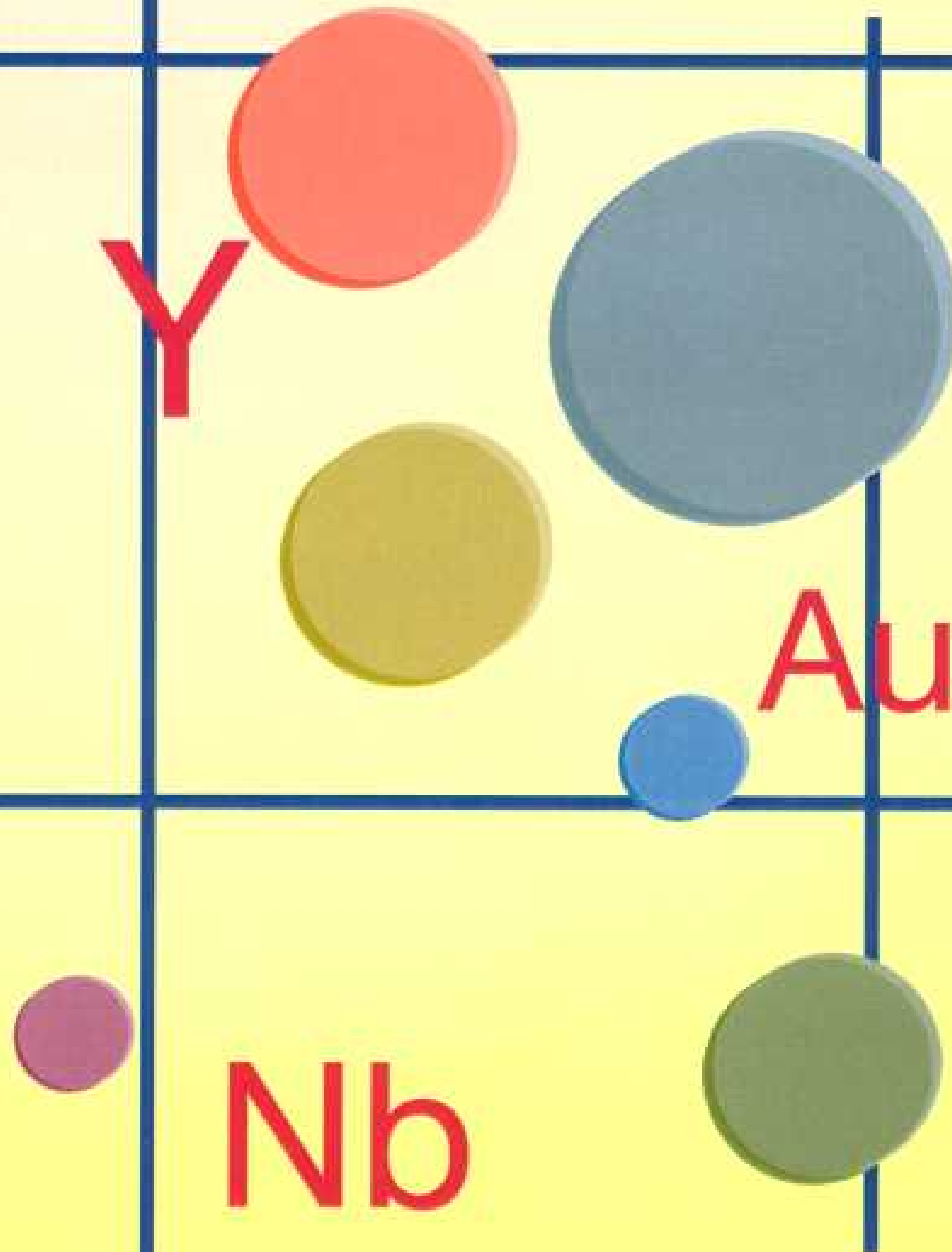
EXPLANATORY NOTES

GOVERNMENT OF WESTERN AUSTRALIA

GEOCHEMICAL MAPPING OF THE WINNING POOL – MINILYA 1:250 000 SHEETS

by A. J. Sanders and S. A. McGuinness

1:250 000 REGOLITH GEOCHEMISTRY SERIES



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY

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A. J. Sanders and S. A. McGuinness

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Geochemical mapping of the Winning Pool – Minilya 1:250 000 sheets

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A. J. Sanders and S. A. McGuinness

Abstract

Regolith and geochemical mapping of the WINNING POOL – MINILYA 1:250 000 map sheets are based on regolith characteristics and sampling of regolith at 1199 sites, comprising 218 sheetwash samples, 485 stream-sediment samples, 24 soil samples, 454 sandplain samples, and 18 lake-sediment samples. The nominal sampling density was one sample per 16 km^2. Each sample has been analysed for 48 major and trace elements, loss on ignition (LOI), pH, and conductivity. The distribution of elements is shown as spot-concentration maps. Geological, landform, and botanical information are summarized, along with near-surface company geochemistry on open-file, and mineral production figures.

A regolith-materials map has been produced using Landsat imagery, aerial photography, synthetic Landsat stereo pairs, and sample-site descriptions. Thirty-six percent of the project area is covered with various sandplain types, which have been divided into eight subunits on the basis of morphology and lithology. Exposed-regime regolith is the second most common regolith type, and is largely over the Gascoyne Complex and strike ridges of Upper Carboniferous to Lower Permian marine and continental sedimentary rocks in the Gooch Range. Regolith morphology and chemistry in western parts of the project area suggest that the recent uplift of anticlines has diverted the course of the Lyndon and Minilya rivers. Throughout the project area, regolith chemistry is strongly influenced by the underlying bedrock as well as weathering and physical transportation by alluvial and eolian activity.

Regolith chemistry has identified potential areas of base metal mineralization, including the Mesoproterozoic Edmund Group and the Phanerozoic Byro Group, Winning Group, and limestones on the western flank of the Giralia Range. Localized, elevated Au concentrations in regolith are recorded over the Gascoyne Complex and in an area of mixed regolith types in the vicinity of the Cardabia Transfer Zone, in the central project area. Pegmatite-associated mineralization is indicated in the northeastern and southeastern parts of the project area associated with rocks of the Gascoyne Complex. Evaporite minerals and heavy mineral sand concentrations have been identified in regolith from coastal areas around Lake MacLeod. Additive element-index maps highlight some of these areas.

KEYWORDS: Regolith, geochemistry, regolith mapping, Southern Carnarvon Basin, Gascoyne Platform, Merlinleigh Sub-basin, Gascoyne Complex, Bangemall Group, Edmund Group.

Introduction

Regolith is unconsolidated or indurated weathered rock, including residual and transported material, which can obscure underlying bedrock. Large areas of Western Australia are covered by regolith, hence an understanding of the distribution of regolith types and their chemistry can offer significant insight into the nature of the bedrock, including the presence and extent of mineralization.

Geochemical signatures of the underlying bedrock may be differentially enriched or diluted due to regolith-forming processes. Thus an understanding of regolith formation and the behaviour of elements in the regolith environment are useful exploration tools.

Regolith and geochemical mapping of the WINNING POOL – MINILYA* 1:250 000 map sheets are part of a regional regolith and geochemical mapping program initiated by the Geological Survey of Western Australia (GSWA) in 1994. The aims of this program are:

- to provide baseline information on the chemistry of regolith to assist mineral exploration;
- to identify metallogenic provinces and specific areas with potential for undiscovered mineralization;
- to assist in the identification of rock types and rock assemblages;

* Capitalized names refer to standard 1:250 000 map sheets, unless otherwise stated.

- to provide geochemical data for the benefit of pastoralists and environmental agencies; and
- to provide measurements of the Earth's gravitational field as discussed in Shevchenko (in prep.).

To date, twenty 1:250 000-scale map sheets have been sampled, covering parts of the northern Yilgarn Craton, Proterozoic rocks between the Yilgarn and Pilbara Cratons, the Northampton Complex, and areas of the Carnarvon Basin and Albany–Fraser Orogen (Fig. 1). Recent map sheets (AJANA, BYRO, Fraser Range region, KINGSTON, STANLEY, WINNING POOL – MINILYA, and WYLOO) have included the collection of gravity data at each regolith sampling site, unless similar or better quality data already existed.

Location and access

The WINNING POOL – MINILYA 1:250 000 sheets (SF 50-13 and part of SF 49-16) are bounded by latitudes 23°00' and 24°00'S and longitudes 113°25' and 115°30'E (Fig. 2; Plate 1). The majority of the project area is under pastoral lease, with pastoral stations partly or wholly on WINNING POOL – MINILYA including Cardabia, Gnaraloo, Hill Springs, Lyndon, Manberry, Mangaroon, Maroonah, Marrilla, Mia Mia, Middalya, Nyang, Towera, Uaroo, Wandagee, Warroora, Williambury, and Winning. The only settlement in the area is Coral Bay, a coastal tourist resort. A gazetteer of localities is presented in Appendix 1.

Major access to the project area is via the sealed Northwest Coastal Highway and Learmonth–Minilya road. Elsewhere, graded shire roads and station tracks and the service road for the Perth–Dampier Gas Pipeline provide restricted access. During wet weather, graded roads may become impassable.

Climate and vegetation

WINNING POOL – MINILYA experience an arid climate with a low and irregular rainfall between 200 and 300 mm annually (Beard, 1981). In January the mean daily maximum temperature at Winning Station is 40.6°C with a mean minimum of 23.0°C. In July the mean daily maximum is 24.7°C with a mean daily minimum of about 10.4°C*. A discussion of climatic variations over the project area is presented in Payne et al. (1980).

WINNING POOL – MINILYA largely lie in the Carnarvon phytogeographic region of the Eremean Botanical Province (Beard, 1981). The dune-dominated coastal and central areas of the map sheets are characterized by hummock grass or spinifex (*Triodia*) with scattered low shrubs (*Acacia*). Saltbushes (*Atriplex*), bluebush (*Maireana*), and currant bush (*Scaevola*) with patchy low tree and shrub cover (*Acacia*) dominate the western drainage areas, whereas the more-elevated limestone pavements host tall shrublands of mixed *Acacia*. The upland regions of central and eastern WINNING POOL – MINILYA are covered in tall, open shrublands of *Acacia*, *Eremophila*, and annual grasslands (Payne et al., 1980).

Physiography and soils

Hocking et al. (1985, fig. 1), following concepts of Finkl and Churchward (1973), divided WINNING POOL – MINILYA into three broad physiographic areas: the MacLeod Region, the Marilla and Mardathuna Regions, and the Lyons, Nanutarra, and Wandagee Regions. The MacLeod Region, in the west, is characterized by anticlinal domes onlapped by Pleistocene marine and eolian deposits. The Marrilla and Mardathuna Regions, in the central part of the project area, consist of low relief, carbonate-rich duricrust platforms overlain by extensive longitudinal dunes. Scattered outcrop and broad alluvial floodplains bound the area where the duricrust has been dissected. In the east, the Lyons and Nanutarra Regions are flat to gently undulating, semi-stripped etchplains interspersed with strike ridges, mesas, and buttes, commonly capped by silcrete and ferricrete. In the Wandagee Region, no resistant cappings are present and a broad, low relief etchplain has formed.

Longitudinal dune fields, which dominate the central part of WINNING POOL – MINILYA, are composed of red sand and red earthy sand (soil mapping code AB17; Bettenay et al. 1967). Bordering the dune fields to the north, south, and west are broad alluvial plains characterized by neutral red earths (My53), alkaline red earths (Mx16/17), and hard-setting alkaline red soils (Oc40). Other hard-setting alkaline red soils (Ob19) in pediplains and hills overlie bentonitic and radiolarian siltstones of the central north. In the west, a carbonate-rich duricrust is extensively developed over the Korojon Calcarenite and soils in this area are largely shallow, alkaline, red earths and loams (Mx19). Calcareous sands and dunes (A18) dominate the coastal zone, giving way in an easterly direction to a barred, coastal lacustrine environment consisting largely of calcareous loams and brown calcareous earths (SV7). Pediplains on granitic, metasedimentary, and sedimentary rocks, which support hard-setting loamy soils and an alkaline reaction trend (OC 46/51/54/55/57), dominate eastern and central-southern WINNING POOL – MINILYA. A thin outlier of the Edmund Group, along the central eastern boundary of the project area, supports stony, shallow earthy loams in ranges and thin loamy soils on calcrete in valley plains (Fa17; Bettenay et al., 1967).

Topographic and remote-sensing datasets

Topographic information used on accompanying maps was obtained from the Department of Land Administration (DOLA) and Australian Land Information Group (AUSLIG). Sources include the Gascoyne 1:1 000 000 topographic map (1979), the Winning Pool and Minilya 1:250 000 Joint Operations Graphics (1983), Landsat Thematic Mapper scenes (27 September 1993 and 11 January 1995), 1:40 000-scale black and white aerial photographs

* Climate data from Commonwealth Bureau of Meteorology website, 2000.

(1976), and Geodata 9 second digital elevation model (DEM; 1996). Bouguer gravity data were acquired for the eastern part of the sheet during the course of regolith sampling (Geological Survey of Western Australia, 1999).

Geology

Early geological investigations on WINNING POOL – MINILYA were carried out by Woodward (1891) and Maitland (1909). The first systematic geological mapping of the Carnarvon Basin portion of the project area was undertaken by the Bureau of Mineral Resources (BMR) between 1948 and 1955. This work, including the first edition of the MINILYA geological sheet (Condon, 1955) and an account of the geology of the Giralia and Marilla Anticlines, was assembled into a review of the entire Carnarvon Basin by Condon (1965, 1967, 1968). West Australian Petroleum (WAPET) carried out investigations of the area in the 1950s and 1960s, culminating in the drilling of several petroleum exploration wells (Thomas and Smith, 1976). Useful summaries of the Carnarvon Basin are presented in Playford et al. (1975) and Hocking (1990) with bibliographies of early Carnarvon Basin work by Ozimic (1970) and Moors (1981a). A comprehensive report on the entire Carnarvon Basin is presented in Hocking et al. (1987).

The geology of the Gascoyne Complex and Edmund Group, which outcrop in the eastern parts of WINNING POOL – MINILYA, has been described by Chuck (1984), Muhling and Brakel (1985), Williams (1986), Myers (1990), Tyler and Thorne (1990), Williams (1990), Cooper et al. (1998), and Martin et al. (1999).

Mapping in the Carnarvon Basin and Gascoyne Complex by the GSWA in the late-seventies led to the release of the geological map and Explanatory Notes for WINNING POOL – MINILYA (Hocking et al., 1985).

The following review of the geological setting of WINNING POOL – MINILYA is largely based on the following GSWA work:

- Gascoyne Complex (Hocking et al., 1985; Myers, 1990);
- Edmund Group (Hocking et al., 1985; Martin et al., 1999); and
- Southern Carnarvon Basin (Hocking et al., 1985, 1987; Hocking, 1994; Iasky et al., 1998; Iasky and Mory, 1999).

Geological setting

WINNING POOL – MINILYA includes parts of the Palaeoproterozoic Gascoyne Complex, Mesoproterozoic Edmund Basin, and Phanerozoic rocks of the Southern Carnarvon Basin (Merlinleigh Sub-basin and Gascoyne Platform).

Basement rocks on eastern WINNING POOL – MINILYA consist of metamorphic rocks and granitoids of the Gascoyne Complex, which is part of the Palaeoproterozoic (2.0 – 1.6 Ga) Capricorn Orogen (Gee, 1979; Myers, 1990). Gee (1979) suggested that the Capricorn Orogen represented deformed geosynclinal sediments deposited between the Archaean Pilbara and Yilgarn Cratons, but Tyler and Thorne (1990) argued that the Capricorn Orogen resulted from the oblique collision of the Pilbara and Yilgarn Cratons during the Palaeoproterozoic.

Daniels (1975) originally used the term ‘Gascoyne Province’ for the area. Following the mapping of Williams et al. (1979, 1983), Hocking et al. (1985), and the more detailed studies of Libby et al. (1986) and Williams (1986), this was renamed the Gascoyne Complex by Myers (1990). In this latter study, five major zones (A–E) based on structure and lithologies were identified (Myers, 1990, fig. 3.2). Gascoyne Complex rocks on WINNING POOL – MINILYA consist largely of the Minnie Creek Batholith (zone D) and granitoid plutons and metasedimentary rocks (zone E). Metasedimentary rocks form part of the Morrissey Metamorphic Suite, which outcrops extensively on MOUNT PHILLIPS (Williams et al., 1979; Sanders et al., 1997). These rocks are thought to be higher grade equivalents of the Wyloo Group (Williams, 1986).

Recent mapping by Sheppard and Occhipinti (2000) in the southern part of the Capricorn Orogen has indicated uncertainty in the age and origin of metasedimentary rocks of the Gascoyne Complex, and they have locally subdivided and renamed metasedimentary units. Their work suggests that metasedimentary rocks of the Gascoyne Complex are not all the same age, and that the Morrissey Metamorphic Suite on WINNING POOL – MINILYA may undergo future revision (Sheppard, S., 2000, written comm.). However, in this study, these rocks will be referred to as the Morrissey Metamorphic Suite or simply Gascoyne Complex metamorphic rocks.

Age determinations on granitoid rocks (Compston and Arriens, 1968; de Laeter, 1976; Williams et al., 1978; Nelson, 1995), basement gneiss, and the Morrissey Metamorphic Suite (Williams et al., 1978) restrict the age of the the Morrissey Metamorphic Suite to between 2470 and 1800 Ma. Recently, Sheppard and Occhipinti (2000) discussed SHRIMP U–Pb zircon data (Nelson, 1998, 1999) from metasedimentary rocks from the southern Capricorn Orogen, which were previously included in the Morrissey Metamorphic Suite. These data indicate a maximum depositional age for the sedimentary precursors of c. 2025 Ma, and metamorphic age of c. 1960 Ma.

Compston and Arriens (1968) cited a Rb–Sr whole-rock isochron age for the Minnie Creek Batholith, near Minnie Creek Homestead on MOUNT PHILLIPS, of 1690 Ma, whereas de Laeter (1976) quoted a Rb–Sr whole-rock isochron age of 1672 ± 18 Ma.

There are sedimentary rocks and dolerite sills in the Mangaroon Syncline in the central east of WINNING POOL – MINILYA, where they unconformably overlie rocks of the Gascoyne Complex. The sedimentary rocks were mapped as Bangemall Group by Williams (1990), and consist of variably deformed terrestrial, alluvial, shallow- and deep-water siliciclastic, and carbonate sedimentary rocks.

Five different stratigraphic schemes for Bangemall Group rocks on EDMUND have been published since 1968. Recent GSWA mapping has highlighted that none of these stratigraphies adequately reflect the observed field relationships (Martin et al., 1999). Previous stratigraphic subdivisions (Daniels, 1969; Chuck, 1984; Muhling and Brakel, 1985; Williams, 1990; Cooper et al., 1998) have been complicated by lateral facies changes and gradational boundaries resulting in inconsistent nomenclature between geographic areas. Furthermore, there is significant disagreement between authors in regard to the definition of subgroups. Martin et al. (1999) presents a provisional revised stratigraphy, with arguments for the elevation of the Bangemall Group to supergroup status, and Edmund and Collier Subgroups to group level.

Deposition of the basal part of the Edmund Group is thought to have taken place at c. 1640 Ma (Nelson, 1995). Prior to deformation, numerous tholeiitic dolerite sills intruded the sequence (Muhling and Brakel, 1985). Nelson (in prep.) recently dated the age of dolerite within the Mangaroon Syncline on EDMUND as 1462 ± 3 Ma.

These Explanatory Notes adopt the nomenclature of Martin et al. (1999), who defined the rocks of the Mangaroon Syncline as the Edmund Group. Previous geochemical Explanatory Notes for MOUNT EGERTON (Morris et al., 1998) and EDMUND (Pye et al., 1998) divided the Edmund Group (previously Edmund Subgroup) into lower and upper sequences seperated by the Discovery Formation (previously Discovery Chert). In light of recent stratigraphic revision and the limited extent of lithologies above the Discovery Formation in the Mangaroon Syncline, the approach of Morris et al. (1998) and Pye et al. (1998) is not adopted here.

The Southern Carnarvon Basin is an elongate, interior-fracture basin (Kingston et al., 1983) extending about 650 km along the western and northwestern coastline of Western Australia between Geraldton and the Exmouth Gulf. The central and northwestern parts of WINNING POOL – MINILYA are included in a north-northwesterly trending, Late Carboniferous to Early Permian depocentre within the Southern Carnarvon Basin (the Merlinleigh Sub-basin), which extends from south of Gascoyne Junction to the Exmouth Gulf. Until recently, the Merlinleigh Sub-basin was defined by the Phanerozoic rocks east of the Ajana, Kennedy Range, and Wandagee Fault Systems (Hocking, 1994). Crostella and Iasky (1997) extended the definition to include the Giralia area, where Permian rocks are below Cretaceous cover. This area, termed the northern Merlinleigh Sub-basin, lies north of the Cardabia Transfer Zone, east of the Rough Range Fault, and west of the Wandagee Fault System (Iasky et al., 1998, fig 1). On WINNING POOL – MINILYA, the Wandagee Fault System coincides with a northerly trending basement high termed the Wandagee Ridge (Hocking, 1994). Depth to basement has been modelled at less than 2000 m (Iasky et al., 1998, fig. 10; Iasky and Mory, 1999, figs 5 and 12).

The Merlinleigh Sub-basin contains up to 8000 m of Ordovician to Permian strata beneath a veneer of Cretaceous and Tertiary rocks, and superficial Quaternary deposits (Iasky et al., 1998, fig. 1). Sedimentation in the Southern Carnarvon Basin began with deposition of the Ordovician Tumblagooda Sandstone, a thick, sheet-braided, fluvial to coastal redbeds succession. A relative rise in sea level allowed the deposition of an overlying carbonate–evaporite section (Dirk Hartog Group). Deposition during the Devonian – Early Carboniferous is represented by terrestrial and marine, siliciclastic and carbonate deposits (Hocking et al., 1987). Regional scale rifting in the Late Carboniferous to Early Permian formed an elongate interior seaway that extended from the Perth Basin into the Coolcalalaya, Byro, and Merlinleigh Sub-basins, to the North West Cape Peninsula, Peedamullah Shelf, and possibly further north. A thick succession of glacigene rocks (Lyons Group) and transgressive fossiliferous carbonates and siliciclastic rocks (Callytharra Formation) filled the rift valley (Iasky et al., 1998).

Further subsidence of the rift valley and a rise in the hinterland to the east led to the deposition of overlying fluvial, deltaic, and marine sediments (Wooramel Group). Another transgression and deposition of sediments in a broad marine-shelf environment followed (Byro and Kennedy Groups; Hocking et al., 1987; Iasky et al., 1998), representing the last major phase of deposition on the onshore part of the basin.

West of the Ajana, Kennedy Range, and Wandagee Fault Systems and south of the Cardabia Transfer Zone is a diamond-shaped area within the Southern Carnarvon Basin (termed the Gascoyne Platform), which extends along the coast from near Coral Bay to Kalbarri (Hocking, 1994; Iasky and Mory, 1999, fig. 1).

The Gascoyne Platform contains an Ordovician to Permian succession below a thin cover of Cretaceous and Cainozoic sedimentary rocks. Until the end of the Devonian, the area now defined by the Gascoyne Platform probably had a structural and depositional history similar to that of the Merlinleigh, Byro, and Coolcalalaya Sub-basins. Although fragmented due to erosion, the geological record suggests that deposition was continuous between the Gascoyne Platform and Merlinleigh Sub-basin until the Early Carboniferous. However, unlike the Merlinleigh Sub-basin, there is no evidence of widespread Late Carboniferous to Early Permian deposition, suggesting that the Gascoyne Platform became a relatively elevated topographic feature by that time. Permian–Carboniferous sedimentary rocks are present only in the northernmost part of the Gascoyne Platform (west WINNING POOL – MINILYA), where they have been intersected in wells drilled on the informally named ‘Salt Marsh anticlines’, east, west, and north of Lake MacLeod (Crostella and Iasky, 1997, fig. 18; Iasky and Mory, 1999, fig. 4).

The Early Cretaceous breakup of Australia from Greater India resulted in deposition over broad areas of the onshore Southern Carnarvon Basin (Winning Group). This succession consists of coastal to nearshore sandstone, overlain by marine shales, radiolarite, siltstone, calcilutite, and calcarenite. On WINNING POOL – MINILYA it forms a westward thickening cover up to 1000 m thick over rocks of the Gascoyne Complex, Merlinleigh Sub-basin, and Gascoyne Platform (Hocking et al., 1985; Iasky et al., 1998).

The tectonic events that separated Australia from Greater India began in the Middle Jurassic and culminated in complete separation by the Early Cretaceous. The major northerly trending Wandagee and Kennedy Range Faults were reactivated, and the northwesterly trending Cardabia Transfer Zone was formed (Crostella and Iasky, 1997).

Tertiary sedimentary rocks on WINNING POOL – MINILYA typically form a veneer consisting of the shallow-marine Cardabia Calcarenite (Cardabia Group of Condon et al., 1956), Giralia Calcarenite, shallow-marine to continental Merlinleigh and Lamont Sandstones, and the shallow-marine Trealla Limestone. Most of these units are exposed on the flanks of the Giralia and Saltmarsh Anticlines, which trend north–south and are asymmetric, with typically steeper eastern flanks.

The main compressional tectonism that generated the Giralia and Saltmarsh Anticlines took place during the Middle Miocene, with pre-existing breakup faults (such as the Rough Range and Giralia Faults) being rejuvenated with minor reverse and significant strike-slip movement (Crostella and Iasky, 1997; Iasky and Mory, 1999). Warping of these anticlines continued into the Quaternary (van de Graaff et al., 1976), and may still be continuing (Hocking et al., 1985, 1987).

The most recent deposits on WINNING POOL – MINILYA also include laterite, silcrete, calcrete, alluvium, colluvium, sandplains, and the lacustrine micritic limestone and calcareous mudstone of the Nadarra Formation (Hocking et al., 1987).

Simplified geology

Recent 1:100 000 geological mapping on GLENBURGH (Occhipinti and Sheppard, 2000), and LANDOR and ERRABIDDY (Sheppard and Occhipinti, 2000), and geochronology by Nelson (1999, 2000), indicate that it may be necessary to revise the rock units of the Gascoyne Complex and their age relationships on WINNING POOL – MINILYA (Sheppard, S., 2000, written comm.). Furthermore, new 1:100 000-scale mapping on EDMUND (Martin et al., 2000, in prep.) and revisions to the Bangemall Supergroup stratigraphy (Martin et al., 1999) indicate that some reinterpretation of Edmund Group rocks in the Mangaroon Syncline on WINNING POOL – MINILYA will also be necessary.

As this revisionary work is not yet completed, the interpreted bedrock geology for WINNING POOL – MINILYA (Figs 3 and 4; Plate 1) is based on the existing mapping of Hocking et al. (1985) and Myers and Hocking (1998). Due to ongoing revision, some variation exists between the simplified geological maps of WINNING POOL – MINILYA and EDMUND (Pye at al., 1998).

The geology on WINNING POOL – MINILYA has been divided into 11 lithological units and forms the basis for the assignment of geological codes in the accompanying datafile WINMIN.CSV. The simplified stratigraphy and descriptions for these units are presented in Table 1, Figure 3, and Plate 1. The subdivision from oldest to youngest is:

Proterozoic
- Gascoyne Complex metamorphic rocks (Morrissey Metamorphic Suite; *Ꝑm*)
- Gascoyne Complex granitoids (*Ꝑg*)
- Edmund Group (*ꝐME*)

Phanerozoic (Middle Devonian – Upper Permian)
- Middle Devonian – Lower Carboniferous sedimentary rocks (*DC*)
- Lyons Group and Callytharra Formation (*PL*)
- Wooramel, Byro, and Kennedy Groups (*P*)

Phanerozoic (Cretaceous)
- Winning Group (*KWI*)
- Toolonga Calcilutite, Korojon Calcarenite, and Miria Formation (*Kt*)

Phanerozoic (Paleogene–Neogene)
- Cardabia Calcarenite, Giralia Calcarenite, and Merlinleigh Sandstone (*Czp*)
- Lamont Sandstone and Trealla Limestone (*Czn*)

Phanerozoic (Quaternary)
- Bundera Calcarenite and coastal lake deposits (*Qm*)

The following brief descriptions of the rock types within each of the subdivisions has largely been summarized from the following GSWA publications:

- Gascoyne Complex (Hocking et al., 1985; Williams, 1986; Myers, 1990);
- Edmund Group (Hocking et al., 1985); and
- Southern Carnarvon Basin (Hocking et al., 1985, 1987).

Gascoyne Complex metamorphic rocks (Morrissey Metamorphic Suite)

Gascoyne Complex metamorphic rocks (Morrissey Metamorphic Suite) are lithologically diverse, and on WINNING POOL – MINILYA include prograde and retrograde pelitic to semipelitic schists, phyllite, quartzite, micaceous quartzite, and thick sequences of paragneiss with pelitic schist intercalations. Metamorphosed conglomerate, arkose, and feldspathic arenite are locally developed. Migmatites are extensive, and calc-silicate rock, marble, and feldspathic dolomite form small but prominent units. In addition, there are minor occurrences of mafic rocks, narrow bodies of amphibolite after dolerite dykes and sills, and quartz–magnetite rock after banded iron-formation (Hocking et al., 1985; Williams, 1986).

Polyphase prograde and retrograde metamorphism of these lithologies has resulted in a wide range of mineral assemblages. Metamorphic grade increases southward, from lowermost greenschist facies in the northeastern Kimbers Syncline, to greenschist–amphibolite facies (affecting the majority of the pelitic and semipelitic schists), to upper amphibolite facies, inferred from the widespread partial melting involved in migmatite formation (Hocking et al., 1985).

Table 1. Simplified geological interpretation for WINNING POOL – MINILYA

Age		*Rock code*	*Description*
PHANEROZOIC	Quaternary	*Qm*	**BUNDERA CALCARENITE** Shoreline, marine, and coastal eolian deposits; includes coastal lake deposits; commonly calcareous and gypsiferous
	Neogene	*Czn*	**LAMONT SANDSTONE and TREALLA LIMESTONE** Marine limestone, and minor marine and continental sandstone
	Palaeogene	*Czp*	**CARDABIA CALCARENITE, GIRALIA CALCARENITE, and MERLINLEIGH SANDSTONE** Marine limestone and sandstone, with minor siltstone and basal greensand
	Cretaceous	*Kt*	**TOOLONGA CALCILUTITE, KOROJON CALCARENITE, and MIRIA FORMATION** Marine limestone, chalk, marl, and greensand; dominantly calcareous pelagic deposits
		KWI	**Winning Group** Marine and coastal shale, siltstone, and radiolarite; dominantly siliceous pelagic deposits with basal sandstone and conglomerate
	Permian	*P*	**Wooramel Group, Byro Group, and Kennedy Group** Marine and continental siltstone, shale, and sandstone
	Upper Carboniferous – Lower Permian	*PL*	**Lyons Group and CALLYTHARRA FORMATION** Marine and continental siltstone, shale, sandstone, and limestone; glacially influenced
	Middle Devonian – Lower Carboniferous	*DC*	**NANNYARRA SANDSTONE, GNEUDNA FORMATION, MUNABIA SANDSTONE, WILLARADDIE FORMATION, MOOGOOREE LIMESTONE, WILLIAMBURY FORMATION, and YINDAGINDY FORMATION** Marine to continental limestone, dolomite, sandstone, siltstone, shale, and conglomerate
PROTEROZOIC		*Ꝑd*	Dolerite sill
		ꝐME	**Edmund Group** Sandstone, siltstone, shale, dolomite, and chert; intruded by dolerite dykes and sills
		Ꝑg	**Gascoyne Complex granitoids** Granodiorite, monzogranite, granite, and pegmatite; includes minor dolerite and gabbro
		Ꝑm	**Gascoyne Complex metamorphic rocks (Morrissey Metamorphic Suite)** Schist, migmatite, gneiss, phyllite, quartzite, and minor calc-silicate rock, marble, and amphibolite

Gascoyne Complex granitoids

Large numbers of S- and I-type granitoid plutons and batholiths intrude the Gascoyne Complex metasedimentary rocks. The S-type plutons consist mainly of muscovite–biotite–tourmaline monzogranite, whereas I-type plutons largely consist of muscovite–biotite granodiorite or granite (Myers, 1990). The southeastern part of WINNING POOL – MINILYA contains the northwest extremity of the 230 km-long and 35 km-wide Minnie Creek Batholith, which is well developed to the southeast on MOUNT PHILLIPS (Williams et al. 1979; Sanders et al., 1997).

Edmund Group

The Edmund Group outcrops in the central east WINNING POOL – MINILYA in the Mangaroon Syncline. Hocking et al. (1985), following the stratigraphy of Muhling and Brakel (1985), mapped the outcropping lithologies in ascending order as: the Irregully Formation, Kiangi Creek Formation, Jillawarra Formation, Discovery Chert, and Devil Creek Formation. These lithologies represent tidal, lagoonal, shallow-, open-, and restricted-marine deposits (Williams, 1990).

Chuck (1984) subdivided the Irregully Formation, adding the Gooragoora Sandstone and Cheyne Springs Formation, and along with the Kiangi Creek Formation, noted the lateral equivalence between these units and the Jillawarra Formation. Recently, Martin et al. (1999) argued that where rocks of the Jillawarra Formation appear laterally equivalent to the Kiangi Creek Formation, they should be considered part of that formation. Martin et al. (1999) also considered that pyritic carbonaceous siltstone and carbonate strata from the lower and upper parts of the Jillawarra Formation respectively (Chuck, 1984) form the newly proposed Blue Billy and Muntharra Formations.

Recent mapping has also shown significant compositional heterogeneity in the Discovery Chert, suggesting the siliceous character of the unit is secondary, replacing rocks ranging from carbonaceous siltstone, to sandstone and conglomerate. In light of this new evidence, Martin et al. (1999) proposed the unit be renamed the Discovery Formation.

However, until remapping is completed, Edmund Group rocks on WINNING POOL – MINILYA will be described largely in accordance with the original mapping and stratigraphy of Hocking et al. (1985).

The Irregully Formation consists of dolomite with thin interbeds of quartz arenite, pebble conglomerate, and shale. The Kiangi Creek Formation consists of quartz arenite beds with less common shale, siltstone, dolomite, and conglomerate, and forms distinct ridges in the southern part of the Mangaroon Syncline. Black, siliceous, locally pyritic shale with local thin chert, siltstone, and dolomite make up the Jillawarra Formation (Hocking et al., 1985). The Discovery Formation (formerly Discovery Chert), consists of massive (chert-like), silicified carbonaceous mudstone and siltstone, and forms a prominent stratigraphic marker in the Edmund Group. The Devil Creek Formation conformably overlies the Discovery Formation and consists of dolomitic breccia, dolograinstone, dolomudstone, and minor stomatolites (Martin et al., 1999).

Middle Devonian – Lower Carboniferous sedimentary rocks

Middle Devonian – Lower Carboniferous sedimentary rocks on WINNING POOL – MINILYA are exposed in structurally complex half-grabens in the Gascoyne Complex, between the Williambury and Lyndon stations. The units in ascending order are: Nannyarra Sandstone, Gneudna Formation, Munabia Sandstone, Willaraddie Formation, Moogooree Limestone, Williambury Formation, and Yindagindy Formation (Hocking et al., 1985). None of the older Ordovician – Lower Devonian units are exposed.

Outcropping along the eastern margin of the basin, the Nannyarra Sandstone rests unconformably on the undulating surface of the Gascoyne Complex. The unit consists of coarse- to fine-grained, variably sorted, thin-bedded sandstone, probably laid down in a braided-fluviatile to shallow-marine environment. Further west, in the subsurface, the unit lies disconformably on Lower Devonian or Silurian units. The Gneudna Formation, which conformably overlies the Nannyarra Sandstone or unconformably rests on Precambrian basement, consists of interbedded carbonate, siltstone, and minor evaporite. Numerous fossiliferous horizons within the unit contain an assortment of marine invertebrates. The environment of deposition ranges from intertidal to shallow marine. The overlying Munabia Sandstone consists of well-sorted, fine- to coarse-grained sandstone with minor siltstone and dolomite. The unit was deposited in a sheet-braided fluviatile environment with minor marine incursions (Moors, 1981b). The Willaraddie Formation is a conglomeratic to sandy sequence, deposited as alluvial fans over the Munabia Sandstone (Moors, 1981b). Some poorly preserved fossils may indicate minor marine or estuarine incursion (Hocking et al., 1987).

The Lower Carboniferous Moogooree Limestone rests, with possible unconformity, on the Willaraddie Formation. It is dominated by limestone and dolomite with minor siliciclastic and evaporitic horizons, deposited in a shallow-marine, carbonate-rich environment, mostly in peritidal conditions. Salinity may have been higher than normal with dolomitization of sediments and deposition of evaporites. The overlying Williambury Formation is similar to the Willaraddie Formation, and represents a return to terrestrial deposition, probably in an upper alluvial fan environment. The mixed marine carbonate and immature sandstones of the Yindagindy Formation indicate deposition in a shallow-marine basin backed by high hinterland with large volumes of terrigenous input. The dominant lithology is medium- to coarse-grained sandstone with thin interbeds of oolitic and algal limestone (Hocking et al., 1985, 1987).

Lyons Group and Callytharra Formation

The Lyons Group is an Upper Carboniferous – Lower Permian glacigene succession consisting of poorly to moderately sorted feldspathic wacke, with less common quartz sandstone, siltstone, tillite, and limestone. It is poorly exposed, although west of Williambury Station, it outcrops as low domes of weathered-out cobbles and boulders of varying composition. Clasts include various types of granitoid, quartzite, quartz, sandstone, siltstone, metamorphic rocks, chert, carbonates, pegmatite, and basalt. Many clasts show plucking, striations, and faceting (Hocking et al., 1987). Laminated, commonly contorted siltstone is located throughout the group with possible varves known from several localities (Condon, 1967). The unit is mainly a glaciomarine deposit, with minor glaciolacustrine and fluvioglacial influences; the varied assemblage of erratics indicates a geologically diverse source area (Hocking et al., 1987).

The Lyons Group is conformably overlain by the middle Lower Permian Callytharra Formation, which consists of calcareous fossiliferous siltstone that typically grades to highly fossiliferous limestone containing abundant brachiopods, crinoids, and bryozoans (Hocking et al., 1987). The formation was deposited in quiet, marine conditions with fine-grained terrigenous input. No glacial erratics have been found within the formation, suggesting the deposit formed after the main Permian ice sheet had dissipated (Hocking et al., 1985). Outcrops of Callytharra Formation are found in the Gooch Range.

Wooramel, Byro, and Kennedy Groups

The middle Lower Permian Wooramel Group is a sandy, silty succession that, on WINNING POOL – MINILYA, consists of the Cordalia Sandstone, Moogooloo Sandstone, and Billidee Formation (Hocking et al., 1985), most of which outcrop in the Gooch Range.

The Cordalia Sandstone is a thin-bedded sandstone to siltstone, deposited in a lower shoreface to shelf environment. To the west, in the subsurface, the unit grades into prodeltaic siltstone. The overlying Moogooloo Sandstone consists of commonly well-sorted, fine- to coarse-grained quartz sandstone, which sparkles in outcrop due to authigenic overgrowths on quartz grains. Fossils are rare and palaeocurrent data (dominantly to the north-northwest) and lithotypes indicate deposition took place in a dominantly fluvial to shallow-marine environment (Hocking et al., 1987). The Billidee Formation is a locally calcareous, fine-grained sandstone and siltstone with interbedded, commonly carbonaceous shale. Deposition on WINNING POOL – MINILYA probably took place in a lower shoreface to offshore environment, although a complex interplay of terrigenous supply, energy levels, water depth, and differential basin subsidence has resulted in significant lateral and vertical variation, which is typical of the unit throughout the Southern Carnarvon Basin (Hocking et al., 1987).

The upper Lower Permian Byro Group is a fine-grained, locally fossiliferous shelf succession, which is conformable on the Billidee Formation, and consists of carbonaceous siltstone and mudstone with fine- grained, cross-stratified sandstone, deposited on a storm-dominated marine shelf. The eight formations within the group in ascending order are: the Coyrie Formation, Mallens Sandstone, Bulgadoo Shale, Cundlego Formation, Quinnanie Shale, Wandagee Formation, Nalbia Sandstone, and Baker Formation (Hocking et al., 1987). The group was deposited within a single palynozone indicating a relatively rapid depositional rate, calculated to be over 300 m per million years (Iasky et al., 1998). Most of the outcrop of the Byro Group on WINNING POOL – MINILYA is in the vicintiy of Wandagee Station in the central south, with scattered outcrop northwards towards Mia Mia Station.

The basal Coyrie Formation is transitional from the underlying Billidee Formation and contains black carbonaceous siltstone and shale overlain by fine-grained, cross-stratified sandstone. The overlying Mallens Sandstone consists of quartzose and silty sandstone, is partly fossiliferous, and strongly bioturbated. The black, carbonaceous, pyritic shale and siltstone of the overlying Bulgadoo Shale was probably deposited under reducing conditions in a quiet, offshore environment. Secondary pyrite, gypsum, and phosphate nodules are present in some horizons. The Cundlego Formation represents a return to high-energy conditions, with interbedded fine-grained sandstone and lesser carbonaceous siltstone, shale, and fossiliferous material deposited in a storm-dominated shoreface to offshore environment. The Quinnanie Shale is restricted to the Wandagee area and consists of carbonaceous shale, siltstone, and minor sandstone with varied fauna, commonly preserved within secondary pyritic and phosphatic nodules (Hocking et al., 1985). The unit formed in conditions similar to those of the Bulgadoo Shale. Condon (1967) considered it to be a lateral variant of the Cundlego Formation.

The overlying Wandagee Formation is an upwards-fining succession of sandstone, silty sandstone, siltstone, and shale deposited in quiet, off-shore conditions. The unit is richly fossiliferous, especially in lower parts where shells are concentrated within sandstone horizons. The Nalbia Sandstone was deposited in a shallow-marine, lower shoreface to transition-zone environment, and consists of fine- to medium-grained sandstone and silty sandstone. The unit is overlain by the Baker Formation, which represents a return to quiet, offshore conditions, with the deposition of locally pyritic, carbonaceous, and fossiliferous siltstone and minor silty sandstone and coarser storm-deposited sandstone (Hocking et al., 1985).

The Lower–Upper Permian Kennedy Group conformably overlies the Byro Group and contains similar siliciclastic rocks deposited in a marine-shelf environment (Iasky et al., 1998). The Kennedy Group contains three formations: the Coolkilya Sandstone, Mungadan Sandstone, and Binthalya Formation. On WINNING POOL – MINILYA, the only exposure is at Wandagee Hill (Hocking et al., 1985).

The Coolkilya Sandstone was deposited primarily in a lower shoreface to marine-shelf environment and consists of locally fossiliferous and calcareous quartz wacke and siltstone. The Mungadan Sandstone consists of bioturbated sandstone to silty sandstone, deposited on a broad marine-shelf under slightly higher energy (wave-influenced) conditions (Hocking et al., 1987). The Binthalya Formation is represented on WINNING POOL – MINILYA by a solitary rubbly outcrop of ferruginized sandstone to siltstone, most probably deposited in an offshore environment (Hocking et al., 1985).

Winning Group

On WINNING POOL – MINILYA, the Nanutarra Formation consists of fine- to coarse-grained, locally pebbly sandtone and subordinate siltstone that interfingers with and underlies the basal Winning Group. Polymictic conglomerate that could be referred to as the Yarraloola Conglomerate is present locally at the base of the Nanutarra Formation. The conglomerate was deposited as fluvial valley fill on the basal Cretaceous unconformity over the Gascoyne Complex. The sandstone and siltstone are marginal marine deposits formed from partial drowning of the Precambrian coastline (Hocking et al., 1987). Outcrops of the Yarraloola Conglomerate and Nanutarra Formation on WINNING POOL – MINILYA are limited to the area between Pleiades Hills and Nyang Station.

The Lower–Upper Cretaceous Winning Group was deposited in a marine transgression that began in the Neocomian and continued through to the end of the Cenomanian. The group comprises the Birdrong Sandstone, Muderong Shale, Windalia Radiolarite, and Gearle Siltstone separated by local disconformities. The Neocomian Birdrong Sandstone consists of weakly lithified sandstone to quartz sand deposited primarily as a shallow-marine, transgressive sand sheet, and is overlain by the fine-grained, low-energy, offshore Aptian Muderong Shale (Hocking et al., 1985, 1987).

Overlying the Muderong Shale is the Aptian–Albian Windalia Radiolarite, a variably porcellanized, radiolarian siltstone (Hocking et al., 1985). Based largely on its position within the shallow-marine Winning Group, this pelagic deposit was most likely laid down in a low-energy, shallow-marine shelf rather than a deep-sea environment (Hocking et al., 1982).

Carbonaceous and pyritic siltstone, claystone, and radiolarite of the Cenomanian Gearle Siltstone conformably overlie the Windalia Radiolarite. The unit was deposited under reducing conditions in a low energy, offshore environment and on WINNING POOL – MINILYA is characterized by bentonitic claystone, barite nodules, and secondary gypsum (Hocking et al., 1985). The Gearle Siltstone is only exposed in the northwest of the study area, largely as deeply weathered residual soil in the eroded crests of the Giralia and Marilla Anticlines (Condon et al., 1956).

Toolonga Calcilutite, Korojon Calcarenite, and Miria Formation

The Coniacian–Maastrichtian Toolonga Calcilutite disconformably overlies the Gearle Siltstone and consists of massive, fossiliferous calcilutite and calcisiltite deposited in inner- to middle-shelf marine environments. Energy levels were typically low except for areas such as the Giralia Anticline, which was structurally and topographically high (Hocking et al., 1987).

The Campanian–Maastrichtian Korojon Calcarenite both conformably overlies and is a lateral equivalent of the Toolonga Calcilutite. The formation differs from the Toolonga Calcilutite by a greater abundance of giant bivalve fragments *Inoceramus* sp., and formed in a slightly shallower and higher energy environment (Hocking et al., 1985).

The Maastrichtian Miria Formation (Miria Marl of Condon, 1954) disconformably overlies the Korojon Calcarenite, and is a thin, persistent, abundantly fossiliferous calcarenite to calcisiltite unit with a marly appearance (Hocking et al., 1985). In the Giralia Anticline, a layer of phosphatic nodules and phosphatized macrofossils commonly marks the base of the unit. The upper contact is marked by a change from whitish marl to greensand (Hocking et al., 1987).

Cardabia Calcarenite, Giralia Calcarenite, and Merlinleigh Sandstone

The Paleocene–Eocene Cardabia Calcarenite was previously termed the Cardabia Group and divided into five formations (Condon et al., 1956; Condon, 1967). Due to difficulty in differentiating parts of the formations and their likely deposition in a single episode, Hocking (1985) reduced the group to formation status (Cardabia Calcarenite) and the constituent formations to members.

In general, the Cardabia Calcarenite consists of a basal greensand, overlain by calcarenite and calcisiltite. The formation is exposed in the northwestern part of WINNING POOL – MINILYA in the Giralia and Marrilla Anticlines. The lower portions are poorly exposed and contain between 20 and 80% medium-grained glauconite sand in a white to grey, chalky matrix, which grades upwards into a commonly hard, well-bedded, glauconitic, calcarenitic grainstone to packstone. The middle part of the unit is more friable and consists of chalky, white calcarenite to calcisiltite, locally rich in bryozoans. This grades up and interfingers with a hard calcarenitic packstone to grainstone, which is in turn overlain in places by a hard, partly glauconitic and bryozoal packstone to wackestone. The depositional environment ranges from quiet, uniform-shelf to open-shelf conditions (Hocking et al., 1987).

The Eocene Giralia Calcarenite is a greenish-brown, variably quartzose and ferruginized, bryozoan calcarenite. The unit is exposed on WINNING POOL – MINILYA on the westward flank of the Giralia Anticline, where it is around 60 m thick. The unit is characterized by large, discoid foraminifers, limonite, goethite, and glauconite and formed in agitated waters on a shallow-marine shelf (Hocking et al., 1987).

The Eocene Merlinleigh Sandstone is a shoreward equivalent of the Giralia Calcarenite, and consists of a coarse to very coarse grained sandstone with lesser medium- to fine-grained sandstone, siltstone, and pebble and granule conglomerate. The sandstone is dominantly a quartz wacke, with lesser quartz sandstone and feldspathic wacke. Fossils are locally present, implying deposition in fluvial to nearshore (possibly part lagoonal) environments (Hocking et al., 1987). The unit is poorly exposed on WINNING POOL – MINILYA, and has been subsequently modified by weathering, forming iron-rich duricrust. Outcrops are mostly small and associated with rocks of the Winning Group in the eastern parts of the project area, near the Southern Carnarvon Basin – Gascoyne Complex contact (Hocking et al., 1985).

Lamont Sandstone and Trealla Limestone

The Miocene Trealla Limestone is a white to cream, highly fossiliferous grainstone to boundstone, locally quartzose in the Giralia Anticline area. The unit conformably overlies, and in places grades into, the Lamont Sandstone, which is a thin, highly silicified quartz sandstone. In the Giralia Anticline, the Trealla Limestone was probably deposited on a moderate-energy, shallow-marine shelf with little terrigenous input (Hocking et al., 1985). Further to the east, silt and quartz-sand content increases, and deposition may have been partly in a lagoonal to coastal environment. The relationship with the Lamont Sandstone suggests it was deposited under similar conditions, but only in isolated areas where there was significant supply and entrapment of terrigenous material (Hocking et al., 1987).

Bundera Calcarenite and coastal lake deposits

Variably carbonate-cemented, calcareous eolianite, coralgal reefs, coquina, and shelly limestone of Pleistocene age underlie most of the coastal plains of the Cape Range Peninsula, extending south onto WINNING POOL – MINILYA, where it outcrops along the coast and around the margins of Lake MacLeod (Hocking et al., 1985, 1987). These deposits are termed the Bundera Calcarenite and within the study area consist of eolian sandstone, shoreline conglomerate, coralgal reefs, beach sand, and shelly limestone and sandstone. Lake MacLeod formed during the Quaternary by barring of the coastline by eolian dunes. The lake contains sand, silt, clay, and evaporitic material (gypsum, anhydrite, and halite) in lake, loess, and marginal-bedded deposits (Hocking et al., 1985).

Recorded mineralization and economic geology

WINNING POOL – MINILYA, which encompasses parts of the Ashburton and Gascoyne mineral fields, have been explored for base metals, nickel, gold, uranium, diamonds, phosphate, bentonite, gypsum, tin, and tantalum. Mineral occurrences recorded on WINNING POOL – MINILYA include gypsum, copper–lead–zinc, gold, uranium, and barite.

On WINNING POOL – MINILYA, three projects have resource figures recorded in the Department of Minerals and Energy (DME) mines and mineral deposits information database (MINEDEX), but there is no recorded production from any of the three projects. These projects include uranium resources at Jailor Bore, and gypsum deposits in lakes and dunes at Lyndon River and Lake MacLeod North. The only recorded production from WINNING POOL – MINILYA reported to the DME's Royalties Branch was 3000 t of construction sand from Warroora Station in 1992.

Evaporite

Bedded gypsum is extensively developed north of Lake MacLeod on WINNING POOL – MINILYA. Inferred resources of 32 Mt at 93.5% $CaSO_4$ and 10.8 Mt at 90.0% $CaSO_4$ are reported in lakes at Lake MacLeod North with additional resources of 45.0 Mt at 87.3% $CaSO_4$ and 1.00 Mt at 92.6% $CaSO_4$ in nearby dune systems (Jones, 1994). At Lyndon River, there are indicated gypsum resources of 40 Mt at 87.9% $CaSO_4$ and 5.3 Mt at 91.2% $CaSO_4$ in lake deposits (Prima Resources Ltd, 1995). Halite is present within evaporite sequences on WINNING POOL – MINILYA just north of Lake MacLeod, but there is no recorded production from this area, although salt is produced from evaporite sequences on QUOBBA (Flint and Abeysinghe, 2000).

Diamonds

CRA Exploration and Stockdale Prospecting conducted diamond exploration between 1978 and 1983 over a cluster of diatremes and intrusions on the Wandagee Fault (Wandagee kimberlite field), a northerly trending zone about 50 km long extending from KENNEDY RANGE to southern WINNING POOL – MINILYA (Harrison, 1985; Jaques et al., 1986). The age of the diatremes and intrusions is post-Permian to pre-Cretaceous. No sizeable or economically diamondiferous kimberlite rocks were identified in the area (Stockdale Prospecting Ltd, 1981). Between 1989 and 1993, Eucla Mining and Billiton Australia carried out exploration for heavy mineral sands in the Coral Bay area within the Giralia Anticline. After locating diamond indicator minerals during rock chip (RC) drilling, the focus shifted to diamond exploration. Follow-up sampling failed to locate definitive targets for diamonds and no further work was conducted (Eucla Mining NL, 1990).

Barite

At Cardabia Creek in the Giralia Anticline, there are small barite crystals in a 30 cm-thick bed within bentonitic shale and siltstone of the Gearle Siltstone. There are nodules of barite up to 30 cm in diameter at Remarkable Hill about 25 km from Cardabia Creek on the western flank of the Giralia Anticline. Condon (1968) suggested the barite was precipitated during sedimentation, and as the Cardabia and Remarkable Hill occurrences exist in a similar stratigraphic position, they could represent a continuous bed. Abeysinghe and Fetherston (1997) believed the nodular occurrence near Remarkable Hill may have been formed by supergene processes.

Gold

A small amount of gold has been mined north of Lyndon Station, located in metamorphic rocks of the Gascoyne Complex.

Uranium

Four different areas have been targeted for uranium exploration on WINNING POOL – MINILYA, including valley calcrete, metamorphic rocks of the Gascoyne Complex, and the Moogooloo Sandstone, Gneudna Formation, and Winning Group of the Southern Carnarvon Basin (Hocking, 1985).

Carnotite mineralization is within calcrete at Jailor Bore, 14 km south-southeast of Lyndon Station. Independent assessment of the prospect recognized that early resource estimates cannot be categorized with confidence according to the Joint Ore Reserves Committee (JORC) code (Acclaim Uranium NL, 1997; Australasian Institute of Mining and Metallurgy et al., 1999).

In 1979, CRA Exploration identified anomalous radioactivity over the Gneudna Formation that was attributed to surface enrichment, and minor occurrences of uranium minerals were reported (CRA Exploration Pty Ltd, 1979).

There is localized carnotite in calcrete overlying uraniferous granite near Quail Spring Well west of Lyndon Station. Investigations showed mineralization grade did not exceed 0.25 kg/tonne (Samantha Mines NL, 1977).

Base metals

Sedimentary-hosted lead–zinc anomalism at Coria Springs, 24 km northeast of Lyndon Station, is in carbonates and ironstones of the Irregully Formation and shales of the Kiangi Creek Formation of the Edmund Group (Ferguson, 1999). Best assay results were 1.05% Pb in a 12 m channel sample, and 1% Zn in an ironstone grab sample (Australian Anglo American Ltd, 1982). Follow-up drilling failed to find significant mineralization at Coria Springs, the anomaly attributed to surface scavenging by carbonaceous black shales.

The carbonate-rich Moogooree Limestone, Gneudna Formation, and Callytharra Formation have been explored for sedimentary-hosted base metal mineralization. Harrison (1985) summarizes open-file company surface geochemical and drilling results for these units, which includes an area near Williambury and Lyndon stations. Diamond drilling of a soil geochemical Pb anomaly (3200 ppm), 17 km northwest of Lyndon Station, located minor galena mineralization in fractured, vuggy dolomite. Diamond drill samples assayed up to 6500 ppm Pb and 1850 ppm Zn, however, the carbonate facies was deemed insufficiently developed to host significant mineralization (Aquitaine Aust Minerals Pty Ltd, 1975).

The Winning Group has been the subject of a number of exploration programs. In the Giralia Anticline, anomalous Ag and Zn values have been reported from sulfide and goethite nodules and microgossan chips in the Gearle Siltstone (International Nickel Australia Ltd, 1980). No significant base metal or silver values were obtained in the follow-up deep drilling program, and it was concluded any mineralization present would be too sparsely distributed to be economic (Harrison, 1985).

Construction materials

Trealla Limestone and calcrete have been quarried from the western part of WINNING POOL – MINILYA for use in local road construction. The limestone is dense, hard, and light cream to white in colour (Abeysinghe, 1998). Rock sourced from the Callytharra Formation and Moogooloo Sandstone has been used locally for paving and building stones. Three thousand tonnes of construction sand were excavated from a site near Warroora Station.

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 Western Australian mineral exploration (WAMEX) database as either open-file or confidential reports. Details of open-file company reports that contain surface or near-surface geochemical data are listed in Appendix 2. For each project, surface geochemical exploration metadata (including shallow drilling) are captured to a maximum depth of 4 m. Projects with fewer than 30 samples have been omitted.

Each project has been assigned an identification number and this is shown, along with project boundaries, on Plate 2.

The projects listed in Appendix 2 are arranged in order of increasing M number for the period 1974 to 1997. When reports are released to open-file, an Item number is assigned. The highest Item number denotes the latest release. Gaps in reporting result from the failure of some tenement holders to lodge reports or because mineral claim holders were not required to report all of their exploration results prior to 1978.

Samples contained within the 19 projects listed in Appendix 2 were analysed for an average of six analytes. The projects are classified according to the targeted mineralization as follows:

- Base metals 41%
- Gold 22%
- Uranium 22%
- Diamond 3%
- Gypsum 3%
- Phosphate 3%
- Nickel 3%
- Tin, tantalum 3%

There has been extensive diamond exploration in the Wandagee, Giralia, and Middalya areas. Samples from this type of exploration have commonly been examined for indicator minerals, and not tested by geochemical methods. Thus, metadata for these samples are not included in Appendix 2 as no geochemical assays have been carried out.

Regolith sampling

Regolith sampling on WINNING POOL – MINILYA was carried out over a two-week period during July–August 1999 by six, two-person sampling teams, each comprising a field assistant and geologist, using two Bell Jet-Ranger helicopters. At each sample site (Plate 1), characteristics of the regolith and surrounding geology were recorded on a standard form presented in Appendix 3. The approach to regolith sampling is also discussed in Appendix 3. A measurement of the Earth's gravitational field was made at each sample site on eastern parts of the project area, based on methodology discussed by Iasky and Shevchenko (1999).

Regolith-materials mapping

A regolith-materials map (Plate 3) has been produced for WINNING POOL – MINILYA using Landsat imagery, 1:250 000-scale geological mapping of Hocking et al. (1985), Landsat synthetic stereo pairs, aerial photography, and field observations recorded at each sample site.

The regolith-materials maps of WINNING POOL – MINILYA, STANLEY (Morris et al., 2000a), KINGSTON (Pye et al., 2000), the Fraser Range region (Morris et al., 2000b), and AJANA (Sanders and McGuinness, 2000) use a revised version of the GSWA regolith classification (Hocking et al., in prep.). These revisions have allowed a greater range of regolith types and compositions to be designated, using subscripts for primary, secondary, and tertiary codes. The current regolith-materials mapping scheme and its evolution is described in Appendix 3.

The assigned regolith codes for each sample on WINNING POOL – MINILYA are listed in the accompanying datafile (WINMIN.CSV) and these codes are described in Plate 3. Table 2 summarizes the occurrence of regolith units by area, sample type, and number of samples per regolith-materials division. A generalized version of the regolith-materials map is presented in Figure 5.

Major features of regolith on WINNING POOL – MINILYA are:

Gascoyne Complex and Edmund Group

- Low exposed-regime regolith and locally derived products (colluvium, low-gradient sheetwash, and sandplain) associated with crystalline rocks.
- Exposed-regime regolith and locally derived products associated with the rugged sedimentary rocks of the Mangaroon Syncline.
- Exposed-regime regolith associated with northerly trending quartz vein ridges.
- Extensive relict valley calcrete along river courses.

Southern Carnarvon Basin

- Exposed-regime regolith associated with strike ridges of the central Gooch Range and western Giralia and Gnargoo Ranges.
- Siliceous and ferruginous duricrust forming mesas and breakaways in the southeast (Williambury–Lyndon stations area) and central north (Winning Station – Pleiades Hills area).
- Deeply weathered, exposed-regime regolith in etchplains of the central south (Wandagee Station area) and northwest (Giralia Anticline area).
- Carbonate-rich duricrust (calcrete) platforms in the central and western areas.
- Extensive longitudinal dune fields over carbonate-rich duricrust in the central and western areas.
- Broad floodplains of the Minilya and Lyndon rivers (between Minilya, Wandagee, and Mia Mia stations).
- Mixed longitudinal dune, sheetwash, and playa terrain in broad topographic lows and floodplains of the Minilya and Lyndon rivers.

Table 2. Regolith units by area and number of samples

Regolith code	*Area (km^2)*	*Percentage of total area*	*Number of samples*	*Percentage of total samples*
Residual (*R*)				
Rf	8	0.04	1	0.08
Rk	877	4.26	46	3.84
Rl	32	0.16	0	0.00
Rz	36	0.18	0	0.00
Total	953	4.64	47	3.92
Exposed (*X*)				
Xgm	1 100	5.34	49	4.09
Xgp	1 606	7.80	73	6.09
Xkc	1 037	5.04	42	3.50
Xk_gc	32	0.15	0	0.00
Xkm	10	0.05	0	0.00
Xls	255	1.24	9	0.75
Xls_g	207	1.00	11	0.92
Xmh	14	0.07	0	0.00
Xmm	18	0.09	1	0.08
Xq	11	0.05	0	0.00
Xqm	10	0.05	0	0.00
Xqs	382	1.85	15	1.25
Xrs	484	2.35	34	2.84
Xzc	250	1.21	14	1.17
Xzs	4	0.02	0	0.00
Total	5 420	26.31	248	20.68
Colluvial (*C*)				
Cf	1	0.01	0	0.00
Cg	32	0.15	2	0.17
Cgm	27	0.13	2	0.17
Cgp	72	0.35	5	0.42
Ck	164	0.79	9	0.75
Cl	309	1.50	22	1.83
Cq	64	0.31	4	0.33
Czc	39	0.19	0	0.00
Total	708	3.43	44	3.67
Low-gradient slope (sheetwash) (*W*)				
W1d	1 996	9.69	108	9.01
W1z	105	0.51	2	0.17
W2	172	0.83	8	0.67
Total	2 273	11.03	118	9.85
Alluvial (*A*)				
A1d	2 418	11.74	276	23.02
A2k	119	0.58	11	0.92
Total	2 537	12.32	287	23.94
Lacustrine (*L*)				
L_l	581	2.82	3	0.25
L_m	25	0.12	2	0.17
L_ge	217	1.05	13	1.08
Total	823	3.99	18	1.50
Sandplain (*S*)				
S_u	1 161	5.64	59	4.92
S_p	1 360	6.60	77	6.42
Sl	1 061	5.15	63	5.25
Total	3 582	17.39	199	16.59
Eolian (*E*)				
E_l	3 046	14.79	177	14.76
E_p	367	1.78	20	1.67
Ek1	63	0.31	0	0.00
Ek2	255	1.24	13	1.08
Ek3	177	0.86	10	0.83
Total	3 908	18.98	220	18.34
Coastal and marine (*K, M*)				
Kk	367	1.78	18	1.50
Mk	25	0.12	0	0.00
Total	392	1.90	18	1.50
TOTAL	**20 596**	**99.99**	**1199**	**99.99**

- Mixed sand, sheetwash, and playa terrain in broad topographic lows of the central north and floodplains of Minilya and Lyndon rivers.
- Extensive barred, coastal lacustrine regolith in the southwest (Lake MacLeod).
- Exposed-regime regolith and locally derived material associated with extensive limestone outcrop of the Giralia and Saltmarsh Anticlines.
- Recent and older (degraded) coastal dune formations.
- Marine regolith associated with the offshore Ningaloo Reef tract.

Residual-regime regolith (*R*)

Residual-regime regolith on WINNING POOL – MINILYA occupies approximately 5% by area and accounts for nearly 4% of regolith samples. Residual-regime units consist of siliceous, ferruginous, and calcareous duricrust, with reworked material and overlying sand. Silica-rich, residual-regime regolith (*Rz*) is developed largely in the southeast and central north of WINNING POOL – MINILYA as duricrust over Middle Devonian – Lower Carboniferous and Winning Group rocks. This regolith type commonly contains some ferruginous material, and may grade into iron-rich duricrust (*Rf*), which is common over Winning Group rocks in the Pleiades Hills – Winning Station area. In the northwestern and western part of the project area, over the Korojon Calcarenite and Trealla Limestone, large areas of residual carbonate-rich duricrust (*Rk*) have developed. Carbonate-rich duricrust (*Rk*) is also thought to underlie much of the eolian sandplain of central WINNING POOL – MINILYA, and is commonly exposed and reworked into alluvial floodplain material in interdunal areas, such as the calcrete exposures in the Burnerburnung Hill area. Small micritic limestone and carbonate-rich mudstone mesas of the Nadarra Formation, northeast of Williambury Station, have also been designated as residual carbonate-rich material (*Rk*). Mixed residual material (*Rl*), exposed in the eroded crest of the Giralia Anticline, probably consists of calcrete derived from nearby calcareous units and gypcrete from the underlying, partly gypsiferous Gearle Siltstone.

Exposed-regime regolith (*X*)

Areas of exposed bedrock, subcrop, or saprock (*X*) constitute approximately 26% by area, and account for just under 21% of regolith samples collected on WINNING POOL – MINILYA. Exposed-regime regolith derived from quartzofeldspathic plutonic rock (*Xgp*) is the dominant exposed-regime regolith type on WINNING POOL – MINILYA, and is commonly derived, with exposed-regime regolith, from quartzofeldspathic metamorphic rocks (*Xgm*). Both units are restricted to the Gascoyne Complex and represented by low domes and pavements, commonly obscured by proximally derived material. Exposed quartzofeldspathic regolith (*Xgp*, *Xgm*) is also common along the Lyndon and Yannarie rivers, although delineating the extent of these units is difficult, due to overlying silicified and incised relict calcretes.

Exposed-regime regolith derived from thin, but extensive, dominantly northerly trending quartz veins (*Xq*) and metadolerite or metagabbro (*Xmm*) are common between Williambury and Towera stations, and probably follow basement faults. Regolith units derived from metamorphosed ferromagnesian rocks (*Xmm*) are scattered throughout the Gascoyne Complex, and are associated with amphibolite, quartz–magnetite rock, and mafic schist. Regolith lenses derived from carbonate- and quartz-rich metamorphic rocks (*Xkm, Xqm*) are common in the far northeast of the project area and east of Williambury Station.

Exposed-regime regolith derived from dolerite sills (*Xmh*) is most common in the Mangaroon Syncline, where it is interlayered with regolith derived from quartz-rich and carbonaceous sedimentary rocks (*Xqs, Xrs*).

Exposed-regime regolith derived from quartz-rich sedimentary rock (*Xqs*) is most common in central WINNING POOL – MINILYA along the Gooch Range, and in the southeast between Williambury and Lyndon stations, where the unit is commonly capped by variably ferruginized silcrete (*Rz*). In addition, there are small pockets of this regolith type in the central south, and in the north near the Southern Carnarvon Basin – Gascoyne Complex boundary. Carbonaceous exposed-regime regolith (*Xrs*) dominates the central south and northwest of the project area. Typically, these exposed regolith units (*Xrs*) are deeply weathered and include significant proportions of overlying residual soil, but as the boundaries are difficult to distinguish, these units are grouped as exposed-regime material.

Exposed-regime regolith derived from siliciclastic glacigene rocks (Lyons Group; Xls_g) is common in the southeast and central parts of WINNING POOL – MINILYA. The unit is poorly exposed and commonly expressed as fields of cobbles and boulders of varying composition. Exposed-regime regolith with heterogeneous composition (*Xls*), including combinations of quartz-, carbonate-, iron-, and glauconite-rich and carbonaceous materials, is in the central south over Byro Group rocks and in the vicinity of the Southern Carnarvon Basin – Gascoyne Complex contact, associated with rocks of the Winning Group and Merlinleigh Sandstone.

Silica-rich exposed-regime regolith is abundant over the Windalia Radiolarite of the central north and northwest (*Xzc*), and over the Discovery Formation in the Mangaroon Syncline (*Xzs*). On AJANA, exposed-regime regolith derived from the Windalia Radiolarite was coded as quartz rich (*Xqc*; Sanders and McGuinness, 2000). With ongoing revision of the GSWA regolith scheme (Hocking et al., in prep.) and refining of the application of the secondary (compositional) codes, it is deemed more appropriate to designate the cryptocrystalline, radiolaria-rich rock as silica rich (*Xzc*).

Exposed-regime, carbonate-rich regolith (*Xkc*) derived from Phanerozoic limestone is common over western areas of WINNING POOL – MINILYA, particularly the flanks of the Giralia and Salt Marsh Anticlines. The Giralia Anticline also contains narrow, but laterally extensive exposed-regime regolith derived from interbeds of glauconitic limestone and greensand (Xk_gc). Exposed carbonate-rich regolith (*Xkc*) is also common in central and southeastern parts of the project area, where it overlies the Callytharra Formation and Moogooree Limestone.

Colluvial (*C*) and low-gradient slope (*W*) regolith

Colluvial (*C*) regolith occupies just over 3% of the project area and accounts for approximately 4% of regolith samples collected. Heterogeneous colluvium (*Cl*) is the dominant colluvial unit on WINNING POOL – MINILYA, distributed throughout the study area in regions of mixed lithology. In the east, heterogeneous colluvium (*Cl*) results from the input of quartzofeldspathic-, ferromagnesian-, quartz-, and carbonate-rich material. Along the footslopes of the Gooch Range, heterogeneous colluvium is a mix of quartz- and carbonate-rich detritus. In the Giralia Anticline and Wandagee Station areas, heterogeneous colluvium includes various proportions of carbonaceous-, carbonate-, glauconite-, quartz-, and silica-rich material. Between Pleaides Hills and Winning Station, heterogeneous colluvium is dominated by mixed silica- and iron-rich material, partly derived from surrounding scattered ferruginous and siliceous duricrust.

Colluvium derived from quartzofeldspathic plutonic rocks (*Cgp*) and quartzofeldspathic metamorphic rocks (*Cgm*) flank much of the granitic and metasedimentary outcrops of the Gascoyne Complex. Quartzofeldspathic colluvium (*Cg*) is common where material is derived from a mixture of these outcropping granitic and metasedimentary rocks.

Silica-rich colluvium (*Czc*) is common in the central north and northwest where it forms aprons below outcrops of Windalia Radiolarite. Carbonate-rich colluvium (*Ck*) is common in western areas on the slopes and depressions bounding exposures of limestone and carbonate-rich duricrust. Small pockets are also known from the Gooch Range, associated with the Callytharra Formation, and from the carbonate rocks of the Mangaroon Syncline.

Quartz- and iron-rich colluvium (*Cq, Cf*) are rare on WINNING POOL – MINILYA. Exposures of quartz-rich colluvium are limited to the southeastern part of the Southern Carnarvon Basin. Although these areas contain extensive exposed, quartz-rich regolith (*Xqs*), most material grades into heterogeneous colluvium (*Cl*) or low-gradient sheetwash (*W*). A small pocket of iron-rich colluvium (*Cf*), associated with iron-rich duricrust (*Rf*), is mapped from the Pleiades Hills area. Here, the regolith is largely siliceous with varying degrees of ferruginization, with most colluvial material being regarded as heterogeneous (*Cl*).

Low-gradient slope material or sheetwash (*W*) accounts for 11% of regolith on WINNING POOL – MINILYA and 10% of regolith samples collected. The undivided unit (*W1d*) is common throughout the area, typically associated with depressions and drainages. In the east, this unit is marginal to alluvium of the Yannarie, Lyndon, and Minilya rivers, and on the low-gradient footslopes bounding the strike ridges of the Gooch Range. In the central south and northwest, it borders the low etchplain outcrops of the Byro and Winning Groups.

Fans of silica-rich, and in part ferruginous, low-gradient sheetwash (*W1z*) are present in the central north, covering low-angle backslopes of the Windalia Radiolarite. In this area, Landsat spectral characteristics and geomorphology indicate that the radiolarian-rich source rock is relatively near surface. Small pockets are also mapped from the central south and northwest, in each case associated with nearby outcrop of the Windalia Radiolarite.

Areas of older low-gradient sheetwash (*W2*) are most common along the Minilya and Yannarie rivers. This unit is consolidated, possibly silicified and carbonate-rich, and commonly forms low erosional terraces, incised by more recent drainage.

Alluvial (*A*) and lacustrine (*L*) regolith

Depositional alluvial and lacustrine regolith (*A*, *L*) constitute just over 16% by area and account for 25% of regolith samples on WINNING POOL – MINILYA. Most alluvial material is in undivided channels and floodplains (*A1d*) of the Yannarie, Lyndon, and Minilya rivers, and consists of unconsolidated to semi-consolidated cobbles, gravel, sand, silt, clay, and calcrete clasts. Dendritic drainage channels are common in the more high-energy eastern terrains, whereas broad floodplains dominate the low-energy western part of the project area, especially in the vicinity of Minilya Station.

Older alluvial material commonly flanks contemporary drainage. It typically contains valley calcrete, and is in places silicified and incised (*A2k*). The majority of the unit is exposed in the upper reaches of the Yannarie and Lyndon rivers, where the material obscures the crystalline rocks of the Gascoyne Complex. Further along the Yannarie River (on EDMUND), calcrete duricrust and valley calcrete is abundant, and associated with carbonate-rich rocks of the Edmund Group (Pye et al., 1998).

Lacustrine regolith (L_l) from Lake MacLeod dominates the southwest portion of WINNING POOL – MINILYA. The surface of the lake is commonly dry except when the Gascoyne, Minilya, and Lyndon rivers flood. Two small, permanent ponds with normal oceanic salinity on the western side of the lake, may have a subsurface connection with the ocean (Hocking et al., 1987).

Other lakes and large playas (L_l) occupy low areas around Winning Station, east of the Gnargoo Range, and in the northwest near Coral Bay. Small interdunal playa lakes (L_l) are also mapped from the eolian dunefields of central WINNING POOL – MINILYA.

Bedded evaporitic deposits (L_ge) border the lakes in the southwest and contain gypsum, anhydrite, and halite. Dune and playa terrains (L_m) bound the lakes in the central north and commonly contain partly consolidated sand with less common silt, clay, and gravel.

Eolian (*E*) and sandplain (*S*) regolith

Eolian (*E*) and sandplain (*S*) regolith are the most common units on Winning Pool – Minilya, occupying over 36% by area and accounting for 35% of samples. Eolian regolith has been subdivided into five types and sandplain regolith into three types, based on site observations, lithology, and sandplain morphology.

Eolian regolith, forming longitudinal dunes (E_l), dominates the central and western parts of the project area, and is characterized by extensive longitudinal dunes that commonly overlie carbonate-rich duricrust. This eolian quartz sand ranges from orange to red-brown and becomes partly calcareous towards the coast (Hocking et al., 1985). In the northwest, the eolian unit (E_l) occupies a shallow depression that extends northwards from Lake MacLeod along the west of the Giralia Range. In the southwest, the eolian unit (E_l) is perched, probably on carbonate-rich duricrust above the Trealla Limestone. Longitudinal dune density and height increase significantly on the western side of the Gooch Range, suggesting much of the sand is locally derived in this area from the quartz-rich strike-ridges. Dune orientation progressively swings from near north–south along the coast to southeast–northwest in the vicinity of Gooch Range, both probably parallel with the strong prevailing wind directions of the Late Pleistocene (Hocking et al., 1985). In the flat-lying and topographically low Minilya and Lyndon river floodplains, longitudinal dune terrain (E_l) grades into mixed longitundinal dune, sheetwash, and playa terrain (E_p).

Beaches, beach ridges, and coastal dunes (*Ek1*) and older degraded coastal dunes on calcarenite (*Ek2* and *Ek3*) composed mostly of calcareous sand are present in the coastal zone. Recent dunes along the current shoreline are commonly parabolic (*Ek1*), whereas the older, degraded, inland dunes are dominantly northerly trending longitudinal (*Ek2* and *Ek3)*. The oldest unit (*Ek3*) partly corresponds with the undifferenіated eolian and marine deposits of the Bundera Calcarenite (Hocking et al., 1985, 1987) and forms in the northwestern part of Winning Pool – Minilya in the vicinity of Airey and Stanley hills.

Undulating sandplain (S_u) is distributed throughout central Winning Pool – Minilya. It is characterized by broad undulations, minor dunes, and even vegetation cover, all of which give an impression of relative landform stability. The unit probably sits on calcareous or siliceous duricrust, and is elevated relative to mixed sandplain, sheetwash, and playa terrain (S_p), which occupies topographic lows (breached duricrust) of the central north and of the Minilya and Lyndon river floodplains.

Heterogeneous sandplain (*Sl*) consists of mixed sand, silt, and clay of eolian, residual, colluvial, and sheetwash origin and on Winning Pool – Minilya, is typically gradational between sandplain (*E* and *S*) and low-gradient slope deposits (*W*) or shallow subcrop (*X*). North of Wandagee Station, heterogeneous sandplain (*Sl*) commonly forms in interdune pavements within the eolian sand cover, with the unit thinly covering bedrock or carbonate-rich duricrust.

Old coastal (*K*) and marine (*M*) regolith

Old coastal and offshore marine regolith (*K*, *M*) constitute nearly 2% by area and old coastal regolith accounts for under 2% of samples on Winning Pool – Minilya. Old coastal material (*Kk*) is dominantly carbonate rich and derived from calcrete, eolian sandstone, shoreline conglomerate, coralgal reefs, beach sand, and shelly limestone and sandstone. The unit largely corresponds with the Bundera Calcarenite (Hocking et al., 1985, 1987) and outcrops along the coast and around the margins of Lake MacLeod. Offshore marine regolith (*Mk*) is associated with the living corals of the Ningaloo Reef tract.

Discussion

The regolith-materials map (Plate 3) shows central Winning Pool – Minilya is dominated by eolian sand (E_l), much of which is probably derived from the sandstones of the Gooch Range (*Xqs*). The large, longitudinal dunes probably overlie carbonate-rich duricrust (calcrete; *Rk*) that is locally exposed in interdune pavements and drainages. Hocking et al. (1985) suggested the formation of the duricrust took place in an arid phase of the Pliocene and major eolian reworking of surface sand and the formation of sizeable longitudinal dunes in an arid phase of the Late Pleistocene.

To the north and west, the carbonate-rich duricrust has been breached. In these relatively low-lying areas, eolian material (E_l) grades into mixed eolian, sandplain, sheetwash, and playa terrain (E_p, S_p) interleaved with broad outwash floodplains of the Lyndon and Minilya rivers (*A1d*). Hocking et al. (1985) suggested calcrete duricust was breached in a humid phase of the Pliocene with widespread deposition of low-gradient sheetwash material (*W2*) and outwash floodplain material (*A1d*) continuing through to the Late Pleistocene.

To the east are strike ridges of the Gooch Range interspersed with flat to gently undulating terrain and mesas capped with either silcrete (*Rz*) or ferricrete (*Rf*). This episode of silcrete and ferricrete formation on Winning Pool – Minilya probably took place in the Oligocene, as the older Eocene Giralia Calcarenite and Merlinleigh Sandstone are ferruginized whereas the younger Miocene Trealla Limestone is not (Hocking et al., 1985).

In the central south, no resistant rocks are present and low etchplains have formed producing exposed-regime regolith (*Xls, Xrs*) of the Byro Group, with any previous calcrete, ferricrete, or silcrete duricrust being completely stripped (Hocking et al., 1985).

Exposed-regime regolith (*Xgp, Xgm*) of the Gascoyne Complex dominates the eastern margin of Winning Pool – Minilya and includes northerly trending exposed-regime regolith over quartz veins (*Xq*) — which probably coincide with fault and shear zones — and north to northeasterly trending dolerite dyke swarms. Valleys within the Gascoyne Complex are commonly filled with older, calcrete-dominated, alluvial material (*A2k*), which has been partly silicified and incised by recent drainage (*A1d*). On Winning Pool – Minilya and Edmund, valley calcrete and calcrete duricrust are spatially associated with carbonate-rich rocks of the Edmund Group.

Western parts of the project area are characterized by the Giralia and Saltmarsh Anticlines, which include exposed-regime regolith derived from Cretaceous and Tertiary sedimentary rocks (*Xzc, Xrs, Xkc,* Xk_gc), overlain by Pleistocene marine and eolian deposits (*Ek1, Ek2, Ek3, Kk*). The main phase of compressional tectonism that generated the anticlines was during the Middle Miocene, in conjunction with the reactivation of pre-existing faults (Crostella and Iasky, 1997). Warping continued into the Quaternary (van de Graaff et al., 1976) and may still be continuing (Hocking et al., 1985, 1987). Much of the area contains significant carbonate-rich duricrust (*Rk*), although the crest of the Giralia Anticline has been breached, producing exposed-regime regolith of the deeply weathered Gearle Siltstone (*Xrs*) and exposed-regime regolith of the commonly silicified Windalia Radiolarite (*Xzc*).

Lacustrine regolith (L_l) from Lake MacLeod formed from the barring of a marine embayment by eolian dunes. During most of the Pleistocene, the lake was open to the sea at both ends and normal oceanic conditions prevailed, as indicated by the presence of fossil coral reefs (Denman and van de Graaff, 1977). The barrier at the northern end may have resulted from limited uplift associated with the formation of anticlines northeast of Warroora Station, and an increased rate of dune activity during the Late Pleistocene arid phase (E_l, *Ek2, Ek3*). The southern end of the lake, on Quobba, was probably open until 5000 years BP, when prograding beach ridges blocked the passage, transforming Lake MacLeod into an evaporite basin (Hocking et al., 1987).

Chemical analysis and quality control

One-thousand, one hundred and ninety-nine regolith samples were analysed in six separate batches by Amdel Laboratories, Wangara, Perth. These batches consisted of 218 sheetwash samples, 485 stream-sediment samples, 24 soil samples, 454 sandplain samples, and 18 lake-sediment samples. In addition, 114 laboratory replicates (i.e. aliquot of the same pulp) and 31 analyses of three GSWA standards were carried out in the six batches. The analysed size fraction was <2 mm to >0.45 mm, which has been used in all regional geochemical mapping programs except Ajana (Sanders and McGuinness, 2000) where the <2 mm fraction was analysed. Twenty-eight samples with relatively high concentrations of one or more analytes were re-analysed by Genalysis Laboratory Services, Maddington, Perth. Fourteen of these samples were further analysed by Genalysis and Amdel to investigate within-sample chemical variations. Thirteen samples were submitted to Genalysis to compare the Zr concentration in the <2 mm fraction and <2 mm to >0.45 mm fraction. This was in response to the relatively high Zr concentrations encountered in the <2 mm fraction on Ajana (Sanders and McGuinness, 2000).

The results of quality control are presented as a series of digital tables (in .CSV format) in Appendix 4. A discussion of sample preparation, analytical techniques, and quality-control procedures is presented in Appendix 3. Final analytical data are presented as a digital file (WINMIN.CSV) and pictorially in Figures 6–52.

Standard and replicate analysis

For the analytical techniques carried out at Amdel (IC3M, IC4M, IC3E, IC4, and FA3; Appendix 3), a total of 62 blank analyses and 134 analyses of Amdel standards (OREAS_42P, OREAS_43P, OREAS_44P, PM7, and PM8) were carried out, spread across the six batches. These data are supplied as digital tables on the accompanying disk, along with the analyses of three GSWA standards (IQC47, IQC45, and IQC42).

Analyses of blanks, GSWA standards, Amdel standards, and replicates generally complied with the quality-control requirements set out in Appendix 3. The three GSWA standards were acceptable in terms of precision and, for most components, acceptable in terms of accuracy compared to consensus values reported by Morris (2000). Exceptions are discussed below.

For the IC3M technique (App4_1.CSV), precision and accuracy were acceptable. One control blank for W in batch 6 of 7 ppm was rechecked by the laboratory and found to be a reporting error. In batches 4 and 6, two lower than expected values were encountered for Sb in the GSWA standard (IQC45; 46.4 and 60.4 ppm). The consensus Sb value for this standard, as reported by Morris (2000), is 138 ppm, although the standard deviation is large, indicating difficulty in obtaining precision. All other analyses of this standard reported Sb values close to those of Morris (2000).

For the IC4M technique (App4_2.CSV), precision and accuracy were acceptable except for a replicate Zr analysis of GSWA 171160 (120 ppm and 59 ppm). This poor reproducibility could reflect the resistance of zircon.

Sample dissolution problems could account for the poor precision of Cr in GSWA standard IQC42 (method IC3E, App4_3.CSV). Values range from 910 to 2170 ppm with an average concentration of 1273 ppm ($n = 7$). As the consensus value is 1755 ppm (Morris, 2000), this suggests that resistant chromite was incompletely dissolved in most analyses.

Results for the IC4 technique (App4_4.CSV) were acceptable apart from replicate loss on ignition (LOI) and total values for GSWA 170879 (LOI — 40.4 and 26.5%; Total — 99. 47 and 86.12%). It appears that not all volatile species have been included in the analysis, leading to a low total. The original analysis, which is reported in the digital data file (WINMIN.CSV), is acceptable.

Gold, Pt, and Pd were analysed using lead-collection fire-assay fusion with an atomic absorption spectroscopy (AAS) finish (FA3 technique; App4_5.CSV). Reproducibility was poor for replicates of all three elements at low concentrations approaching the detection limit (1–3 ppb). Analysis of GSWA and Amdel standards with higher level concentrations (PM7, PM8, IQC47, IQC45, and IQC42) were acceptable, although one Pt concentration in the IQC47 standard from batch 5 was higher than expected (14 ppb). The consensus value of Morris (2000) is 5 ppb, and all other analyses of this standard reported Pt values close to these levels.

Repeat analysis of samples with high analyte concentrations

Twenty-eight samples with relatively high concentrations of one or more analytes were re-analysed by Genalysis Laboratory Services. Where discrepancies were found between the Amdel and Genalysis determinations, samples were resubmitted to both laboratories for further review. Fourteen such samples were further analysed investigating various size fractions, and the composition of archives and pulps. Results of all repeat analyses are presented as digital tables in Appendix 4 (App4_6.CSV).

After multiple analyses, reproducibility was generally satisfactory between laboratories. For some elements, however, some analyte concentration issues were not resolved, and these are discussed in Table 3 under their GSWA numbers.

Discussion

High values encountered in the first round of analysis by Amdel were checked by re-analysis of both pulp and archive material. In general, high values were reproducible in pulp but not always reproducible in archive material. This suggests a number of possibilities:

- Inhomogeneous distribution of some components (particularly Au, Pt, Pd, and Sn) within and between the analytical and archive samples.
- Low-level cross contamination of some pulp material.
- Difficulties in analytical precision at levels approaching detection limits.
- Difficulties in the analysis of components resistant to complete dissolution.

There may be geologically reasonable grounds for the weakly elevated Pd and Pt concentrations in GSWA 170283 and 170388 from the area between Pleiades Hills and Nyang Station, and GSWA 171115 from the Giralia Anticline area. Other nearby samples also have weakly elevated Pd and Pt concentrations, suggesting some lithological control (Figs 35 and 36). The failure to reproduce values in either the pulp or archive may be due to inhomogeneous distribution of Pd and Pt in the samples or the general lack of precision at levels approaching detection or both. The Pt concentration in GSWA 170388 may also be influenced by a weak 'analytical tail' (see **Differences within and between batches**).

The difficulty in obtaining acceptable reproducibility for GSWA 170330 (from the Gooch Range area) may be due to bimodal grain size distribution of the sample, resulting in insufficient material for multiple determinations of the analytical size fraction (<2 mm to >0.45 mm). Subsequent analyses of the sample may have been undertaken on dominantly finer or coarser material with spurious results. The most reliable determinations were from analysis of archive material by Genalysis and these values were incorporated in WINMIN.CSV, with the exception of Au for which the original Amdel value is reported.

GSWA 170428, 170533, 170534, and 170535, from mixed eolian sand and calcrete terrain in the Burnerburnung Hill area, all contain low Au concentrations (Fig. 18). The spatial association of these samples and their location in calcrete-dominated interdune pavements, above the inferred location of the Cardabia Transfer Zone, may provide geologically reasonable grounds for the Au levels. Gold values are reproducible in pulp but not always reproducible in the archive. Furthermore, in the original analytical run, GSWA 170532, 170533, 170534, and

Table 3. Samples for which analyte concentration issues are not resolved

Sample	*Comments*
170283	poor Pd reproducibility, analytical (4 ppb), pulp and archive (<dl)
170330	poor reproducibility for a number of major and trace elements (e.g. SiO_2, Ba)
170388	poor Pt reproducibility, analytical (4 ppb), archive (<dl)
170428	poor Au reproducibility, analytical (19 ppb), pulp (45 ppb), archive (1, 1, 2, and 7.2 ppb)
170460	poor Au reproducibility, analytical (8 ppb), pulp (18 ppb), archive (<dl, 1, 2.5, and 4 ppb)
170533	poor Au reproducibility, analytical (4 ppb), pulp (7 ppb), archive (2 ppb)
170534	poor Au reproducibility, analytical (3 ppb), pulp (4 ppb), archive (1 ppb)
170535	poor Au reproducibility, analytical (3 ppb), pulp (7 ppb), archive (<dl)
170639	poor Sn reproducibility, analytical (18 ppm), pulp (23 ppm), archive (<dl, 0.8, and 1.3 ppm)
170717	poor Sn reproducibility, analytical (18 ppm), pulp (20 ppm), archive (0.7 and 0.8 ppb)
170944	poor Sn reproducibility, analytical (11 ppm), pulp (16 ppm), archive (<dl, 0.8, and 1.2 ppm)
171100	poor Au reproducibility, analytical (4 ppb), pulp (5 ppb), archive (<dl)
171109	poor Sn reproducibility, analytical (15 ppm), pulp (17 ppm), archive (0, 0.7, and 0.8 ppm)
171115	poor Pd reproducibility, analytical (4 ppb), pulp (<dl)

NOTE: dl: detection limit

170535 follow an Amdel standard (PM7, Au = 98 ppb), hence there is the possibility of low-level cross contamination of these pulps, although it is more likely Au is inhomogeneously distributed in these samples. This is further supported by the typically bimodal nature of the material, with significant fine eolian sand intermixed with fine carbonate-coated gravels. Inhomogeneous distribution of Au may also explain poor reproducibility in GSWA 170460 (northeast of Lyndon Station), where elevated Au is repeatable in the pulp, but has lower levels in the archive. However, the Au analysis of GSWA 171100, from coastal areas northeast of Gnaraloo, is less well-supported on geological grounds. Here, the weakly elevated Au value is not associated with other Au-bearing samples (Fig. 18) and the analysis of GSWA 171100 follows an Amdel standard (PM8, Au = 41 ppb). This suggests that low-level cross contamination of the pulp is possible, although the poor reproducibility could also reflect lower precision at levels approaching detection. Contamination of these samples during milling (which would result in elevated Au in the pulp) is considered unlikely as high Au-bearing samples (such as standards) are all seperately premilled. Furthermore, contamination imparted by the milling process would most likely form a series of elevated Au values (‘analytical tail’); however, the highest Au-bearing samples (GSWA 170428 and 170460) occur in isolation in the analytical series.

GSWA 170639, 170944, and 170717 all contain elevated Sn values, which are reproducible in pulp but not in archive. This suggests inhomogeneous distribution of Sn (e.g. cassiterite), incomplete dissolution of cassiterite, or contamination. GSWA 170639 and 170944 were analysed after GSWA standard IQC47 and Amdel standard OREAS_44P respectively, although both these standards only contain low Sn concentrations, ruling out cross contamination. Further evidence of the difficulty in obtaining reproducible Sn values are shown from GSWA 170993, 171010, 171011, and 171080, which were submitted to Genalysis for checking of other elevated components. Tin was analysed following sodium peroxide fusion (DX/MS) rather than mixed acid digest (used in Amdel’s IC3M technique). Higher concentrations were consistently recorded following sodium peroxide fusion, highlighting the issue of incomplete dissolution.

Differences within and between batches

Although standard and blank values are acceptable for each batch of data, some within- and between-batch differences are possible for analytes at low concentrations, including Ag, Pt, and Sn. Batch 2 blank and standard values are acceptable, but background concentrations for Pt appear 1–2 ppb higher for GSWA 170384 to 170399. GSWA 170384 follows GSWA standard IQC42 (Pt = 9 ppb) in the analytical run and it is possible that an ‘analytical tail’ exists at lower levels, as has been reported from other regolith geochemical mapping programs (Morris et al., 2000b). Most of the GSWA samples in the range 170384–170399 are from the area between Pleiades Hills and Nyang Station, where dominantly Cretaceous rocks outcrop above shallow crystalline basement (Fig. 36). This area also coincides with a gravity anomaly (Geological Survey of Western Australia, 1999), which, in conjunction with other nearby slightly elevated Pt samples (batch 1 — GSWA 170093 and 170098), may give a geologically valid reason for the existence of these higher values. Nonetheless, care should be taken when interpreting Pt or any other element data at low levels.

For both Ag and Sn in regolith on WINNING POOL – MINILYA (Figs 16 and 42), the highest values are recorded roughly west of the Wandagee Fault, with consistently lower values recorded to the east. Due to the progression of sampling from east to west over the project area, most samples east of the Wandagee Fault were analysed in batches 1, 2, and 3, whereas most samples to the west were analysed in batches 4, 5, and 6. This leads to the possibility that the differences in concentrations from east to west are due to low-level batch effects. However, interpretation of these analytes, in conjunction with the regolith-materials map (Plate 3), suggests there may be geologically valid reasons for higher values in western parts (see **Regolith chemistry**).

Size fraction analysis

Thirteen samples with relatively high Zr concentrations from western parts of WINNING POOL – MINILYA were resubmitted to Genalysis to compare concentrations of Zr in the <2 mm fraction to that of the <2 mm to >0.45 mm fraction. This was in response to the relatively high Zr concentrations found in the <2 mm fraction on AJANA (Sanders and McGuinness, 2000), and to test whether Zr was preferentially enriched in the finer portions of the sample (i.e. <0.45 mm). The data are presented as digital tables in Appendix 4 (App4_6.CSV).

Concentrations of Zr, Ce, La, Nb, Ta, and Th were similar between the two size fractions, suggesting there is little preferential enrichment in the fine component (<0.45 mm), compared with the <2 mm to >0.45 mm size fraction. Some variation exists in the Nb concentrations but this may be attributed to incomplete dissolution of resistate phases, rather than grain-size control.

Element-distribution maps

The concentration of various components is shown as a series of spot-concentration maps in relation to simplified geology (Figs 6–52). These maps are ordered in terms of major-element oxides (including LOI), then alphabetically by trace elements. Silica is not presented as values are consistently high over the project area. On these maps, the circle diameter is proportional to concentration with star symbols indicating concentrations greater than 2.5 standard deviations above the mean. Thus, stars correspond to values that lie either at the end of, or beyond, a normal distribution curve and are designated as anomalous. The exact element value can be obtained by identifying the GSWA number from the sample-site location plan (Plate 1) and then referring to the digital datafile (WINMIN.CSV). Copies of the 1:250 000-scale element-concentration maps are available from the DME's information centre.

Regolith chemistry

The combined effects of bedrock composition and physical and chemical weathering largely control the chemistry of regolith. Bedrock control is important on WINNING POOL – MINILYA owing to the variety of rock types present, which include crystalline rocks of the Gascoyne Complex and Phanerozoic sedimentary rocks. Input from eolian, alluvial, and coastal processes (both previously and currently active within the project area) can also affect the composition of regolith.

Samples with anomalous concentrations of an analyte (or analytes) are listed in Table 4. Data in this table include a simplified geological code, locational data, regolith code, type of sample media, and list of anomalous elements.

The following discussion of spot-concentration maps (Figs 6–52) is made in relation to the simplified geology (Plate 1) and includes comments on the possible control exerted by regolith-forming processes (Plate 3). The terms high, moderate, and low are used in relation to the concentration of an element relative to other values in the project area.

Gascoyne Complex metamorphic rocks and granitoids

In the southeast of WINNING POOL – MINILYA, exposed-regime regolith over rocks of the Gascoyne Complex (dominantly *Xgp* and *Xgm*) has relatively high concentrations of Na_2O with some scattered samples having moderate to high TiO_2, Fe_2O_3, MgO, Co, Sc, and V. Elevated Na_2O concentrations in the southeast probably reflect the type and proportion of plagioclase in granitoids of the Minnie Creek Batholith, whereas high concentrations of TiO_2, Fe_2O_3, MgO, Co, Sc, and V indicate that dolerite dykes and amphibolites in this area also exert a strong influence on regolith chemistry. Similar relationships were recorded by Sanders et al. (1997) in regolith over the Minnie Creek Batholith on MOUNT PHILLIPS. In the northeast of the project area, high Na_2O, Be, Bi, Ta, and W values in regolith coincide with an area of northwesterly trending faults, overlain by exposed-regime regolith (*Xgp*, *Xgm*) largely derived from granitoid and gneissic rocks with minor zoned pegmatites and schist (Hocking et al., 1985). Other relatively high Be, Bi, and Ta values are west of Lyndon Station (where Middle Devonian – Lower Carboniferous sedimentary rocks outcrop in half grabens within the Gascoyne Complex) and south of Lyndon Station near the Jailor Bore uranium prospect (see **Recorded mineralization and economic geology**). Near both these areas, regolith derived from northerly trending quartz veins (*Xq*) traces major basement faults. Other elements with moderate to high concentrations in regolith over the Gascoyne Complex include, Al_2O_3, K_2O, Ce, Cu, Ga, La, Nb, Pb, Rb, and Th.

Edmund Group

Regolith samples are limited in regolith over rocks of the Edmund Group exposed in the Mangaroon Syncline. In the vicinity of Coria Springs and Winning Hill, regolith samples have relatively high concentrations of TiO_2, Fe_2O_3, MnO, MgO, Co, Cu, Ni, Pb, Sb, Sc, V, Y, and Zn. This association indicates that regolith chemistry is strongly influenced by dolerite sills and black shales within the Mangaroon Syncline. Pye et al. (1998) described a similar suite of elevated components in regolith derived from extensively developed dolerite and black shale in the Edmund Group on EDMUND. Exposed-regime regolith (*Xqs*) near Coria Springs has the highest concentrations of Cu and Zn for WINNING POOL – MINILYA and relatively high Pb concentrations, reflecting nearby base metal anomalism in carbonates, ironstones, and shales of the Irregully and Kiangi Creek Formations (see **Recorded mineralization and economic geology**). The relatively high values of these elements in regolith near Winning Hill suggest further base metal anomalism is present along the Mangaroon Syncline.

Middle Devonian – Lower Carboniferous sedimentary rocks

Apart from SiO_2, analytes are generally low in concentration in regolith derived from quartz- and carbonate-rich, Middle Devonian – Lower Carboniferous sedimentary rocks (*Xqs*, *Xkc*). High SiO_2 and low CaO values in regolith indicate most regolith material is derived from quartz-rich rocks or silcretes (*Rz*) that cap the unit. Moderately high concentrations of TiO_2, Ce, La, Th, and Zr reflect the regolith chemistry of the adjacent Gascoyne Complex and may be of detrital origin. Fault-bounded areas within the Gascoyne Complex yield an assortment of mafic- and pegmatite-associated elements in regolith with moderate to high concentrations of Be, Bi, Co, Cr, Cu, Ta, and W. These high values typically coincide with exposed-regime regolith associated with northerly trending quartz veins (*Xq*) and metamorphosed dolerite or gabbro (*Xmm*). Lead is in moderate concentration in southern parts of this area and may be associated with carbonate-rich, exposed-regime regolith (*Xkc*) of the Gneudna Formation and Moogooree Limestone, which have been the subject of base metal exploration in the past (see **Mineralization potential**).

Lyons Group and Callytharra Formation

There are moderate concentrations of TiO_2, Al_2O_3, Ce, Co, Ga, La, Pb, Y, and Zr in regolith overlying the Lyons Group and Callytharra Formation. There are similar concentrations of a number of these elements in regolith over other units in the southeast of the project area, including crystalline rocks of the Gascoyne Complex and Middle Devonian – Lower Carboniferous sedimentary rocks. This suggests that Phanerozoic sedimentary rocks that outcrop in eastern parts of the project area are dominated by detritus derived from the Gascoyne Complex. High concentrations of other components are in two areas of intense faulting: the first 20 km east of

Table 4. Samples with individual or multiple elements with anomalous concentrations

GSWA	*MGA coordinates easting*	*northing*	*Batch*	*Regolith code*	*Geological code*	*Sample medium*	*Analytes with anomalous concentrations*
170005	337551	7369983	1	*Xgp*	*Ᵽg*	Stream	Co, Pb
170007	338327	7359348	1	*Xgp*	*Ᵽg*	Stream	TiO_2, V
170009	329937	7351687	1	*Cgp*	*Ᵽg*	Stream	Bi, Ce, La, Th
170023	263735	7359873	1	*Xrs*	*P*	Stream	Fe_2O_3, MnO, Co, Pb
170024	260686	7370404	1	*Xrs*	*P*	Stream	MnO
170026	248477	7364859	1	*Xrs*	*P*	Stream	MnO, P_2O_5, Ce, Co, La, Pb, Y
170027	249245	7359030	1	*W1d*	*P*	Stream	Y
170038	343195	7384755	1	*Xgm*	*Ᵽm*	Stream	K_2O
170039	341491	7394926	1	*Xqs*	*ᵽME*	Stream	TiO_2, MnO, Co, Cu, Sc, V, Zn
170043	343085	7428534	1	*A1d*	*Ᵽm*	Stream	Be, Ta
170044	346115	7439282	1	*A1d*	*Ᵽg*	Stream	W
170045	340794	7442085	1	*Xgm*	*Ᵽm*	Stream	W
170046	341072	7451948	1	*Xgm*	*Ᵽm*	Stream	Bi
170048	330309	7454466	1	*Xqs*	*ᵽME*	Stream	W
170054	330657	7432366	1	*A1d*	*ᵽME*	Stream	TiO_2
170059	326380	7373175	1	*Xgp*	*Ᵽg*	Stream	Be, Nb, Ta, Th
170066	314023	7365450	1	*A1d*	*DC*	Sheetwash	Zr
170067	322436	7366142	1	*A1d*	*Ᵽg*	Stream	K_2O, Rb
170070	314323	7382885	1	*Cl*	*Ᵽg*	Stream	K_2O, Rb
170109	266024	7358205	1	*A1d*	*P*	Stream	Cr
170111	256715	7370492	1	*Xrs*	*P*	Stream	P_2O_5
170113	249348	7362136	1	*A1d*	*P*	Stream	MnO, Co, Pb, Y
170135	256548	7373781	1	*A1d*	*P*	Stream	Li
170136	249652	7373239	1	*Xrs*	*P*	Stream	P_2O_5, Li, Ni, Zn
170138	249743	7389549	1	*A1d*	*P*	Sheetwash	Li
170145	290868	7399005	1	*A1d*	*KWI*	Stream	Cr
170149	329472	7364102	1	*Xgp*	*Ᵽg*	Stream	Na_2O
170158	312771	7378666	1	*A1d*	*Ᵽg*	Stream	Bi, Cr
170166	281059	7413396	1	*A1d*	*KWI*	Stream	Fe_2O_3, Cr, V
170192	316427	7382224	1	*A1d*	*Ᵽg*	Stream	Rb
170205	341867	7355709	2	*Xgp*	*Ᵽg*	Stream	Na_2O
170218	294462	7373579	2	*E_l*	*KWI*	Stream	Th
170227	259376	7362924	2	*Xrs*	*P*	Stream	Al_2O_3, P_2O_5, Ce, Cu, Ga, La, Li, Nb, Sc, Th, Y, Zn
170243	341674	7426105	2	*Xgp*	*Ᵽg*	Stream	Th
170247	338227	7451910	2	*Xgm*	*Ᵽm*	Stream	Bi
170253	333840	7436892	2	*Xgm*	*Ᵽg*	Sheetwash	Be
170274	306768	7386264	2	*A1d*	*Ᵽg*	Sheetwash	Be, Ta
170283	289480	7407641	2	*A1d*	*KWI*	Stream	Pd
170307	336681	7355297	2	*Xgp*	*Ᵽg*	Stream	TiO_2, Na_2O
170317	274083	7381984	2	*E_l*	*PL*	Stream	SiO_2
170318	272527	7374558	2	*Xqs*	*P*	Stream	SiO_2
170321	270547	7378026	2	*E_l*	*P*	Sandplain	SiO_2
170323	252970	7375992	2	*Xrs*	*P*	Stream	As, Ba, Ni
170328	269129	7386214	2	*Xqs*	*P*	Stream	SiO_2
170329	266675	7390086	2	*E_l*	*P*	Sheetwash	Zr
170342	345366	7447915	2	*Xgp*	*Ᵽg*	Stream	Bi
170345	321054	7452568	2	*A1d*	*Ᵽm*	Stream	Th
170349	324515	7440662	2	*A2k*	*Ᵽg*	Stream	Ta
170359	302148	7426383	2	*Xgp*	*Ᵽg*	Sandplain	K_2O
170376	327716	7379738	2	*Xgp*	*Ᵽg*	Stream	Rb
170377	318052	7389896	2	*Xgp*	*Ᵽg*	Sheetwash	Pb
170382	305480	7422775	2	*A1d*	*Ᵽg*	Stream	Ce, La, Th
170385	282280	7421990	2	*S_u*	*KWI*	Sandplain	Pt
170388	294227	7425915	2	*E_l*	*Ᵽg*	Sandplain	Pt
170396	282283	7454353	2	*E_l*	*KWI*	Sandplain	Pt
170402	340949	7378059	3	*W1d*	*Ᵽg*	Stream	Rb
170407	336616	7347786	3	*Xmm*	*Ᵽg*	Stream	Al_2O_3, MgO, Co, Cu, Ni, Sc
170409	320522	7345669	3	*Cl*	*Ᵽg*	Stream	K_2O, Rb
170417	290395	7386058	3	*E_l*	*KWI*	Sandplain	SiO_2
170426	253501	7372517	3	*Xrs*	*P*	Stream	P_2O_5, As, Co, Cu, Ni, Pb, Y, Zn
170428	250356	7386379	3	*Rk*	*P*	Sheetwash	Au
170443	337522	7425451	3	*A1d*	*Ᵽm*	Stream	MnO
170447	333930	7451835	3	*Cl*	*Ᵽm*	Stream	Bi, W
170448	324229	7450142	3	*Xgm*	*Ᵽm*	Stream	TiO_2
170452	332532	7442137	3	*Xgp*	*Ᵽg*	Stream	Ta
170453	332277	7433561	3	*Xgm*	*Ᵽm*	Stream	Be
170456	332717	7410318	3	*A1d*	*ᵽME*	Stream	Cu
170460	330375	7394372	3	*Xgm*	*Ᵽm*	Sheetwash	Au

Table 4. (continued)

GSWA	*MGA coordinates easting*	*northing*	*Batch*	*Regolith code*	*Geological code*	*Sample medium*	*Analytes with anomalous concentrations*
170484	313466	7391118	3	*Xgp*	*Ƥg*	Sheetwash	K_2O, Rb
170513	257530	7366831	3	*A1d*	*P*	Stream	As, Pb
170521	291510	7357005	3	*A1d*	*PL*	Stream	As
170533	254051	7382451	3	E_l	*P*	Lake	Au
170536	265989	7386175	3	E_l	*P*	Sandplain	SiO_2
170544	334703	7375025	3	*Xgp*	*Ƥg*	Stream	Be, Bi
170551	305523	7362527	3	Xls_g	*PL*	Stream	Zr
170567	315566	7415340	3	*A1d*	*Ƥg*	Stream	K_2O
170577	312440	7438949	3	*A1d*	*Ƥm*	Stream	Ag
170580	324792	7425004	3	*Xgm*	*Ƥm*	Stream	TiO_2
170597	249445	7442149	3	*W1d*	*KWI*	Sandplain	U
170599	256288	7443634	3	*A1d*	*KWI*	Stream	Fe_2O_3, Mo, Sb, Se, U, V
170614	256610	7439103	4	*A1d*	*KWI*	Stream	Fe_2O_3, As, Cr, Cu, In, Mo, Sb, Se, U, V
170623	258213	7430235	4	S_p	*PL*	Sandplain	Te
170639	230239	7385810	4	E_l	*KWI*	Sandplain	Sn
170671	184738	7349443	4	*A1d*	*Qm*	Soil	Al_2O_3, MgO, Na_2O, Ce, Ga, La
170676	181988	7386237	4	L_ge	*Qm*	Soil	MgO, S, Sr
170678	174743	7398457	4	*Xkc*	*Czn*	Sheetwash	Zr
170691	186469	7406114	4	*A1d*	*Qm*	Sheetwash	S
170696	194006	7369831	4	*A1d*	*Czn*	Soil	Ga
170699	170461	7354286	4	L_ge	*Qm*	Lake	Sr
170704	252718	7439386	4	*A1d*	*KWI*	Stream	Ni, Pt, Sb
170717	211020	7444367	4	*A1d*	*KWl*	Stream	Sn
170718	207354	7451174	4	*Xzc*	*KWl*	Stream	Ni, Zn
170723	190688	7431026	4	*A1d*	*Czn*	Stream	Sb
170727	226471	7429320	4	*W1d*	*KWI*	Sheetwash	Sn
170731	202253	7425906	4	*Xrs*	*KWl*	Stream	Ba
170756	202500	7369847	4	S_p	*Czn*	Lake	Al_2O_3, Ga
170760	185547	7346349	4	L_ge	*Qm*	Lake	MgO
170761	188633	7350172	4	*Kk*	*Qm*	Sheetwash	Al_2O_3
170767	238785	7349480	4	*Xrs*	*P*	Stream	Zn
170780	242372	7371031	4	*Xls*	*P*	Stream	Al_2O_3, Ce, Ga, La, Li, Nb, Sc
170785	166000	7354349	4	*Kk*	*Qm*	Sheetwash	Sr
170792	169939	7390626	4	*Xkc*	*Czn*	Sheetwash	Zr
170813	238207	7442243	5	L_l	*KWI*	Stream	Fe_2O_3, P_2O_5, Cr, Se, U, V
170814	245184	7441844	5	*Sl*	*KWI*	Sheetwash	Cr
170816	253863	7442074	5	*A1d*	*KWI*	Stream	S
170837	246106	7378574	5	*Cq*	*P*	Sheetwash	Nb
170853	214270	7394262	5	S_p	*Czn*	Sandplain	TiO_2, Fe_2O_3, MgO
170867	198036	7370468	5	*A1d*	*Czn*	Soil	Sn
170869	180626	7354196	5	*Kk*	*Qm*	Soil	Sr
170871	178153	7350480	5	*Kk*	*Qm*	Soil	Sr
170872	185708	7352559	5	*A1d*	*Qm*	Stream	Al_2O_3, MgO, Na_2O, Ga, Li, Sc
170875	186777	7370346	5	*A1d*	*Czn*	Sheetwash	Te
170878	182851	7389829	5	L_ge	*Qm*	Soil	S
170879	182687	7397739	5	*Xkc*	*Czp*	Stream	CaO, LOI
170891	185842	7398368	5	L_ge	*Qm*	Soil	MgO, S, U
170894	194451	7378094	5	L_ge	*Czn*	Sheetwash	Ag, Nb
170901	209441	7448997	5	*A1d*	*KWl*	Stream	U
170903	196563	7442009	5	*Xkc*	*Czp*	Stream	CaO, LOI
170906	202423	7432975	5	*A1d*	*KWl*	Stream	Ba
170916	199360	7420515	5	*Cl*	*KWl*	Stream	Se
170917	199710	7416970	5	*Xkc*	*Czp*	Stream	CaO, P_2O_5, LOI
170928	258028	7406421	5	E_l	*P*	Stream	SiO_2
170944	241588	7413127	5	*W1d*	*KWI*	Stream	Au, Sn
170953	237974	7358239	5	*A1d*	*KWI*	Stream	Y
170958	210166	7362813	5	*A1d*	*Czn*	Stream	Nb
170961	234351	7362118	5	*A1d*	*KWI*	Stream	Ag
170963	244458	7365098	5	*A1d*	*P*	Stream	La, Y
170979	174362	7442559	5	*Ek2*	*Qm*	Sandplain	Sr
170982	185884	7442638	5	E_l	*Czn*	Sandplain	Ag
170987	186083	7402227	5	*A1d*	*Qm*	Sandplain	S
170993	182016	7358150	5	*Kk*	*Qm*	Sheetwash	Te
170995	154154	7374278	5	E_l	*Czn*	Sandplain	Ag
170997	166162	7390630	5	*Xkc*	*Czn*	Sandplain	Te
171005	210478	7441891	6	*Xrs*	*KWl*	Sandplain	Fe_2O_3, Mo, U, Zn
171011	192971	7434163	6	*A1d*	*Czn*	Stream	As, Ni, Sb, Te, V
171012	192725	7431183	6	*Xkc*	*Czn*	Stream	Sb

Table 4. (continued)

GSWA	MGA coordinates easting	MGA coordinates northing	Batch	Regolith code	Geological code	Sample medium	Analytes with anomalous concentrations
171013	202069	7429090	6	*A1d*	*KWl*	Soil	Ba, Mo
171021	191112	7426626	6	*A1d*	*Czn*	Sandplain	Sn
171022	190076	7417767	6	*Rk*	*Czn*	Lake	Zr
171080	182152	7394570	6	*Xkc*	*Czp*	Sheetwash	CaO, LOI, Cd
171083	178531	7418564	6	E_l	*Qm*	Sandplain	Cu
171100	154102	7366150	6	E_l	*Czn*	Sandplain	Au
171109	266736	7434364	6	*W1z*	*KWI*	Sandplain	Au, Sn
171111	203747	7446239	6	*Xrs*	*KWl*	Stream	Ba
171113	193306	7438646	6	*A1d*	*Czp*	Stream	Sb
171115	199864	7433058	6	*Cl*	*KWl*	Sheetwash	Pd
171116	206481	7436483	6	*Xrs*	*KWl*	Stream	Ba, Mo, Pd, Se
171121	234002	7430047	6	S_p	*KWI*	Sandplain	Ag
171125	201643	7422613	6	*A1d*	*KWl*	Stream	Ba, Se
171126	193708	7420446	6	*Xkc*	*Czp*	Stream	CaO, LOI
171127	201957	7418369	6	*Ck*	*Kt*	Stream	Te
171145	202671	7386087	6	E_p	*Czn*	Sandplain	Te
171153	170761	7347496	6	L_ge	*Qm*	Soil	S
171154	182336	7350921	6	*A1d*	*Qm*	Stream	Na_2O, Ce, Li, Nb
171161	240461	7347508	6	*W1d*	*P*	Stream	Se
171188	168872	7394272	6	*Rk*	*Czn*	Sandplain	Sr
171189	174378	7389757	6	*Xkc*	*Czn*	Sandplain	Zr
171190	176120	7384771	6	*Xkc*	*Czp*	Stream	CaO, LOI
171201	171909	7373451	6	*Xkc*	*Czp*	Stream	CaO, LOI

NOTE: Eastings and northings have been projected into MGA Zone 50 coordinates

Middalya Station, and the second in a 20 km zone north of Moogooloo Hill. In both areas elevated values for CaO and LOI can be related to exposed-regime regolith (*Xkc*) derived from limestones of the Callytharra Formation. Values for MnO and As are also relatively high. North of Moogooloo Hill, one sample contains high Ba and a number of samples have detectable Ag, Au, and Pd concentrations, although the latter values are close to the level of detection and must be interpreted with caution (see **Chemical analysis and quality control**).

Wooramel, Byro, and Kennedy Groups

Regolith over the southern portion of the Wooramel, Byro, and Kennedy Groups has high concentrations of several components. Regolith in northern areas is dominated by eolian sand (E_l) and most analyte concentrations have probably been diluted by SiO_2. Near Wandagee Station, regolith has elevated concentrations of Al_2O_3, Fe_2O_3, MnO, P_2O_5, As, Ce, Co, Ga, La, Li, Nb, Ni, Pb, Y, and Zn with modest Ba, Be, Cr, Cu, Sc, Th, and V. This area is dominated by carbonaceous and heterogeneous exposed-regime regolith (*Xrs*, *Xls*) derived from carbonaceous and pyritic shales and fine-grained sandstones and siltstones of the Byro Group. These lithologies are cut by numerous northerly trending faults, which extend along the eastern margin of the Wandagee Ridge. Sanders et al. (1998) recorded comparable elevated elements in similar lithologies of the Byro Group on GLENBURGH, which suggests this unit has acted as a regional-scale depositional centre for a wide range of materials. North of Wandagee Station, analyte concentrations decrease as exposed-regime regolith material gives way to mixed sandplain (*Sl*), carbonate-rich duricrust and calcrete (*Rk*), and longitudinal dune terrain (E_l). Some components, such as Al_2O_3, P_2O_5, Ce, Ga, La, Li, Nb, and Ni, remain relatively high in regolith up to 20 km north of Wandagee Station, indicating that bedrock is either near surface or has been reworked as overlying carbonate-rich duricrusts and calcretes (*Rk*). This area of mixed regolith types contains a number of samples with Au values above the detection level, including the highest Au value in regolith for the project area (GSWA 170428, 19 ppb) from a carbonate-rich, interdune pavement (*Rk*). These samples with low-level Au concentrations may reflect control by the major north-westerly trending Cardabia Transfer Zone and numerous other northerly trending faults along the eastern margin of the Wandagee Ridge. Nevertheless, care should be taken in interpreting all analyte values close to the detection level (see **Chemical analysis and quality control**).

Winning Group

Much of the Winning Group is covered with sandplain (S_u) and eolian dunes (E_l). High SiO_2 probably dilutes much of the geochemical signature of this unit, except in three areas of significant outcrop — in the Pleiades Hills, in the vicinity of Winning Station, and in the eroded crest of the Giralia Anticline. Exposed-regime regolith in the Pleiades Hills area is derived from rocks of the Windalia Radiolarite and Muderong Shale (*Xzc*, *Xls*). These regolith units rapidly grade downslope into heterogeneous colluvium (*Cl*) and low-gradient sheetwash (*W1d*). In this area, Fe_2O_3, P_2O_5, As, Cr, Cu, and V are high with scattered, low to moderate values for In, Mo, Sb, Se, Th, U, and W. Regolith in the vicinity of Winning Station is dominated by silica-rich, in part ferruginous, low-gradient sheetwash (*W1z*) above shallow subcrop of the Windalia Radiolarite, grading downslope into lacustrine material (L_m, L_l). Components with elevated concentrations in regolith include Fe_2O_3, P_2O_5, As, Cr, Cu, In, Mo, Ni, Se, Sn, Te, U, and V with moderate levels of Ba and Zn. The main regolith type in the eroded crest of the Giralia Anticline is carbonaceous exposed-regime material (*Xrs*) derived from the underlying carbonaceous and pyritic Gearle Siltstone. This northwestern area is characterized by exceptionally high concentrations of Ba in regolith possibly associated with beds of nodular barite (see **Recorded mineralization and economic geology**). Other elements with high concentrations include Fe_2O_3, CaO, LOI, As, Mo, Ni, Se, U, and Zn with scattered samples containing moderate concentrations of P_2O_5, Co, Cu, In, Pd, S, Sn, and V. The elevated CaO and LOI concentrations in regolith are related to calcrete and gypcrete (*Rl*) that cover parts of the Gearle Siltstone in the western areas of the Giralia Anticline. Moderate Ba values are also recorded in regolith beyond the Giralia Anticline in low-gradient sheetwash (*W1d*) below outcrops of the Gearle Siltstone between 12 Mile Bore and Mia Mia Pool. An arcuate depression consisting of mixed sand, sheetwash, and playa terrain (S_p) extends from Mia Mia Pool to east of Windalia Bore near the Southern Carnarvon Basin – Gascoyne Complex contact. This regolith unit is delineated by consistent, although low, concentrations of K_2O and Rb, suggesting the unit contains flood material carried westward from the Gascoyne Complex and may represent an earlier course of the Lyndon River. Diversion of the Lyndon River to its current, more southerly position may have resulted from relatively recent uplift of coastal anticlines.

Toolonga Calcilutite, Korojon Calcarenite, and Miria Formation

In the northwestern part of WINNING POOL – MINILYA, much of the Toolonga Calcilutite, Korojon Calcarenite, and Miria Formation are covered with a carbonate-rich, duricrust platform (*Rk*) overlain by undulating sandplain (S_u), with exposed-regime material (*Xkc*) around the margins and along the eastern flank of the Giralia Range. In this area, regolith contains moderate levels of TiO_2, Al_2O_3, Ce, Co, Cr, Cu, Ga, La, Nb, Ni, Sc, Th, V, and Zr. Relatively low CaO and LOI concentrations in the northern parts suggest the surface is mostly covered by quartz sand. Higher CaO and LOI concentrations are recorded south of Cardabia Bore, where incision of the sand cover and duricrust has exposed more carbonate-rich regolith material (*Xkc, Ck*). Exposed-regime regolith (*Xkc*) also overlies these units in the Gnargoo Range area and MgO, CaO, LOI, and P_2O_5 in regolith are correspondingly high. Further to the south, these units are typically covered by alluvial material (*A1d*) with mixed sand, sheetwash, and playa terrain (S_p), low-gradient sheetwash material (*W1d*), and isolated, carbonate-rich duricrust (*Rk*). Apart from SiO_2, all other analytes are typically low in concentration within these regolith units.

Cardabia Calcarenite, Giralia Calcarenite, and Merlinleigh Sandstone

There are only small areas of regolith derived from the Merlinleigh Sandstone, which are limited to an area around Pleiades Hills. Due to its restricted nature, regolith derived from the Merlinleigh Sandstone is not discussed here. Regolith derived from the Cardabia and Giralia Calcarenites is dominated by exposed-regime material (*Xkc*, Xk_gc) along the Giralia Range, and in the Salt Marsh Anticlines west and east of northern Lake MacLeod. The few regolith samples over these narrow, northerly trending calcarenites have elevated concentrations of CaO, LOI, and Cd. Elevated concentrations of other analytes are recorded nearby, particularly in regolith along the western flank of the Giralia Anticline, overlying younger (Neogene) sedimentary rocks (discussed below).

Lamont Sandstone and Trealla Limestone

Several analytes have elevated concentrations in regolith over the Lamont Sandstone and Trealla Limestone, which outcrop either side of Lake MacLeod, extending northwards along the western slopes of the Giralia Range, and to the northeast towards Mia Mia Station. In the vicinity of Warroora Station, regolith is dominated by carbonate-rich, exposed- and residual-regime material (*Xkc*, *Rk*) and contains moderate to high concentrations of TiO_2, Al_2O_3, P_2O_5, Ce, Co, Cu, Ga, La, Li, Nb, Ni, Sc, Th, Y, and Zr with scattered In, Sr, and Te. Relatively low CaO and LOI concentrations suggest surface carbonates have been leached with the preferential enrichment of more-resistant components. These resistant components may have been of detrital origin, transported by the ancestral Minilya and Lyndon rivers, and subsequently incorporated with carbonate-rich material by coastal and eolian processes. Similar element associations in coastal limestones north of the mouth of the Murchison River on AJANA were attributed to the incorporation of detrital components within carbonate-rich material by coastal processes, after transportation from the Yilgarn Craton and Northampton Complex by a proto-Murchison River (Sanders and McGuinness, 2000). Coastal eolian activity and relatively recent uplift of anticlines have resulted in barring of the northern end of Lake MacLeod, near Warroora Station, an area previously open to the sea (see **Regolith-materials mapping, Discussion**, p. 15). Generally high values for components associated with detrital minerals in regolith north, south, and east of Warroora Station suggest this area may contain outwash material of the Minilya or Lyndon rivers, reworked by coastal action. Patches of higher CaO, LOI, and Sr values along the coast, southwest of Warroora and Gnaraloo stations, probably relate to recent carbonate-rich, eolian deposits (*Ek1*, *Ek2*) onlapping older regolith.

Regolith between Minilya and Mia Mia stations is dominated by the Minilya and Lyndon river floodplains (*A1d*) with mixed sand, sheetwash, and playa terrain (E_p, S_p). There is a broad suite of components with elevated concentrations in this area, particularly east of Minilya Station in the extensive outwash fan of the Minilya River.

This includes moderate to high TiO_2, Al_2O_3, P_2O_5, Ce, Co, Cu, Ga, La, Li, Nb, Ni, Sc, Th, Y, and Zr and locally In and Sn. The near-identical suite of elements recorded for regolith near Warroora Station suggests this area may contain early outwash material of the Minilya River, reworked by coastal action. The course of the Minilya River possibly extended in a northwesterly direction, through the now-mixed sand, sheetwash, and playa terrain (E_p, S_p) from west of Wandagee Station towards the north of Gnargoo Range. Further uplift of coastal anticlines may have diverted the course of the river, which now empties into Lake MacLeod, southwest of Minilya Station.

Regolith over the Lamont Sandstone and Trealla Limestone west of the Giralia Range is characterized by exposed-regime material (*Xkc*) grading downslope through colluvium (*Ck*) and low-gradient sheetwash (*W1d*) into eolian sand (E_l). High concentrations of CaO and LOI in regolith reflect relatively fresh carbonate-rich parentage. Elevated As, Cd, Ni, Sb, Te, and V with local Ag and Sn in the area may have some lithological association (e.g. Xk_gc) or may be indicative of sedimentary-hosted base metal mineralization within the western areas of the Giralia Anticline, which is discussed below (see **Mineralization potential**).

Bundera Calcarenite and coastal lake deposits

Regolith over the Bundera Calcarenite and coastal lake deposits consists of carbonate-rich, coastal eolian material (*Ek1*, *Ek2*, and *Ek3*); carbonate-rich, older coastal and marine deposits (*Kk*); and lacustrine material (L_l, L_ge). Along the northwest coastline, modern coastal dunes (*Ek1*) give way in an easterly direction to progressively older, more lithified, degraded and topographically elevated eolian material (*Ek2*, *Ek3*). Due to its narrow nature, there are few samples over the most-seaward eolian unit (*Ek1*). Samples over the broader eolian unit (*Ek2*) have high concentrations of CaO, LOI, and Sr reflecting the dominance of carbonate material in the regolith. Further inshore, eolian regolith material (*Ek3*) may have been leached: CaO, LOI, and Sr values are low and SiO_2 concentrations increase as regolith material grades through to dominantly quartz-rich eolian sand (E_l).

Southwest of Minilya Station, regolith is dominated by older coastal and marine material (*Kk*) along the shores of Lake MacLeod. In many regolith samples Al_2O_3, MgO, Na_2O, Ce, Cu, Ga, La, Li, Nb, Sc, Sr, Th, and Y are high, with moderate concentrations of TiO_2, P_2O_5, LOI, Co, Ni, U, V, Zn, and Zr. Some samples also contain low to moderate concentrations of In, Sn, and W. This broad range of components indicates the area is influenced by deposition of resistate detrital material in outwash floodplains of the Minilya River, and precipitates associated with carbonate rocks and evaporitic material surrounding Lake MacLeod.

Samples in lacustrine regolith (L_l) are rare, but samples in bedded evaporitic deposits (L_ge) surrounding and to the north of Lake MacLeod have high MgO, CaO, LOI, S, Sc, Sr, and U with moderate concentrations of Al_2O_3, Cu, Ce, Ga, La, Nb, Th, and Y, and localized elevated Na_2O and Se values. The high values are typically associated with evaporitic deposits including anhydrite and gypsum, but other components in moderate concentrations also indicate a detrital influence.

Statistical treatment of regolith chemical data

Although element-concentration maps (Figs 6–52) permit visual comparison of regolith chemistry with bedrock geology, statistical comparison is necessary to determine any significant differences in regolith composition (e.g. between geological units or regolith units).

Numerous statistical tests are available for comparing groups of normally distributed data. However, many geological datasets follow a non-normal distribution, with a majority of low element concentrations and only few high values giving a positive skew to the distribution (Koch and Link, 1970). Transformation of non-normally distributed data can be carried out so that a parametric (normal) test of population difference can be applied. 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). Following this, parametric (normal) statistical tests can be undertaken to compare two or more populations (e.g. Student's t-test or Tukey's Honestly Significant Difference). An assumption of this approach is that population sizes are large and the addition of a constant and log normalization will produce a sufficiently normal (parametric) dataset. This may not always be the case, suggesting other, non-parametric tests may be more appropriate for comparing regolith chemistry (Morris et al., 2000b). The non-parametric equivalent of the Student's t-test for independent samples is known as the Mann-Whitney U test or the Wilcoxon rank-sum test (Swan and Sandilands, 1995). The Mann-Whitney U test examines the equality of medians (i.e. the middle value in a set of ranked data), and as it is calculated on ranked data rather than raw data, it is less sensitive to outliers, and so is more robust than the equivalent parametric tests. However, caution should be exercised in using the Mann-Whitney U test where there are a large amount of zero or near zero data. In such cases, the ranking process may unrealistically highlight the importance of values that are only just above detection level.

Due to the analytical complications introduced near the detection limit (see **Chemical analysis and quality control**), only elements that have median values greater than ten times the detection level are discussed statistically.

The Mann-Whitney U test has been used for statistically comparing several geological units and regolith types. The statistical tests performed on WINNING POOL – MINILYA are as follows:

- comparison of element concentrations from various sand-dominated regolith units (E_l, E_p, S_u, and S_p);
- comparison of element concentrations from two coastal eolian regolith units (*Ek2*, *Ek3*);

- comparison of element concentrations from two exposed-regime regolith units over the Gascoyne Complex (*Xgp*, *Xgm*);
- comparison of element concentrations from two carbonaceous, exposed-regime regolith units (*Xrs*) over the Wooramel, Byro, and Kennedy Groups (*P*) and Winning Group (*KWI*).

All statistical tests were carried out at the 95% significance level and statistical results, arithmetic mean, median, and standard deviation values are presented in Tables 5–10.

- **Comparison of element concentrations from various sand-dominated regolith units (E_l, E_p, S_u, and S_p)**

Various sand-dominated regolith units (largely differentiated on geomorphological grounds) have been statistically compared to determine any differences in chemistry. Values for the mean, median, and standard deviation for these regolith units are shown in Table 5 and results of statistical comparison are shown in Table 6.

Most component concentrations are similar, as all four units are dominated by silica sand, although the largely eolian unit with extensive longitudinal dunes (E_l) has statistically significant higher median concentrations of SiO_2 than the other three units. This suggests that quartz sand is preferentially enriched in the eolian terrain. The mixed eolian, sheetwash, and playa unit (E_p) contains statistically higher median concentrations of Al_2O_3, Fe_2O_3, K_2O, Ba, Ce, Cu, La, Nb, Pb, Rb, Th, and V compared with the longitudinal dune terrain (E_l), suggesting that the playa component may concentrate clay and detrital minerals. It is possible that the mixed eolian, sheetwash, and playa environment, northeast of Minilya Station, may contain floodplain material or represent old drainage now overprinted by sandplain and dunes (see **Regolith chemistry**). The mixed sandplain, sheetwash, and playa unit (S_p) is chemically similar to its more dune-dominated counterpart (E_p), and is commonly adjacent to this unit. However, compared to dune-dominated regolith (E_p), the sandplain, sheetwash, and playa (S_p) regolith contains statistically significant higher median concentrations of K_2O, Ba, and Sr. This may be due to low but consistent concentrations of these components (probably in clays or feldspars) in the large, arcuate sandplain, sheetwash, and playa depression of the central north (S_p), which may contain floodplain material and represent an earlier course of the Lyndon River (see **Regolith chemistry**). The undulating sandplain unit (S_u) typically contains few dunes and is mostly found in more topographically elevated regions above outcrop or duricrust (notably above the Windalia Radiolarite and rocks of the Gascoyne Complex). Compared with the longitudinal dune terrain (E_l), the undulating sandplain (S_u) has statistically significant higher median concentrations of Al_2O_3, K_2O, Ba, Pb, Rb, and Th, suggesting the unit has a higher clay component and possibly a weak granitic signature.

- **Comparison of element concentrations from two coastal eolian regolith units (*Ek2*, *Ek3*)**

The above statistical test demonstrates small variations over sand-dominated units from interior parts of WINNING POOL – MINILYA. There are other eolian units with higher carbonate contents along the coast. Due to its elongate nature, no samples were recorded over the youngest eolian unit (*Ek1*) immediately adjacent to the current shoreline. However, 13 and 10 samples were collected over the older, more-degraded, inland eolian units (*Ek2* and *Ek3* respectively), and their chemical concentrations are compared statistically. Values for the mean, median, and standard deviation for these regolith units are presented in Table 7 and results of statistical comparison are presented in Table 10.

The younger, less-elevated eolian unit closer to the coast (*Ek2*) has statistically higher median concentrations of CaO, LOI, Ce, La, and Sr. The CaO, LOI, and Sr suggest the eolian material (*Ek2*) is dominated by carbonate-rich material with minor detrital components, as indicated by Ce and La. The far greater concentrations of SiO_2 in the more-inland eolian unit (*Ek3*) suggest that surface carbonate may have been leached, and this unit grades into more quartz-rich eolian material (E_l) on the western flank of the Giralia Range. Leaching of originally calcareous dune sand to form yellow and red residual quartz-sand is discussed by Langford (2000) over the Pleistocene Tamala Limestone in the Geraldton area. Similar surface leaching may account for the relatively low CaO and elevated SiO_2 in the oldest eolian unit (*Ek3*; dominantly Pleistocene Bundera Calcarenite; see **Regolith chemistry**).

- **Comparison of element concentrations from two exposed-regime regolith units over the Gascoyne Complex (*Xgp*, *Xgm*)**

Values for the mean, median, and standard deviation for the exposed-regime regolith units (*Xgp*, *Xgm*) are shown in Table 8. Results from the statistical comparison of these regolith types are presented in Table 10.

Eastern parts of WINNING POOL – MINILYA are dominated by exposed-regime regolith derived from either granitoid rocks (*Xgp*) or metamorphic rocks (*Xgm*) of the Gascoyne Complex. Statistical analysis has been applied to identify any difference in the chemistry of these exposed-regime regolith units, which may reflect differences in bedrock chemistry. Although most components have similar median values, regolith derived from granitoids (*Xgp*) has statistically higher median concentrations of Al_2O_3, Na_2O, Ba, and Sr compared with regolith derived from metamorphic rocks (*Xgm*). All four components are typical of granitic rocks and probably reflect the type and proportion of plagioclase in granitoids of the Minnie Creek Batholith (see **Regolith chemistry**). Exposed-regime regolith derived from metamorphic rocks (*Xgm*) has statistically significant higher median concentrations of Nb, Th, and Zr. These components are commonly associated with resistate phases.

- **Comparison of element concentrations from two carbonaceous, exposed-regime regolith units (*Xrs*) over the Wooramel, Byro, and Kennedy Groups (*P*) and Winning Group (*KWI*)**

Arithmetic mean, median, and standard deviations for the two exposed-regime regolith units (*Xrs*) are reported in

Table 5. Arithmetic mean, median, and standard deviation for various sand-dominated regolith units (E_l, E_p, S_u, and S_p)

	E_l (n = 177)			E_p (n = 20)			S_u (n = 59)			S_p (n = 77)		
Element	*Mean*	*Median*	*σ*	*Mean*	*Median*	*σ*	*Mean*	*Median*	*σ*	*Mean*	*Median*	*σ*
						Percent						
SiO_2	89.8	91.2	7.2	88.8	89.3	3.8	88.5	89.4	8.6	87.2	89.0	8.1
TiO_2	0.18	0.17	0.08	0.21	0.19	0.07	0.19	0.17	0.07	0.25	0.18	0.43
Al_2O_3	3.4	3.2	1.6	4.3	3.8	1.5	4.0	4.1	1.2	4.4	4.1	2.1
Fe_2O_3	2.2	2.0	1.0	2.4	2.3	0.6	2.3	2.1	0.8	2.9	2.2	2.2
MnO	–	–	0.02	0.01	–	0.02	–	–	0.02	0.01	–	0.03
MgO	0.1	0.1	0.2	0.2	0.1	0.2	0.1	0.1	0.1	0.4	0.2	1.5
CaO	0.7	–	3.3	0.1	–	0.1	0.8	–	4.7	0.5	0.1	1.9
Na_2O	0.1	–	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.3	0.2	0.1
K_2O	0.8	0.7	0.5	1.1	1.3	0.4	1.2	1.5	0.6	1.3	1.4	0.5
P_2O_5	0.01	–	0.02	0.03	–	0.03	0.01	–	0.02	0.04	0.05	0.03
LOI	2.2	1.5	2.9	1.8	1.6	1.0	2.1	1.5	3.9	2.1	1.5	1.9
						Parts per million[(a)]						
Ag	–	–	0.1	–	–	0.1	–	–	–	–	–	0.1
As	3	3	4	4	4	2	3	2	3	4	4	3
Au (ppb)	–	–	1	–	–	–	–	–	1	–	–	1
Ba	191	174	210	240	255	56	208	227	82	362	291	274
Be	–	–	–	–	–	–	–	–	–	–	–	–
Bi	–	–	0.1	–	–	–	–	–	–	–	–	–
Cd	–	–	–	–	–	–	–	–	–	–	–	–
Ce	16.3	13.9	8.6	21.4	18.5	7.7	16.9	16.1	6.0	22.5	20.1	10.4
Co	3	3	2	4	4	2	3	3	1	4	4	2
Cr	28	19	26	26	18	18	29	19	21	29	22	21
Cu	12	11	5	13	13	4	11	11	3	13	12	5
Ga	4	4	2	6	5	3	5	5	1	6	5	3
In	–	–	–	–	–	–	–	–	–	–	–	–
La	9.9	8.7	4.9	12.7	10.7	4.5	10.5	10.5	3.8	12.9	11.6	5.6
Li	10	8	5	12	10	6	8	8	3	11	9	8
Mo	–	–	1	1	–	1	–	–	1	–	–	1
Nb	6.7	5.5	3.5	10.1	9.0	4.2	6.0	5.8	1.9	8.5	7.3	5.0
Ni	10	9	4	11	10	4	9	9	3	10	9	6
Pb	9	8	4	10	10	3	11	11	4	12	11	4
Pd (ppb)	–	–	1	–	–	–	–	–	1	–	–	1
Pt (ppb)	–	–	1	–	–	–	–	–	1	–	–	1
Rb	35.8	34.1	17.8	46.5	48.6	16.7	49.4	53.4	21.7	51.3	51.2	19.9
S (%)	–	–	–	–	–	–	–	–	–	–	–	–
Sb	–	–	0.2	–	–	0.1	–	–	0.1	0.1	–	0.2
Sc	2	2	2	3	3	1	2	2	1	3	2	2
Se	0.2	–	0.4	0.3	–	0.5	0.3	–	0.5	0.3	–	0.5
Sn	1	1	2	1	1	1	–	–	1	1	1	1
Sr	40	25	74	33	32	12	35	31	66	43	39	23
Ta	–	–	–	–	–	–	–	–	–	–	–	–
Te	–	–	–	–	–	0.1	–	–	–	–	–	–
Th	5.0	4.6	2.5	6.1	5.1	1.9	5.6	5.4	1.6	6.2	5.7	2.3
U	0.7	0.7	0.3	0.9	0.8	0.2	0.9	0.8	0.3	1.0	0.9	0.4
V	34	31	23	43	38	17	33	30	13	45	37	28
W	–	–	–	–	–	–	–	–	–	–	–	–
Y	4	3	2	5	5	2	4	4	2	6	5	3
Zn	12	8	9	16	15	8	10	9	5	16	13	12
Zr	112	95	62	116	117	30	99	87	50	111	93	60

NOTE:
(a) unless otherwise shown
n number of samples
ppb parts per billion
– less than detection level
σ standard deviation

Table 9, and the results of statistical comparison are presented in Table 10.

Statistical analysis shows a number of differences in the chemistry between carbonaceous, exposed-regime regolith units (*Xrs*) over the Permian Bulgadoo and Quinnanie Shales of the central south (*P*), and over Cretaceous Gearle Siltstone of the Giralia Anticline area (*KWI*). Regolith derived from the carbonaceous and pyritic siltstones of the Giralia area contains statistically significant higher median concentrations of CaO, LOI, Ba, Sr, and U. The higher Ba is consistent with barite occurrences in the Giralia Anticline, whereas the other components probably reflect the influence of

Table 6. Statistical differences (Mann-Whitney U test) between various sand-dominated regolith units (E_l, E_p, S_u, and S_p)

E_p	S_u	S_p	←2 Item 1↓
$\underline{SiO_2}$, Al_2O_3, Fe_2O_3, K_2O, Ba Ce, Cu, La, Nb, Pb, Rb, Sr, Th, V	$\underline{SiO_2}$, Al_2O_3 , K_2O Ba, Pb, Rb, Th	$\underline{SiO_2}$, Al_2O_3, Fe_2O_3, K_2O, Ba Ce, Cu, La, Nb, Pb, Rb, Sr, Th	E_l
–	$\underline{\text{Ba}}$, $\underline{\text{Ce}}$, $\underline{\text{Cu}}$, $\underline{\text{La}}$ $\underline{\text{Nb}}$, $\underline{\text{V}}$, $\underline{\text{Zr}}$	K_2O, Ba, $\underline{\text{Nb}}$, Sr, $\underline{\text{Zr}}$	E_p
–	–	Ba, Ce, Cu, La, Nb Sr, V	S_u

NOTE: Underlined components have statistically higher median concentrations in the regolith type denoted in Item 1, other components have statistically higher median concentrations in regolith type denoted in Item 2. Results are from the Mann-Whitney U test at the 1-tailed 95% significance level. Only components with median values >10 × detection level are included

nearby carbonate-rich material (Trealla Limestone and calcrete). Regolith derived from carbonaceous and pyritic shales of the central south has statistically significant higher median concentrations of SiO_2 and Pb. The greater silica content suggests the Bulgadoo and Quinnanie Shales have a greater siliciclastic component, whereas the Gearle Siltstone has a greater marine influence. Elevated Pb is consistent with the higher base metal concentrations of the central south (Figs 34 and 56).

Speciality maps

Regolith pH and conductivity

Maps of regolith acidity–alkalinity and conductivity are presented in Figures 53 and 54. Regolith over the Gascoyne Complex has a slightly acidic to neutral pH, with the exception of valley-calcrete dominated areas near the eastern boundary of the project area (along the Yannarie River), which tend to be alkaline. Much of the sand-dominated areas of central WINNING POOL – MINILYA have lower pH values with more alkaline regolith over the north-northwesterly trending Gooch Range, and over the Byro Group. Regolith is neutral to marginally alkaline in the vicinity of the Minilya River from near Wandagee Hill to north of Minilya Station. An abrupt increase in pH coincides with the transition from sand-dominated regolith (S_p, S_u, and E_l) to alluvium (*A1d*), low-gradient sheetwash (*W1d*), carbonaceous exposed-regime regolith (*Xrs*), and carbonate-rich duricrust (*Rk*) on the eastern flank of the Giralia Anticline. West of this line, regolith is typically alkaline, with the highest pH values recorded in various regolith types over the Gearle Siltstone in the centre of the Giralia Anticline, and along the western flank of the Giralia Range. High pH values in regolith extend southwards along the flanks of Lake MacLeod (*Xkc*, *Kk*), giving way to lower pH values in quartz-rich eolian sands (E_l) north of Gnaraloo Station.

Table 7. Arithmetic mean, median, and standard deviation for two coastal eolian regolith units (*Ek2* and *Ek3*)

	Ek2 (n = 13)			*Ek3 (n = 10)*		
Element	*Mean*	*Median*	*σ*	*Mean*	*Median*	*σ*
			Percent			
SiO_2	55.1	53.2	12.1	88.0	91.1	8.5
TiO_2	0.05	0.05	0.03	0.05	0.06	0.04
Al_2O_3	1.2	1.2	0.3	1.3	1.3	0.2
Fe_2O_3	0.7	0.7	0.2	1.1	1.1	0.3
MnO	–	–	–	–	–	–
MgO	0.7	0.6	0.3	0.1	0.1	0.1
CaO	22.7	24.1	6.8	4.2	1.7	5.1
Na_2O	0.1	0.1	0.1	–	–	–
K_2O	0.4	0.4	0.1	0.5	0.5	0.1
P_2O_5	0.05	0.06	0.04	–	–	–
LOI	19.3	20.5	5.8	4.1	1.9	4.1
			Parts per million[(a)]			
Ag	0.1	0.1	0.1	–	–	–
As	2	2	2	1	2	1
Au (ppb)	–	–	–	–	–	–
Ba	93	86	21	116	117	16
Be	–	–	–	–	–	–
Bi	–	–	–	–	–	–
Cd	–	–	–	–	–	–
Ce	8.7	8.5	2.1	6.3	5.9	1.5
Co	1	1	1	1	1	1
Cr	15	14	9	13	8	10
Cu	4	4	2	9	8	4
Ga	2	2	1	2	2	1
In	–	–	–	–	–	–
La	5.3	5.1	1.4	4.0	4.2	0.8
Li	4	4	1	5	5	–
Mo	–	–	–	–	–	–
Nb	2.5	2.5	1.0	2.6	2.5	0.6
Ni	3	2	3	4	4	2
Pb	6	6	3	6	5	2
Pd (ppb)	–	–	–	1	–	1
Pt (ppb)	–	–	1	–	–	–
Rb	17.6	17.4	3.3	19.5	19.5	2.4
S (%)	–	–	–	–	–	–
Sb	–	–	–	–	–	–
Sc	–	–	1	–	–	–
Se	0.6	–	0.8	0.2	–	0.5
Sn	–	–	–	1	1	1
Sr	1 038	1 070	382	171	56	211
Ta	–	–	–	–	–	–
Te	–	–	–	–	–	–
Th	2.0	2.1	0.5	2.2	2.2	0.3
U	0.9	0.9	0.3	0.4	0.4	0.1
V	8	8	3	8	8	2
W	–	–	–	–	–	–
Y	5	5	1	2	2	1
Zn	2	–	2	1	–	2
Zr	40	42	16	55	51	28

NOTES: (a) unless otherwise shown
n number of samples
ppb parts per billion
– less than detection level
σ standard deviation

Most conductivity values for the project area are low. The highest values (GSWA 170671 and 170872) are in the vicinity of Lake MacLeod, particularly in evaporitic beds at its northern margin (L_ge) and along its eastern flank, southwest of Minilya Station (*Kk*). Other higher conductivity readings are recorded in various regolith

Table 8. Arithmetic mean, median, and standard deviation for two exposed-regime regolith units over the Gascoyne Complex (*Xgp* and *Xgm*)

	Xgp (n = 73)			*Xgm (n = 49)*		
Element	*Mean*	*Median*	*σ*	*Mean*	*Median*	*σ*
			Percent			
SiO_2	81.1	80.4	5.4	82.7	82.0	4.5
TiO_2	0.33	0.24	0.33	0.36	0.28	0.29
Al_2O_3	8.4	9.0	2.3	7.7	8.0	2.2
Fe_2O_3	2.7	2.3	1.5	2.9	2.6	1.3
MnO	0.03	–	0.04	0.04	–	0.05
MgO	0.4	0.4	0.3	0.5	0.4	0.3
CaO	0.8	0.4	1.1	0.3	0.2	0.3
Na_2O	1.2	1.0	0.7	0.8	0.8	0.5
K_2O	2.7	2.6	0.9	2.5	2.5	0.9
P_2O_5	0.03	–	0.03	0.03	–	0.04
LOI	1.7	1.4	1.6	1.6	1.5	0.7
			Parts per million[(a)]			
Ag	–	–	–	–	–	–
As	2	2	1	2	2	2
Au (ppb)	–	–	1	1	–	1
Ba	465	453	160	374	372	139
Be	1	1	1	2	1	2
Bi	0.1	–	0.6	0.2	–	0.5
Cd	–	–	–	–	–	–
Ce	30.9	28.2	13.8	30.7	27.5	13.2
Co	6	5	4	6	5	4
Cr	14	10	12	16	12	13
Cu	14	14	5	16	15	6
Ga	10	10	3	10	10	3
In	–	–	–	–	–	–
La	17.5	16.2	7.6	17.0	15.0	7.3
Li	8	7	4	10	11	5
Mo	–	–	–	–	–	–
Nb	9.6	8.3	5.7	10.8	10.2	4.8
Ni	9	8	4	11	9	5
Pb	18	16	8	18	17	6
Pd (ppb)	–	–	1	–	–	0
Pt (ppb)	–	–	1	–	–	1
Rb	100.7	97.1	36.7	101.5	101.0	38.1
S (%)	–	–	–	–	–	–
Sb	–	–	–	–	–	–
Sc	4	3	2	4	3	2
Se	0.4	–	0.6	0.3	–	0.6
Sn	1	1	1	2	2	1
Sr	86	72	53	57	56	28
Ta	–	–	2	1	–	1
Te	–	–	–	–	–	–
Th	8.4	7.1	4.8	9.8	9.3	4.3
U	1.6	1.5	0.6	1.6	1.6	0.5
V	45	36	40	44	34	34
W	1	–	1	1	1	1
Y	6	6	2	6	5	2
Zn	16	13	9	19	19	10
Zr	75	66	44	85	79	38

NOTES: (a) unless otherwise shown
n number of samples
ppb parts per billion
– less than detection level
σ standard deviation

Table 9. Arithmetic mean, median, and standard deviation for two carbonaceous, exposed-regime regolith units (*Xrs*) over the Wooramel, Byro, and Kennedy Groups (*P*) and over the Winning Group (*KWI*)

	Xrs (over P) (n = 22)			*Xrs (over KWI) (n = 12)*		
Element	*Mean*	*Median*	*σ*	*Mean*	*Median*	*σ*
			Percent			
SiO_2	77.5	82.9	12.5	66.2	71.3	19.4
TiO_2	0.29	0.21	0.21	0.27	0.26	0.10
Al_2O_3	5.9	4.3	4.2	4.4	4.4	1.7
Fe_2O_3	7.3	6.8	4.3	6.5	4.9	4.2
MnO	0.13	0.09	0.14	0.01	–	0.03
MgO	0.5	0.4	0.4	0.8	0.9	0.3
CaO	1.4	1.1	1.4	8.2	3.2	12.4
Na_2O	0.4	0.4	0.2	0.3	0.2	0.6
K_2O	1.1	1.0	0.6	0.9	0.9	0.4
P_2O_5	0.15	0.13	0.11	0.09	0.08	0.03
LOI	4.8	3.3	3.4	11.7	8.8	8.9
			Parts per million[(a)]			
Ag	–	–	0.1	–	–	0.1
As	26	20	23	16	12	12
Au (ppb)	–	–	–	1	1	1
Ba	820	507	827	3 543	1 230	5 726
Be	1	1	1	1	1	1
Bi	0.1	–	0.2	–	–	–
Cd	–	–	–	–	–	–
Ce	46.5	33.0	30.1	30.4	29.7	10.4
Co	11	11	8	7	6	3
Cr	46	36	33	41	31	25
Cu	21	18	11	17	15	4
Ga	9	6	7	6	7	2
In	–	–	–	–	–	–
La	25.4	18.8	15.7	17.9	17.0	5.3
Li	27	16	24	12	13	4
Mo	2	2	2	7	6	5
Nb	13.2	8.4	11.9	9.6	9.9	3.7
Ni	27	22	18	24	21	10
Pb	27	25	17	14	13	6
Pd (ppb)	1	–	1	1	1	1
Pt (ppb)	–	–	1	1	1	1
Rb	45.8	38.0	27.9	38.8	44.5	15.0
S (%)	0.1	–	0.2	0.2	0.2	0.1
Sb	0.4	–	0.5	0.4	–	0.5
Sc	6	4	4	4	5	2
Se	1.1	1.1	0.9	1.4	1.3	1.1
Sn	1	1	1	2	1	2
Sr	93	62	59	328	260	276
Ta	–	–	1	–	–	–
Te	–	–	–	–	–	–
Th	10.3	7.3	6.5	7.2	7.7	2.5
U	1.7	1.2	1.0	3.6	3.0	1.7
V	120	86	75	105	100	40
W	1	–	1	–	–	–
Y	15	12	9	10	9	3
Zn	56	48	39	47	39	26
Zr	120	84	72	117	109	56

NOTES: (a) unless otherwise shown
n number of samples
ppb parts per billion
– less than detection level
σ standard deviation

Table 10. Statistical differences (Mann-Whitney U test) between various regolith units (*Ek2* and *Ek3*; *Xgp* and *Xgm*; *Xrs* over *P* and *Xrs* over *KWI*)

Ek2	*←2 Item 1↓*	***Xgp***	*←2 Item 1↓*	***Xrs (over P)***	*←2 Item 1↓*
$\underline{SiO_2}$, $\underline{Fe_2O_3}$, CaO LOI, $\underline{Ba}$, Ce, La, Sr	***Ek3***	Al_2O_3, Na_2O, Ba, $\underline{Nb}$, Sr, $\underline{Th}$, $\underline{Zr}$	***Xgm***	SiO_2, $\underline{CaO}$, $\underline{LOI}$, $\underline{Ba}$, Pb, $\underline{Sr}$, $\underline{U}$	***Xrs (over KWI)***

NOTES: Underlined components have statistically higher median concentrations in the regolith type denoted in Item 1, other components have statistically higher median concentrations in regolith type denoted in Item 2. Results are from the Mann-Whitney U test at the 1-tailed 95% significance level. Only components with median values >10 × detection level are included

types from the centre of the Giralia Range, near lakes in the vicinity of Winning Station, and towards the centre of the project area near Burnerburnung Hill.

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 commonly additive (e.g. element a + element b + element c, etc.), but the relative concentration and concentration range of each element must be taken into account. 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 standardized scores are then summed to create an elemental association suite.

Six element-index plots have been compiled for WINNING POOL – MINILYA. These comprise a chalcophile index (summed standard scores of As, Bi, Mo, Sb, Se, Sn, and W; Fig. 55); base metals index (summed standard scores of As, Cu, Pb, Sb, and Zn; Fig. 56); ferro-alloy index (summed standard scores of Co, Cr, Mo, Ni, and V; Fig. 57); resistate components index (summed standard scores of TiO_2, Ce, La, Nb, Ta, Th, Y, and Zr; Fig. 58); pegmatite index (summed standard scores of Be, Bi, Nb, Sn, Ta, and W; Fig. 59); and black shale index (summed standard scores TiO_2, MnO, Ag, As, Ba, Cd, Ce, Co, Cr, Cu, La, Ni, Pb, Sb, Se, U, V, and Zn; Fig. 60). Many samples with high standard scores have anomalous concentrations of individual elements (Table 4).

Chalcophile index

Areas of relatively high chalcophile-index scores include within the vicinity of Winning and Wandagee stations, Giralia Anticline, Pleiades Hills, and the northeast of WINNING POOL – MINILYA. Near Winning Station, a group of high chalcophile-index values is in alluvium (*A1d*) associated with low-gradient sheetwash material (*W1d*, *W1z*), largely derived from the near-surface, silica-rich Windalia Radiolarite. This low-gradient sheetwash grades upslope into colluvial and exposed-regime regolith (*Cl*, *Czc*, and *Xzc*) and grades downslope into lacustrine regolith (L_l, L_m). This area includes the highest chalcophile-index score in sample GSWA 170614. Other high values are in alluvium (*A1d*) derived from radiolaria-rich rocks in the vicinity of Pleiades Hills, and on the southern margin of the project area, 25 km south-southwest of Wandagee Station. A band of high values is recorded from the eroded crest of the Giralia Anticline, largely in regolith over the carbonaceous Gearle Siltstone and Windalia Radiolarite (*A1d*, *Xrs*, and *Xzc*). On the western flank of the anticline, elevated chalcophile-index values are in alluvium (*A1d*) draining carbonate-rich material (*Xkc*). High index scores in the vicinity of Wandagee Station largely correspond with carbonaceous regolith (*Xrs*) over the Byro Group. In the northeast, a cluster of samples with high chalcophile-index scores is associated with exposed-regime regolith largely derived from faulted granitoid and gneissic rocks, and contains localized zoned pegmatites and schist (*Xgp*, *Xgm*). Here, the elevated chalcophile-index scores can largely be attributed to high Bi and W concentrations (see **Pegmatite index**).

Base metal index

Areas of high base-metal index scores are similar to those of the chalcophile index, apart from the northeast of WINNING POOL – MINILYA and the Mangaroon Syncline. Elevated values are near Winning Station (including the highest index score in GSWA 170614), Pleiades Hills, in the eroded crest of the Giralia Anticline and its western flank, and over the Byro Group in the central south of the project area. A high value near the eastern boundary of the project area corresponds with exposed-regime regolith (*Xqs*; GSWA 170039), near the Coria Springs Cu, Pb, and Zn occurrence in the Mangaroon Syncline. In the northeast of the project area, a single elevated value is found in quartz-rich exposed-regime regolith (*Xqs*) of the Edmund Group (GSWA 170048). Moderate values are recorded along the eastern flank of Lake MacLeod, extending across to near Warroora Station.

Ferro-alloy index

The ferro-alloy index also highlights the area around Winning Station, Pleiades Hills, the Giralia Anticline, and near Wandagee Station. A high value is also recorded in the Mangaroon Syncline near Coria Springs, and in the far southeast of the project area in exposed-regime regolith (*Xmm*) derived from metamorphosed dolerite or gabbro (GSWA 170407). Other low to moderate ferro-alloy index scores in regolith, southwest of Lyndon Station, are near to northerly trending, metamorphosed dolerite and gabbro sills near the faulted contact between the Gascoyne Complex and Middle Devonian – Lower Carboniferous rocks. The elevated index scores in various regolith types along the eastern and northern boundaries of Lake MacLeod may be largely detrital, associated with early and contemporary outwash of the Lyndon and Minilya rivers (see **Regolith chemistry**).

Resistate components index

The resistate components index highlights regolith over the Gascoyne Complex, Byro Group, and the outwash from the Minilya River in the southwest. The highest index score for the project area (GSWA 170227) is from exposed-regime regolith (*Xrs*) near the course of the Minilya River, 10 km southeast of Wandagee Station. Elevated resistate-components index scores in carbonaceous exposed-regime regolith (*Xrs*) over the Byro Group suggest these units have been a 'sink' for detrital components. Sanders et al. (1998) recorded elevated resistate-components index scores in similar lithologies of the Byro Group on GLENBURGH. The mostly likely source of the detritus is granitoids and metasedimentary rocks of the Gascoyne Complex, which throughout WINNING POOL – MINILYA contain scattered, moderate to high resistate-components index scores in regolith. The highest resistate-components index score over the Gascoyne Complex is from near the Jailor Bore uranium prospect (GSWA 170059), with other elevated values north of the Yannarie River along the eastern margin of the project area and west of White Hills. It is likely that the Minilya River has reworked and transported material from the Gascoyne Complex and Byro Group, depositing it on outwash floodplains near Minilya Station. Black shales of the Byro Group may be the main source of resistate material, as the outwash plains of the Lyndon River, which sources rocks of the Gascoyne Complex but not shales of the Byro Group, have noticeably lower resistate-components index scores. Moderate to high resistate-components index scores in the vicinity of Warroora Station suggests this area may contain early outwash material of the Minilya River, reworked by coastal processes (see **Regolith chemistry**).

Pegmatite index

The highest pegmatite-index score is from GSWA 170043, immediately north of the Yannarie River in the northeast of WINNING POOL – MINILYA. There are a number of other elevated scores in this area in exposed-regime regolith largely derived from granitoid and gneissic rocks with localized, zoned pegmatites and schist (*Xgp*, *Xgm*). There is also a series of northwesterly trending faults in this area. Pye et al. (1999, fig. 57) reported similar elevated pegmatite-index scores in regolith over Gascoyne Complex metamorphic rocks on WYLOO. Other relatively high pegmatite-index scores are west of Lyndon Station, where Middle Devonian – Lower Carboniferous sedimentary rocks outcrop in faulted half grabens within the Gascoyne Complex, and south of Lyndon Station near the Jailor Bore uranium prospect.

Black shale index

Morris et al. (1998, fig. 56) and Pye et al. (1998, fig. 56) discussed the application of a metalliferous black shale index for regolith samples from MOUNT EGERTON and EDMUND respectively. Due to the abundance of carbonaceous regolith (*Xrs*) from various parts of WINNING POOL – MINILYA, a similar index is applied. The index map highlights the area near Wandagee Station, although the highest index score recorded is in regolith near the Coria Springs Cu, Pb and Zn occurrence (GSWA 170039). This elevated score is consistent with high scores reported by Pye et al. (1998, fig. 56) in the Mangaroon Syncline on EDMUND, in regolith associated with dolerite and pyritic black shales of the Jillawarra Formation (see **Simplified geology**). Other moderate to high scores over northeastern parts of the project area are also associated with Edmund Group rocks. The collection of elevated scores in regolith near Wandagee Station confirms that black shale units of the Byro Group (notably the Quinnanie and Bulgadoo Shales) have concentrated a large range of components, which was also reported for the Bulgadoo Shale on GLENBURGH (Sanders et al., 1998). A band of northerly trending, elevated black-shale index scores are in the eroded crest of the Giralia Anticline, an area dominated by carbonaceous exposed-regime regolith (*Xrs*) derived from the Gearle Siltstone. High scores near Winning Station and Pleiades Hills are associated with regolith derived from the Windalia Radiolarite, whereas around eastern and northern Lake MacLeod, the higher scores may relate to detrital material possibly sourced from the Byro Group.

Mineralization potential

Most of the mineral exploration on WINNING POOL – MINILYA has focused on base metals, gold, and uranium (Appendix 2; Plate 2), along with exploration for diamonds over diatremes and intrusions in the Wandagee Station area. Harrison (1985) emphasized the potential for sedimentary-hosted base metal mineralization in rocks of the Southern Carnarvon Basin, in particular in carbonates or shales at the edges of a basin, either in contact with basement rocks where basement rocks are at shallow depth, or where faulting controls the migration of mineralizing fluids. Such areas include Middle Devonian – Lower Carboniferous rocks in structurally complex half-grabens in the Gascoyne Complex, and sedimentary rocks near the Wandagee Ridge. Gravity modelling shows the Wandagee Ridge is at a depth of less than 2000 m on WINNING POOL – MINILYA (Iasky and Mory, 1999, fig. 5).

Copper and Zn in regolith are highest in GSWA 170039 over the Edmund Group in the Mangaroon Syncline, near to known base metal anomalism at Coria Springs. Ferguson (1999) discussed the Cu, Pb, and Zn occurrence at Coria Springs from exploration work by Australian Anglo. Drilling found no significant mineralization, and the elevated base-metal values were attributed to surface scavenging by carbonaceous black shales. Other high base-metal index scores in regolith over the Edmund Group may also be attributed to scavenging by black shales. Nevertheless, Ferguson (1999) indicated that the setting of the Edmund Basin, with its structural history and shelf to marine sandstone and shale-dominated lithologies, has high potential for clastic-hosted, lead–zinc mineralization. This is borne out in part by the discovery of Western Australia's largest Pb–Cu–Ba deposit (Abra) in clastic and carbonate sedimentary rocks of the central Bangemall Superbasin (Cooper et al., 1998).

Harrison (1985) suggested that black shales of the Byro Group (the Bulgadoo and Quinnanie Shales) would provide ideal conditions for base metal mineralization if mineralized brines were debouched into the basin during or soon after deposition. High black-shale and base-metal index scores are recorded from carbonaceous regolith over the Byro Group on WINNING POOL – MINILYA, with similar high scores reported from the Byro Group on GLENBURGH (Sanders et al., 1998). Both areas are near major structural features (the Wandagee Fault on WINNING POOL – MINILYA and the Errabiddy Shear Zone and Madeline Fault on GLENBURGH), which may have acted as fluid pathways.

Other areas with potential for base metal mineralization include the Gearle Siltstone in the Giralia Anticline and Windalia Radiolarite near Winning Station and Pleiades Hills, with high chalcophile-, base-metal, ferro-alloy, and black-shale index scores recorded in these areas. The Winning Group has been the subject of a number of exploration programs for base metals, after anomalous Ag and Zn concentrations were reported from sulfide and goethite nodules and microgossan chips in the Gearle Siltstone (International Nickel Australia Ltd, 1980). Harrison (1985) argued that the presence of bentonitic siltstone and tuffaceous horizons containing shards of devitrified glass, and angular, feldspar phenocrysts in the Gearle Siltstone provide evidence of distal volcanism. He also reported that volcanic rocks have been intersected in three offshore oil-exploration wells and distal volcanism has been cited as a possible factor in sedimentary-hosted base metal formation.

Harrison (1985) drew comparisons between the geological and tectonic setting of other parts of the Winning Group (within the Southern Carnarvon Basin) and the present-day Red Sea rift. The unusually high silica content of the Windalia Radiolarite, together with the presence of sulfides, iron oxides, and carbonates, are characteristics similar to those of mineral deposits in brine pools of the Red Sea and could be related to fumarolic and hydrothermal activity associated with rifting. High base-metal and ferro-alloy index scores were also found in association with the Winning Group on AJANA (Sanders and McGuinness, 2000).

Barite concentrations are high in carbonaceous regolith over the Gearle Siltstone. Condon (1968) suggested barite was deposited as a precipitate during sedimentation, but Abeysinghe and Fetherston (1997) believed a nodular occurrence near Remarkable Hill on the western flank of the Giralia Anticline may have formed by supergene processes. South of Remarkable Hill, near the inferred trace of the Cardabia Transfer Zone, elevated As, Cd, Ni, Sb, Te, and V with scattered Ag and Sn in regolith suggest the possibility of sedimentary-hosted base metal mineralization along the western flank of the Giralia Range. Crostella and Iasky (1997, fig. 2) discussed the structure of the Giralia area using drilling, seismic, and gravity data. They identified a number of approximately northerly trending normal and reverse faults, in conjunction with the Cardabia Transfer Zone, beneath the Giralia Anticline area. Moors (1980), from a study of borehole temperatures, had shown several areas of anomalous geothermal gradients related to faults and other basement structures, which he attributed to possible fluid migration updip and along fault planes. Harrison (1985) argued that these faults may form suitable conduits for mineralized brines, enhancing the potential of base metal mineralization in the Southern Carnarvon Basin.

Carbonate-rich rocks of the Gneudna Formation, Moogooree Limestone, and Callytharra Formation have been explored for base metals. Harrison (1985) argued that the results of these exploration programs, coupled with epigenetic barite, galena, and sphalerite mineralization near Mount Sandiman Station on KENNEDY RANGE, provide evidence that mineralizing brines have been generated in the basin. Faulting along the Southern Carnarvon Basin – Gascoyne Complex margin may have provided conduits for mineralized fluids. However, most base metal components in regolith over the carbonate-rich units in the southeast of the project area are relatively low with only scattered, higher As, Cu, and Pb values.

There are moderate to high resistate-components index scores for regolith in samples near Minilya and Warroora stations. This largely detrital material has probably been derived from the Byro Group and Gascoyne Complex, which also have high resistate-components index scores. During most of the Pleistocene, Lake MacLeod was open to the sea near Warroora Station (Hocking et al., 1987). A barrier at the northern end may have resulted from localized uplift of anticlines northeast of Warroora Station and increased eolian activity, reducing Lake MacLeod to a restricted embayment and later into an evaporite basin (see **Regolith-materials mapping**). The elevated resistate-component levels near Warroora Station suggest this area may contain early outwash material from the Minilya and Lyndon rivers, reworked by coastal processes. Continued uplift and deposition in western areas may have diverted the Minilya and Lyndon rivers to their current course, now emptying into southeast and northern Lake MacLeod respectively. Harrison (1985) emphasized that coastal mineral-sand deposits form where siliciclastic material substantially exceeds the supply of carbonate material, a common situation adjacent to present or ancient river mouths. Heavy mineral fractions can be concentrated in the surf zone and transported by longshore drift, and ultimately deposited in dunes and along shorelines.

Relatively recent eustatic changes have formed raised shorelines within the Southern Carnarvon Basin. Denman and van de Graaff (1977) have described Pleistocene marine terraces in the Lake MacLeod area, typically associated with the Bundera Calcarenite, which includes both shoreline and dune deposits. These elevated deposits, in conjunction with favourable provenance (Gascoyne Complex and Byro Group), method of terrigenous supply (ancestral Minilya and Lyndon rivers), and high resistate-components index scores in regolith, suggest the Lake MacLeod area, particularly near Warroora and Minilya stations, may be prospective for economic deposits of mineral sands. Harrison (1985) also discussed the mineral-sand potential of the Eocene Merlinleigh Sandstone and Miocene Lamont Sandstone. Both these units contain fluviatile and marine sands, and probably received their terrigenous input from an ancestral Lyndon River. However, resistate-components index scores in regolith from near these units are typically low.

Platinum and Pd concentrations are commonly low in regolith throughout the project area (maximum 4 ppb). Some higher concentrations are associated with regolith derived from the Winning Group near Pleiades Hills, Winning Station, and the Giralia Anticline. A group of Pt values southwest of Nyang Station, near the Gascoyne Complex – Southern Carnarvon Basin contact, correspond with a broad, northerly trending gravity high (Geological Survey of Western Australia, 1999). However, all Pt and Pd values over the project area are close to the detection limit (up to 4 ppb) and should be interpreted with caution (see **Chemical analysis and quality control**).

The concentrations of Au are typically low in analyzed regolith from WINNING POOL – MINILYA. Gold values near the detection level are scattered throughout the project area; over the Gascoyne Complex, over parts of Lyons Group and Callytharra Formation, near Gnaraloo, Winning, and Mia Mia stations, and the Giralia Anticline and Gnargoo Range areas. The maximum concentration of 19 ppb (GSWA 170428) is associated with a number of other low Au values in regolith. The area is dominated by carbonate-rich material and eolian sands overlying rocks of the Byro Group near Burnerburnung Hill, and coincides with the inferred trace of the Cardabia Transfer Zone and other approximately northerly trending faults (Shevchenko, in prep.). However, care must be taken in interpreting these values as most are only just above detection and the reproducibility of the Au assays between the pulp and archive was poor (see **Chemical analysis and quality control**). The second highest Au value reported in regolith is 8 ppb (GSWA 170460, 13 km northeast of Lyndon Station) over Gascoyne Complex metasedimentary rocks. Although the reproducibility of Au in the archive was poor, the known Lyndon Station Au occurrence (in similar rock types 19 km to the northwest) adds potential for Au mineralization in the area.

The high pegmatite-index scores in numerous samples from the northeast of the project area suggest some potential for pegmatite-related mineralization, including Ta and W. Other high index scores are recorded near the Jailor Bore uranium prospect and the faulted contact between the Gascoyne Complex and rocks of the Middle Devonian – Lower Carboniferous. These areas may also contain pegmatites associated with major basement faulting.

A number of exploration programs targeting uranium have been undertaken on WINNING POOL – MINILYA. Carnotite mineralization is within calcrete at Jailor Bore, although only low U concentrations were reported in nearby regolith. Although the mineralization is in calcrete, the source of uranium may have been pegmatites of the Gascoyne Complex, as indicated by the elevated pegmatite-index scores for the area. Harrison (1985) discussed the potential of sedimentary-hosted uranium deposits in the Southern Carnarvon Basin in relation to possible uranium-rich source rocks, namely muscovite-bearing granitoids and pegmatites of the Gascoyne Complex. Targets over the Southern Carnarvon Basin have included the Moogooloo Sandstone, Gneudna Formation, and lower parts of the Winning Group, including the Yarraloola Conglomerate and Nanutarra Formation. The highest U concentrations in regolith for the project area are around lakes near Winning Station and in the eroded crest of the Giralia Anticline, both overlying rocks of the Winning Group. Elevated values are also recorded in regolith along the margins of Lake MacLeod.

The Wandagee Fault has been the target of an extensive diamond exploration program, concentrating on a cluster of diatremes and intrusions. Although it was concluded that no economically diamondiferous kimberlite rocks existed (Stockdale Prospecting Ltd, 1981), the association with major fault systems raises possibilities for further exploration (Harrison, 1985). A number of faults on WINNING POOL – MINILYA may represent major tensional fractures, which could act as sites for kimberlite intrusion.

Kojan et al. (1995) and Abeysinghe (1998) have discussed the potential of high-quality limestone resources in the Mandu, Tulki, and Trealla Limestones of the Cape Range area to the north of WINNING POOL – MINILYA. Transportation costs limit the location of mining operations, suggesting the Trealla Limestone within the project area would be a less favourable option than limestone units of Cape Range, which is in closer proximity to deep-water ports of the Exmouth Gulf. However, on WINNING POOL – MINILYA Trealla Limestone and associated calcrete, which is extensive in western areas, has been quarried for use in local road construction (Hocking et al., 1985). Three thousand tonnes of limesand have been extracted from a site near Warroora Station for construction purposes. Rock sourced from the Callytharra Formation and Moogooloo Sandstone has been used locally for paving and building stones (Hocking et al., 1985).

Semiprecious chalcedony (known as 'mookaite'), formed by the opaline silicification of the silica-rich Windalia Radiolarite, is located at Mooka Station on KENNEDY RANGE. Opaline silicification and porcellanization of the Windalia Radiolarite is commonly recorded in sample forms on WINNING POOL – MINILYA (Appendix 3), and good-quality, semiprecious, red- and white-banded agate forms nodules in sedimentary rocks on Wandagee

Station (Flint and Abeysinghe, 2000). Although so far limited to semiprecious stones, anecdotal evidence suggests conditions may be favourable for the formation of precious opal within the Winning Group.

The high silica content of some sand samples associated with silica-rich and siliciclastic lithologies has some economic potential. The silica-rich Windalia Radiolarite has been used for road construction and building on WINNING POOL – MINILYA (Hocking et al., 1985).

The barring of a former marine embayment and subsequent concentration of salt by evaporation formed bedded evaporitic deposits in Lake MacLeod. Dampier Salt operates large evaporation pans to the south on QUOBBA and in 1998 produced 1.26 Mt of salt and 792 852 t of gypsum (Fetherston and Abeysinghe, 2000). There is no production on WINNING POOL – MINILYA, although halite and gypsum are present in evaporitic sequences north of Lake MacLeod.

In summary, the potential mineralization on WINNING POOL – MINILYA includes:

- Base metals and ferro-alloy-related components in the Edmund Group (Mangaroon Syncline).
- Base metals and ferro-alloy-related components in the Winning Group near Winning Station, Pleiades Hills, and the Giralia Anticline.
- Base metals and ferro-alloy-related components in the carbonate-rich rocks on the western side of the Giralia Range.
- Base metals and ferro-alloy-related components in the carbonaceous rocks of the Byro Group.
- Ferro-alloy-related components from the southeast Gascoyne Complex and the Gascoyne Complex – Southern Carnarvon Basin contact.
- Mineral sands around Lake MacLeod in the vicinity of Warroora and Minilya stations.
- Gold mineralization in the Gascoyne Complex and anomalism in carbonate-rich material over rocks of the Byro Group near Burnerburnung Hill.
- Pegmatite-related mineralization in the northeast and southeast Gascoyne Complex typically associated with faulting.
- Uranium associated with the Winning Group near Winning Station and the Giralia Anticline, and also the margins of Lake MacLeod.
- Diamond potential associated with major tensional faults within the Southern Carnarvon Basin.
- Limestone and limesand resources associated with the Trealla Limestone and calcrete.
- Chalcedony formed from opaline silicification of the silica-rich Windalia Radiolarite and possibly precious opal associated with the Winning Group.
- Silica sands associated with silica-rich and siliciclastic lithologies.
- Evaporitic deposits of halite and gypsum associated with Lake MacLeod and marginal bedded deposits.

Summary and conclusions

Regional-scale regolith and geochemical mapping on WINNING POOL – MINILYA involved the collection of 1199 regolith samples (218 sheetwash, 485 stream-sediment, 24 soil, 454 sandplain, and 18 lake samples), representing a nominal sample density of one sample per 16 km^2. Each sample has been analysed for 48 components, comprising major-element oxides, LOI, trace elements, acidity–alkalinity (pH), and conductivity. These data are presented as either spot-concentration maps or speciality maps.

Regolith-materials mapping of WINNING POOL – MINILYA has used an expanded version of the GSWA regolith-classification scheme, which allows a greater range of regolith types and compositions to be defined (Hocking et al., in prep.). This was well suited to regolith classification within the project area, which consists of a broad range of regolith types overlying crystalline rocks of the Gascoyne Complex, sedimentary rocks and dolerites of the Edmund Group, and sedimentary rocks of the Southern Carnarvon Basin. The map has been compiled from Landsat imagery, aerial photography, Landsat synthetic stereo pairs, sample-site descriptions, and previous geological mapping (Hocking et al., 1985). Eolian sands and sandplain material (*E*, *S*) are the dominant regolith types on WINNING POOL – MINILYA and occupy over 36% by area collectively. Exposed-regime regolith (*X*) occupies the second greatest area (26%), largely in eastern parts of the project area associated with the Gascoyne Complex and strike ridges of the Gooch Range. The most extensive, single regolith type is eolian sand with abundant longitudinal dunes (E_l) dominating central parts of the project area (15% of total area). Undivided alluvium (*A1d*) is also common throughout WINNING POOL – MINILYA, occupies over 12% by area, and is particularly common near Minilya Station, representing the outwash floodplains of the Minilya River.

Regolith-materials mapping highlighted a number of sandplain morphologies and the influence of subsurface duricrusts and past alluvial activity in their formation. A relationship can be successfully established between the age of coastal eolian formations and their relative elevation, induration, and dune morphology.

Quality-control procedures have shown that precision and accuracy of laboratory and GSWA standard analysis are satisfactory, although some variation is seen in elements at low concentration and in elements resistant to complete dissolution. Difficulty in gaining reproducibility in some Au, Pt, Pd, and Sn analyses may be due to inhomogeneous distribution of these components in the sample, or lack of precision at concentrations approaching detection level. Quality-control methods show that low-level cross contamination of pulp material or from the milling processes is unlikely but cannot be completely ruled out. Weak inter- and intra-batch differences are indicated in some elements at concentrations near detection level (e.g. Ag, Pt, and Sn). Interpretation of these analytes in conjunction with the regolith-materials map suggest there may be geological explanations for low-level inter- and intra-batch variations. Size-fraction analysis shows there is little preferential enrichment in Ce, La, Nb, Ta, Th, and Zr concentrations in the fine fraction (<0.45 mm) compared to the standard regional gochemical mapping program analytical fraction (<2 mm to >0.45 mm).

Regolith chemical data are presented as a series of spot-concentration maps against a background of simplified geology. Data show that regolith chemistry is influenced by both parent rock and regolith-forming processes. The regolith composition of the southeast Gascoyne Complex is strongly influenced by the Minnie Creek Batholith, with metamorphosed dolerites and gabbros in conjunction with north-northeasterly trending dolerite dyke swarms adding a mafic signature to the regolith chemistry of this area. Northerly trending quartz veins that coincide with major basement faults may also exert influence on regolith chemistry in the southeast of the project area. The northeast Gascoyne Complex is charcterized by elevated pegmatite-related components in an area of northwesterly trending faults. Regolith composition from the Edmund Group, within the Mangaroon Syncline, shows an association strongly influenced by dolerite sills and black shales. The area also includes elevated base-metal associations, which are consistent with known Cu, Pb, and Zn anomalism at Coria Springs.

Middle Devonian – Lower Carboniferous sedimentary rocks lie in fault-bounded, structurally complex half grabens in the Gascoyne Complex. Regolith composition over these sedimentary rocks contains relatively high SiO_2, consistent with quartz-rich lithologies and silcretes in the area. Relatively low CaO suggests that the limestone units (Gneudna Formation and Moogooree Limestone) do not contribute as much to the regolith composition as siliciclastic units. Moderately high concentrations of resistate components reflect a provenance from the adjacent Gascoyne Complex, and may be of detrital origin. Localized elevated pegmatite and mafic components are in close proximity to a series of northerly trending basement faults, and are commonly associated with nearby quartz veins and metamorphosed dolerite and gabbro. Regolith composition over the Lyons Group and Callytharra Formation is dominated by detrital components, probably originally derived from the Gascoyne Complex and incorporated during glaciomarine to fluvioglacial activity. Other components with elevated concentrations over this unit are associated with limestones of the Callytharra Formation. Regolith composition over the Wooramel, Byro, and Kennedy Groups in the central south of the project area is characterized by a broad range of elevated components, mostly associated with black shale units (the Bulgadoo and Quinnanie Shales). Towards the north, these high concentrations become progressively lower as exposed-regime regolith gives way to more carbonate-rich and eolian sand-dominated terrain.

Regolith over the Cretaceous Winning Group is dominated by various types of sandplain, with correspondingly high SiO_2 concentrations. In the vicinity of Pleiades Hills, Winning Station, and in the eroded crest of the Giralia Anticline, a number of component concentrations are near maximum for WINNING POOL – MINILYA, and are mostly associated with the Windalia Radiolarite and Gearle Siltstone. The Giralia Anticline area is characterized by exceptionally high concentrations of Ba in regolith possibly associated with beds of nodular barite. The Toolonga Calcilutite, Korojon Calcarenite, and Miria Formation in the northwest of WINNING POOL – MINILYA are largely covered with carbonate-rich duricrust, various sandplains, alluvium, and local exposures of limestone. Elevated CaO and LOI values are focused on areas of exposure with the majority of the regolith characterized by moderate levels of largely resistate-related components.

Regolith over the Cardabia and Giralia Calcarenites is dominated by exposed-regime material along the Giralia Range and in the Salt Marsh Anticline, and characterized by elevated CaO, LOI, and Cd concentrations. A number of other elements are high over the adjacent Lamont Sandstone and Trealla Limestone, which also include resistant components and those typically associated with sedimentary-hosted base metal mineralization. Elevated resistate-component concentrations near Warroora Station suggest this area contains early outwash material of the Minilya River, reworked by coastal action. The course of the Minilya River may have been diverted by uplift of coastal anticlines and increased Pleistocene eolian activity causing barring north of Lake MacLeod. Regolith composition over the Bundera Calcarenite and coastal lake deposits typically shows a carbonate and evaporitic association with signs of deposition of resistate detrital material in outwash floodplains of the Minilya River.

Statistical treatment of regolith chemical data has been undertaken to test the composition of sand-dominated regolith types to compare the chemistry of quartzofeldspathic regolith over the Gascoyne Complex, and to compare the chemistry of carbonaceous regolith over Permian and Cretaceous lithologies. Overall, the various sand units have similar compositions; however, statistically significant differences for a number of components suggest the combined effect of bedrock, alluvial, and eolian processes control chemical composition. Statistical differences between older and younger coastal eolian deposits may reflect increased leaching of surface carbonate material in the older unit. Quartzofeldspathic exposed-regime regolith derived from granitoid and metamorphic rocks of the Gascoyne Complex shows statistically significant differences in a small number of components, suggesting different parentage. Comparison between carbonaceous regolith types shows statistically significant differences for several analytes, including greater carbonate-related components and Ba over Cretaceous rocks, and high SiO_2 and Pb over Permian rocks.

Regolith chemistry has been used to construct six additive element-index maps, which highlight areas of potential mineralization. The chalcophile index highlights the areas around Winning and Wandagee stations, the Giralia Anticline, and Pleiades Hills. The distribution of elevated base-metal, ferro-alloy, and black-shale index scores is similar to that of the high chalcophile scores, but also emphasizes the potential of the Edmund Group rocks in the Mangaroon Syncline. The resistate components index shows enrichment over the Gascoyne Complex, Byro Group, and outwash from the Minilya River in the southwest, whereas the pegmatite index highlights the northeast of the project area and the vicinity of Lyndon Station.

Areas of lower pH regolith on WINNING POOL – MINILYA include the Gascoyne Complex and sand-dominated central areas, whereas more alkaline regolith in the western parts of the project area are associated with carbonate-rich rocks and duricrust. Most conductivity values for the project area are low, but higher values are in the vicinity of Lake MacLeod associated with beds of evaporite.

Regolith geochemical mapping on WINNING POOL – MINILYA has shown several areas worthy of further investigation in terms of economic geology. These include the base metal potential of the Edmund, Byro, and Winning Groups and Neogene rocks on the western flank of the Giralia Range. Localized, elevated Au concentrations in regolith are recorded over the Gascoyne Complex and in an area of mixed regolith types in the vicinity of the Cardabia Transfer Zone in the central project area. Pegmatite-associated mineralization may be present in the northeastern and southeastern parts of the project area associated with rocks of the Gascoyne Complex, and evaporite and mineral-sand concentrations have been identified in regolith from coastal areas around Lake MacLeod.

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Appendix 1

Gazetteer of localities

Locality	*MGA coordinates* *Easting*	*Northing*
12 Mile Bore	230848	7438407
Airey Hill	178552	7446487
Burnerburnung Hill	249930	7381832
Cardabia	172583	7440594
Cardabia Bore	204850	7426494
Coral Bay	169437	7437290
Coria Springs	338414	7397220
Gnaraloo	145832	7360799
Jailor Bore	329097	7372358
Lyndon	320889	7384683
Mia Mia	237727	7411771
Mia Mia Pool	217402	7413340
Middalya	272627	7353750
Minilya	191306	7359193
Moogooloo Hill	269069	7388032
Nyang	299335	7451502
Pleiades Hills	288000	7402000
Quail Spring Well	315734	7383195
Remarkable Hill	201180	7450110
Stanley Hill	177028	7437243
Towera	307357	7435845
Wandagee	250455	7369351
Wandagee Hill	239988	7361740
Warroora	172328	7399566
White Hills	313500	7410000
Williambury	311389	7359596
Windalia Bore	274858	7422618
Winning	248245	7437076
Winning Hill	332355	7409399

NOTE: All coordinates have been projected to MGA Zone 50 coordinates

Appendix 2

Open-file surface geochemistry for WINNING POOL – MINILYA as at November 1999

Key

ID no.	Project reference number allocated for these notes (see Plate 3)
M no.	GSWA project reference number An asterisk beside the M number indicates that not all the samples for the listed activities fall within WINNING POOL – MINILYA; that is, the total number of samples includes some taken on adjacent sheets
I no.	The Item number, or DME library reference number for a group of related open-file reports on microfiche; this number replaces the M number for project identification
A no.	GSWA report reference number
Year	The year that the report was written
Activity type	The geochemical exploration activity (drilling details are only included if analytical samples are taken within 0–4 m depth): NGRD: Includes rock-chip, lag, costean (up to 4 m depth), and grab samples RAB: Rotary air blast drilling RC: Reverse circulation drilling SOIL: Surface or shallow soil samples SSED: Stream sediment
No.	The number of analytical samples
Method	The analytical method used to determine the elements listed: AAS: Atomic absorption spectroscopy BCL: Bulk cyanide leach FA: Fire assay ICP-MS: Inductively coupled plasma mass spectrometry ICP-OES: Inductively coupled plasma optical emission spectrophotometry MS: Mass spectrometry SIE: Selective ion electrode XRF: X-ray fluoresence
Activity elements	The elements for which analyses were carried out
Description	Various sample details such as the sieve size fraction, sample density, and so on, depending on the information provided in the report

NOTES: For public use all open-file company reports are provided on microfiche in the 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 geochemical surveys for

ID no.	*M no.*	*Year*	*I no.*	*A no.*	*Activity type*	*No.*	*Method*	*Activity elements*
1	*1623	1974	146	5401	RC	240		U_3O_8,Sr,Rb
2	*1697	1973	656	5622	NGRD	79		Cu,Co,Pb,Zn,Ni,U,Ag
3	*2143	1978	665	8038	NGRD	226	AAS	Cu,Ni,Ag,Pb,Zn,Co,Cr
					"		XRF	U_3O_8,Th,Bi
4	*2356/2	1980	2039	9238	SOIL		AAS	Cu,Pb,Zn,Ag,Cd,Co,Ni
					NGRD		AAS	Cu,Pb,Zn,Ag,Cd,Co,Ni,Mn
					"		XRF	Mo,Sn,W,As,Bi,Sb,Au,U
					SSED		AAS	Cu,Pb,Zn,Ni,Co,Au,Mo,Li,As,Bi,W
					"		XRF	U,Sn
5	*2356/3	1980	2553	16568	SOIL		AAS	Cu,Pb,Zn,Ag,Cd,Co,Ni
					"		XRF	U
					NGRD		AAS	Cu,Pb,Zn,Ag,Cd,Co,Ni,Mn,Li
					"		XRF	Mo,Sn,W,As,Bi,Sb,Au,U
				16569	SSED		AAS	Cu,Pb,Ni,Zn,Co,Ag,Cd,Mo,Li,As,Bi,W
					"		XRF	Sn,U
6	2460	1980	2656	8923	SOIL		AAS	Cu,Ag,Pb,Zn,Cd
					NGRD		AAS	Cu,Pb,Zn,Ag,Cd,Co,Ni,Mn
					"		XRF	Mo,Sn,W,As,Bi,Sb,Au,U
					SSED			Cu,Ni,Pb,Zn,Sn,W,Mo,Bi,Li,As,Sb,Co,Cr,V,Ag,Nb,Ta,U,Mn
7	*2817/2	1982	1638	11763	SOIL		AAS	Cu,Pb,Zn,Ni,Co,Mo,V,K
					"			U
					"		XRF	As
					SSED		AAS	Cu,Pb,Zn,Ni,Co,Mo,V,K
					"		XRF	As,Sb,W,U,Th
					"			U
					NGRD		AAS	Cu,Pb,Ni,Co,Fe,Mn,Zn,K,V
					"		XRF	U,Th,As,Mo,W,Bi,Ce,La,Nb,Sb,Se,Sn
					"			U,U_3O_8,ThO_2
				11764	SSED	>2575		Cu,Pb,Zn,Ni,Co,Mn,Ag,U,Bi,As,Fe,Ca,Cr,Mg,Al,Ti,V,Ba,Sr,Mo
7a		1983		12165	SOIL	1800	AAS	Cu,Pb,Zn,Ni,Co
					"		XRF	Bi
					"			U_3O_8
8	3636/2	1986	4067	18876	NGRD	82		$CaSO_4.2H_20$
9	*4515	1988	3835	24001	RC	148	FA/AAS	Au,Pt,Pd
					"		AAS	Bi,Pb,Ag,Mo,As
					"		ICP	Cu,Zn,Ni,Ba,Na,Fe,Al,K,Ca,Mn,Mg,Zr,Th,Ce,La,Nb,Co,Cr,P,V,B
					"		Fluorimetry	U
				24003	SOIL	481	FA/AAS	Au,Pt,Pd
					"		AAS	Bi,Pb,Ag,Mo,As
					"		ICP	Cu,Zn,Ni,Ba,Na,Fe,Al,K,Ca,Mn,Mg,Zr,Th,Ce,La,Nb,Co,Cr,P,V,B
					"		Fluorimetry	U
					RAB		FA/AAS	Au,Pt,Pd
					"		AAS	Bi,Pb,Ag,Mo,As
					"		ICP	Cu,Zn,Ni,Ba,Na,Fe,Al,K,Ca,Mn,Mg,Zr,Th,Ce,La,Nb,Co,Cr,P,V,B
					"		Fluorimetry	U

WINNING POOL – MINILYA as at November 1999

Description
60 RC holes totalling 835 m. Samples taken at one metre intervals downhole. Airbourne radiometic–magnetic survey also conducted over tenement
Rock chips from irregular quartz vein at Ten Mile Well averaged 1.9% Cu
Rock-chip samples randomly collected along main mineralization. Twenty nine samples assayed 100 ppm U_3O_8 or above Bi not assayed for all samples
Number of phases with grid spacings of 100 ⑨ 25 m and 200 x 50 m, sieve: -80 mesh Six lines of rock-chip samples over soil anomalies and ironstone outcrops at spacing of 12 m. Some ferruginous grab samples Density of one sample in 3 km^2. -20 + 80 mesh and -80 mesh fractions assayed
Sieve: -80 mesh Rock-chip samples Stream-sediment samples of -20 + 80 mesh, some heavy mineral concentrate samples of -80 mesh fraction
Sampling grid of 200 m ⑨ 50 m, sieve: -80 mesh Rock chips collected over selected ironstone outcrops at 2 m intervals along four lines 100 m apart Stream-sediment sampling conducted in several phases, some samples reanalysed for Sn, W, Nb, U
Part of orientation survey. Gully soils sieved to -80 mesh in laboratory from original -20 mesh fraction Part of orientation survey. Includes magnetic concentrate samples from active stream beds, generally around -20 mesh in grain size Part of orientation survey. Includes rock samples (rubble and float), handpicked ironstone samples and more rounded pisolitic ironstone samples Three phases of follow up stream-sediment sampling Sieve: -80 mesh. Samples chosen from aerial photos
Average grade of deposit is 91.2%. One high grade sample (95% gypsum) was also analysed for acid insolubles, NaCl, CO_2, Fe_2O_3, Al_2O_3, and MgO
Sampled at 1 m intervals Two phases of soil sampling, 30 orientation samples (sieve: -20 + 40, -40 + 60, -60 + 80, and -80 mesh) and 451 follow-up samples (sieve: -40 + 80 mesh) 4 040 m of drilling

Appendix 2.

ID no.	*M no.*	*Year*	*I no.*	*A no.*	*Activity type*	*No.*	*Method*	*Activity elements*
9 (cont.)	*4515	1989	3835	27159	SOIL	83		U,Bi,As,Cu,Pb,Ag,Zn,Co,Ni,Cr,V,Fe,Mn,P,Ba,Ca,Na,K,Mg,B,Al
					"			Zr,Ce,La,Nb,Th,Mo,Sn,W,Au,Pt,Pd
					NGRD	90		U,Bi,As,Cu,Pb,Ag,Zn,Co,Ni,Cr,V,Fe,Mn,P,Ba,Ca,Na,K,Mg,B,Al
					"			Zr,Ce,La,Nb,Th,Mo,Sn,W,Au,Pt,Pd
					RAB	1		U,Bi,As,Cu,Pb,Ag,Zn,Co,Ni,Cr,V,Fe,Mn,P,Ba,Ca,Na,K,Mg,B,Al
					"			Zr,Ce,La,Nb,Th,Mo,Sn,W,Au,Pt,Pd
					RC		AAS	Au,Pt,Pd,Ag,Pb,Bi,Cu
					"		Nitrous oxide–AAS	As,Mo
					"		Vapour hydride–AAS	As,Sn
					"		Fluorimetry	U
					"		ICP-OES	Cu,Na,Mg,P,K,Ca,V,Mn,Fe,Co,Ni,Zn,Zr,Nb,Ba,La,Ce,Th
					"		Colorimetry	W
10	6137	1989	3875	27275	SSED	16	BCL	Au,Pt,Pd,Cu,Ni,Zn,Ag
					NGRD	16	AAS	Au,Ag,Cu,Pb,Zn,Pt,Pd
11	*6177	1989	4106	27454	SOIL	72	AAS	Ag,Cu,Pb,Zn
					SSED	27	AAS	Ag,Cu,Pb,Zn
12	*6333	1989	4862	30234	SSED	336	ICP-MS	Ag,Bi,Mn,Mo,Pb,U,W,P,V,Zn,Ni,Cu,Sr
					"		ICP	Au,Pt,Pd
					"		XRF	Ba
					"		SIE	F
					SSED	13	ICP-MS	Ag,Bi,Mn,Mo,Pb,U,W,P,V,Zn,Ni,Cu,Sr
					"		ICP	Au,Pt,Pd
					"		XRF	Ba
					"		SIE	F
					SSED	17	ICP-MS	Mn,Mo,U,P,Sr,V
					NGRD	53	ICP-MS	Ag,Bi,Mn,Mo,Pb,U,W,P,Zn,Ni,Cu,Sr
					"		ICP	Au,Pt,Pd
					"		XRF	Ba,As
					"		SIE	F
					NGRD	85	AAS	As,Cd
					"		ICP-MS	P,Ba,U
					"		ICP	P_2O_5,SiO_2,MnO,Fe_2O_3,Na_2O,MgO,K_2O,Al_2O_3
					NGRD	5	ICP	P_2O_5,Al_2O_5,Fe_2O_3,SiO_2,MgO,CaO,MnO,Na_2O,K_2O,Cd
					"			S,C
					"		SIE	F
					"		ICP-MS	U,Ba
13	6834	1990	6018	32111	SSED	133	BCL	Au
					"			
					SOIL	163	FA/ICP-MS	Au
					"		AAS	Cu,Pb
					"		ICP-OES	As
					"		Aqua Regia/AAS	Au
					"		AAS	Cu,As
					NGRD	100	FA	Au
					"			Ag,As,Cu,Pb,Zn
13a	6834	1992	6018	35357	NGRD	70	FA	Au
					"		AAS	Cu,Pb,Zn,Ag
					"			As
					SOIL	60	FA/AAS	Au
					SSED		BCL	Au
14	7038	1991	7158	34571	SOIL	1065	AAS	Cu,Pb,Fe,Mn,Zn
					"			
					NGRD	74	AAS	Cu,Pb,Zn,Ag,Fe
					RC	3		Mn,Fe,Pb,Zn,Cu,Ag

(continued)

Description
Auger holes, maximum depth 2 m
RAB samples, 2–3 m depth
18 RC holes. Sieve: -80 and -200 mesh. Summary statistics, histograms and scatter graphs for the dataset are presented
Stream-sediment sampling conducted over part of the Bangemall Group
Generally poor results, some anomalous samples over the site of the previously discovered, subeconomic 'Inco Anomaly'
Samples collected from streams draining from the Moogooree Limestone, results were disappointing
Dry screened to -200 mesh, several analytical problems encountered, statistical analysis of data is included in the report
Anomalous Au values appear to cluster along the Giralia Fault
Wet screened to -200 mesh
Samples from phosphate rich areas within drainages. Four separate fractions: -40 + 80 mesh, -80 + 200 mesh, -200 mesh, -2 mm + 1 mm
Whole rock samples
Representative phosphate samples and >2 mm nodule samples taken from costean walls
Benefication samples collected from five costeans
Samples collected in three phases from active stream channels. Sample weight of 2 kg. Sieve: -3 mm. BCL anomalies (up to 9.5 ppb Au) indicated over an area of 2 ⑨ 7 km (1:25 000; 1:10 000)
Samples from shovelled pits at 50 m spacing. Sieve: -80 mesh. Two phases of sampling. No significant anomalous zones (1:10 000)
Rock-chip – grab sampling during routine mapping. Best results from a 700 m long silicified arenite ridge with disseminated pyrite. Maximum assay of 0.39 g/t Au, with elevated Pb and As (1:25 000)
33 grab samples taken during geological mapping. Five traverses over Billy Goats Knob produced 37 rock chip samples (1:25 000)
50 ⑨ 200 m grid. Samples collected by shovel from 10–50 cm depth. Single high Au value of 1400 ppb (1:25 000; 1:10 000)
(1:25 000; 1:10 000)
Soil sampling carried out over gridded areas: 200 m ⑨ 50 m; 100 m ⑨ 50 m; 50 m ⑨ 50–100 m. Maximum zinc assay of 390 ppm. 500 m ⑨ 500 m irregular zinc anomaly outlined (1:10 000; 1:5 000)
Rock chip - collected over gossanous outcrop. Maximum values of 2 300 ppm Pb and 2 400 ppm Zn (1:10 000; 1:5 000)
Weakly disseminated galena mineralization encountered in all three holes (1:5 000)

Appendix 2.

ID no.	*M no.*	*Year*	*I no.*	*A no.*	*Activity type*	*No.*	*Method*	*Activity elements*
15	7296	1992	6189	35284	NGRD	30	MS	Au,Cu,Zn,Ag,Pb
					"		AAS	As,Sr,Mo,Ba,U
16	*7606	1992	6473	36714	SSED	276	ICP	Cu,Pb,Zn,Ag,Fe,Mn
17	8219/1	1993	8607	39589	SSED	55		
18	9920	1996	9750	47059	SSED	78	BCL	Au,Cu,Ag
					"		AAS	Au,Mn,Fe,Co,Ni,Cu,Zn,Ag,Pb
					"		ICP-MS	As,Mo,Sb,W,Bi
					NGRD	12	AAS	Au,Mn,Fe,Co,Ni,Cu,Zn,Ag,Pb
					"		ICP-MS	As,Mo,Sb,W,Bi
		1997		51558	SSED	31	BCL	Au
					SOIL	20	AAS	Au,Mn,Fe,Co,Cr,Cd,V,Ni,Cu,Zn,Ag,Pb
					"		ICP-MS	As,Mo,Sb,Bi
					NGRD	7	AAS	Au,Mn,Fe,Co,Cd,Cr,V,Ni,Cu,Zn,Ag,Pb
					"		ICP-MS	As,Mo,Sb,Bi
19	10331	1997	9220	49942	SSED	22	BCL	Au,Pd
					"			As,Cu,Ni,Pb,Zn
					SOIL	270		Au,As,Cu,Pb,Zn
19a				49943	SSED	207	BCL	Au,Pd
					"			As,Cu,Ni,Pb,Zn
					"	148	FA	Au,Pd
					"			As,Ag,Cu,Ni,Pb,Zn
					SOIL	28		Au,As,Cu,Pb,Zn
					NGRD	20	FA	Au
					"			Ag,As,Ba,Cu,Ni,Pb,Zn
19b				49944	SSED	202	BCL	Au,Pd
					"			As,Cu,Ni,Pb,Zn
					"	126	BCL	Au,Pd
					"			Ag,As,Cu,Ni,Pb,Zn
					SOIL	39		Au
					"			
					"	270		Au,As,Cu,Pb,Zn
					"			
					NGRD	20	FA	Au

(continued)

Description
Rock-chip – grab samples of 1–2 kg. Five samples with >100 ppm Zn. Maximum values of 70 ppm Cu, 81 ppm Pb, and 340 ppm As (1:40 000)
Samples taken from streams draining exposed Lower Proterozoic metasediments. Sample density 1 per 4.5 km^2. Sieve: -80 mesh (1:100 000)
Samples inspected for chromite, pyrope, ilmenite, picroilmenite, Ti-magnetite, and garnet. Some species were analysed by electron microprobe
12 stream samples assayed greater than 1.00 ppb. Sample weight of 2.5 kg. Sieved to -0.5 mm at site. Collected from channel margin and bank facies
Sample weight of 200 g. Sieved to -80 mesh at site. Collected from channel margin and bank facies
Surface samples of outcrop taken at small mine workings in the area
Sample weight of 2.5 kg. Sieved to -0.5 mm at site. Collected from channel margin and bank facies
Sample weight of 200 g. Sieved to -80 mesh at site. Each sample is a composite of 5 or 6 pits (15 cm) within 30 m radius of sample site.
Best soil result was 33 ppb Au from the Vindaloo prospect
Surface samples of outcrop. Best result of 0.1 g/t Au from the Vindaloo prospect
11 first pass and 11 follow-up samples comprising fine overbank material adjacent to active stream channels. Weight of sample 2 kg. Sieved to -80 mesh
200 g sub-samples of the -80 mesh fraction taken from 17 of the original 22 samples (1:40 000)
Samples collected at depths of 5–20 cm over a 40 ´ 400 m grid (Clark Well Grid). Samples sieved on site to -80 mesh. Weight of sample 100–200 g (1:10 000)
Sample density of 1 per 0.5 to 1.0 sq km. Sample weight of 2 kg. Sieve -80 mesh (1:40 000)
200 g subsamples of the -80 mesh fraction taken from original 2 kg sample
Second phase of sampling conducted to confirm first phase anomalies (1:40 000)
Two pace and compass traverses. Sample depth 10–20 cm. Sieved on site to produce 100–200 g of -80 mesh material (1:40 000)
Rock-chip samples collected during follow-up reconnaissance of stream-sediment and soil geochemical anomalies (1:40 000)
Reconnaissance samples with a density of 1 sample per 0.5 to 1.0 sq km. Sample weight of 2 kg. Sieve -80 mesh (1:40 000)
200 g subsamples of the -80 mesh fraction
Follow-up sampling. Sample weight of 2 kg. Sieve -80 mesh. 13 samples mistakenly analysed for Au and Pd by a fire assay technique (1:40 000)
200 g subsamples of the -80 mesh fraction (1:40 000)
4 pace and compass soil traverses, 40 m interval on traverses 1 and 2, 100 m on lines 3 and 4. Sample weight 100–200 g. Depth of sampling 5–20 cm Sieve -80 mesh (1:40 000)
Samples collected at depths of 5–20 cm over a 40 ⑨ 400 m grid (Clark Well Grid). Samples sieved on site to -80 mesh. Weight of sample 100–200 g (1:10 000)
Rock-chip samples collected during follow-up reconnaissance of stream-sediment and soil geochemical anomalies (1:40 000)

Appendix 3

Summary of sampling procedure, regolith classification, and analytical procedures

Regolith sampling

The aim of the Geological Survey of Western Australia's (GSWA's) regolith sampling program is to sample regolith from sites representative of the 4 × 4 km sampling polygon of interest. The preferred sampling medium is active stream sediment, sampled from lower order streams draining the sample polygon. In areas where drainage is absent or only weakly developed, sheetwash (colluvium), soil, sand, or lake sediment is sampled. Sampling sites are chosen using Landsat Thematic Mapper (TM) imagery and topographic maps, combined with a 4 × 4 km grid overlay. The site locations are digitized and assigned a unique site name made up of part of the relevant 1:100 000 map sheet name and a number. For example, GRA95 would correspond to site 95 on the GRANITE PEAK* 1:100 000 sheet (on the NABBERU 1:250 000 sheet).

The actual sampling site in the field is determined by the geologist, who can move the site from the designated position in order to facilitate access, or avoid areas of human or animal activity, or areas of standing water.

Stream sediments

Stream sediments in single, well-defined channels are sampled by trenching perpendicular to the flow direction. Narrow streams are sampled from pits excavated along their length, whereas braided stream systems are sampled from pits in several individual channels.

Sheetwash (colluvium) or soil

Sample sites are selected towards the centre of the 4 × 4 km polygon. Where a clear slope direction can be identified, regolith is composited from three pits excavated 30 m apart, perpendicular to the slope direction. Where no clear slope direction can be identified, regolith is sampled from three pits forming the apices of an equilateral triangle, whose sides are 30 m long.

Lake sediments

Lake sites are chosen to maximize ease of access. They are sampled as for sheetwash with no discernible slope.

* Capitalized names refer to standard 1:100 000 and 1:250 000 map sheets.

Sandplain

In areas of active sand dunes, sandplain samples are taken from three pits along the swale. In sandplain areas lacking active dunes, sampling is carried out as for sheetwash sites.

Prior to excavating pits or trenches, the top 5–10 cm of material is removed to minimize any surface-related contamination. Pits and trenches are excavated to a depth of 30 cm. If the excavated material is sufficiently dry, it is sieved at the site to –6 mm through a plastic sieve into a graduated sieve pan, then thoroughly mixed using a small shovel. Regolith, either sieved or unsieved, is divided into an archive sample (weighing about 3 kg) and an analytical sample (weighing about 2 kg) using graduated rings in the sieve pan. Information such as the unique GSWA sample number, site number, a map sheet identifier, and the relevant geologist's initials are recorded on each bag. A soft aluminium tag, on which the GSWA number is written, is included with the analytical sample. Analytical and archive samples are distinguished by the use of different-coloured nylon bag ties.

Sample-recording form

An example of the sample-recording form is shown in Figure 3.1. At each sampling site, the sample's MGA coordinates (GDA94 grid, read from a hand-held GPS), the sample-site number, GSWA number, sampling date, sampler's initials, and nature of sample (e.g. stream, sheetwash, channel, or pit) are recorded. The cross section is used to record the position of the sample in an idealized landform profile. The composition of the regolith is recorded in terms of iron-rich, lithic, and non-lithic components, using a series of letters signifying abundance (i.e. **A**bundant: >30%; **C**ommon: 5–30%; **R**are: 1–5%; **T**race: <1%). Within each category, the relative abundance of each component is recorded using a numerical system from 1 (most abundant) to >1 (least abundant), or the A, C, R, T designations. Fresh bedrock-fragment types (if present) are recorded in the same way. Fields also exist for recording the nature of the surrounding regolith, any grain coatings, nature of fine-grained material, nature and distribution of bedrock and secondary units, and characteristics of the stream site (if appropriate). A free-form section (Remarks) allows for specific entries pertinent to the site that are not covered in the preceding sections.

Regolith-materials classification

Three regolith-materials classification schemes have been used during the course of the GSWA regional regolith and

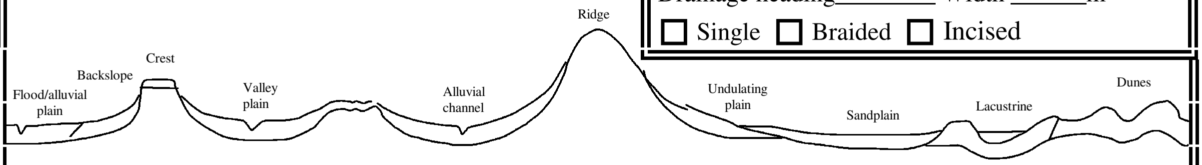
WINNING POOL - MINILYA

Sheet SF 49/50 - 16/13 **Zone** 49/50	**Loc/n No**____________	**GSWA No**____________	**Date**__________
Site Ref__________________	__________________ **E**	__________________ **N**	**Sampler**_______

☐ Channel ☐ Pit/hole ☐ Single Point ☐ Multipoint ☐ Shtwash ☐ Creek ☐ Soil ☐ Lake ☐ Sandplain

Drainage heading________ Width ______m

☐ Single ☐ Braided ☐ Incised



Regional Site Description (Geomorph, veg canopy, hydro etc):

Surrounding (200m) regolith code Left_________ Right _________(facing downstream/slope).
Regolith material description:

Surface regolith material: ___%clasts ___%Sand ___%Clay ___%Other___________ Colour ________________

Downhole regolith material: ___%clasts ___%Sand ___%Clay ___ %Other___________ Colour _______________

Sieved to size Y/N %Osize____ Depth: ______

SURFACE CLASTS ☐ Gravel (2-5mm) ☐ Stones (5-64mm) ☐ Cobbles (64-256mm) ☐ Boulders(>256mm)
Abundant : >30% Common : 5-30% Rare : 1-5% Trace : <1%

Iron-rich Abnt/**C**omn/**R**are/**T**r ☐	**Lithic A**bnt/ **C**omn / **R**are/ **T**r ☐	**Non-Lith A**bnt/**C**omn/**R**are/**T**r ☐	
☐ Pisoliths	☐ Saprolite fragments	☐ Feldspar	☐ Quartz (sand)
☐ Nodules ☐ Ferrug. Granules 2-4mm	☐ Saprock Fragments (below)	☐ Calcrete	☐ Other_________
☐ Ferrug. duricrust	☐ Fresh B'rock frag's (below)	☐ Hardpan	________________
☐ Gossan fragments	☐ Vein quartz	☐ MnO_2	________________
☐ Ferrug lithic fragments	☐ Other Silica	☐ Silcrete	________________

Clast Lithology (F= Fresh, S= Saprock)

☐ *M*afic	☐ *G*ranitic	☐ *S*andstone	☐ *C*hert	______________________
☐ *U*ltramafic	☐ Quartzite	☐ *Ark* / *G*wk	☐ *C*arbonate	______________________
☐ *F*elsic	☐ *BIF*	☐ *S*hale/Siltstone	☐ Other	______________________

Secondary coating on ☐ **clasts and/or** ☐ **grains:** ☐ Fe ☐ Mn ☐ Silica ☐ Carbonate ☐ Clay ☐ Salt

Primary and Secondary Lithological Units

Rock O/c Dist. Dir. 1.____________________ ____ m _____ 2.____________________ ____ m _____
3.____________________ ____ m _____ 4.____________________ ____ m _____

Secondary Units Nearby: ☐ Hardpan ☐ Consolidated Colluvium ☐ Calcrete ☐ Silcrete ☐ Duricrust
☐ Mottled Zone ☐ Saprolite ☐ Saprock ☐ Gyps Dune ☐ Sand Dune ☐ Salt

REMARKS (photos, contamination, anthropogenic influence etc)

Figure 3.1. Sample recording form for WINNING POOL – MINILYA

geochemical mapping program. All three are based on the regolith–landform RED scheme of Anand et al. (1993) and Anand and Smith (1994), where regolith is classified according to its position in an idealized landform profile as relict (R), erosional (E), or depositional (D). Relict-regime regolith is commonly in areas of higher topographic elevation (e.g. upland surfaces and plateaus), and includes areas of siliceous and ferruginous duricrust ('laterite'). The erosional regime includes areas of outcrop and subcrop where there is a net loss of material caused by downslope transport. Areas of net material gain comprise the depositional regime, including active alluvial channels, areas of sheetwash, overbank deposits, sandplain, and lakes.

The three schemes reflect an ongoing change in the focus of the GSWA's regolith geochemistry program, from relatively simple granite–greenstone associations of the Yilgarn Craton to more complex associations such as the Capricorn and Albany–Fraser Orogens.

Maps produced early in the GSWA regional regolith and geochemical mapping program focused on Archaean granite–greenstone associations of the Yilgarn Craton (e.g. MENZIES 1:250 000: Kojan and Faulkner, 1994; LEONORA 1:250 000: Bradley et al., 1995), which had few regolith–landform divisions, reflecting the lack of relief and limited number of lithologies. Regolith was subdivided according to its landform position (using R, E, D), slope position, and lithology. For example, in the erosional regime, E2v corresponded to erosional-regime regolith (E) derived from mafic igneous rock (v) that was upslope (2) from lithologically similar material that would be termed E4v. Alluvium of the depositional regime was separated using numerical qualifiers, such as DA4 (alluvium in active alluvial channels), DA5 (overbank deposits), DA7 (playa lake and associated deposits), and DA8 (calcrete). Sandplain was denoted as D9. This system has drawbacks, in that it only works well for lithologically simple map sheets, relies on a qualitative determination of slope position, and requires identification of the parent rock type to indicate the composition of regolith — the latter was commonly difficult for fine-grained, better sorted regolith, such as that of the depositional regime.

The shift in focus of the GSWA's regolith geochemistry program to Proterozoic successions of the Capricorn Orogen involved a change to map sheets with a relatively diverse lithology and physiography, combined with a less arid climate. This resulted in an increase in the number of regolith–landform divisions and increasingly complex regolith–landform maps. Several factors prompted a revision of the regolith-classification scheme. These included a need to simplify the regolith–landform maps, produce a more objective classification scheme, and introduce criteria that would enable the compositional classification of regolith independent of parent rock type. This change in scheme also coincided with the need for a universal regolith-classification scheme that could be used throughout GSWA.

The revised scheme retained the regolith–landform approach, and used a set of 11 primary codes for the subdivision of regolith in terms of landform position (Table 3.1). These codes aimed to satisfy a wide range of physiographic associations. The issue of regolith composition was addressed by a series of secondary codes, including some designations for common regolith types (e.g. h: hardpan; w: consolidated colluvium) that were not strictly compositionally based. These secondary codes highlighted the composition of the regolith rather than the parent rock type. In situations where the parent rock type was identifiable (usually in the erosional regime), this could be designated using a set of tertiary codes (Table 3.1)

This revised scheme relied on placing the regolith in an idealized landform profile, and making basic macroscopic and mesoscopic (hand lens) observations about regolith composition. The scheme did not rely on detailed knowledge of regolith-forming processes. The revised scheme resulted in a reduction in the number of regolith–landform types, and hence a more simple regolith–landform map. In addition, the revised scheme allowed a more rigorous approach to statistical analysis of regolith chemistry according to regolith type, as there were usually larger sample populations for each regolith–landform subdivision.

Following implementation of this revised regolith-classification scheme on several GSWA 1:250 000 regolith–landform maps (e.g. MOUNT EGERTON: Morris et al., 1998; TUREE CREEK: Coker et al., 1998), several improvements were made to the scheme, as discussed by Hocking et al. (in prep.). These changes included expansion and some modification of the primary (environment or process), secondary (compositional), and tertiary (parent rock or cement) code sets, and the optional use of subscripts to primary, secondary, and tertiary codes to allow further subdivision of regolith.

An example of this approach to describe a gravel bar in an alluvial channel derived from ferromagnesian volcanic rock (basalt) would result in the code $A_g mv_b$, where A is a primary code denoting an alluvial environment, and the subscript ($_g$) indicates a gravel bar. The secondary code (m) defines the composition as ferromagnesian material, whereas the tertiary code (v) indicates derivation from volcanic parent rock. The subscript ($_b$) denotes the parent lithology as basalt. Lists of primary codes, selected primary code qualifiers, secondary codes and qualifiers, and tertiary codes with common qualifiers are shown in Tables 3.2 to 3.5.

Quality control during the analysis of regolith

Quality control aims to assess the precision and accuracy of chemical analysis using a series of standards (for which compositions are known), replicate and duplicate samples, and blank determinations. Precision is the closeness of agreement of independent test results obtained under prescribed conditions, whereas accuracy is the closeness of agreement between the result of a measurement and the true value (Thompson and Ramsey, 1995). Both precision and accuracy can only be reliably assessed when the analyte concentration is sufficiently

Table 3.1. Primary, secondary, and tertiary codes, prior to revision

Regolith code		*Description*
Primary codes — environment		
R	relict	Relicts of an ancient land surface, including overlying and proximal reworked material
E	erosional	Exposed rock, saprock, saprolite, with thin locally derived debris
C	colluvial	Proximal mass-wasting products grading into sheetwash. Noticeable slope
W	diluvial	Distal sheetwash; minimal gradient; poorly defined drainage
A	alluvial	Alluvium in fluvial channels, and distal floodplain deposits with recognizable drainage systems
O	overbank	Overbank alluvial deposits
L	lacustrine	Inland lakes, associated dunes, and playa deposits, and some coastal lakes (not formed by coastal barring). Includes saline and freshwater playas, and eolian deposits (e.g. gypsiferous dunes) associated with such lake systems
S	eolian	Eolian dunes and sandplains, including interdunes
B	beach	Deposits at or above high water mark, adjacent to marine and tidal-related areas
T	tidal	Deposits between high- and low-water marks
M	marine	Sea-bed deposits, extending from below wave base. Includes reefs
Secondary codes — composition		
b	black soil, gilgai	
c	clay-mineral rich	
e	evaporite	
f	iron rich (ferruginous)	
g	quartzofeldspathic	
h	hardpan	
k	carbonate rich (including calcrete)	
m	ferromagnesian	
q	quartz rich	
r	carbonaceous	
u	ultramafic	
w	compacted and/or weakly cemented material (includes consolidated colluvium)	
x	mineral-rich material	
y	gypsiferous	
z	siliceous (including silcrete)	
Tertiary codes — rock qualifiers and specified compositional qualifiers		
m	metamorphic	
p	plutonic	
v	volcanic	
s	sedimentary	
h	halite	
a	aluminous	
n	magnesite	

above the detection level, which is the lowest level at which the analyte can be reliably measured using the technique under consideration. Precision is assessed using a series of GSWA and laboratory reference standards for which there are consensus or recommended values. In the GSWA regional regolith and geochemical mapping program, precision is deemed acceptable if the percent relative standard deviation (RSD% = (standard deviation/mean) × 100) is less than 20 for multiple analyses, provided the analyte concentration is more than 20 times (in some cases 10 times) the detection level. Measurement of a replicate sample (i.e. a second analysis of the same sample pulp) also assesses precision, as well as any change in analytical conditions during a sample run (machine drift), and any variation in analytical conditions between batches (batch effects). In future regolith programs carried out by GSWA, the Half Relative Difference (HRD) factor ((assay #1– assay #2)/(assay #1 + assay #2) × 100; Shaw et al., 1998) will be used to assess replication, with a value of 10% deemed acceptable.

Accuracy is assessed using GSWA and laboratory standard analyses, with an acceptable accuracy if the analyte concentration lies within 20% of the recommended or consensus value, provided the analyte concentration is greater than 10 or 20 times the detection level. These data can also be used to assess machine drift and batch effects.

Background levels are assessed by periodic analysis of blanks, with acceptable background levels in the GSWA program being less than three times the detection level.

For each analytical batch of between 120 and 200 samples (batch size depends on the laboratory), up to three GSWA standards are included as blind checks (i.e. with the GSWA number only), resulting in about 10 standard analyses per map sheet. These standards include a laterite (IQC47), a gossan (IQC45), and an amphibolite (IQC42), which span a wide SiO_2 interval of 42–88%.

Rigorous application of criteria for acceptability of results in terms of accuracy and precision assumes sample

Table 3.2. Revised primary regolith codes

Primary landform code	*Environment and process*	*Notes*
R	Residual	Principally relicts of an ancient weathered land surface, derived by in situ weathering. Includes overlying proximal disaggregated and reworked material. Does not refer to relict-depositional regimes
X	Exposed	Used for rock (optional) and weathered rock of uncertain protolith
C	Colluvial	Proximal mass-wasting deposits grading into sheetwash with a significant to perceptible slope
W	Low-gradient slope	Distal sheetwash and slope deposits where the gradient is minimal, and drainage is not clearly defined
A	Alluvial/fluvial	Alluvium in channels. Includes deltaic deposits
F	Floodplain/overbank	Floodplain deposits in recognizable drainage systems, alluvial terrace deposits Grades into alluvium
L	Lacustrine	Inland lakes, dune and playa terrain, and some coastal lakes (those not formed by coastal barring). Includes saline and fresh-water playas and claypans, and minor eolian deposits directly associated with the lake system (fringing gypsiferous dunes, etc.)
E	Eolian	Eolian dunes, interdune areas, and sandplain
S	Sandplain	Dominantly sandplain, may be of residual or mixed origin
B	Wave-dominated coastal (beach)	Beaches, beach ridges, barrier bars and lagoons, and back-beach dunes
T	Tide-dominated coastal	Intertidal and supratidal flats and channels, estuaries, and mangrove flats
M	Marine	Marine deposits such as coralgal reefs, shell banks, and sea-grass banks

homogeneity and the suitability of the analytical technique to the analyte under consideration. With a wide range in composition — Morris et al. (1997) reported a SiO_2 range of 7% to 96% for regolith on NABBERU (1:250 000) — and the concentration of resistate phases (e.g. rutile, chromite, and zircon) lower in the landform profile, it is unlikely that one preparation or analytical technique is suitable for all samples. Morris et al. (1998) discussed this problem with regard to analysis of niobium on MOUNT EGERTON and TUREE CREEK (1:250 000). They concluded that precise and accurate analysis of high field strength elements such as niobium is difficult, as these elements were common in resistate phases, such as rutile, which are difficult to dissolve prior to analysis by inductively coupled plasma (ICP) techniques. One approach to reducing these problems is to use different preparation or analytical techniques depending on analyte concentration. For example, Morris et al. (1998) report chromium data for regolith on MOUNT EGERTON according to two techniques: for concentrations of less than 100 ppm, data are reported after mixed acid digestion and inductively coupled plasma mass spectrometric (ICP-MS) analysis; for values greater than 100 ppm, data are reported following fusion and mixed acid digest and inductively coupled plasma optical emission spectrometric (ICP-OES) analysis. Although this approach can produce more acceptable data, the niobium issue on MOUNT EGERTON and TUREE CREEK as discussed by Morris et al. (1998) was not resolved by using different preparation or analytical techniques. Another factor in this approach is that of cost, which increases with the number of sample digests or techniques employed.

Batch effects have been noted for gold in regolith on EDMUND (1:250 000; Pye et al., 1998) and GLENBURGH (1:250 000; Sanders et al., 1998). In both cases, gold at levels of less than 4 ppb (detection level of 1 ppb) were subject to batch control.

Quality-control data for regolith on KINGSTON are presented as a series of digital datafiles on the accompanying floppy disk. For GSWA standards, the consensus values are taken as averages of analyses carried out at individual laboratories during the course of the GSWA regolith program. Consensus values for laboratory standards have been provided by the respective laboratories.

Typical analytical schemes from three commercial laboratories are outlined below.

Genalysis Laboratory Services

All regolith samples were oven dried at GSWA's Carlisle base. Approximately 2 kg of each sample (either sieved to <2 mm or to <6 mm) was supplied to the laboratory. Following further drying, an aliquot of each sample was sieved to between 2 and 0.45 mm. This material was pulverized to <75 µm in a zirconia ring mill (for analysis of SiO_2, TiO_2, Fe_2O_3, Al_2O_3, MnO, MgO, K_2O, and Cr), or a chrome-steel jumbo ring mill (for analysis of CaO, Na_2O, P_2O_5, Ag As, Ba, Be, Bi, Cd, Ce, Co, Cu, Ga, In, La, Li, Mo, Nb, Ni, Pb, Rb, Sc, Se, Sn, Sr, Ta, Te, Th, U, V, W, Y, Zn, and Zr).

Table 3.3. Examples of primary code qualifiers

Primary landform/process	*Landform element or pattern*	*Suggested primary code*	*Suggested subscript code*
Colluvial (proximal slope)		*C*	
	Landslide		C_l
Wash (sheet-flood, distal slope)		*W*	
	Playa, pan		W_p
Floodplain		*F*	
	Delta		F_d
	Alluvial plain		F_p
Alluvial		*A*	
	Stream channel		A_c
	Delta		A_d
	Alluvial fan		A_f
	Gravel bar		A_g
Lacustrine		*L*	
	Fringing dunes		L_d
	Fringing bedded deposits		L_g
	Dune and playa terrain		L_m
	Lake, excluding fringing deposits		L_l
	Playa, pan		L_p
Eolian		*E*	
	Dunefield		E_d
	Dune		E_e
	Longitudinal dunefield		E_l
	Mobile dune		E_m
	Interdune pavements		E_p
	Lunette		E_u
Sandplain, residual, uncertain, and mixed		*S*	
	Gravel deflation pavement		S_p
Wave-dominated coastal (beach)		*B*	
	Beach (foreshore)		B_f
	Mobile dunes		B_m
Tide-dominated coastal		*T*	
	Tidal bar, in channel		T_b
	Tidal delta		T_d
	Estuary		T_e
	Lagoon		T_l
Marine		*M*	
	Coral reef		M_r

Seven different analytical methods were used:

1. Silver, As, Ba, Be, Bi, Cd, Ce, Co, Ga, In, La, Li, Mo, Pb, Rb, Sb, Sn, Sr, Te, Th, U, W, and Y were analysed by ICP-MS using a combined mixed acid digest (Genalysis code A/MS). The pulverized sample was digested in a hydrofluoric–perchloric–nitric acid mixture for at least 24 hours, evaporated to fume dryness and leached in hydrochloric acid.
2. Manganese oxide, Na_2O, P_2O_5, Cr, Cu, Ni, Sc, V, and Zn were analysed by ICP-OES using a mixed acid digest (Genalysis code A/OES). The pulverized sample was digested in a hydrofluoric–perchloric–nitric acid mixture for at least 24 hours, evaporated to fume dryness, and leached in hydrochloric acid.
3. SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, K_2O, and S were analysed by ICP-OES using an alkaline oxidative fusion with sodium peroxide in a nickel crucible followed by leaching with hydrochloric acid (Genalysis code DX/OES).
4. Niobium, Ta, and Zr were analysed by ICP-MS using an alkaline oxidative fusion with sodium peroxide in nickel crucibles followed by leaching with hydrochloric acid (Genalysis code DX/MS).
5. The precious metals Au, Pd, and Pt were analysed by fire-assay lead collection and ICP-MS analysis (Genalysis code FA*MS).
6. Selenium was analysed by precipitation of selenium metal followed by aqua-regia digestion and ICP-MS analysis (Genalysis code A*MS)
7. Loss on ignition (LOI) was determined by gravimetric means (Genalysis code GRAV).

Analabs

The total sample was dried to 110°C, jaw crushed if necessary, split then milled in a chromium-free mill to a nominal particle size of 90% less than 75 µm. An

Table 3.4. Revised secondary codes and qualifiers

Code	*Composition*	*Qualifier*	*Composition*
a	aluminous/bauxitic		
b	black soil, gilgai		
c	clay	c_c	chlorite
		c_g	glauconite
		c_I	illite
		c_k	kaolin
		c_m	montmorillonite
		c_s	smectite
d	undivided		
e	evaporite	e_a	anhydrite
		e_g	gypsum
		e_h	halite
f	ferruginous		
g	quartzofeldspathic		
h	heavy mineral	h_a	apatite
		h_g	garnet
		h_i	ilmenite
		h_l	leucoxene
		h_m	magnetite
		h_o	monazite
		h_r	rutile
		h_z	zircon
i	limonite		
k	carbonate	k_a	aragonite
		k_c	calcite
		k_d	dolomite
		k_m	magnesite
l	heterogeneous		
m	ferromagnesian		
o	goethite		
q	quartz		
r	carbonaceous/organic	r_c	coal
		r_h	humus
		r_p	peat
u	ultramafic		
x	other mineral	x_i	mica
		x_m	manganese
z	siliceous		

Table 3.5. Revised tertiary codes and qualifiers for parent rock or cement type

Parent rock or cement		*Parent rock qualifier*	
a	aluminous cement		
c	chemical/biochemical sedimentary deposit	c_c	chert
		c_d	dolomite
		c_i	iron-formation
		c_l	limestone
		c_t	diatomite
f	duricrust		
h	hyperbyssal	h_d	dolerite
		h_p	porphyry
i	iron cement		
k	carbonate cement		
m	metamorphic	m_g	gneiss
		m_p	pelite
		m_m	psammite
		m_s	schist
o	fossiliferous	o_s	shells
		o_c	coral/coralgal
p	plutonic	p_a	alkali granite
		p_g	gabbro
		p_d	diorite
		p_g	granite
		p_m	monzogranite/monzonite
		p_o	granodiorite
		p_s	syenogranite/syenite
		p_t	tonalite
s	siliciclastic sedimentary rock	s_c	conglomerate
		s_m	mudstone, siltstone, shale
		s_s	sandstone, arenite, wacke
u	ultramafic	u_d	dunite
		u_k	komatiite
		u_p	peridotite
		u_y	pyroxenite
		u_s	serpentinite/talc rock
v	volcanic	v_a	andesite
		v_b	basalt
		v_d	dacite
		v_l	latite
		v_r	rhyolite
		v_t	trachyte
		v_2	volcaniclastic
z	silica cement		

analytical pulp of approximately 200 g was subsampled from the bulk and the milled residue and any split retained for future reference. All the preparation equipment was flushed with barren feldspar prior to the commencement of the job and after each batch.

The following analytical schemes were used:

1. Silica, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, and P_2O_5 were measured by X-ray fluorescence spectrometry (XRF) on a glass fusion disc (Analabs code X408).
2. Loss on ignition (LOI) was determined gravimetrically, by heating the sample to 1000°C (Analabs code V955).
3. A series of trace elements were measured by ICP-MS, following sample digestion with nitric, hydrochloric, hydrofluoric, and perchloric acids (Analabs code G104). Elements measured include: Ag, As, Ba, Be, Bi, Cd, Ce, Co, Ga, In, La, Li, Mo, Nb, Ni, Pb, Rb, Sb, Sc, Sn, Ta, Th, U, W, and Y (Analabs code M104).
4. The G104 digest (at 3. above) was used for the analysis of Sr, V, and Zr by ICP-OES (Analabs code I104).
5. An aliquot of the G104 digest (at 3. above) was analysed by atomic absorption spectrometry (AAS) for Cr, Cu, and Zn (Analabs code A104).
6. The volatile metals Se and Te were analysed by hydride generation AAS (Analabs code H109), from a chromate-enhanced hydrochloric and nitric acid digestion carried out at low temperature (Analabs code G109).

7. Sulfur (as S) was evolved at high temperature in a stream of oxygen, and the resultant gas was measured in an infrared cell (Analabs code V821).
8. A 50 g subsample of the assay pulp was fused in a lead collection fire assay. The prill was dissolved in aqua regia (i.e. hydrochloric and nitric acid) and the resultant solution presented to an ICP-MS (Analabs code F627) for analysis of Au, Pd, and Pt.

Amdel Laboratories

Following oven drying, an aliquot of each sample was sieved to between 2 and 0.45 mm. This material was pulverized to <75 µm in a chrome-free bowl pulverizer; imparted contamination during milling estimated by the manufacturer is 50 ppm Mn and 5000 ppm Fe, with no detectable contamination for Co, Cu, Mo, Ni, Pb, V, or Zn.

Six analytical methods were used:

1. Silica, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, and P_2O_5 were analysed by ICP-OES following a lithium metaborate fusion and dilute hydrochloric acid digestion (Amdel code IC4).
2. Silver, As, Bi, Cd, Ce, Co, Cu, Ga, In, La, Mo, Nb, Pb, Rb (up to 20 ppm; IC4M >20 ppm), Sb, Se, Sn, Sr (up to 500 ppm; IC3E >500 ppm), Te, Th, U, W, and Y were analysed by ICP-MS following mixed-acid sample digestion (hydrofluoric–perchloric–nitric–hydrochloric) for 24 hours. Samples were evaporated to fume dryness and dissolved in hydrochloric acid prior to analysis (Amdel code IC3M).
3. Barium, Be, Cr (up to 100 ppm; IC4E >100 ppm), Li, Ni, S (up to 5%; analysis by Leco (Amdel code VOL2) >5%), Sc, V, and Zn were analysed by ICP-OES (Amdel code IC3E). Samples were digested using a hydrofluoric–perchloric–nitric–hydrochloric acid mixture for 24 hours, then evaporated to fume dryness and dissolved in dilute hydrochloric acid.
4. Tantalum and Zr were analysed by ICP-MS following a lithium metaborate fusion and dilute hydrochloric acid digestion (Amdel code IC4M).
5. Gold, Pt, and Pd were collected in a lead collection fire-assay fusion. Following cupellation, the prill was dissolved in aqua regia (i.e. hydrochloric and nitric acids), then analysed by graphite furnace AAS (Amdel code FA3).
6. Loss on ignition (LOI) was determined by gravimetric means (Amdel code GRAV7).

Determination of regolith pH and total dissolved solids

The acidity–alkalinity (pH) and total dissolved solids (TDS) of all regolith samples were measured at the GSWA Carlisle base. For both types of measurements, a subsample was mixed with deionized water in the ratio of 1:5, then shaken vigorously. After standing overnight, the pH was measured using a portable Jenway pH meter, calibrated using standard solutions of pH=4 and pH=7. The electrode was rinsed in deionized water between each measurement of unknowns. The conductivity of each sample (i.e. a measure of the TDS) was made using a SCAN4 conductivity meter, calibrated using a buffer solution of 11.67 millisiemens/centimetre (mS/cm). Electrodes were rinsed between every measurement of unknowns.

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Appendix 4

GSWA and laboratory standard data and quality-control data

(These data are presented on the accompanying disk as .CSV files)

App4_1	Winning Pool – Minilya (blanks, GSWA standards, Amdel standards, and replicates for method IC3M) (App4_1.CSV)
App4_2	Winning Pool – Minilya (blanks, GSWA standards, Amdel standards, and replicates for method IC4M) (App4_2.CSV)
App4_3	Winning Pool – Minilya (blanks, GSWA standards, Amdel standards, and replicates for method IC3E) (App4_3.CSV)
App4_4	Winning Pool – Minilya (blanks, GSWA standards, Amdel standards, and replicates for method IC4) (App4_4.CSV)
App4_5	Winning Pool – Minilya (blanks, GSWA standards, Amdel standards, and replicates for method FA3) (App4_5.CSV)
App4_6	Comparison of high values between Amdel and Genalysis. Checks by various methods and size fractions (App4_6.CSV)

Figures

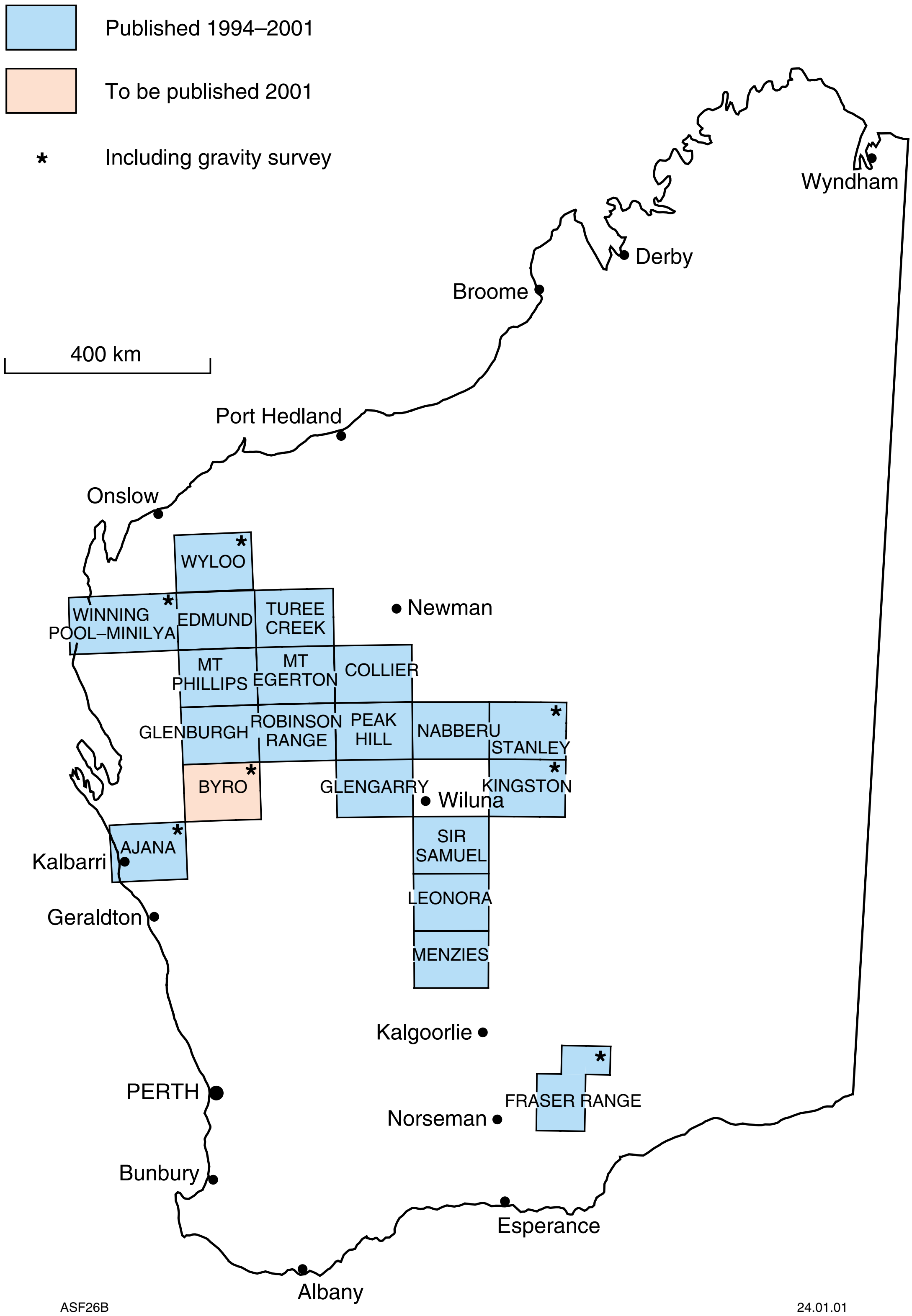
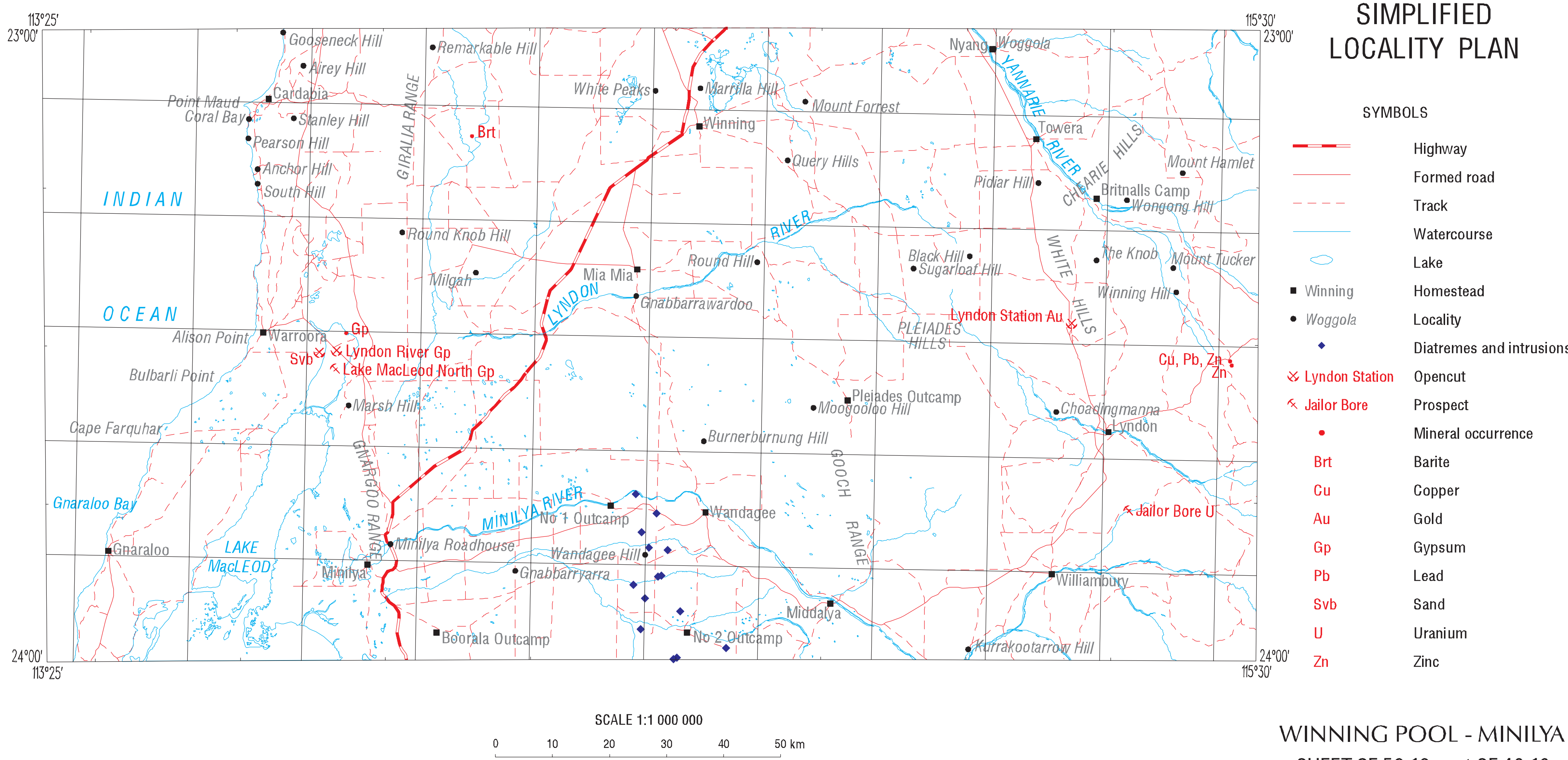


Figure 1. Status of GSWA regional regolith and geochemical mapping program

SIMPLIFIED LOCALITY PLAN



WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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Figure 2

INTERPRETED BEDROCK GEOLOGY

PHANEROZOIC

QUATERNARY

- BUNDERA CALCARENITE: shoreline, marine, and coastal eolian deposits; includes coastal lake deposits; commonly calcareous and gypsiferous

NEOGENE

- LAMONT SANDSTONE and TREALLA LIMESTONE: marine limestone, and minor marine and continental sandstone

PALEOGENE

- CARDABIA CALCARENITE, GIRALIA CALCARENITE, and MERLINLEIGH SANDSTONE Marine limestone and sandstone, with minor siltstone and basal greensand

CRETACEOUS

- TOOLONGA CALCILUTITE, KOROJON CALCARENITE, and MIRIA FORMATION Marine limestone, chalk, marl, and greensand; dominantly calcareous pelagic deposits

Winning Group

- Marine and coastal shale, siltstone, and radiolarite; dominantly siliceous pelagic deposits with basal sandstone and conglomerate

PERMIAN

Wooramel Group, Byro Group, and Kennedy Group

- Marine and continental siltstone, shale, and sandstone

Lyons Group and CALLYTHARRA FORMATION

- Marine and continental siltstone, shale, sandstone, and limestone; glacially influenced

DEVONIAN

- Marine to continental limestone, dolomite, sandstone, siltstone, shale, and conglomerate

PROTEROZOIC

- Dolerite sill

Edmund Group

- Sandstone, siltstone, shale, dolomite, and chert; intruded by dolerite dykes and sills

Gascoyne Complex

- Granodiorite, monzogranite, granite, and pegmatite; includes minor dolerite and gabbro
- Schist, migmatite, gneiss, phyllite, quartzite, and minor calc-silicate rock, marble, and amphibolite (Morrissey Metamorphic Suite)

Geological boundary

Fault, exposed

Fault, concealed or inferred

SYMBOLS

■ Winning	Homestead
• *Woggola*	Locality
◆	Diatremes and intrusions
Lyndon Station	Opencut
Jailor Bore	Prospect
•	Mineral occurrence
Brt	Barite
Cu	Copper
Au	Gold
Gp	Gypsum
Pb	Lead
Svb	Sand
U	Uranium
Zn	Zinc

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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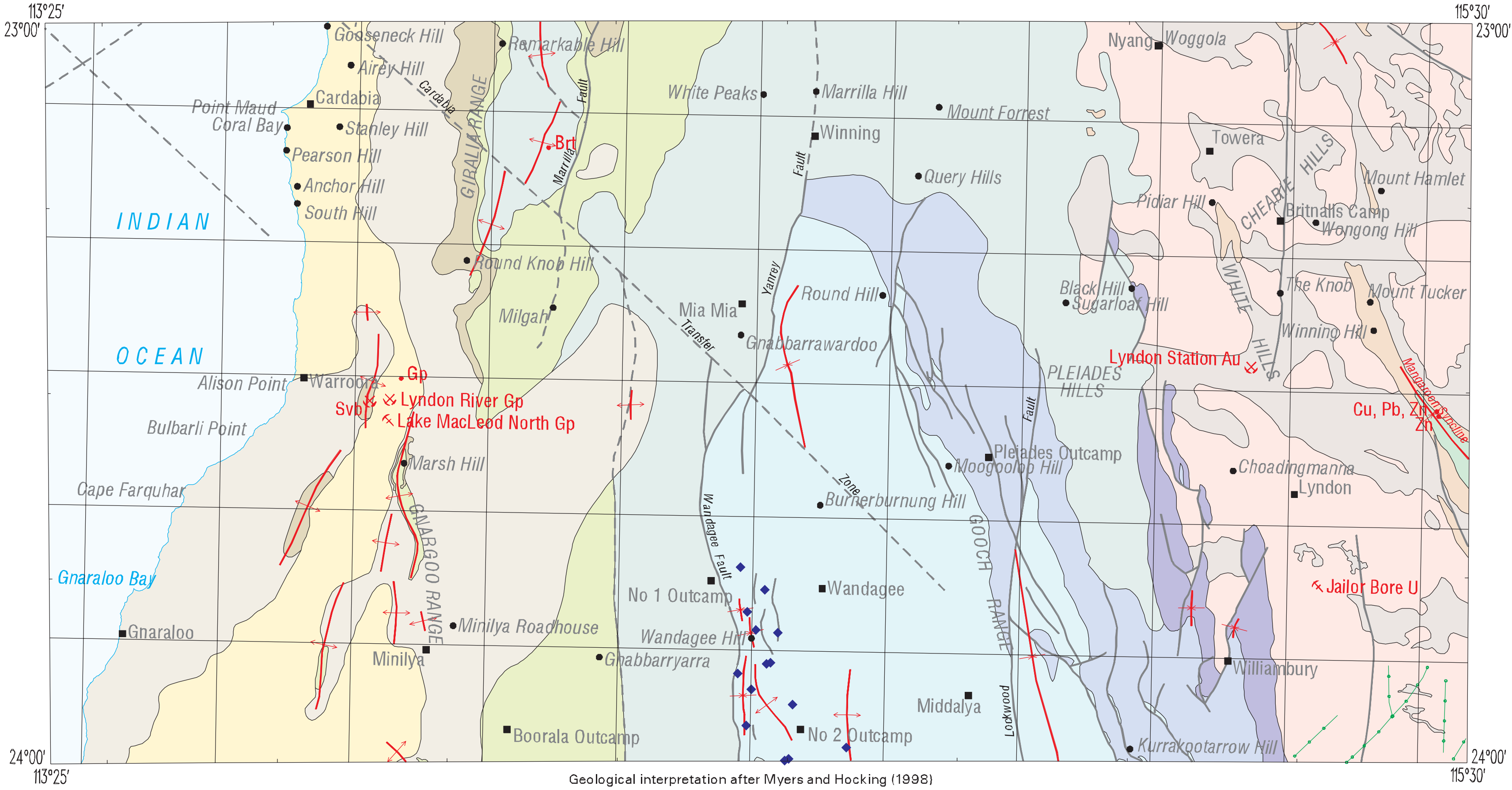
Figure 3

08 Feb 01 14:22:51

INTERPRETED BEDROCK GEOLOGY



Geological interpretation after Myers and Hocking (1998)

SCALE 1:1 000 000

0 10 20 30 40 50 km

See Figure 3 for reference

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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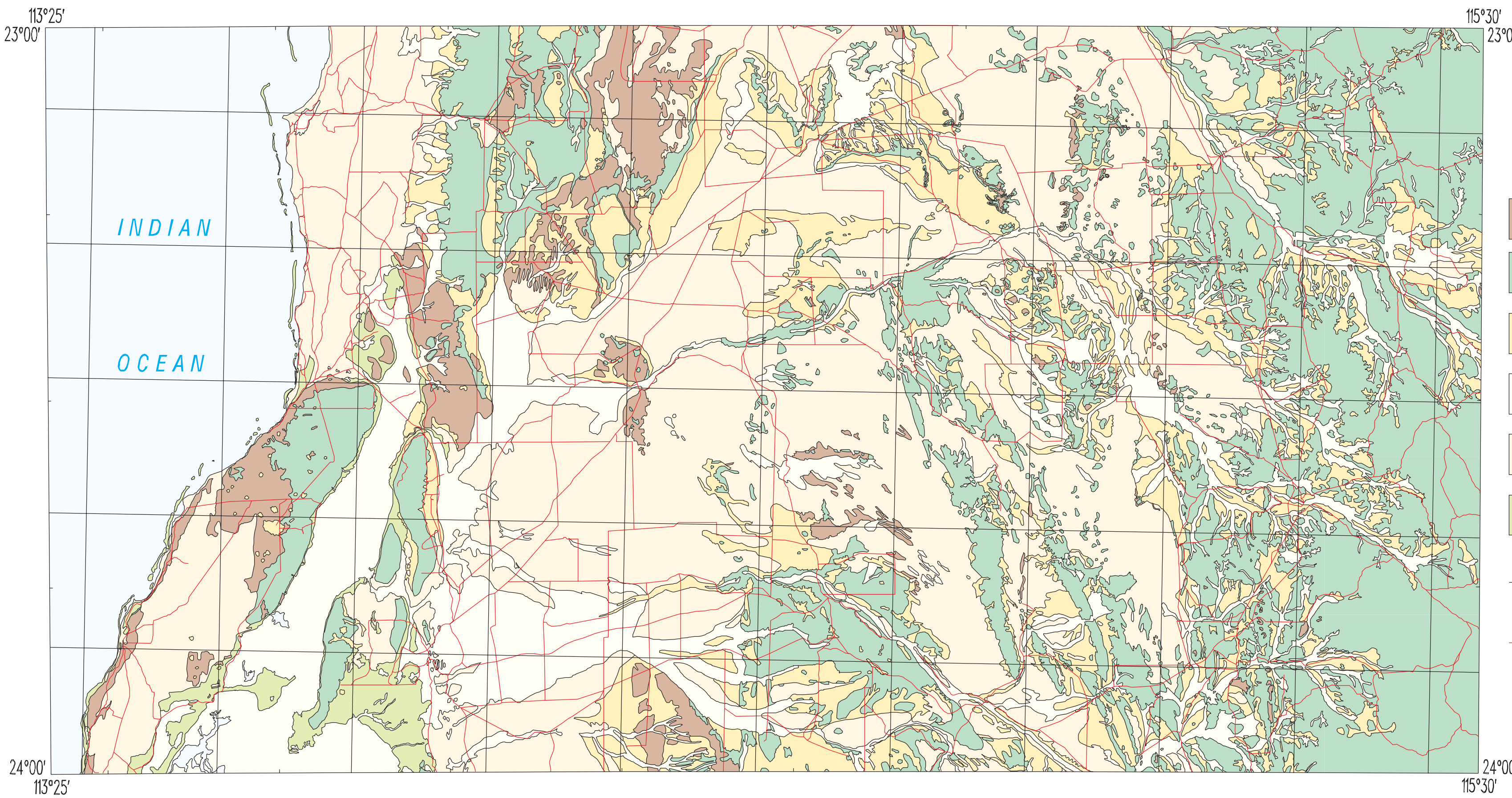
Figure 4

GENERALIZED REGOLITH



- Residual
- Exposed
- Colluvial (includes low-gradient slope)
- Alluvial and lacustrine
- Sandplain and eolian
- Coastal and marine
- Regolith boundary
- Road or track

SCALE 1:1 000 000

0 10 20 30 40 50 km

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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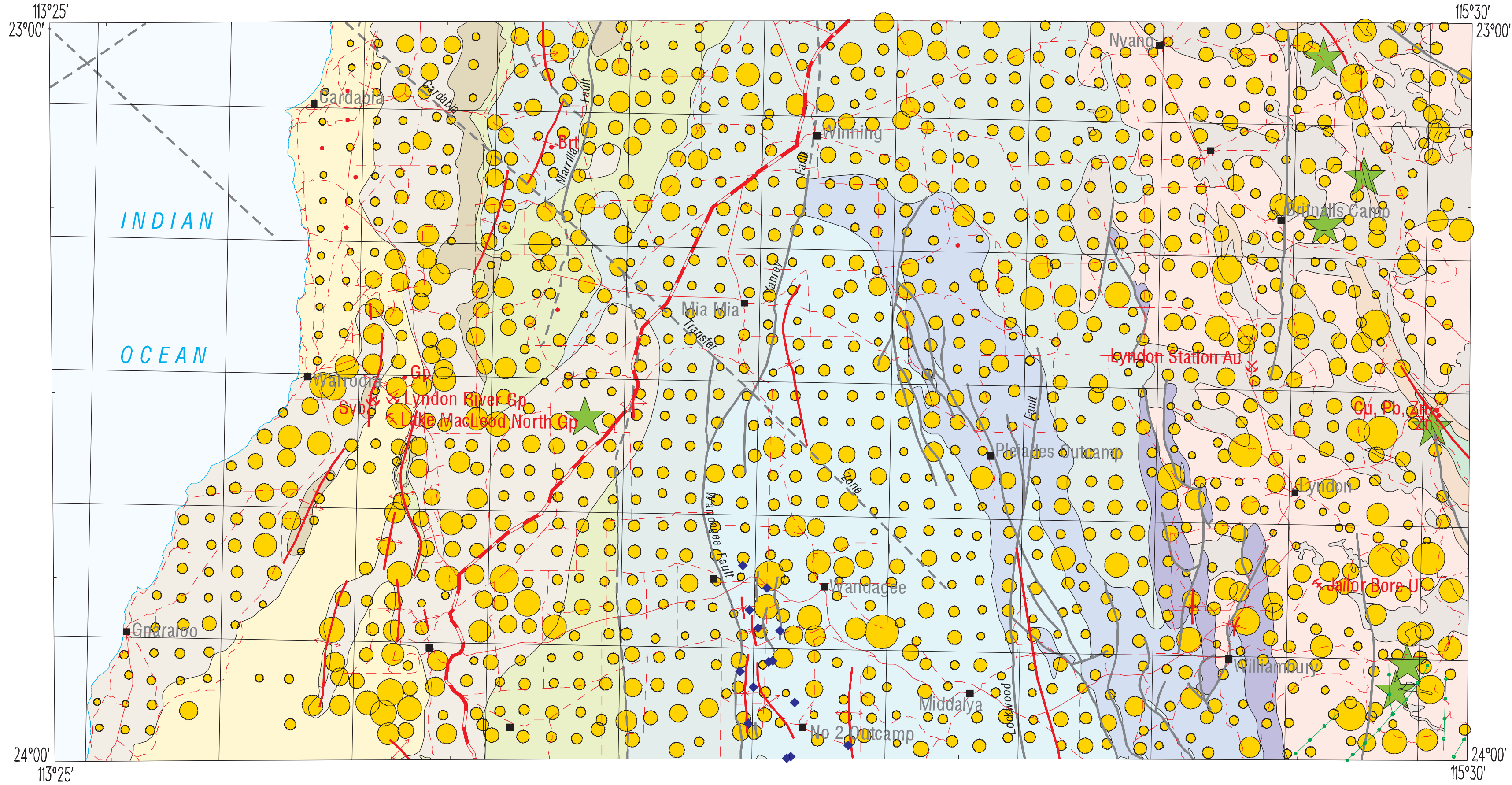
Figure 5



TiO_2
TITANIUM OXIDE

Maximum value:
3.83 %

0.89 %
0.47 %
0.05 %

Below 0.05 % theoretical detection limit

> 0.89 %

SCALE 1:1 000 000
0 10 km

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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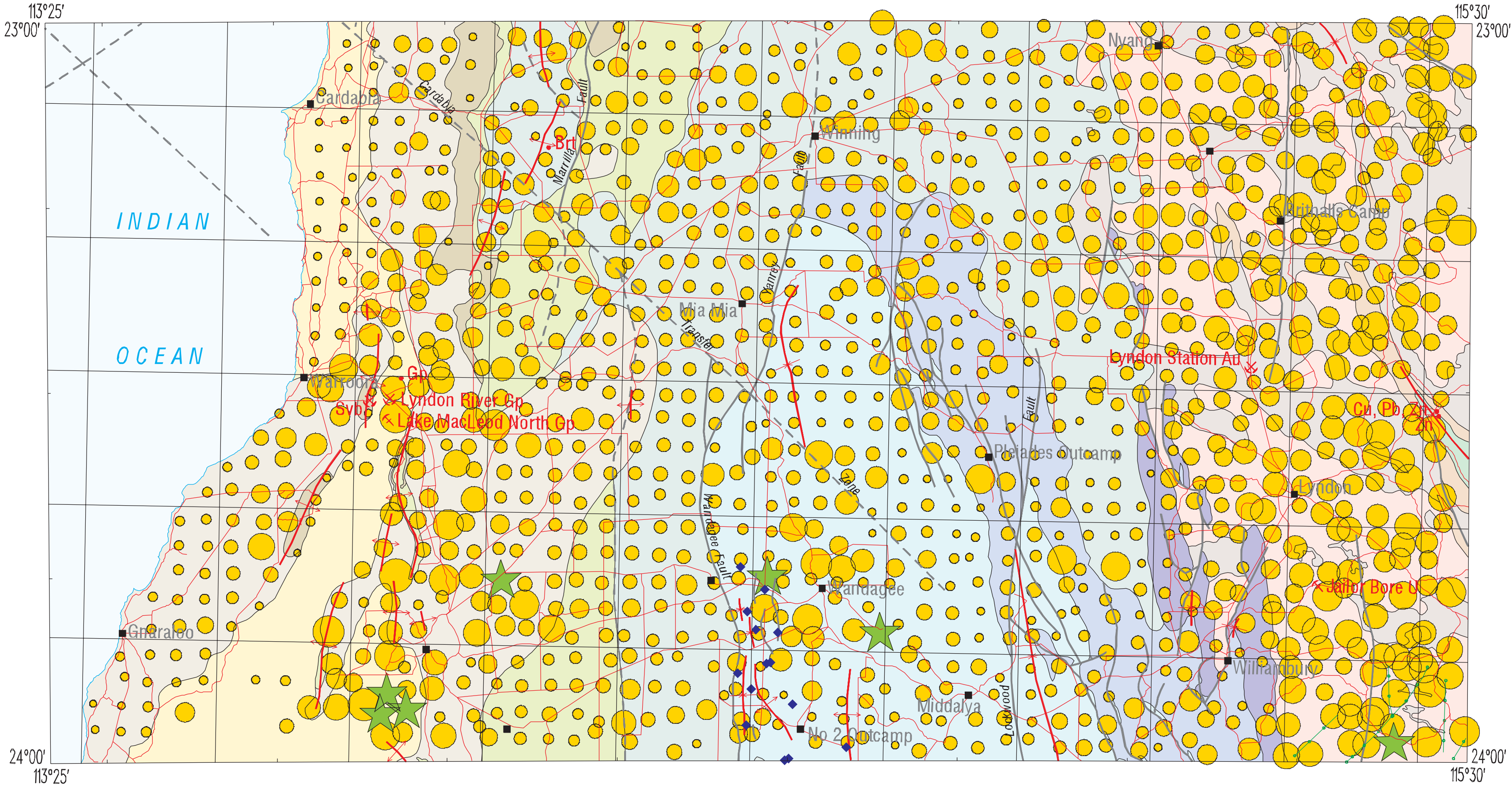
Figure 6

08 Feb 01 12:06:35



Al_2O_3 ALUMINIUM OXIDE

Maximum value: 19.0 %

13.7 %

7.3 %

0.8 %

Below 0.1 % theoretical detection limit

> 13.7 %

SCALE 1:1 000 000

0 10 km

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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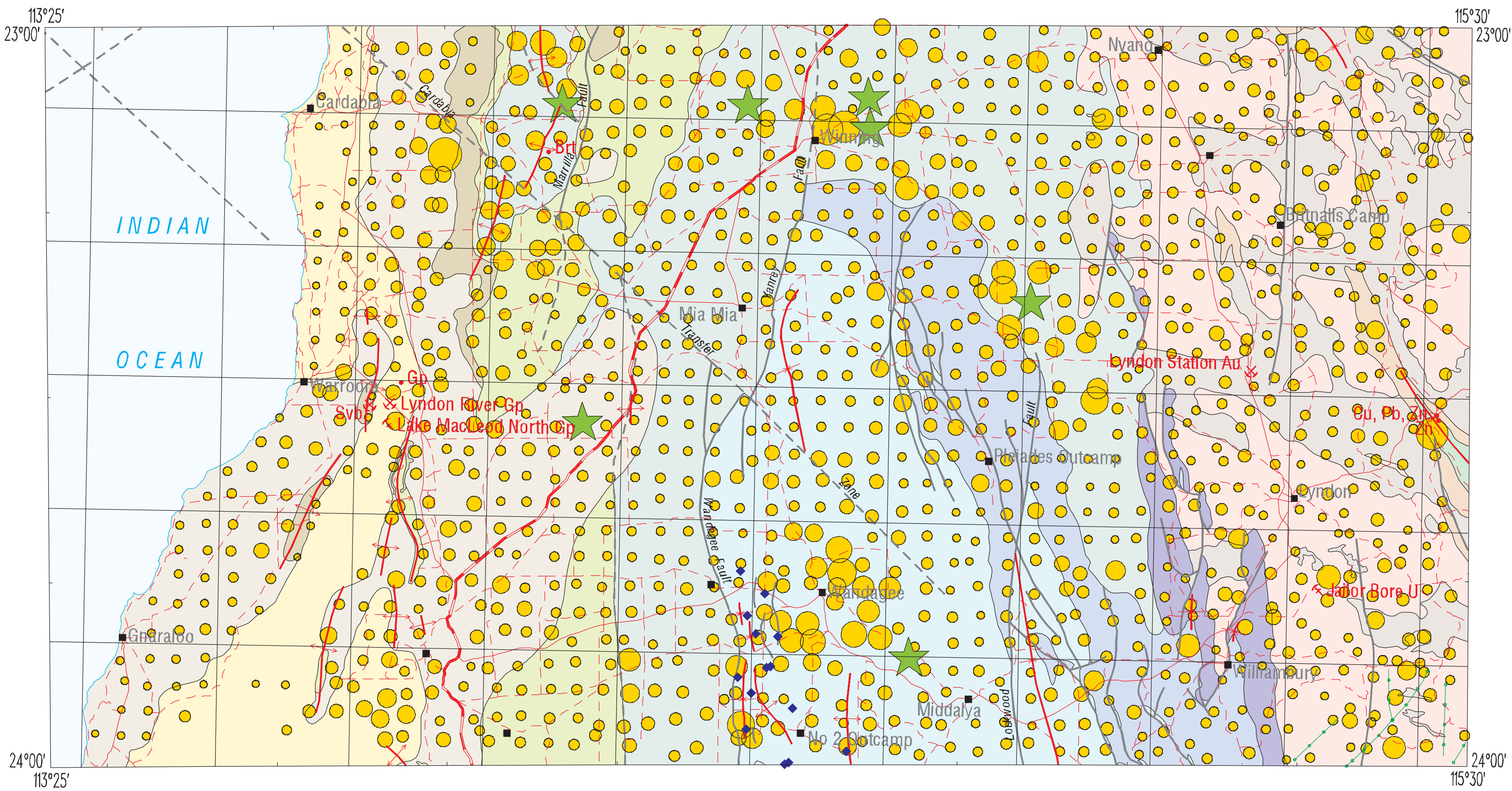
Figure 7



Fe_2O_3
FERRIC OXIDE

Maximum value: 27.3 %

16.3 %
8.4 %
0.5 %

Below 0.1 % theoretical detection limit

> 16.3 %

SCALE 1:1 000 000
0 10 km

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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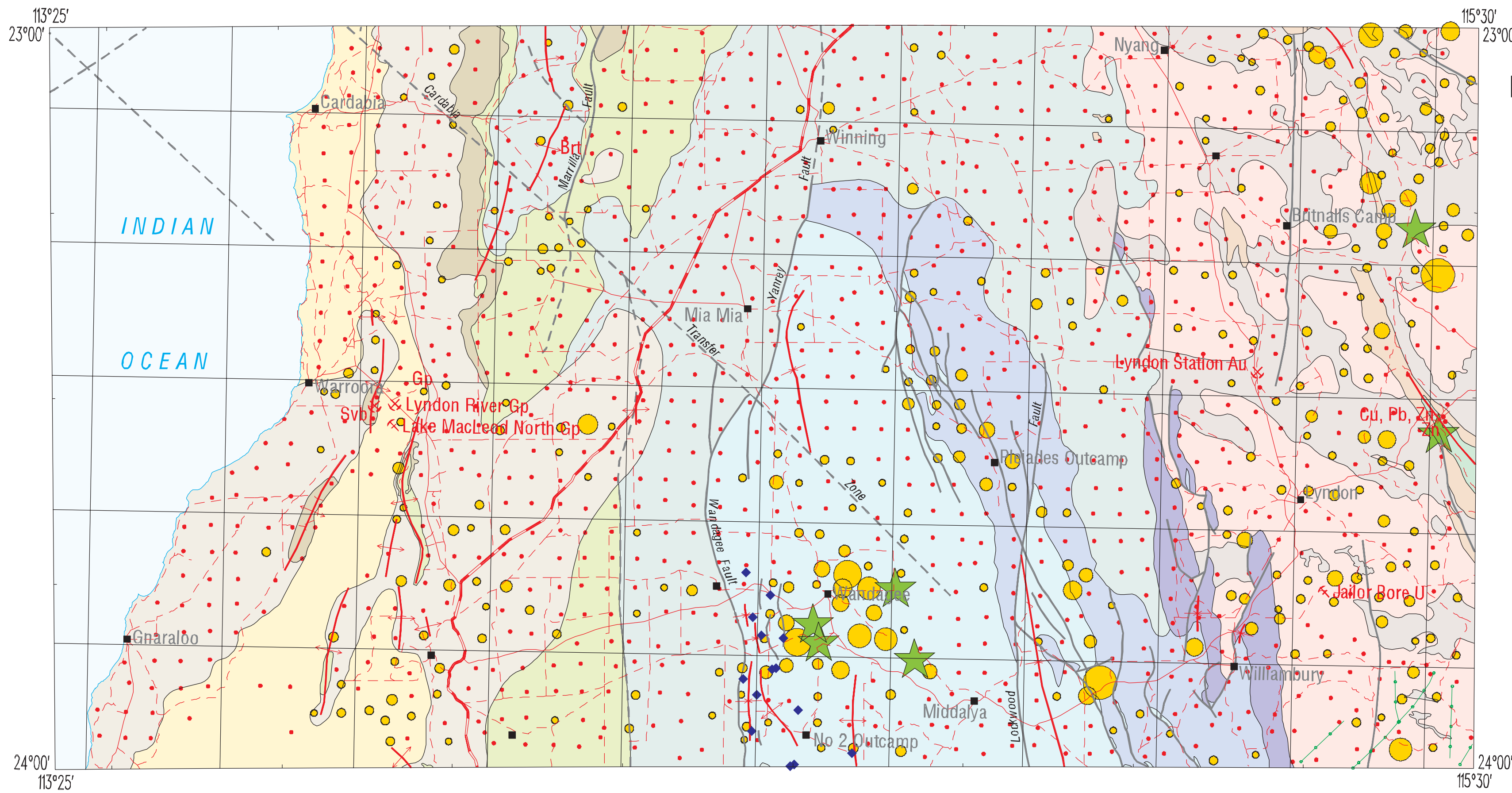
Figure 8



MnO

MANGANESE OXIDE

Maximum value:
0.54 %

0.32 %
0.19 %
0.05 %

Below 0.05 % theoretical detection limit

> 0.32 %

SCALE 1:1 000 000
0 10 km

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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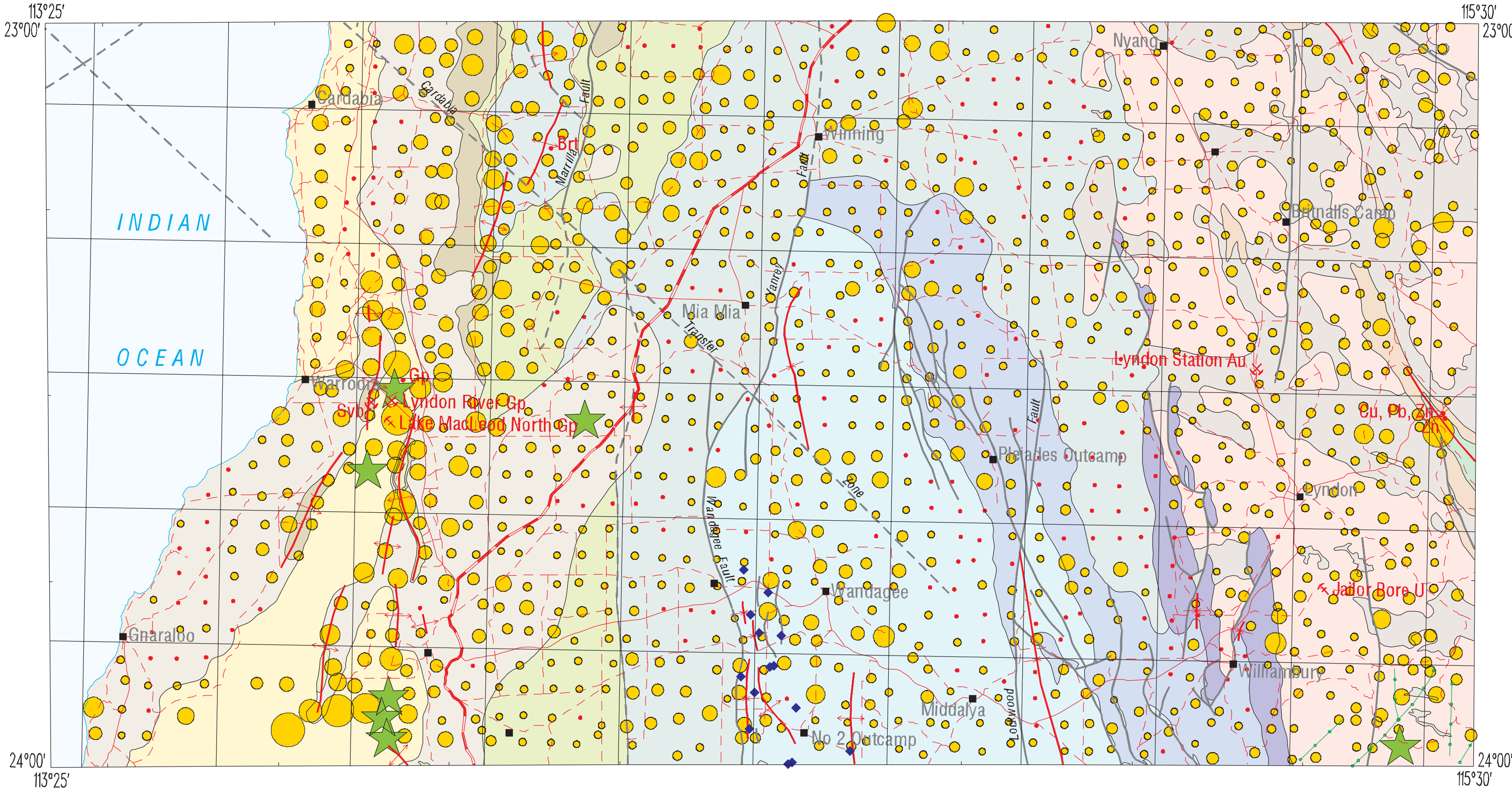
Figure 9

08 Feb 01 12.11.15



MgO
MAGNESIUM OXIDE

Maximum value:
13.3 %

3.3 %
1.7 %
0.1 %

Below 0.1 % theoretical detection limit

> 3.3 %

SCALE 1:1 000 000
0 10 km

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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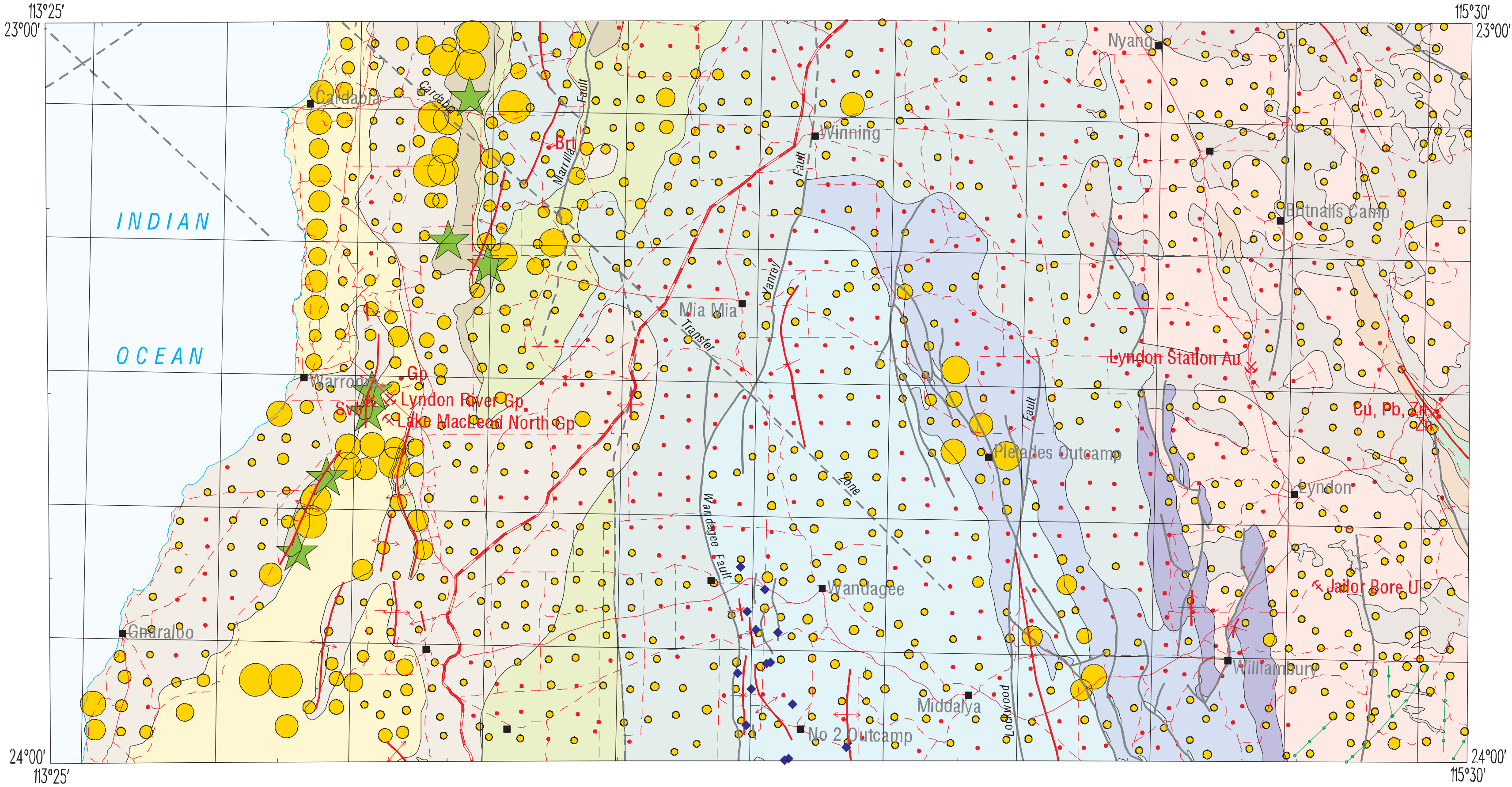
Figure 10

08 Feb 01 12:12:06

CaO
CALCIUM OXIDE



Maximum value: 52.4 %

45.9 %

23.0 %

0.1 %

Below 0.1 % theoretical detection limit

> 45.9 %

SCALE 1:1 000 000

0 10 km

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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Figure 11

08 Feb 01 12:13:32

Na_2O
SODIUM OXIDE

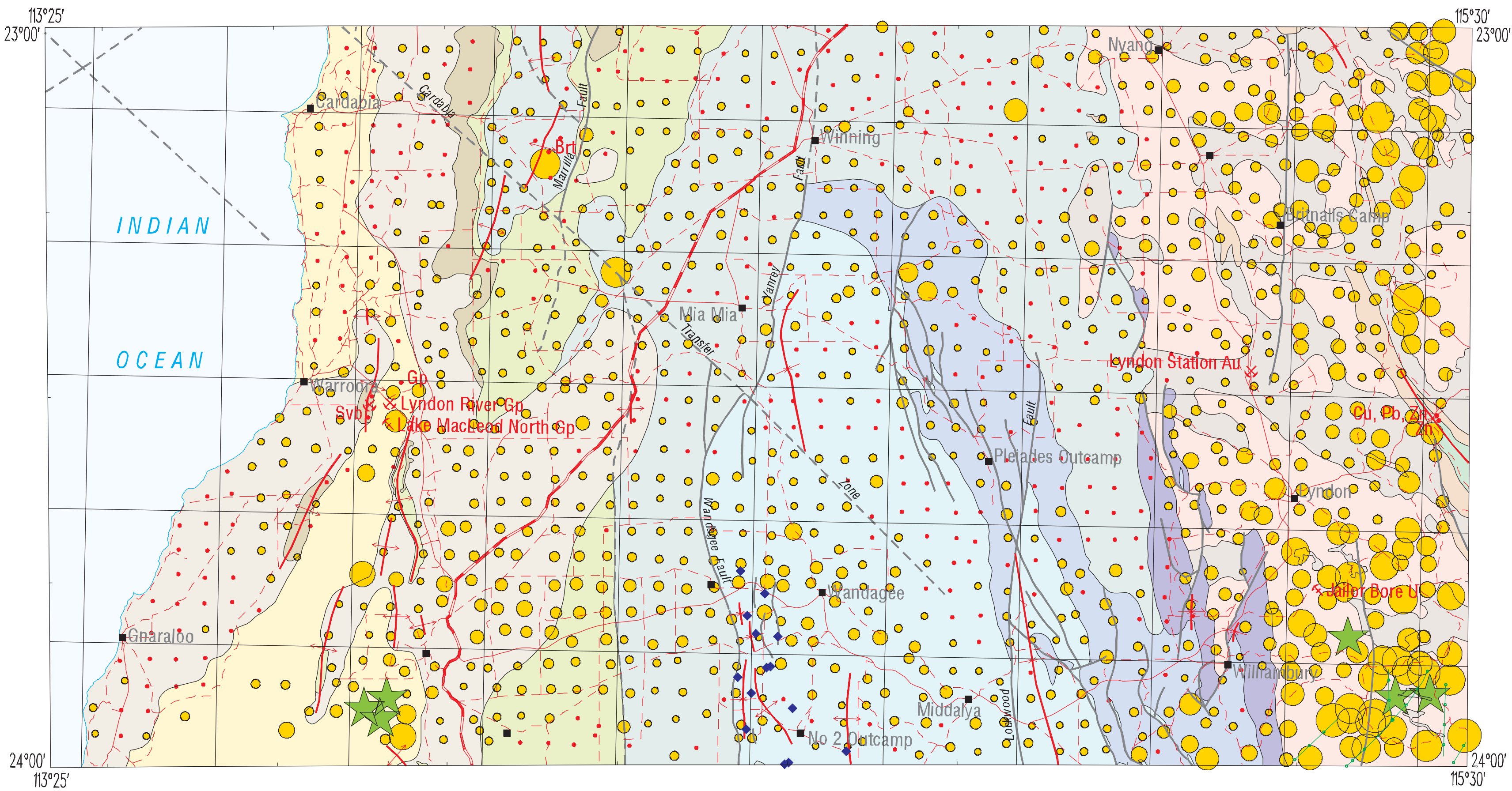
Maximum value: 4.2 %

2.4 %
1.3 %
0.1 %

Below 0.1 % theoretical detection limit

> 2.4 %

SCALE 1:1 000 000
0 10 km



WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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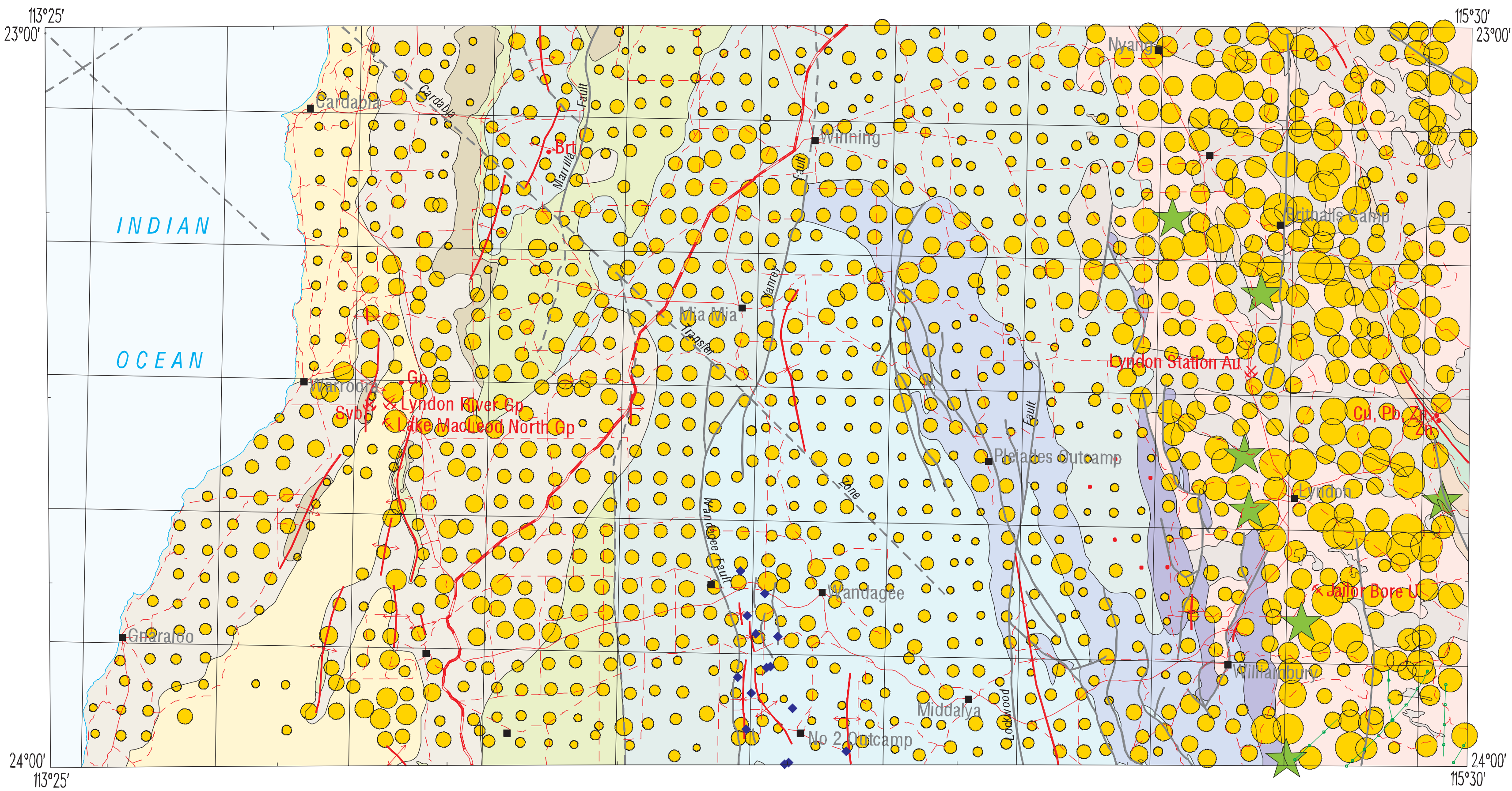
Figure 12



K_2O
POTASSIUM OXIDE

Maximum value: 5.8 %

4.5 %
2.3 %
0.1 %

Below 0.1 % theoretical detection limit

> 4.5 %

SCALE 1:1 000 000
0 10 km

WINNING POOL - MINILYA
SHEET SF 50-13, part SF 49-16
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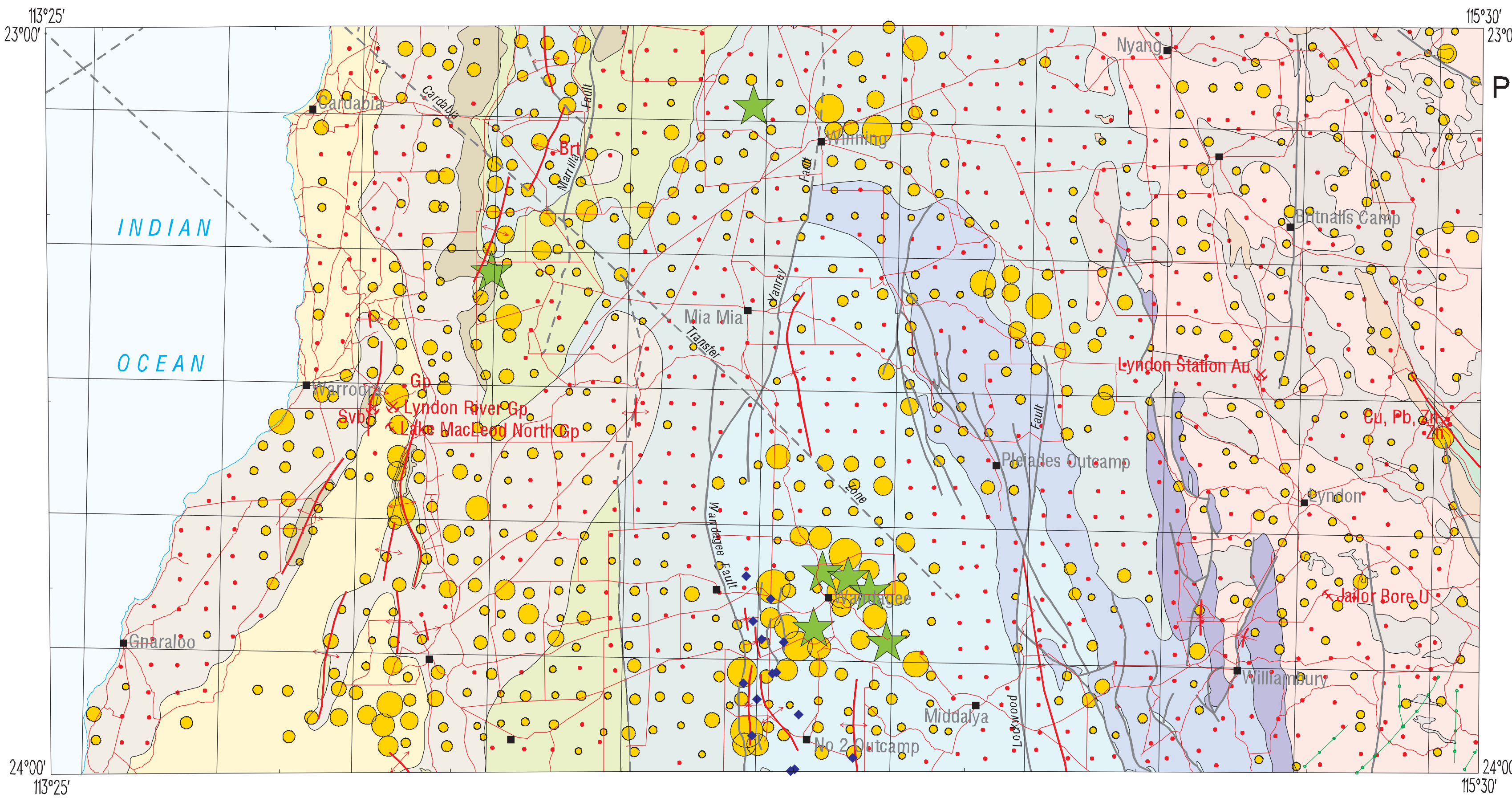
Figure 13

08 Feb 01 12:16:05



P_2O_5
PHOSPHOROUS OXIDE

Maximum value: 0.62 %

0.25 %
0.15 %
0.05 %

Below 0.05 % theoretical detection limit

> 0.25 %

SCALE 1:1 000 000
0 10 km

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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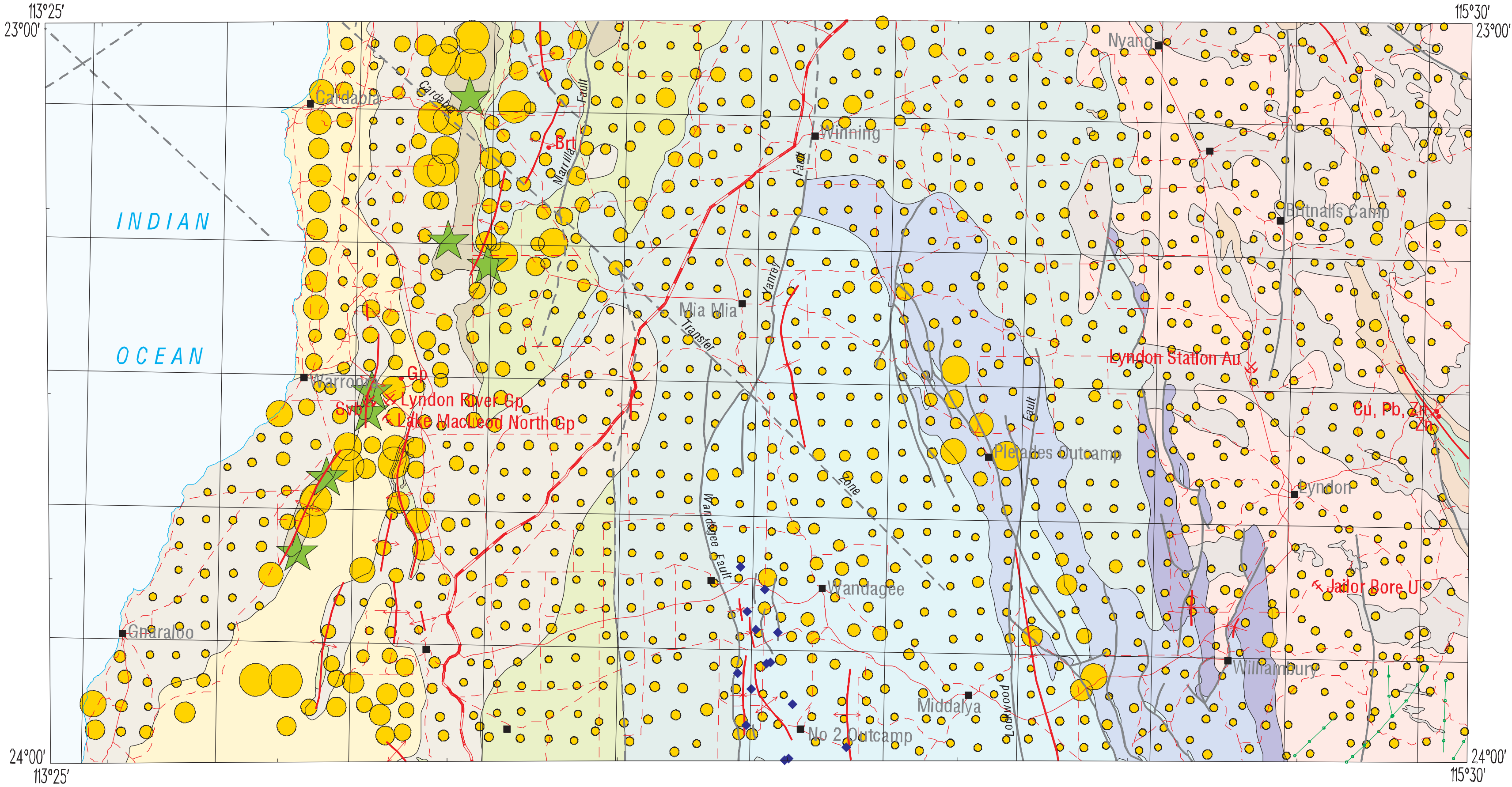
Figure 14

08 Feb 01 12.17.43



LOI
LOSS ON IGNITION

Maximum value: 41.5 %

38.2 %

19.3 %

0.3 %

Below 0.1 % theoretical detection limit

> 38.2 %

SCALE 1:1 000 000

0 10 km

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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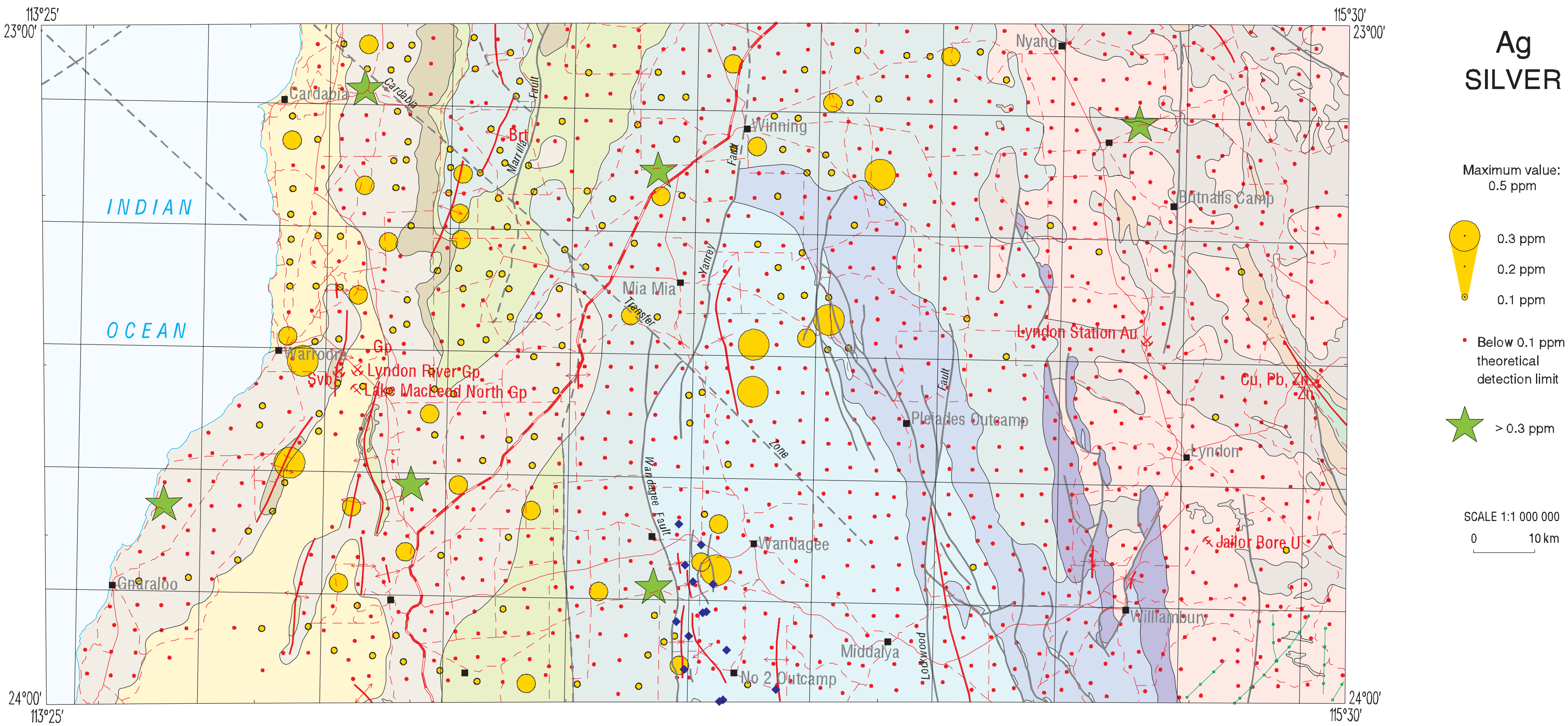
Figure 15

08 Feb 01 12.18.50



WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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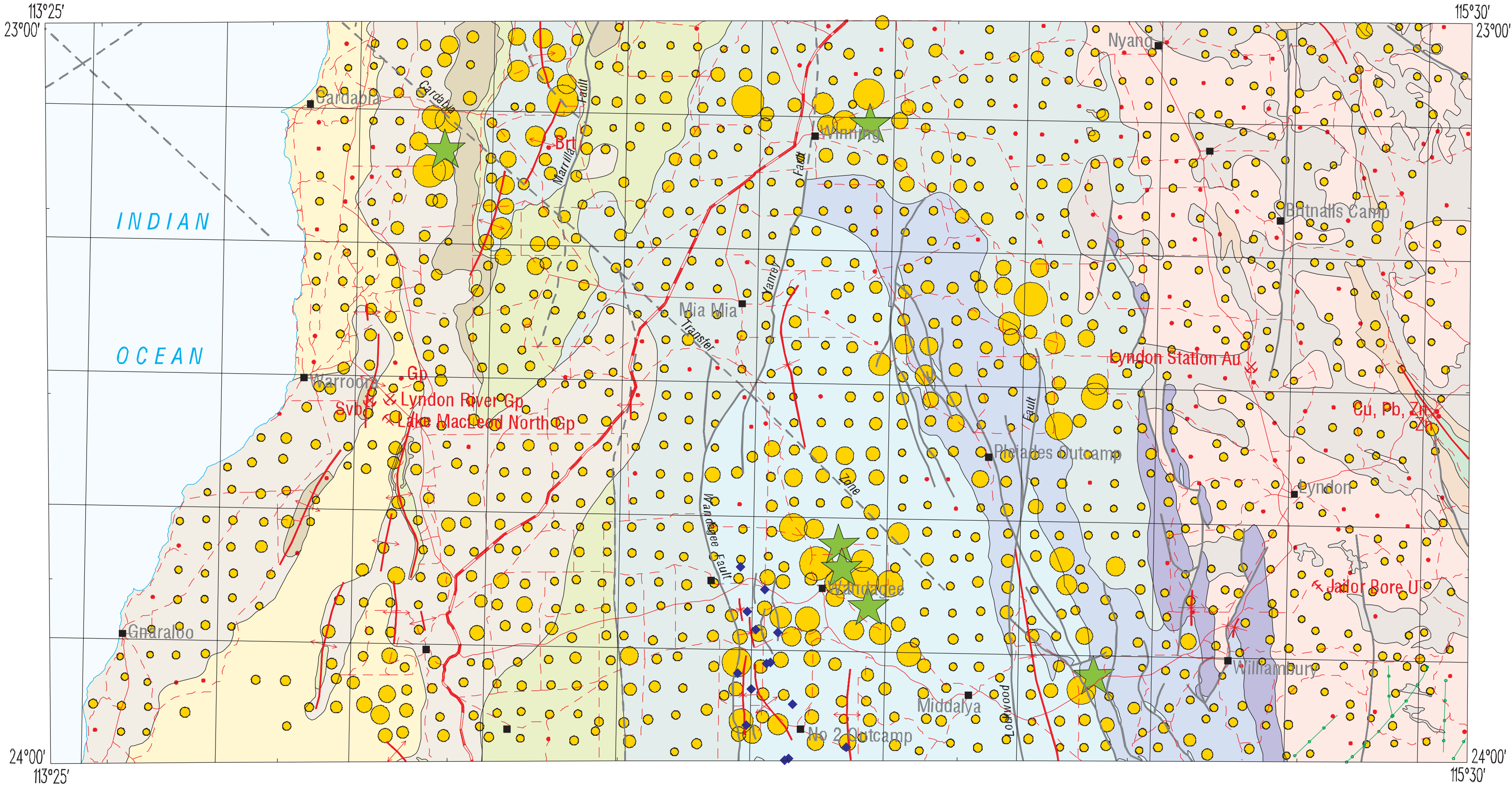
Figure 16



As
ARSENIC

Maximum value:
127 ppm

49 ppm

25 ppm

1 ppm

Below 1 ppm theoretical detection limit

> 49 ppm

SCALE 1:1 000 000

0 10 km

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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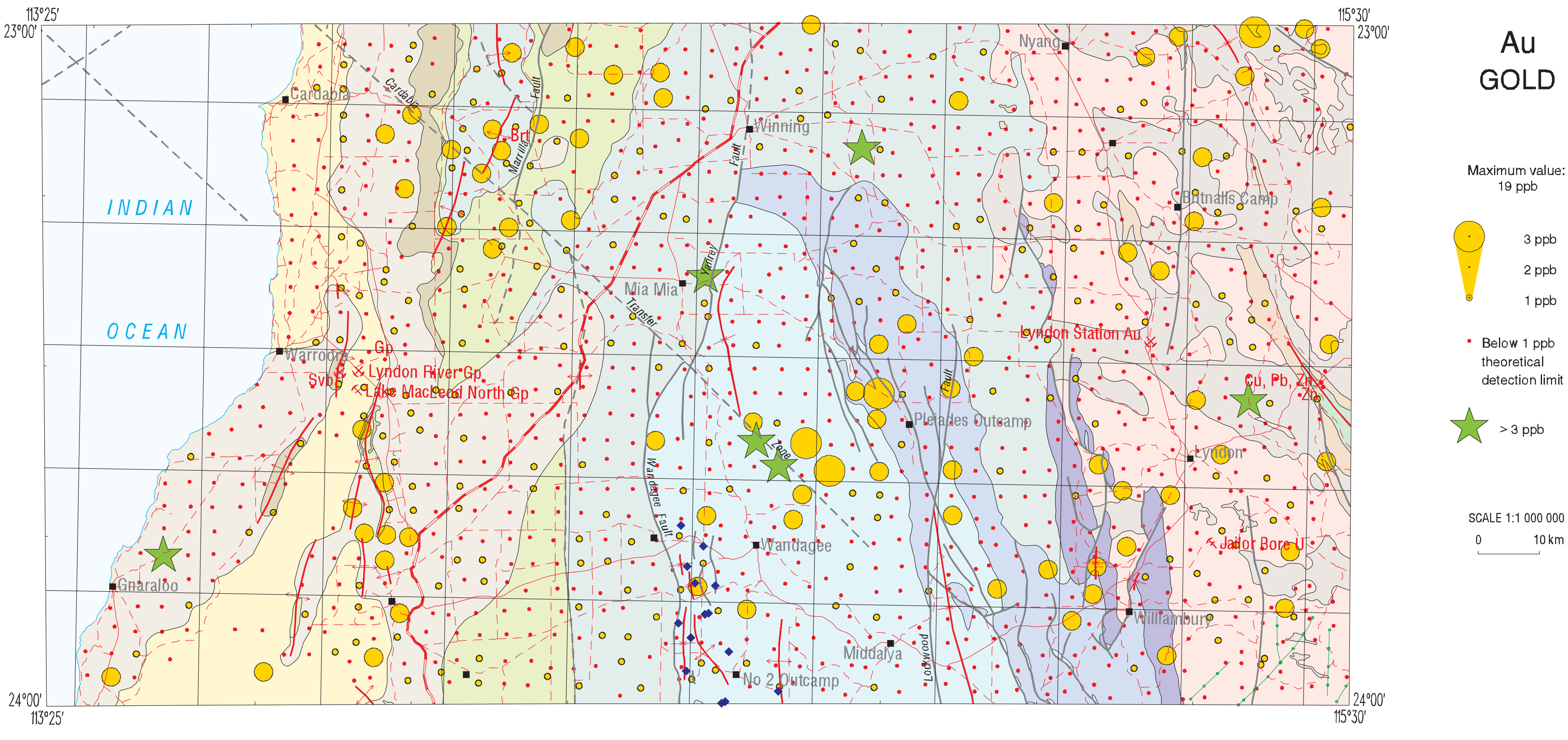
Figure 17



WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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Figure 18

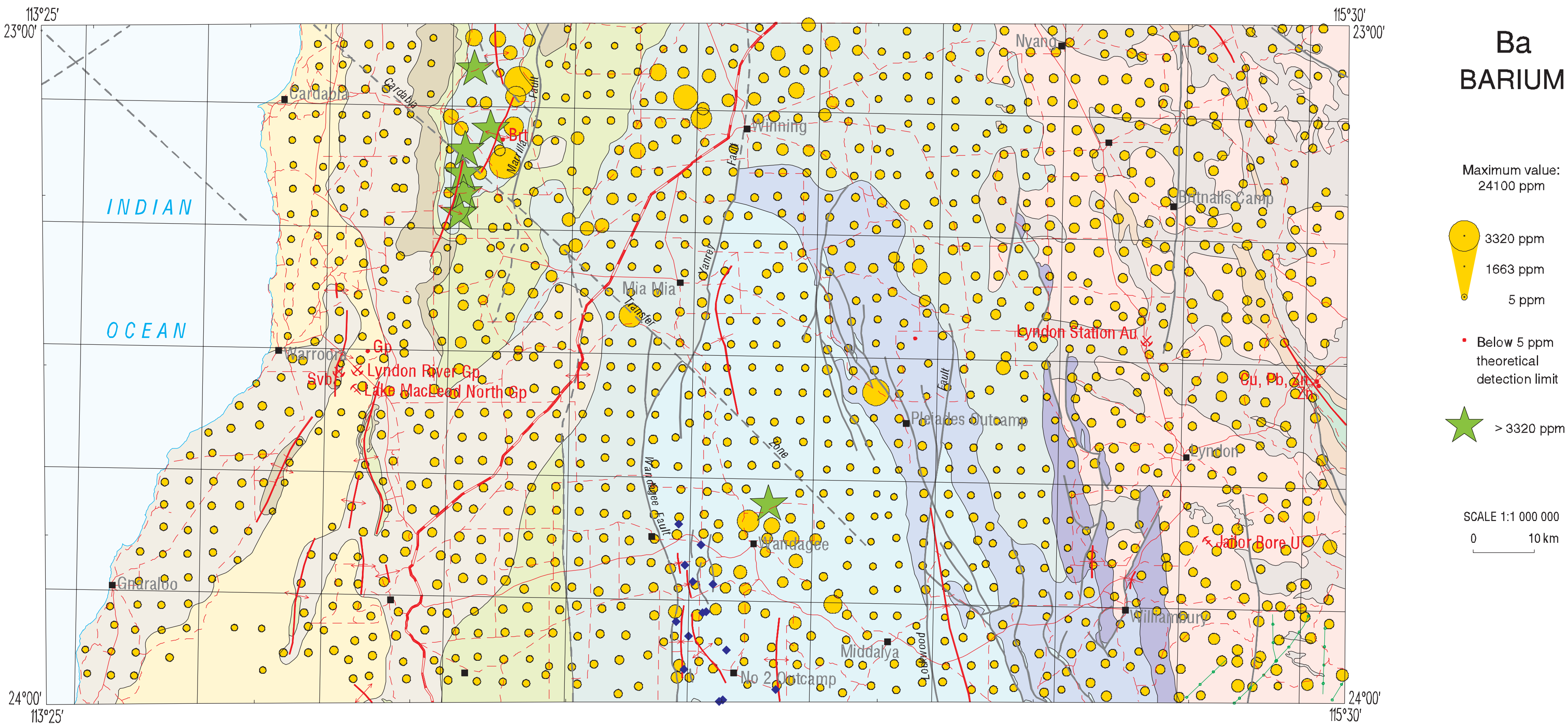

Figure 19

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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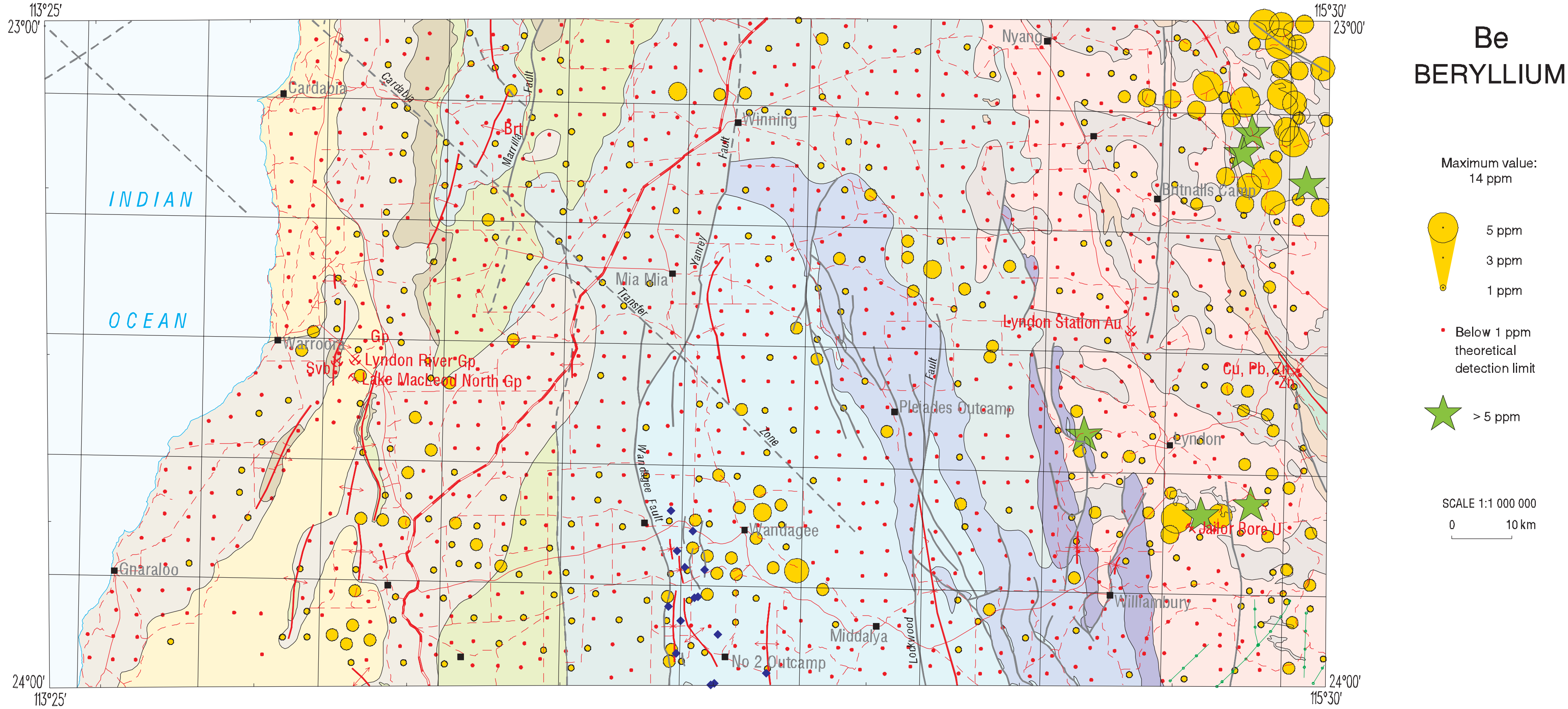
08 Feb 01 12:23:27



WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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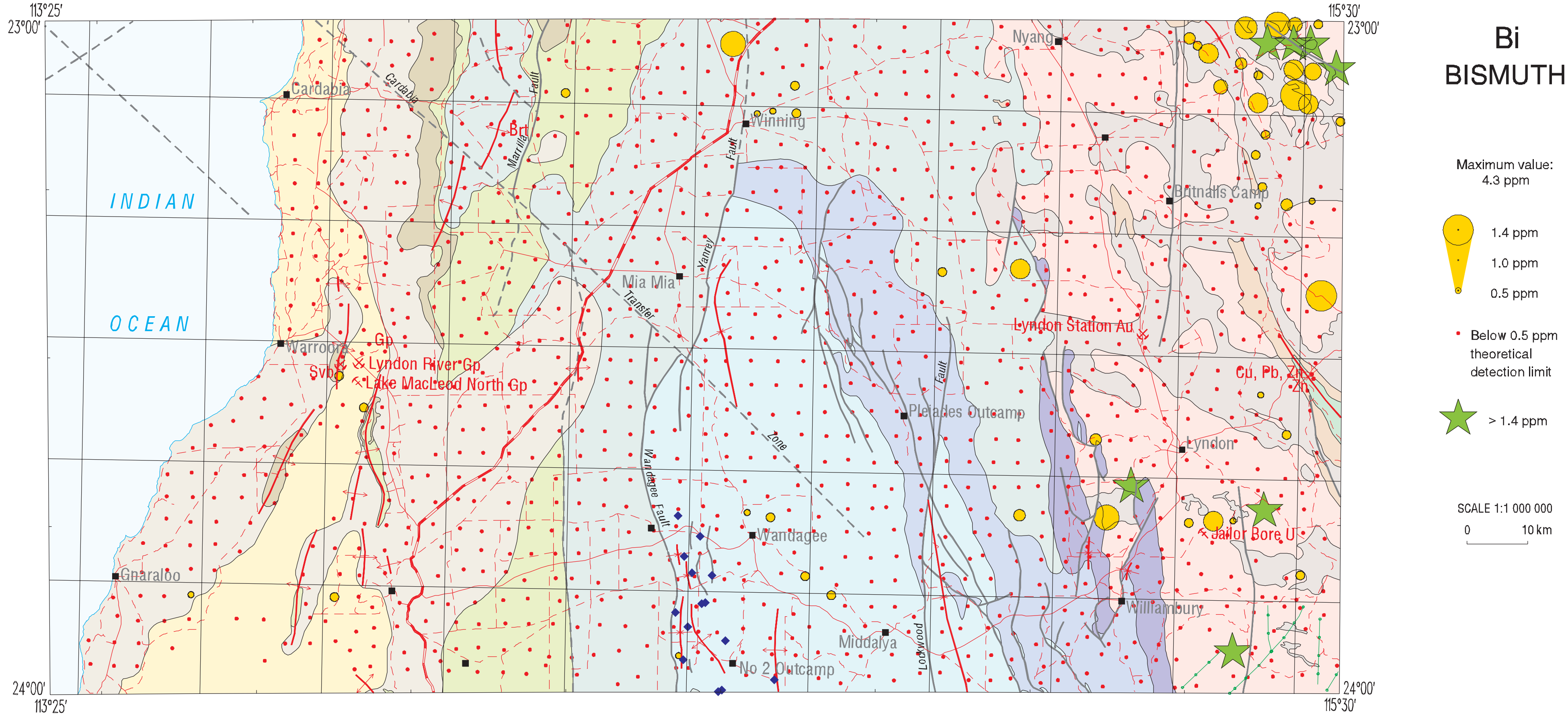
Figure 20

08 Feb 01 12:25:02



WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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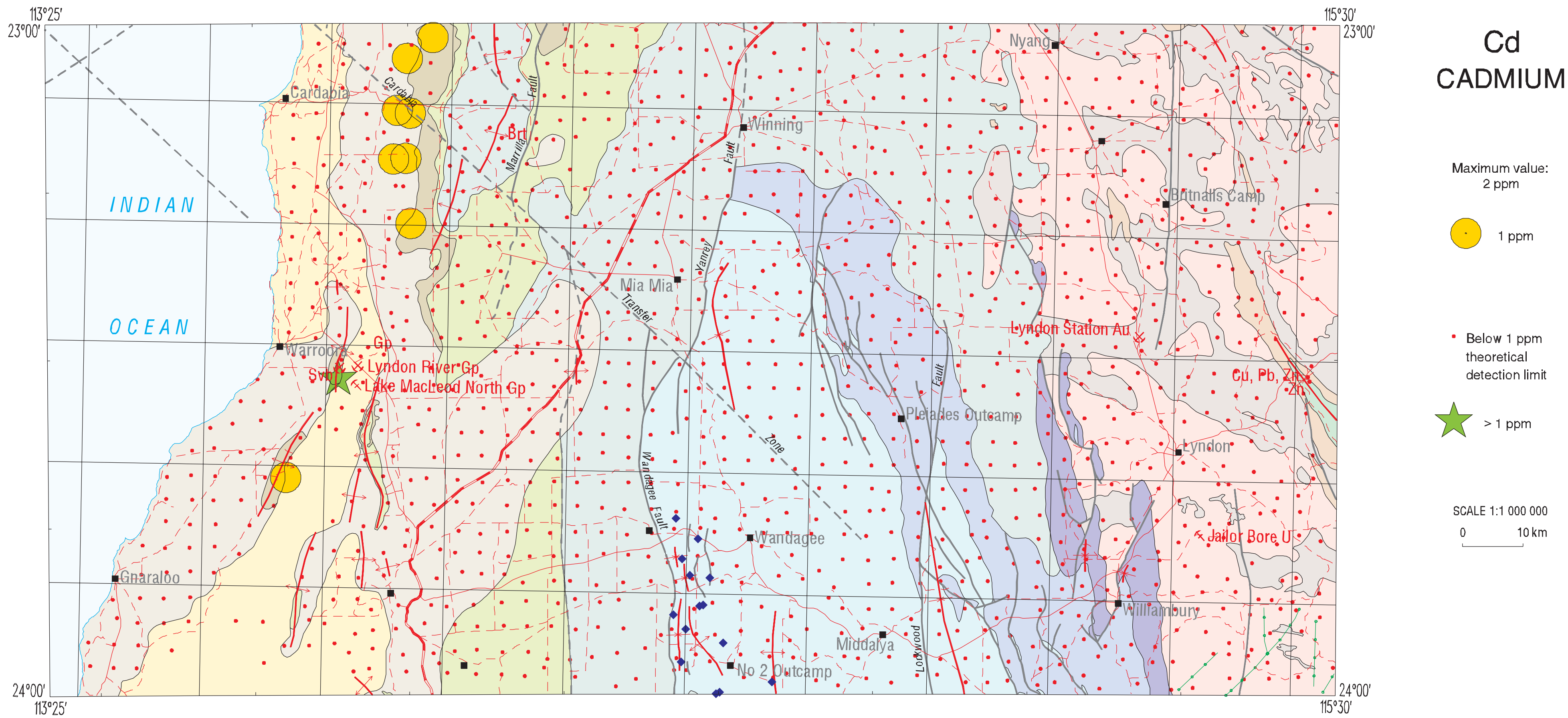
Figure 21

08 Feb 01 12:25:58



WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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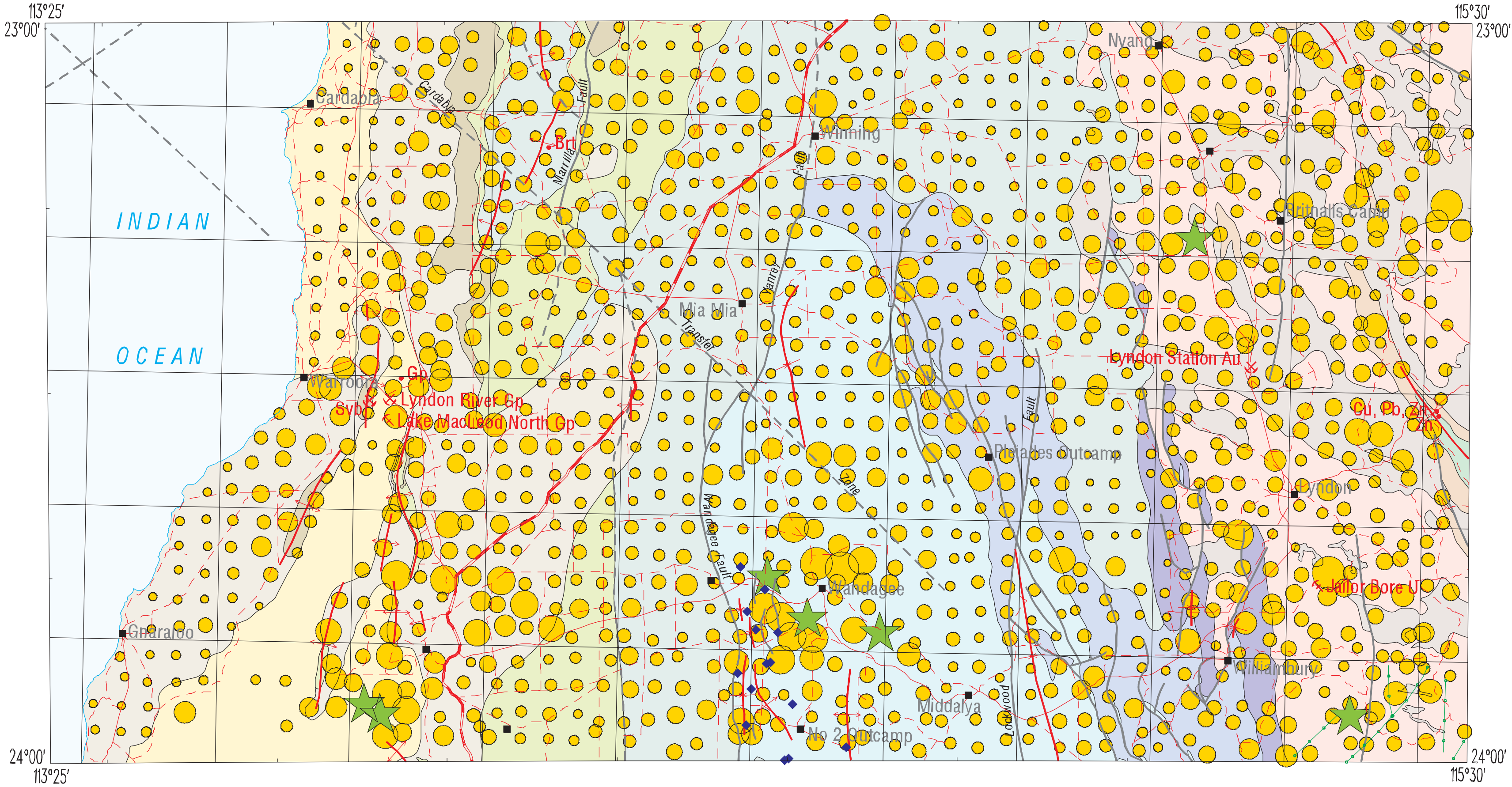
Figure 22

08 Feb 01 12:26:39



Ce
CERIUM

Maximum value:
254.0 ppm

89.8 ppm
46.5 ppm
3.1 ppm

Below 0.5 ppm theoretical detection limit

> 89.8 ppm

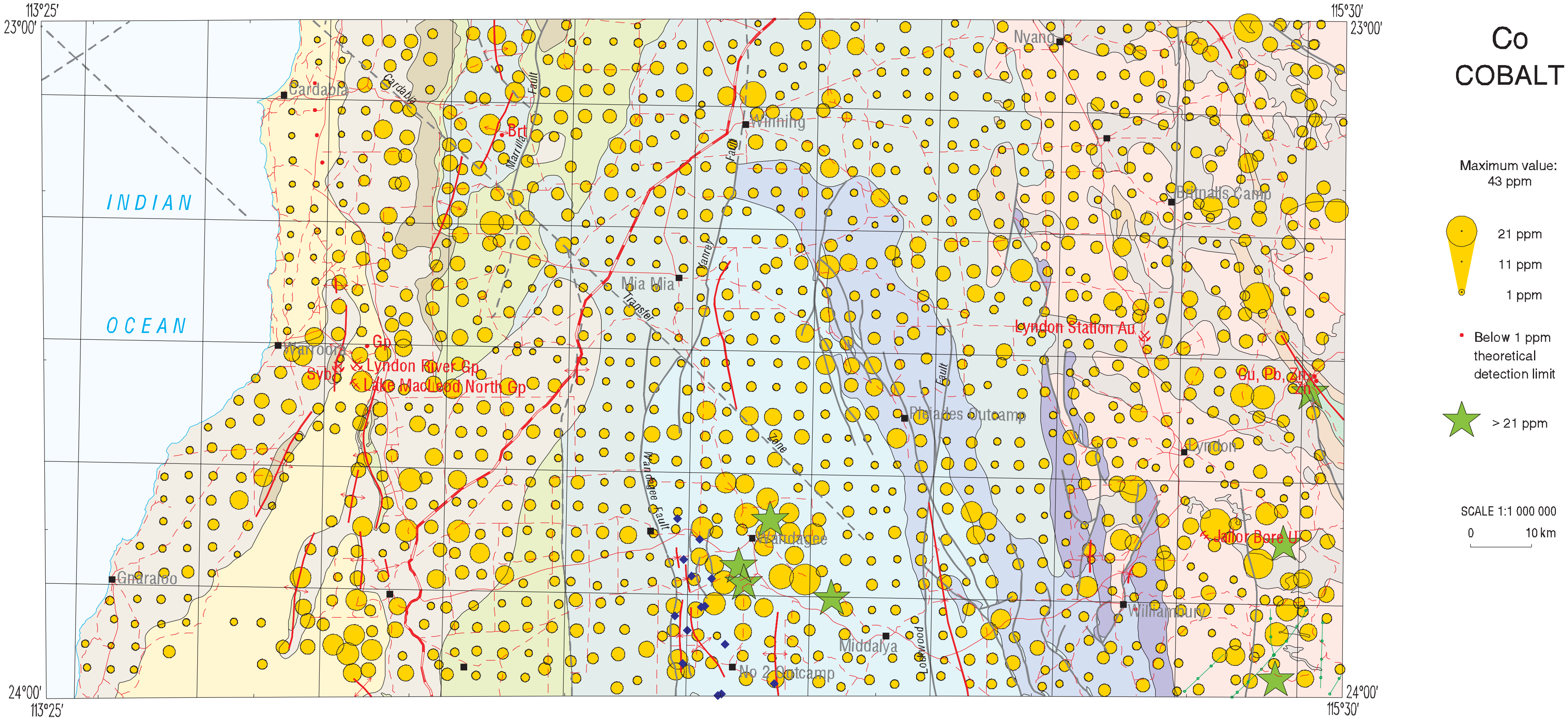
SCALE 1:1 000 000
0 10 km

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

First Edition 2001

Figure 23



WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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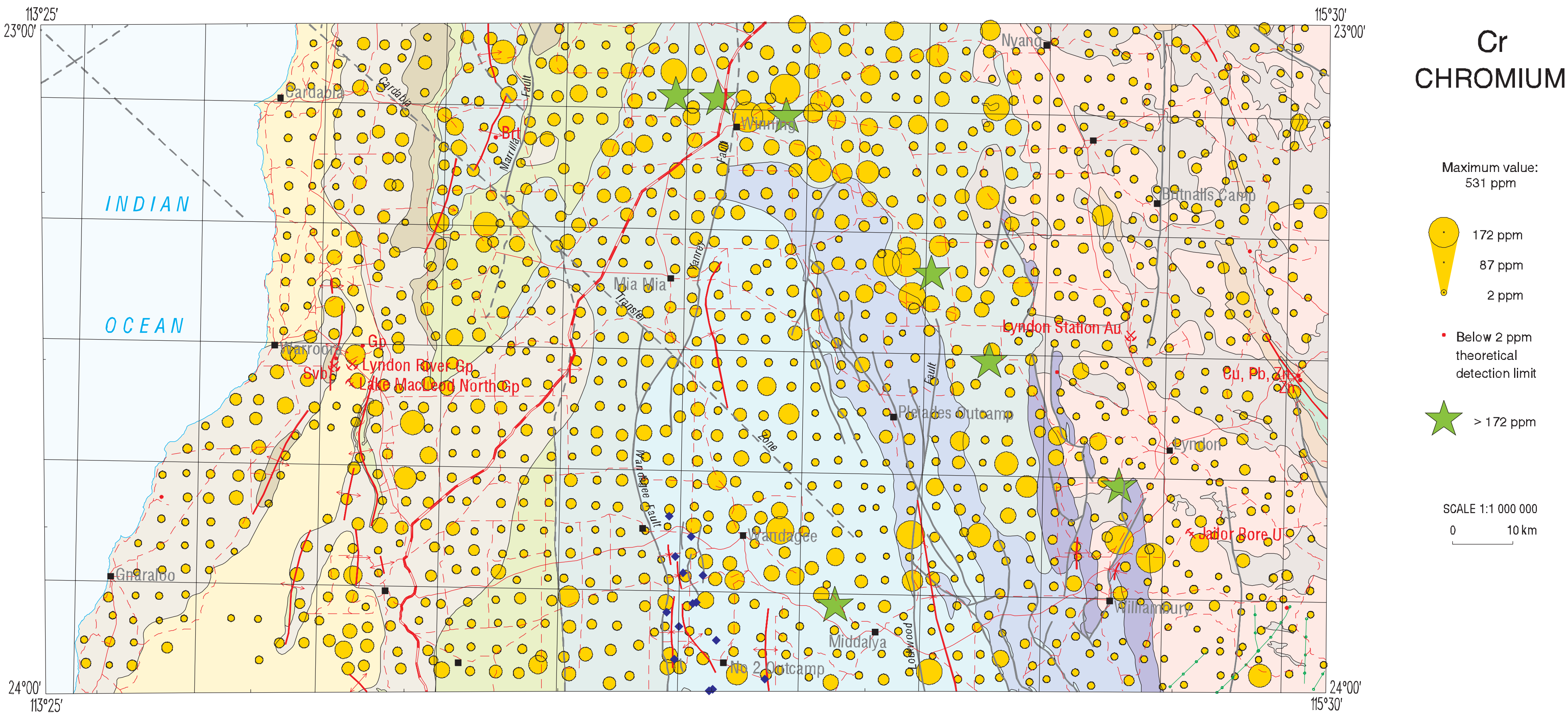
Figure 24

08 Feb 01 12:28:53



WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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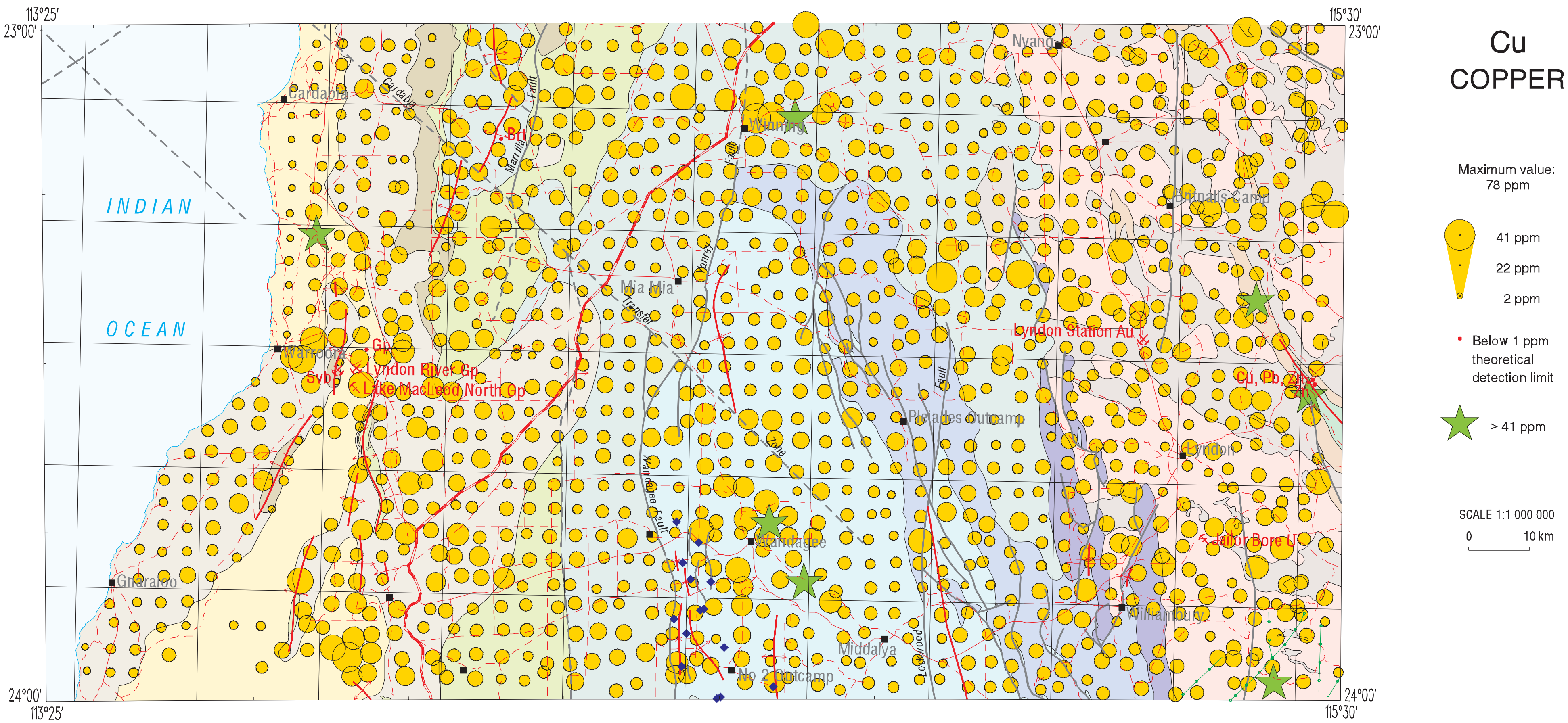
Figure 25

08 Feb 01 12:30:31



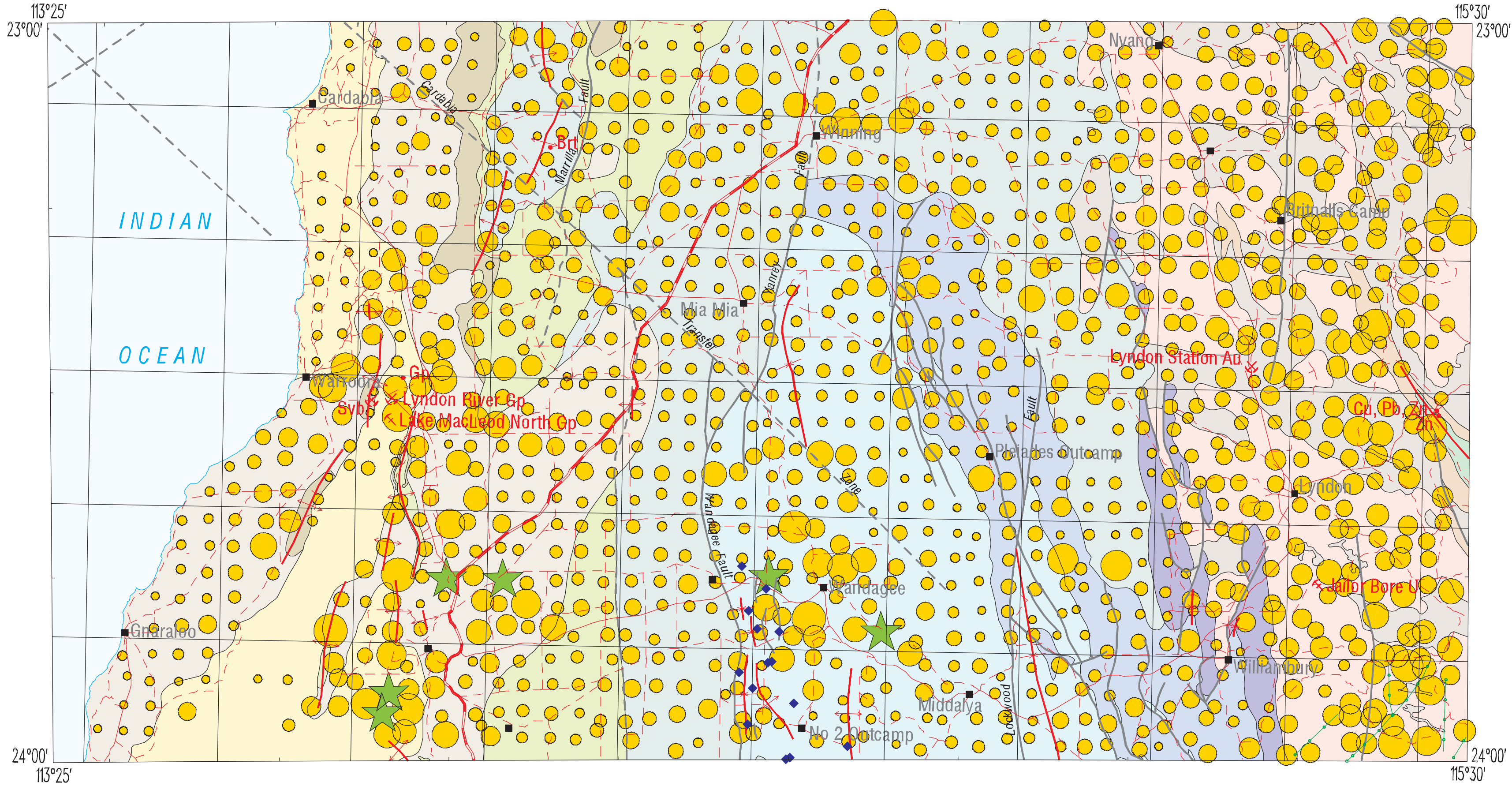
WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

First Edition 2001

Figure 26

08 Feb 01 12:32:05



Ga
GALLIUM

Maximum value:
32 ppm

20 ppm
11 ppm
1 ppm

Below 1 ppm theoretical detection limit

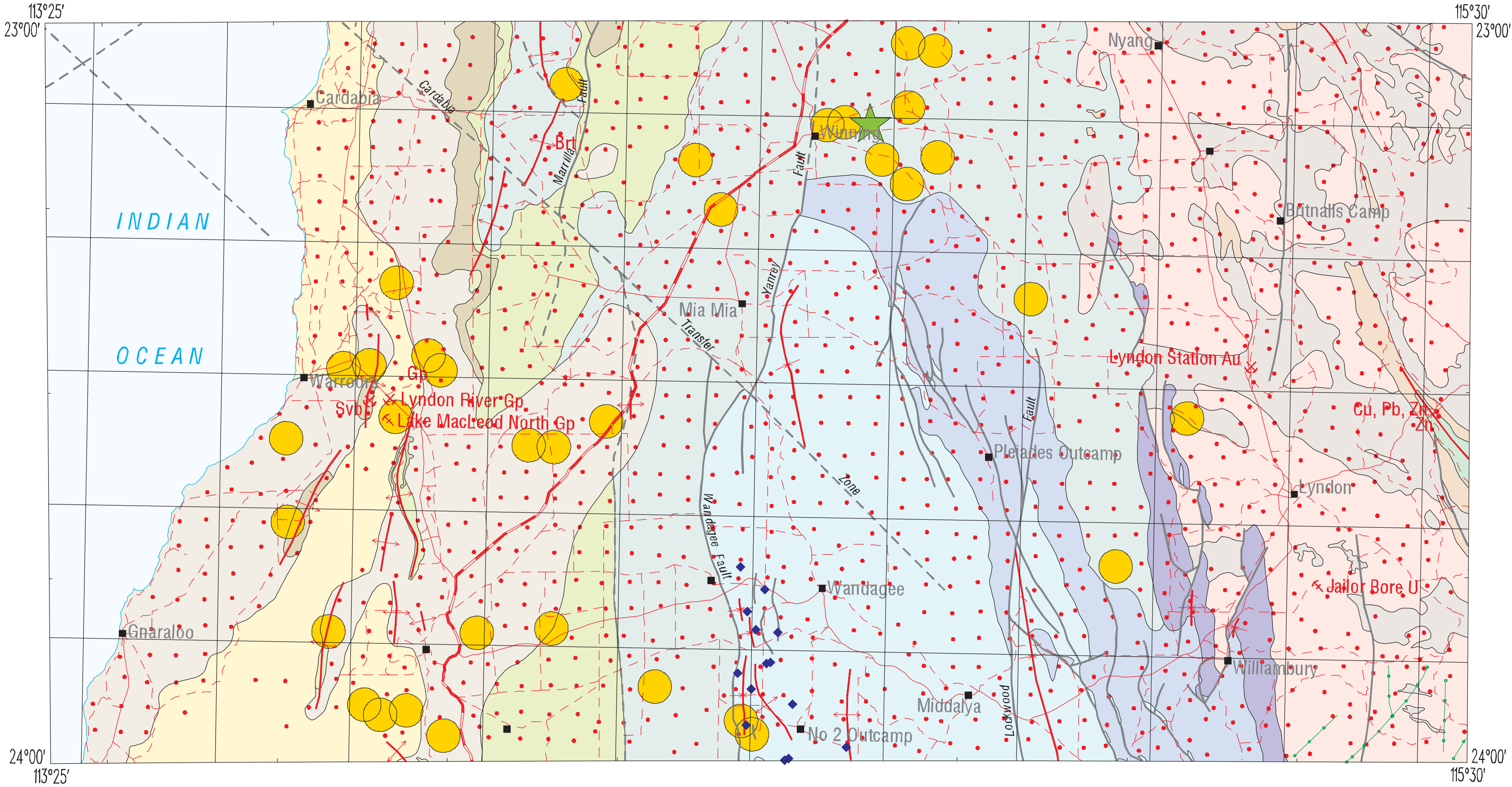
> 20 ppm

SCALE 1:1 000 000
0 10 km

WINNING POOL - MINILYA
SHEET SF 50-13, part SF 49-16
First Edition 2001

Figure 27

08 Feb 01 12:33:38



In
INDIUM

Maximum value: 0.2 ppm

0.1 ppm

Below 0.1 ppm theoretical detection limit

> 0.1 ppm

SCALE 1:1 000 000

0 10 km

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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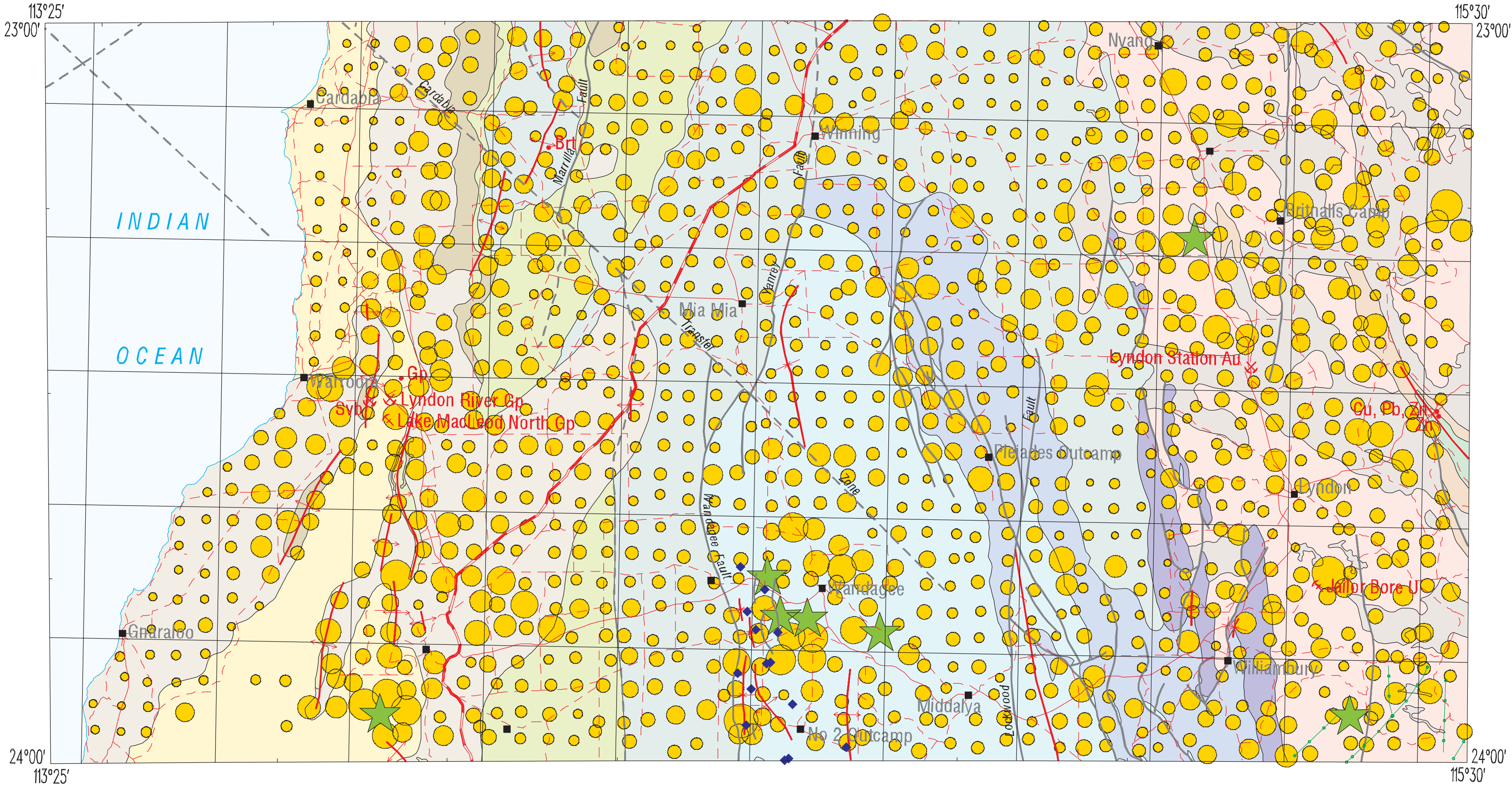
Figure 28

08 Feb 01 12.35.14



La
LANTHANUM

Maximum value:
144.0 ppm

49.5 ppm
25.9 ppm
2.2 ppm

Below 0.2 ppm theoretical detection limit

> 49.5 ppm

SCALE 1:1 000 000
0 10 km

WINNING POOL - MINILYA
SHEET SF 50-13, part SF 49-16
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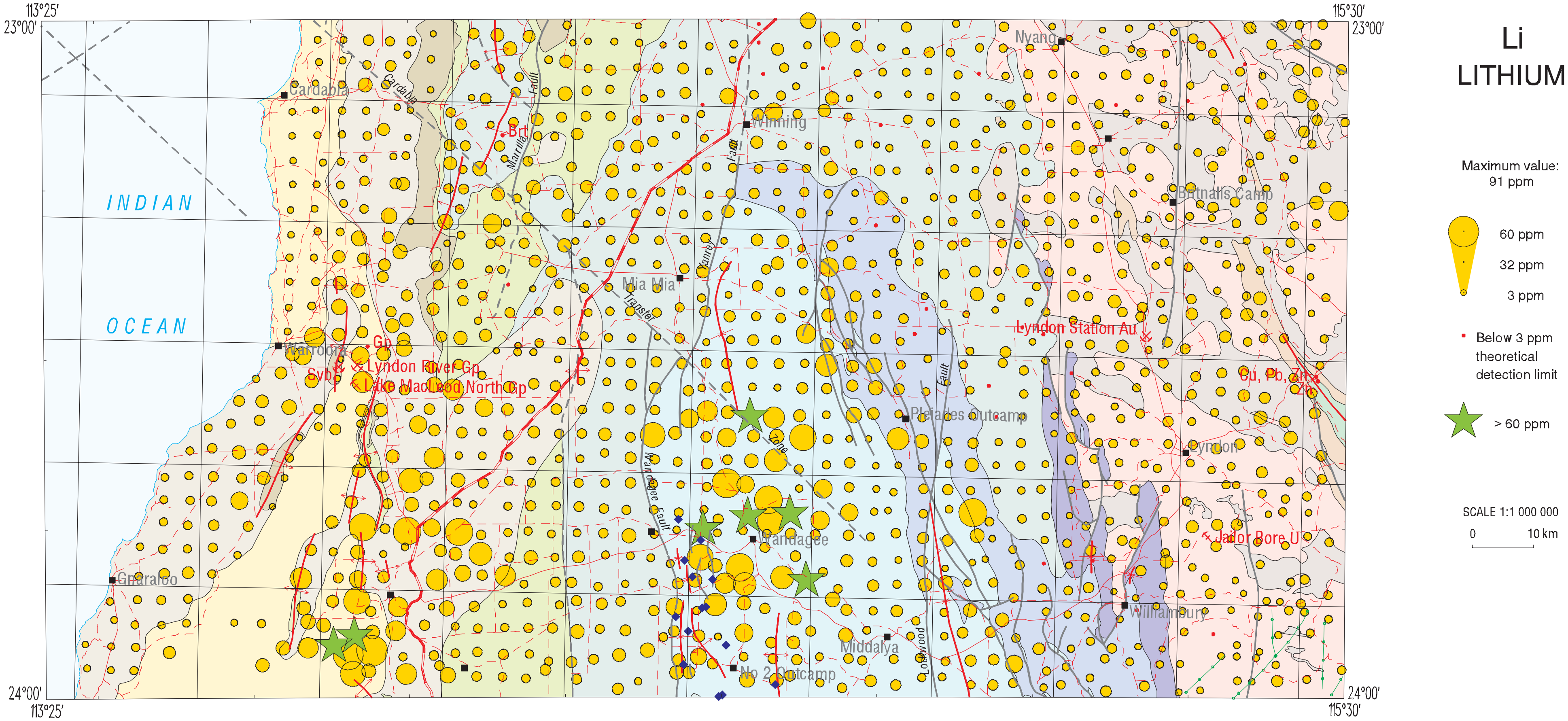
Figure 29

08 Feb 01 12:35:54

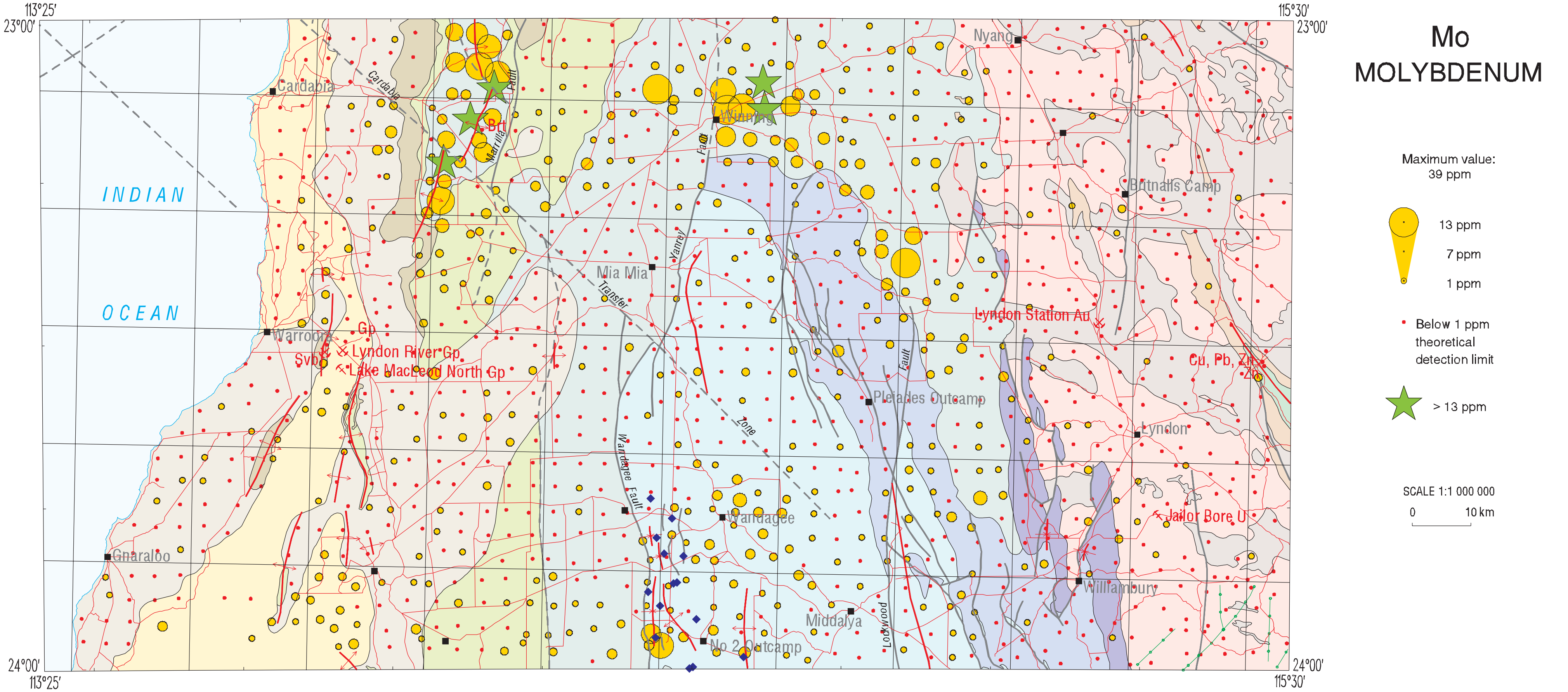


WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

First Edition 2001

Figure 30

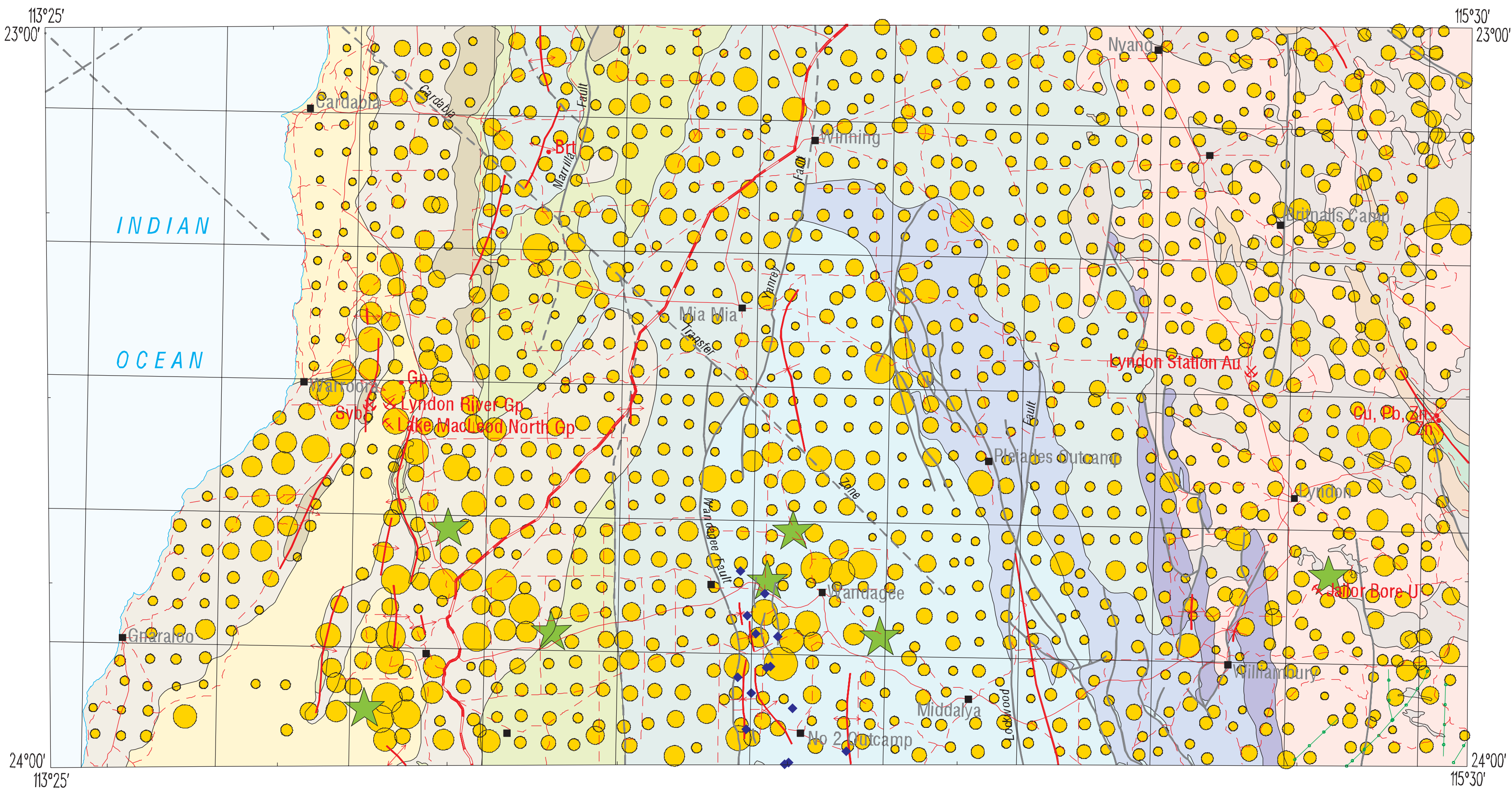


WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

First Edition 2001

Figure 31



Nb
NIOBIUM

Maximum value:
55.4 ppm

35.7 ppm
18.3 ppm
0.8 ppm

• Below 0.5 ppm theoretical detection limit

★ > 35.7 ppm

SCALE 1:1 000 000

0 10 km

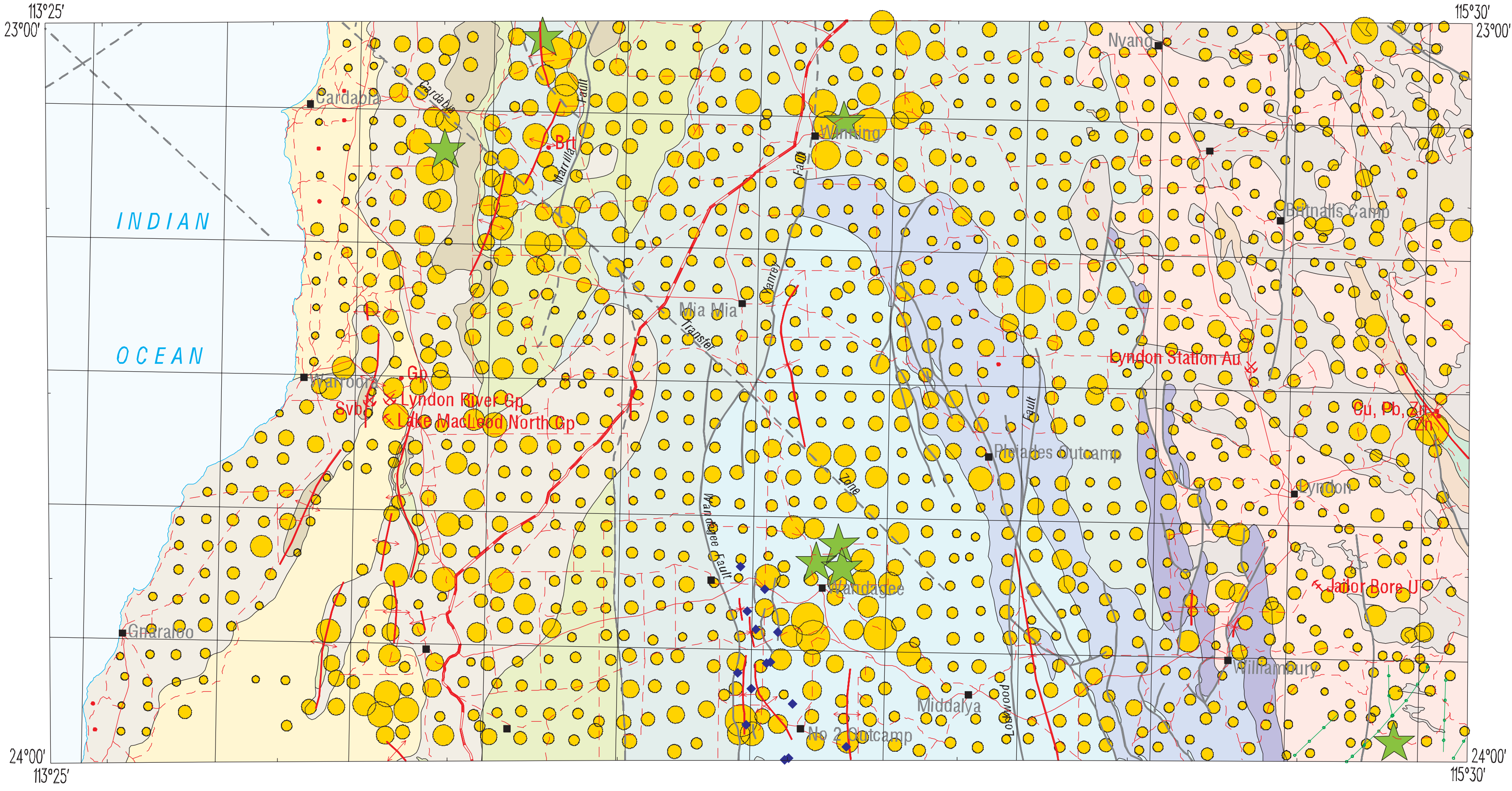
WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

First Edition 2001

Figure 32

08 Feb 01 12:39:55



Ni
NICKEL

Maximum value:
101 ppm

50 ppm
26 ppm
2 ppm

Below 2 ppm theoretical detection limit

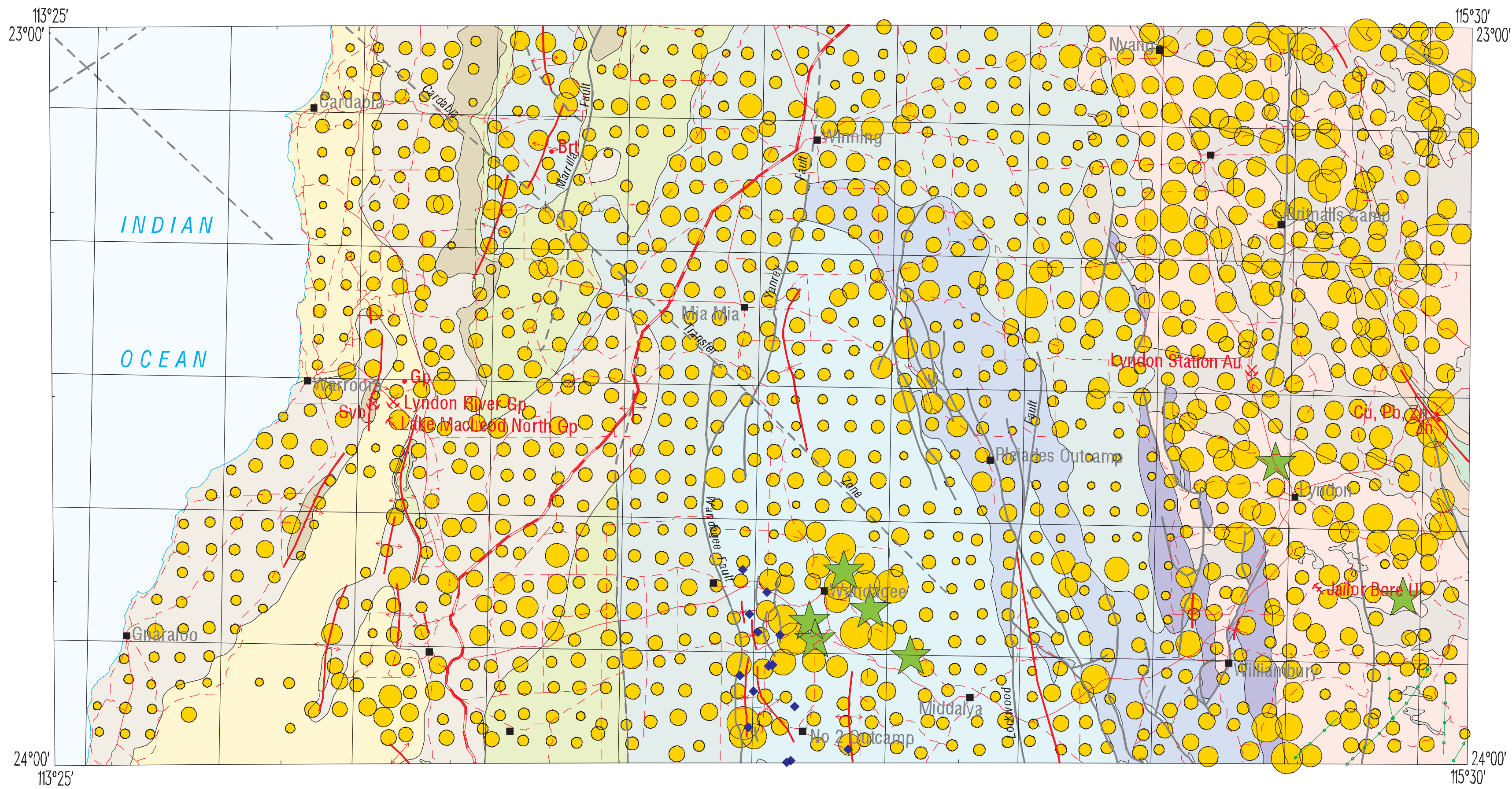
> 50 ppm

SCALE 1:1 000 000
0 10 km

WINNING POOL - MINILYA
SHEET SF 50-13, part SF 49-16
First Edition 2001

Figure 33

08 Feb 01 12.41.29



Pb
LEAD

Maximum value:
64 ppm

40 ppm
21 ppm
2 ppm

• Below 1 ppm theoretical detection limit

★ > 40 ppm

SCALE 1:1 000 000
0 10 km

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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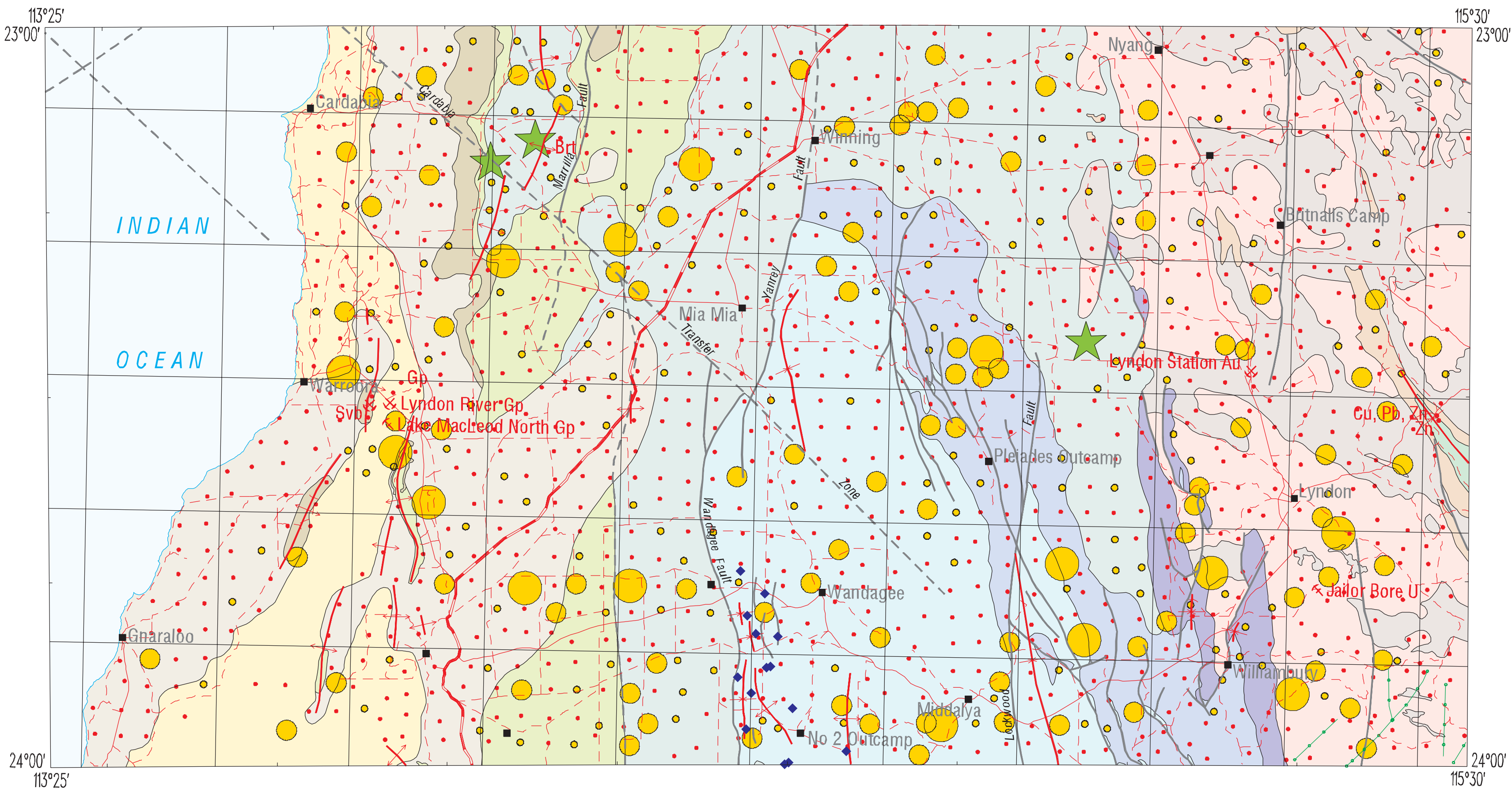
Figure 34

08 Feb 01 12:43:03



Pd
PALLADIUM

Maximum value:
4 ppb

3 ppb
2 ppb
1 ppb

Below 1 ppb theoretical detection limit

> 3 ppb

SCALE 1:1 000 000
0 10 km

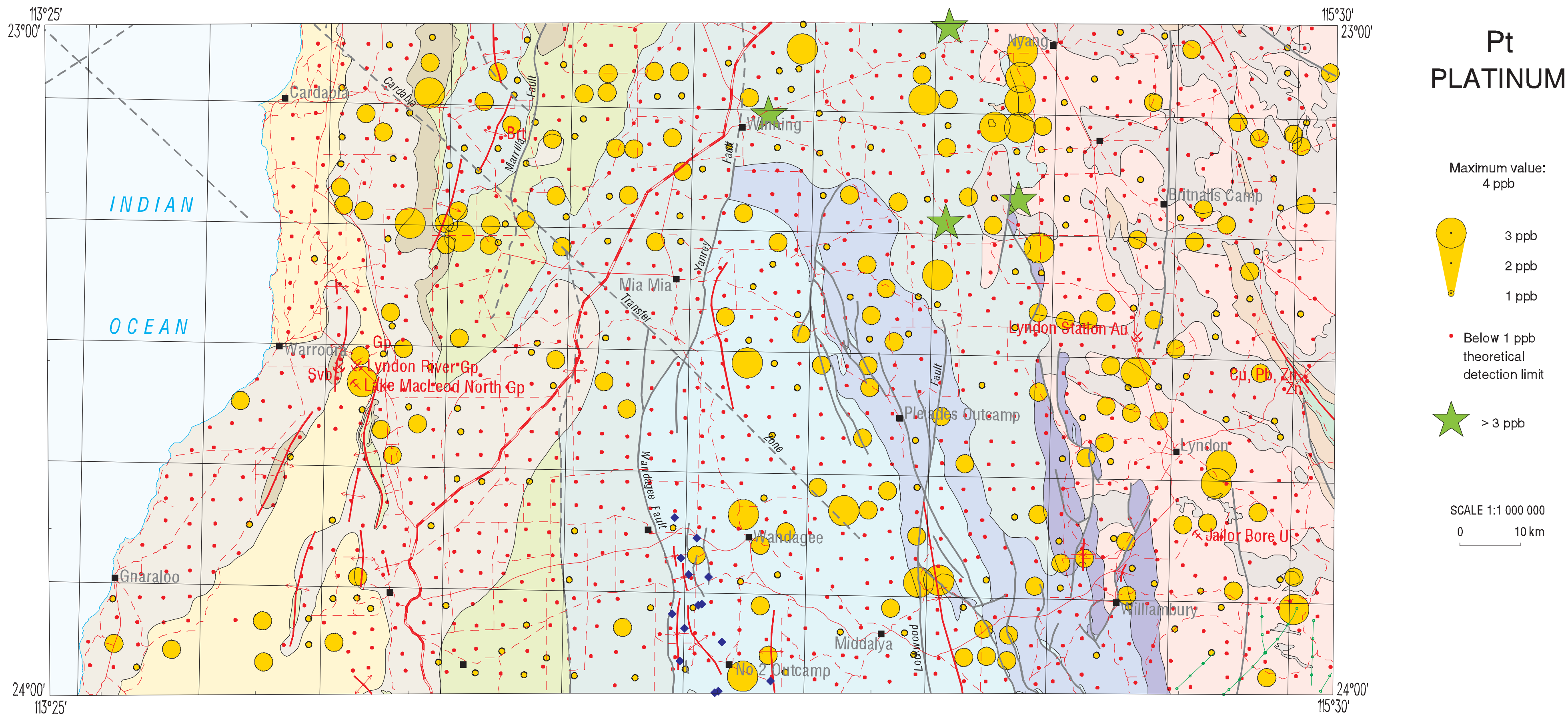
WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

First Edition 2001

Figure 35

08 Feb 01 12.44.38



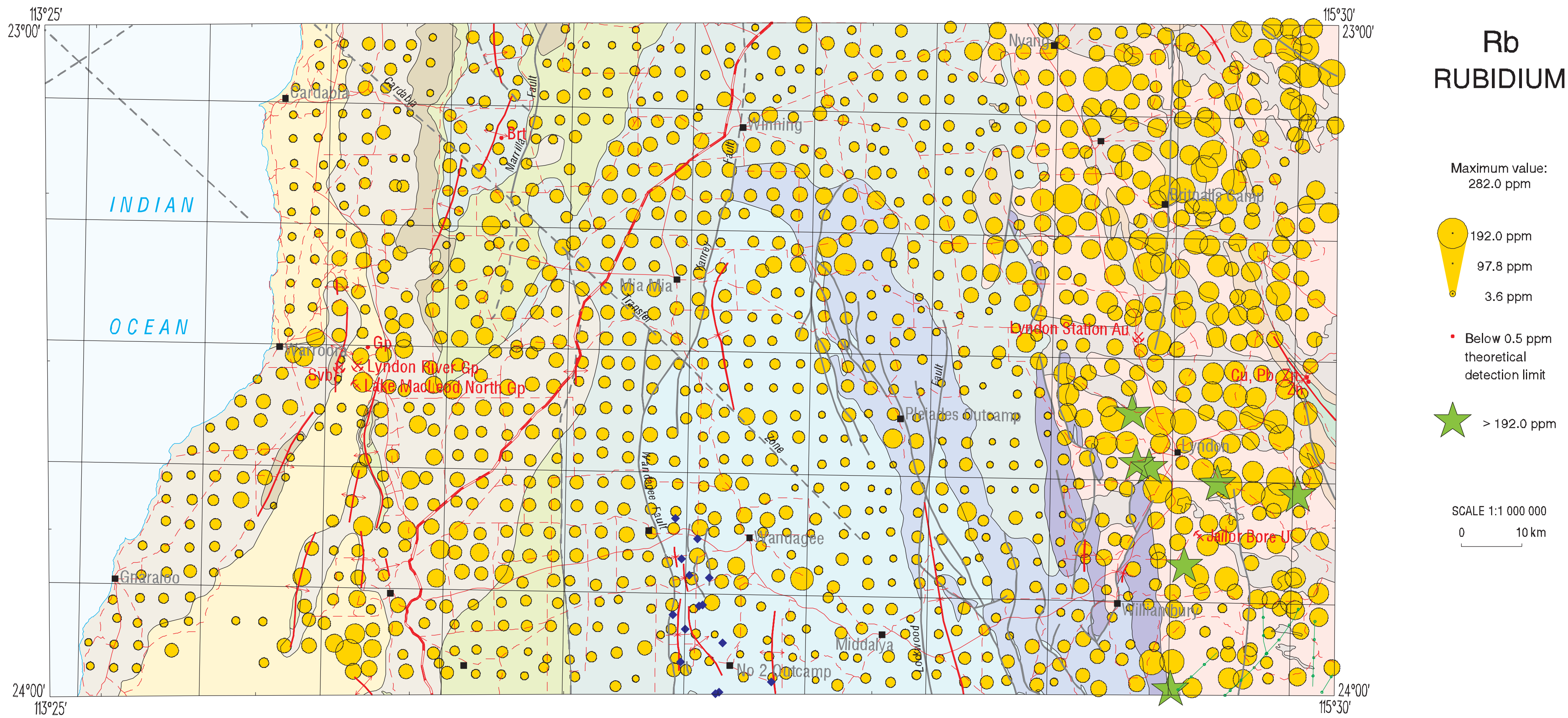
WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

First Edition 2001

Figure 36

08 Feb 01 12.45.27



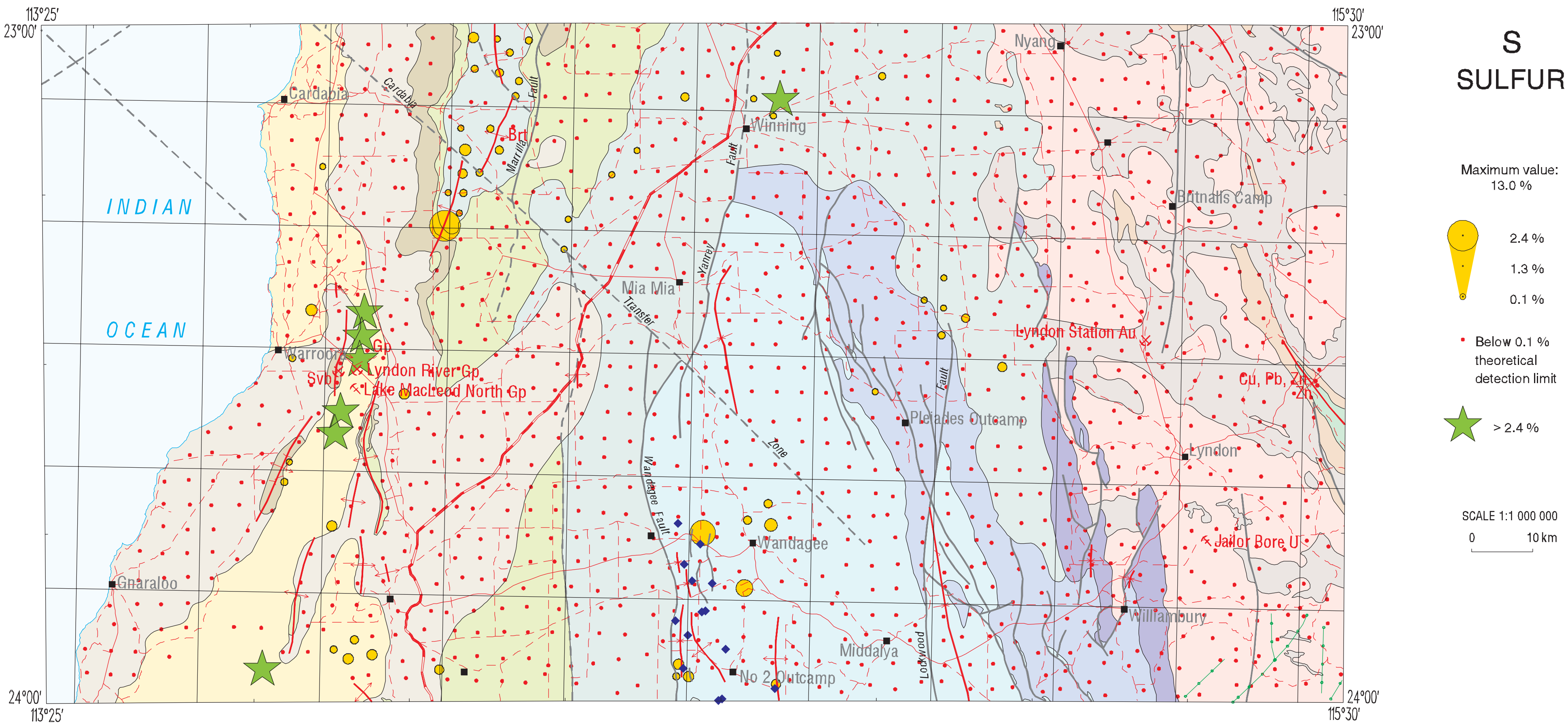
WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

First Edition 2001

Figure 37

08 Feb 01 12:46:19

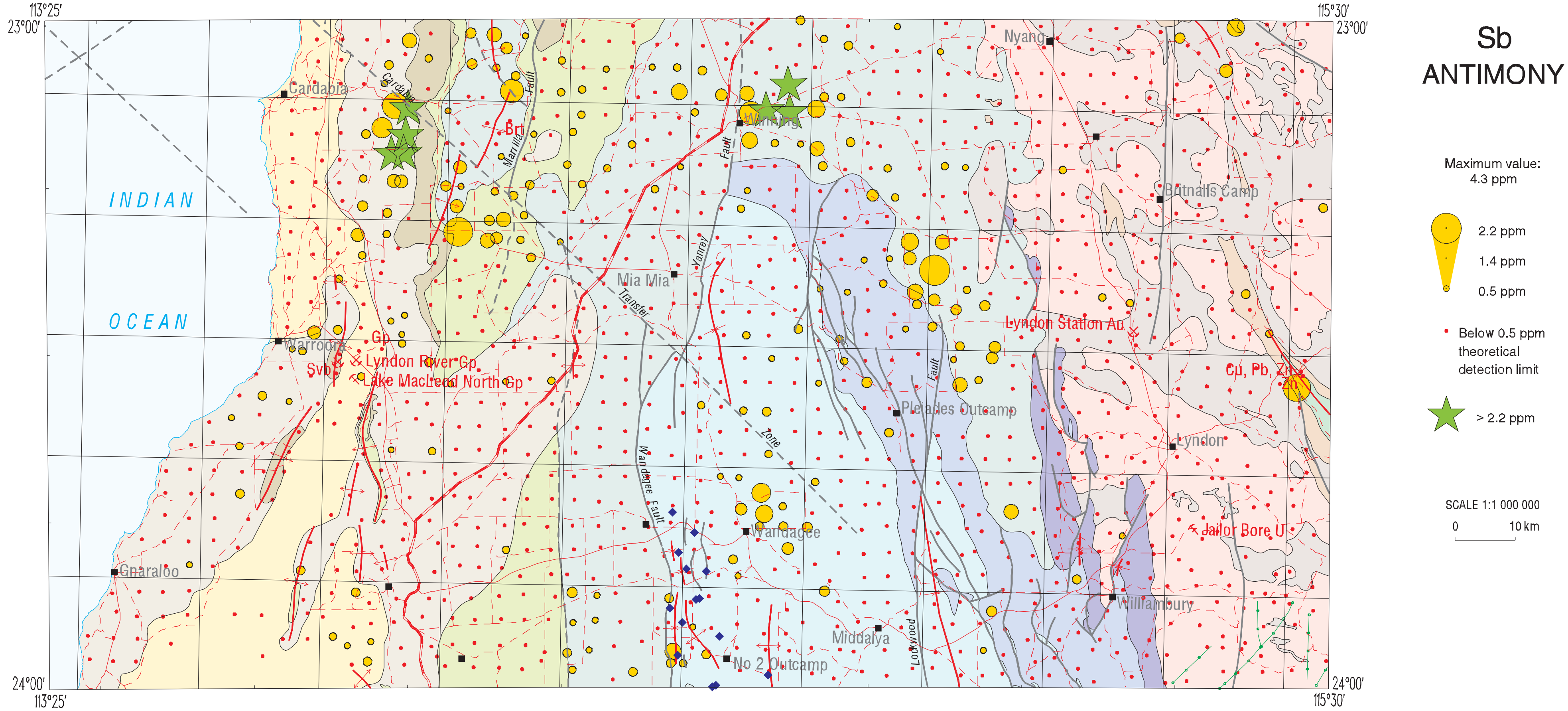


WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

First Edition 2001

Figure 38

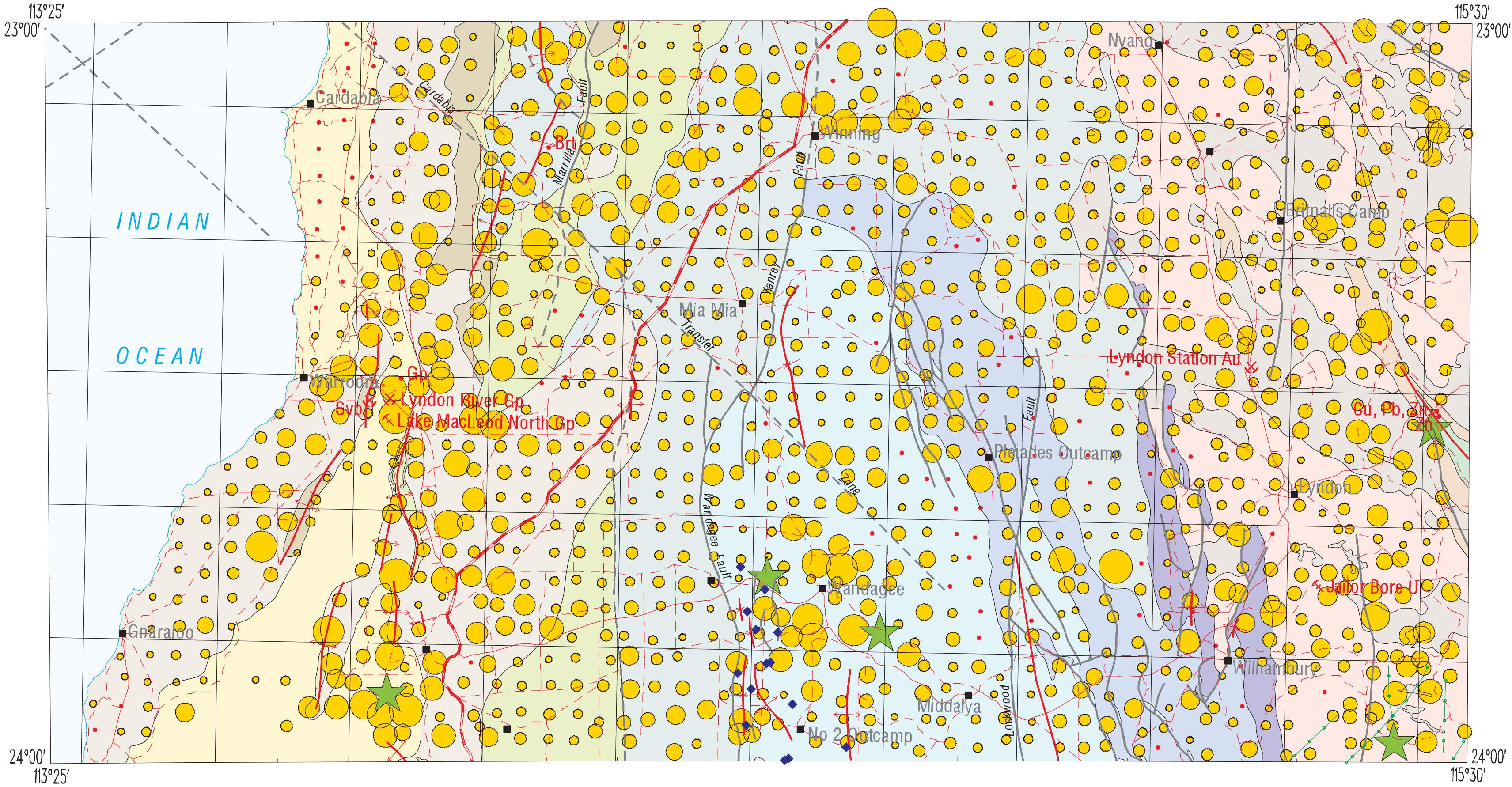


WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

First Edition 2001

Figure 39



Sc
SCANDIUM

Maximum value: 20 ppm

12 ppm
7 ppm
1 ppm

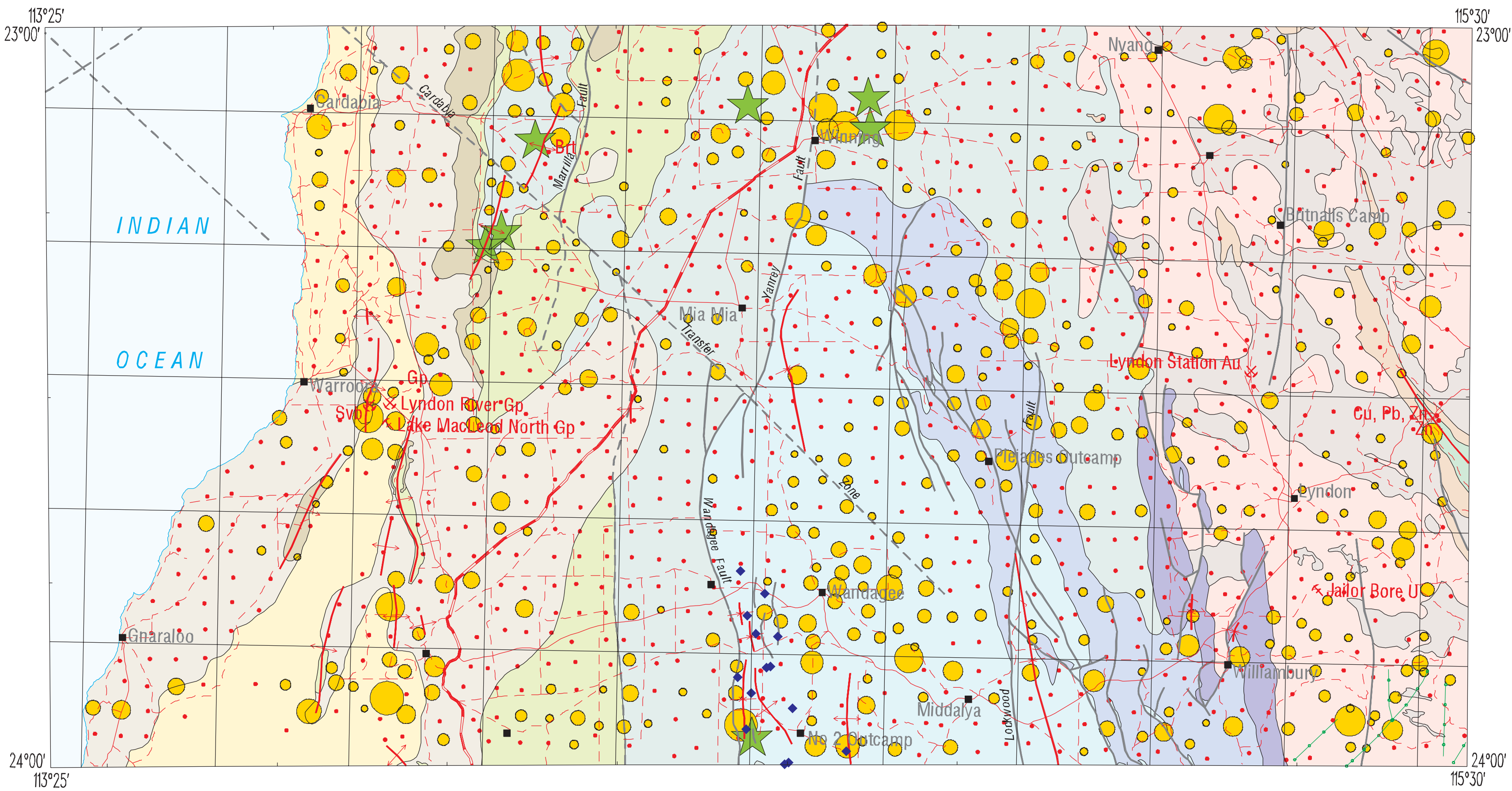
Below 1 ppm theoretical detection limit

> 12 ppm

SCALE 1:1 000 000
0 10 km

WINNING POOL - MINILYA
SHEET SF 50-13, part SF 49-16
First Edition 2001

Figure 40



Se
SELENIUM

Maximum value:
4.2 ppm

3.2 ppm
1.9 ppm
0.5 ppm

Below 0.5 ppm theoretical detection limit

> 3.2 ppm

SCALE 1:1 000 000

0 10 km

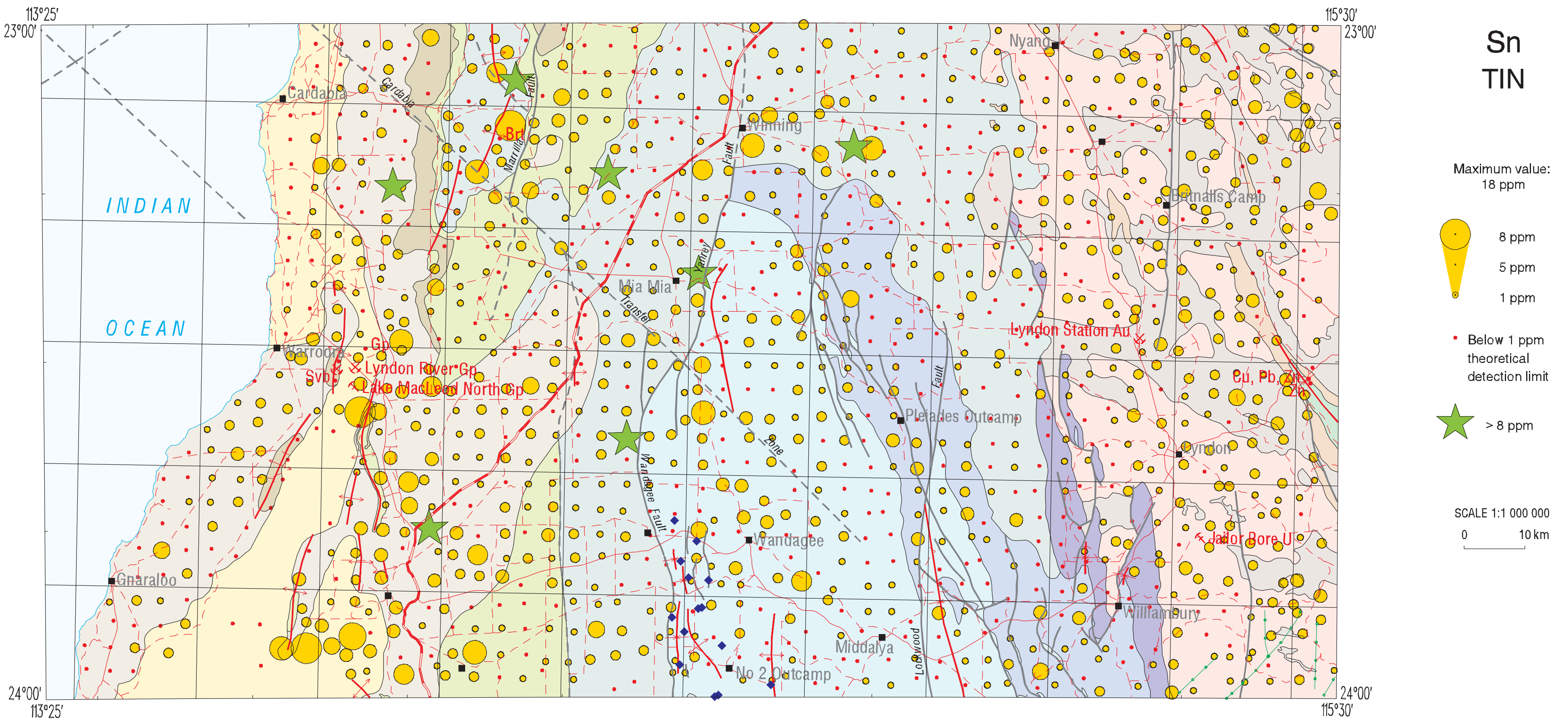
WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

First Edition 2001

Figure 41

08 Feb 01 12.50.49



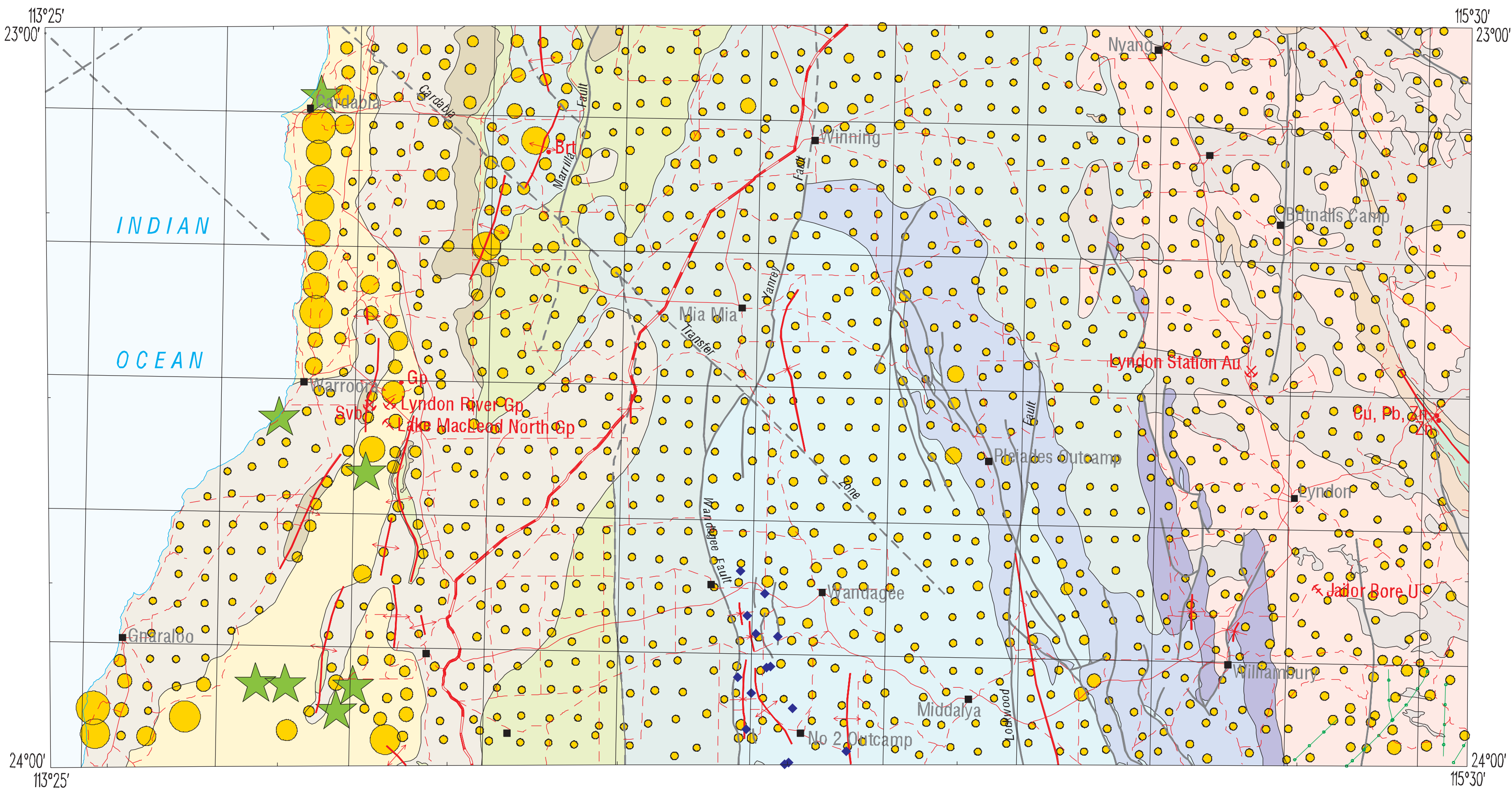
WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

First Edition 2001

Figure 42

Sr
STRONTIUM



Maximum value: 5750 ppm

1460 ppm

732 ppm

3 ppm

Below 1 ppm theoretical detection limit

> 1460 ppm

SCALE 1:1 000 000

0 10 km

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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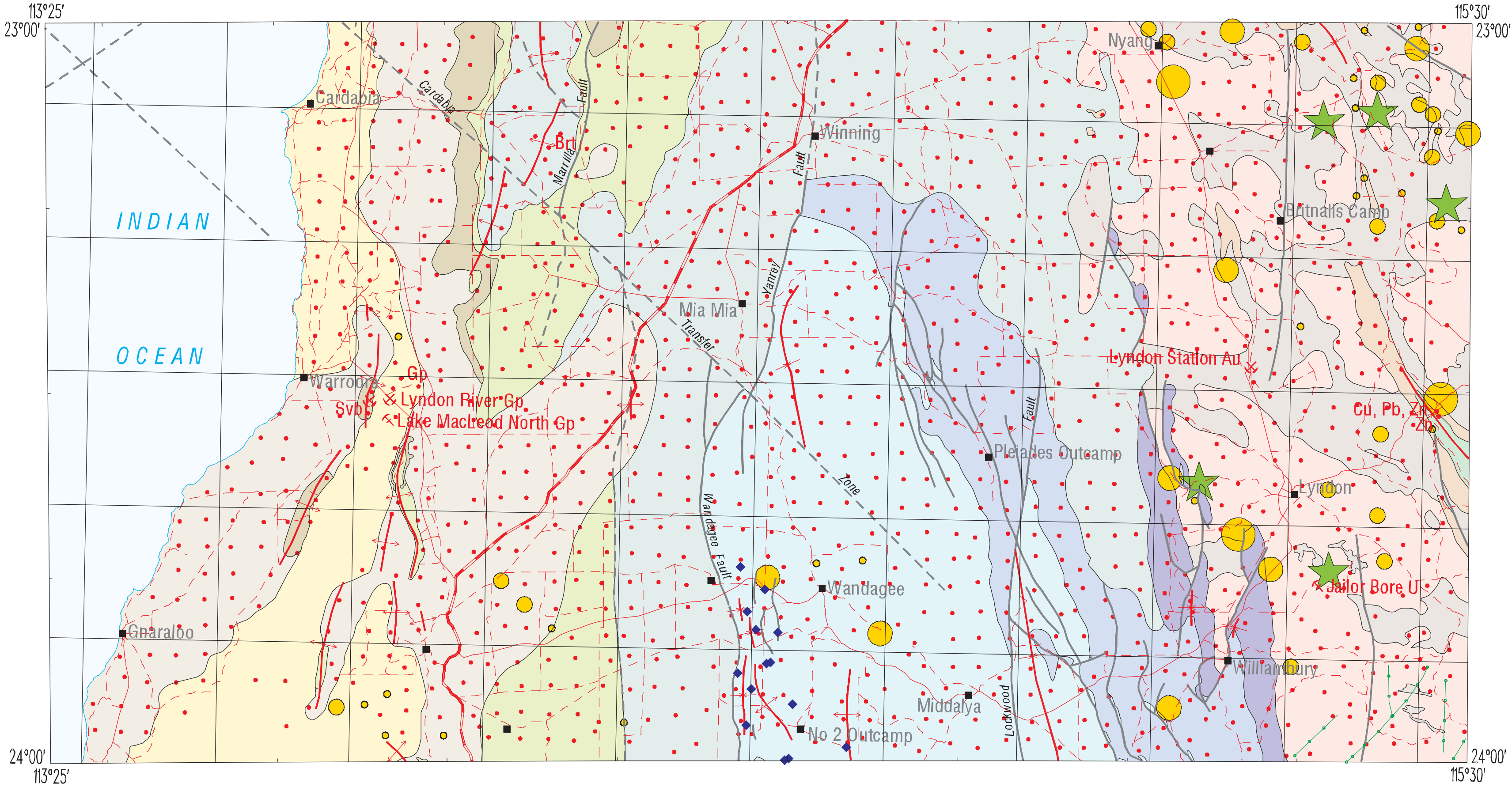
Figure 43

08 Feb 01 12:52:58



Ta
TANTALUM

Maximum value:
17 ppm

5 ppm
4 ppm
2 ppm

Below 2 ppm theoretical detection limit

> 5 ppm

SCALE 1:1 000 000
0 10 km

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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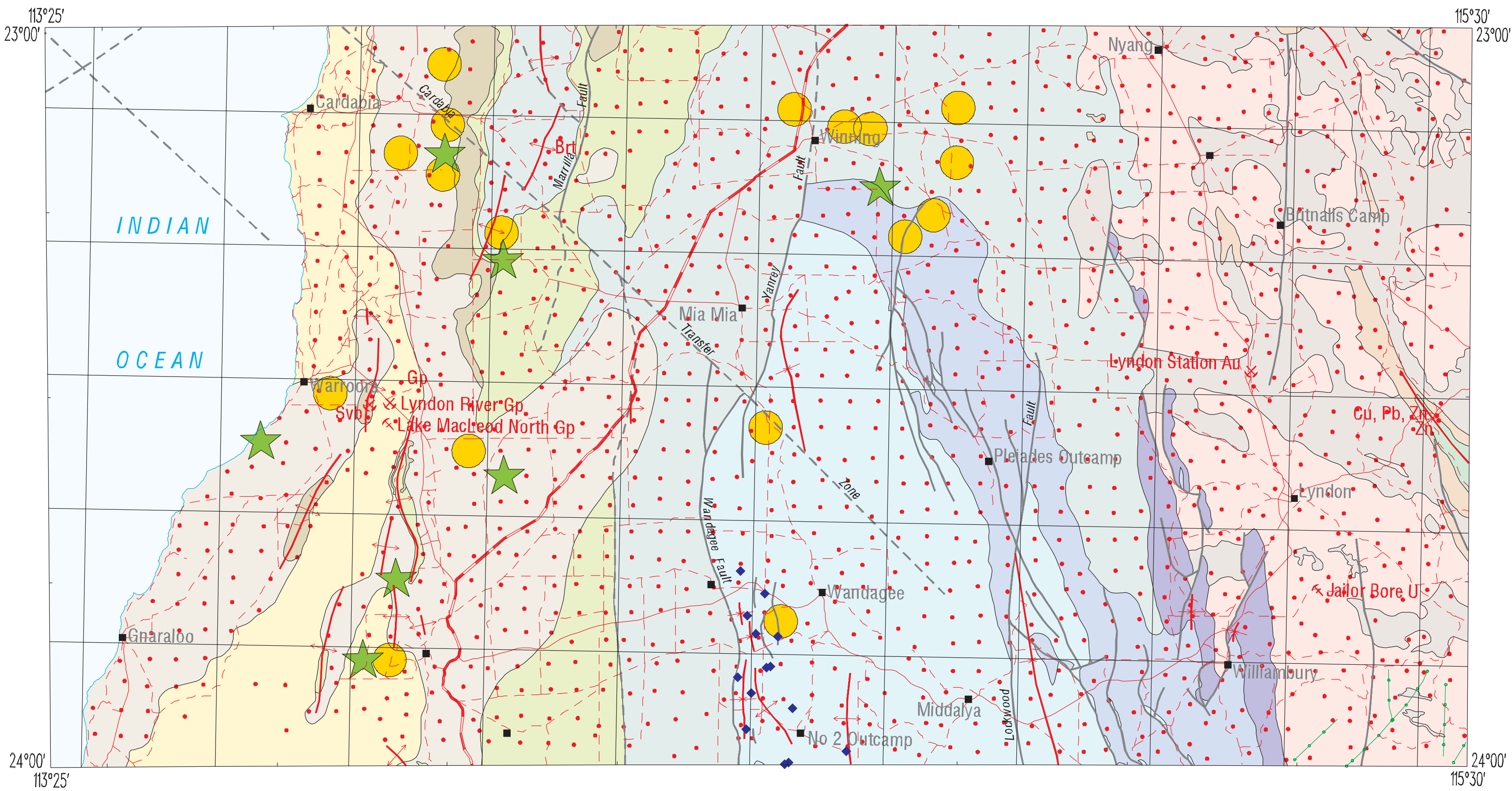
Figure 44

08 Feb 01 12:54:32

Te
TELLURIUM



Maximum value:
0.5 ppm

0.2 ppm

Below 0.2 ppm theoretical detection limit

> 0.2 ppm

SCALE 1:1 000 000

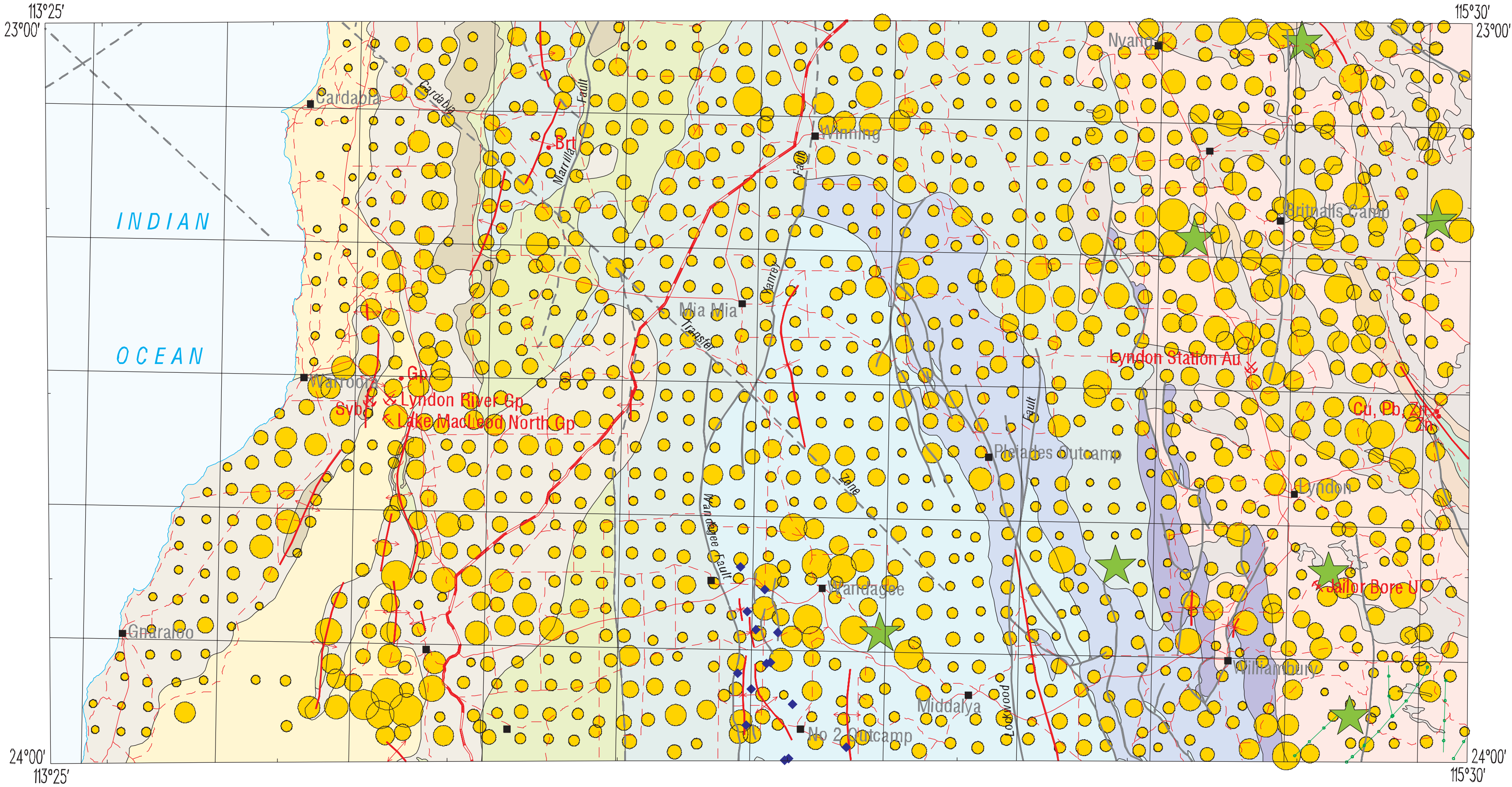
0 10 km

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

First Edition 2001

Figure 45



Th
THORIUM

Maximum value: 71.7 ppm

22.3 ppm
11.9 ppm
1.4 ppm

• Below 0.1 ppm theoretical detection limit

★ > 22.3 ppm

SCALE 1:1 000 000
0 10 km

WINNING POOL - MINILYA
SHEET SF 50-13, part SF 49-16
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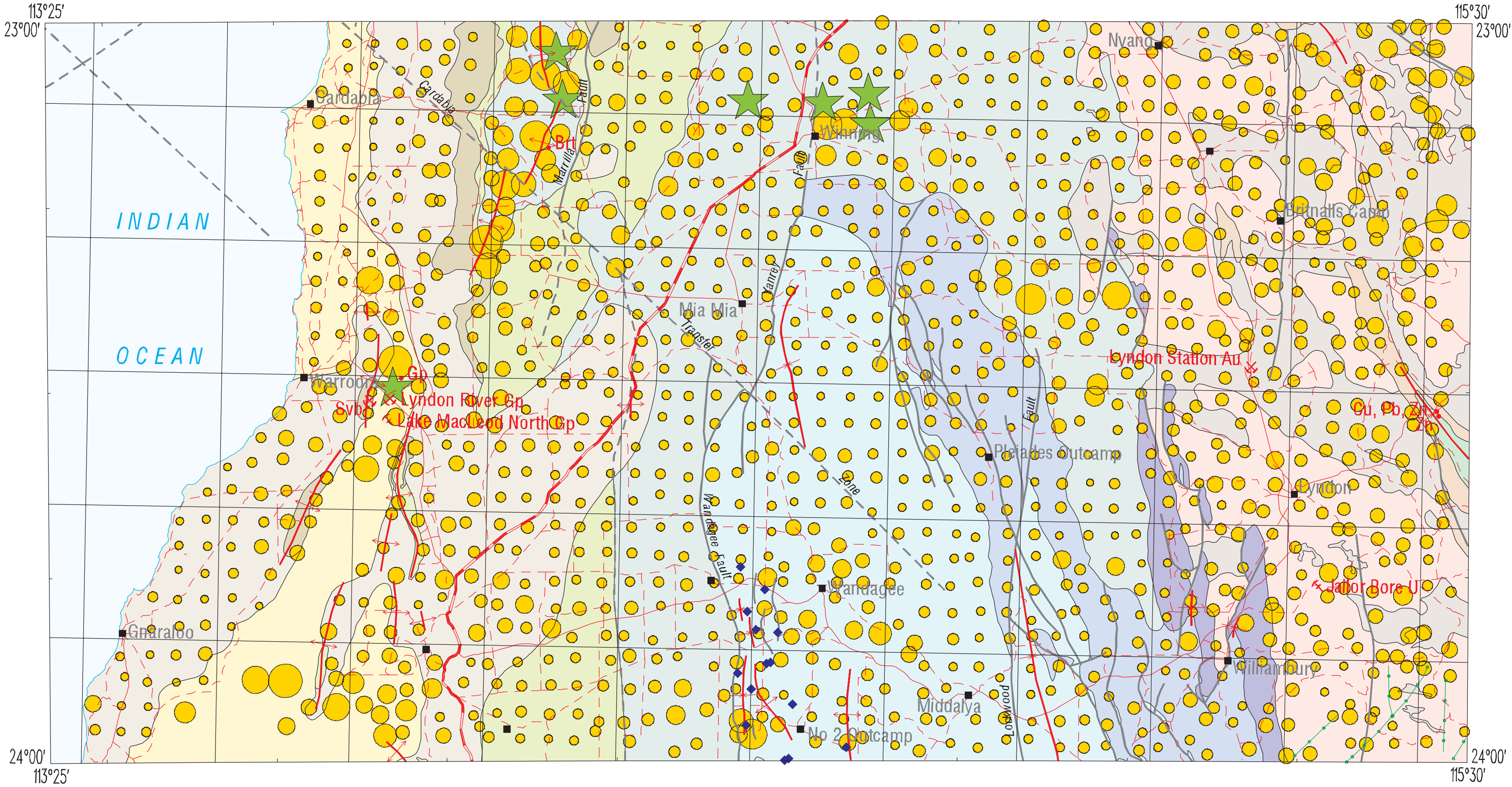
Figure 46

08 Feb 01 12:55:50

U
URANIUM



Maximum value: 14.0 ppm

6.0 ppm
3.1 ppm
0.2 ppm

Below 0.1 ppm theoretical detection limit

> 6.0 ppm

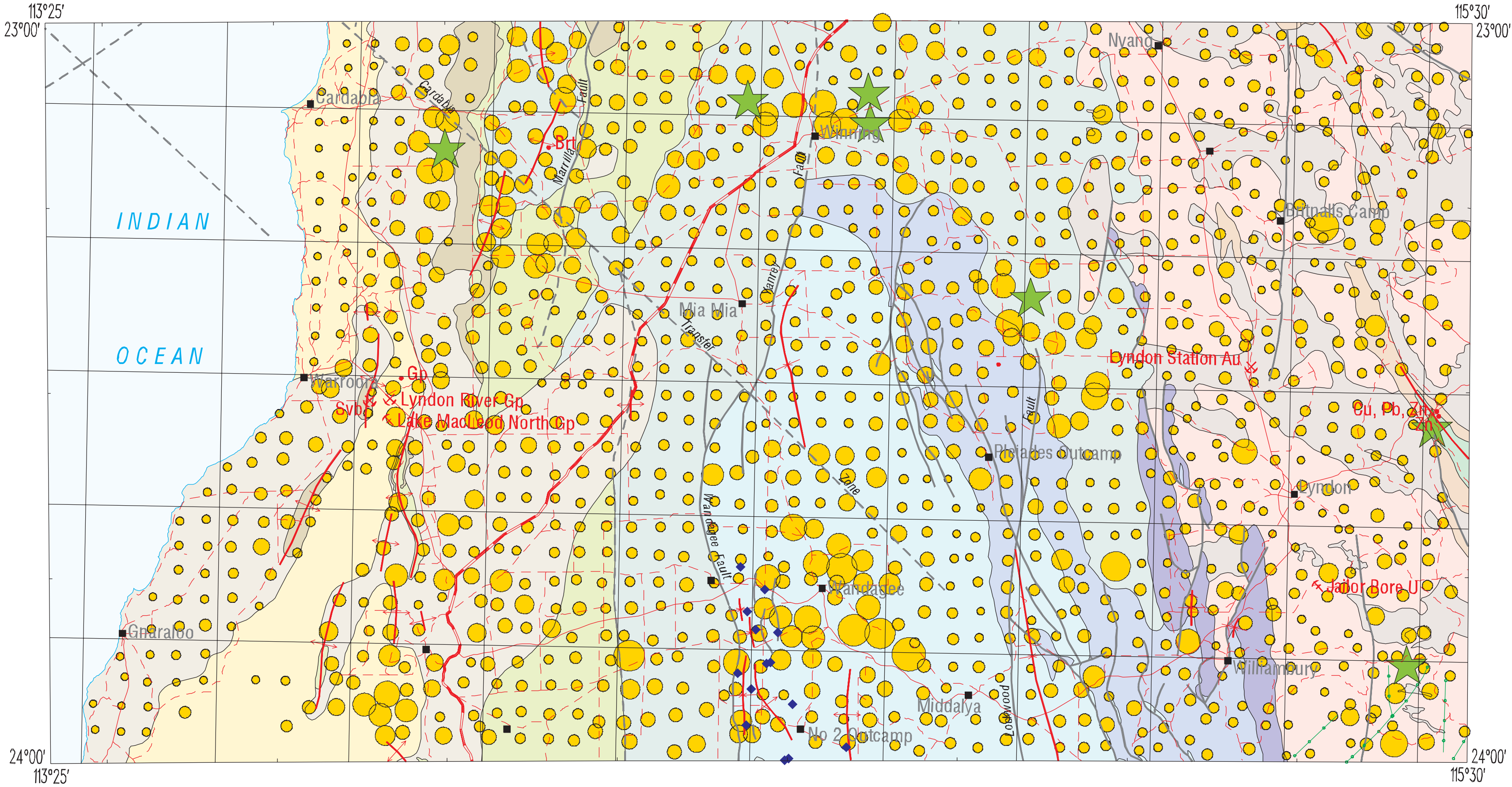
SCALE 1:1 000 000
0 10 km

WINNING POOL - MINILYA
SHEET SF 50-13, part SF 49-16
First Edition 2001

Figure 47

08 Feb 01 12.57.25

V
VANADIUM



Maximum value: 456 ppm

260 ppm

131 ppm

2 ppm

Below 2 ppm theoretical detection limit

> 260 ppm

SCALE 1:1 000 000

0 10 km

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

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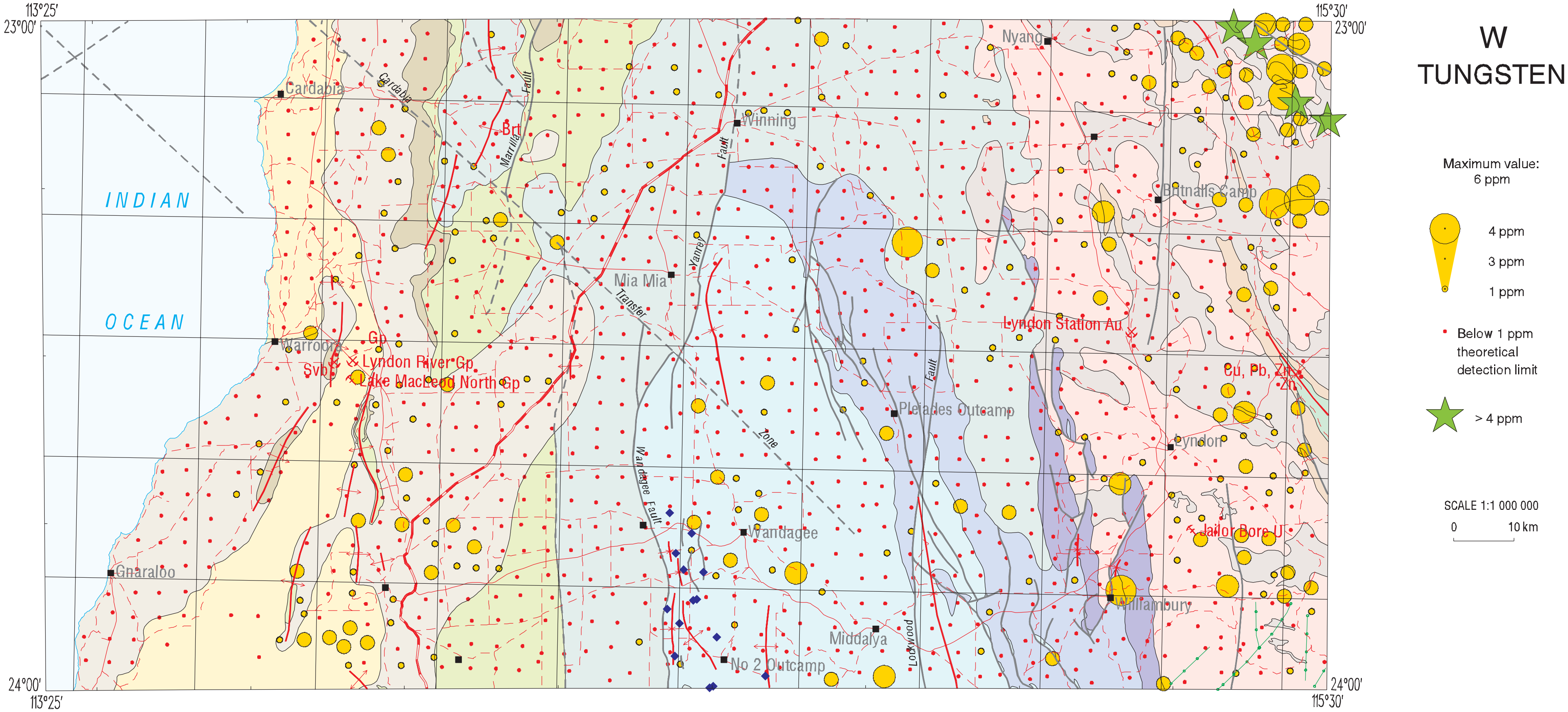
Figure 48

08 Feb 01 12:58:57



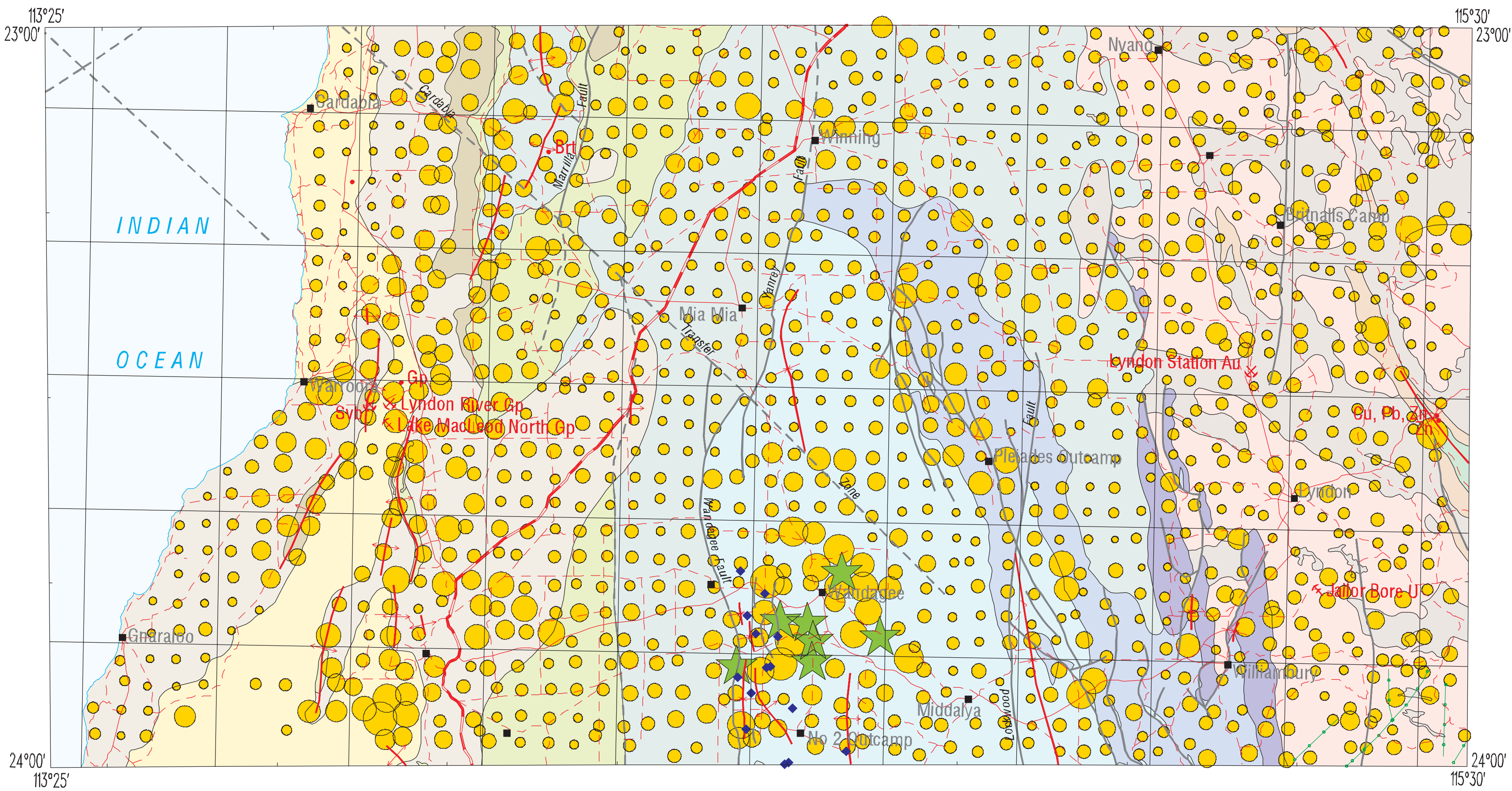
WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

First Edition 2001

Figure 49

08 Feb 01 13:00:30



Y
YTTRIUM

Maximum value: 38 ppm

25 ppm

13 ppm

1 ppm

Below 1 ppm theoretical detection limit

> 25 ppm

SCALE 1:1 000 000

0 10 km

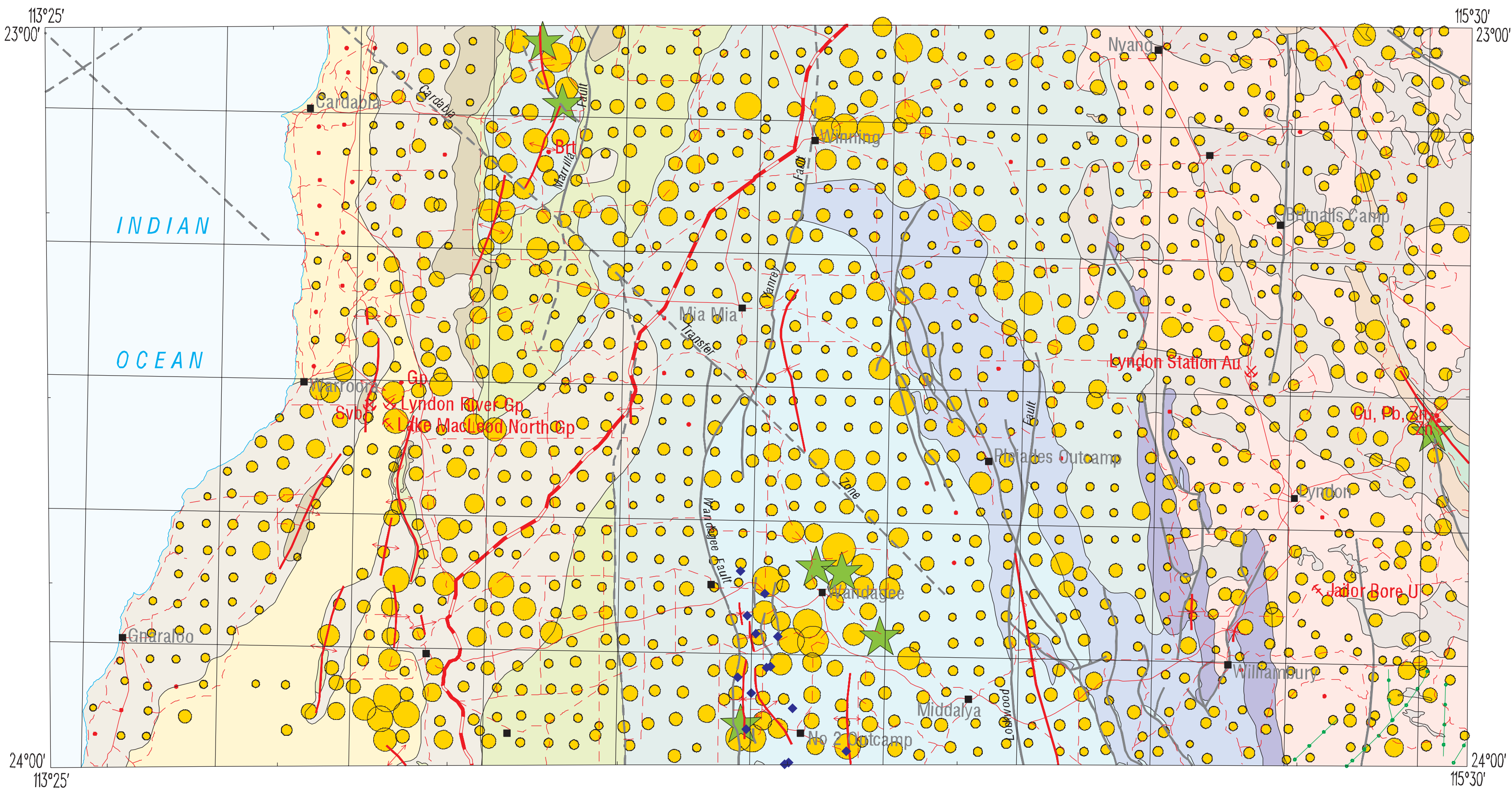
WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

First Edition 2001

Figure 50

08 Feb 01 13.01.18



Zn
ZINC

Maximum value: 159 ppm

105 ppm
54 ppm
2 ppm

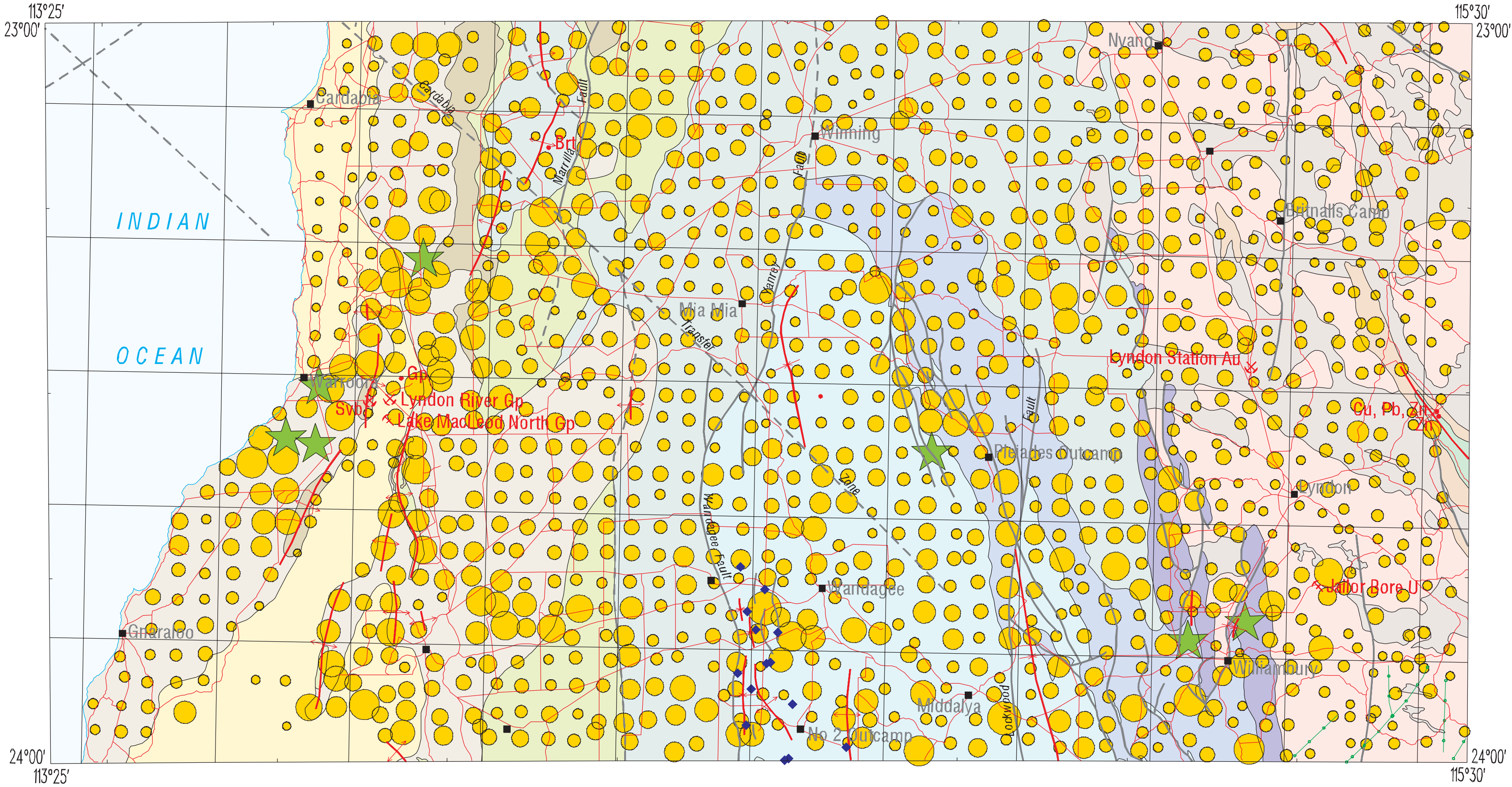
Below 2 ppm theoretical detection limit

> 105 ppm

SCALE 1:1 000 000
0 10 km

WINNING POOL - MINILYA
SHEET SF 50-13, part SF 49-16
First Edition 2001

Figure 51



Zr
ZIRCONIUM

Maximum value:
565 ppm

392 ppm
199 ppm
5 ppm

Below 5 ppm theoretical detection limit

> 392 ppm

SCALE 1:1 000 000
0 10 km

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

First Edition 2001

Figure 52

08 Feb 01 13.42.16

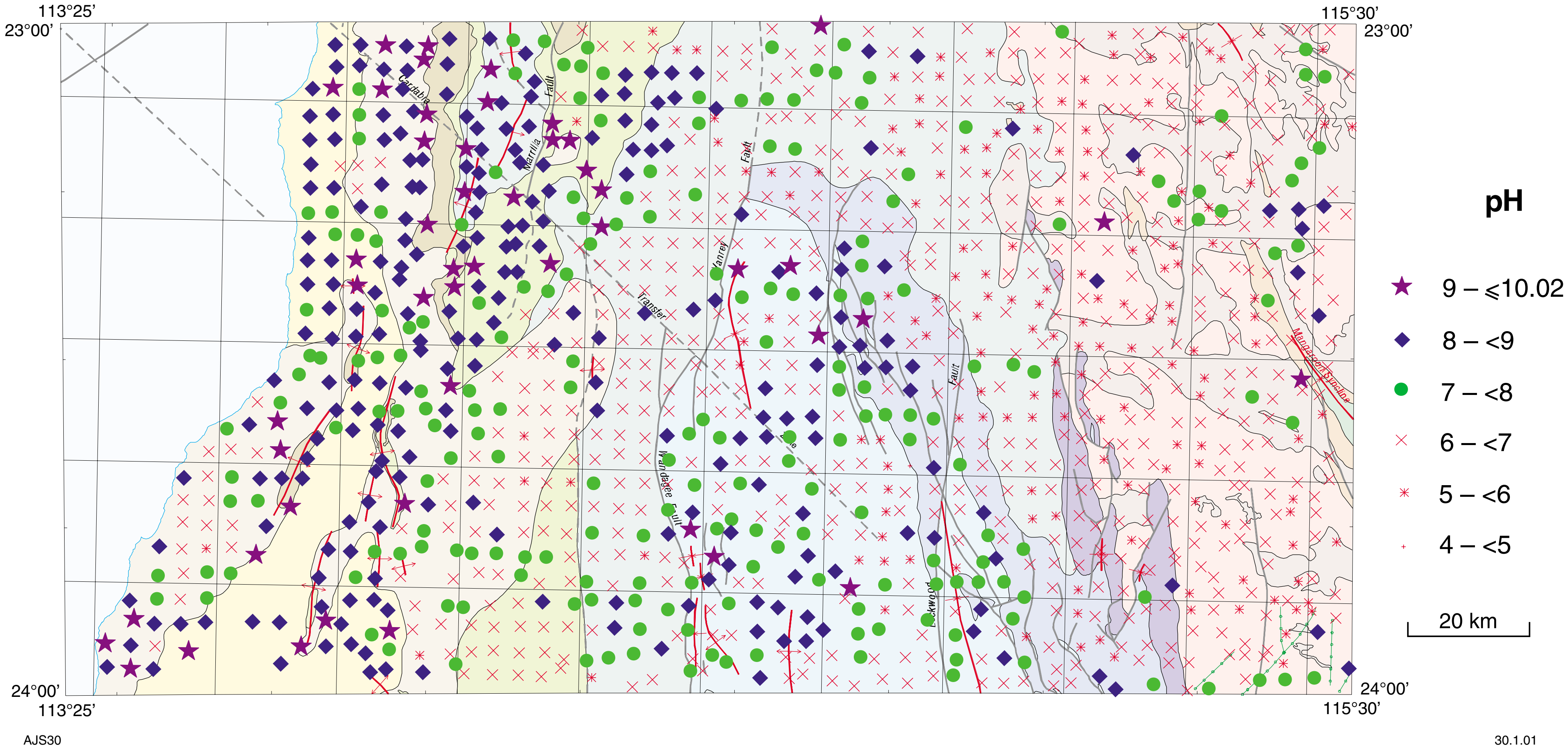


Figure 53. Regolith acidity–alkalinity. See Figure 3 for reference

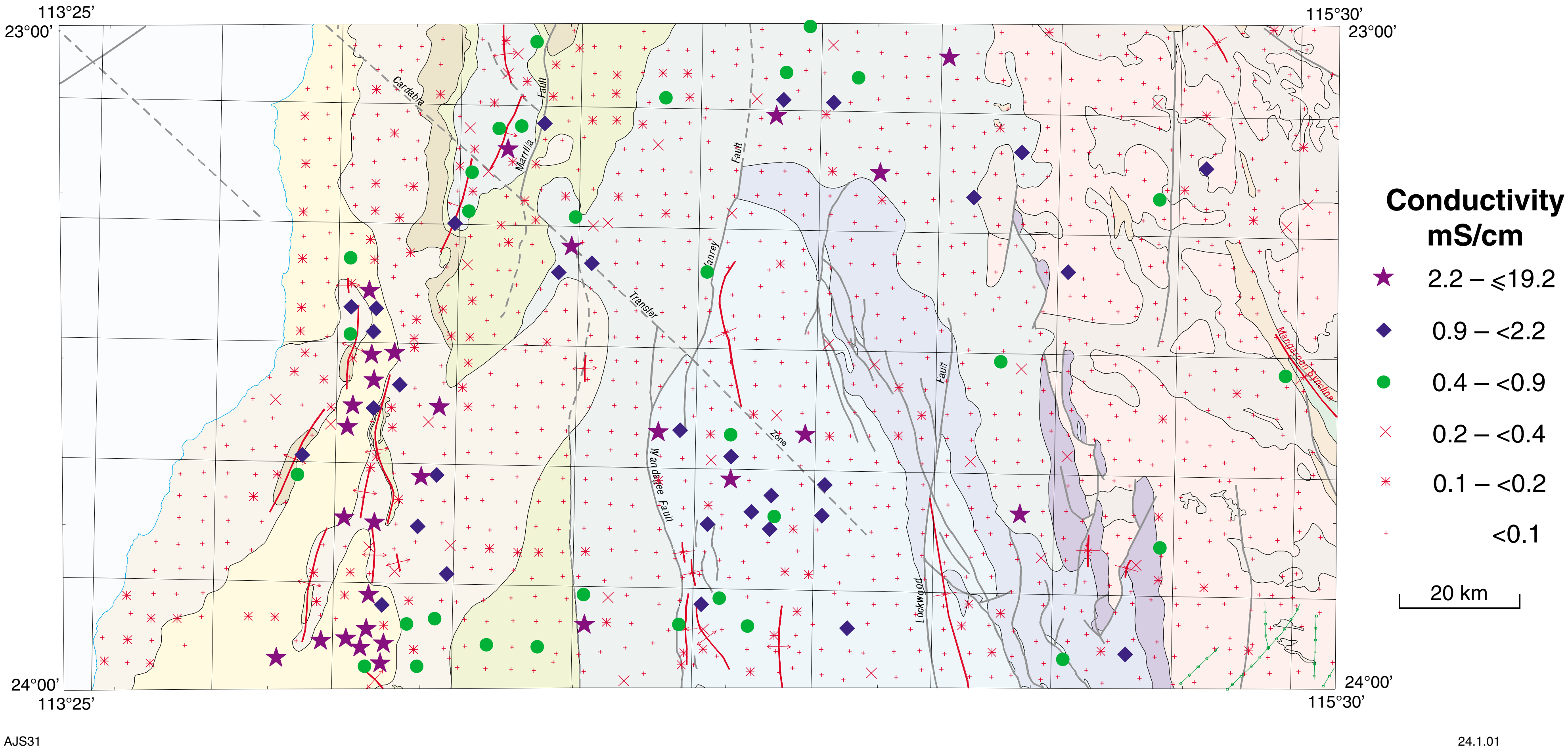
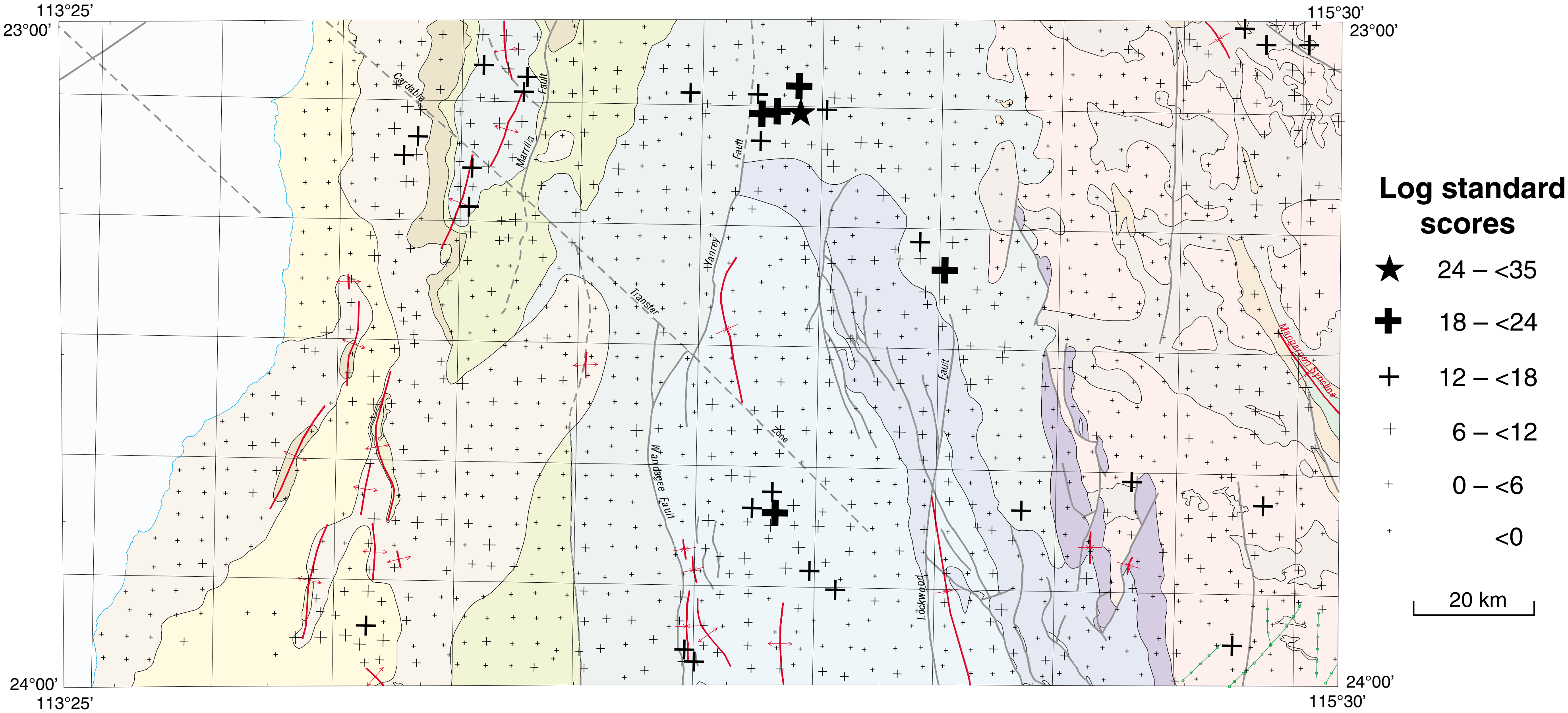


Figure 54. Conductivity of regolith. See Figure 3 for reference



AJS32

30.1.01

Figure 55. Chalcophile-index map (As, Bi, Mo, Sb, Se, Sn, and W). See Figure 3 for reference

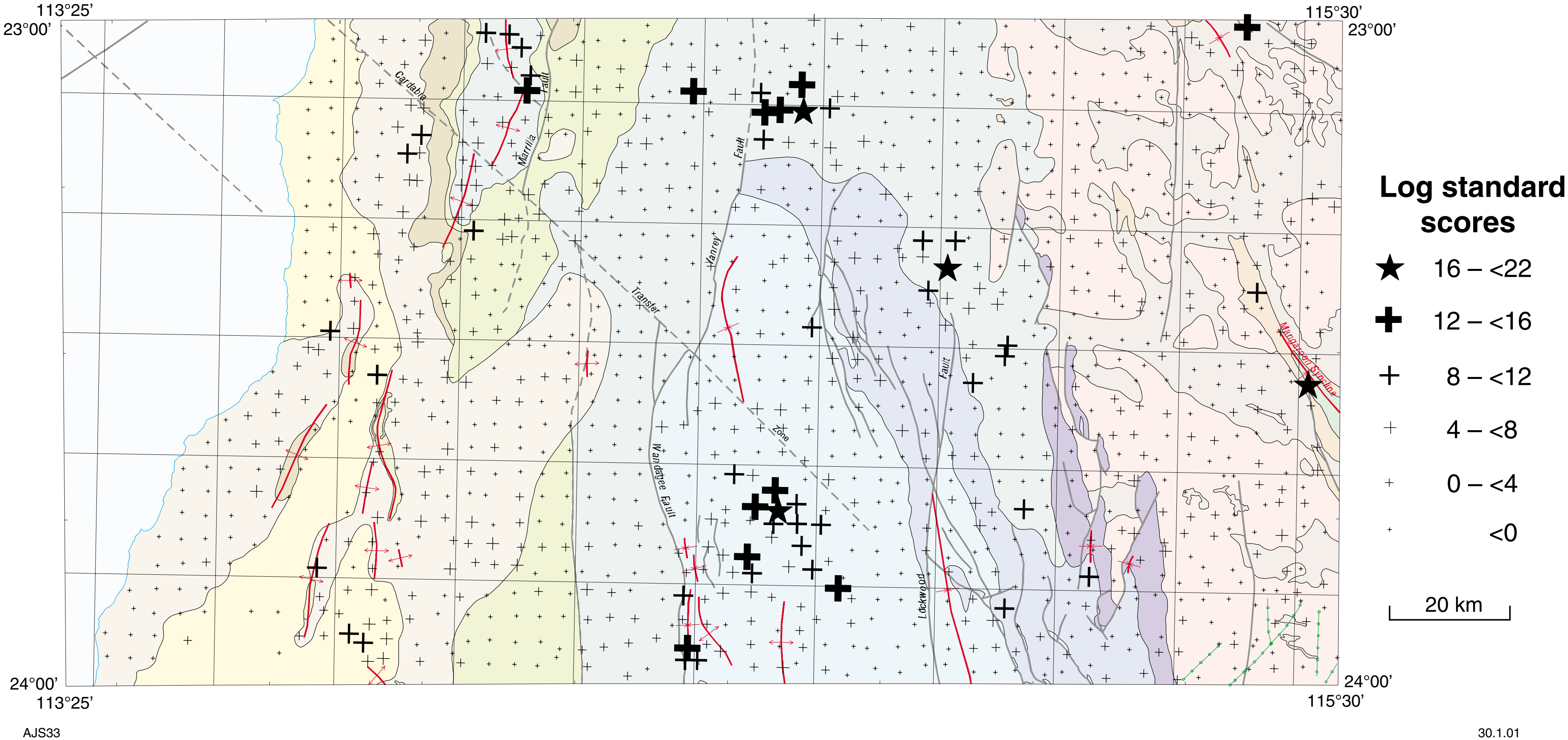


Figure 56. Base-metals-index map (As, Cu, Pb, Sb, and Zn). See Figure 3 for reference

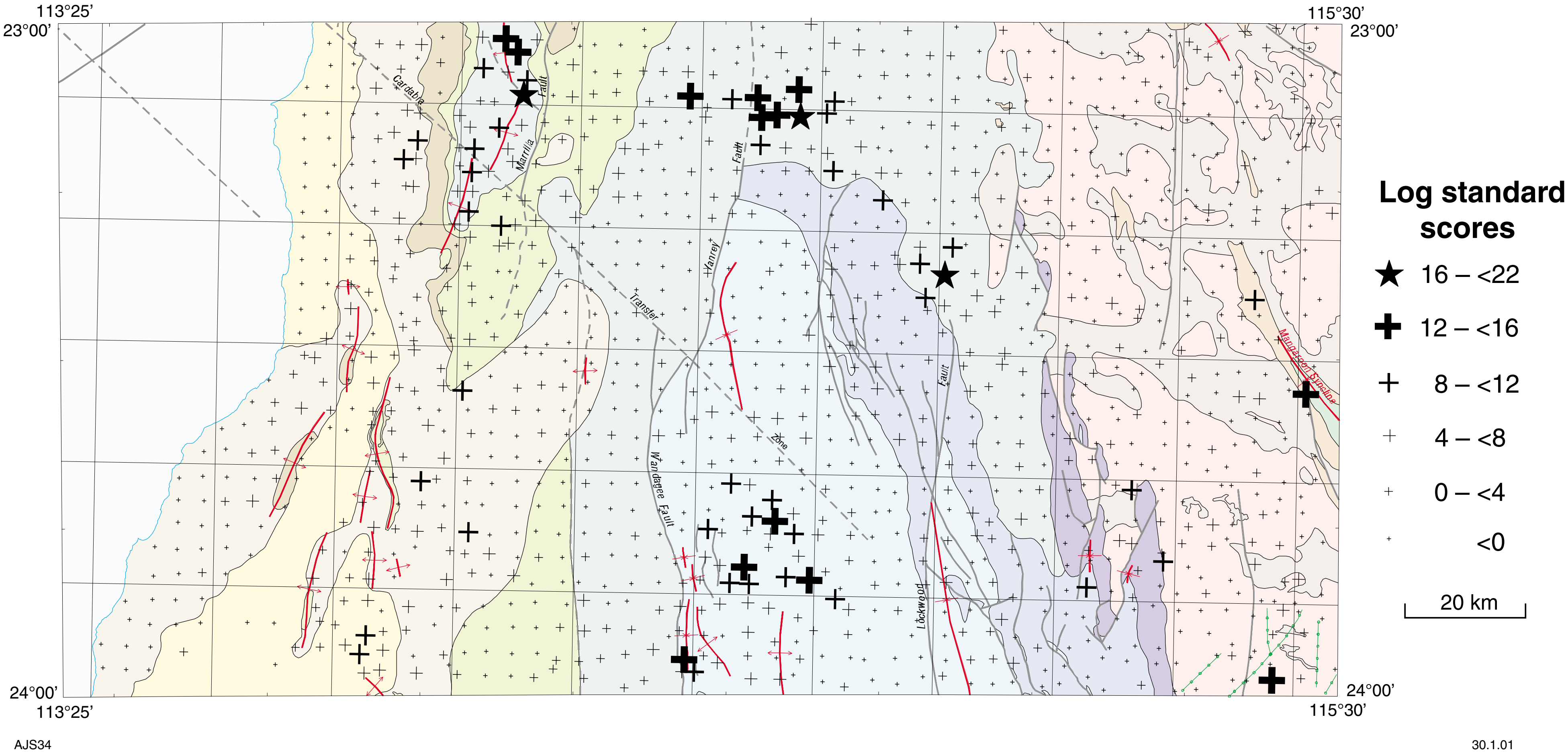


Figure 57. Ferro-alloy-index map (Co, Cr, Mo, Ni, and V). See Figure 3 for reference

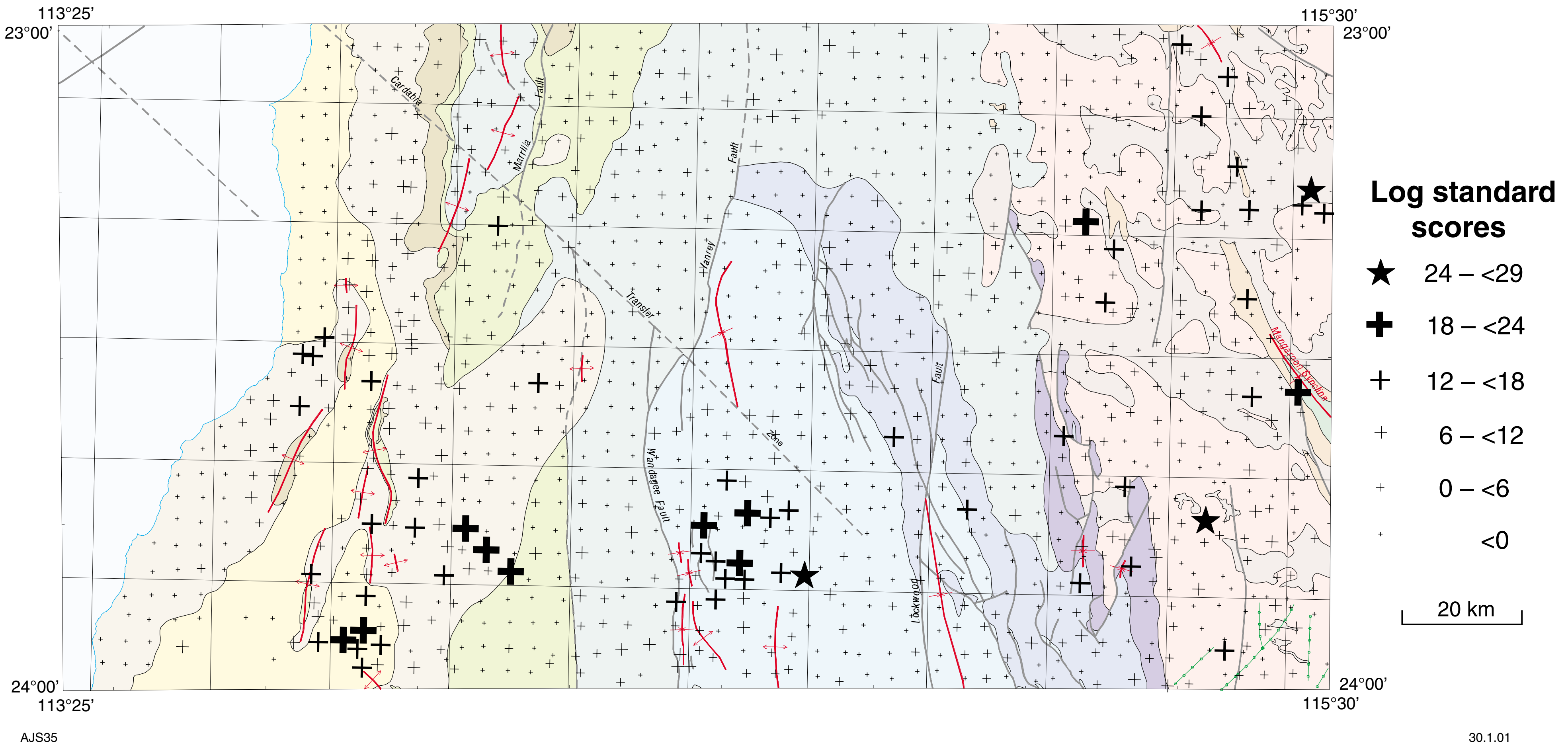


Figure 58. Resistate-components-index map (TiO_2, Ce, La, Nb, Ta, Th, Y, and Zr). See Figure 3 for reference

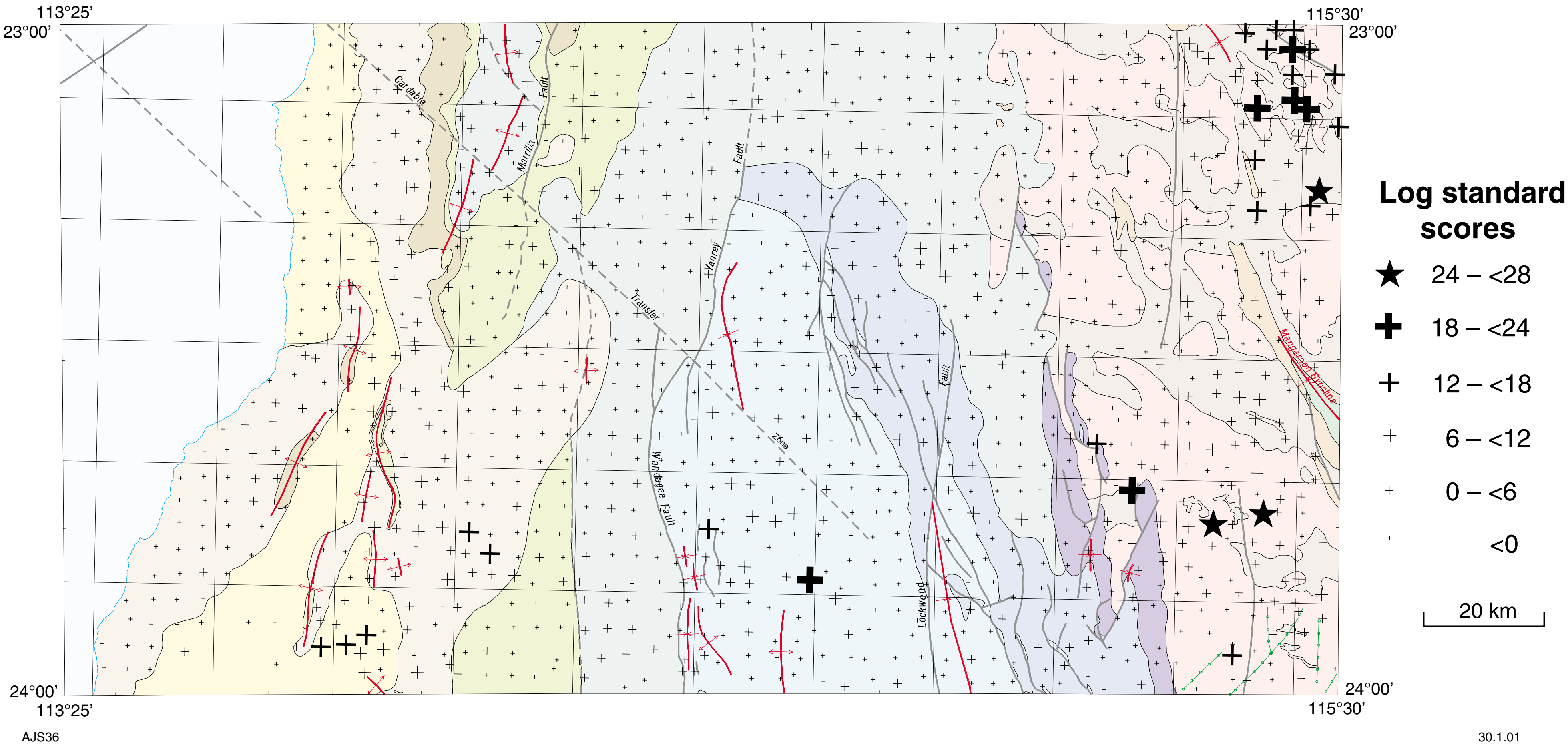
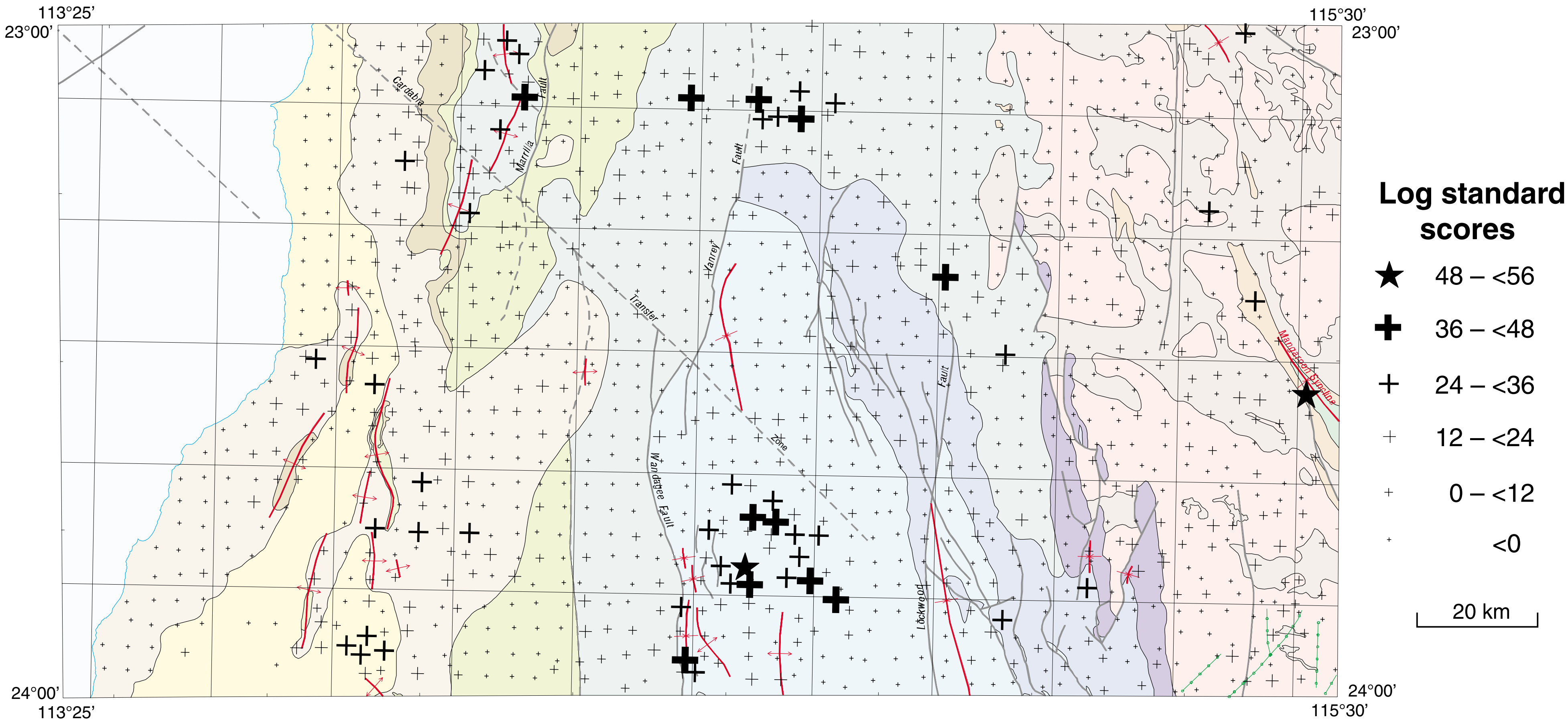


Figure 59. Pegmatite-index map (Be, Bi, Nb, Sn, Ta, and W). See Figure 3 for reference



AJS37

30.1.01

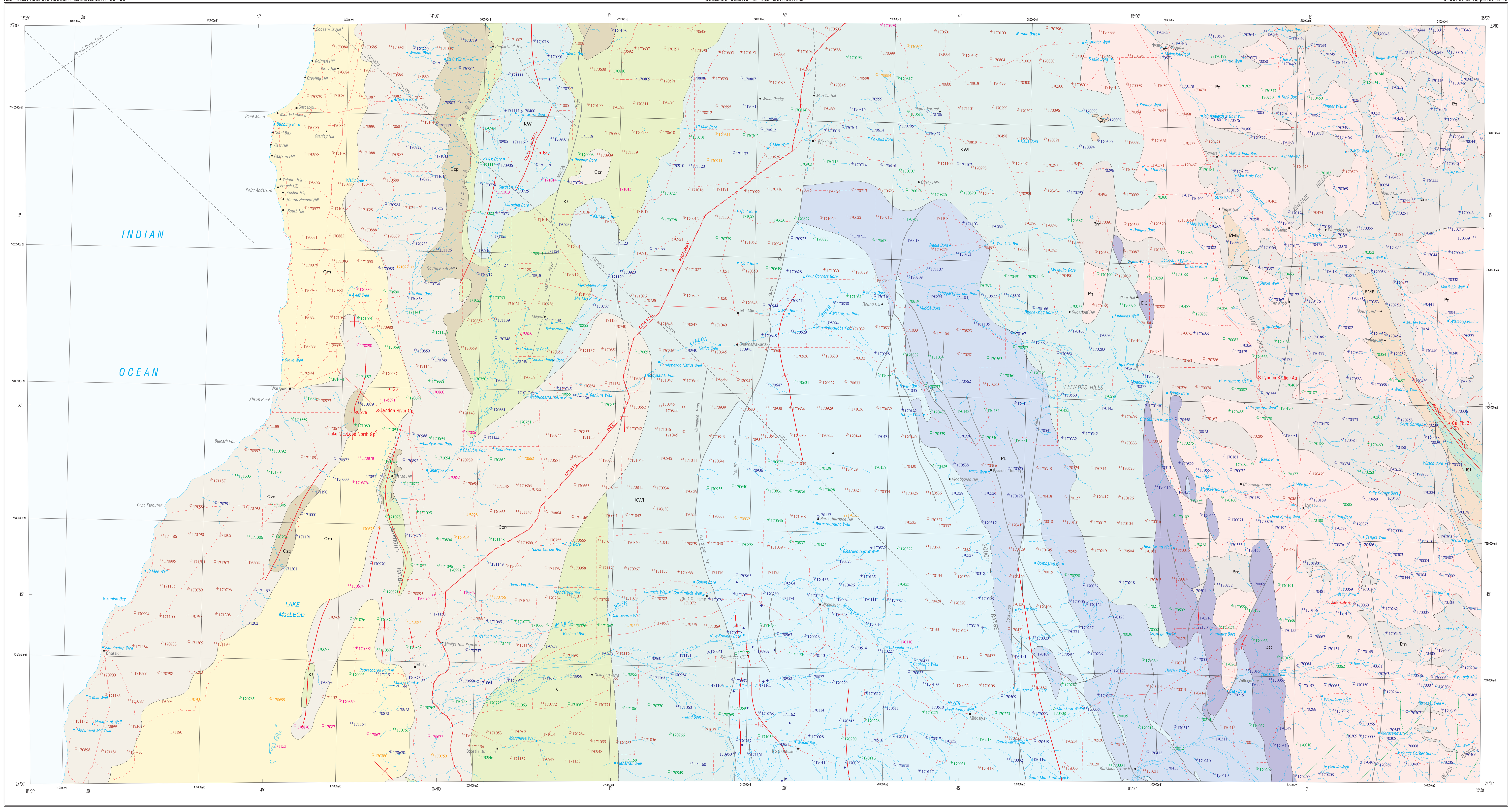
Figure 60. Black-shale-index map (TiO_2, MnO, Ag, As, Ba, Cd, Ce, Co, Cr, Cu, La, Ni, Pb, Sb, Se, U, V, and Zn). See Figure 3 for reference

AUSTRALIA 1:250 000 REGOLITH GEOCHEMISTRY SERIES

WINNING POOL - MINILYA

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET SF 50-13, part SF 49-16



SAMPLE LOCATIONS

Sample point reference

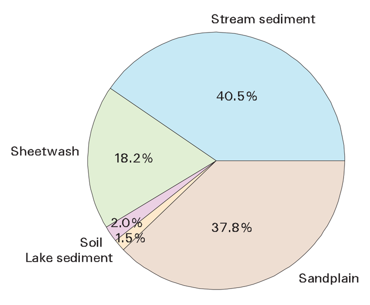
170003 Stream sediment

170010 Sheetwash

170110 Soil

170533 Lake sediment

170011 Sandplain



Total sample sites 1199

GEOLOGICAL INTERPRETATION

PHANEROZOIC

QUATERNARY

- Qm — BUNDERA CALCARENITE: shoreline, marine, and coastal eolian deposits; includes coastal lake deposits; commonly calcareous and gypsiferous

NEOGENE

- Czn — LAMONT SANDSTONE and TREALLA LIMESTONE: marine limestone, and minor marine and continental sandstone

PALEOGENE

- Czp — CARDABIA CALCARENITE, GIRALIA CALCARENITE, and MERLINLEIGH SANDSTONE Marine limestone and sandstone, with minor siltstone and basal greensand

CRETACEOUS

- Kt — TOOLONGA CALCILUTITE, KOROJON CALCARENITE, and MIRIA FORMATION Marine limestone, chalk, marl, and greensand; dominantly calcareous pelagic deposits

Winning Group

- KWI — Marine and coastal shale, siltstone, and radiolarite; dominantly siliceous pelagic deposits with basal sandstone and conglomerate

PERMIAN

Wooramel Group, Byro Group, and Kennedy Group

- P — Marine and continental siltstone, shale, and sandstone

Lyons Group and CALLYTHARRA FORMATION

- PL — Marine and continental siltstone, shale, sandstone, and limestone; glacially influenced

DEVONIAN

- DC — Marine to continental limestone, dolomite, sandstone, siltstone, shale, and conglomerate

PROTEROZOIC

- Ꝑd — Dolerite sill

Edmund Group

- ꝐME — Sandstone, siltstone, shale, dolomite, and chert; intruded by dolerite dykes and sills

Gascoyne Complex

- Ꝑg — Granodiorite, monzogranite, granite, and pegmatite; includes minor dolerite and gabbro
- Ꝑm — Schist, migmatite, gneiss, phyllite, quartzite, and minor calc-silicate rock, marble, and amphibolite (Morrissey Metamorphic Suite)

Geological boundary — Anticline

Fault, exposed — Syncline

Fault, concealed or inferred — Dolerite dyke

SYMBOLS

	Highway		Diatremes and intrusions
	Formed road	Lyndon Station	Opencut
	Track	Jailor Bore	Prospect
	Watercourse		Mineral occurrence
	Lake	Brt	Barite
	Pool, spring, bore, well	Cu	Copper
Winning	Homestead	Au	Gold
Woggola	Locality	Gp	Gypsum
		Pb	Lead
		Svb	Sand
		U	Uranium
		Zn	Zinc

Edited by N. Tetlaw, K. Greenberg, and G. Loan

Cartography by M. Vicentic

Topography from Australian Surveying and Land Information Group, and Department of Land Administration Sheets SF 50-13 and part SF 49-16

This map was compiled and produced using a Geographic Information System (ArcInfo), and the data are available in digital form

Published by the Geological Survey of Western Australia. Copies of this map, or extracts of the data, are available from the Information Centre, Department of Minerals and Energy, 100 Plain Street, East Perth, W.A., 6004. Phone (08) 9222 3459, Fax (08) 9222 3444

Compiled by A. J. Sanders 2000

Sampling by A. Sanders (GSWA) and E. Bosanquet, J. Moore, R. Blackmore, E. Mikucki, N. Nasev, and J. Hanson

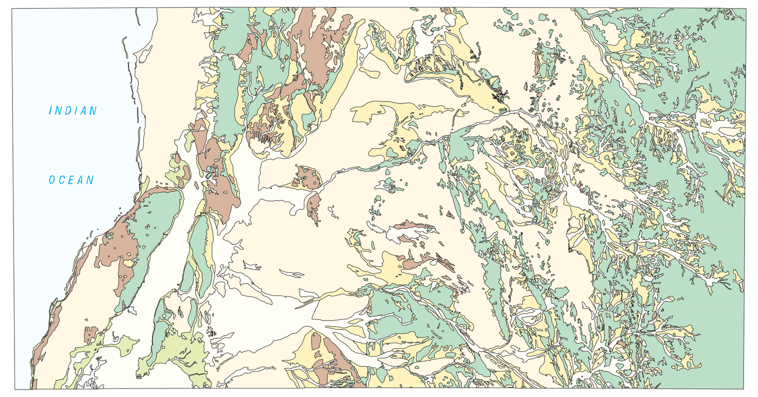
Total sample sites: 1199; 485 stream sediment, 218 sheetwash, 24 soil, 18 lake sediment, and 454 sandplain

Analyst: Amdel Laboratories
Minimum sample size: 1.5 kg
Fraction of sample analysed: >0.45mm <2mm

Geological interpretation after Myers and Hocking (1998)

The recommended reference for this map is:
SANDERS, A. J., 2001, Sample locations, Winning Pool - Minilya, W.A. Sheet SF 50-13 and part sheet SF 49-16, *in* Geochemical mapping of the Winning Pool - Minilya 1:250 000 sheets *by* A. J. SANDERS and S. A. McGUINNESS: Western Australia Geological Survey, 1:250 000 Regolith Geochemistry Series Explanatory Notes, Plate 1

GENERALIZED REGOLITH



- Residual
- Exposed
- Colluvial (includes low-gradient slope)
- Alluvial and lacustrine
- Sandplain and eolian
- Coastal and marine

SCALE 1:1 500 000

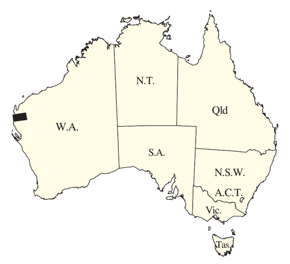
SCALE 1:250 000

5000 0 5 10 15 20 25 30
METRES KILOMETRES

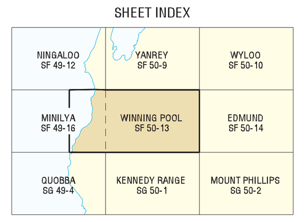
UNIVERSAL TRANSVERSE MERCATOR PROJECTION
HORIZONTAL DATUM: GEOCENTRIC DATUM OF AUSTRALIA 1994
VERTICAL DATUM: AUSTRALIAN HEIGHT DATUM

Grid lines indicate 20 000 metre interval of the Map Grid Australia, Zone 50

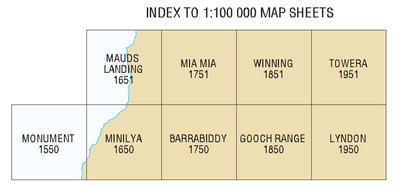
The Map Grid Australia (MGA) is based on the Geocentric Datum of Australia 1994 (GDA94)
GDA94 positions are compatible within one metre of the datum WGS84 positions



SHEET INDEX



INDEX TO 1:100 000 MAP SHEETS



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

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

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
TIM GRIFFIN, DIRECTOR

SAMPLE LOCATIONS

REGOLITH GEOCHEMISTRY SERIES

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

FIRST EDITION 2001

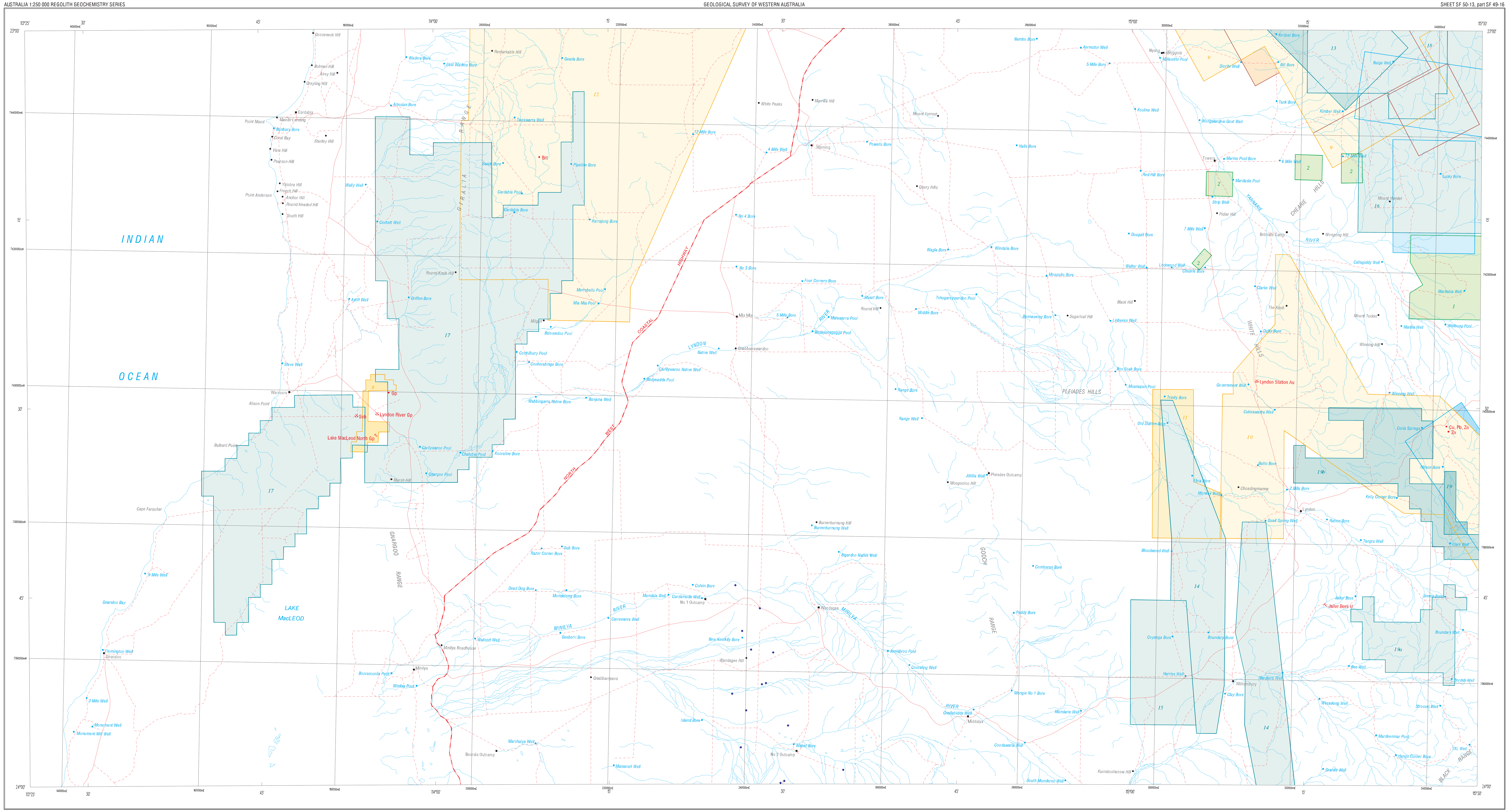
WARNING: Inks are water soluble and will fade with prolonged exposure to light

WINNING POOL - MINILYA

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

AUSTRALIA 1:250 000 REGOLITH GEOCHEMISTRY SERIES

SHEET SF 50-13, part SF 49-16



COMPANY PROJECTS WITH SURFACE GEOCHEMISTRY DATA IN OPEN-FILE REPORTS (at November 1999)

Project period reported within

(Various colour shades used for ease of project identification)

1966 - 1970

1971 - 1975

1976 - 1980

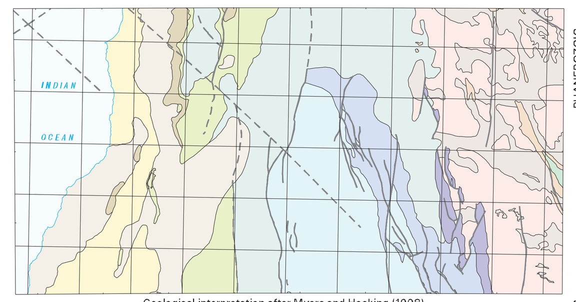
1981 - 1985

1986 - 1990

1991 - 1997

Number within project area is a database ID number (see Appendix 2 of the Explanatory Notes)

INTERPRETED BEDROCK GEOLOGY



Geological interpretation after Myers and Hocking (1998)

SCALE 1:2 000 000

PHANEROZOIC

QUATERNARY — BUNDERA CALCARENITE: shoreline, marine, and coastal eolian deposits; includes coastal lake deposits; commonly calcareous and gypsiferous

NEOGENE — LAMONT SANDSTONE and TREALLA LIMESTONE: marine limestone, and minor marine and continental sandstone

PALEOGENE — CARDABIA CALCARENITE, GIRALIA CALCARENITE, and MERLINLEIGH SANDSTONE: Marine limestone and sandstone, with minor siltstone and basal greensand

CRETACEOUS — TOOLONGA CALCILUTITE, KOROJON CALCARENITE, and MIRIA FORMATION: Marine limestone, chalk, marl, and greensand; dominantly calcareous pelagic deposits

Winning Group: Marine and coastal shale, siltstone, and radiolarite; dominantly siliceous pelagic deposits with basal sandstone and conglomerate

PERMIAN — Wooramel Group, Byro Group, and Kennedy Group: Marine and continental siltstone, shale, and sandstone

Lyons Group and CALLYTHARRA FORMATION: Marine and continental siltstone, shale, sandstone, and limestone; glacially influenced

DEVONIAN — Marine to continental limestone, dolomite, sandstone, siltstone, shale, and conglomerate

PROTEROZOIC

Dolerite sill

Edmund Group: Sandstone, siltstone, shale, dolomite, and chert; intruded by dolerite dykes and sills

Gascoyne Complex: Granodiorite, monzogranite, granite, and pegmatite; includes minor dolerite and gabbro

Schist, migmatite, gneiss, phyllite, quartzite, and minor calc-silicate rock, marble, and amphibolite (Morrissey Metamorphic Suite)

Geological boundary

Fault, exposed

Fault, concealed or inferred

SYMBOLS

Highway		Diatremes and intrusions	
Formed road		Lyndon Station	Opencut
Track		Jailor Bore	Prospect
Watercourse			Mineral occurrence
Lake		Brt	Barite
Pool, spring, bore, well		Cu	Copper
Winning	Homestead	Au	Gold
Woggola	Locality	Gp	Gypsum
		Pb	Lead
		Svb	Sand
		U	Uranium
		Zn	Zinc

Edited by N. Tetlaw, K. Greenberg, and G. Loan

Cartography by M. Vicentic

Topography from Australian Surveying and Land Information Group, and Department of Land Administration Sheets SF 50-13 and part SF 49-16

This map was compiled and produced using a Geographic Information System (ArcInfo), and the data are available in digital form

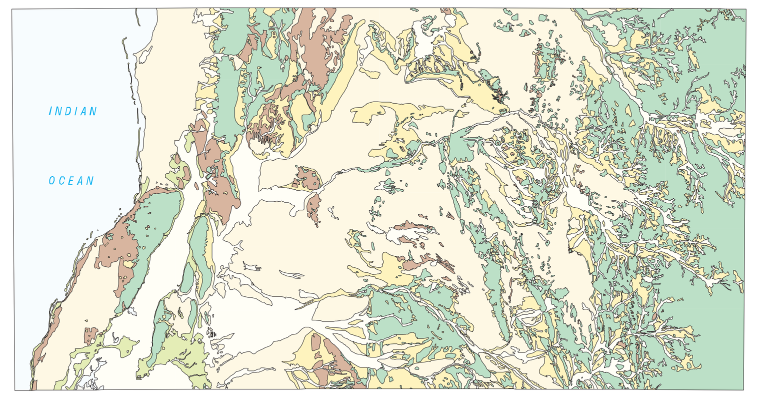
Published by the Geological Survey of Western Australia. Copies of this map, or extracts of the data, are available from the Information Centre, Department of Minerals and Energy, 100 Plain Street, East Perth, W.A., 6004. Phone (08) 9222 3459, Fax (08) 9222 3444

Compiled by S. A. McGuinness 1999

Compiled from the Geological Survey of Western Australia SPINDEX database and open-file mineral exploration reports

The recommended reference for this map is:
McGUINNESS, S. A., 2001, Company projects with surface geochemistry data in open-file reports (at November 1999), Winning Pool - Minilya, W.A. Sheet SF 50-13 and part sheet SF 49-16, *in* Geochemical mapping of the Winning Pool - Minilya 1:250 000 sheets *by* A. J. SANDERS and S. A. McGUINNESS: Western Australia Geological Survey, 1:250 000 Regolith Geochemistry Series Explanatory Notes, Plate 2

GENERALIZED REGOLITH



Residual

Exposed

Colluvial (includes low-gradient slope)

Alluvial and lacustrine

Sandplain and eolian

Coastal and marine

SCALE 1:1 500 000

SCALE 1:250 000

5000 METRES 0 5 10 15 20 25 30 KILOMETRES

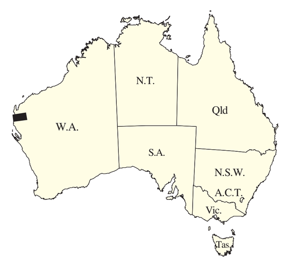
UNIVERSAL TRANSVERSE MERCATOR PROJECTION

HORIZONTAL DATUM: GEOCENTRIC DATUM OF AUSTRALIA 1994

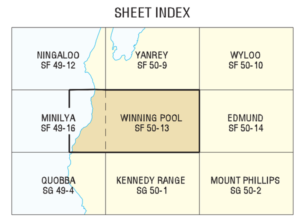
VERTICAL DATUM: AUSTRALIAN HEIGHT DATUM

Grid lines indicate 20 000 metre interval of the Map Grid Australia, Zone 50

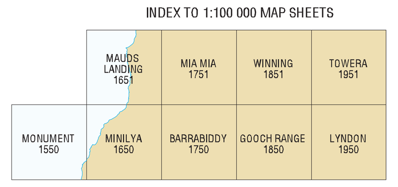
GDA — The Map Grid Australia (MGA) is based on the Geocentric Datum of Australia 1994 (GDA94). GDA94 positions are compatible within one metre of the datum WGS84 positions



SHEET INDEX



INDEX TO 1:100 000 MAP SHEETS



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

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

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
TIM GRIFFIN, DIRECTOR

COMPANY PROJECTS WITH SURFACE GEOCHEMISTRY DATA IN OPEN-FILE REPORTS (at November 1999)

REGOLITH GEOCHEMISTRY SERIES

WINNING POOL - MINILYA

SHEET SF 50-13, part SF 49-16

FIRST EDITION 2001

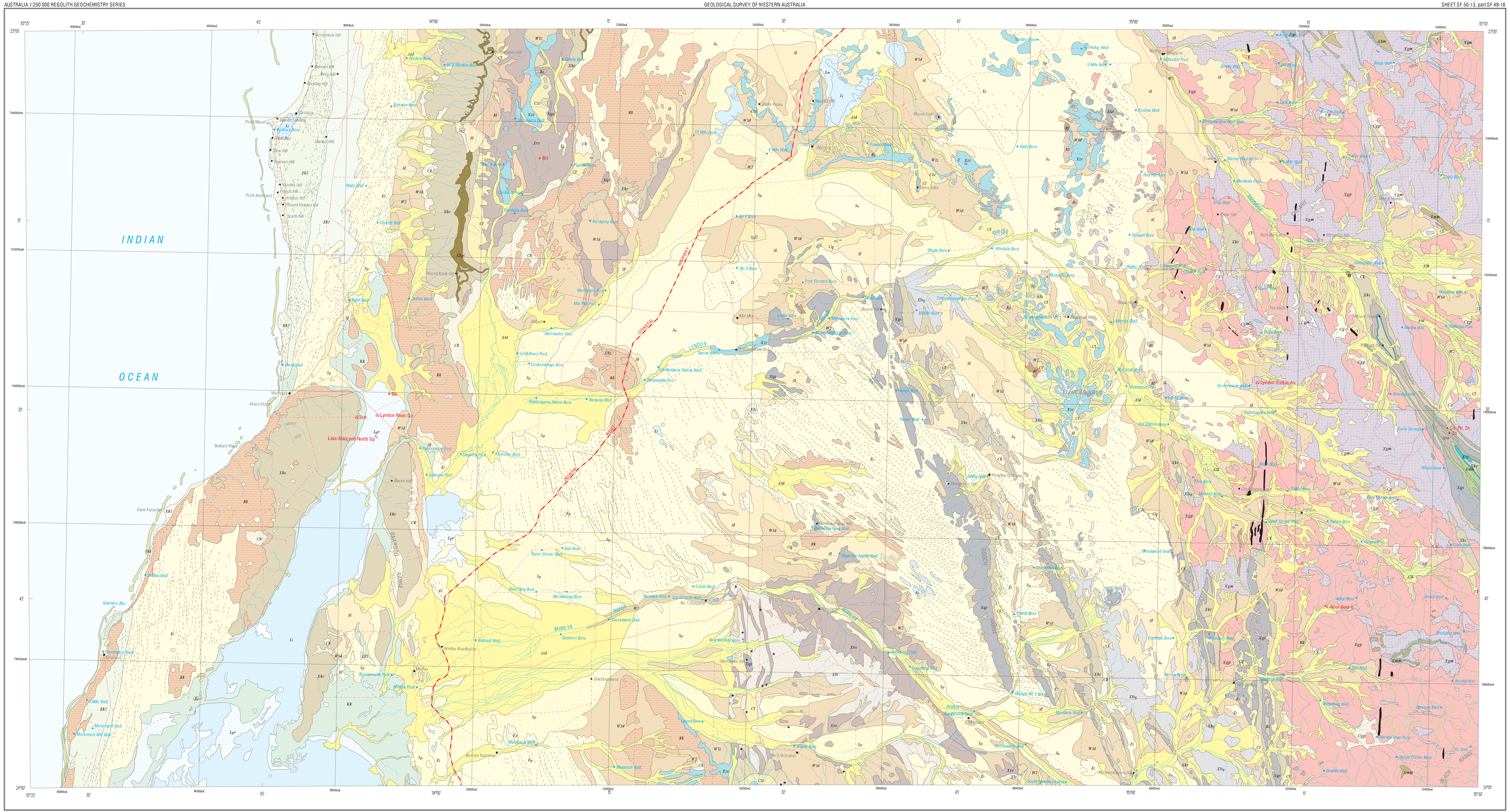
WARNING: Inks are water soluble and will fade with prolonged exposure to light

WINNING POOL - MINILYA

AUSTRALIA 1:250 000 REGOLITH GEOCHEMISTRY SERIES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET SF 50-13, part SF 49-16



REGOLITH MATERIALS

REFERENCE

RESIDUAL *(R)* - Residual sand, duricrust, and proximal reworked material derived by weathering in situ

- *Rf* comprising mainly iron-rich material (ferricrete)
- *Rk* comprising mainly carbonate-rich material (authigenic limestone and calcrete); includes Nadarra Formation
- *Rl* comprising mainly mixed material (calcrete and gypcrete)
- *Rz* comprising mainly silica-rich material (silcrete)

EXPOSED *(X)* - Outcrop of saprock, bedrock, and subcrop with locally derived sand, silt, clay, and rubble

- *Xgm* derived from quartzofeldspathic metamorphic rock (migmatite, schist, phyllite, and gneiss)
- *Xgp* derived from quartzofeldspathic plutonic rock (granite, monzogranite, granodiorite, and tonalite)
- *Xkc* derived from carbonate-rich sedimentary rock (includes Precambrian and Phanerozoic limestones; fossiliferous and quartzose in part)
- *Xkgc* derived from carbonate-rich, glauconitic bioclastic sedimentary rock (lower Cardabia Calcarenite)
- *Xkm* derived from carbonate-rich metamorphic rock (metamorphosed dolomite and marble)
- *Xls* derived from heterogeneous sedimentary rock (quartz wacke, siltstone, shale, limestone, greensand, and carbonaceous siltstone)
- *Xlsg* derived from heterogeneous siliciclastic glacigene sedimentary rock (Lyons Group)
- *Xmh* derived from ferromagnesian hypabyssal rock (dolerite)
- *Xmm* derived from ferromagnesian metamorphic rock (mafic schist, amphibolite and quartz-magnetite rock, and metamorphosed dolerite, and gabbro)
- *Xq* derived from quartz-rich rock (quartz vein)
- *Xqm* derived from quartz-rich metamorphic rock (quartzite and thin calc-silicate rock)
- *Xqs* derived from quartz-rich siliciclastic sedimentary rock (sandstone, siltstone, conglomerate, and wacke)
- *Xrs* derived from carbonaceous siliciclastic sedimentary rock (black shale, siltstone, wacke, chert, and carbonate; deeply weathered, locally pyritic; includes black soil
- *Xzc* derived from silica-rich biochemical sedimentary rock (Windalia Radiolarite)
- *Xzs* derived from silica-rich sedimentary rock (Discovery Formation of the Edmund Group)

COLLUVIAL *(C)* - Unconsolidated and semi-consolidated silt, sand, gravel, and rubble

- *Cf* comprising mainly iron-rich material
- *Cg* derived mainly from quartzofeldspathic rock
- *Cgm* derived mainly from quartzofeldspathic metamorphic rock (migmatite, schist, phyllite, and gneiss)
- *Cgp* derived mainly from quartzofeldspathic plutonic rock (granite, monzogranite, granodiorite, and tonalite)
- *Ck* derived mainly from carbonate-rich rock (calcrete and limestone)
- *Cl* derived from mixed rock types
- *Cq* derived mainly from quartz-rich rock (siltstone, sandstone, conglomerate, and wacke)
- *Czc* derived mainly from silica-rich rock (Windalia Radiolarite)

LOW-GRADIENT SLOPE *(W)* - Sand- and clay-dominated colluvium and sheetwash

- *W1d* undivided
- *W1z* containing abundant silica-rich material; ferruginous in part (commonly above shallow subcrop of Windalia Radiolarite)
- *W2* consolidated and incised in part (silicified, calcreted)

ALLUVIAL *(A)* - Cobbles, gravel, sand, silt, and clay in alluvial channels and floodplains

- *A1d* undivided
- *A2k* dominated by valley calcrete; silicified and incised in part

LACUSTRINE *(L)* - Clay, silt, sand, gravel, and evaporitic material

- *Ll* in lakes and large playas
- *Lm* in mixed dune and playa terrain
- *Lge* in fringing bedded deposits; gypsum, anhydrite, and halite

SANDPLAIN *(S)* - Eolian and residual sand

- *Su* in undulating sandplain; dunes locally developed
- *Sp* in mixed sandplain, sheetwash, and playa terrain; dunes locally developed
- *Sl* in mixed sandplain and colluvium and sheetwash

EOLIAN *(E)* - Eolian sand

- *El* in extensive longitudinal dune, terrain
- *Ep* in mixed longitudinal dune, sheetwash, and playa terrain
- *Ek1* in recent coastal dunes, beaches, and beach ridges, derived in part from carbonate-rich material
- *Ek2* in degraded coastal dunes, derived in part from carbonate-rich material (calcarenite)
- *Ek3* in degraded coastal dunes, derived in part from carbonate-rich material (partly Bundera Calcarenite)

COASTAL *(K)* - Old wave- and tide-dominated coastal, and marine deposits

- *Kk* derived mainly from carbonate-rich material (coquinite, calcarenite, and coralgal reefs; Bundera Calcarenite)

MARINE *(M)* - Offshore marine deposits

- *Mk* derived mainly from carbonate-rich material (coralgal reefs - Ningaloo Reef tract)

SYMBOLS

- Regolith boundary
- Sand dune
- Highway
- Formed road
- Track
- Watercourse
- Permanent water
- Pool, spring, bore, well
- Winning — Homestead
- Woggola — Locality
- Diatremes and intrusions
- Lyndon Station — Opencut
- Jailor Bore — Prospect
- Mineral occurrence
- Brt — Barite
- Cu — Copper
- Au — Gold
- Gp — Gypsum
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Compiled by A. J. Sanders 2000

Field observations 1999 by A. Sanders (GSWA) and E. Bosanquet, J. Moore, R. Blackmore, E. Mikucki, N. Nasev, and J. Hanson

Compiled using Landsat TM images (1993 and 1995 data), 1976 black and white aerial photography, published Geological Survey of Western Australia Geological Series map, Winning Pool - Minilya 1984, and field observations 1999

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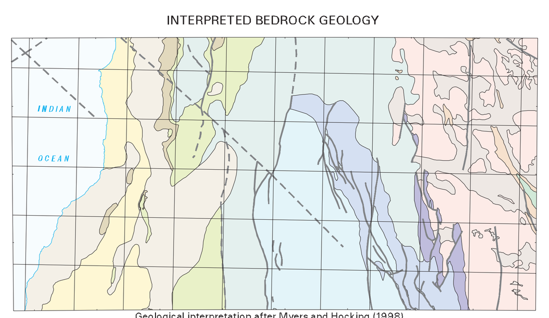
SANDERS. A. J., 2001, Regolith materials, Winning Pool - Minilya, W.A. Sheet SF 50-13 and part sheet SF 49-16, *in* Geochemical mapping of the Winning Pool - Minilya 1:250 000 sheets *by* A. J. SANDERS and S. A. McGUINNESS: Western Australia Geological Survey, 1:250 000 Regolith Geochemistry Series Explanatory Notes, Plate 3

INTERPRETED BEDROCK GEOLOGY



Geological interpretation after Myers and Hocking (1998)

SCALE 1:2 000 000

PHANEROZOIC

- QUATERNARY: BUNDERA CALCARENITE: shoreline, marine, and coastal eolian deposits; includes coastal lake deposits; commonly calcareous and gypsiferous
- NEOGENE: LAMONT SANDSTONE and TREALLA LIMESTONE: marine limestone, and minor marine and continental sandstone
- PALEOGENE: CARDABIA CALCARENITE, GIRALIA CALCARENITE, and MERLINLEIGH SANDSTONE — Marine limestone and sandstone, with minor siltstone and basal greensand
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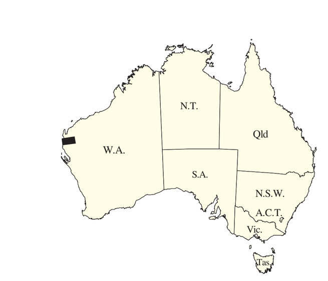
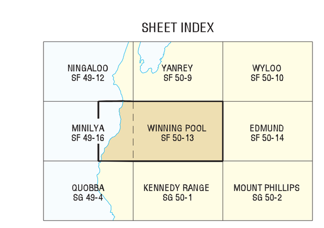


SHEET INDEX



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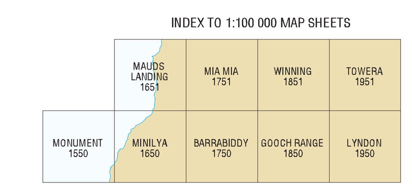

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