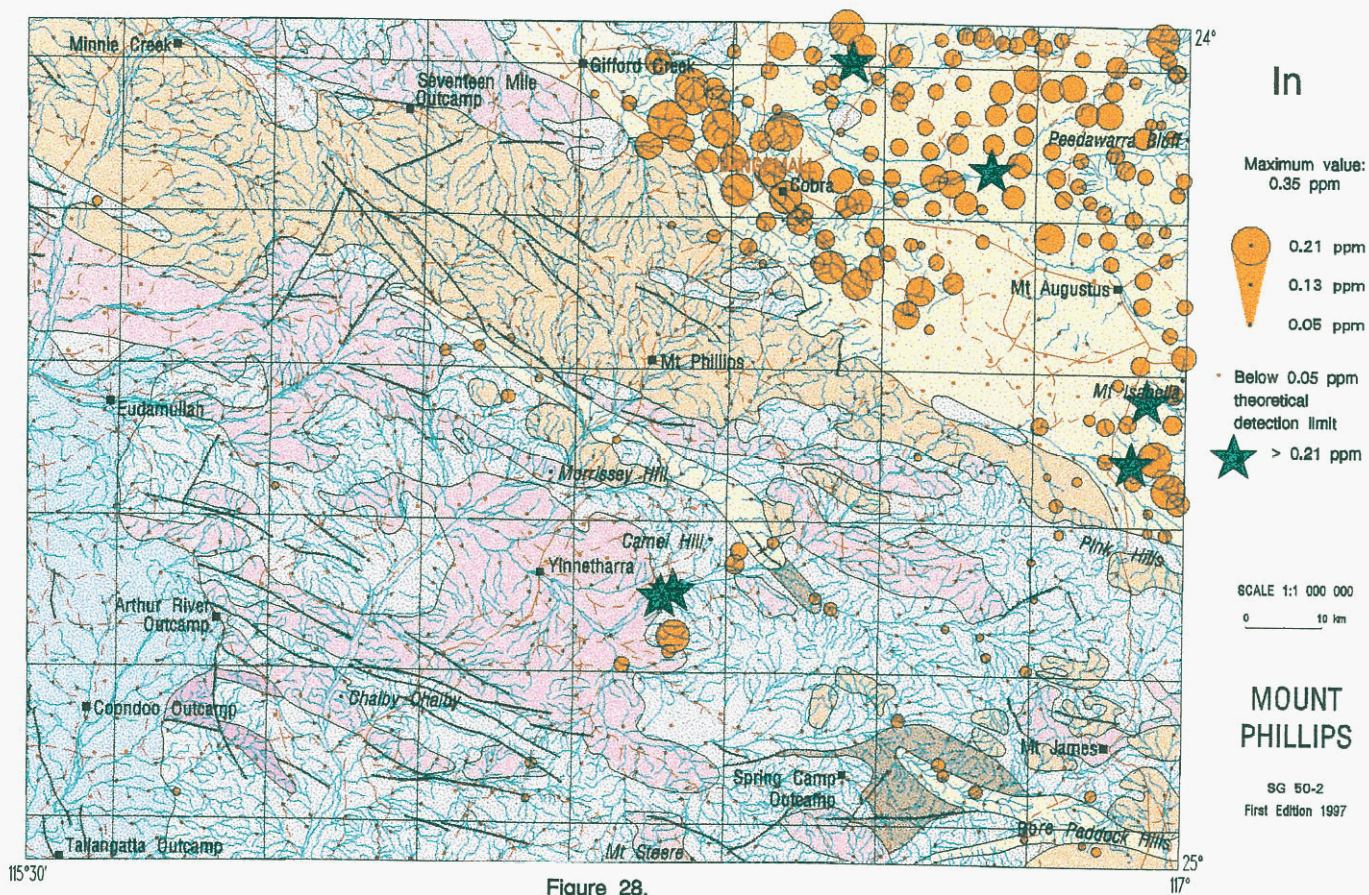


Figure 25.





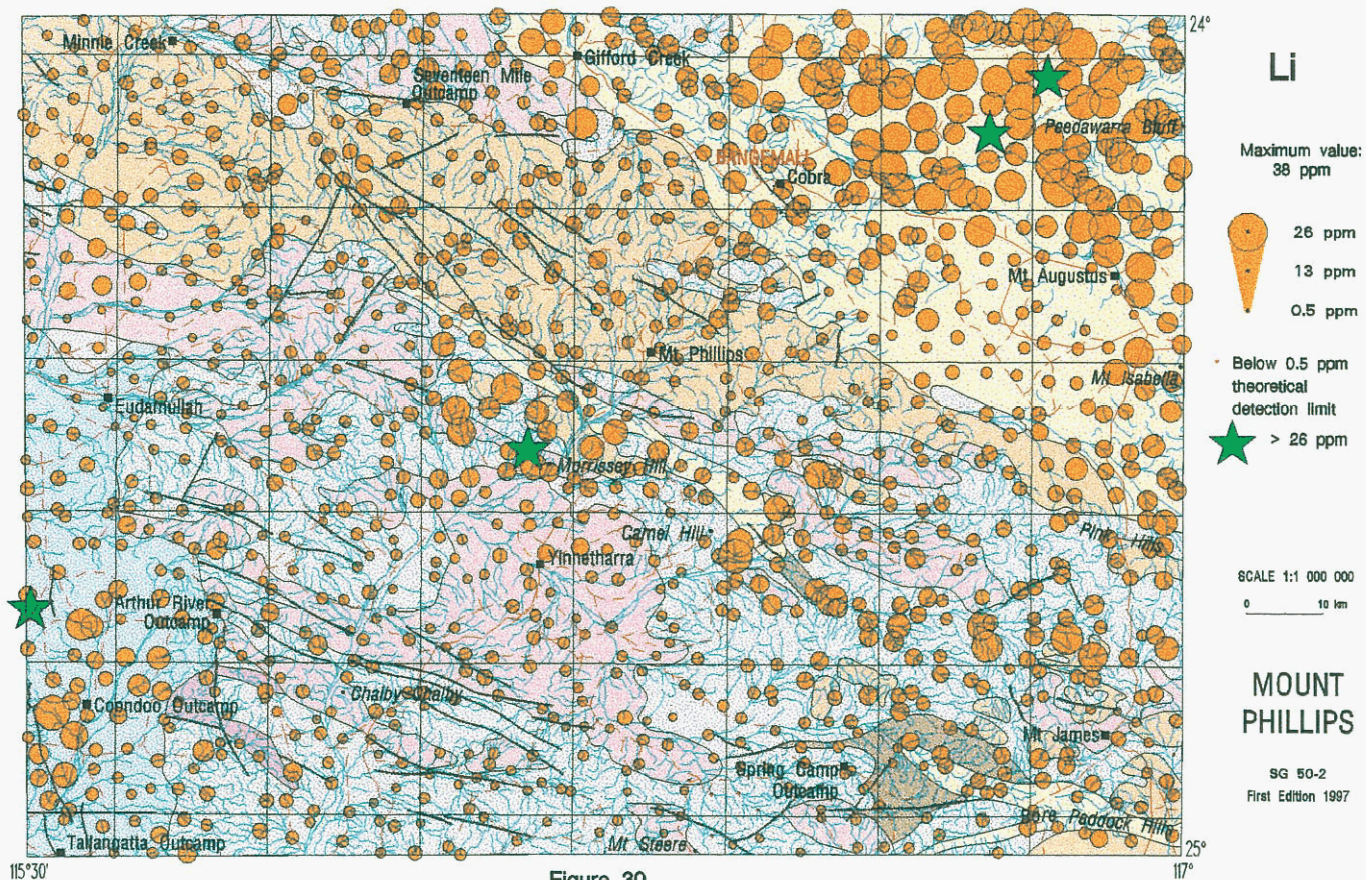


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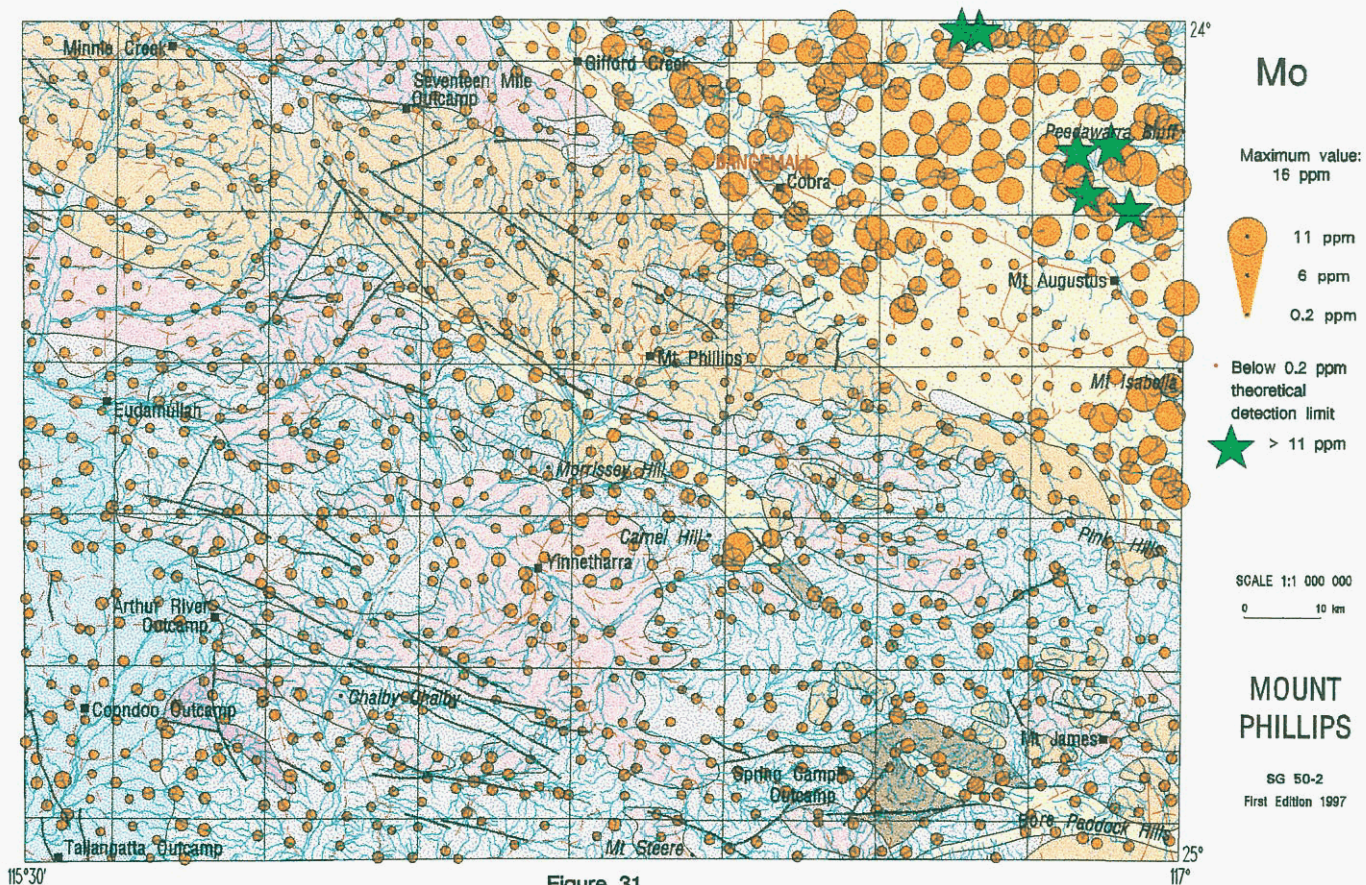
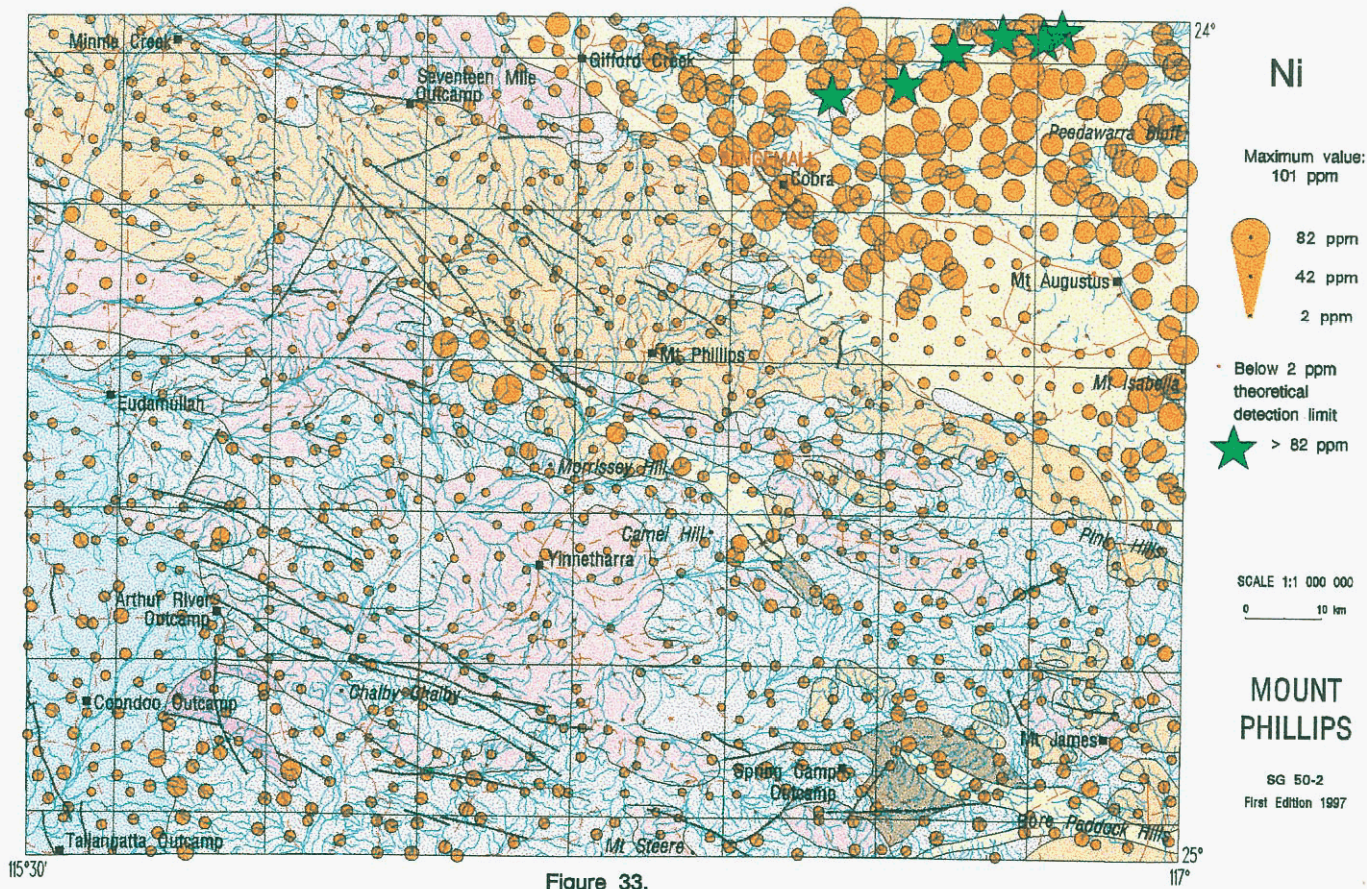
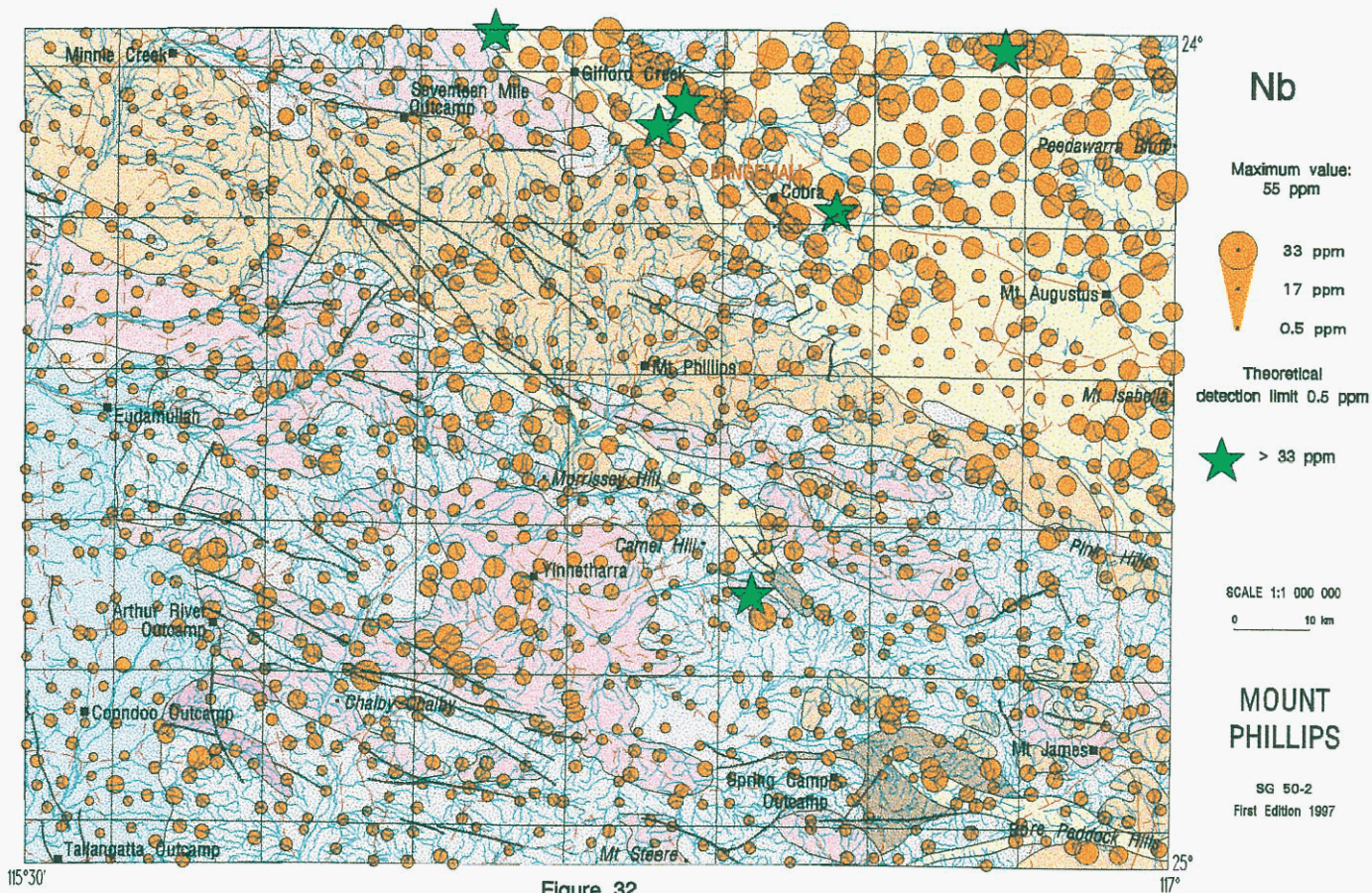


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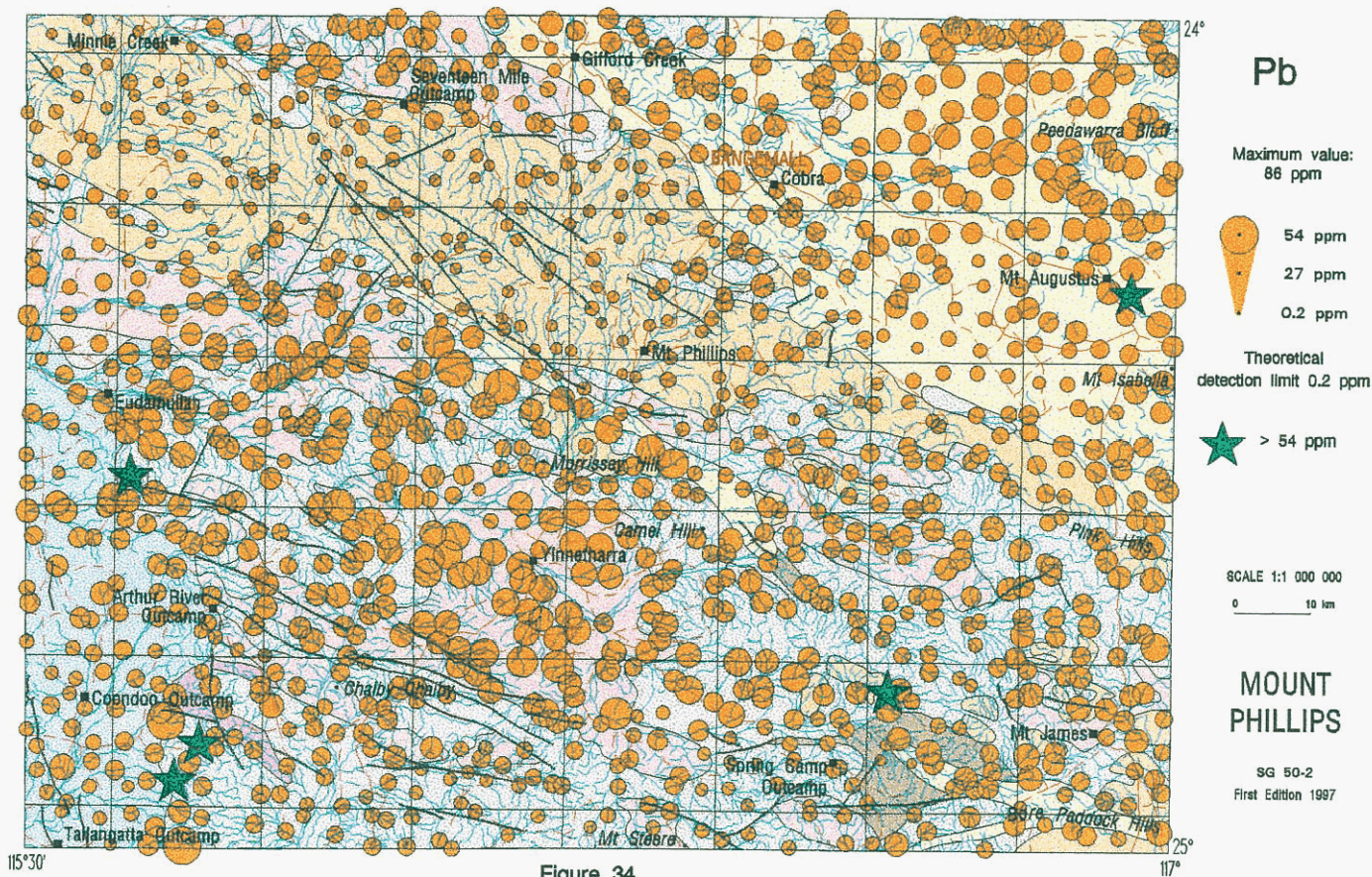


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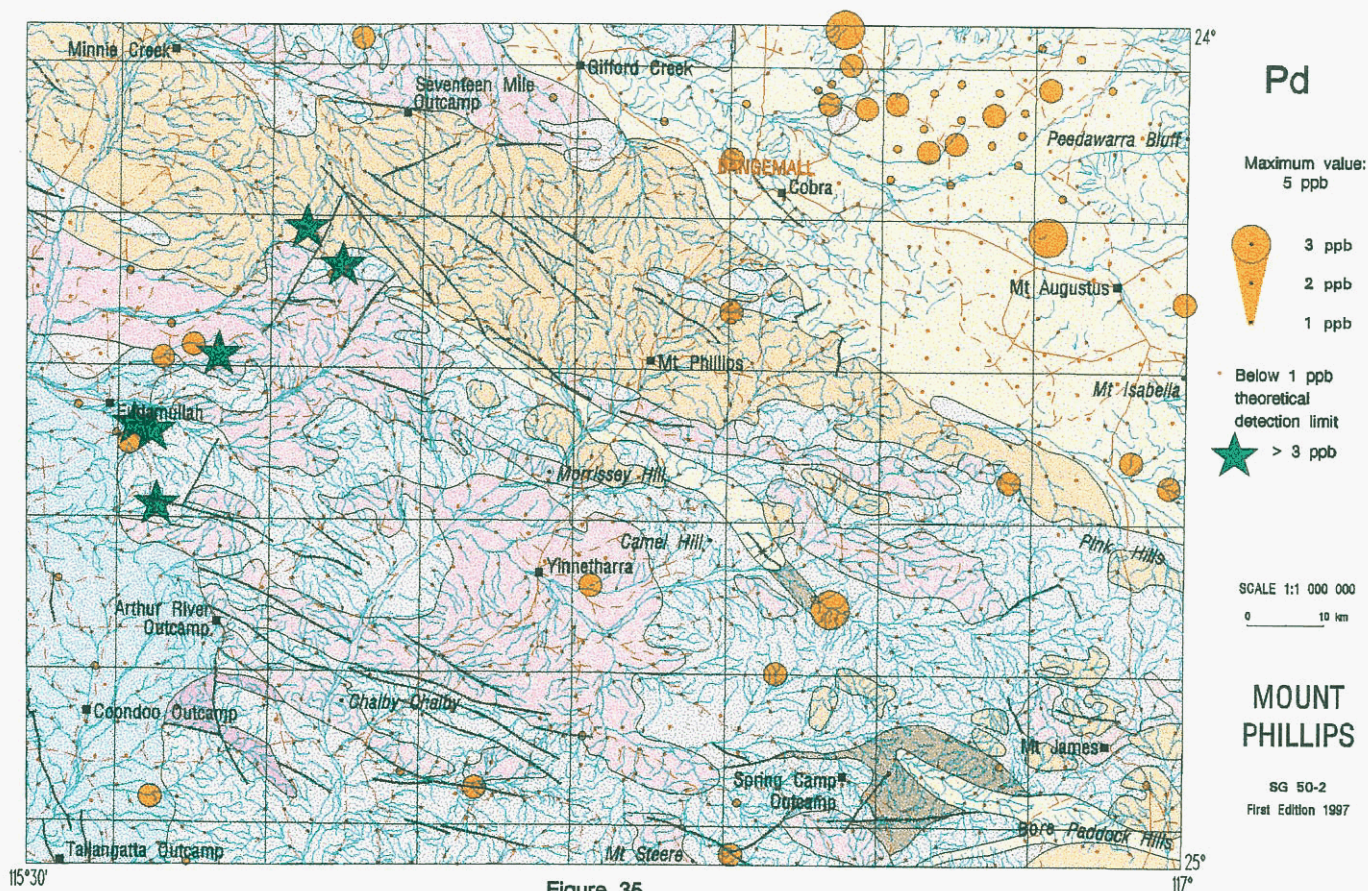


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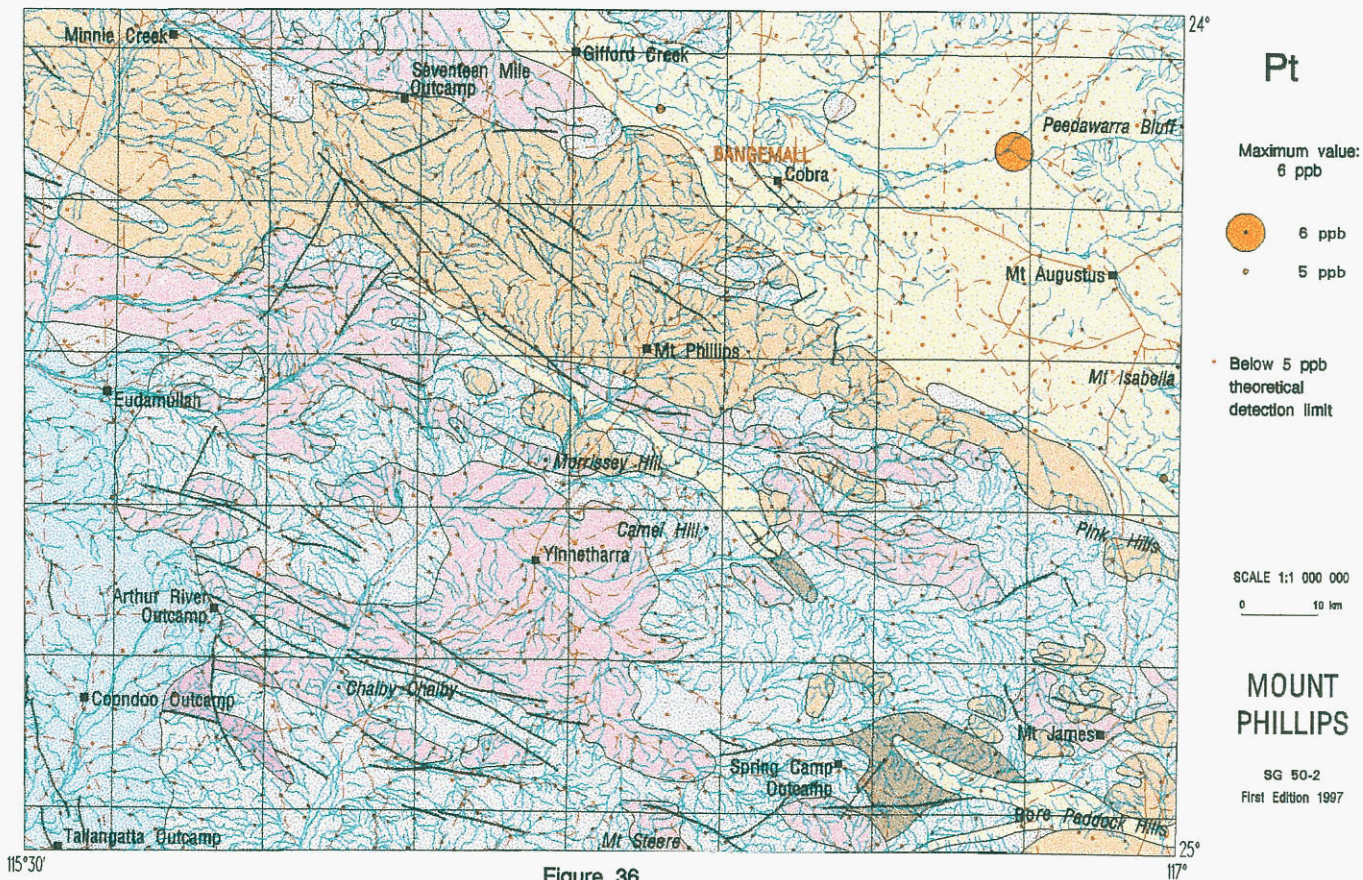


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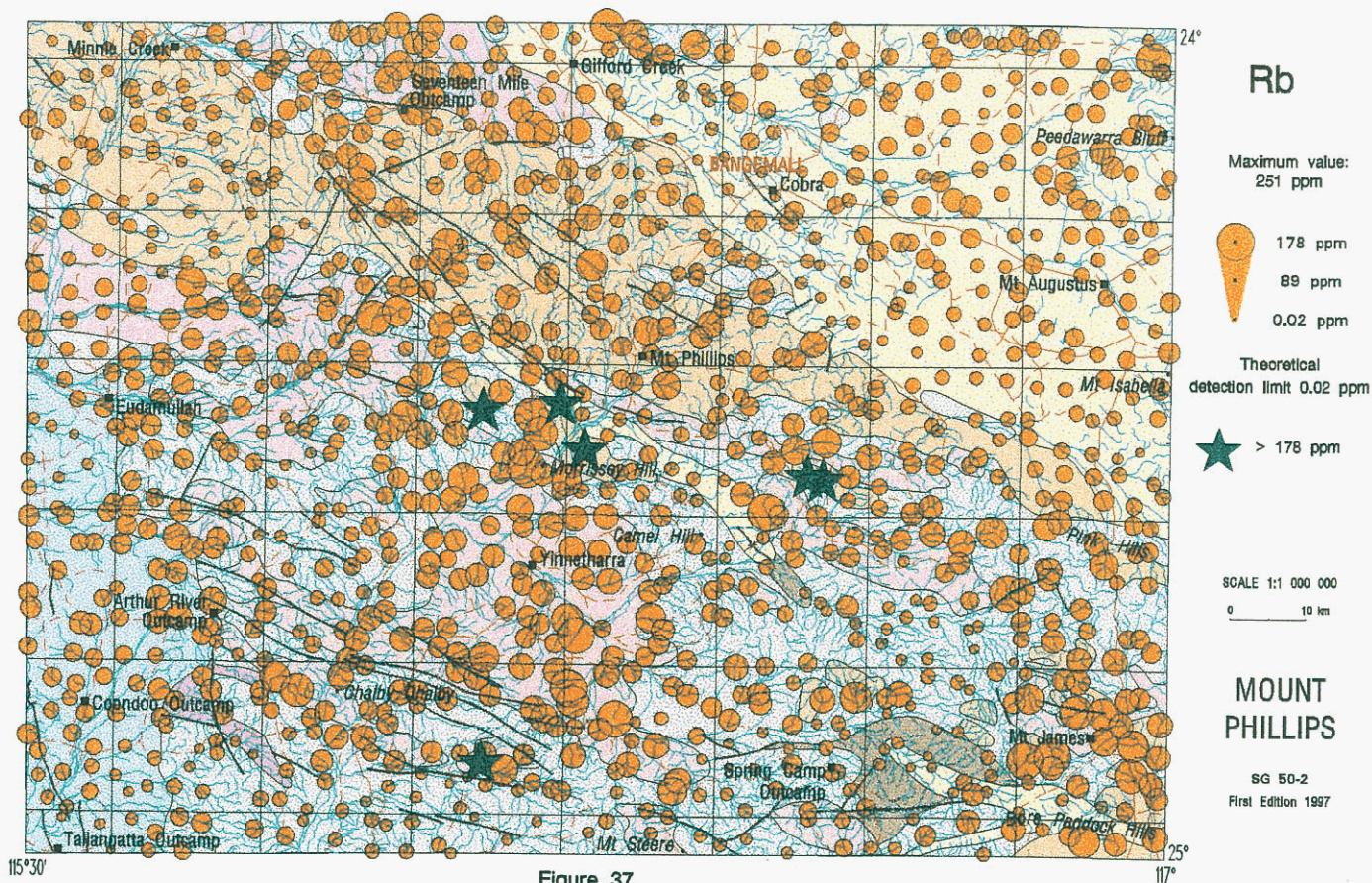
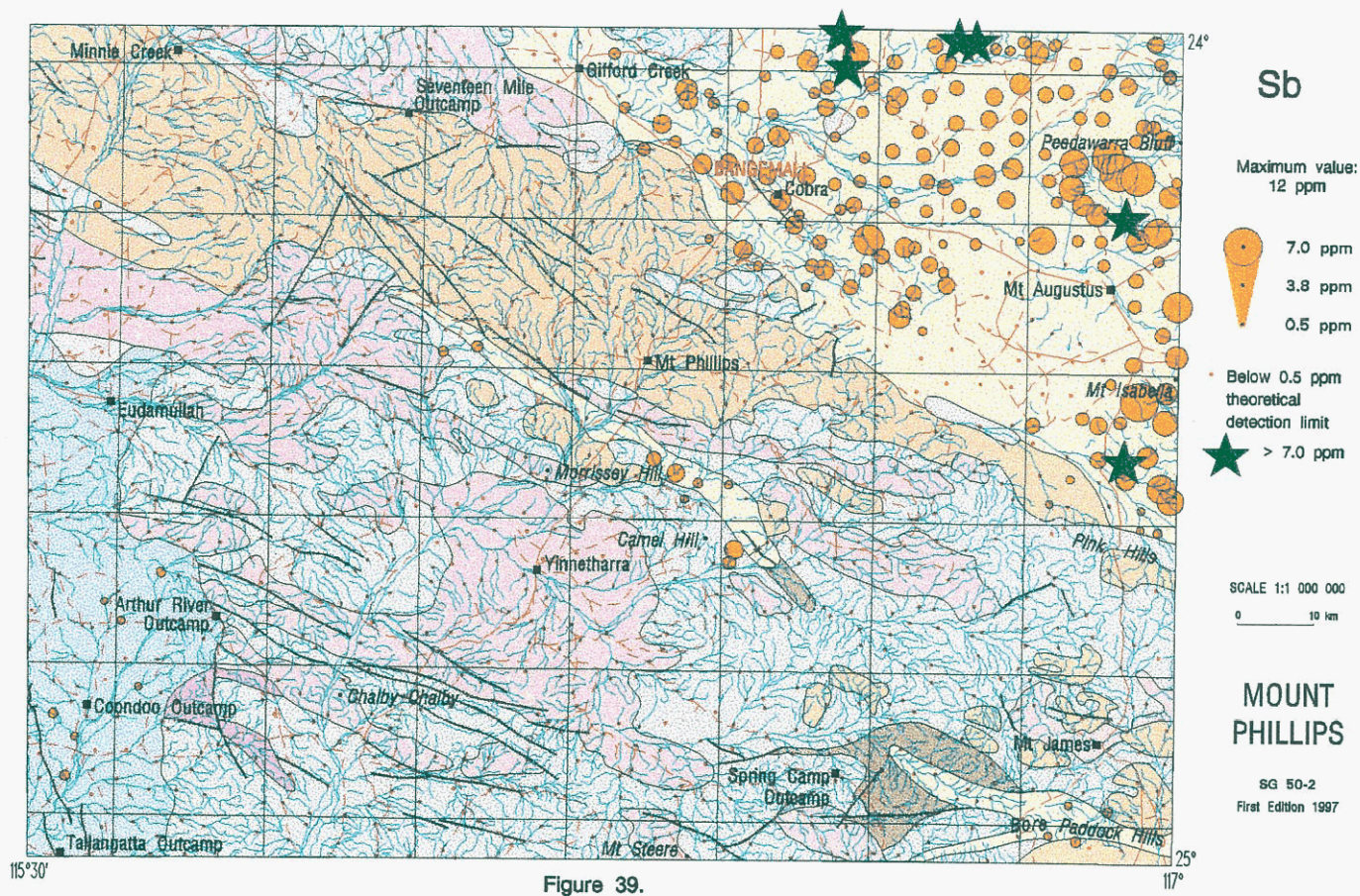
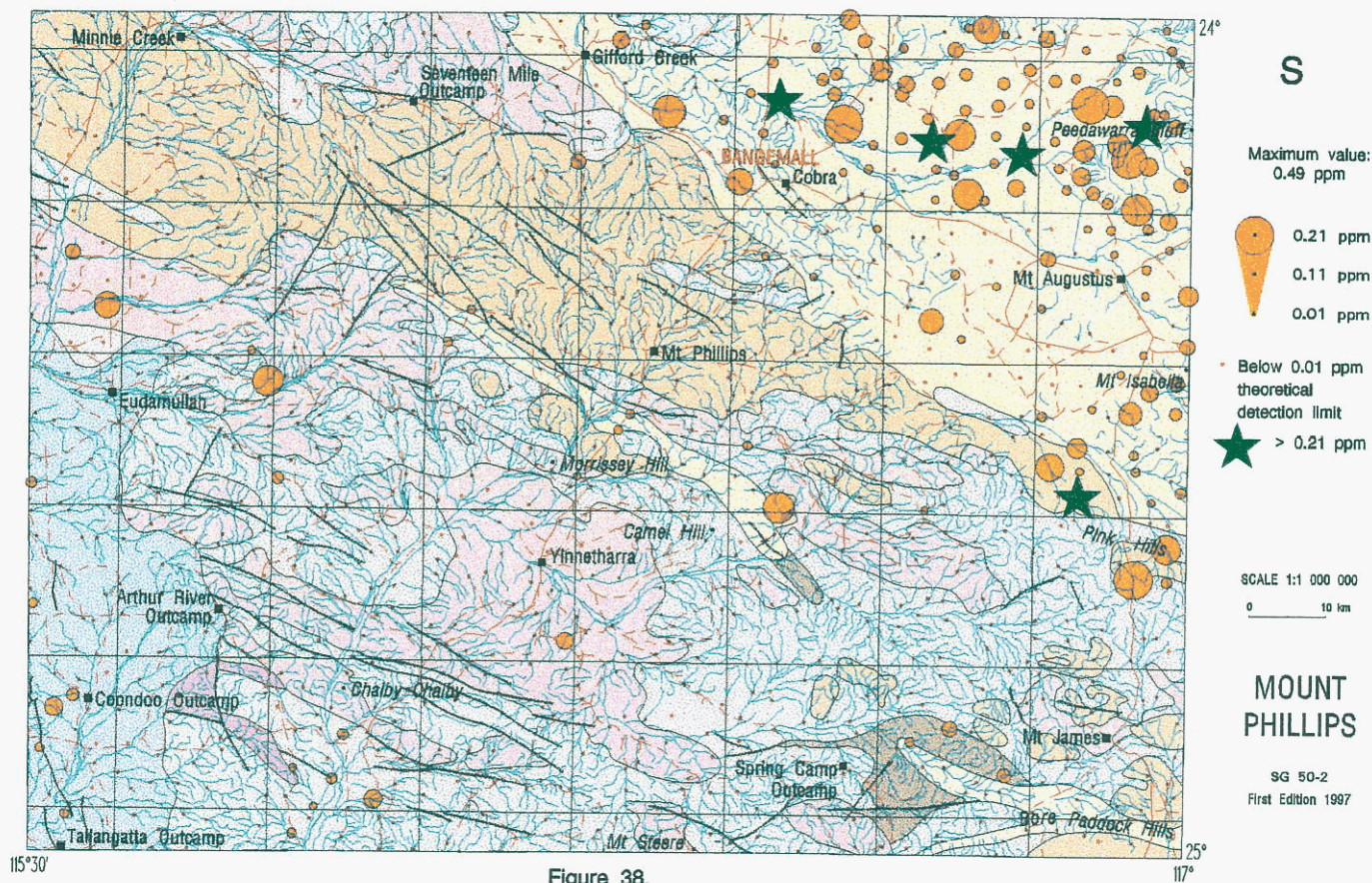
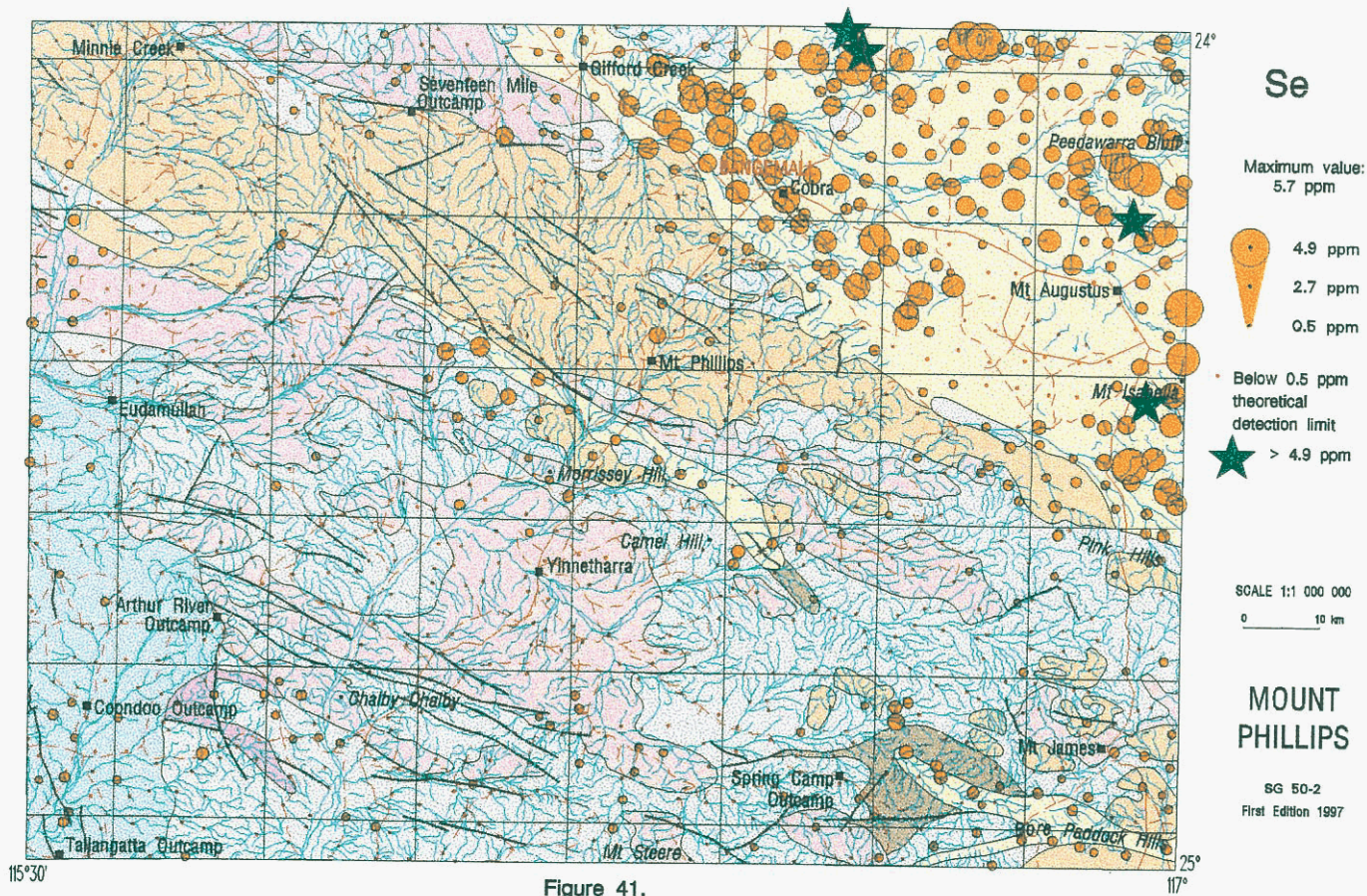
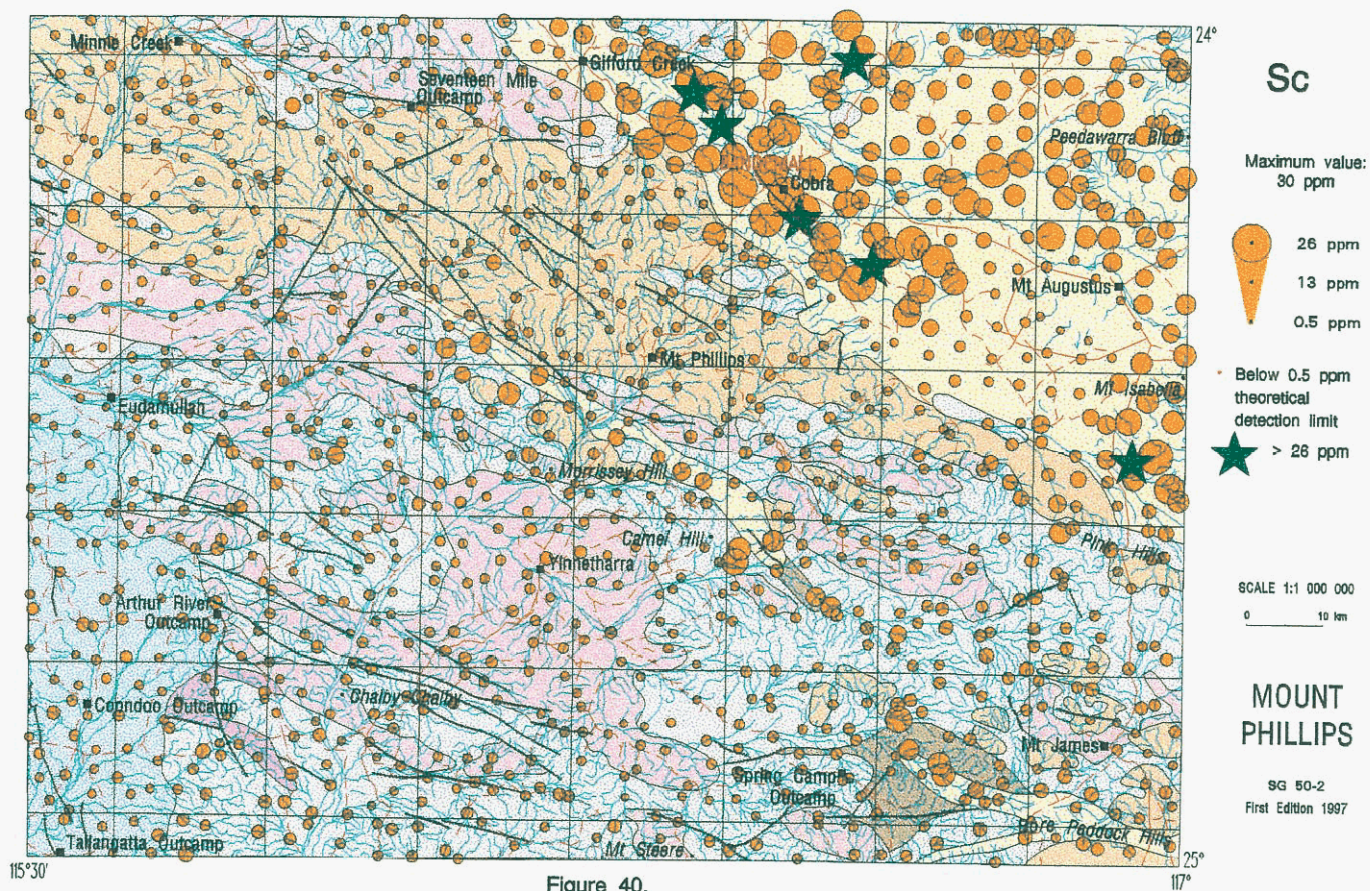


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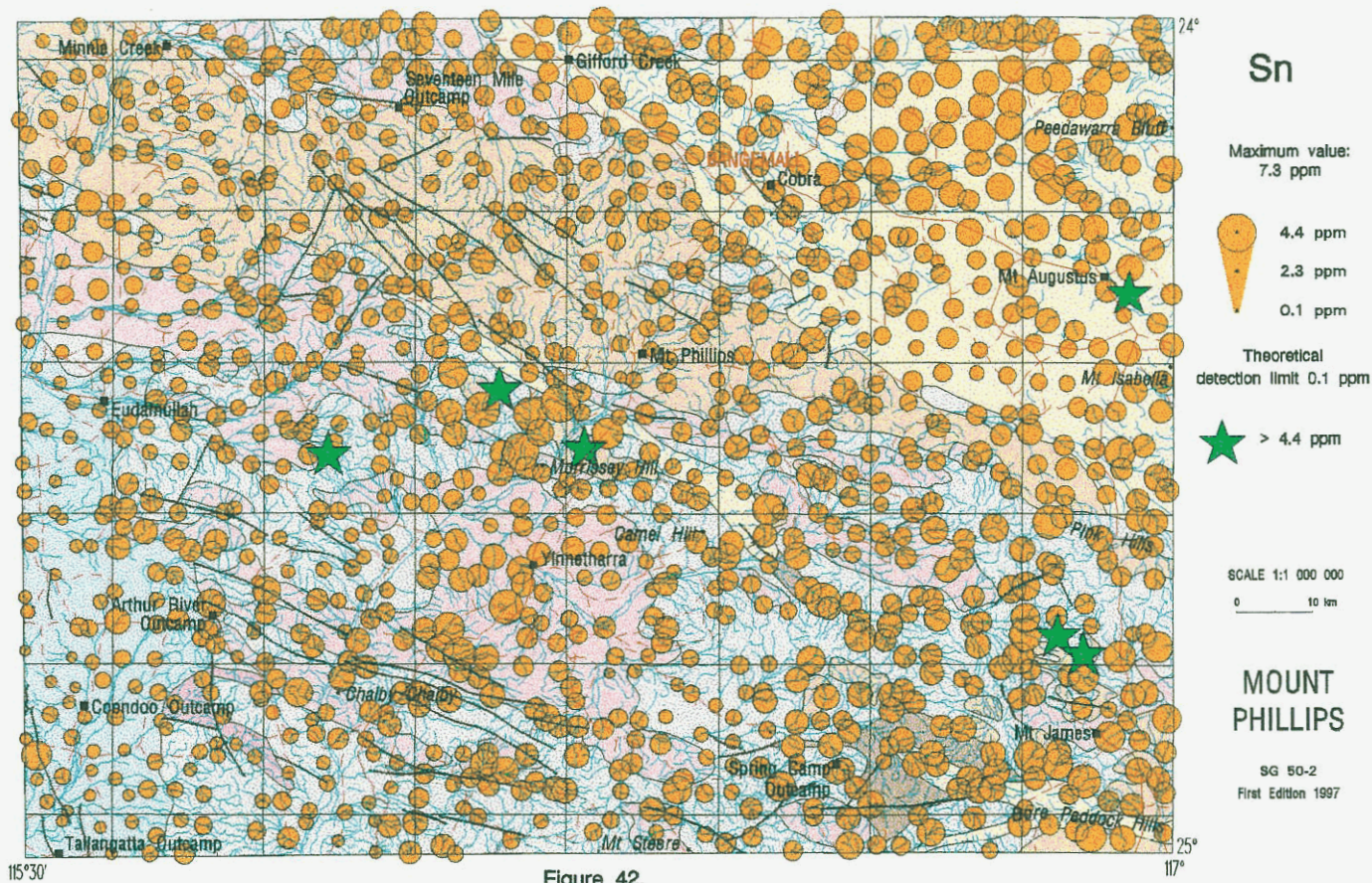


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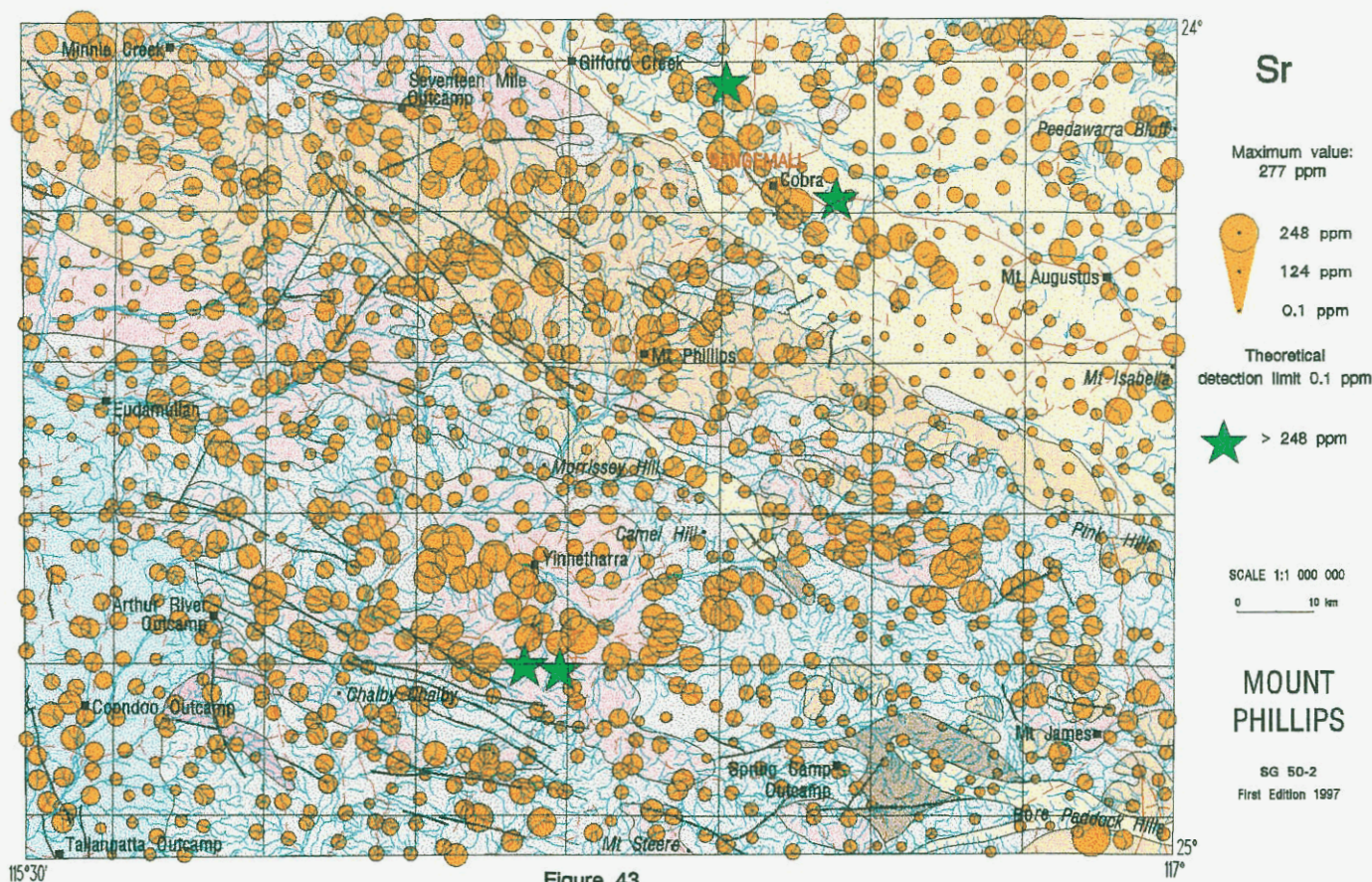
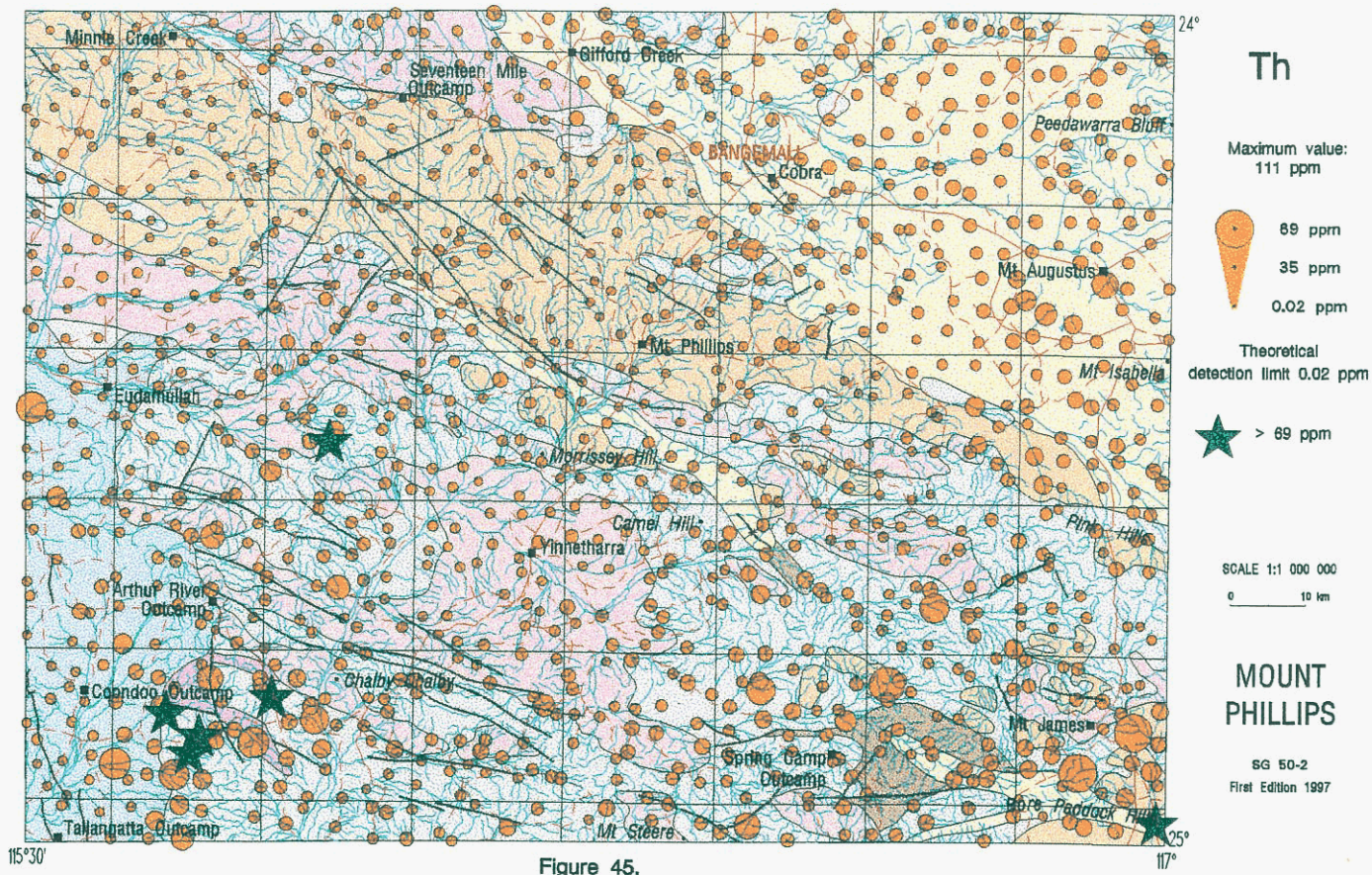
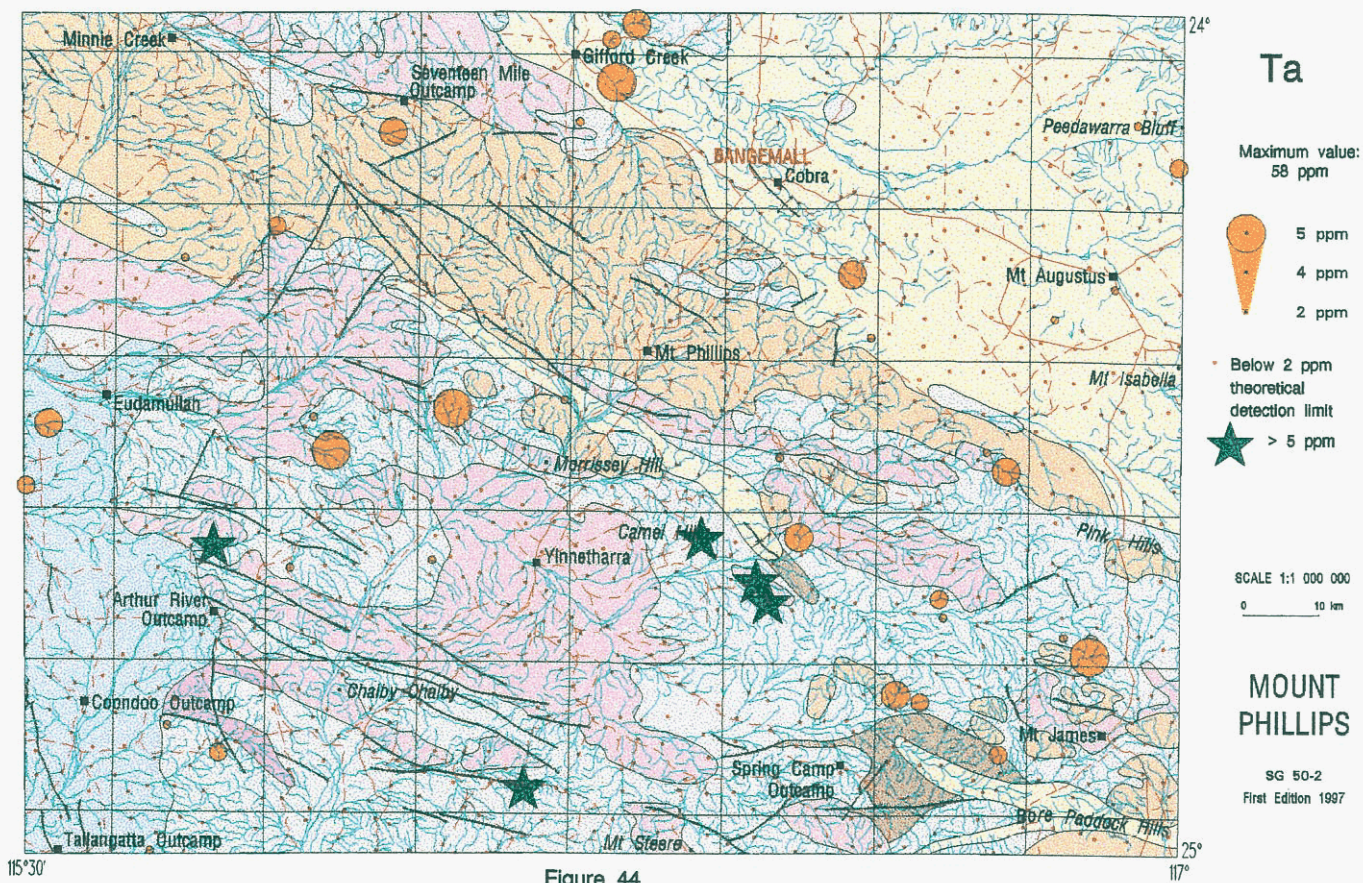
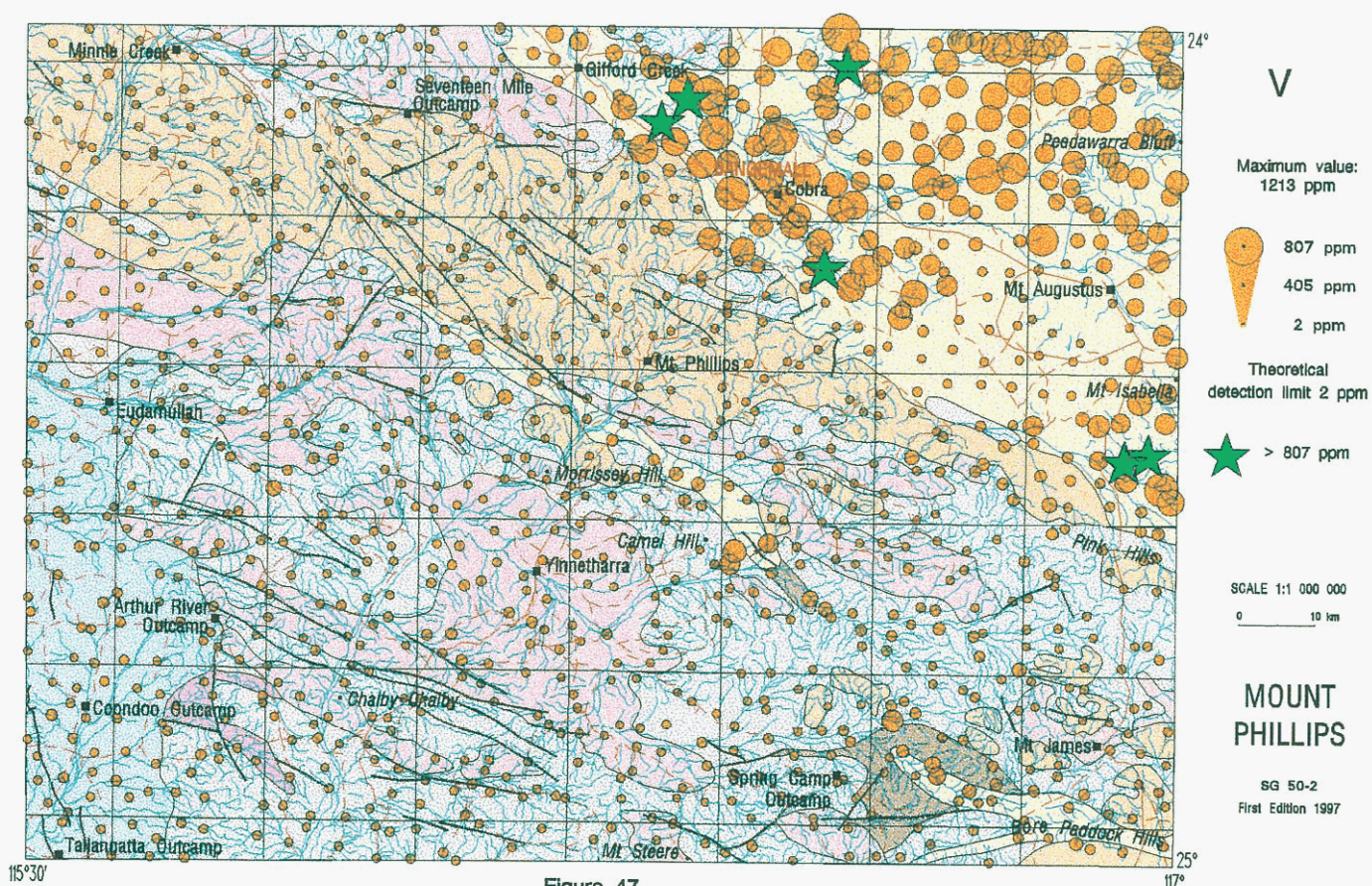
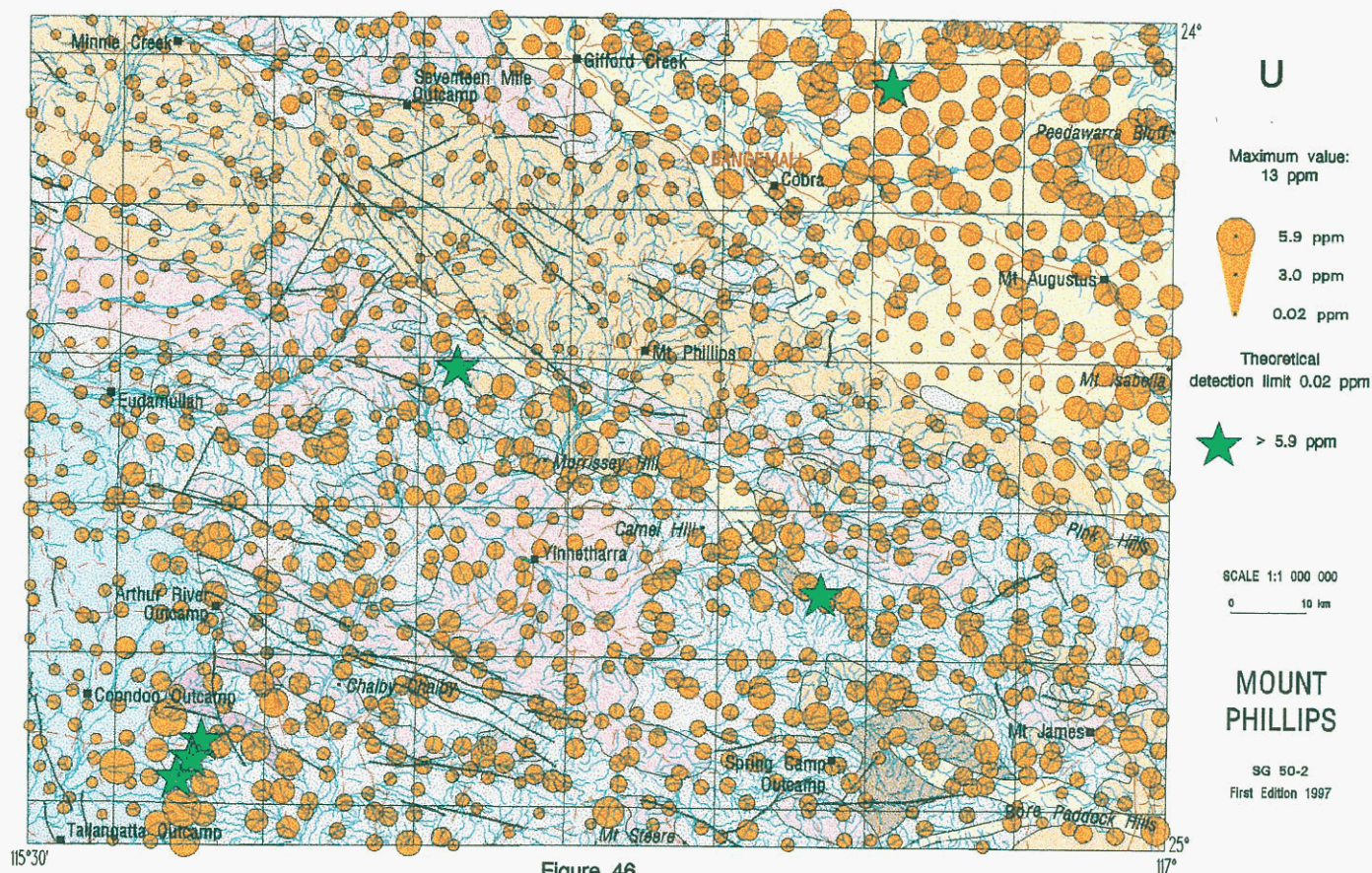
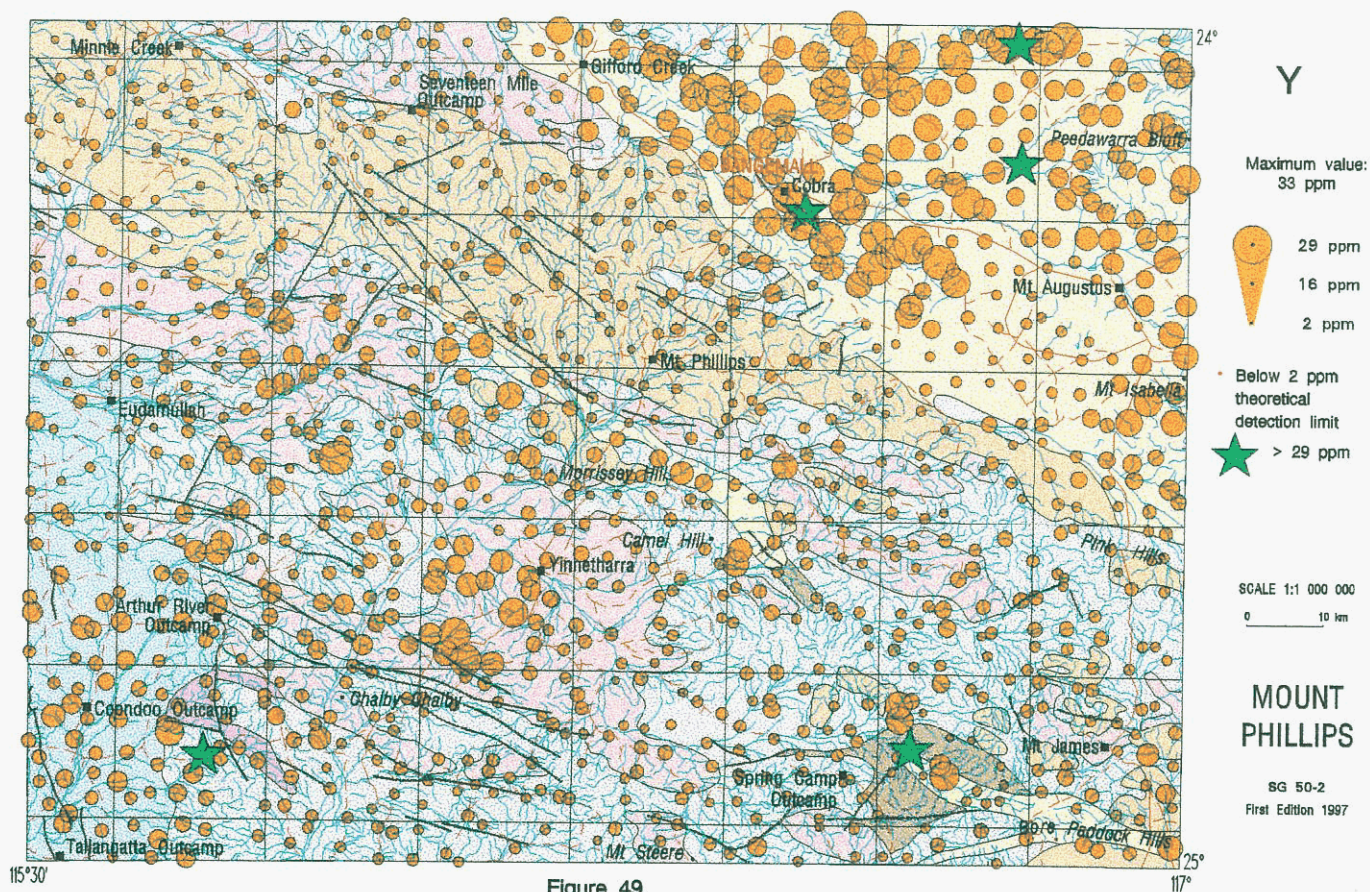
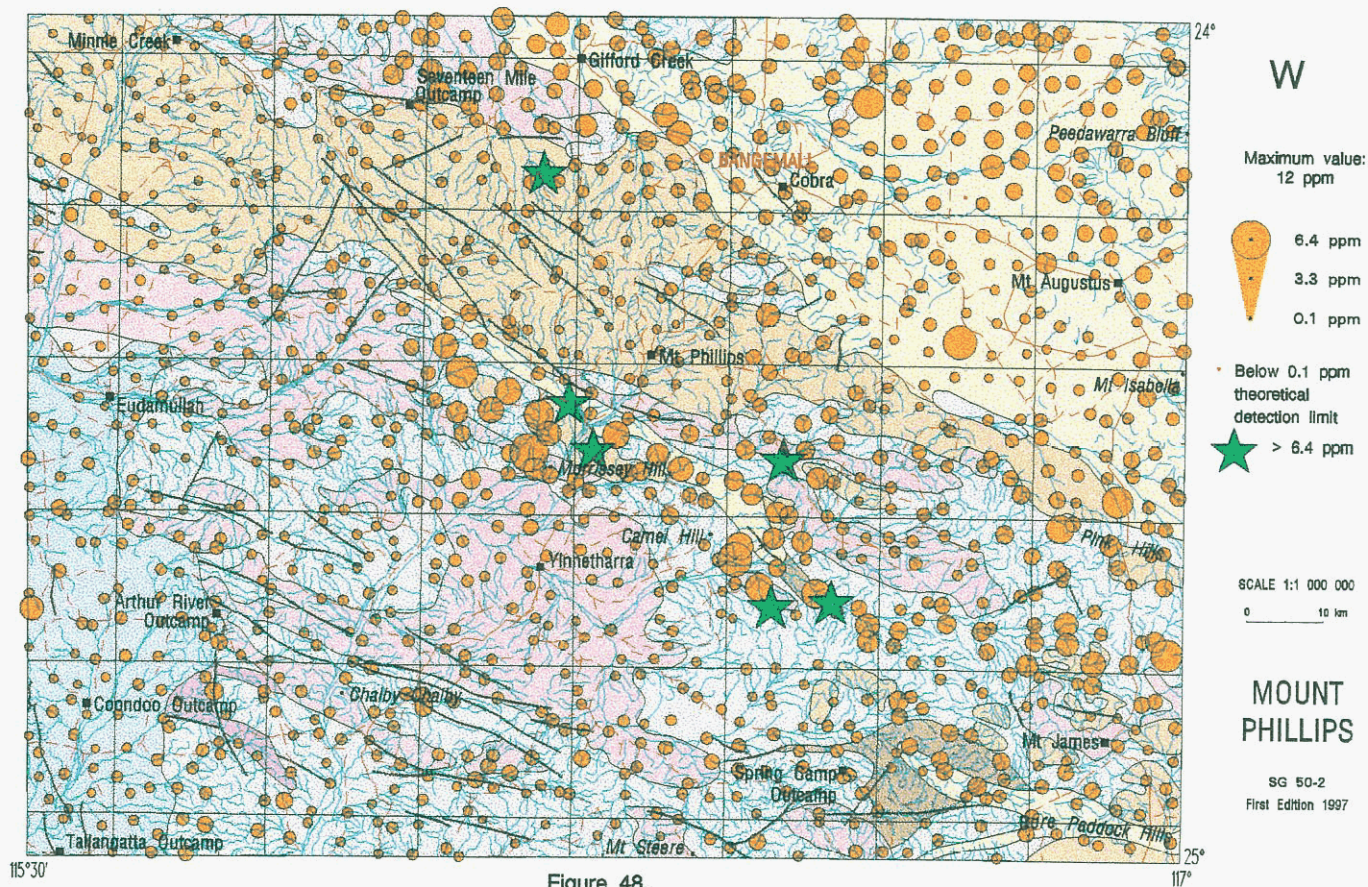


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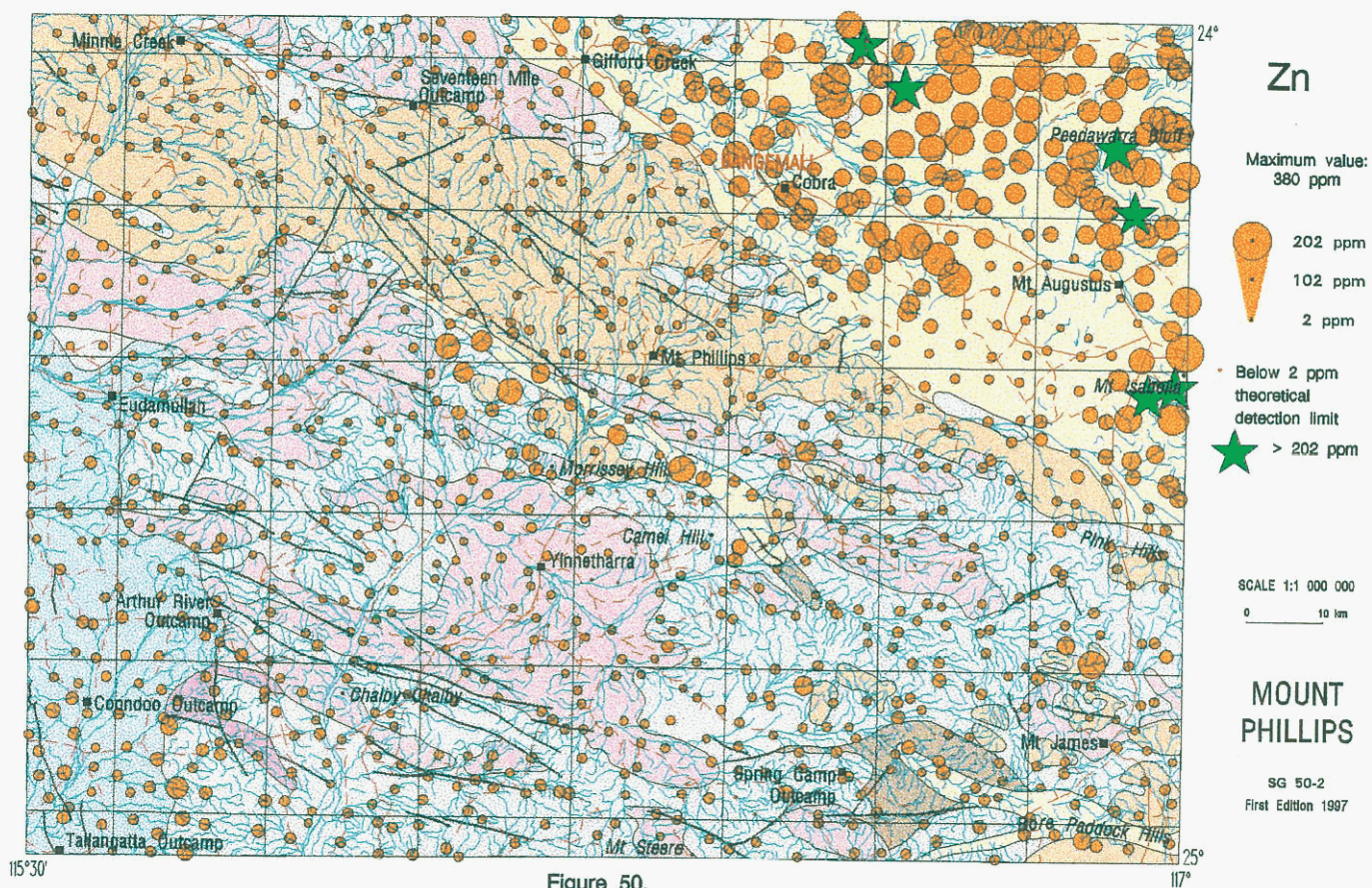


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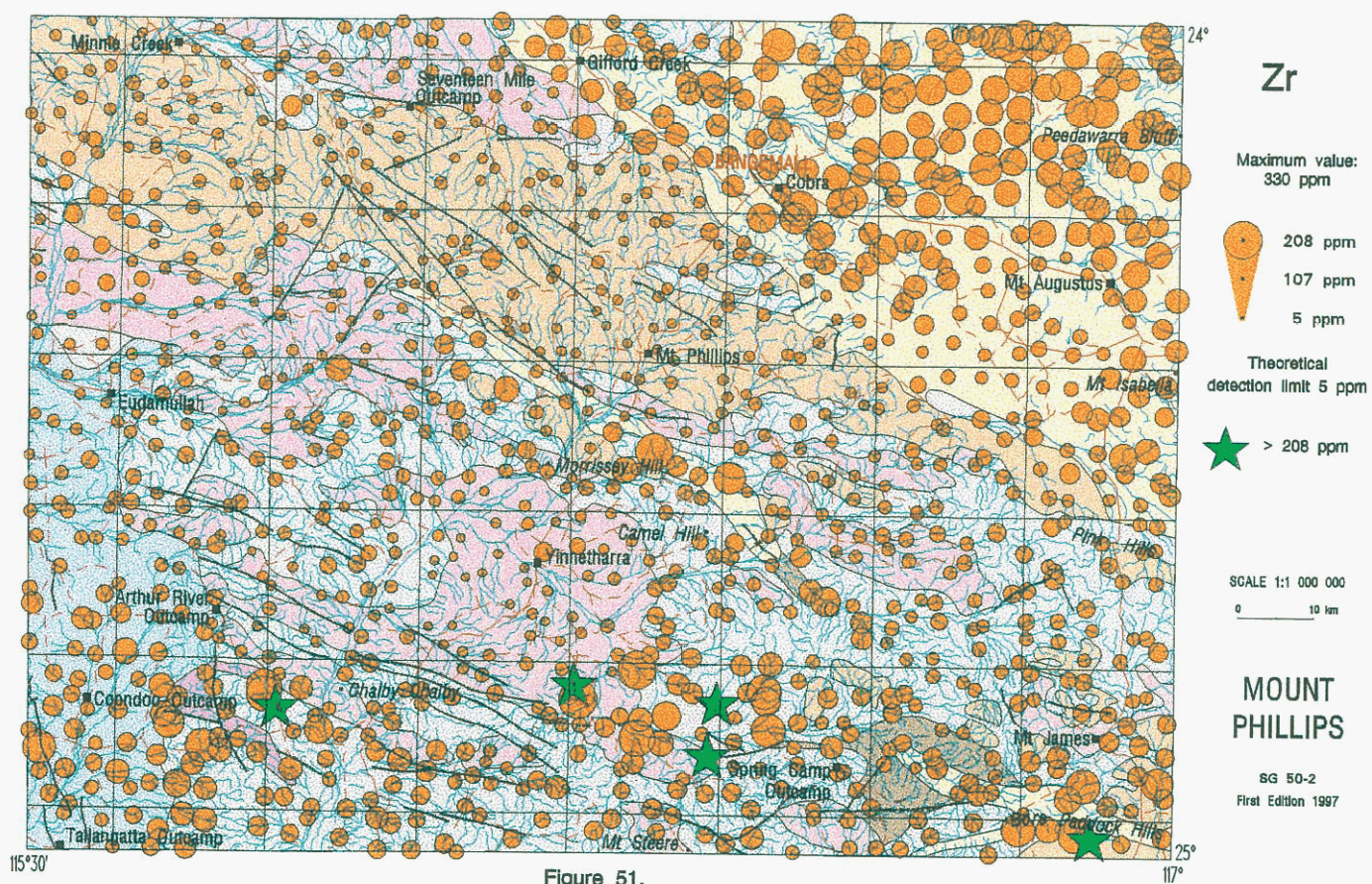


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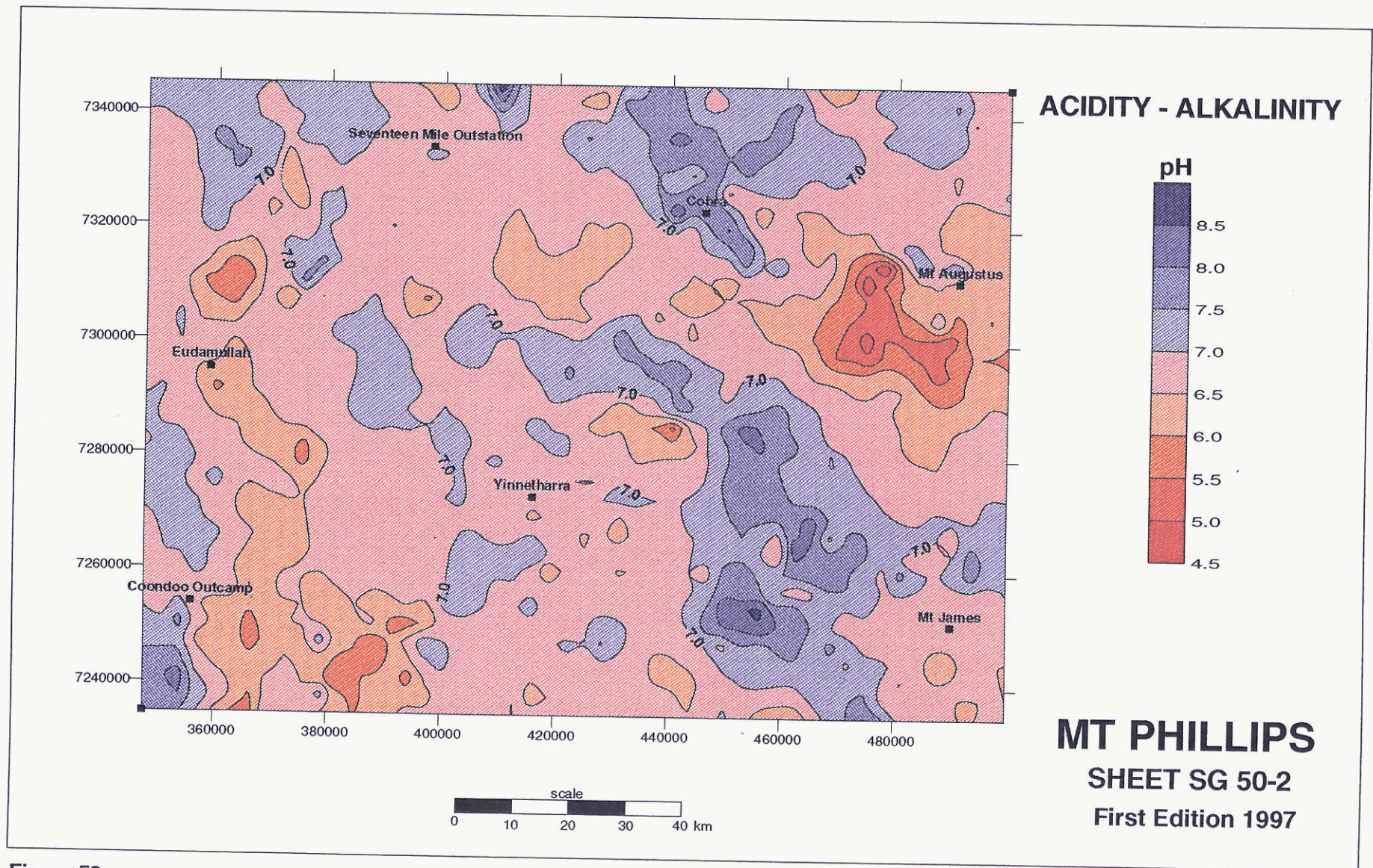


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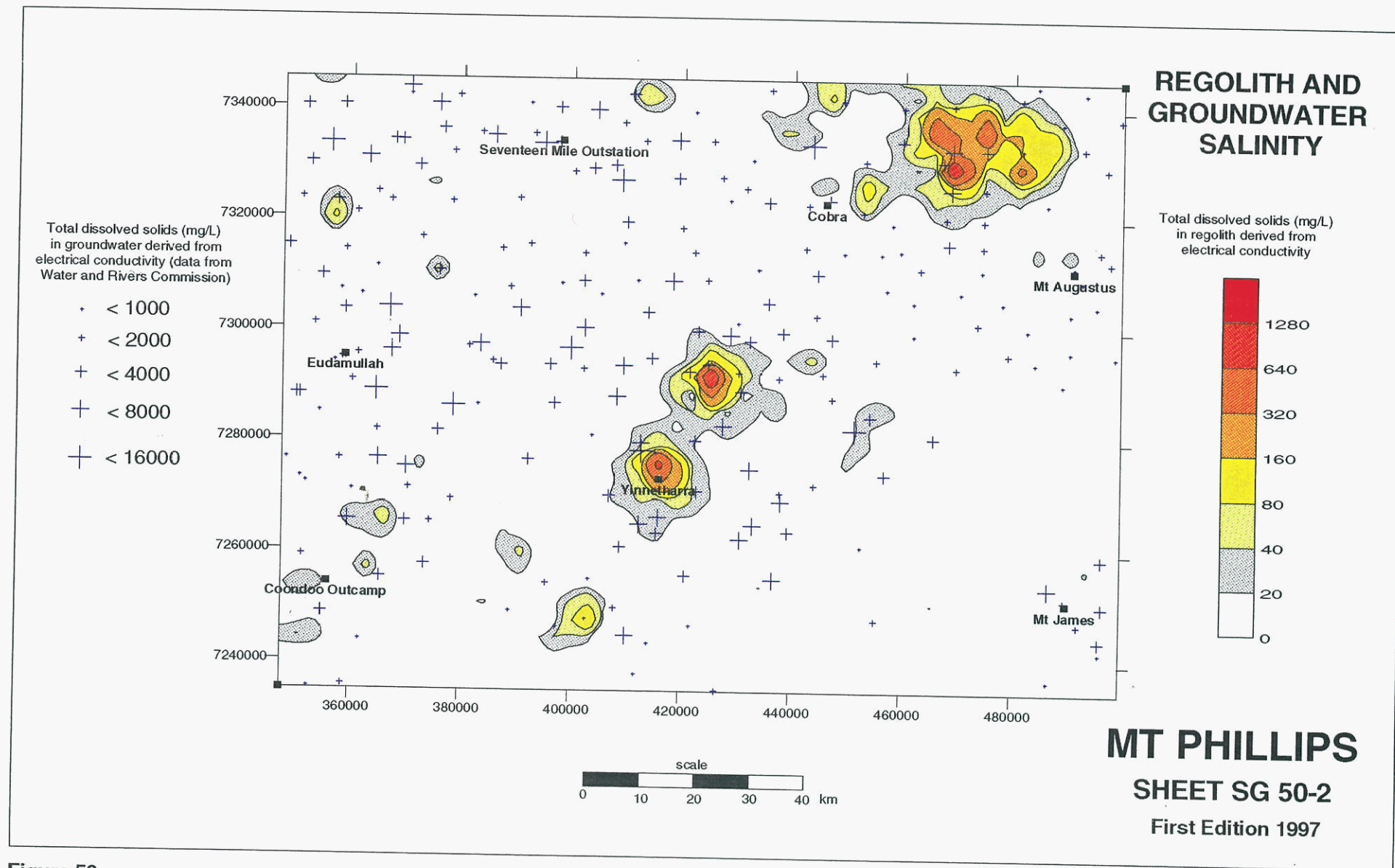


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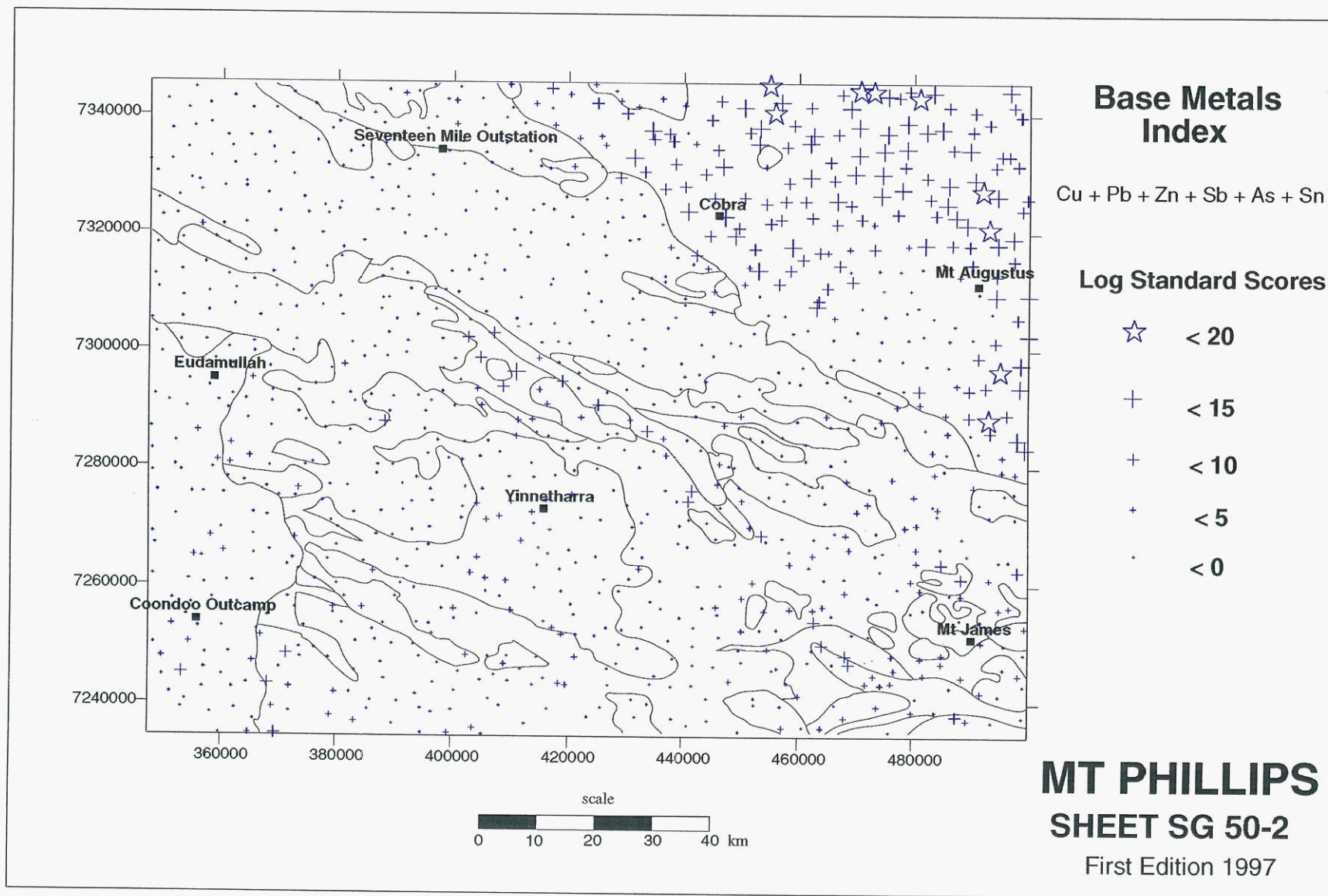


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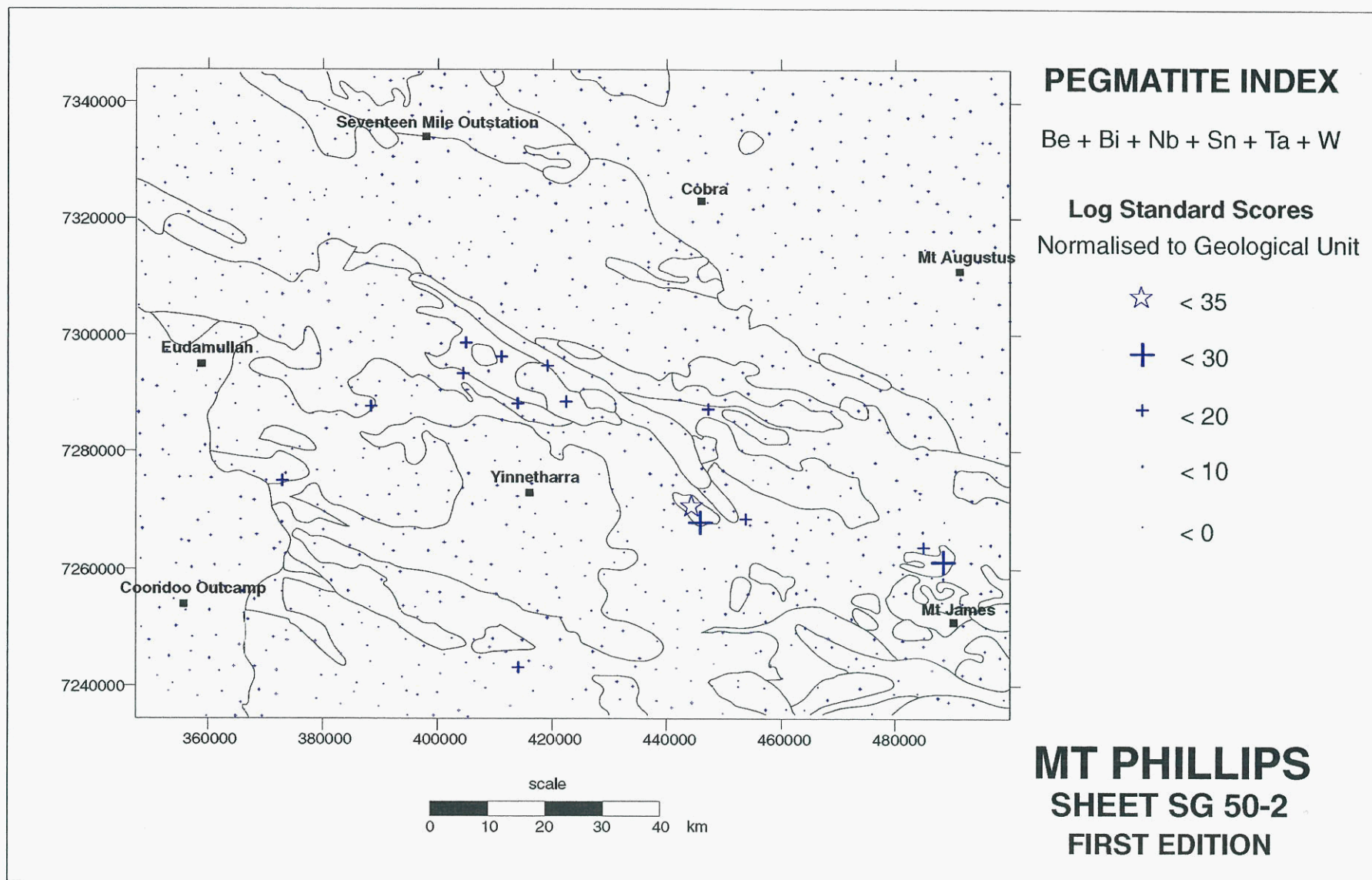
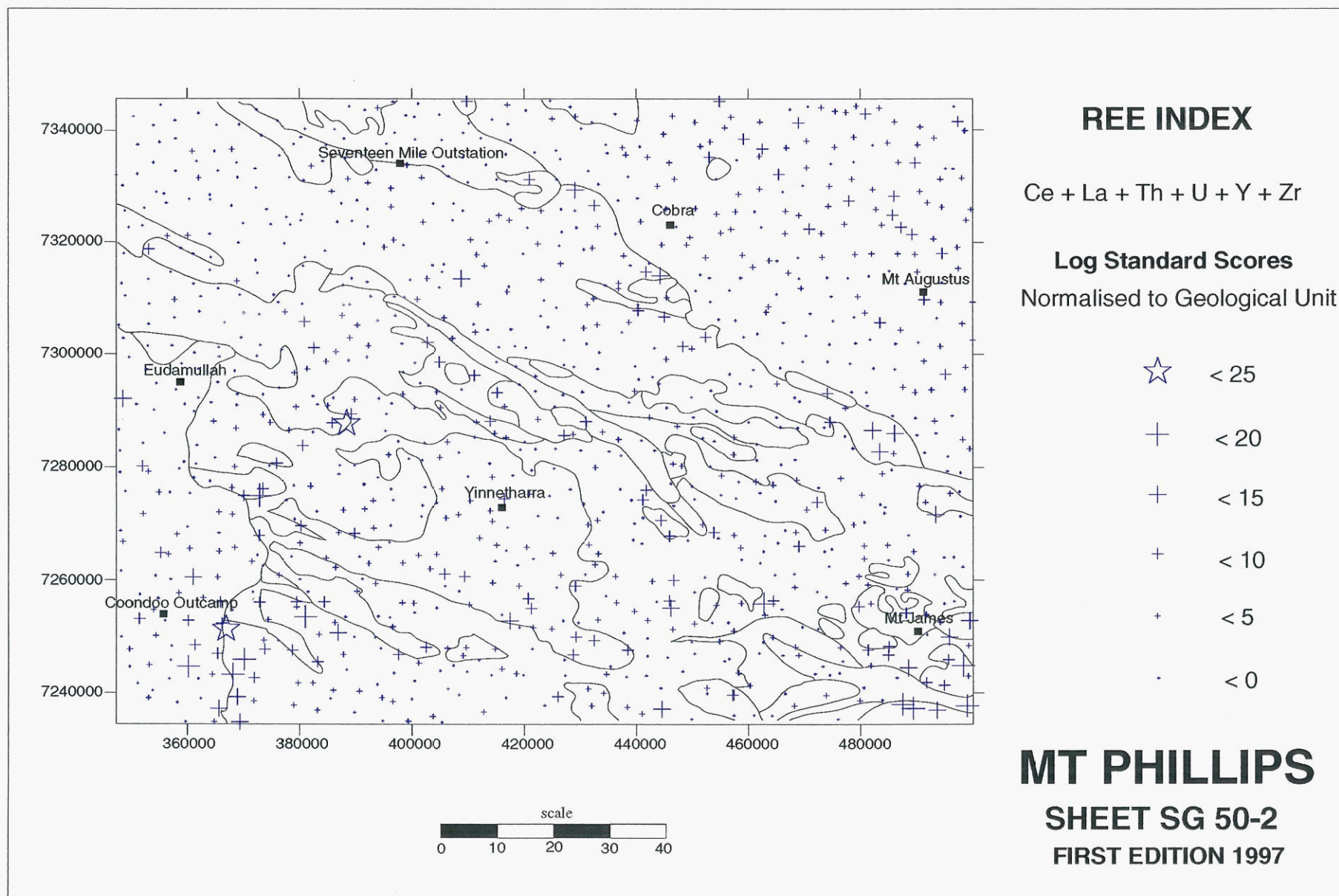


Figure 55.



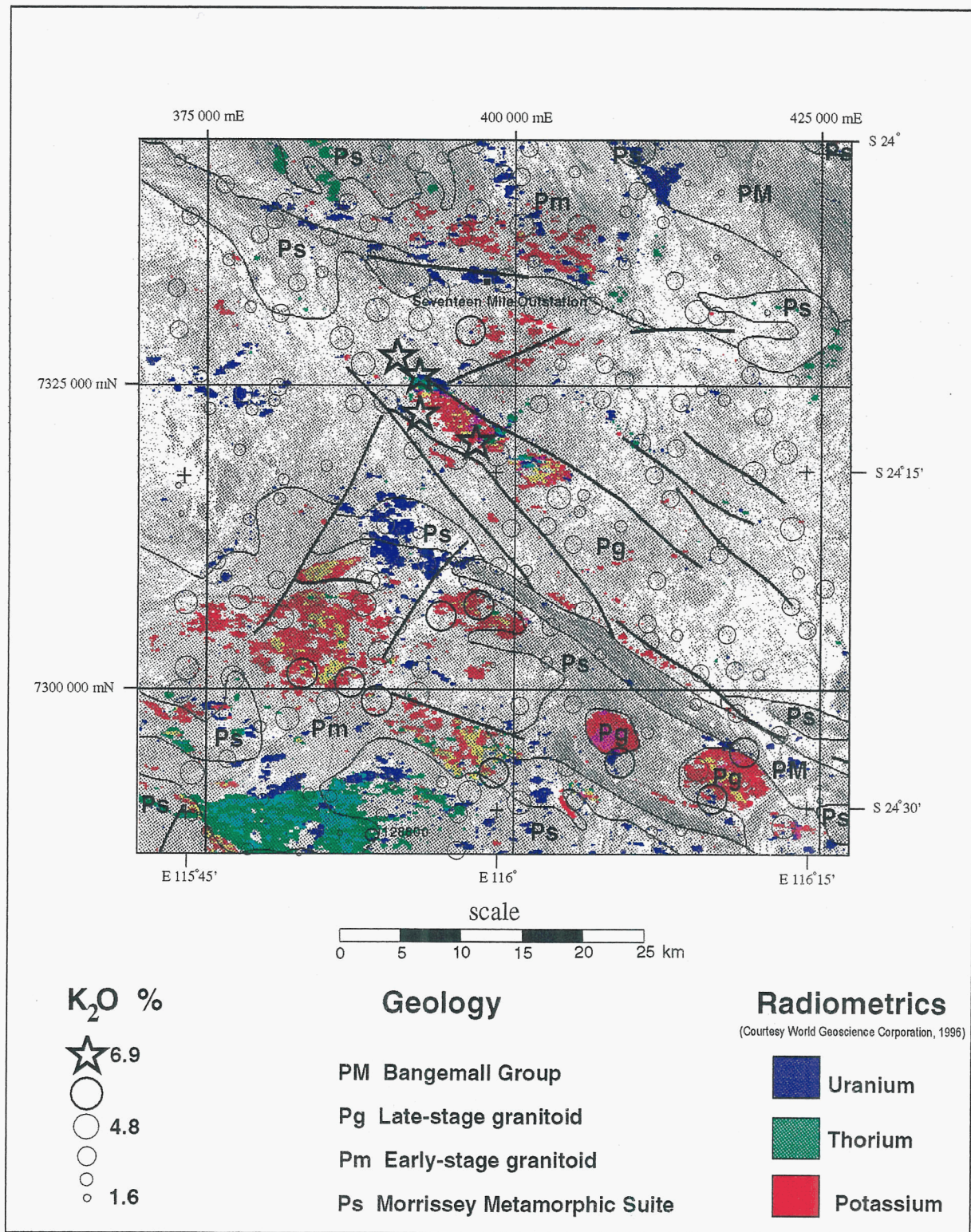
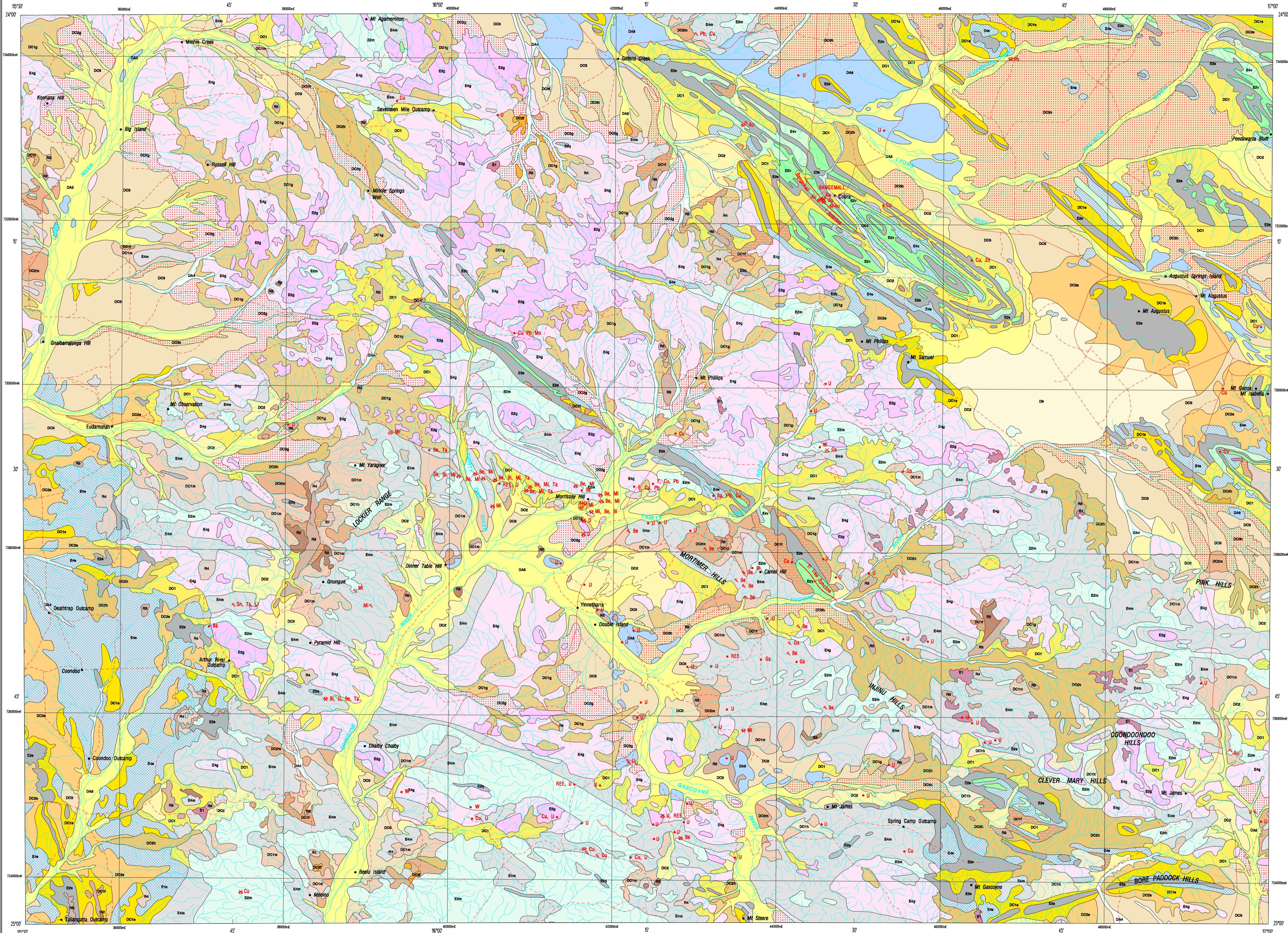


Figure 57. Combined map of Landsat (shaded grey), radiometric data, geology and regolith geochemistry (K<sub>2</sub>O) of part of MOUNT PHILLIPS



RELICT REGIME

- R1 Ferruginous siltstones, granules, and nodules
- R2 Iron-rich duricrust forming remnant land surfaces
- R3 Silcrete, often weakly ferruginized; includes areas of silicified caliche and karst
- R4 Quartz-rich sand and silt overlying R1-R3 materials; may be locally inverted

EROSIONAL REGIME

- E1 Mottled zone and sporadic, generally poorly exposed except in upland areas with isolated drainage
- E2g Granitoid rock outcrop of saprock and bedrock, and areas of outcrop with locally derived sands and sandy clays. Coarse (boundary) lag may be present adjacent to prominent ridges
- E2v Mottled rock outcrop of saprock and bedrock, and areas of outcrop with locally derived sands and sandy clays. Coarse (boundary) lag may be present adjacent to prominent ridges
- E2s Sedimentary rock outcrop of saprock and bedrock, and areas of outcrop with locally derived sands and sandy clays. Coarse (boundary) lag may be present adjacent to prominent ridges
- E2m Metamorphic rock outcrop of saprock and bedrock, and areas of outcrop with locally derived sands and sandy clays. Coarse (boundary) lag may be present adjacent to prominent ridges
- E2c Prominent ridges, possibly quartz-filled shear zones
- E4g Granitoid rock. Lag of locally derived ferruginous and/or lithic fragments in a sandy clay to sand-rich matrix, associated with actively eroding outcrops
- E4v Mottled rock. Lag of locally derived ferruginous and/or lithic fragments in a sandy clay to sand-rich matrix, associated with actively eroding outcrops
- E4s Sedimentary rock. Lag of locally derived ferruginous and/or lithic fragments in a sandy clay to sand-rich matrix, associated with actively eroding outcrops
- E4m Metamorphic rock. Lag of locally derived ferruginous and/or lithic fragments in a sandy clay to sand-rich matrix, associated with actively eroding outcrops

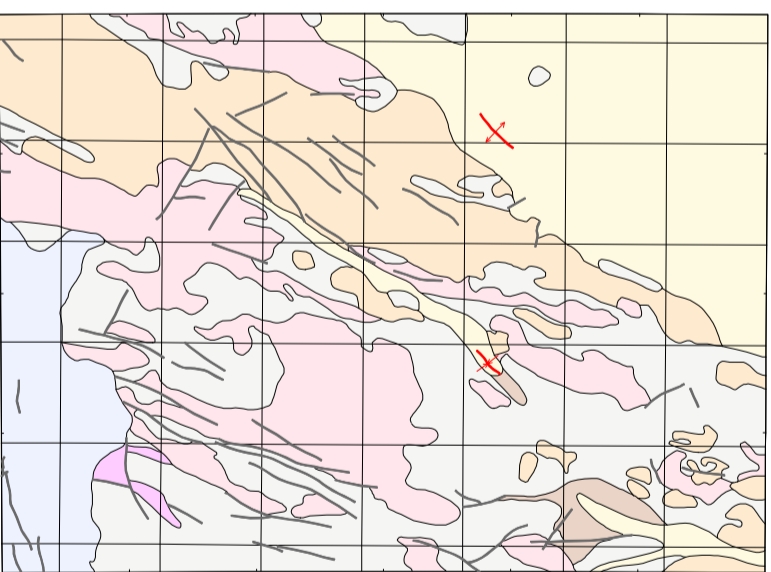
DEPOSITIONAL REGIME

- DOMINANTLY COLLOIDAL
  - DC1 Medium to coarse-grained rock detritus in sandy clay-rich colluvial matrix, generally in upland areas
  - DC1g As for DC1 derived mainly from granitoid rock
  - DC1s As for DC1 derived mainly from sedimentary rock
  - DC1m As for DC1 derived mainly from metamorphic rock
  - DC1f As for DC1 derived from various sources; strongly ferruginized clasts of various composition
  - DC2 Consolidated colluvium; reddish brown and poorly bedded; proximal to outcrops
  - DC2f Fine to medium-grained detritus (clasts 4 - 25 mm) mainly of lithic origin, in sandy clay colluvial matrix, generally topographically lower than DC1
  - DC2g As for DC2 derived mainly from granitoid rock
  - DC2s As for DC2 derived mainly from sedimentary rock
  - DC2m As for DC2 derived mainly from metamorphic rock
  - DC2f As for DC2 derived from various sources; strongly ferruginized clasts of various composition
  - DC2h Consolidated colluvium; reddish brown and poorly bedded; moderately distal to outcrops
  - DC3 Sandstone dominated colluvium or sheetwash; merges into alluvial plane (DAS)
  - DC3f Non-lithic ferruginous detritus (mostly <10mm), possibly magnetic, in red sandy clay. May include basaltic grains; position comparable with DC3
  - DC3h Consolidated colluvium (hardpan); reddish brown and poorly bedded; distal to outcrops
- DOMINANTLY ALLUVIAL
  - D4 Gravely sand and sandy clay of active alluvial channels with mixtures of ferruginous and variably altered lithic fragments
  - D4S Sand or clay rich silt/clay and colluvium on broad drainage floors, including overbank deposits and terraces. Includes non-saline claypanes; silcrete fragments
  - D4B Calcrete; includes karst and silicified caliche
- DOMINANTLY EOLIAN
  - D8 Sand, silt or loess in origin. May form dunes to thin sheets. May overlie sheetwash, soil or bedrock

SYMBOLS

- Regolith boundary
- Minor road
- Track
- Breakaway
- Watercourse, ephemeral
- Homestead
- Locality
- Mining centre
- Mine, not being worked
- Opencut
- Opencut, not being worked
- Prospect
- Mineral occurrence
- Barite, Beryl
- Bismuth minerals
- Copper, Dravite, Fluorite
- Gold, Gemstones
- Lead, Lithium
- Mica, Molybdenum
- Rare Earth Elements
- Scheelite
- Tantalite-columbite, Tin
- Uranium, Zinc

GEOLOGICAL INTERPRETATION



Geological Interpretation after S. J. Williams et al. (1983)



SHEET INDEX

WINNING POOL SG 50-13	EDMUND SG 50-14	TUREE CREEK SG 50-15
KENEDY RANGE SG 50-1	MOUNT PHILLIPS SG 50-2	MOUNT EGBERTON SG 50-3
WOORAMEL SG 50-6	GLENBURGH SG 50-8	ROBINSON RANGE SG 50-7

REGOLITH MATERIALS

REGOLITH GEOCHEMISTRY SERIES

MOUNT PHILLIPS

SHEET SG 50-2

FIRST EDITION 1997

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Edited by D. Ferdinando and G. Loan  
Cartography by G. Jose and E. Green  
Topography from Australian Surveying and Land Information Group Sheet SG 50-2 and modified from geological field survey (1985)  
This map is also available in digital form  
Published by the Geological Survey of Western Australia. Copies of this map, or extracts from the database, are available from the Mining Information Centre, Department of Minerals and Energy, 100 Plain Street, East Perth, 6004. Phone (08) 9222 3459, Fax (08) 9222 3444



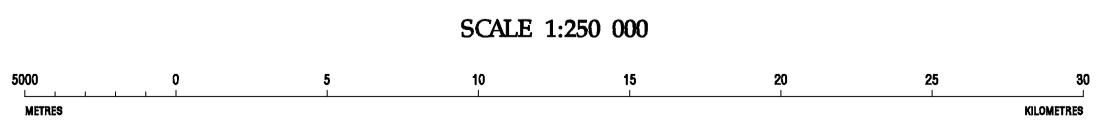
DEPARTMENT OF MINERALS AND ENERGY  
L.C. RANFORD, ACTING DIRECTOR GENERAL



GOVERNMENT OF WESTERN AUSTRALIA  
HON. NORMAN MOORE, M.L.C.  
MINISTER FOR MINES



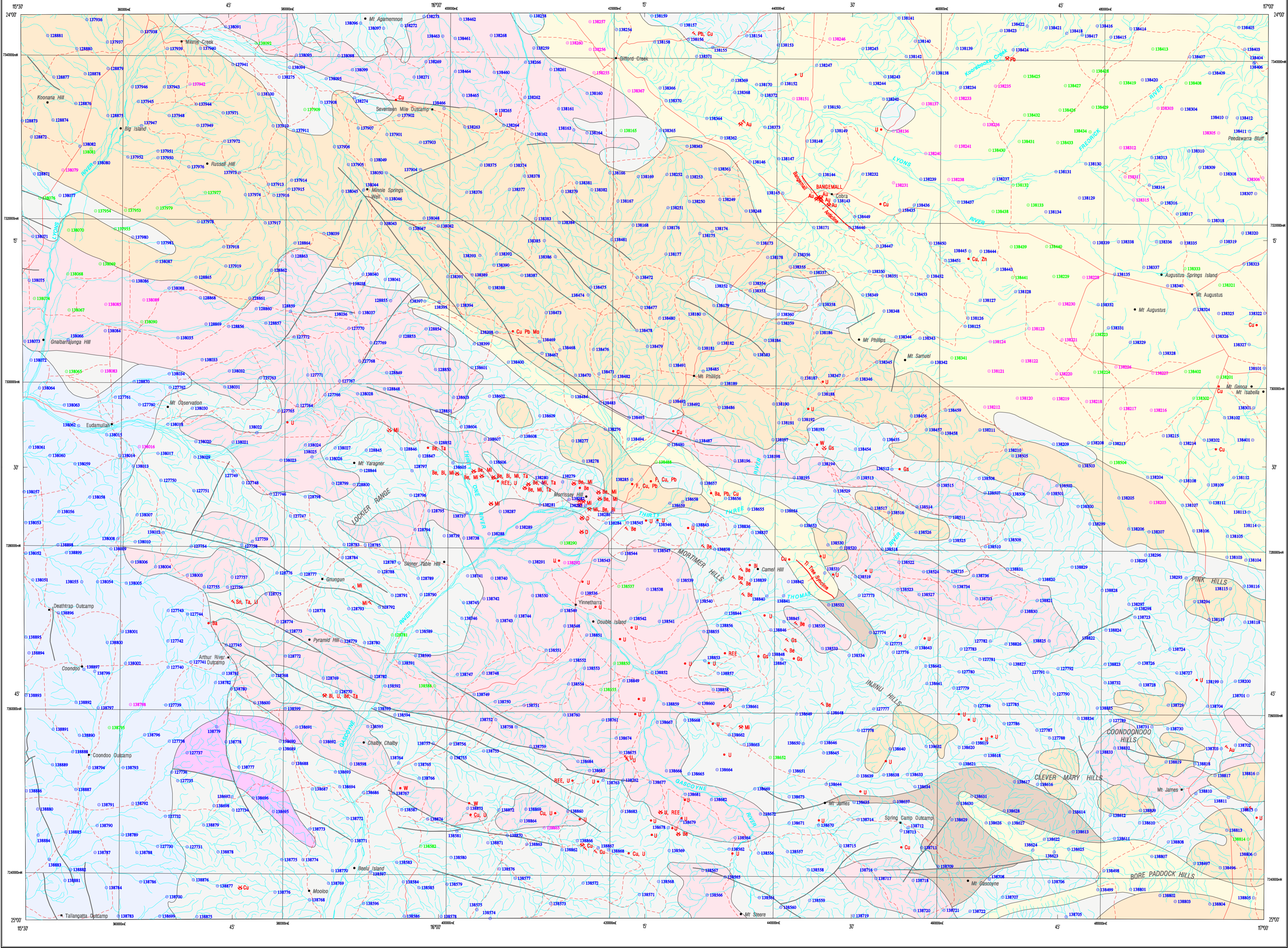
GEOLOGICAL SURVEY OF  
WESTERN AUSTRALIA  
PETRO GUJ, DIRECTOR



TRANSVERSE MERCATOR PROJECTION  
Grid lines indicate 20 000 metre interval of the Australian Map Grid Zone 50

Compiled by A.J. Sanders and A.G. Subramanya, 1996  
Field observations by A. Subramanya (GSWA), P. Penna, S. Keeling and E. Mead (Geochemex Australia) 1995  
The recommended reference for this map is: SANDERS, A.J., MORRIS, P.A., SUBRAMANYA, A.G., and FAULKNER, J.A. 1997, Mount Phillips, W.A. sheet SG 50-2 -- Regolith Materials: Western Australia Geological Survey, 1:250 000 Regolith Geochemistry Series, Plate 1

SAMPLE LOCATIONS



- SYMBOLS**
- Minor road
  - Track
  - Watercourse, ephemeral
  - Homestead
  - Locality
  - Mining centre
  - Mine, not being worked
  - Opencut
  - Opencut, not being worked
  - Prospect
  - Mineral occurrence
  - Barite, Beryl
  - Bismuth minerals
  - Copper, Dravite, Fluorite
  - Gold, Gemstones
  - Lead, Lithium
  - Mica, Molybdenum
  - Rare Earth Elements
  - Scheelite
  - Tantalite-columbite, Tin
  - Uranium, Zinc
- Sample point references**
- Stream sample
  - Sheetwash sample
  - Soil sample

GEOLOGICAL INTERPRETATION

- PALEOZOIC PERMIAN**
- Sandstone, siltstone, limestone; largely glaciene
- PROTEROZOIC**
- Bangerell Group: shale, sandstone, dolomite, chert, and siltstone; interbedded with dolomite silt
  - Mount James Formation: metamorphosed granite, conglomerate, chert, shale, sandstone, siltstone, and phyllite
  - Later-stage granitoid rock, granodiorite, adamellite, granite, and pegmatite
  - Early-stage gneissic granitoid rock, granodiorite, granitic pegmatite, anorthosite, adamellite, and tonalite
  - Morrissey Metamorphic Suite: schist, phyllite, granofels, quartzite, chert, amphibolite, paragneiss, migmatite, calc-silicate gneiss, granite, metamorphosed greywacke, siltstone, and conglomerate
- ARCHAEO**
- Gneiss and gneissic granitoid rock
- Geological boundary**
- Fault
  - Anticline
  - Syncline



SAMPLE LOCATIONS

REGOLITH GEOCHEMISTRY SERIES

MOUNT PHILLIPS

SHEET SG 50-2

FIRST EDITION 1997

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Edited by: D. Ferdinando and G. Loan

Cartography by: G. Jose

Topography from Australian Surveying and Land Information Group Sheet SG 50-2 and modified from geological field survey (1995)

This map was compiled digitally from the geochemical database held by the Geological Survey of Western Australia and stored in the ORACLE database management system; compiled and produced using a Geographic Information System, ArcInfo

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DEPARTMENT OF MINERALS AND ENERGY  
L.C. RANFORD, ACTING DIRECTOR GENERAL

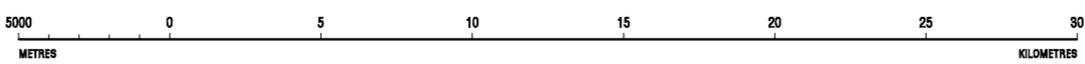


GOVERNMENT OF WESTERN AUSTRALIA  
HON. NORMAN MOORE, M.L.C.  
MINISTER FOR MINES



GEOLOGICAL SURVEY OF  
WESTERN AUSTRALIA  
PIETRO GUL, DIRECTOR

SCALE 1:250 000



TRANSVERSE MERCATOR PROJECTION  
Grid lines indicate 20 000 metre interval of the Australian Map Grid Zone 50

Sampling by: A. Subramanya (GSWA), P. Penna, S. Keeling, and E. Mead (Geochemex Australia), 1995

Total sample sites: 1035; 57 sheetwash, 933 stream sediment, and 48 soil

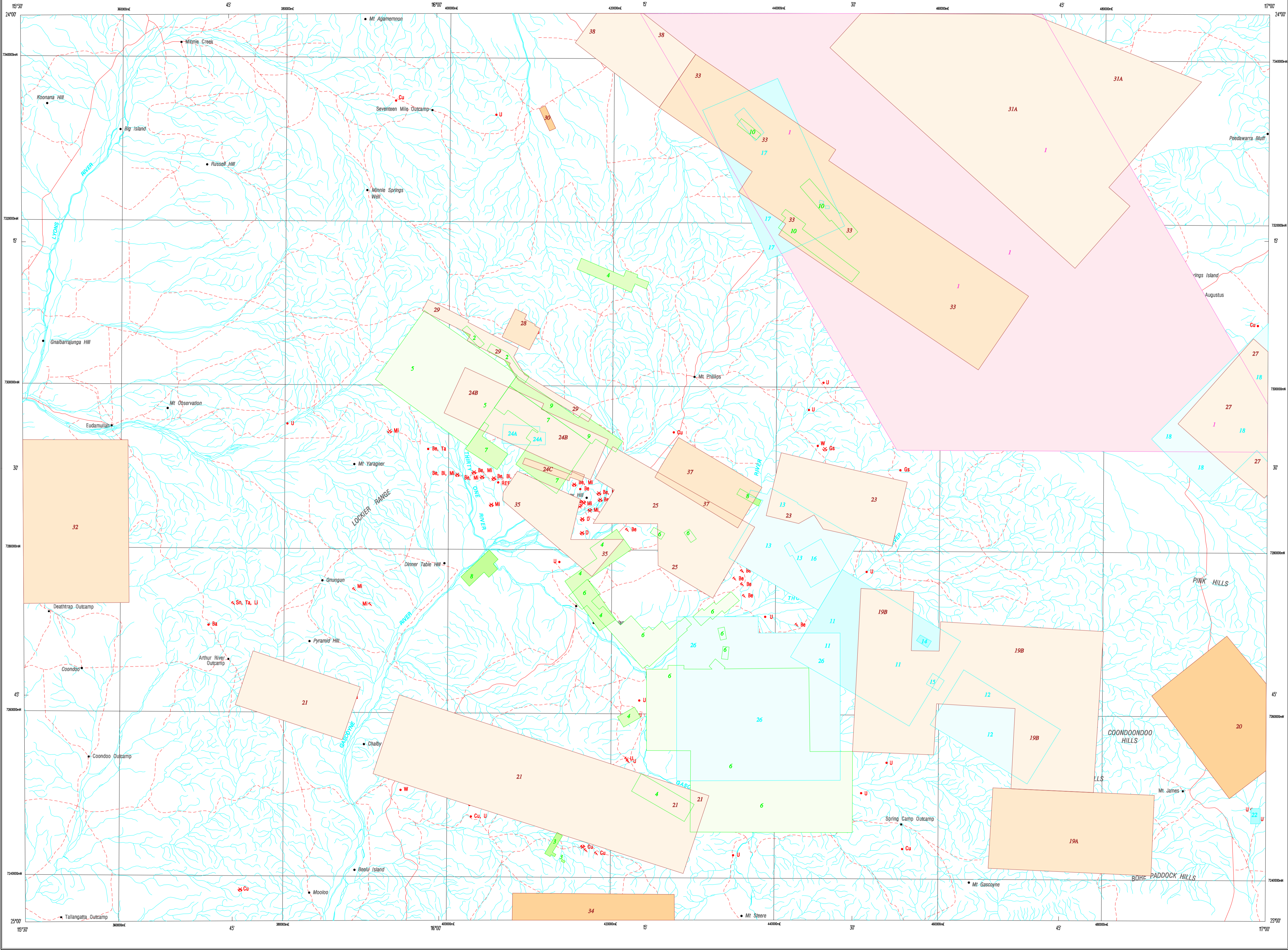
Analyst: Andel Laboratories. Minimum sample size: 1.5 kg. Fraction of sample analysed: > 0.6mm < 2mm

Geological interpretation after S. J. Williams et al. (1983)

The recommended reference for this map: SANDERS, A.J., MORRIS, P.A., SUBRAMANYA, A.G., and FAULKNER, J.A., 1997. Mount Phillips, W.A., Sheet SG 50-2 - Sample locations. Western Australia Geological Survey, 1:250 000 Regolith Geochemistry Series, Plate 2

WARNING: Inks are water soluble and will fade with prolonged exposure to light

MOUNT PHILLIPS  
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA



COMPANY PROJECTS WITH SURFACE  
GEOCHEMISTRY DATA IN OPEN FILE  
REPORTS (at December 1995)  
PROJECTS REPORTED BETWEEN 1968 AND 1985

**SYMBOLS**

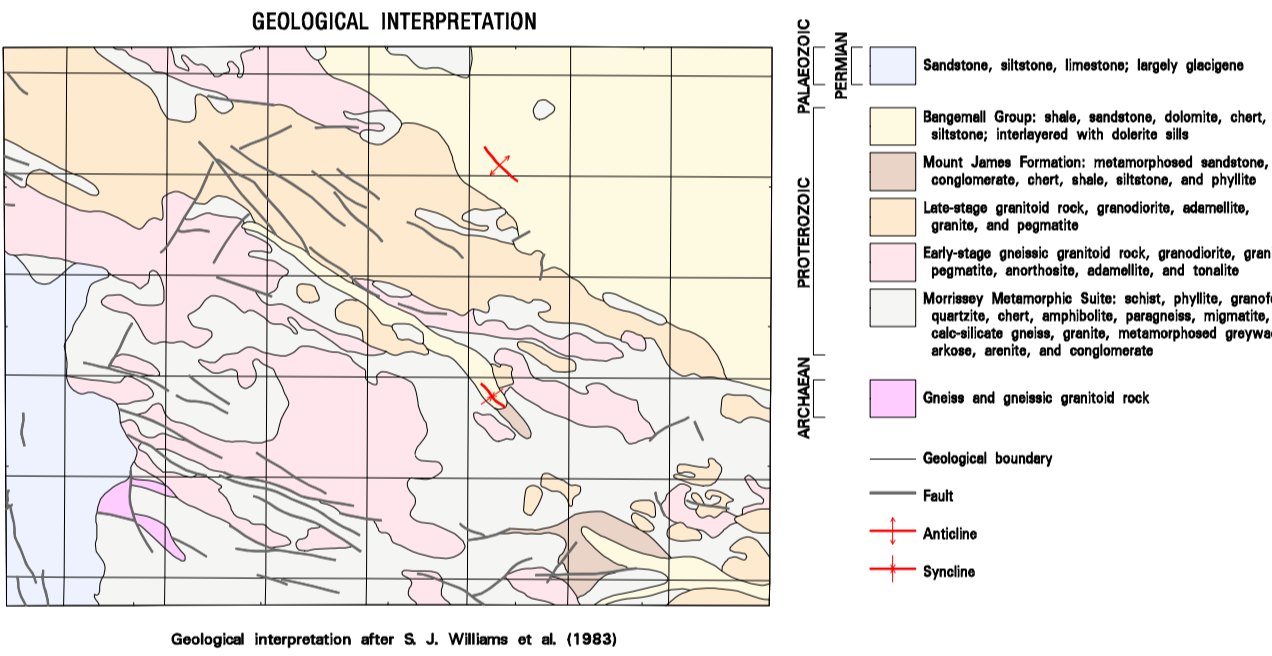
**Period Project Reported Within**  
(Various colour shades used for ease of project identification)

1968 - 1970	1971 - 1975	1976 - 1980	1981 - 1985	1986 - 1990	1991 - 1995
-------------	-------------	-------------	-------------	-------------	-------------

Number within project area is a database ID number (See Appendix 3)

See PLATE 4

**Minor road**  
**Track**  
**Watercourse, ephemeral**  
**Mt Phillips**  
**Mt Genoa**  
**BANGEMALL**  
**Mine, not being worked**  
**Opencut**  
**Opencut, not being worked**  
**Prospect**  
**Mineral occurrence**  
**Barite, Beryl**  
**Bismuth minerals**  
**Copper, Dravite, Fluorite**  
**Gold, Gemstones**  
**Lead, Lithium**  
**Mica, Molybdenum**  
**Rare Earth Elements**  
**Scheelite**  
**Tantalite-columbite, Tin**  
**Uranium, Zinc**



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WINNING POOL SG 50-13	EDMUND SG 50-14	TURKEE CREEK SG 50-15
KENNEDY RANGE SG 50-1	MOUNT PHILLIPS SG 50-2	MOUNT EGBERTON SG 50-3
WODRAMEL SG 50-5	GLENBURGH SG 50-6	ROBINSON RANGE SG 50-7

**INDEX TO 1:100 000 MAP SHEETS  
WITHIN MT PHILLIPS 1:250 000**

EUDAMULLAH 2049	MOUNT PHILLIPS 2148	MOUNT AUBUSTUS 2249
LOCKER 2048	YINNETHARRA 2148	PINK HILLS 2248

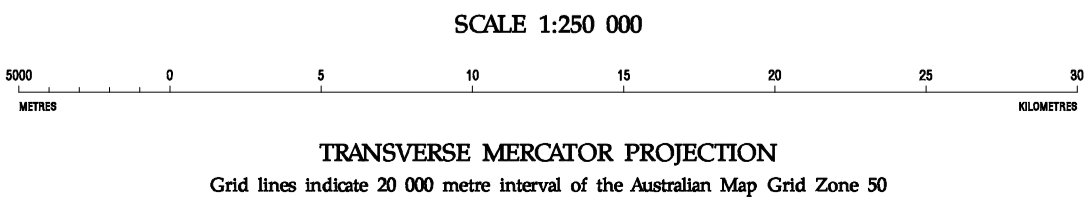
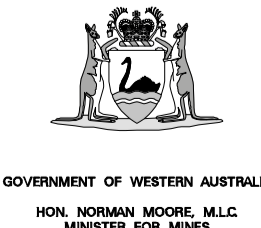
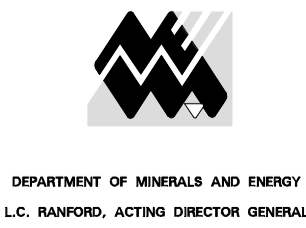


COMPANY PROJECTS WITH SURFACE  
GEOCHEMISTRY DATA IN OPEN FILE  
REPORTS (at December 1995)  
PROJECTS REPORTED BETWEEN 1968 AND 1985

REGOLITH GEOCHEMISTRY SERIES  
MOUNT PHILLIPS

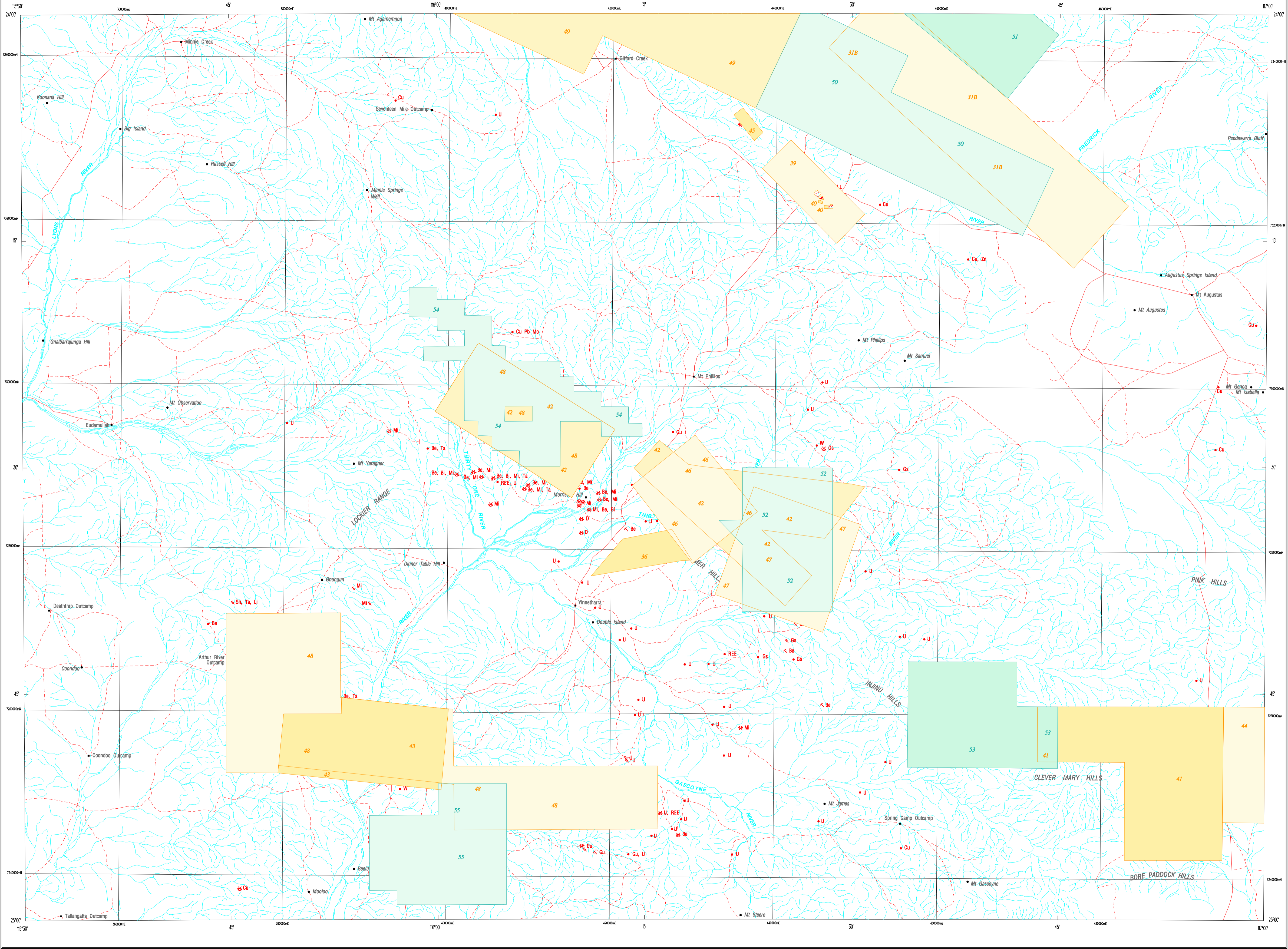
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Cartography by G. Jose and D. Ladbroke  
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Compiled by: J.A. Faulkner 1996  
Compiled from open file mineral exploration reports held by the Geological Survey of Western Australia  
Tenement boundaries have been generalized for the purpose of this map to an accuracy of + or - 500 metres. Refer to specific project reports for precise boundary descriptions  
The recommended reference for this map is: FAULKNER, J.A., 1997, Mount Phillips, W.A. sheet SG 50-2 -- Company projects with surface geochemistry data in open file reports (at August 1995), projects reported between: 1968 and 1985: Western Australia Geological Survey, 1:250 000 Regolith Geochemistry Series, Plate 3

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COMPANY PROJECTS WITH SURFACE  
GEOCHEMISTRY DATA IN OPEN FILE  
REPORTS (at December 1995)

PROJECTS REPORTED BETWEEN 1986 AND 1994

**SYMBOLS**

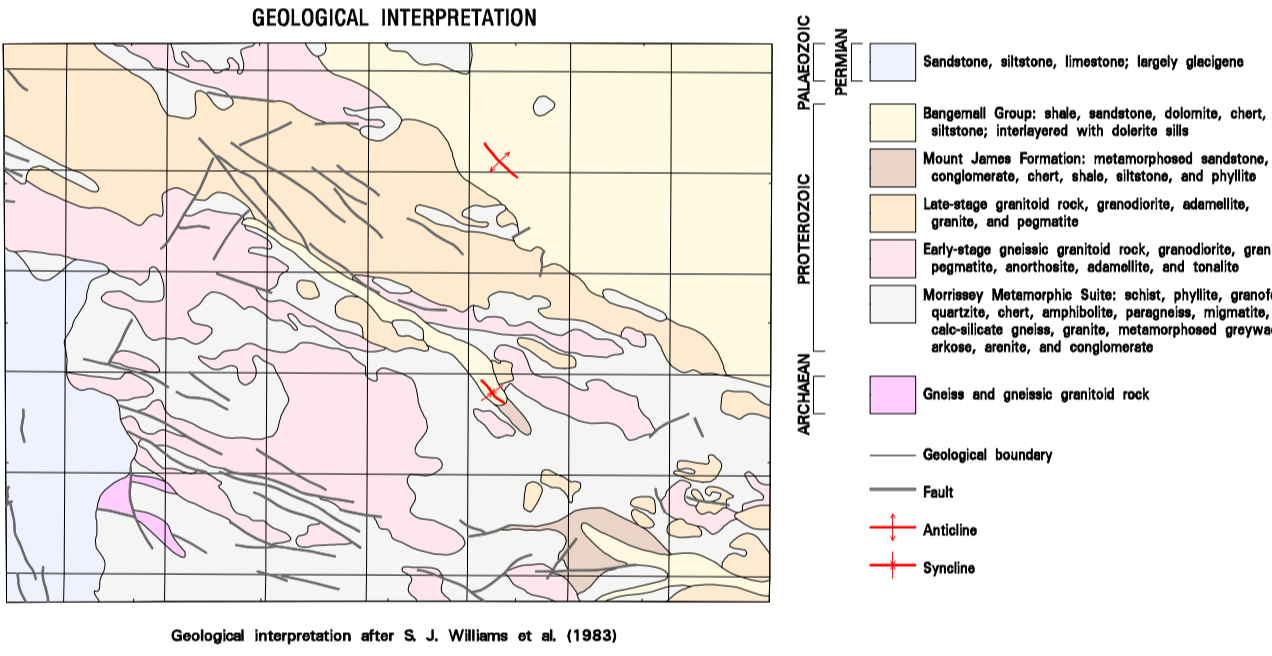
**Period Project Reported Within**  
(Various colour shades used for ease of project identification)

1968 - 1970  
1971 - 1975  
1976 - 1980  
1981 - 1985  
1986 - 1990  
1991 - 1995

See PLATE 3

Minor road  
Track  
Watercourse, ephemeral  
Mt Phillips  
Mt Gidong  
BANGEMALL  
Mine, not being worked  
Opencut  
Opencut, not being worked  
Prospect  
Mineral occurrence  
Barite, Beryl  
Bismuth minerals  
Copper, Dravite, Fluorite  
Gold, Gemstones  
Lead, Lithium  
Mica, Molybdenum  
Rare Earth Elements  
Scheelite  
Tantalite-columbite, Tin  
Uranium, Zinc

Number within project area is a database ID number (See Appendix 3)



**SHEET INDEX**

WINNING POOL SF 50-13	EDMUND SF 50-14	TURKEE CREEK SF 50-15
KENNEDY RANGE SG 50-1	MOUNT PHILLIPS SG 50-2	MOUNT EGBERTON SG 50-3
WODRAMEL SG 50-5	GLENBURGH SG 50-6	ROBINSON RANGE SG 50-7

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WITHIN MT PHILLIPS 1:250 000**

EUDAMULLAH 2049	MOUNT PHILLIPS 2148	MOUNT AUGUSTUS 2249
LOCKIER 2048	YINNETHARRA 2148	PINK HILLS 2248

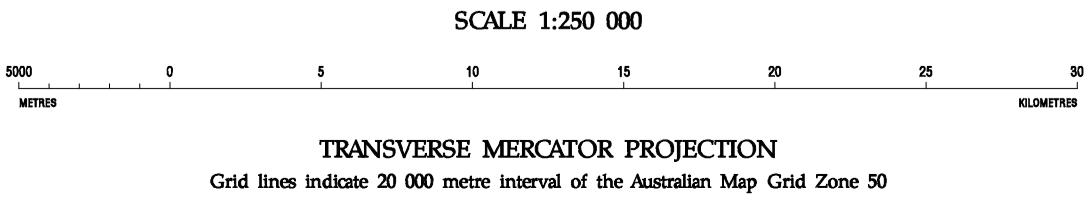
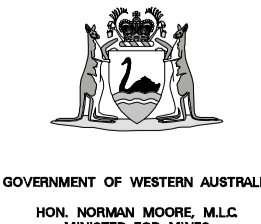
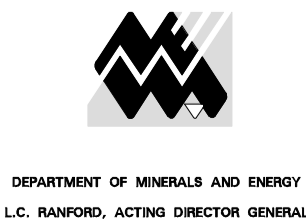


COMPANY PROJECTS WITH SURFACE  
GEOCHEMISTRY DATA IN OPEN FILE  
REPORTS (at December 1995)

PROJECTS REPORTED BETWEEN 1986 AND 1994

REGOLITH GEOCHEMISTRY SERIES  
**MOUNT PHILLIPS**  
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FIRST EDITION 1997  
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Edited by D. Ferdinando and G. Loan  
Cartography by G. Jose and D. Ladbroke  
Topography from Australian Surveying and Land Information Group sheet SG 50-2 and modified from geological field survey (1995)  
This map was compiled from open file mineral exploration reports held by the Geological Survey of Western Australia and produced digitally using a Geographic Information System, Arc/info  
This map is also available in digital form  
Published by the Geological Survey of Western Australia. Copies of this map, or extracts from the database, are available from the Mining Information Centre, Department of Minerals and Energy, 100 Plain Street, East Perth, 6004. Phone (08) 9222 3459, Fax (08) 9222 3444



Compiled by: J.A. Faulkner 1996  
Compiled from open file mineral exploration reports held by the Geological Survey of Western Australia  
Tenement boundaries have been generalized for the purpose of this map to an accuracy of + or - 500 metres. Refer to specific project reports for precise boundary descriptions  
The recommended reference for this map is: FAULKNER, J.A., 1997, Mount Phillips, W.A. sheet SG 50-2 -- Company projects with surface geochemistry data in open file reports (at August 1995), projects reported between: 1986 and 1994: Western Australia Geological Survey, 1:250 000 Regolith Geochemistry Series, Plate 4

WARNING: Inks are water soluble and will fade with prolonged exposure to light