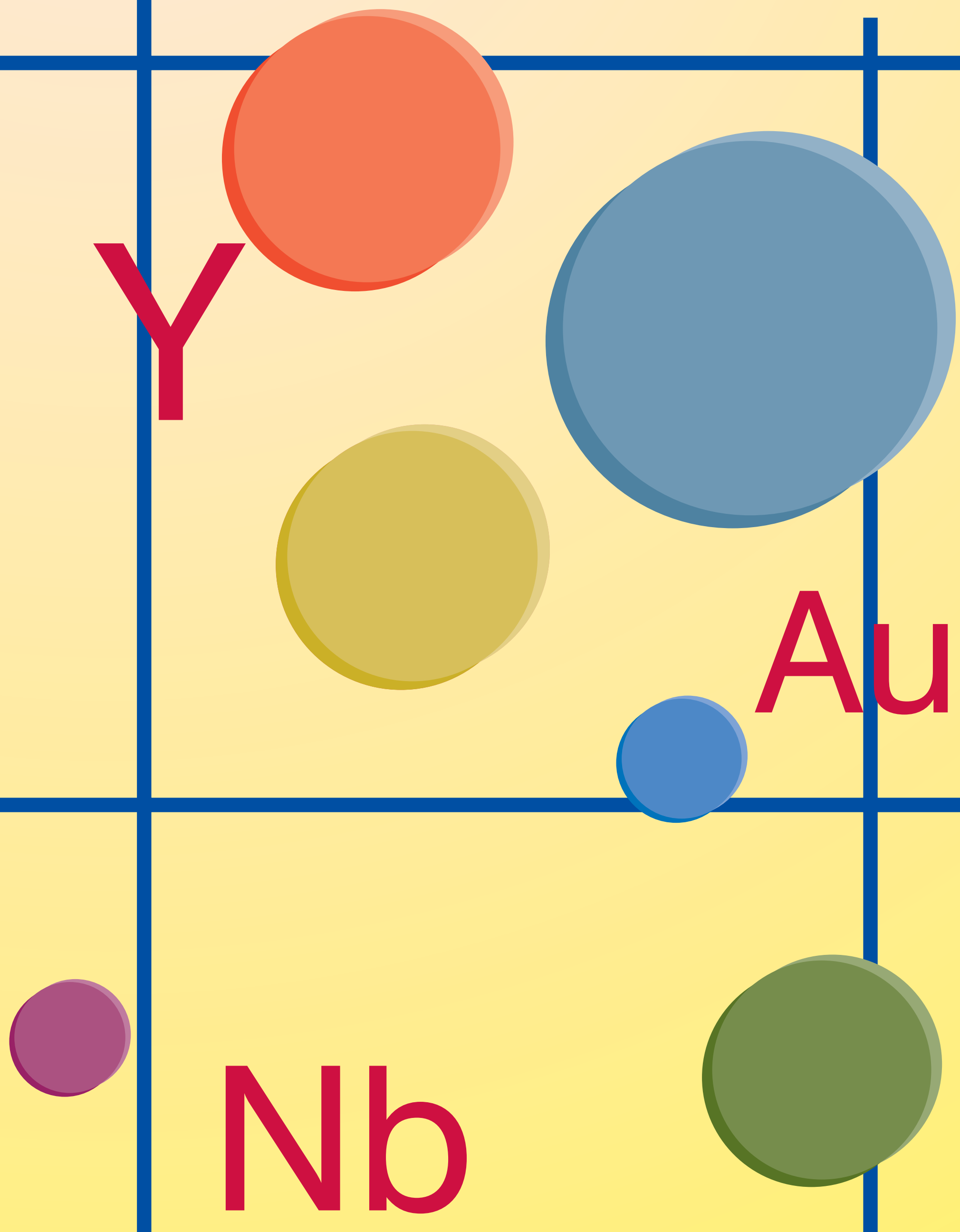
EXPLANATORY NOTES

GOVERNMENT OF WESTERN AUSTRALIA

GEOCHEMICAL MAPPING OF THE BYRO 1:250 000 SHEET

by P. A. Morris and A. L. Verren

1:250 000 REGOLITH GEOCHEMISTRY SERIES



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY

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P. A. Morris and A. L. Verren

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Geochemical mapping of the Byro 1:250 000 sheet

by

P. A. Morris and A. L. Verren*

Abstract

Regolith and geochemical mapping of the BYRO 1:250 000 map sheet has been completed as part of the regional regolith and geochemical mapping program of the Geological Survey of Western Australia (GSWA). A total of 1016 regolith samples have been collected, comprising 240 stream-sediment samples, 228 sandplain samples, 528 sheetwash samples, 16 lake-sediment samples, and 4 soil samples. Each sample has been analysed for 48 elements, as well as for acidity–alkalinity (pH) and conductivity. Results for major element oxides (except SiO_2) and trace elements (except Cd) are shown as spot-concentration maps. Additive-index maps have been produced for various combinations of trace elements.

A regolith-materials map has been compiled, based on a three-tier classification scheme using sample-site descriptions, Landsat imagery, and aerial photographs. The most common regolith type on BYRO is low-gradient slope material (sheetwash), which accounts for over 30% of regolith by area. Exposed-regime regolith and colluvium each account for approximately 15% of regolith, whereas relict or residual regolith and lacustrine regolith account for a further 7% each.

The limited range in lithology of the Archaean Murchison Granite–Greenstone Terrane on BYRO is reflected in the uniform composition of regolith. In contrast, the lithological diversity of the Narryer Terrane is shown by higher contents of several analytes, for example elements such as Fe, Ti, Cr, Cu, and V that are associated with mafic rocks. High levels of elements such as La, Ce, Nb, Zr, and Cr in regolith derived from granitoids of both terranes is indicative of the concentration of resistate phases resulting from weathering and mechanical sorting. Despite the limited evidence of ultramafic rocks in outcrop, the high concentration of Mg, Cr, Ni, and Sc in some samples close to ultramafic rocks shows that this rock type may be of wider extent. Some regolith samples in the same area have high concentrations of platinum group elements (Pt and Pd). Gold in regolith is usually present at low levels, although anomalous concentrations are recorded from regolith over Murchison Granite–Greenstone Terrane granitoids and at Mount Narryer.

Regolith over the Proterozoic Badgeradda Group has high concentrations of Fe, Ti, As, Cu, Sb, Bi, Sc, V, Mn, Co, Zn, and Zr. The high Fe_2O_3 content of regolith may mean that supergene enrichment of these elements has resulted from the scavenging effects of iron. Regolith over the Phanerozoic rocks has a lacustrine chemistry, although high levels of some trace elements (e.g. Zn) could be a result of erosion of the Badgeradda Group and deposition in lake systems.

Areas worthy of further exploration include those with ultramafic-hosted copper, nickel, chromite, and platinum-group element mineralization in the central-northern part of BYRO; parts of the Badgeradda group to determine if high levels of several elements are due only to supergene enrichment; and pegmatite mineralization in the Jack Hills greenstone belt.

KEYWORDS: Byro, geochemistry, regolith, mapping, analysis, mineralization.

Introduction

Regolith, which is unconsolidated or indurated weathered rock, covers large areas of Western Australia. Although regolith can blanket bedrock mineralization, it can provide important information on the nature and distribution of mineralization, as regolith is derived by the physical and chemical weathering of bedrock and can therefore retain some imprint of the parent rock composition. Furthermore, regolith itself can host economic gold (Glasson et al., 1988) and nickel deposits (Burger, 1996; Monti and Fazakerley, 1996; Brand et al., 1996; Hellsten et al., 1998). If regolith is to be used as an exploration tool, or sought as a host to mineralization, it is essential to have some understanding of both the distribution of different regolith

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types and the chemistry of regolith, and how both of these relate to parent rock.

Recognizing the importance of regolith, the Geological Survey of Western Australia instituted a program in 1994 to systematically sample and map regolith on a regional scale in selected areas of Western Australia. To date, 19 sets of maps and explanatory notes have been published (Fig. 1). The program is based on making observations and collecting regolith at sample sites located at a nominal density of one site per 16 km^2. Each regolith sample is subsequently analysed for between 45 and 50 analytes, and the data presented as both a digital dataset and a series of spot-concentration maps. Other maps illustrate regolith distribution and areas of exploration-company activity involving surface geochemical techniques. Accompanying explanatory notes provide discussion of regional geology and mineralization, regolith classification, and mineralization potential. A recent addition to the program has been the measurement of the Earth's gravitational field at each sample site, thus providing significant improvements to the quality of gravity data in most areas (Howard and Shevchenko, 2000).

Early in the GSWA regolith geochemistry program, the emphasis was on the northern Eastern Goldfields (e.g. MENZIES*: Kojan and Faulkner, 1994; LEONORA: Bradley et al., 1995). Subsequent projects have concentrated on the less well-explored Capricorn Orogen between the Pilbara and Yilgarn Cratons (e.g. NABBERU: Morris et al., 1997; MOUNT PHILLIPS: Sanders et al., 1997; MOUNT EGERTON: Morris et al., 1998; EDMUND: Pye et al., 1998; WYLOO: Pye et al., 1999; KINGSTON: Pye et al., 2000; STANLEY: Morris et al., 2000a), part of the Albany–Fraser complex (Morris et al., 2000b), and Archaean–Cainozoic rocks on AJANA (Sanders and McGuinness, 2000) and WINNING POOL – MINILYA (Sanders and McGuinness, 2001)

Location and access

Regolith mapping and sampling, chemical analysis of regolith, and gravity capture have been carried out on BYRO, which lies between latitudes 26°00' and 27°00'S and longitudes 115°30' and 117°00'E, straddling the Yalgoo, Murchison, and Gascoyne mineral fields. Apart from the Murchison Shire office, the only permanent residents on the sheet area are found on pastoral leases (Fig. 2 and Plate 1). Pastoral leases either wholly or partly on BYRO include Ballythunna, Curbur, Byro, Mount Narryer, Meeberrie, Muggon, Boolardy, Nookawarra, Manfred, Milly Milly, and Wooleen. BYRO is serviced by a series of graded roads, including the Mullewa–Carnarvon road that bisects the map sheet from north to south. Access throughout the remainder of the map sheet is afforded by a series of station tracks, although hilly country in the eastern part of the map sheet is difficult to traverse (Williams et al., 1983). After heavy rain, most tracks and graded roads become impassable due to flooding.

The coordinates of locations discussed here are presented in Appendix 1.

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

Climate and vegetation

Climatic information for the Gascoyne–Murchison region (including BYRO) discussed below is taken from the Gascoyne–Murchison climatic survey published by the Bureau of Meteorology (1998). BYRO experiences a semi-arid to arid climate characterized by hot summers and mild winters. Rainfall is largely confined to two periods (May–July and January–March), and results from cloudbanks and tropical depressions from the northwest, cold fronts from the southwest, and troughs and low-pressure systems from the east. Total rainfall varies widely from year to year, but average annual rainfall figures throughout the map sheet are similar. For example, at Boolardy Homestead the annual rainfall varies from 31 to 518 mm, but the average rainfall of 209 mm is similar to that for Mount Narryer (195 mm), Manfred (202 mm), and Byro (213 mm) homesteads. At Boolardy Homestead, about 60% of the annual rainfall usually falls between May and October. Flooding on BYRO is worst in January, when heavy rain is associated with tropical low-pressure systems or cyclones.

January is typically the hottest month, and July is usually the coolest. On BYRO, the mean maximum temperature in January is close to 40°C, and the mean minimum temperature is about 23°C. In July, the mean maximum temperature is about 20°C, and the mean minimum temperature is between 6 and 8°C. Evaporation is about 3200 mm per year, reaching a maximum of about 17 mm per day in January, and a minimum of 2 mm per day in July.

Beard (1976) has discussed the vegetation of the Murchison area, and the following is taken from that publication. BYRO lies in the Eremaean Botanical Province (also known as the Austin Botanical District), and straddles the Byro and Upper Murchison Subregions. On BYRO, the Byro Subregion extends from the western margin of the map to the Murchison River, and the Upper Murchison Subregion extends east from the Murchison River to the eastern boundary of the map sheet.

The Byro Subregion contains mulga woodland with *Eremophila* as both understory and in less densely vegetated areas. *Acacia* and *Grevillea* are found on sand ridges, whereas areas of salt flats support *Atriplex*, *Maireana*, *Frankenia*, and samphire, with scattered *Acacia*. Eucalypts and casuarinas are found along watercourses and in lake areas.

Vegetation in the Murchison subregion bears the imprint of human habitation, in that in many areas trees are scattered and regeneration is poorly developed. On flat areas, mulga woodland is the dominant vegetation. On hills developed over granitoid or gneissic rocks, mulga scrub is well developed, but this becomes scattered over areas of sandplain. On some low-lying plains, more saline areas support halophytes, although in areas of more active drainage (such as in reaches of the Murchison River) halophytes are replaced by phreatophytes, with *Acacia* scrub and scattered eucalypts along drainage courses.

Physiography and soils

Williams et al. (1983) have discussed the physiography of BYRO, and the following is based on their work. They emphasized the control of geology on topography, with a gradual increase in elevation from about 250 m above sea level (ASL) over Phanerozoic rocks in the west to over 400 m ASL over Precambrian rocks in the southeast. The topography over Phanerozoic rocks rarely varies by more than 70 m, whereas that over Precambrian rocks varies by up to 200 m. Areas of Phanerozoic rocks in the western part of the map sheet are characterized by rocky or duricrust-capped hills usually overlain or surrounded by featureless sandplains. Williams et al. (1983) described an extensive paleodrainage system in this area composed of dunes and playas as part of the south-flowing Yarra Yarra Creek system.

In contrast, areas of Precambrian rocks are characterized by a variety of terrain types including rocky hills and duricrust-capped bedrock, which give way downslope to areas of sheetwash and then alluvial valleys. The highest areas are all in excess of 500 m ASL, including Mount Narryer, Mount Murchison, and Jack Hills. All consist of resistant lithologies such as banded iron-formation and quartzite.

Most drainages are part of the Murchison River catchment, and few streams flow throughout the year.

The soil types on BYRO (Bettenay et al., 1967) follow the broad geologic subdivisions shown on Figures 3 and 4, and Plate 1. Soils overlying the Carnarvon Basin include acid red earths and loamy soils, the former overlying reddish hardpan. In areas of playas and dunes, soil types include alkaline, neutral, and acid red earths locally overlying red-brown hardpan. Overlying the granitoid gneiss of the Narryer Complex to the east, the soils are earthy loams overlying red-brown hardpan.

Slightly undulating to flat areas around and to the east of the Murchison River carry thin, acid red earths and earthy loams. Red-brown hardpan forms scattered outcrops. On more undulating areas underlain by granitic rocks, shallow earthy loams cover red-brown hardpan. To the east of Milly Milly Homestead, earthy loams are found overlying hardpan. Saline alluvial flats in drainage depressions (e.g. Murchison River) are characterized by hard alkaline and neutral red soils, and saline red soils. Areas of calcrete support brown calcareous soils.

Topographic and remote-sensing datasets

Topographic information used on the accompanying maps of BYRO was obtained from the Department of Land Administration (DOLA) and the Australian Land Information Group (AUSLIG). Data sources include the BYRO 1:250 000 Topographic Map (Series 1501, Edition 1), first (Williams et al., 1983) and second (Myers, 1997) edition 1:250 000-scale geology maps, 1:50 000 black and white aerial photographs (1995), Landsat Thematic Mapper (TM) scenes (1998), and a Landsat synthetic stereoimage using AUSLIG 9 second DEM.

Geology

Geological setting

BYRO consists of three broad lithological associations — largely crystalline Archaean rocks of the Yilgarn Craton (Murchison Granite–Greenstone and Narryer Terranes: Myers, 1990a, 1997; Watkins, 1990; Watkins and Hickman, 1990) found in the eastern two-thirds of the map sheet, and Proterozoic (Badgeradda Group: Williams, 1990; Williams et al., 1983) and Phanerozoic (Lyons, Wooramel, and Byro Groups: Williams et al., 1983; Hocking, 1990; Hocking et al., 1987) sedimentary rocks in the western part of the map sheet (Figs 3 and 4, Plate 1). Only summaries of the stratigraphy and regional relationships are given here, with the emphasis on lithological content in order to form a basis for discussion of variations in regolith chemistry. Detailed discussions of lithology, stratigraphy, and structure are given in the references cited.

Eroded fault scarps near Mount Narryer (Williams, 1979) attest to the seismic activity of this area.

Yilgarn Craton

Yilgarn Craton rocks on BYRO are largely composed of Archaean granitoid and granitoid gneiss (Fig. 4, Plate 1; Myers, 1990b). Rocks of the Narryer Terrane (Myers, 1990a) or Narryer Gneiss Complex (Myers, 1988) are juxtaposed against rocks of the Murgoo Gneiss Complex and upper Archaean granite of the Murchison Granite–Greenstone Terrane to the southeast by the Yalgar and Balbalinga Faults (Fig. 4 and Plate 1). Myers (1990a; 1993; 1995) regarded the two terranes as separate pieces of continental crust until their collision at 2750–2650 Ma. The subdivision of Murchison Granite–Greenstone and Narryer Terrane rocks shown in Figure 4, Plate 1, and Table 1 is derived from Myers (1997), which has drawn on detailed mapping and SHRIMP U–Pb geochronology (e.g. Nelson, 1995, 1996, 1999, 2000; Wiedenbeck and Watkins, 1993; Schiotte and Campbell, 1996; Nutman et al., 1991, 1993). Occhipinti et al. (in prep.) have recently summarized the lithologies, structure, stratigraphy, and geochronology of the Narryer Terrane.

Narryer Terrane

The Narryer Terrane, which contains the oldest known rocks in the Yilgarn Craton (Myers, 1990a,b; 1993), includes orthogneiss, metasedimentary rocks, and layered intrusive rocks. The oldest rocks (Meeberrie Gneiss; Fig. 4 and Plate 1) were derived from 3730 Ma tonalite and c. 3600 Ma granitoid. Of similar age are anorthosite, gabbro, and ultramafic rocks of the Manfred Complex. Deformed and metamorphosed versions of these rocks were intruded by 3400 Ma granite (now Dugel Gneiss) and 3300 Ma granite, with intrusion accompanied by high-

Table 1. Summary of stratigraphy and lithology for Byro

Group or Terrane	*Unit*	*Lithology*	*Depositional structure*	*Depositional setting*	*Relationship to underlying beds*	*Reference*
Palaeozoic and Proterozoic						
Byro Group	Coyrie Formation	Bioturbated siltstone and fine-grained sandstone	Graded beds	Offshore quiet marine	Conformable	Condon (1954); Hocking et al. (1980, 1987); Myers (1997)
Wooramel Group	Keogh Formation	Siltstone, sandstone, minor claystone, and carbonaceous shale	Trough cross-bedding, flaser and lenticular bedding, herringbone cross-stratification	Subtidal to deltaic	Conformable	Konecki et al. (1958); Hocking et al. (1980, 1987); Myers (1997)
	Moogooloo Sandstone	Quartzose or feldspathic sandstone and siltstone; minor claystone and carbonaceous shale	Trough cross-bedding, planar cross-bedding, minor ripple lamination	Deltaic to fluvial	Unconformable on Callytharra Formation	Craig (1950); McWhae et al. (1958); Hocking et al. (1980, 1987); Myers (1997); Mory (1996); Mory and Backhouse (1997); Williams et al. (1983)
Lyons Group	Callytharra Formation	Interbedded fossiliferous siltstone and limestone	Massive to poorly bedded	Marine shelf	?conformable (not exposed on Byro)	Williams et al. (1983); Hocking et al. (1987); Mory (1996); Mory and Backhouse (1997)
	Carandibby Formation	Micaceous claystone, siltstone, shale, and sandstone	Massive to poorly bedded	Low-energy offshore marine	Conformable	Williams et al. (1983); Hocking et al. (1987); Mory (1996); Mory and Backhouse (1997)
	Undivided	Immature sandstone, siltstone, shale, micaceous claystone, and tillite; numerous glacial erratics	Clasts are striated and facetted. Sandstones are trough cross-bedded and cross-stratified. Varved siltstones	Glaciomarine with minor glaciolacustrine and fluvioglacial sediments	Unconformable	van de Graaff (1981); Hocking et al. (1980, 1987); Myers (1997); Mory (1996); Mory and Backhouse (1997)
Badgeradda Group	Yarrawolya Formation	Siltstone and silty sandstone, locally hematitic	Small-scale cross-bedding, current lineations, drop pebbles	–	Unconformable	Perry and Dickins (1960); Williams et al. (1983); Hocking et al. (1980); Myers (1997)
	Coomberarie Formation	Silty sandstone	Small-scale cross-bedding	–	–	Williams et al. (1983)
	Errabiddy Formation	Feldspathic sandstone; minor pebble-conglomerate lenses	Cross-bedding, asymmetric ripples	–	–	Williams et al. (1983)
	Woodrarrung Formation	Thin-bedded feldspathic and quartzose sandstone	Rare cross-bedding	–	–	Williams et al. (1983); Myers (1997)

Table 1. (continued)

Group or Terrane	*Unit*	*Lithology*	*Depositional structures*	*Depositional setting*	*Relationship to underlying beds*	*Reference*
ARCHAEAN **Narryer Terrane**	Yarra Yarra Granite	Coarse-grained, equigranular, leucocratic granulite-facies monzogranite	–	–	–	Williams et al. (1983); Myers (1997)
	Churla Granite	Coarse-grained, equigranular, leucocratic granulite-facies monzogranite	–	–	–	Williams et al. (1983); Myers (1997)
	Balla Granite	Coarse-grained, porphyritic to equigranular amphibolite-facies monzogranite, with inclusions of Eurada Gneiss	–	–	–	Williams et al. (1983); Myers (1997)
	Impey Granite	Heterogeneous, coarse-grained, porphyritic to equigranular amphibolite-facies monzogranite	–	–	–	Williams et al. (1983); Myers (1997)
		Coarse-grained, equigranular to porphyritic granitoid, locally with inclusions of amphibolite, ultramafic rock, metasedimentary rock, or gneiss	–	–	–	Williams et al. (1983); Myers (1997)
	Yallalong Granite	Coarse-grained, equigranular, leucocratic granulite-facies monzogranite	–	–	–	Williams et al. (1983); Myers (1997)
	Wandarrie Granite	Coarse-grained, equigranular leucocratic monzogranite	–	–	–	Williams et al. (1983); Myers (1997)
		Undivided metasedimentary rocks including banded iron-formation, quartz–magnetite rock, pelite, quartzite, conglomerate, sandstone, silicic schist, mylonite, quartz–mica schist, and micaceous quartzite; subordinate metagabbro, ultramafic schist, and amphibolite	–	–	–	Williams et al. (1983); Myers (1997)
	Milga Gneiss	Granodioritic gneiss	–	–	–	Williams et al. (1983); Myers (1997)
	Dugel Gneiss	Monzogranitic and syenogranitic gneiss	–	–	–	Williams et al. (1983); Myers (1997)

Table 1. (continued)

Group or Terrane	*Unit*	*Lithology*	*Depositional structure*	*Depositional setting*	*Relationship to underlying beds*	*Reference*
	Eurada Gneiss	Monzogranitic to tonalitic gneiss with inclusions of Meeberrie Gneiss and Dugel Gneiss	–	–	–	Williams et al. (1983); Myers (1997)
	Meeberrie Gneiss	Monzogranitic to tonalitic gneiss veined by Eurada Gneiss and Dugel Gneiss	–	–	–	Williams et al. (1983); Myers (1997)
Murchison Granite–Greenstone Terrane	Weiragoo Granite	Porphyritic to equigranular amphibolite-facies monzogranite	–	–	–	Williams et al. (1983); Myers (1997)
	Cundarra Granite	Coarse-grained, equigranular to porphyritic amphibolite-facies monzogranite	–	–	–	Williams et al. (1983); Myers (1997)
	Tching Granite	Amphibolite-facies monzogranite with inclusions of Bearra Gneiss	–	–	–	Williams et al. (1983); Myers (1997)
	Bearra Gneiss	Dioritic and leucogranitic gneiss, possibly an earlier phase of the Tching Granite	–	–	–	Williams et al. (1983); Myers (1997)

grade metamorphism. Following the middle to upper Archaean (3100–2700 Ma) deposition of sedimentary rocks (now quartzite, pelite, and banded iron-formation (BIF) in the Mount Narryer and Jack Hills area, with the latter termed the Jack Hills greenstone belt), granitoid magmas were emplaced at about 2750–2620 Ma. Myers (1993) has argued that this coincided with the collision of the Murchison Granite–Greenstone and Narryer Terranes, thus resulting in metamorphism and widespread deformation.

Murchison Granite–Greenstone Terrane

In contrast to the Narryer Terrane, the Murchison Granite–Greenstone Terrane is composed of both granitoid and greenstone, although on BYRO it is represented only by the Murgoo Gneiss Complex (Myers, 1990a,b), which consists of middle to upper Archaean Bearra Gneiss (Myers, 1997) intruded by upper Archaean granitoid. The geological history of the Murchison Granite–Greenstone Terrane, which has been discussed by Watkins and Hickman (1990), is not as complex as that of the Narryer Terrane. It has involved several episodes of magmatism, deformation, and metamorphism (Watkins and Hickman, 1990), as summarized in Table 2.

Proterozoic rocks (Badgeradda Group)

Proterozoic siliciclastic sedimentary rocks are largely found in the southwestern part of BYRO, with less extensive outcrops in the central-northern part of the map sheet near Mount Rebecca, and northwest of Mount Narryer Homestead (Plate 1). These rocks comprise siltstone and sandstone through to conglomerate (Perry and Dickins, 1960). Condon (1965) considered the Badgeradda Group to be part of the Carnarvon Basin sequence, but Muhling and Brakel (1985) argued that the Badgeradda Group may represent part of the Bangemall Basin succession deposited in a separate basin. Hocking et al. (1987) also considered them to be separate from the Carnarvon Basin sequence, a view reinforced by Williams (1990), who argued that the basal part of the Badgeradda Group rested unconformably on rocks of the Narryer Terrane.

Detailed descriptions of constituent units of the Badgeradda Group have been provided by Perry and Dickins (1960) and Williams et al. (1983), and only a summary is given here (Table 1). The lowest unit in the Badgeradda Group is the Woodrarrung Formation (Woodrarrung Sandstone in Williams et al., 1983), which is a feldspathic and quartzose sandstone found in the southwest of BYRO. The overlying Errabiddy Sandstone (renamed the Errabiddy Formation by Myers, 1997) is a pale-brown to grey-white, medium-grained, and typically feldspathic sandstone, with locally developed pebble-conglomerate lenses. The overlying Coomberarie Formation, which is apparently conformable on the Errabiddy Formation (Williams et al., 1983), is well exposed north of Coombrarri Well, and consists of reddish-white, thin-bedded siltstone and sandstone. According to Perry and Dickins (1960), the overlying Yarrawolya Formation consists of an upper fine-grained hematitic sandstone and a lower unit of siltstone.

Phanerozoic rocks

Phanerozoic rocks of the Carnarvon Basin succession are found on the western side of BYRO (Fig. 4 and Plate 1). They form part of the Byro Sub-basin, which is a half-graben of Upper Carboniferous and Permian sedimentary rocks unconformably overlying or in faulted contact with the Badgeradda Group to the south, and in faulted contact with the Yilgarn Craton to the east (Hocking et al., 1987). Hocking et al. (1987) argued that the Carnarvon Basin succession on BYRO could be divided into two depositional events — an early mixed siliciclastic and carbonate glacial-dominated phase represented by the Lyons Group and Callytharra Formation, and a later siliciclastic sequence deposited under fluvial, deltaic, and shallow-marine conditions, represented by the Wooramel, Byro and Kennedy Groups.

Table 2. Geological history of the Murchison Granite–Greenstone Terrane

Event	*Lithology*
Deposition of Luke Creek Group	Lower part: submarine tholeiitic basalt, high-Mg basalt. Upper part: basic and silicic volcanic rocks, volcaniclastic rocks
Intrusion	Monzogranite and granodiorite sheets
Deformation and metamorphism	Development of pegmatite-banded gneiss from granitoid
Deposition of Mount Farmer Group	Volcanic and epiclastic rocks deposited on the Luke Creek Group and pegmatite-banded gneiss
Intrusion	Monzogranite; development of amphibolite-facies contact-metamorphosed rocks
Deformation and metamorphism[a]	Greenschist to amphibolite facies
Intrusion	Granitoid
Deformation	–

NOTE: (a) affects both the Murchison Granite–Greenstone and Narryer Terranes

SOURCE: after Watkins (1990)

Hocking et al. (1987), Hocking (1990), Mory (1996), Mory and Backhouse (1997), and Hocking (2000) have provided detailed accounts of the lithology, stratigraphy, distribution, thickness, depositional environment, faunal content, and age of the Phanerozoic rocks of the Byro Sub-basin, and only a summary is presented here (Table 1). Units with limited exposure on Myers' (1997) BYRO map sheet (such as the Cainozoic Pindilya Group north of Curbur Station) are not shown on either Figure 4 or Plate 1, although they are discussed in the context of the Carnarvon Basin lithologies in Hocking et al. (1987).

Fluvial to shallow-marine glacially derived rocks of the Lyons Group (Lyons Formation of Williams et al., 1983) rest unconformably on Archaean or Proterozoic rocks. They are usually found as boulder-strewn colluvium on BYRO, along with isolated outcrops of feldspathic sandstone, siltstone, and shale. The unit is probably about 1200 m thick (Konecki et al., 1958). Many conglomerate clasts show signs of a glacial origin, with well-developed striations, facetting, and plucking. The clasts comprise granitoid, quartzite, quartz sandstone and siltstone, metamorphic rock, chert, carbonate-rich rock, pegmatite, and mafic volcanic rock (Hocking et al., 1987). The Carandibby Formation of the Lyons Group consists of a variety of lithologies, including micaceous claystone, siltstone, shale, and sandstone (Table 1).

The Wooramel Group on BYRO consists of quartz- or feldspar-rich sandstone and siltstone, with subordinate amounts of claystone and carbonaceous shale (Moogooloo Sandstone). The overlying Keogh Formation is lithologically similar to the Moogooloo Sandstone (Table 1), but was deposited in a quieter, more shallow-water environment (Williams et al., 1983).

The Byro Group comprises nine stratigraphic units (Hocking et al., 1987), but only the lowermost unit (Coyrie Formation) is exposed on BYRO, where it is usually seen as a ferruginized siltstone scree (Williams et al., 1983). Scattered glacial debris is observed in this unit in parts of the Byro Sub-basin (Hocking et al., 1987).

The Tertiary Pindilya Formation forms scattered outcrops in the western part of BYRO that are too small to be shown in terms of the simplified geology (Fig. 4 and Plate 1). Williams et al. (1983) describe this unit as a silicreted, possibly fluviatile, sandstone and conglomerate that is unconformable on Permian rocks. Both Williams et al. (1983) and Hocking et al. (1987) suggested a Miocene age, the latter based on a lateral correlation with the Lamont Sandstone.

Recorded mineralization and economic geology

BYRO straddles the boundaries of the Gascoyne, Murchison, and Yalgoo mineral fields. Although the area has been explored for a variety of commodities (including gold, copper, nickel, chromite, iron ore, corundum, barite, silica, rare earth elements (REE), platinum, diamond, and non-precious gemstones), there are no significant mineral deposits on the map sheet.

Gold

Johnson (1950) first reported gold on BYRO from high-grade gneiss near Mount Dugel, although no evidence of gold mineralization in this area was reported by Williams et al. (1983). Several companies have examined meta-sedimentary rocks in the Mount Narryer region for Witwatersrand-style palaeoplacer mineralization. CRA reported minor gold occurrences in conglomerates (Bromley, 1985), including 0.65 ppm from a matrix-supported quartz-pebble conglomerate 5 km southwest of Mount Dugel Well, 0.43 ppm from a pyritic-banded chert 500 m southeast of Mount Dugel, and 0.26 ppm from a matrix-supported quartz-pebble conglomerate 500 m southwest of Mount Narryer. Visible gold was reported from heavy mineral concentrates southeast and northwest of Mount Narryer. Oresearch N. L. (1988) found the highest gold values in trough-and-fill structures near the base of conglomeratic units, similar to the Witwatersrand occurrence, including gold values up to 1.66 ppm in soil and 1.8 ppm in rock. Johnson and Pawlitschek (1995) argued that clast-supported, polymictic conglomerates were more prospective than matrix-supported and oligomitic conglomerate units. Based on structural and geophysical characteristics, Western Mining Corporation prospected the Jack Hills greenstone belt, but only weakly anomalous (<300 ppb) gold results were recorded (Mazzoni, 1991).

Copper and nickel

Copper

Copper mineralization has been reported northeast of Melun Bore (Byro prospect) and north of Byro Homestead. The Byro prospect was divided into the Byro West and Byro East sections by Jododex Australia Pty Ltd (1973). No anomalous nickel or copper geochemical targets were defined in the Byro East section, although a manganese-stained limonitic rock developed over ultramafic rocks (resembling a nickel gossan) assayed 1230 ppm copper and 1.1% nickel (Jododex Australia Pty Ltd, 1973). In the Byro West section, rock-chip samples of gossanous, jasperlitic ironstone with visible malachite in the fractures assayed up to 9.4% copper (Jododex Australia Pty Ltd, 1973; Greig, 1993; Purkait, 1994). Jododex Australia Pty Ltd (1973) sampled three gossanous outcrops over a distance of 1800 m along the eastern contact of ultramafic and metasedimentary rocks. Native copper and chalcopyrite were reported in drillholes. One drillhole contained anomalous copper over the entire length of 71 m, with a maximum value of 2% (Purkait, 1994). Examination of the drill logs and summaries suggests that the reported copper mineralization (native copper and chalcopyrite) intersected in the Byro West section is related to supergene remobilization of copper from a serpentinite-hosted disseminated nickel-sulfide deposit.

A small copper prospect 2 km north of Byro Homestead (Byro Homestead prospect) consists of a north-trending quartz reef containing malachite-stained, limonitic gossanous material developed in banded granitic gneiss (Williams et al., 1983). The prospect is in granulite-facies leucocratic monzogranite of the Yarra Yarra Granite (Myers, 1997). Tarcoola Gold Limited (1991) assayed ferruginous quartz with minor copper staining, with one sample returning 290 ppm gold and 2.2% copper.

Nickel

At Byro West (Byro prospect), north-northwesterly striking bodies of serpentinized peridotite and meta-pyroxenite up to 8 km long (Marston, 1984; Myers, 1997) are largely mantled by laterite. They form a series of ridges and low hills within even-grained to porphyritic granitoids with abundant inclusions of amphibolite and ultramafic rock (Myers 1997). Drilling over the period 1971–74 intersected nickel mineralization (up to 0.9% nickel) in weathering profiles up to 40 m thick. This enrichment has been attributed to the presence of the nickeliferous chlorite mineral nimite (Marston, 1984) in the weathered zone (Jododex Australia Pty Ltd, 1973). Drilling outlined a lateritic nickel resource estimated at about 100 000 tonnes averaging 1.4% nickel for 1000 tonnes of contained nickel (Marston, 1984). Soil sampling (Tarcoola Gold Limited, 1991) outlined anomalous nickel (up to 1.23%) further along strike.

Apart from the Byro prospect (Jododex Australia Pty Ltd, 1973; Marston, 1984), nickel exploration has been undertaken over small ultramafic bodies in the Meegea Hill, Partnership Bore, Noonie Hill, and Pingarra Creek areas.

Small ultramafic bodies in the Meegea Hill area, consisting of chlorite–tremolite–talc–serpentine assemblages after peridotite, have been examined for nickel mineralization. Associated laterites usually have low nickel values and only trace amounts of copper and cobalt, and include several small uneconomic nickeliferous gossans (Williams et al., 1983). No visible sulfides were recognized (Summers, 1969). Four kilometres northwest of Partnership Bore, Pacminex Pty Ltd examined an ultramafic body with a strike length of over 800 m and a width of up to 60 m (Horsley, 1974a). The layered body consists of serpentinized metapyroxenite to metadunite. No sulfides were recognized in drillcore, despite up to 0.5% nickel and 1% Cr being detected in drillchips and core (Horsley, 1974a). Union Minière Development and Mining Corporation Limited (1972) examined a 1800 × 600 m differentiated ultramafic body on the northern flank of Noonie Hill in the Jack Hills greenstone belt. The body consists of chlorite–tremolite–amphibole–serpentine (–talc) after dunite, peridotite, and pyroxenite. No gossans or other evidence of sulfide mineralization were found. A maximum of 4900 ppm Ni was returned from a small outlier on the southern flank of Noonie Hill. Samples with greater than 1000 ppm Ni also have weakly anomalous cobalt (>100 ppm) values (Union Minière Development and Mining Corporation Limited, 1972). At Pingarra Creek, about 18 km southwest of Nookawarra Homestead, a cluster of talc–carbonate–chlorite–serpentine bodies (Williams et al., 1983) are hosted in metamorphosed heterogeneous, porphyritic to even-grained monzogranites of the Weiragoo Granite (Myers, 1997). No nickel mineralization was detected (Williams et al., 1983).

Drilling of serpentinized peridotite at Iniagi Well returned a maximum value of 2.7% Ni over 0.3 m in a zone averaging 1.4% Ni over 4 m (Muller, 1971). Barker (1982a) reported a single high value of 4.05% nickel with 0.18% cobalt from a trench sample of weathered ultramafic rock. Fine-grained sulfides, pyrite, and chalcopyrite have been recorded in drillcore from the associated norites (Summers, 1970).

Chromite

Chromite mineralization has been reported from Iniagi Well, 13 km south-southeast of Byro Homestead, and from Taccabba Well, 2 km northwest of Milly Milly Homestead (Williams et al., 1983).

At Iniagi Well, eluvial chromite has been recorded from soils over a concealed layered mafic–ultramafic complex (Baxter, 1978; Goldsworthy, 1990a). The complex consists of a northeasterly facing layered body containing a number of peridotitic and noritic intrusive rocks (Wroe, 1977) with layers or slivers of the host paragneiss (Wroe, 1978). Based on more recent drilling, Goldsworthy (1990a,b) concluded that these rocks are the base of a layered, predominantly anorthosite–norite–gabbro complex that has been highly disrupted and tectonized. The intrusions have undergone upper amphibolite- to lower granulite-facies metamorphism (Wroe, 1978; Williams et al., 1983).

Electrolytic Zinc Company of Australasia showed that the chromite bodies formed narrow lenses or pods in both the ultramafic rocks and the host quartz–plagioclase paragneiss areas (Muller, 1971; Wroe, 1977; Goldsworthy, 1990b). Disseminated chromite was exposed in costeans (Muller, 1971) and intersected in drillholes beneath the pods of massive chromite (Goldsworthy, 1990b). The best result for channel samples collected by Newmont Australia was 10 m at 11.8% Cr (17.25% Cr_2O_3; Goldsworthy, 1990b). Wroe (1978) concluded that the chromite was not present in economic quantities.

A concealed metamorphosed mafic–ultramafic body in upper amphibolite- to lower granulite-facies terrain has been reported from Taccabba Well (Williams et al., 1983). Percussion drilling by Pacminex intersected sheared, schistose ultramafic rock with minor quartz veining, and biotite–magnetite–chromite rock. The best assays were 3% Cr over 2 m from the ultramafic rock, and 3.8% Cr over 3 m (including 4.25% over 1 m) from the biotite–magnetite–chromite rock (Horsley, 1973). Follow-up diamond drilling intersected 1 m of chromite- and magnetite-rich rock underlain by 2 m of gabbro containing cumulate chromite. Assay results reported were 0.5 m at 7% Cr (10% Cr_2O_3) and 0.5 m at 8.3% Cr (12% Cr_2O_3; Barker, 1982b). The magnetite–chromite band is 1.5 km long and marginal to a metalherzolite (Williams et al., 1983), and also contains traces of pyrite and chalcopyrite (Horsley, 1974b).

Iron ore

Small lenses of massive, micaceous hematitic iron ore and iron-rich hematite–quartz rock have been reported from the Jack Hills greenstone belt and the Mount Narryer area (Williams et al., 1983; Williams and Myers, 1987). The iron ore has been formed by the supergene enrichment of Archaean banded iron-formation during Tertiary lateritization (Elias, 1982). Total iron ore reserves for the Jack Hills greenstone belt are estimated at about 94 Mt, most of which is found on BELELE (Elias, 1982). Maitland (1898) estimated less than 10 000 tonnes on BYRO.

Corundum

Corundum has been reported from several areas on BYRO, with an eluvial deposit covering about 0.5 ha present 4 km east of Thoolmugga Well, north of the Byro – Milly Milly road. The deposit overlies monzogranitic to tonalitic gneisses of the Meeberrie Gneiss, which contains inclusions of c. 3730 Ma Manfred Complex and veins of Dugel Gneiss (Myers, 1997). Other areas of corundum float include 1 km north of the above deposit, 4.5 km north-northeast of Thoolmugga Well, and 5.5 km north-northeast of Byro Homestead (Williams et. al., 1983; Myers 1997). The corundum crystals, which are up to 80 mm long, have a bronze chatoyance (i.e. changeable lustre or colour marked by a narrow band of light) and are strongly zoned. Many are rimmed by hercynite, and are weakly magnetic due to minute ilmenite and magnetite inclusions in the hercynite margin (Williams et al., 1983). Corundum float in the Thoolmugga Well is derived from a small outcrop (approximately 2 m^2) consisting of randomly orientated corundum crystals in the quartzo-feldspathic matrix to an amphibolite found within gneiss (Summers, 1969). The outcrop is close to the edge of a younger acid igneous complex consisting of fine- to coarse-grained granite with aplite and pegmatite dykes (Summers, 1969). The area of corundum float, 5.5 km north-northeast of Byro Homestead (Williams et al., 1983), consists of twinned blue-grey corundum crystals (Williams et al., 1983) overlying coarse, even-grained leucocratic monzogranite (Yarra Yarra Granite of Myers, 1997).

Barite and lead

A number of thin barite–galena veins up to 50 cm wide are exposed in costeans 3 km southeast of Mongolia Bore, on the western side of the Badgeradda Range. The veins are hosted in gently east-dipping (less than 5°), laminated to thinly bedded, micaceous siltstone of the Yarrawolya Formation (Williams et al., 1983) close to or at the contact with the underlying silty sandstones of the Coomberarie Formation (Bennett, 1989). Although there are numerous veins, the overall deposit is small.

Rare earth minerals

Stream-sediment and soil samples recovered by Australian Anglo American Prospecting east of Byro Homestead contain elevated levels of titanium (5.1%), phosphorus (2.22%), thorium (2.9%), cerium (3.9%), lanthanum (220 ppm), and yttrium (3000 ppm) in heavy mineral concentrates. The rare earth minerals monazite, thorian monazite, and xenotime were identified, along with rutile, zircon, amphibole, and iron oxide (Codner and Kaplan, 1982). Further exploration failed to detect any carbonate-rich material indicative of carbonatite intrusions (Codner and Kaplan, 1982). Codner and Kaplan (1982) concluded that the heavy mineral anomalies were produced by natural concentration of rare earth-bearing detrital minerals derived from the weathering of gneisses that have relatively high concentrations of these minerals.

Silica

McNab (1992) reported a north-northeasterly striking quartz vein emplaced in a vertical shear zone within the Impey Granite. He reported a resource estimated at about 172 000 tonnes of high-grade silica in addition to a further 30 000 tonnes of float. However, concerns were expressed about its suitability for electric arc-type furnaces, due to a possible lack of thermal stability (McNab, 1992).

Tiger-eye opal

Tiger-eye and cats-eye opal were discovered in 1899, about 2 km south-southwest of Melun Well. The locality (locality 40 of Summers, 1969), known as the Bulgarro (or Bularoo) opal mine, is probably the same as that which produced 54.4 kg of tiger-eye opal (‘Byro opal’) in 1960 (Williams et al., 1983). This material is a silicified asbestiform mineral found as irregular veins in the opalized silica capping developed on deeply weathered serpentinite (Summers, 1969; Williams et al., 1983).

Opaline silica

Small amounts of potentially gem-quality opaline silica have been found north of Meegea Hill and near Iniagi Well. All deposits have been found in jasperoidal silica cappings on ultramafic rocks (Williams et al., 1983).

Beryl

Beryl has been reported from a small southwesterly trending drainage about 3 km west-northwest of Mount Murchison (Williams et al., 1983; Williams and Myers, 1987; Myers, 1997). The deposit is in alluvium and colluvium over the Impey Granite (Myers, 1997). Williams and Myers (1987) suggested that the beryl is spatially associated with a northeasterly trending quartz-filled fault or shear.

Building stone

Flaggy fine-grained sandstone of the Yarrawolya Formation has been used as a building and flagging stone at Muggon Homestead (Perry and Dickins, 1960). The sandstone was quarried 1.5 km south of Yarrawolya Pool (Williams et al., 1983). At Meeberrie, Mount Narryer, and Boolardy Homesteads, locally quarried gneiss and gneissic granite has been used as building material (Williams et al., 1983).

Geochemical surveys in open-file company reports

To comply with the Mining Act of 1978, mineral exploration companies must lodge reports detailing exploration activities on all tenements they hold in Western Australia. These reports are listed in the Department of Minerals and Energy (DME) Western Australian mineral exploration (WAMEX) database as either open-file or confidential reports. Details of open-file reports that contain surface or near-surface (including costeans and shallow drilling to 4 m) geochemical data for BYRO are presented in Appendix 2. Reports common to a particular exploration project have been grouped and assigned an identification number (ID no.), as shown in Appendix 2. The identification numbers, along with the project boundaries, are shown on Plate 2. Most projects cover a single area, although some projects may cover two or more distinct areas. Project reports with fewer than 30 geochemical samples have been omitted.

The projects listed in Appendix 2 are arranged in chronological order. They cover the period 1969 to 1998. Individual project reports are assigned an M number on receipt by GSWA. When project reports are released to open-file, the M number is replaced by an item (I) number, with the latest releases having the highest I number. Gaps in the reporting may result from the failure of some tenement holders to lodge reports, or the lack of a requirement for mineral-claim holders to report exploration results prior to 1978.

Of the 26 projects listed in Appendix 2, target commodities were gold (23%), diamonds (19%), copper and nickel (15%), gold and platinum (12%), chromite and platinum (8%), and nickel, copper, and chromite (8%). The remaining 15% of the projects targeted carbonatites and rare earth minerals, platinum, copper, and zinc.

Regolith sampling

Regolith sampling on BYRO was carried out over a two-week period during August 2000 by six, two-person sampling teams (each comprising a field assistant and a geologist) using two Bell Jet-Ranger helicopters. The approach to regolith sampling and the form used to record characteristics of regolith and surrounding geology are detailed in Appendix 3. A measurement of the earth's gravitational field was also made at each sample site, based on methodology defined by Howard and Shevchenko (2000). The distribution of sample sites is shown on Plate 1.

Table 3. Regolith units by area and number of samples

Regolith code	*Area (km²)*	*No. of samples*	*% of all samples*	*% of total area*
Residual regime				
Rf	274	10	1.0	1.7
R_sg	359	16	1.6	2.2
Rz	354	14	1.4	2.1
Rzs	128	8	0.8	0.8
Rzu	10	–	–	0.1
Total	**1 125**	**48**	**4.8**	**6.9**
Exposed regime				
Xfc_i	10	–	–	0.1
Xgm	319	14	1.4	1.9
Xgp	1 577	87	8.5	9.5
Xgs	246	14	1.4	1.5
Xlm	53	1	0.1	0.3
Xls_g	338	15	1.4	2.0
Xls_m	43	2	0.2	0.3
Xmm	15	1	0.1	0.1
Xqs	24	1	0.1	0.1
Xum	9	1	0.1	0.1
Total	**2 634**	**136**	**13.3**	**15.9**
Depositional regime				
Colluvial				
Cd	176	11	1.1	1.1
Cg	432	30	3.0	2.6
Cgp	1 044	81	8.0	6.3
Cgs	48	2	0.2	0.3
Cl	737	65	6.4	4.4
Cz	31	1	0.1	0.2
Subtotal	*2 468*	*190*	*18.8*	*14.9*
Sheetwash				
Wd	4 400	318	31.2	26.5
W_f	176	11	1.1	1.1
Wz	23	2	0.2	0.1
Subtotal	*4 599*	*331*	*32.5*	*27.7*
Alluvial				
A1d	2 382	98	9.6	14.4
A2d	227	15	1.5	1.4
A1k	119	2	0.2	0.7
A_f	90	4	0.4	0.5
Subtotal	*2 818*	*119*	*11.7*	*17.0*
Lacustrine				
L_l	63	–	–	0.4
L_m	991	57	5.6	6.0
Subtotal	*1 054*	*57*	*5.6*	*6.4*
Sandplain and eolian				
Sl1	412	26	2.6	2.5
Sl2	1 446	109	10.7	8.7
Subtotal	*1 858*	*135*	*13.3*	*11.2*
Total	**12 797**	**832**	**75.6**	**77.2**
TOTAL	**16 556**	**1 016**	**100.0**	**100.0**

Regolith-materials mapping

Landsat imagery, 1:250 000-scale geological mapping (Myers, 1997), Landsat synthetic stereopairs, and field observations recorded at each sample site have been used to produce a regolith-materials map for BYRO (Plate 3). Regolith-materials maps of BYRO, WINNING POOL – MINILYA (Sanders and McGuinness, 2001), AJANA (Sanders and McGuinness, 2000), STANLEY (Morris et al., 2000a), KINGSTON (Pye et al., 2000), and the Fraser Range region (Morris et al., 2000b) use a revised version of the GSWA regolith classification (Hocking et al., 2001). This revised scheme uses a series of primary, secondary, and tertiary codes and subscripts to designate a wide range of regolith types. The scheme is summarized in Appendix 3.

In the accompanying datafile BYRO.csv, each sample has been assigned a regolith code. Code descriptions are shown on Plate 3, and Table 3 summarizes regolith units according to area and number of samples. Figure 5 is a generalized regolith map, where regolith units shown on Plate 3 are grouped into higher level categories.

Major subdivisions of regolith on BYRO are:

- Areas of exposed-regime regolith and colluvium derived from granitoid rocks (*Xgp* and *Cgp)* separated by low-gradient sheetwash deposits (*Wd*) in the vicinity of the Weiragoo Range, Scrubby Range, and the southeastern corner of the map sheet corresponding to the Murchison Granite–Greenstone Terrane.
- Exposed-regime regolith derived from variably metamorphosed granitoid rocks (*Xgp*, *Xgm*), metasedimentary rocks (Xfc_i), and metamorphosed igneous rocks (*Xlm*, *Xum*), and related colluvial deposits (*Cgp*, *Cg*, *Cl*) surrounded by sheetwash (*Wd*) in the Jack Hills – Erawondoo Hill area in the northeast of BYRO (Narryer Terrane).
- Granitoid-dominated regolith (*Xgp*, *Xgm*) with residual iron-rich (*Rf*), siliceous (*Rz*), or sandy (R_sg) units, and related downslope deposits (*Cg*, *Cgp*, *Cl*, *Wd*) between the Meeberrie Fault and the Murchison River (Narryer Terrane).
- Lacustrine-dominated regolith (L_l, L_m) and mixed sandplain regolith (*Sl1*, *Sl2*) over the Lyons and Wooramel Groups, with scattered areas of exposed-regime regolith derived from sedimentary rocks (Xls_g, Xls_m) and related colluvial deposits (*Cgs*, *Cl*).
- Regolith derived from quartzofeldspathic sedimentary rocks (*Xgs*, *Cgs*) and residual iron-rich cappings (*Rf*) developed over the Badgeradda Group.
- Alluvial deposits in major drainages and tributaries (*A1d*) containing deposits of older more consolidated alluvium (*A2d*), and carbonate-rich alluvium (*A1k*).

Residual-regime regolith (*R*)

Residual-regime regolith on BYRO occupies approximately 7% by area and accounts for almost 5% of regolith samples. Residual-regime units are subdivided according to composition or parent rock type or both. They consist of both ferruginous and siliceous duricrust units, locally reworked material, and sand deposits. Areas of iron-rich duricrust (ferricrete; *Rf*) are most widespread in the Narryer Terrane. This regolith type is less common elsewhere on BYRO, apart from well-developed areas of ferruginous duricrust over parts of the Badgeradda Group in the southwest of the map sheet. Sand derived by weathering in situ of quartzofeldspathic rocks (R_sg) forms vegetated, plateau-like surfaces on or near Archaean granitoid rocks, and accounts for over 2% of all regolith and 16 samples. Similar to the disposition of ferricrete, silcrete (*Rz*) is largely found over Narryer Terrane lithologies, particularly over granitoid rocks (*Xgp*). It is also common over parts of the Lyons Group. Residual, silica-rich regolith developed over Phanerozoic sedimentary rocks has been designated *Rz*, and siliceous caprock over ultramafic rock has been assigned *Rzu*. The latter is confined to the Narryer Terrane. Both of these regolith types are of limited extent (10 km^2) and have not been sampled.

Exposed-regime regolith (*X*)

Bedrock, subcrop, or saprock (*X*) occupy about 16% of BYRO and account for 136 or about 13% of samples. Regolith derived from ferruginous chemical sedimentary rock (banded iron-formation or quartz–magnetite rock; Xfc_i) forms small areas totalling about 10 km^2 in the Jack Hills region north of Boundary Bore, and west of Butcher Well. Bedrock, saprock, and subcrop corresponding to either metamorphosed quartzofeldspathic rock (*Xgm*; 2% by area and 14 samples), or plutonic rock (*Xgp*; about 10% by area and 87 samples) is found throughout both the Murchison Granite–Greenstone and Narryer Terranes on BYRO. Quartz- and feldspar-rich regolith derived from sedimentary rocks (*Xgs*; about 2% by area and 14 samples) is found in the vicinity of the Badgeradda Group, the Lyons Group in the northwest of the map sheet, and immediately west of the Meeberrie Fault.

Exposed-regime regolith derived from heterogeneous metamorphic rock has been designated *Xlm*. It is found as short, arcuate belts northeast of Jailor Outcamp and north of Halleen Well, both within the Narryer Terrane. The unit accounts for about 0.3% of regolith by area and one sample. The Lyons Group is composed of heterogeneous sedimentary rocks typical of glacigene successions, and exposed-regime regolith derived from these rocks has been designated Xls_g (2% by area and 15 samples). Regolith derived from heterogeneous, fine-grained sedimentary rocks (Xls_m) corresponds to part of the Lyons Group (the Coyrie Formation of Myers, 1997) in the northwestern part of BYRO. This regolith type accounts for 0.3% of regolith and two samples.

Regolith corresponding to small areas of metamorphosed mafic rock (*Xmm*) is found as elongate bodies within Archaean granitoid, or associated with metasedimentary and ultramafic rock in the Jack Hills area in the northeast of BYRO. It accounts for 0.1% of regolith by area and one sample. Quartz-rich sedimentary rocks are found in the Lyons Group adjacent to the Meeberrie Fault, and form part of the Wooramel Group in the northwest of the map sheet. The small areas of this regolith type (0.1% by area) have been designated as *Xqs*. Small pods of ultramafic rock outcrop in the Weiragoo Hills area (Murchison Granite–Greenstone Terrane) and in the vicinity of Meegea Hill (Narryer Terrane), and elongate bodies are interleaved with metasedimentary rocks in the Jack Hills area. Regolith associated with these units has been designated *Xum* (0.1% by area).

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

Colluvial regolith is widespread on BYRO, accounting for about 15% of regolith and almost 19% of samples. It is particularly common between areas of outcrop and sheetwash in the southeast of the map sheet on the flanks of major drainages, and adjacent to lake areas in the western part of the map sheet. Areas of undivided colluvium (*Cd;* 1.1% of regolith) are found throughout the map sheet, usually isolated from any particular rock type. Quartz- and feldspar-rich colluvium (*Cg*; 2.6% by area) has been identified downslope from areas where metamorphosed quartzofeldspathic rocks (*Xgm*) and quartzofeldspathic plutonic rocks (*Xgp*) are found together, such as west of the Murchison River between Impey Well and Billabiddy Well (Plate 3). Small areas of this regolith type are also found over parts of the Badgeradda Group in the southwest of BYRO. There is a strong spatial relationship between some areas of quartzofeldspathic colluvium derived from plutonic rocks (*Cgp*) and outcrop or subcrop of granitoid rocks (*Xgp*), such as over both the Murchison Granite–Greenstone and Narryer Terranes. In these areas, colluvium forms aprons between areas of outcrop and in turn gives way downslope to areas of sheetwash (*Wd*).

Small areas of colluvium derived from quartzofeldspathic sedimentary rocks (*Cgs*) are found over parts of the Badgeradda Group, downslope from outcropping quartzofeldspathic sedimentary rocks (*Xgs*). This type of colluvium is of limited extent on BYRO (0.3% by area), and is represented by only two samples.

Apart from colluvium derived from quartzofeldspathic plutonic rocks (*Cgp*), colluvium derived from mixed rock types (*Cl*) is the most common type of colluvium developed on BYRO, accounting for over 4% of regolith by area and 65 samples. It is found mainly in two areas — over the Narryer Terrane (particularly in the vicinity of Erawondoo Hill) and over the Lyons Group. In the Erawondoo Hill area, the intimate interleaving of Archaean metasedimentary and igneous rocks means that it is not possible to assign individual colluvial units to a parent rock using a tertiary qualifier, and this type of colluvium has been designated *Cl*. Elsewhere in the Narryer Terrane, colluvium is found downslope from areas of granitoid rock (*Xgp* and *Xgm*) that is capped by areas of ferricrete (*Rf*) and siliceous duricrust (*Rz*), such as in the vicinity of Thoolmugga Well in the central-northern part of BYRO. Colluvium downslope from these areas is clearly of mixed parentage, and is designated *Cl* accordingly. Glacigene rocks of the Lyons Group consist of sandstone, shale, siltstone, and tillite, hence colluvium derived from this unit is of a heterogeneous nature, and has also been designated *Cl*.

Colluvium containing abundant silica-rich material (*Cz*) is of limited extent (0.2% by area and one sample). It is found adjacent to residual sand over granitoid rocks (R_sg), such as northwest of Deep Well in the Narryer Terrane, and on the margin of a sandplain unit west of Condalye Well, over the Lyons Group. In most occurrences, this regolith type is found below low-profile breakaways, as a pale-blue unit on Landsat 741 images.

Low-gradient slope deposits comprising sand- and clay-dominated colluvium and sheetwash (*W*) are usually found downslope from colluvial deposits, and commonly grade into alluvial regolith. This is the most common regolith type on BYRO, accounting for over 32% of regolith and 331 samples. Low-gradient slope deposits are dominated by undivided material (*Wd*), which occupies over 31% of BYRO and accounts for 318 samples. They are found flanking major drainages in the eastern three-quarters of the map sheet, and are therefore largely found over the Archaean Murchison Granite–Greenstone and Narryer Terranes. Contiguous areas of this regolith type are also found over the Byro Group, and over parts of the Badgeradda Group in the southwest of the map sheet. Where low-gradient slope deposits contain high concentrations of stream channels and form fan-shaped areas, they have been classified as sheet-flow and fan deposits (W_f). This regolith type is found in the southeast of BYRO, the Jack Hills area, and west of Dallah Well, where sheetwash fans debouche into drainage channels. It accounts for about 1% of regolith and eleven samples.

Silica-rich sheetwash (*Wz*) is uncommon on BYRO, occupying only 0.1% by area and accounting for only two samples. It is a distinctive unit on Landsat 741 images, forming pale-blue areas downslope from breakaways, such as east of Doondie Well.

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

Alluvium in active drainage channels (*A1d*) is common in the Murchison River and its tributaries, and in the Yarra Yarra Creek system in the western part of the map sheet. Although it comprises over 14% of regolith on the map sheet, it only accounts for about 10% of samples because major drainages such as the Murchison River were avoided during the sampling program, as they are not representative of the surrounding geology. Within areas of active alluvium (*A1d*) are scattered areas of vegetated alluvium that are locally incised and therefore probably more consolidated. They have been identified as an older alluvial phase (*A2d*). Within drainage systems and adjacent to lake deposits are areas of carbonate-rich alluvium ('valley calcrete'; *A1k*), which appear as pale-pink to purple areas on Landsat 741 imagery, occasionally with weakly developed vegetation. They occupy about 1% of all regolith and account for two samples.

Floodplain deposits (A_f) are usually transitional between areas of sheetwash (*Wd*) and well-defined alluvial channel deposits (*A1d*), such as west of Shed North Well. These floodplain deposits are usually not confined to channels, and support a sparse vegetation cover. They account for less than 1% of all regolith and four samples. Over Phanerozoic rocks, alluvial floodplain deposits are found adjacent to, and in some places transitional with, marginal lake deposits (L_m), such as in the northwest of the map sheet.

Lacustrine regolith (*L*) comprises clay, silt, sand, gravel, and evaporitic material found either in or adjacent to drainage depressions. Regolith in lake systems (L_l), which is most common in the western part of the map sheet, consists of saline clay and silt. Regolith adjacent to lakes, as mixed dune and playa terrain (L_m), is the most common type of lacustrine regolith on BYRO, accounting for 6% of regolith and 57 samples. It is well developed over the Lyons Group and over parts of the Badgeradda Group. Over the Lyons Group, this regolith type often contains small, active drainage channels and pockets of colluvium, but it is not possible to separate these as individual regolith units at the scale of mapping. The unit is characterized by halophytic vegetation and local development of gypsum and halite crystals at the surface.

Sandplain regolith (*S*)

Eolian and residual sand on BYRO is largely confined to areas of Phanerozoic and Proterozoic rocks to the west of the map sheet, but it is also found over parts of the Narryer Terrane in the vicinity of Mount Narryer and Meeberrie homesteads. Morris et al. (2000b) recognized an extensive area of sandplain of diverse origin in the Fraser Range region, and classified this as *Sl*, to indicate derivation from nearby protoliths, with some eolian and sheetwash input. On BYRO, a similar regolith type has been subdivided on the basis of age. The younger unit (*Sl1*; almost 3% by area and 26 samples) comprises broad expanses of weakly vegetated sandplain with local dune development. Dunes show a weak southwesterly–northeasterly orientation near Spinifex Well, but a more northerly orientation further south near Dink Bore. This type of sandplain is weakly incised on the margins, where it usually gives way to lacustrine regolith (L_m or L_l). Other areas of sandplain are morphologically similar, but are more heavily vegetated and less incised, and as they probably represent an older generation of sandplain, they have been designated *Sl2*. This unit accounts for almost 9% of regolith on the map sheet and 109 samples. Regolith units *Sl1* and *Sl2* are different to flat-lying units of sand-dominated regolith largely found over Archaean lithologies (R_sg), which most commonly overlie granitoid rocks and are more heavily vegetated, and lack dune morphology. However, in the Mount Narryer and Meeberrie Homestead areas, sandplain showing both eolian and residual characteristics (i.e. *Sl1* and *Sl2*) is developed on or near Archaean rocks, and it is possible that this material has been transported eastwards from areas of Phanerozoic rocks. Small areas of residual sandy regolith (R_sg) have been mapped over parts of the Badgeradda Group near the Meeberrie Fault.

Discussion

Regolith-materials mapping of BYRO has highlighted several features of the nature of regolith and its relationship to bedrock that are of use in interpreting regolith chemistry:

- A close relationship between exposed-regime regolith derived from granitoid rocks (*Xgp* and *Xgm*) and weathered and transported products of this regolith (*Cg* and *Cgp*, and eventually *Wd*) is apparent in the Murchison Granite–Greenstone Terrane. Similar downslope relationships can be observed in the Narryer Terrane, but the more diverse lithologies in this terrane mean that some downslope regolith is derived from a variety of protoliths, and is accordingly classified (*Cl*).
- Residual units (*Rf*, *Rz*, R_sg, *Rzu*) are more compositionally diverse over rocks of the Narryer Terrane than over the Murchison Granite–Greenstone Terrane, reflecting the higher degree of lithological diversity in the Narryer Terrane.
- Sand-dominated regolith on BYRO can be broadly divided on the basis of lithological association — residual sand developed over Archaean granitoid rocks (R_sg; mainly over the Narryer Terrane) is well vegetated and lacks dune forms, whereas sandplain over post-Archaean rocks in the west of BYRO (*Sl1* and *Sl2*) is less well-vegetated, locally incised (*Sl2*), and usually supports dunes. In the Mount Narryer and Meeberrie Homestead areas, this sand-dominated material appears to have been transported eastwards over Archaean rocks.

Chemical analysis

Quality control

One thousand and sixteen regolith samples were analysed in four separate batches by Amdel Laboratories, Perth. The samples comprise 240 stream-sediment samples, 528 sheetwash samples, 16 lake-sediment samples, 228 sandplain samples, and 4 soil samples. In addition, multiple analyses of three in-house GSWA standards were carried out in each batch, along with analyses of duplicates and laboratory standards. Laboratory procedures and the quality-control approach are summarized in Appendix 3. Criteria used by GSWA to assess precision and accuracy include:

- Measurement of analytical blanks where acceptable levels are less than three times the detection level for the analyte in question.
- Multiple analysis of reference materials (standards) and calculation of the percent relative standard deviation or RSD% (i.e. 100 × (standard deviation/average)). Acceptable levels for RSD% are less than 20.
- Comparison of averaged or individual analyses of reference materials with consensus or suggested values (e.g. Potts et al., 1992; Morris, 2000). Analyses should agree within 20% of literature values.
- Comparison of duplicate analyses using the half relative deviation, or HRD (i.e. (assay 1 – assay 2)/(assay 1 + assay 2) × 100; Shaw et al., 1998). Acceptable HRD values are less than 10.

In the following section, the quality of analytical data is discussed according to technique. Blank analyses and analyses of various standards and duplicates are presented digitally in Appendix 4, and a guide to this file (guide.csv) is presented on the CD.

For the major element oxides, all blank analyses (14 in each batch) were acceptably low (Amdel technique IC4). One hundred and four samples were analysed in duplicate, providing acceptable agreement between the primary sample and the duplicate for all major element oxides at concentrations more than ten times the detection level in terms of HRD. The three laboratory standards (OREAS 42_P, OREAS 43_P, and OREAS 44_P) were each analysed eight times in each of the four batches. For each batch, both precision (in terms of RSD%) and accuracy (in terms of HRD) were acceptable. Analyses of three GSWA standards (laterite GRMWA47, gossan GRMWA45, and amphibolite GRMWA42; labelled GSWA1, GSWA2, and GSWA3 in Appendix 4) were also used to assess precision and accuracy, which were acceptable in all cases.

Beryllium, Cr, Li, Ni, S, Sc, V, Zn, and Ba were analysed by inductively coupled plasma optical emission spectrometry (ICP-OES; Amdel code IC3E). All 56 blank analyses were acceptably low, and analyses of primary samples and duplicates agreed well as measured by HRD. Apart from an RSD% value of 21 for Sc in batch 2 for OREAS 42_P, accuracy and precision were acceptable for all laboratory standards. Zinc in GSWA laterite standard GRMWA47 produced low average values (batch 1: 16 ppm (n = 4); batch 2: 8 ppm (n = 4); batch 3: 14 ppm (n = 4); batch 4: 19 ppm (n = 3)) compared to a suggested value of 25 ppm (Morris, 2000), although 16 determinations of this standard carried by Amdel (reported in Morris, 2000) produced a mean and standard deviation of 28 ± 13 ppm Zn. Percent RSD values of 34 (batch 1), 49 (batch 2), and 33 (batch 4) for Zn in this standard also indicate poor precision. GSWA gossan standard GRMWA45 produced an RSD% of 23 (n=4) in batch 1. Combining all these data for Zn in GSWA47, both precision (RSD% = 44) and accuracy (average 14 ppm compared to a suggested value of 25 ppm) are low. In amphibolite GRMWA42, low precision for Cr analysis is shown by an RSD% of 33 (n = 15), with a suggested Cr concentration value of 1755 ppm (Morris, 2000).

Twenty-three trace elements were determined by inductively coupled plasma mass spectrometry (ICP-MS; Amdel code IC3M). Blank analyses for all batches were acceptably low and, apart from Nb, primary samples and duplicates were well in agreement in terms of HRD values. Poor duplication in Nb was found in four samples, although all levels are close to ten times detection level. Primary and duplicate analyses for Nb include 8 and 1.8 ppm in GSWA 173302, 4.9 and 1.8 ppm in GSWA 173303, 2.6 and 6.7 ppm in GSWA 173939, and 4.5 and 8.2 ppm in GSWA 174054. Analyses of laboratory standards produced acceptable results in terms of both precision and accuracy. Average Pb concentrations in gossan GRMWA45 were low in three of the four batches, compared to the consensus value (468 ppm), and were 375 ppm in batch 1, 368 ppm in batch 2, and 363 ppm in batch 4. Analyses of this standard by Amdel (reported in Morris, 2000) include a mean and standard deviation of 492 ± 73 ppm Pb (n = 16). Precision was acceptable in all cases, apart from batch 1 (RSD% = 34). Average Sb concentrations were low in amphibolite GRMWA42 for batches 1 (58 ppm; n = 3) and 3 (78 ppm; n = 3) compared to the suggested value of 138 ppm, although Amdel data cited in Morris (2000) provided a mean and standard deviation of 103 ± 26 ppm (n = 11). The RSD% for Cu in laterite GRMWA47 was 23, and the average W concentration in amphibolite GRMWA42 was 1197 ppm compared to a suggested value of 1481 ppm. Amdel data (Morris, 2000) for W in this standard include a mean and standard deviation of 1284 ± 351 ppm (n = 11).

Tantalum and Zr were measured by inductively coupled plasma mass spectrometry (Amdel code IC4M). Analyses of blanks, duplicates, and laboratory standards all satisfied quality-control criteria. Analyses of GSWA standards were acceptable, apart from Zr in GRMWA45 for batch 1 (n = 4), which averaged 35 ppm compared to a suggested value of 29 ppm (Morris, 2000). The RSD% was 29.

Fire assay analysis for both blanks, duplicates, and laboratory standards was acceptable, apart from RSD% values of 37 and 21 for Pt and Pd in laboratory standard PM8 in batch 4 (caused by one low analysis of Pt and Pd). Gold values for GSWA reference materials range from 147 ppb (consensus gold value in GRMWA42) through to proposed values of 9 ppb in GRMWA47 and 35 ppb in GRMWA45 (Morris, 2000). In most cases, poorer accuracy and precision was achieved for GRMWA47, but improved with increasing concentration (i.e. to GRMWA42). In GSWA reference materials, both Pd and Pt levels are all less than 10 ppb (Morris, 2000), with correspondingly low precision and accuracy (e.g. RSD% usually greater than 40).

Nine pulped samples were submitted to Genalysis Laboratory Services for analysis, and these data were compared to analyses carried out by Amdel. For analytes greater than 10 times the detection level, HRD was less than 10, with a few exceptions. Amdel reported lower Ce concentrations for two samples, including GSWA 173598 (Amdel 1160 ppm; Genalysis 1476 ppm). The HRD was greater than 10 for Cr in five duplicates, with four of the five values reported by Amdel being lower than those reported by Genalysis. Poor agreement was also noted for analysis of Nb in four samples, although there is no consistency in one lab reporting higher or lower values. Amdel reported 133 ppm Nb in GSWA 173259 (the maximum value on BYRO), whereas Genalysis reported 69 ppm. Amdel reported higher Sr and U concentrations than Genalysis for two samples, and the HRD was greater than 10 for V in two samples and Y in one sample. Amdel reported lower levels of Zr than Genalysis for two samples, including GSWA 173598 (Amdel 221 ppm; Genalysis 648 ppm).

The majority of analytes that show poor duplication between Amdel and Genalysis are those that are commonly found in minerals that are resistant to dissolution, such as Ce (allanite, monazite), Cr (chromite), Nb (rutile), V (iron–titanium oxides), and Zr (zircon).

Discussion

In general, precision and accuracy fall within acceptable limits, with reduction in data quality at concentrations approaching the detection level. Data are usually acceptable for analysis of laboratory standards, with most identified discrepancies being confined to the analysis of GSWA in-house standards. However, using these standards to assess accuracy is difficult, as there are few consensus values. This is exemplified in the case of low average values for Zn in GRMWA47 (laterite) ranging from 8 to 19 ppm, where the suggested value of 25 ppm has a standard deviation of 11 ppm (n = 51), and the data for Amdel analyses alone are 28 ± 13 ppm (n = 16). A similar situation exists for Pb in GRMWA45 (gossan), where analyses range from 363 ppm in batch 4 to 375 ppm in batch 1, compared to a consensus value of 468 ppm (standard deviation of 58 ppm) in Morris (2000).

Comparison of data derived from different laboratories indicates some variation between laboratories, particularly for analytes usually found in resistate phases such as Nb, Zr, Ce, and Cr. In many cases, Amdel provides lower assay results for analytes than Genalysis, although in some cases there is no consistent pattern between the two laboratories. The effects of incomplete sample dissolution has been discussed by Morris et al. (1998) in relation to the analysis of Nb in regolith from MOUNT EGERTON and TUREE CREEK. Although ICP-OES and ICP-MS provide rapid analysis of a variety of analytes at low cost, the technique has the major drawback of requiring the sample to be completely dissolved prior to analysis.

Assessing the quality of precious metal (Au, Pd, Pt, and Ag) data is difficult in that none of the laboratory or GSWA standards analysed have precious metal abundances of the same order as those in regolith from BYRO. The problem is compounded by the lower precision and accuracy of analysis at levels approaching detection. Available data suggest that reproducibility of precious metal concentrations of less than 5 ppb is poor.

Element-distribution maps

The concentration of various analytes is shown as a series of spot-concentration maps in relation to simplified geology (Figs 6–51), with analytes ordered in terms of major element oxides (including LOI) and then trace elements in alphabetical order. Silica and Cd have not been plotted, as the former shows a relatively uniform distribution over BYRO, and all analysed regolith samples have less than detection level (1 ppm) Cd. On spot-concentration maps, the diameter of the circle is proportional to the analyte concentration. Star symbols indicate concentrations greater than 2.5 standard deviations above the mean, which has been taken throughout the GSWA program as being at anomalous levels. The exact analyte concentration can be determined by identifying the GSWA number from the sample-site location plan (Plate 1), and then referring to the digital datafile (BYRO.CSV). Spot-concentration maps at 1:250 000 scale are available from DME's Information Centre.

Regolith chemistry

The chemistry of regolith results from the combined effects of bedrock composition, and physical and chemical weathering, along with input from external sources such as aeolian processes (e.g. Hawkes and Webb, 1962). Examples of these effects are discussed below. The terms high, moderate, and low are used relative to analyte concentrations throughout BYRO. Samples with anomalous concentrations of one or more analyte are listed in Table 4, along with locational information, sample medium, geological unit, regolith code, and a list of anomalous analytes. In the following discussion, regolith chemistry is discussed in relation to simplified geology (Plate 1), with comments where necessary about controls exerted by regolith-forming processes. Emphasis is placed on samples or groups of samples with anomalous concentrations of one or more analytes, especially where element associations can be related to either bedrock composition or regolith-forming processes, or both.

Murchison Granite–Greenstone Terrane

The Murchison Granite–Greenstone Terrane is largely composed of variably metamorphosed granitoids (Plate 1 and Table 1), and as most samples have been collected from areas of exposed-regime regolith (*Xgp*), associated colluvium (*Cgp*), and intervening areas of sheetwash (*Wd*), it is likely that many regolith samples have retained a bedrock signature. This is consistent with the usually low and even distribution of the major element oxides (TiO_2, Al_2O_3, MgO, MnO, K_2O, P_2O_5, and LOI) and many trace elements throughout this area, although there are some exceptions. Calcium, Na_2O, and Sr concentrations are higher in regolith over the central part of the Weiragoo Granite than on the margin, and this may indicate some chemical zonation of the granite, as reported for Archaean granitoid on the southeastern margin of the Yilgarn Craton by Morris et al. (2000b). Several samples of regolith from areas of colluvium and sheetwash have anomalous concentrations of La, Ce, Th, or W, which may have resulted from the protracted weathering of granitoid, and mechanical sorting during transportation causing the concentration of such resistate phases as allanite and monazite (Codner and Kaplan, 1982). More speculatively, higher W values may indicate some W mineralization of granitoids.

Narryer Terrane

The Narryer Terrane is dominated by granitoid rocks, but it also contains metasedimentary and metamorphosed igneous rocks throughout the terrane (Plate 1), such as in the northeast of BYRO in the vicinity of Erawondoo Hill. In regolith over the Meeberrie Gneiss, four stream-sediment samples, and two samples of sheetwash have anomalous concentrations of one or more analytes (Table 4). GSWA 173605, from exposed-regime regolith (*Xgm*) has anomalous concentrations of TiO_2, Nb, and Zr, consistent with high levels of resistate phases such as rutile and zircon. At the sample site, clasts of granitoid, pegmatite, and vein quartz have been recorded. Sample GSWA 173260, which is located close to exposed-regime regolith derived from ultramafic rocks (*Xum*), has anomalous concentrations of MgO, CaO, and Ni. Sample GSWA 173187, which is located in exposed-regime regolith derived from metamorphosed mafic rock (*Xmm*), contains anomalous Au (3 ppb).

Four samples of regolith collected over the Dugel Gneiss have anomalous concentrations of several analytes. GSWA 173580, a stream sediment collected from regolith downslope from granitoid rocks (*Cgp*), has anomalous concentrations of CaO, Pd (4 ppb), and Sr. Sample GSWA 173873 is from a stream draining exposed-

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

GSWA no.	MGA coordinates Easting	Northing	Batch	Regolith code	Geological unit	Sample medium	Analytes with anomalous concentrations
172902	358283	7063372	1	*Sl2*	Badgeradda Group	Sandplain	CaO
172910	351096	7115258	1	*Sl1*	Wooramel Group	Sandplain	SiO_2
172914	383619	7112672	1	*Sl2*	Lyons Group	Sandplain	SiO_2
172930	407233	7121909	1	*A1d*	Badgeradda Group	Stream	MgO
172938	414242	7086372	1	*Xgp*	Yarra Yarra Granite	Stream	Sn
172940	370392	7058134	1	*Cl*	Lyons Group	Sheetwash	Pb
172946	351479	7033550	1	*Rf*	Badgeradda Group	Sheetwash	Li, Sb
172948	354722	7015089	1	*Rf*	Badgeradda Group	Sheetwash	Fe_2O_3 ,As, Cu, Sb, Ga
172949	362197	7015207	1	*Rf*	Badgeradda Group	Lake	LOI, Be, S, Sb, Sn, Sr, TDS
172952	386521	7014732	1	*Xgp*	Yallalong Granite	Sheetwash	TDS
172974	434182	7114673	1	*Wd*	Ag	Sandplain	MnO
172988	422871	7058595	1	*Cg*	Milga Gneiss	Stream	K_2O, Pb, Rb
172998	442254	7110335	1	*Rz*	Ag	Sheetwash	Pb
173003	446560	7097813	1	*A1d*	Ag	Stream	Ta
173024	482209	7041936	1	*Cgp*	Tching Granite	Sheetwash	K_2O
173025	478551	7038127	1	*Wd*	Tching Granite	Sheetwash	K_2O
173045	486319	7062554	1	*Cgp*	Bearra Gneiss	Sheetwash	W
173050	494586	7097148	1	*Cgp*	Ag	Soil	Ce, La, Th, W
173061	494271	7091061	1	*A1d*	Weiragoo Granite	Sheetwash	MgO
173101	366168	7065446	1	*Rzs*	Lyons Group	Sheetwash	Ba
173102	358221	7066484	1	*Sl2*	Lyons Group	Sandplain	SiO_2
173106	358276	7094583	1	L_m	Lyons Group	Sandplain	SiO_2
173112	365444	7118097	1	L_m	Wooramel Group	Stream	SiO_2, P_2O_5
173119	378025	7066511	1	L_m	Lyons Group	Sheetwash	Al_2O_3, LOI
173126	374004	7103180	1	L_m	Lyons Group	Lake	S, TDS
173143	353448	7028944	1	*Xgs*	Badgeradda Group	Sheetwash	Li
173144	358407	7025668	1	*Xgs*	Badgeradda Group	Sheetwash	Ba
173145	357966	7021520	1	*Xgs*	Badgeradda Group	Stream	Be, Zn
173146	362409	7018136	1	*Cl*	Badgeradda Group	Stream	As, Bi, Cu, Te, Ga
173147	371825	7018704	1	*Wd*	Badgeradda Group	Stream	TiO_2, Fe_2O_3, Cu, V
173152	362130	7026822	1	*Xgs*	Badgeradda Group	Sheetwash	Al_2O_3, LOI, Li, W, Zn
173153	362224	7034426	1	*Sl2*	Lyons Group	Sandplain	SiO_2
173177	412500	7037769	1	*Xgm*	Milga Gneiss	Stream	K_2O, Rb
173187	439817	7065302	1	*Cg*	Meeberrie Gneiss	Stream	Au
173188	434830	7074213	1	*Wd*	Ag	Sheetwash	Bi
173192	440943	7102538	1	*Xgp*	Ag	Sheetwash	Ba
173193	446549	7109349	1	*Xgp*	Ag	Sheetwash	Na_2O
173205	429672	7046918	2	*Wd*	Ag	Sandplain	W
173211	442322	7018512	2	*Wd*	Impey Granite	Sheetwash	Co
173227	477426	7054696	2	*Cgp*	Weiragoo Granite	Sheetwash	Pb
173234	477658	7074928	2	*Xgp*	Weiragoo Granite	Stream	Na_2O, Au, Sr
173248	466408	7042727	2	*Wd*	Weiragoo Granite	Sheetwash	Cr
173249	454625	7045528	2	*Rz*	Meeberrie Gneiss	Stream	Se
173259	490696	7103133	2	*Xmm*	Un.	Sheetwash	Nb, Rb, Sn, Ta
173260	497443	7102964	2	*Xgm*	Meeberrie Gneiss	Stream	MgO, CaO, Ni
173261	498592	7111187	2	*Cl*	Meeberrie Gneiss	Stream	Sr
173267	458216	7114706	2	*Wd*	Ag	Sheetwash	Co
173304	367587	7071462	2	*Rzs*	Lyons Group	Sheetwash	MgO, LOI, Zn
173347	401541	7068810	2	*Sl1*	Churla Granite	Stream	Zr
173348	390666	7050165	2	*Wd*	Churla Granite	Sheetwash	Cr, Se,
173350	386912	7037723	2	*Sl2*	Wandarrie Granite	Sandplain	Cu
173351	381692	7038101	2	*Sl2*	Badgeradda Group	Sandplain	Cu, Sn
173362	402285	7041971	2	*Sl2*	Eurada Gneiss	Sheetwash	Se
173365	406191	7018087	2	*A1d*	Balla Granite	Sandplain	LOI, Co, U, TDS
173372	410548	7066494	2	A_f	Churla Granite	Stream	Cr, Te
173374	417450	7073704	2	*Rf*	Churla Granite	Sheetwash	Nb, W
173381	421062	7123608	2	*Rf*	Yarra Yarra Granite	Sheetwash	TiO_2, Cu, Pd, Pt
173383	438937	7122733	2	*Cgp*	Ag	Stream	Cr, Ni, Pt, Sc, V
173388	430310	7084703	2	*Cgp*	Ag	Stream	Na_2O
173389	394198	7053747	2	L_m	Churla Granite	Sandplain	S
173398	426443	7018582	2	*Wd*	Impey Granite	Sheetwash	Te
173399	432668	7015030	2	*Xgp*	Impey Granite	Sheetwash	Rb
173415	465489	7014306	2	*Wd*	Cundarra Granite	Sheetwash	Te, W
173418	498064	7015063	2	*Wd*	Tching Granite	Sheetwash	Te
173424	468629	7029697	2	*A1d*	Tching Granite	Sheetwash	CaO
173429	498253	7046241	2	*Wd*	Tching Granite	Sandplain	Au
173436	462884	7098383	2	*A2d*	Ag	Lake	Ag

Table 4. (continued)

GSWA no.	MGA coordinates Easting	Northing	Batch	Regolith code	Geological unit	Sample medium	Analytes with anomalous concentrations
173442	493265	7111011	2	*Cl*	Dugel Gneiss	Sheetwash	W
173453	458181	7086191	2	*A1d*	Ag	Sheetwash	TDS
173463	473949	7086473	2	*Wd*	Weiragoo Granite	Stream	K_2O, Rb
173526	390150	7094396	3	*Wd*	Byro Group	Sandplain	Ba
173535	409454	7086785	3	R_sg	Yarra Yarra Granite	Sheetwash	Cu, Mo, Se, Ga
173546	353679	7035401	3	*Rf*	Badgeradda Group	Sheetwash	Al_2O_3, LOI, Li
173547	351154	7027563	3	L_m	Badgeradda Group	Sheetwash	MnO, Li
173548	353952	7018465	3	*Xgs*	Badgeradda Group	Stream	Fe_2O_3, As, Bi, Cu, Sb, Sc, V, Ga
173549	358325	7014974	3	*Rf*	Badgeradda Group	Stream	Fe_2O_3, As, Cu, Sb, Sc, Ga
173550	366048	7014874	3	*Wd*	Badgeradda Group	Sheetwash	TiO_2, MnO, Co, Sc, V, Zn, Zr
173551	373548	7015478	3	*A1d*	Badgeradda Group	Stream	TiO_2, V
173569	421900	7106589	3	*Rf*	Yarra Yarra Granite	Sheetwash	Se
173574	438277	7114539	3	*Cl*	Ag	Stream	Cr, Ni
173580	426382	7074597	3	*Cgp*	Dugel Gneiss	Stream	CaO, Pd, Sr
173596	433988	7102707	3	*Wd*	Yarra Yarra Granite	Sheetwash	MnO, TDS
173597	438008	7106567	3	*Cl*	Ag	Stream	P_2O_5, Ce, La, Th, W
173598	445040	7113523	3	*Xgp*	Ag	Stream	P_2O_5, Ce, La, Pb, Th, U, W
173600	451635	7117341	3	*Cgp*	Ag	Stream	Th
173602	450559	7106359	3	*Wd*	Ag	Sheetwash	Pd
173605	442830	7078391	3	*Xgm*	Meeberrie Gneiss	Stream	TiO_2, Nb, Zr
173611	487690	7019687	3	*Wd*	Tching Granite	Sheetwash	Au
173639	477040	7078255	3	*Cgp*	Weiragoo Granite	Stream	P_2O_5, Ce, La, Th, W
173713	370396	7118356	3	*Sl1*	Lyons Group	Sandplain	Cr
173724	369834	7077944	3	L_m	Lyons Group	Sheetwash	Ba
173745	354219	7026357	3	*Xgs*	Badgeradda Group	Stream	As
173747	358519	7017617	3	*Cl*	Badgeradda Group	Sheetwash	Fe_2O_3, As, Bi, Sb, Sc
173748	366696	7018394	3	*Wd*	Badgeradda Group	Sheetwash	S, Sr,
173749	375031	7016817	3	*Rf*	Badgeradda Group	Sheetwash	TiO_2, Fe_2O_3, Cu, Sc, V
173759	381955	7049960	3	L_m	Lyons Group	Sheetwash	Al_2O_3, Li
173760	378538	7042344	3	Xls_g	Lyons Group	Sheetwash	Zr
173765	387249	7026089	3	*Cgs*	Badgeradda Group	Stream	Cu
173776	410565	7018777	3	*A1d*	Balla Granite	Stream	MgO
173803	446050	7064686	4	*Wd*	Impey Granite	Sheetwash	MgO
173812	429200	7021520	4	*A1d*	Impey Granite	Stream	Nb
173813	433542	7022763	4	*A1d*	Impey Granite	Stream	Ag
173820	428478	7026616	4	*A1d*	Impey Granite	Stream	Ag, Nb
173830	472860	7054836	4	*Xgp*	Weiragoo Granite	Stream	Ag
173834	494048	7066475	4	*Wd*	Tching Granite	Stream	Ag
173841	469792	7065824	4	*Xgp*	Weiragoo Granite	Sheetwash	Na_2O, Sr
173844	489125	7067894	4	*Cgp*	Bearra Granite	Stream	Bi
173850	461769	7049790	4	*Wd*	Weiragoo Granite	Sheetwash	MnO
173853	453232	7049409	4	*Xgm*	Meeberrie Gneiss	Sheetwash	CaO, Na_2O
173864	498107	7107157	4	*Xgp*	Ag	Stream	Co, Ni
173873	449839	7093071	4	*A1d*	Dugel Gneiss	Stream	P_2O_5, Ce, La, Th, U, W, Zr
173876	450132	7074436	4	*A1d*	Ag	Sheetwash	U
173905	370969	7073079	4	*Cl*	Lyons Group	Sheetwash	Zn
173938	409854	7109938	4	R_sg	Yarra Yarra Granite	Sheetwash	Al_2O_3
173952	381035	7041074	4	*Cl*	Lyons Group	Sheetwash	Mo
173979	418352	7101945	4	*Cgp*	Ag	Stream	Pb
173984	441445	7118840	4	*Cgp*	Ag	Stream	Ce, La, U, W
173991	398327	7050153	4	*Rz*	Yallalong Granite	Stream	Zr
173993	417244	7049114	4	*Cg*	Milga Gneiss	Sheetwash	Rb
173994	417643	7042750	4	*Wd*	Balla Granite	Sheetwash	P_2O_5
173999	429354	7017813	4	*Wd*	Impey Granite	Stream	Nb
174032	484950	7045635	4	*A1d*	Tching Granite	Sheetwash	CaO
174051	489585	7110500	4	*Cl*	Dugel Gneiss	Sandplain	Ba
174064	453622	7082610	4	*A1d*	Ag	Sheetwash	Ni
174065	454173	7078307	4	*A1d*	Ag	Sheetwash	MnO, Ni, U, Zn

NOTES: Ag: Undivided Narryer Terrane granitoid
Un.: Undivided Narryer Terrane metasedimentary rocks

regime regolith (*Xgp* and *Xgm*). The sample contains anomalous concentrations of P_2O_5, Ce, La, Th, U, W, and Zr, consistent with a concentration of resistate phases such as monazite, allanite, apatite, and zircon derived from granitoid through weathering, and concentrated through mechanical sorting.

Of the three regolith samples from over the Milga Gneiss with anomalous analyte concentrations, two have anomalous levels of K_2O and Rb, and the third has anomalous Rb. The regolith units from which these samples are sourced have a strong quartzofeldspathic signature (*Cg* and *Xgm*), and the high K_2O and Rb contents are consistent with a strong bedrock imprint. Undivided metasedimentary rocks (unit As on Plate 1) form thin, areally restricted units on BYRO, accounting for only 1% by area. Only one regolith sample taken from over these units has anomalous analyte concentrations (GSWA 173259; Jack Hills greenstone belt, near Erawondoo Hill). This regolith sample, which has the highest concentrations of Nb (133 ppm), Rb (309 ppm), Sn (9 ppm), and Ta (15 ppm) recorded from regolith on BYRO, is derived from mafic metamorphosed rocks (*Xmm*) along strike from areas of regolith derived from metamorphosed ultramafic rocks (*Xum*). Site observations include the presence of laminated quartz–magnetite metasedimentary clasts, granitoid, and schistose chlorite-rich lithologies.

Sixteen percent of BYRO is occupied by undivided granitoid rocks of the Narryer Terrane (Ag on Plate 1), with a correspondingly high number of samples (24) with anomalous concentrations of analytes in regolith. Of these, eight samples have anomalous concentrations of two or more analytes, and amongst these samples two broad element associations can be recognized. Phosphorus, Ce, La, Th, U, and W are at anomalously high levels in some or all of four samples (GSWA 173597, 173598, 173050, and 173984). Three of the four samples are from colluvium (*Cgp* and *Cl*), whereas the fourth is from an area of exposed-regime regolith over granitoid rock (*Xgp*). This analyte assemblage is similar to that recorded from regolith over other granitoid bodies in the Murchison Granite–Greenstone and Narryer Terranes, and is indicative of protracted weathering of a granitoid protolith leading to concentration of resistate phases. The second association comprises a group of regolith samples with anomalous concentrations of several metals — GSWA 173574 (Cr, Ni), 173383 (Cr, Ni, Pt, Sc, V), 173864 (Co, Ni), 173602 (Pd), and 173436 (Ag). Most of the samples are of transported regolith (dominantly colluvium), and all except GSWA 173436 are found close to areas of exposed-regime regolith derived from ultramafic rock (*Xum*).

Of the eight regolith samples with anomalous element concentrations from over the Impey Granite, seven have anomalous concentrations of only one element. Three of these samples have anomalous concentrations of either Nb or Ag, and one sample (GSWA 173820) has anomalous levels of both Ag and Nb. Three of these four samples are stream sediments collected from channels draining areas of exposed-regime regolith over granitoid rocks (*Xgp*), whereas the fourth sample (GSWA 173999) is in sheetwash (*Wd*) downslope from the same granitoid body. A common feature of all four sample sites is the development of hardpan, either as a surface on or near to granitoids, or as clasts.

Of the three samples with anomalous analyte concentrations in regolith from over the Balla Granite, one of them (a sandplain sample, GSWA 173365) is found in alluvium (*A1d*) of the Murchison River. The anomalous LOI and U, and a high TDS value for this sample is typical of regolith found in drainage areas, which often has high carbonate concentrations and high salinity, hence the high LOI, U, and TDS values. The sample also has anomalous concentrations of Co. The five regolith samples with anomalous concentrations over the Churla Granite comprise one sandplain sample, two sheetwash samples, and two stream sediments. The association of Nb, W (GSWA 173374); Cr, Te (GSWA 173372); and Cr, Se (GSWA 173348) with drainages and areas of sheetwash and colluvium is indicative of the accumulation of resistate phases (including chromite) following granitoid weathering. According to site observations, colluvium contains scattered ferruginized lithic fragments, some of which are magnetic.

Amongst the six samples with anomalous analyte concentrations over the Yarra Yarra Granite, two samples have metal associations, and both have been collected from areas of ferricrete (*Rf*). Both of the samples (GSWA 173381 and 173535) have high Fe_2O_3 contents (18.3% and 17.0% respectively), and GSWA 173381 has the highest Pd (41 ppb) and Pt (6 ppb) recorded in regolith from BYRO. GSWA 173535 has the highest Mo content in regolith (9 ppm), and an anomalous Ga concentration. At site GSWA 173381, Fe-rich duricrust has completely replaced any outcropping lithology, whereas at site GSWA 173535, ferruginous lithic fragments are found in a sandy to clay-rich colluvium.

Proterozoic rocks (Badgeradda Group)

Twenty-three regolith samples (one lake sediment, two sandplain, eleven sheetwash, and nine stream sediment) from BYRO with anomalous concentrations of one or more analytes are found over the Badgeradda Group, and some of these samples contain the highest concentration of several analytes. In addition, regolith in this area has high, but not anomalous, concentrations of MgO, P_2O_5, In, Nb, Ni, Pb, Se, Ta, U, and detectable Pd and Pt. Three analyte associations can be recognized.

The first association includes sample GSWA 172949, which is a lake-sediment sample found over ferricrete (*Rf*). It has anomalous concentrations of LOI, Be, S, and Sr (typical of lake-sediment samples recorded in the GSWA regolith geochemistry program), as well as anomalous concentrations of Sb and Sn. Sheetwash sample GSWA 173748 has anomalous concentrations of S and Sr. The second association comprises four sheetwash samples (GSWA 173152, 173546, 172946, and 173143), which share anomalous concentrations of Al_2O_3, LOI, Li, and MnO, consistent with their high clay contents. Some have anomalous levels of W and Zn. The third association comprises a suite of eight samples (GSWA 172948, 173747, 173749, 173548, 173549, 173147, 173550, 173551), which share anomalous concentrations of Fe_2O_3, TiO_2, As, Cu, Ga, Sb, Bi, Sc, V, MnO, Co, Zn, and Zr. These samples are from ferricrete (*Rf*), exposed-regime regolith derived from quartzofeldspathic sedimentary rocks (*Xgs*), areas of colluvium derived from several rocks types (*Cl*), or sheetwash (*Wd*). All of these regolith types show a strong spatial relationship — ferricrete (*Rf*) overlies exposed-regime regolith (*Xgs)*, and colluvial and sheetwash deposits are downslope from exposed-regime regolith (*Xgs)*. Sample-site information shows that in all cases iron-rich lithic fragments are a common component of regolith, and at some sites (e.g. GSWA 173747) ferruginous sandstone clasts are accompanied by ferruginous nodules, pisolites, and granules. Strongly magnetic ferruginous clasts are found at GSWA 173749, and ferricrete cobbles are recorded from GSWA 173551.

Phanerozoic rocks

Nine sheetwash samples, five sandplain samples, and a sample of lake sediment have anomalous concentrations of several elements in regolith over the Lyons Group. Four of the sandplain samples have anomalous concentrations of SiO_2, whereas sheetwash samples have anomalous concentrations of Al_2O_3, LOI, Li, Ba, MgO, Zn, Zr, Mo, and Pb.

Discussion

Element associations identified in regolith samples from Byro provide examples of the influence of bedrock or weathering or both on the composition of regolith. An example of bedrock control is provided by the granitoid-dominated lithologies typical of the Murchison Granite–Greenstone Terrane and parts of the Narryer Terrane, where many analytes in regolith are found at uniform levels. The distribution of CaO, Na_2O, and Sr over the Weiragoo Granite emphasizes the relationship of regolith and bedrock, where variations in the chemistry of these three analytes are consistent with compositional zonation within the granite.

Some stream-sediment samples derived from areas of granitoid rock, and some areas of colluvium and sheetwash downslope from granitoid rocks contain high concentrations of such elements as La, Ce, Th, U, Zr, and P. This association indicates the concentration of resistate minerals such as allanite, monazite, and zircon in regolith as a result of weathering of granitoid and mechanical sorting (Morris and Sanders, in press). Some regolith samples from over the Churla Granite have anomalous concentrations of Cr and Nb, which could also mean that other resistate phase such as chromite and rutile are concentrated during weathering and transport. In a study of various sample media over Archaean greenstones in the northern Eastern Goldfields, Morris and Sanders (in press) showed that stream sediments often preserve a bedrock signature, as they were probably periodically recharged by relatively fresh bedrock detritus. However, in several cases on Byro, stream sediments in areas of granitoid exposure do not contain a notable bedrock signature. Due to their higher content of labile phases such as feldspar, it is likely that granitoid detritus is more rapidly weathered than that derived from greenstones. Some samples with high La, Ce, Th, U, Zr, and P_2O_5 contents also have anomalously high W contents, which could mean that W-bearing minerals are found in some areas of granitoid.

Ultramafic rock is found only as small exposures in parts of the Narryer Terrane on Byro (Myers, 1997), but the high concentrations of elements such as Mg, Ni, Sc, Cr, Pt, Pd, and V in samples close to exposed-regime regolith derived from ultramafic rock (*Xum*) shows that if a bedrock has a significantly different compositional signature to surrounding units, this signature can be preserved in derived regolith. However, in other cases, controls on regolith chemistry are less clear, such as sample GSWA 173259 (Erawondoo Hill) that has the highest levels of Nb, Rb, Sn, and Ta recorded in regolith from Byro. This sample has been collected from an area of quartz-veined granitoid and quartz–magnetite rock, with abundant magnetic material in the regolith, but there is no clear indication of what is causing the elevated concentrations of these elements. Possibilities include regolith derived from fractionated granitoid or pegmatite material.

The influence of regolith-forming processes on the composition of regolith is shown by several examples on Byro. Regolith samples from ferricrete units (*Rf*) over parts of the Yarra Yarra Granite have high concentrations of Fe_2O_3, and one sample has the highest concentrations of Pd and Pt in regolith on the map sheet. Several samples of regolith from over the Impey Granite have anomalous concentrations of Ag plus or minus Nb. At all sample sites, hardpan is found as either a secondary unit, or as surface clasts. In both of these examples, elevated platinum group element (PGE) concentrations and Ag plus or minus Nb may therefore be related to the formation of ferricrete and hardpan respectively.

Lake sediments in the western parts of the map sheet have high values for LOI, Be, S, and Sr, which is typical of regolith with a high carbonate, clay, and sulfate content, as has been described elsewhere in GSWA's regional regolith geochemistry program (Morris et al., 1997). Over the Lyons Group, regolith from sandplain areas has anomalously high levels of SiO_2, and as these areas contain well-developed dunes, the high SiO_2 may reflect aeolian input. Clay-rich sheetwash samples, common over the Lyons Group, typically have high Al_2O_3 and Li contents.

Regolith over parts of the Badgeradda Group shows the combined influence of lithology and weathering on the composition of regolith. Several samples over this unit in the southwest of Byro have elevated contents of Fe_2O_3 and TiO_2 as well as As, Cu, Sb, Bi, Sc, V, Mn, Co, Zn, and Zr. According to Williams et al. (1983), the Yarrawolya Formation contains hematitic sandstone, and good exposures of red-brown sandstone are seen in the southwest of Byro. In addition, ferricrete (*Rf*) is well developed over parts of the Badgeradda Group in this area (Plate 3), and samples with anomalous concentrations of Fe_2O_3 and other analytes come from sites with various types of Fe-rich lithologies. Taking into account the composition of the parent rock and the development of ferricrete, it is possible that the elevated concentrations of at least some of these elements in regolith over the

Badgeradda Group are due to scavenging by Fe. This is discussed below (**Speciality maps**). Weathering and subsequent transportation of this material into lake systems to the north may also account for high levels of elevated concentrations of some elements (e.g. Zn) in lake sediments over the Lyons Group.

Statistical treatment of regolith chemical data

Spot-concentration maps (Figs 6–51) allow a rapid comparison of regolith chemistry relative to bedrock geology, but statistical analysis means that differences in the chemistry of regolith populations according to such criteria as sample media, bedrock unit, or regolith unit can be quantitatively examined. Such a quantitative approach is discussed in the following section. Problems of comparing datasets of unequal size, where the data are usually positively skewed and follow a non-normal distribution, have been discussed by several authors (Koch and Link, 1970; Swan and Sandilands, 1995) and have been specifically addressed within the GSWA regolith program by Morris et al. (1998).

In order to produce a dataset that more closely resembles a normal distribution and to avoid the problem of zero values, data can be log transformed after addition of a constant (Rock, 1988). Following this, geometric mean values can be calculated, and standard statistical tests can be carried out for comparison of mean values for two (Student's t-test) or more than two (Tukey's HSD) sample populations. The application of this approach within the GSWA program has been discussed by Morris et al. (1997, 1998). One major assumption of this approach is that addition of a constant and log normalization produces a sufficiently normally distributed dataset for the application of such parametric tests as Student's t-test and Tukey's HSD. When datasets are small or not normally distributed, non-parametric tests may be more appropriate.

The non-parametric equivalent of the Student's t-test for independent samples is known as either the Mann–Whitney U test or the Wilcoxon rank-sum test (Swan and Sandilands, 1995). Whereas Student's t-test tests the hypothesis of equality of population means, the Mann–Whitney U test tests for the equality of medians (i.e. the middle value in a set of ranked data). For many geochemical datasets, particularly those containing large amounts of zero or near-zero data, the use of tests such as the Mann–Whitney U test (where data are ranked before being statistically compared) must take into account the problems introduced by having a significant number of data of the same value, usually zero in the case of regolith geochemistry. In this situation, the Mann–Whitney approach may unrealistically highlight the importance of the few non-zero data. This must be borne in mind, although it is accepted that the Mann–Whitney U test is more appropriate for testing geochemistry, as most such datasets are positively skewed.

Tests of median equality have been carried out at the 99% probability level for data from BYRO. In order to avoid the influence of poorer precision and accuracy at low concentrations, only analytes where one or both median values are greater than ten times the detection level are discussed. It is unrealistic to report median values of trace elements to the level of precision presented in BYRO.CSV, and these median values are reported as integers in the relevant tables.

Statistical comparison of sample media over the Weiragoo Granite

Morris and Sanders (in press), in an example from Archaean greenstones in the northern Eastern Goldfields, have shown that there can be significant compositional differences between sample media types taken from over the same lithologies. As the Weiragoo Granite occupies a significant area in the southeast of BYRO, there are sufficient samples to test compositional differences according to sample media. Median values for stream sediment (n = 25) and sheetwash (n = 73) are shown in Table 5. The Mann–Whitney U test shows that stream sediments have statistically higher median values for Al_2O_3, Na_2O, K_2O, Ba, Ce, Ga, La, Sr, and Th, and lower median values for SiO_2, TiO_2, Fe_2O_3, LOI, Cr, V, Zn, and Zr. There is no difference in median values for Pb and Rb. The association of Al_2O_3, Na_2O, K_2O, Ba, and Sr in stream sediments could mean a higher feldspar content compared to sheetwash, whereas higher Ce and La could be due to a higher monazite content. Higher resistate-mineral contents in sheetwash are indicated by higher median values for SiO_2 (quartz), TiO_2 (rutile), Cr (chromite), and Zr (zircon), whereas higher Fe_2O_3 and V is consistent with a higher degree of ferruginization. These observations are consistent with some of the findings of Morris and Sanders (in press), who argue that stream sediments over Archaean greenstones were frequently recharged by fresh bedrock material, whereas the overall differences between stream sediments and sheetwash reflect the combined effects of bedrock recharge, weathering, and mechanical sorting during transportation.

Statistical comparison of colluvium derived from granitoid rocks (*Cgp*) and sheetwash (*Wd*) over the Murchison Granite–Greenstone Terrane

As discussed above, the Murchison Granite–Greenstone Terrane comprises a limited range of lithologies (largely granitoid rocks), with well-developed downslope relationships between exposed-regime regolith (dominated by *Xgp*), colluvium (*Cgp*), and sheetwash (*Wd*). This presents the opportunity to examine changes in chemistry with increased distance of transport, and (presumably) more advanced stages of weathering.

Median values for colluvium derived from granitoid rocks (*Cgp*) and sheetwash (*Wd*) over the Murchison Granite–Greenstone Terrane (Table 6) have been statistic-

Table 5. Median values for sheetwash and stream sediments over the Weiragoo Granite

	DL[(a)]	*Sheetwash (n=73)*	*Stream (n=25)*
		Percent	
SiO_2	0.1	82.8	79.8
TiO_2	0.05	0.23	0.15
Al_2O_3	0.1	8	10.4
Fe_2O_3	0.1	2.7	2.1
MnO	0.05	–	–
MgO	0.1	0.1	0.1
CaO	0.1	0.1	0.6
Na_2O	0.1	0.3	2
K_2O	0.1	2.5	3.1
P_2O_5	0.05	–	–
LOI	0.1	2.1	1.1
		Parts per million[(b)]	
Ag	0.1	–	–
As	1	2	–
Au (ppb)	1	0	–
Ba	5	756	875
Be	1	–	1
Bi	0.5	–	–
Cd	1	–	–
Ce	0.5	28	42
Co	1	4	3
Cr	2	24	14
Cu	1	10	6
Ga	1	11	14
In	0.1	–	–
La	0.2	17	26
Li	3	6	3
Mo	1	–	–
Nb	0.5	5	4
Ni	2	9	7
Pb	1	18	22
Pd (ppb)	1	–	–
Pt (ppb)	1	–	–
Rb	0.5	74	79
S (%)	0.1	–	–
Sb	0.5	–	–
Sc	1	3	2
Se	0.5	–	–
Sn	1	–	–
Sr	1	44	114
Ta	2	–	–
Te	0.2	–	–
Th	0.1	11	17
U	0.1	2	2
V	2	27	18
W	1	–	–
Y	1	6	7
Zn	2	18	10
Zr	5	112	88

NOTES:
n number of samples
ppb parts per billion
(a) detection level
(b) unless otherwise stated
– less than detection level

Table 6. Median values for colluvium derived from granitoid (*Cgp*) and sheetwash (*Wd*) over the Murchison Granite–Greenstone Terrane

	DL[(a)]	*Colluvium (n=32)*	*Sheetwash (n=122)*
		Percent	
SiO_2	0.1	80.3	83.3
TiO_2	0.05	0.23	0.22
Al_2O_3	0.1	10.0	7.9
Fe_2O_3	0.1	2.6	2.5
MnO	0.05	–	–
MgO	0.1	0.1	0.0
CaO	0.1	0.3	0.0
Na_2O	0.1	1.2	0.3
K_2O	0.1	3.0	2.7
P_2O_5	0.05	–	–
LOI	0.1	1.9	2.0
		Parts per million[(b)]	
Ag	0.1	–	–
As	1	1	2
Au (ppb)	1	–	–
Ba	5	880	762
Be	1	–	–
Bi	0.5	–	–
Cd	1	–	–
Ce	0.5	34.2	24.2
Co	1	4	3
Cr	2	18	26
Cu	1	8	9
Ga	1	14	11
In	0.1	–	–
La	0.2	21.6	14.5
Li	3	5	5
Mo	1	–	–
Nb	0.5	5.1	4.2
Ni	2	7	8
Pb	1	22	19
Pd (ppb)	1	–	–
Pt (ppb)	1	–	–
Rb	0.5	89.2	80.0
S (%)	0.1	–	–
Sb	0.5	–	–
Sc	1	3	3
Se	0.5	–	–
Sn	1	–	–
Sr	1	64	39
Ta	2	–	–
Te	0.2	–	–
Th	0.1	13.3	10.5
U	0.1	2.6	2.0
V	2	23	26
W	1	–	–
Y	1	7	6
Zn	2	17	16
Zr	5	111	98

NOTES:
n number of samples
ppb parts per billion
(a) detection level
(b) unless otherwise stated
– less than detection level

ally compared. Median values for SiO_2 and Cr are higher, and median values for Al_2O_3, Na_2O, K_2O, Ba, Ce, Ga, Nb, Pb, Rb, Sr, Th, U, and Y are lower in sheetwash compared to colluvium. There is no statistical difference in the median values for Fe_2O_3, LOI, V, or Zr, and the remaining median values were too low for reliable statistical analysis. This comparison highlights several downslope changes in regolith composition. Firstly, the higher median values for Al_2O_3, Na_2O, K_2O, Ba, Rb, and Sr, and the lower SiO_2 value point to a higher content of feldspar (or its weathered product) in colluvium relative to sheetwash. Secondly, as Fe_2O_3 and V show no difference in median values, Fe-rich material is conserved in the transition from colluvium to sheetwash. Thirdly, the behaviour of elements such as Cr, Ce, Nb, Pb, Th, U, Y, and Zr give some information on the behaviour of resistate mineral phases — chromite appears to be concentrated in sheetwash relative to colluvium, whereas allanite (Ce, Th, U, and Y) and rutile (Nb) are retained in colluvium, and zircon is conserved.

Statistical comparison of stream-sediment data over the Murchison Granite–Greenstone and Narryer Terrane granitoid rocks

Table 7 shows median values for stream-sediment data over the Murchison Granite–Greenstone and Narryer Terrane rocks grouped according to the stratigraphic subdivisions summarized in Table 1. A statistical comparison using the Mann–Whitney U test shows that stream sediments over the Murchison Granite–Greenstone Terrane have higher SiO_2, Na_2O, K_2O, Ba, Rb, and Sr, and lower TiO_2, Fe_2O_3, LOI, Cr, Cu, Nb, Th, V, and Zr than stream sediments over Narryer Terrane rocks. There is no statistical difference in the median values for Al_2O_3, La, Ce, and Pb. If stream sediments represent one of the best regolith proxies for bedrock, as suggested by Morris and Sanders (in press), then the difference in median values for these two sample populations indicates a higher feldspar content in Murchison Granite–Greenstone Terrane rocks, and a higher mafic-mineral content and possibly resistate-phase content (chromite, rutile, and zircon) in Narryer Terrane rocks. Thus, this statistical exercise points to fundamental differences in the lithologies of these two terranes.

Table 7. Median values for stream sediments over the Murchison Granite–Greenstone and Narryer Terranes

	DL[(a)]	*Narryer (n=160)*	*Murchison (n=46)*
		Percent	
SiO_2	0.1	78.5	80.95
TiO_2	0.05	0.3	0.15
Al_2O_3	0.1	9.85	9.7
Fe_2O_3	0.1	3.9	2.2
MnO	0.05	–	–
MgO	0.1	0.15	0.1
CaO	0.1	0.3	0.5
Na_2O	0.1	1	1.4
K_2O	0.1	2.1	3.05
P_2O_5	0.05	–	–
LOI	0.1	2.2	1.25
		Parts per million[(b)]	
Ag	0.1	–	–
As	1	2	1
Au (ppb)	1	–	–
Ba	5	727	888
Be	1	–	–
Bi	0.5	–	–
Cd	1	–	–
Ce	0.5	36	32
Co	1	4	2
Cr	2	51	17
Cu	1	11	6
Ga	1	14	13
In	0.1	–	–
La	0.2	23	20
Li	3	4	4
Mo	1	–	–
Nb	0.5	6	5
Ni	2	12	7
Pb	1	20	19
Pd (ppb)	1	–	–
Pt (ppb)	1	–	–
Rb	0.5	64	83
S (%)	0.1	–	–
Sb	0.5	–	–
Sc	1	4	2
Se	0.5	–	–
Sn	1	–	–
Sr	1	64	76
Ta	2	–	–
Te	0.2	–	–
Th	0.1	17	14
U	0.1	2	2
V	2	50.5	19
W	1	–	–
Y	1	7	6
Zn	2	14	10
Zr	5	149	88

NOTES:
n number of samples
ppb parts per billion
(a) detection level
(b) unless otherwise stated
– less than detection level

Statistical comparison of sandplain units *Sl1* and *Sl2*

The two different groupings of heterogeneous sandplain (*Sl1* and *Sl2*) identified on BYRO are separated on the basis of morphology and relative stability (shown by vegetation cover and degree of incision). As such, they should show similar composition if they have been derived by similar processes involving local derivation coupled with some eolian and sheetwash input, as discussed above. Median values for both sandplain types are shown in Table 8. A statistical comparison shows that only median values for Ba and Zr are statistically different at the 95% level, with both values being lower in the older *Sl2* unit. There is no statistical difference in the median values for SiO_2, Al_2O_3, TiO_2, Fe_2O_3, LOI, Ce, Cr, La, Nb, Rb, Th, and V, and the remaining median values

Table 8. Median values for mixed sandplain units *Sl1* and *Sl2*

	DL[(a)]	*Sl1* (n=26)	*Sl2* (n=109)
		Percent	
SiO_2	0.1	90.8	91.1
TiO_2	0.05	0.22	0.21
Al_2O_3	0.1	3.5	3.5
Fe_2O_3	0.1	2.5	2.4
MnO	0.05	–	–
MgO	0.1	–	–
CaO	0.1	–	–
Na_2O	0.1	–	–
K_2O	0.1	0.2	0.2
P_2O_5	0.05	–	–
LOI	0.1	1.7	1.6
		Parts per million[(b)]	
Ag	0.1	–	–
As	1	3	3
Au (ppb)	1	–	–
Ba	5	138	79
Be	1	–	–
Bi	0.5	–	–
Cd	1	–	–
Ce	0.5	9.2	9.0
Co	1	2	2
Cr	2	34	31
Cu	1	6	6
Ga	1	5	5
In	0.1	–	–
La	0.2	5.8	6.0
Li	3	6	5
Mo	1	–	–
Nb	0.5	3.3	3.0
Ni	2	6.5	6
Pb	1	6	6
Pd (ppb)	1	–	–
Pt (ppb)	1	–	–
Rb	0.5	10.4	10.7
S (%)	0.1	–	–
Sb	0.5	–	–
Sc	1	3	2
Se	0.5	–	–
Sn	1	–	–
Sr	1	9	8
Ta	2	–	–
Te	0.2	–	–
Th	0.1	4.7	4.5
U	0.1	0.7	0.7
V	2	28	28
W	1	–	–
Y	1	2	2
Zn	2	8	9
Zr	5	114	88

NOTES:
n number of samples
ppb parts per billion
(a) detection level
(b) unless otherwise stated
– less than detection level

were too low for statistical analysis. This comparison confirms a common origin for these two sandplain regolith types, with higher Zr and Ba contents possibly due to exotic input of zircon and barite into the younger *Sl1* unit.

Statistical comparison of sandplain dominantly developed over granitoid rocks (R_sg) and sandplain of mixed origin (*Sl1* and *Sl2*)

The distribution of sand-dominated regolith in the Murchison Granite–Greenstone and Narryer Terranes suggests that this regolith is developed by weathering in situ of a granitoid protolith, whereas both *Sl1* and *Sl2* are probably of mixed origin — in part locally derived, with some aeolian and sheetwash input. The different origins for these two types of sand-dominated regolith have been tested by a comparison of medians (Table 9). For this exercise, the median value for sandplain of mixed origin has been calculated using data for both *Sl1* and *Sl2*, as the statistical comparison of median values discussed above shows little compositional difference between these two regolith units.

Statistical analysis shows that the median value for SiO_2 is higher in sandplain of mixed origin, but median values are lower for Al_2O_3, Fe_2O_3, LOI, Ba, Ce, Cr, Cu, Ga, La, Nb, Pb, Rb, Sr, Th, U, V, and Zr. All other median values are too low for statistical testing, and no median values show no statistical difference. This statistical comparison shows that sandplain over granitoid rocks (R_sg) has a higher content of feldspar or its weathering products (shown by higher Al_2O_3, Ba, Rb, and Sr), is more ferruginous (higher Fe_2O_3, Ga, and V), and has a higher content of resistate mineral components such as allanite and monazite (Ce, La, Th, and U), rutile (Nb), and zircon (Zr). All these observations are consistent with this unit being developed by weathering in situ of granitoid rocks, whereas the dominance of SiO_2 in sandplain of mixed origin could reflect derivation from siliciclastic rocks of the Lyons and Wooramel Groups, coupled with the input of mineralogically mature sheetwash material and quartz-rich eolian material.

Speciality maps

Regolith pH and conductivity

The acidity–alkalinity (pH) of regolith can affect the mobility of elements in regolith (Hawkes and Webb, 1962), and measurements of pH for each regolith sample collected on BYRO have been undertaken. The pH values range from 4.2 to 9.7 (Fig. 52), with the majority of regolith samples with low values found over Phanerozoic rocks, although values are also low in regolith over parts of the Murchison Granite–Greenstone and Narryer Terranes. More alkaline regolith samples (i.e. pH >7) are found along major drainages (e.g. Murchison River, Yarra Yarra Creek system), with weakly acidic regolith (i.e. pH 6–7) corresponding to sheetwash flanking major drainages over the Murchison Granite–Greenstone and Narryer Terranes. Regolith conductivity

Table 9. Median values for sandplain developed over granitoid (*R_sg*) and sandplain of mixed origin (*Sl1* and *Sl2*, designated *Sl*)

	DL[(a)]	*R_sg* (n=16)	*Sl* (n=135)
		Percent	
SiO_2	0.1	81.5	91.0
TiO_2	0.05	0.37	0.21
Al_2O_3	0.1	7.4	3.5
Fe_2O_3	0.1	5.9	2.4
MnO	0.05	–	–
MgO	0.1	–	–
CaO	0.1	–	–
Na_2O	0.1	–	–
K_2O	0.1	0.4	0.2
P_2O_5	0.05	–	–
LOI	0.1	3.5	1.6
		Parts per million[(b)]	
Ag	0.1	–	–
As	1	5	3
Au (ppb)	1	–	–
Ba	5	130	84
Be	1	–	–
Bi	0.5	–	–
Cd	1	–	–
Ce	0.5	16.7	9.1
Co	1	3	2
Cr	2	132.5	32
Cu	1	13.5	6
Ga	1	14.5	5
In	0.1	–	–
La	0.2	9.7	5.9
Li	3	6	5
Mo	1	2	–
Nb	0.5	6.5	3.0
Ni	2	10	6
Pb	1	12	6
Pd (ppb)	1	–	–
Pt (ppb)	1	–	–
Rb	0.5	18.2	10.7
S (%)	0.1	–	–
Sb	0.5	–	–
Sc	1	5	2
Se	0.5	0.5	–
Sn	1	1	–
Sr	1	11	8
Ta	2	–	–
Te	0.2	–	–
Th	0.1	13.9	4.5
U	0.1	1.5	0.7
V	2	105	28
W	1	1	–
Y	1	4	2
Zn	2	13	9
Zr	5	153	90

NOTES:
n number of samples
ppb parts per billion
(a) detection level
(b) unless otherwise stated
– less than detection level

values are generally low, with 97% of samples having values of less than 1 mS/cm, and 2% of samples between 1 and 2 mS/cm. The maximum conductivity value is 14.2 mS/cm from a lake-sediment sample over the Lyons Group.

Element-index maps

Combining pathfinder elements into an additive index has been used to highlight areas of mineralization in arid terrains of the Yilgarn Craton (Smith and Perdrix, 1983; Smith et al., 1989). Although their approach concentrated on analyses of ferruginized duricrust (or laterite), the additive-index approach 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) showed how a greenstone chalcophile index could be used to identify areas of known and potential gold mineralization on SIR SAMUEL. Indices are usually additive (e.g. element a + element b + element c, and so on), but account must be taken of the relative concentration and concentration range of each element to ensure that an element showing anomalous concentrations, even at low abundances, is given equal importance to an element showing anomalous concentrations at a higher level of concentration (i.e. higher concentration elements do not negate the importance of other elements that may be found at lower concentrations). Firstly, data are log transformed (following addition of a constant to take account of zero values), which reduces the effect of extremely high or low values. The transformed data are then expressed as a standard normal deviate (i.e standardized), thus allowing direct comparison of elements regardless of concentration (Rock, 1988). The standardized scores are then summed to create an elemental association suite.

Chalcophile index

Contoured chalcophile-index scores (Fig. 53) are shown in relation to interpreted structures, based on magnetic and gravity data for BYRO discussed by Blundell et al. (in prep.). Areas of relatively high chalcophile-index scores include the southwestern part of BYRO over the Badgeradda Group; in the southeastern and central parts of the Lyons Group in the western part of the map sheet; and over parts of the Narryer Terrane. Blundell et al. (in prep.) have noted the coincidence of high chalcophile scores and interpreted structures in the following areas:

- The Carnarvon Basin area (1 on Fig. 53), at the intersection of a north-northeastern fault trace and the western extension of a magnetic lineament displacing the Meeberrie Fault at location 3.
- The southwestern part of the map sheet over the Badgeradda Group (2 on Fig. 53), where Blundell et al. (in prep.) have interpreted structures as deep-seated faults.
- At a magnetic lineament intersecting the offset in the Meeberrie Fault (3 on Fig. 53).
- The southwesterly oriented fault extending from the offset in the Meeberrie Fault into areas of Proterozoic and Phanerozoic rocks (4 on Fig. 53).
- Near to, but not coincident with, a gravity high in the northern-central part of BYRO (5 on Fig. 53). Blundell et al. (in prep.) argue that gravity highs in this area of BYRO are close to a magnetic high to the north on GLENBURGH. The presence of small areas of ultramafic

rock in this area, combined with gravity and magnetic data, could indicate larger ultramafic bodies at depth.

- The Jack Hills greenstone belt in the northeastern part of BYRO (6 on Fig. 53), where high chalcophile-index scores coincide with the largest-amplitude magnetic anomaly on the map sheet. Gravity highs are also found associated with some high chalcophile-index scores in this area. This coincides with areas of unexposed greenstone or ultramafic complexes.

Pegmatite index

Figure 54 shows contoured values for a pegmatite index (i.e. summed standard scores for As, Sb, Sn, Ga, W, Nb, and Ta; Smith et al., 1989, fig. 3). The contour plot is broadly similar to the chalcophile index (Fig. 53), with high values in the southwest of BYRO over parts of the Badgeradda Group and patches of higher values extending to the northeast. A major difference is the bullseye anomaly in the Erawondoo Hill area that is due to the high Ta, Nb, and Sn values (the maximum in regolith on BYRO) in sheetwash sample GSWA 173259.

It has been suggested above that the high concentration of some analytes in regolith over the Badgeradda Group may be due to the scavenging effect of Fe during regolith-forming processes, as regolith from this area has some of the highest Fe_2O_3 contents on BYRO. Hawkes and Webb (1962) have suggested that precipitation of Fe- and Mn-rich oxides may also involve fixing of other minor elements. They illustrated this by discussion of elevated Pb, Zn, and Fe concentrations in stream sediments, even though the streams did not drain any areas of known sulfide mineralization. On BYRO, the Fe_2O_3 content of regolith and pegmatite-index values show a broad positive correlation (Fig. 55), although samples GSWA 173259 (undivided Archaean rocks in the Erawondoo Hill area) and GSWA 172949 (Badgeradda Group) have high pegmatite-index values but not excessively high Fe_2O_3 contents. In contrast, a number of samples with high Fe_2O_3 contents are found over the Badgeradda Group (filled blue circles) and several of these plot close to or above the 1:1 line (i.e. have high pegmatite-index scores). This correlation between pegmatite score and Fe_2O_3 is taken as evidence for some scavenging of elements by Fe_2O_3. One of the two samples with a high pegmatite score but low Fe_2O_3 (GSWA 173259) comes from the Jack Hills greenstone belt, but GSWA 172949 is from regolith over the Badgeradda Group. As it has a low Fe_2O_3 content (8.1%), the high pegmatite-index score cannot be attributed to scavenging by Fe, but is probably of primary origin. The significance of this is discussed below.

Mineralization potential

BYRO has been explored for a variety of commodities including gold, copper, nickel, platinoids, iron ore, base metals, semi-precious stones, rare earth minerals, and building stone, but no economic deposits of any commodity have been found to date. Gold exploration has largely centred on placer-style mineralization in the Mount Narryer region, and one sample with anomalous gold concentration from this area (GSWA 173187; 3 ppb) was analysed in this program. Other samples with anomalous gold concentrations are from regolith over the Murchison Granite–Greenstone Terrane — GSWA 173234 (5 ppb; Weiragoo Granite), and GSWA 173429 and 173611 (3 ppb), both from regolith over the Tching Granite.

Silver levels in regolith only reach 0.8 ppm on BYRO, and samples with the highest Ag concentrations are all found in regolith from over the Murchison Granite–Greenstone or Narryer Terranes. Samples with some of the highest Ag values also have high Nb, and a common feature of these samples is their association with hardpan. Thus, it is likely that the high Ag and Nb concentrations result from supergene enrichment during regolith formation.

Copper and nickel exploration has focused on the northern-central parts of BYRO, although apart from GSWA 173381 (164 ppm Cu) in regolith from over the Yarra Yarra Granite, most samples with high Cu concentrations in regolith from BYRO are from the Badgeradda Group (Fig. 25). However, the seven highest concentrations of Ni in regolith (53–86 ppm) are found in samples from over the Narryer Terrane, some of which are from the central-northern part of the map sheet.

Parts of BYRO that have been explored for copper and nickel have also been examined in terms of platinum group elements. Exploration has concentrated on areas of ultramafic and associated rocks (serpentinized peridotite, dunite, and pyroxenite), such as in the Meegea Hill area. Palladium and Pt levels are generally low in regolith, with a maximum of 41 ppb Pd and 6 ppb Pt in sheetwash sample GSWA 173381 from an area of ferricrete (*Rf*) northwest of Deep Well. In this area are small outcrops of ultramafic rock, and as nearby regolith samples have anomalous concentrations of Mg, Ni, Cr, Sc, and V, there is a suggestion of PGE association with ultramafic rocks. In a discussion of regional geophysics and chalcophile-index scores calculated from regolith, Blundell et al. (in prep.) suggested that although areas of high chalcophile-index scores in the central-northern part of BYRO did not coincide directly with any geophysical features, gravity highs in this area may indicate the presence of deep-seated ultramafic rocks. Furthermore, Sanders et al. (1998) noted the highest Pd (8 ppb) and Pt (15 ppb) levels in regolith from GLENBURGH were from immediately north of GSWA 173381, and regolith in this area also had high concentrations of Cr, Co, and Ni. They attributed high concentrations of these elements to the influence of mafic and ultramafic rocks.

Chromite mineralization has also been reported from the central-northern part of BYRO, particularly in the Iniagi Well and Taccabba Well areas. Similar to Cu, Ni, and PGE mineralization, chromite mineralization is spatially associated with ultramafic rocks. Some of the highest Cr contents in regolith, reaching 899 ppm, are found over parts of the Narryer Terrane. Statistical analysis discussed above has shown that high Cr in regolith probably results from weathering and mechanical sorting during transportation, and the effects of weathering and sorting should be taken into account when assessing whether high Cr in regolith is indicative of mineralization.

Veins containing barite and lead have been reported from the Badgeradda Range area in the southwestern part of BYRO. High Ba values in regolith are found throughout the map sheet (Fig. 19), including the Badgeradda Group, and sheetwash sample GSWA 173144 has an anomalously high concentration of Ba (3470 ppm). The same area also has some high Pb values in regolith, although none are at anomalous levels (Fig. 33). For both the chalcophile-index and pegmatite-index maps (Figures 53 and 54) regolith over the Badgeradda Group has high index values, although the high Fe_2O_3 content of many of these samples with elevated scores (Fig. 55) could mean that chalcophile- and pegmatite-related elements have been enriched by scavenging of Fe. This, however, is not so for the odd samples that have high scores but low Fe_2O_3 contents (Fig. 55), which could mean that the tapping of crustal fluids by deep-seated faults is a possibility (Blundell et al., in prep.). One sample from over the Jack Hills greenstone belt (GSWA 173259) has both high pegmatite and chalcophile-index scores, yet low Fe_2O_3 (6.1%). The anomalous chemistry of this sample is unusual, and the area bears further investigation.

In summary, although the mineralization potential of BYRO has not been translated into economic deposits, several areas and commodities bear further investigation, especially if several data types (regolith mapping, regolith chemistry, geophysics) are integrated. These include:

- Gold associated with sedimentary rocks (i.e. placer style of mineralization) in the Mount Narryer area.
- Copper, nickel, chromite, and PGE mineralization associated with ultramafic rocks in the central-northern part of the map sheet.
- Base metal and pegmatite associations in the Badgeradda Group, and whether anomalous concentrations of several elements in regolith reflect weathering processes or tapping of mineral-rich fluids by crustal faults, or both.
- A pegmatite association in the Jack Hills area.

Summary and conclusions

The composition and distribution of regolith on BYRO largely reflects the underlying bedrock. Exposed-regime regolith, which broadly correlates with areas of outcrop, subcrop, and spatially associated lag (16% of regolith), is particularly common in areas of granitoid that dominate the Archaean Murchison Granite–Greenstone and Narryer Terranes. Exposed-regime regolith gives way downslope to areas of colluvium, and both the Murchison Granite–Greenstone and Narryer Terranes support extensive areas of low-gradient sheetwash (*Wd*), which is the most common regolith type on the map sheet (27.7% by area and 331 samples). The biggest contrast in regolith content between the Murchison Granite–Greenstone and Narryer Terranes is the amount and diversity of residual or relict regolith units, with the Narryer Terrane supporting a variety of siliceous (*Rz*, *Rzu*), ferruginous (*Rf*), and sandy (R_sg) units compared to the Murchison Granite–Greenstone Terrane, and accounting for much of the 7% of this regolith type found on BYRO. Ferruginous duricrust (*Rf*) is also well developed over parts of the Badgeradda Group.

Exposed-regime regolith and compositionally related downslope units (e.g. Xls_g and *Cl*) are also found over Proterozoic and Phanerozoic rocks in the western part of BYRO, but this area is more strongly characterized by the development of lacustrine deposits (L_l and L_m), which together comprise 6.4% of regolith on BYRO. The Yarra Yarra Creek system in this area, along with the Murchison River in the eastern part of the map sheet, contains extensive deposits of alluvium (*A1d*, *A1k*, *A2d*, and locally A_f) that account for 17% of regolith on BYRO. Sandplain in the western part of BYRO is of mixed origin, with local input from underlying rocks, input of transported regolith (sheetwash), and some aeolian reworking. This regolith type (11% of regolith by area) has been divided according to age (*Sl1* and *Sl2*). Heterogeneous sandplain (*Sl1* and *Sl2*) has a different morphology and vegetation cover to sandplain developed over Archaean granitoid rocks on BYRO (R_sg), which is probably of residual origin and derived by weathering in situ of the underlying granitoid.

Chemical analysis, carried out by Amdel Laboratories, largely conformed to prescribed quality-control parameters. For some analytes, such as Au, Pt, and Pd that are typically at or near to detection level, precision and accuracy are difficult to assess, as there are few standards with well-characterized low-level analyte concentrations. Based on available data, it is unlikely that precious-metal abundances at levels less than 5 ppb in regolith are reliable. Analytes for which there was generally lower precision and accuracy, even at high concentrations, include La, Ce, Nb, Zr, Cr, and V, which are usually found in minerals such as monazite, allanite, rutile, zircon, chromite, and oxide minerals that can be resistant to dissolution and are therefore difficult to accurately and precisely analyse by ICP methods. Incomplete dissolution may explain discrepancies in the concentrations between some analytes for the nine samples that were analysed by a second laboratory.

Regolith over the Murchison Granite–Greenstone Terrane shows little range in the concentration of most major element oxides and trace elements, thus reflecting the dominance of granitoid bedrock. However, higher concentrations of CaO, Na_2O, and Sr in regolith from the central parts of one granitoid body indicate some compositional zoning of the bedrock. Several samples of sheetwash, colluvium, or stream sediment derived from granitoid rocks of both the Murchison Granite–Greenstone and Narryer Terranes contain anomalously high concentrations of La, Ce, P, Zr, or Th, which is probably the result of the concentration of REE-bearing minerals and zircon following the weathering of granitoid. Codner and Kaplan (1982) reported high levels of REE in stream sediments on BYRO and attributed them to accumulation of suitable minerals due to granite weathering.

The greater lithological diversity of Narryer Terrane rocks compared to those of the Murchison Granite–

Greenstone Terrane is seen in samples with anomalous concentrations of elements such as Mg, V, Pd, Pt, Cr, Ni, Sc, and Co, many of which can be spatially linked to regolith derived from mafic metamorphic rocks (*Xmm*) or ultramafic rocks (*Xum*), even though such regolith types are poorly represented on BYRO (both *Xmm* and *Xum* represent less than 0.1% by area of BYRO). Samples with high levels of Ag plus or minus Nb in regolith over parts of the Impey Granite are all found in areas of hardpan, and it is likely that the development of hardpan has concentrated these elements. Similarly, ferricrete over parts of the Yarra Yarra Granite contains the highest levels of Pd (41 ppb) and Pt (6 ppb) recorded on BYRO. Anomalous levels of Ta, Nb, Rb , and Sn — the highest on BYRO — come from a sample overlying the Jack Hills greenstone belt in the northeast of BYRO. Anomalously high concentrations of Cr in regolith from drainages or areas of sheetwash indicate the preferential concentration of chromite during weathering.

Some of the highest concentrations of analytes in regolith are found over the Proterozoic Badgeradda Group, and it is likely that the scavenging effect of Fe during regolith formation has contributed to the supergene concentration of these elements, which include As, Cu, Sb, Bi, Sc, V, Mn, Co, and Zn. However, in at least one case, high concentrations of these elements are found in regolith with low Fe_2O_3, and the coincidence of samples with high concentrations of some analytes with regional structures interpreted from geophysics requires further investigation into whether crustal faults are tapping mineral-rich fluids.

Regolith over the Lyons Group has anomalous concentrations of Al, Li, Ba, and Mg (in addition to high LOI), an association typical of saline lake deposits. High Zn, Pb, and Mo contents may result from weathering and transport of regolith from the Badgeradda Group into areas of deposition. As would be expected, the highest SiO_2 contents in regolith are found in samples from areas on or close to sandplain (*Sl1* and *Sl2*).

Statistical treatment of regolith chemical data has taken advantage of the lithological uniformity of the Murchison Granite–Greenstone Terrane to examine the effects of sample medium on regolith chemistry. Stream-sediment chemistry bears a stronger bedrock signature than sheetwash, although stream sediments have higher median values for La and Ce, suggesting that some REE-bearing minerals from granitoids are preferentially retained in the stream environment, which is generally consistent with the findings of Morris and Sanders (in press). A statistical comparison of granitoid-derived colluvium (*Cgp*) and sheetwash (*Wd*) over the Murchison Granite–Greenstone Terrane demonstrates changes in the downslope composition of regolith due to weathering. Colluvium has higher median values for elements such as Al, Na, K, Ba, Rb, and Sr, and lower values for Si, consistent with a higher feldspar content in colluvium and a higher degree of weathering in sheetwash. Additionally, similar median values for Fe_2O_3 and V indicates that Fe-rich material is conserved, whereas other median values show that some resistate phases are held in colluvium and others are concentrated in sheetwash.

Statistical comparison of stream-sediment data over the Murchison Granite–Greenstone and Narryer Terranes reflects the lithological diversity of the former, in particular its higher content of mafic rocks.

A statistical comparison of sandplain developed over granitoid (R_sg) with sandplain of mixed origin (*Sl1* and *Sl2*) shows that sandplain developed over granitoid has a strong feldspar signature, along with higher median values for elements indicative of ferruginization and resistate mineral retention, all consistent with derivation by weathering in situ of the underlying granitoid. The depletion of mixed sandplain in many analytes, apart from SiO_2, compared to sandplain over granitoid attests to a different parentage, and to the likelihood of eolian input.

Regolith acidity–alkalinity and conductivity largely show that low-pH samples are usually found in drainages, and more saline areas (such as those in the western part of BYRO) have regolith samples with higher conductivity values. However, only 15 of the regolith samples have conductivity values greater than 1 mS/cm.

A chalcophile-index map and a pegmatite-index map broadly highlight similar areas on BYRO. Areas of high chalcophile-index scores in many cases coincide with structures interpreted from gravity or magnetic data, or coincide with gravity highs (Blundell et al., in prep.). However, in some cases such as in the northern-central part of BYRO, high chalcophile scores are not associated with any structural feature, and it is possible that in these situations regolith chemistry is solely controlled by bedrock.

Areas worthy of investigation in terms of mineralization on BYRO include:

- Copper, Ni, Cr, and PGE mineralization associated with ultramafic rocks in the northern-central part of the map sheet.
- Gold mineralization in the Mount Narryer area.
- Base metal and pegmatite-related mineralization over parts of the Badgeradda Group.
- Pegmatite mineralization over parts of the Jack Hills greenstone belt.

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Appendix 1

Gazetteer of localities

	MGA coordinates	
	Easting	*Northing*
Ballythunna Homestead	366676	7116413
Billabiddy Well	451509	7090122
Boolardy Homestead	453887	7015176
Boundary Bore	395312	7043463
Butcher Well	454572	7051409
Byro Homestead	415358	7115481
Coombrarie Well	361663	7018491
Condalye Well	387333	7046164
Curbur Homestead	394014	7072336
Dallah Well	461542	7102253
Deep Well	422775	7118004
Dink Bore	367173	7037439
Doondie Well	383269	7103852
Erawondoo Hill	494287	7103853
Halleen Well	480850	7103275
Impey Well	432812	7030162
Iniagi Well	427987	7095595
Jack Hills	495142	7106001
Jailor Outcamp	431521	7065118
Manfred Homestead	454327	7074982
Meeberrie Homestead	397994	7017019
Meegea Hill	444872	7110228
Melun Bore	434014	7117703
Melun Well	435272	7114247
Milly Milly Homestead	469198	7115830
Mongolia Bore	352614	7029717
Mount Dugel	447504	7086967
Mount Dugel Well	444540	7083074
Mount Murchison	442808	7039779
Mount Narryer	438334	7066126
Mount Narryer Homestead	438334	7066126
Mount Rebecca	400320	7113488
Muggon Homestead	355379	7055062
Nookawarra Homestead	487862	7090824
Noonie Hill	488911	7101373
Partnership Bore	454058	7097479
Piljong Well	426721	7027203
Shed North Well	456762	7114529
Spinifex Well	353091	7063158
Taccabba Well	463276	7114685
Thoolmugga Well	436068	7105622
Yarrawolya Pool	355503	7035101

Appendix 2

Open-file surface geochemistry for BYRO as at August 2000

Key

ID no.: Project reference number allocated for these notes (see Plate 2)

M no.: GSWA project reference number
An asterisk beside the M number indicates that not all the samples for the listed activities fall within BYRO; that is, the total number of samples includes some taken on adjacent sheets

I no.: The Item number, or Department of Minerals and Energy (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 4m depth), and grab samples
- RAB: Rotary air blast drilling
- SOIL: Surface or shallow soil samples
- SSED: Stream sediment
- UNDIF: Undifferentiated

No.: The number of analytical samples

Method: The analytical method used to determine the elements listed

- AAS: Atomic absorption spectroscopy
- BCL: Bulk cyanide leach
- ETA: Electron thermal atomization
- FA: Fire assay
- BLEG: Bulk leach extraction of gold
- ICP: Inductively coupled plasma
- ICP-MS: Inductively coupled plasma mass spectrometry
- ICP-OES: Inductively coupled optical emission spectrometry
- XRF: X-ray fluorescence

Activity elements: The elements for which analyses were carried out. An asterisk beside an element means that not all samples were assayed for that element

Analyst: The analytical laboratory where the analyses were carried out

- TEL: Trace Element Laboratories
- MIN: Minlabs
- CCL: Classic Comlabs Ltd
- GLS: Genalysis Laboratory Services
- ANA: Analabs
- ALS: Australian Laboratory Services
- ARA: Assay Research Australia
- AAL: Australian Assay Laboratories
- AMD: Amdel
- UT: Ultra Trace
- SGS: SGS Australia Pty Ltd
- SL: Sheen Laboratories
- ASE: Analytical Services
- DIA: Diatech Heavy Mineral Services
- NOR: Normets Pty Ltd
- WMC: Western Mining Corporation
- SPL: Stockdale Prospecting Ltd
- CRAE: CRA Exploration Pty Ltd
- AS: Analytical Services

DD: Indicates those projects for which deep drilling has been conducted

Comment: 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 or CD 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 surface geochemistry

ID no.	M. no	I. no.	A. no.	Year	Activity type	No.	Method	Activity elements	Analyst	DD
1a	299	957	9057	1969	SOIL/SSED/NGRD	990	AAS	Cu,Ni,Co,Zn,Pb	SL	
					NGRD	73	AAS	Cu,Ni,Zn	SL	
					SOIL/SSED	696	AAS	Cu,Ni,Zn	SL	
1b			827, 1435	1971	NGRD	532	?	Cu,Ni,Co,Pb,Zn,S,Pd*, Pt*	?	Y
1c			2510, 2163	1972	AUGER NGRD	107	AAS	Cu,Ni,Pb,Zn,Cr,Ti,V	TEL	
2	753	1788	2304	1971	NGRD	60	?	Cu,Ni*,Co*	?	
3	781	2547	2427	1971	NGRD	83	?	Cu,Ni,Zn,Cr*,Mn*	?	
			3545,	1972	SOIL	3049	AAS	Cu,Ni,Zn	?	Y
			3546		AUGER SOIL	106	AAS	Cu,Ni		
4	1040	164	3178	1972	NGRD	54	?	Cu,Ni,Zn,Fe*	?	
					SOIL	252	AAS	Cu,Ni,Zn	?	
5	1225/1	959	3758	1973	NGRD	28	?	Cu,Ni,Co,Cr,Pb,Zn	?	Y
					SOIL	101	AAS	Cu,Ni,Co,Cr,Pb,Zn	?	
6a	1996	874	7340	1977	NGRD	588	?	Cu,Ni,Co,Cr,Pb,Zn,Ag,Fe, Mn,Pt*	WMC	Y
					SOIL	199	?	Cu,Ni,Cr,Pb,Zn	WMC	
6b			7341	1977	NGRD	395	?	Cu,Ni,Co,Cr,Pb,Zn,Ag,Fe, Mn,FeO*,Cr_2O_3*	WMC	
					SOIL	407	?	Cu,Ni,Cr,Pb,Zn	WMC	
6c			8205	1978	SOIL	368	?	Cu,Ni,Cr,Pb,Zn	WMC	Y
					RAB	14	?	Cu,Ni,Co,Cr,Pb,Zn,Fe, Pt*,Pd*	WMC	
7	2493	1034	9001,	1980	SSED/SOIL	144			SPL	Y
			9320		SOIL	155			SPL	
					SSED	17			SPL	
					SOIL	34	?	Cu,Ni,Co,Cr,Zn,U	ANA	
8a	2900	1653	10653	1982	SSED	45	XRF	Ce,La,Th	?	
8b			11520	1982	SOIL	6	XRF	Li,P,Ti,Rb,Sr,Ba,La,Ce,Th	ANA	
					NGRD	25	XRF	Li,P,Ti,Rb,Sr,Ba,La,Ce,Th	ANA	
					SOIL	72	XRF	Li,P,Ti,Sr,Ba,La,Ce,Th	ANA	
					SSED	17	XRF	Li,P,Ti,Sr,Ba,La,Ce,Th	ANA	
					SOIL	185	XRF	Li,P,Ti,Co*,Ni*,Cu*,Y,Nb, Ba,La,Ce,Ta,Th	ANA	
					NGRD	8	XRF	Li,P,Ti,Co*,Ni*,Cu*,Y,Nb, Ba,La,Ce,Ta,Th	ANA	
					NGRD	9	XRF	Li,P,Ti,Rb,Sr,Ba,La,Ce,Th	ANA	
					NGRD	8	XRF	Li,P,Ti,Sr,Ba,La,Ce,Th	ANA	
9	3000	1487	11295	1982	NGRD	82	?	Cu,Ni,Cr,Pb,Zn,Ag,Au*, As*,Sn*,W*,Bi*	AMD	
10	3956	1805	16087	1985	NGRD	35	FA	Au	CCL	
					SSED	12		Au	CRAE	
					SSED	12	FA	Au	CCL	
					NGRD	38	?	Au,Th,U,Pt,Pd	ANA	

for BYRO as at August 2000

Description
Reconnaissance sampling. Stream sediments and soil sieved to -80#. Rock samples crushed to -80# Samples collected from in situ rock Soil samples collected from the B or C horizon over a 500 × 200 ft grid. 60 repeat samples were collected Samples taken from 10 costeans. Some samples also analysed for Pd and Pt Auger drilling, approximately 300 vacuum drillholes were drilled, 107 samples taken from –4 m depth
Primary dispersion sampling of ultrabasic rock outcrops at Noonie Hills
Grab sampling of rocks during geological mapping Sample depth was approx. 6 inches. Grids: 400 × 100 ft and 200 × 50 ft Shallow drilling averaging 9 ft in depth. Sample comprised rock chips from bottom of hole
Surface samples taken to assist mapping. Some studied in thin section Depth: 6 inches. Sieve: -80 #
Rock-chip samples of mafic rocks cropping out in a BIF–mafic zone Samples taken using a power auger. Depth: 15–60 cm, Sieve: -80#, Grid: 50 × 25 m
Blanket ironstone sampling. Grid: 1000 × 100 m Soil sampling over a north–south-trending fracture zone. Grid: 1000 × 50 m. Depth: 10 cm Blanket ironstone sampling. Grid: 1000 × 500 m Soil sampling on west side of an intrusive belt. Grid: 200 × 20 m. Depth: 10 cm Soil sampling across a fracture zone. Grid 200 × 50 m. Sieve: -10 + 36 #. Depth: 10 cm Percussion drilling (seven holes) beneath geochemical anomalies along a fracture zone. Depth: 0–4 m
Mineralogical examination of stream-sediment and loam samples for heavy minerals and kimberlite indicators. Sampling area: 800 km^2 Mineralogical examination of loam samples for kimberlite indicators. Sampling area: 7 km^2 Mineralogical examination of stream sediment for kimberlite indicators. Sampling area: 7 km^2 Orientation samples collected over an aeromagnetic anomaly. Sampling area: 1 km^2
Heavy-mineral concentrate sampling from drainages Sieve: -80# Rock samples taken over circular features (possible alkaline intrusive plugs) and in drainage basins Soil samples sieved to -80# Stream-sediment samples taken from a circular feature identified from airphotos Sieve: -80# Rock samples from drainages Rock samples from circular features identified from airphotos Rock samples from circular features identified from airphotos
Reconnaissance rock-chip sampling
Composite rock-chip samples. Weight: 1.0–0.8 kg Stream gravel samples. Weight: 20 kg. Sieve: -2.8 mm. Heavy mineral concentrate +2.95 SG Mineralogical examination of non-magnetic concentrate split for gold Heavy-mineral concentrate split submitted for gold analysis. Three repeat analyses Composite rock-chip samples

Appendix 2.

ID no.	M. no	I. no.	A. no.	Year	Activity type	No.	Method	Activity elements	Analyst	DD
11a	4176	3328	16800	1985	NGRD	32	AAS	Cu,Ni,Co,Cr,P		
					“		ICP	Fe,Mg,Al,Si,S,Cr		
					SSED	25	AAS	Cu,Ni,Co,Cr,P	?	
					“		ICP	Fe,Mg,Al,Si,S,Cr		
					NGRD	6	AAS	Cu,Ni,Co,Cr,Pb,Zn, Fe, Mn,Mo,Au		
							XRF	As,W,Sn		
11b			18890	1986	NGRD	18	AAS	Cr	AS	
					“		ICP	Au	AS	
					SSED	16	AAS	Cr	AS	
					“		ICP	Au,Pt,Pd	AS	
12	4267	3036	18822	1986	SOIL	51	AAS	Cu,Ni,Co,Cr		
					“		FA/AAS	Pt,Pd		
					SSED	25		Pt,Pd		
					NGRD	17		Pt,Pd		
13	4699*	3269	21145, 21146	1987	SSED	680	FA/BCL	Au,Pt,Pd,Cu*	GLS/MIN	
					NGRD	225	AAS	Au,Ag*,Cu*,As*,Pt*,Pd*	GLS/MIN	
14a	4527	3814	20264	1987	NGRD	297	?	Au,Cu*,Zn,*Pb*	ANA	
					SSED	382	?	Au	ANA	
14b			24015	1988	NGRD	13	?	Au	ANA	
					SSED	389	AAS	Au	ANA	
					SSED	107	AAS	Au	ANA	
					NGRD	136	AAS	Au	ANA	
					SOIL	72	AAS	Au	ANA	
					SOIL	531	AAS	Au	ANA	
14c			26660	1988	SOIL	168	AAS	Au	ANA	
					NGRD	49	AAS	Au	ANA	
15	6284	3887	28189	1988	SSED	27	BLEG	Au	CCL	
					SSED	27	XRF/AAS	As,Ce,La,Mo,Pb,Y,Zn, Zr	CCL	
					SSED	75	BLEG	Au, Cu, Ag	CCL	
					SSED	75	XRF/AAS	As,Cs,Cu,In,La,Nb,Pb, Rb,Sr,Zn	CCL	
					SOIL	473	BLEG	Au	CCL	
					SOIL	55	XRF/AAS	As,Cs,Cu,Pb,Zn	CCL	
					SOIL	67	BLEG	Au	CCL	
					NGRD	6	AAS	Au,As	CCL	
16	6104*	3873	27455	1989	SSED	67	BCL	Cu,Pb,Zn,Au,Ag,Pd	AAL	
					SSED		AAS	Pb,Zn	AAL	
					SOIL	321	AAS	Au,Cu,Zn,Ag,Pb,Ba	AAL	
					NGRD	5	AAS	Cu,Pb,Zn,Au,Ag	AAL	
					NGRD		FA/ETA	Pt,Pd	AAL	
					SOIL	170	AAS	Cu,Zn,Ag,Pb	GLS	
					SOIL		ETA	Au	GLS	
					SOIL		XRF	Ba	GLS	
					SSED	8		Au, Pd, Pt, Ag	GLS	
17	6434	4014	29016	1989	SSED	74	BCL	Au	SGS	
					SSED	74		Ni,Cr	SGS	
					SSED	74	XRF	Nb	SGS	
					NGRD	26	BCL	Au	SGS	
					NGRD	26		Ni,Cr	SGS	

(continued)

Description
Grab samples Steam-sediment samples collected downstream from chromitite lens Pisolitic laterite samples Regional sampling of magnetic pisolites Stream-sediment sampling over areas where previous anomalous Cr values were obtained
Samples taken along grid line at 10 m intervals. Weight: 500 g. Depth: 10–20 cm
FA: 6 litres of sieved (-80#) material collected and pan concentrated. Samples collected from poorly developed drainages and smaller tributaries BCL: 3 litres of sieved (-80#?) material treated by bulk sample assay technique. Samples collected from major drainages Float and outcrop material proximal to stream samples and from prospecting traverses across drainages of anomalous stream samples
Reconnaissance rock-chip sampling Gold results (ppm) shown on plan 1:20 000 Systematic regional stream-sediment sampling Samples collected from streams with previous recorded values of >8 ppb. Samples located 50–100 m apart along streams. Sieve: -10 + 40# Preliminary rock-chip sampling of heavy mineral and conglomerate units Reconnaissance soil sampling lines with sample spacing approximately 20 m Infill soil sampling. Grid: 100 × 20 m. Sieved -10 + 40# Follow-up soil sampling. Grid: 100 × 20 m. Sieved -10 + 40# Rock-chip sampling carried out where soil values from previous programs were greater than 20 ppb
Vehicle collected stream BLEG samples Sieved -80# Helicopter collected stream BLEG samples Sieved -80# Soil BLEG samples collected from a 2000 × 200 m grid covering 210 km^2 Sieved -80# Auger penetrated only 1.5 m due to cemented duricrust. Samples collected from 1000 × 200 m grid covering 20 km^2 Vein quartz samples collected from vicinity of low-level gold anomaly
Weight: 4 kg. Sieve: -6 mm. Gold detection limit: 1 ppb Weight: 2 kg. Sieve: -6 mm. 40 m intervals along selected traverses Five rock-chip samples taken from E09/260 Follow-up sampling program. Five 2 km E–W traverses. Samples collected at 100 m intervals with infills at 50 m over prospective areas
Numbers of samples collected not detailed in the report. Report refers to details of stream sediment, soil and rock-chip samples collected as follow-up to Geoscan AMSS anomalies by a previous tenement holder. Assays for these samples are included in the report along with assays from current phase of exploration. The two phases of results are not differentiated. The two phases of sampling are plotted on the sample location map. Not all of the first phase of sampling is shown. Unable to distinguish between the two phases of sampling. Sample numbers on the map do not correspond fully with the available assay results

Appendix 2.

ID no.	**M. no**	**I. no.**	**A. no.**	**Year**	**Activity type**	**No.**	**Method**	**Activity elements**	**Analyst**	**DD**
17 (cont)					NGRD	26	XRF	Nb	SGS	
					UNDIF	69	BCL	Au	SGS	
					UNDIF	69		Ni,Cr	SGS	
					UNDIF	69	XRF	Nb	SGS	
18a	6277	5323	28140, 28141	1989	SSED	56			ANA/NOR	
					SSED	22	ICP-OES	Ni,Cr,Y,Nb,Ba,La,Ce,Nd, Th,Mg,P,K,Ti,Rb,Sr	ANA	
18b			31240	1990	SSED	19				Y
					SSED	2				
					SOIL	1				
					SSED	19	ICP-OES	Ni,Cr,Y,Nb,Ba,La,Ce,Nd, Th,Mg,P,K,Ti,Rb,Sr	ANA	
					SSED/SOIL	3	ICP-OES	Ni,Cr,Y,Nb,Ba,La,Ce, Nd,Th,Mg,P,K,Ti,Rb,Sr	ANA	
18c			31826	1990	SOIL	29			DIA	
					SOIL	20	AAS, ICP	Ni,Cr,Nb,Ba,La,Ce,Cu,Pb, Zn,Ag,Au	ALS	
19	6483	6054	29527	1989	NGRD	130	AAS	Cr	GLS	
			32073	1990	SSED	16	AAS	Au,Pt,Pd,Cr,Cu,Ag	GLS	
					NGRD	37	AAS	Au,Cu,Zn,As,Pb	GLS	
					RAB	26	AAS	Au,Pt,Pd,Cr,Cu	GLS	Y
20	7138*	5916	34566	1991	SSED	41	AAS	Au,Cu,Zn,Ag,As	WMC	
					NGRD	110	AAS	Au,Cu,Zn,Ag,As	WMC	
					SOIL	138	AAS	Au.As,Ag	WMC	
					SSED	450	?	Au,Ni,Cu,Fe,Pb,Zn,Bi,As, Sb,W	WMC	
					SSED	107	?	Au	WMC	
					SOIL	138	?	Au	WMC	
					NGRD	36	?	Au	WMC	
21a	8158	8307	38953	1993	SOIL	986	AAS	Au	AMD	
					NGRD	4	ICP/AAS	Au,As,Ag,Cd,Co,Cu,Fe, Mn,Mo,Ni,Pb,P,V,Zn,Bi	AMD	
21b			41979	1994	SSED	40	ETA	Au,V,Cr,Mn,Co,Ni,Cu,Zn, As,Mo,Ag,Pb,Bi,Cd	GLS	
					NGRD	12	ETA	Au,V,Cr,Mn,Co,Ni,Cu,Zn, As,Mo,Ag,Pb,Bi,Cd	GLS	
22a	8965	7946	42235	1994	SSED	186	BLEG	Au,Ag,Pd,Cu	ARA	
					SOIL	541	BLEG	Au,Ag,Pd,Cu	ARA	
					SOIL	541	ICP	Cu,Zn,Pb,Ni,Fe,Mn,Mo,As	AAL	
					SOIL	583	FA	Au	ALS	
					SOIL	583	ICP	Cu,Zn,Pb,Ni,Fe,Mn,Mo,As	ALS	
					NGRD	686	FA	Au	ALS	
					NGRD	686	ICP	Cu,Zn,Pb,Ni,Fe,Mn,Mo,As	ALS	
22b			44544	1995	NGRD	69	FA	Au	ALS	
					SSED	4	FA/BLEG	Au	ALS	
23	9623/3*	9387	51969	1996	SSED	45			SPL	
					SOIL	11			SPL	
24	9650/3	8881	49019	1996	SSED	127	BCL	Au,Pd	ANA	
					SSED	127	ICP-OES	Cu,Ni,Pb,Zn,As	ANA	

(continued)

Description

Weight: 20 kg. Sieve: +3.35 mm, +0.3 mm and -0.3 mm. Observed for chromite, pyrope garnet, zircon, rutile and other diamond indicators
Concentrates from drainage samples. Sieve: -0.3 mm

Weight: 50 kg. Sieve: +0.4 mm, +0.25 mm. Mineralogical examination of stream samples for kimberlite indicators. Only chromites reported
Weight: 50 kg. Sieve: +0.4 mm, +0.25 mm. Mineralogical examination of stream samples for kimberlite indicators. Only chromites reported
Weight: 50 kg. Sieve: +0.4 mm, +0.25 mm. Mineralogical examination of loam samples for kimberlite indicators. Only chromites reported
Concentrates from drainage samples. Sieve: -0.4 mm

Concentrates from drainage and soil samples. Sieve: -0.4 mm

Weight: 22 kg. 20 samples to test 'Murchison hardpan – cement' as a secondary source of kimberlitic indicator minerals
9 samples testing magnetic anomalies
Concentrates from sediment samples

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9 costeans sampled at 2 m intervals
Samples from all streams in tenement
Samples from all BIF's in tenement
101 RAB holes drilled. 5 m composite samples from 26 holes assayed

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Reconnaissance stream and soil samples collected in two fractions, -6 mm + 2 mm and -2 mm
Reconnaissance rock samples
Reconnaissance soil samples
Weight: 2 kg. Regional drainage survey. Nominal density 1 sample/km^2. -6 mm + 2 mm fraction assayed

Stream samples collected from vicinity of weakly Au-anomalous reconnaissance stream-sample sites
Soil samples collected from vicinity of weakly Au-anomalous reconnaissance stream-sample sites
Rock samples collected from vicinity of weakly Au-anomalous reconnaissance stream-sample sites

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Samples collected at 25 m intervals along lines 500 m apart then combined into 50 m composites for analysis
Samples from outcropping gossans

Two size fractions collected from each location; -5 mm + 2 mm and -2 mm

Weight: 2 kg

Three phases of sampling. Sample spacing varies from 1000 × 1000 m down to 100 × 500 m and 5 × 1000 m in areas of interest

Petrographic analysis of selected samples
A trap-site bulk sample (-8 mm) and a fine (-2 mm) sample were collected from each site

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Reconnaissance stream-sediment samples examined for kimberlitic indicator minerals
Loam samples collected from magnetic anomalies and examined for kimberlitic indicator minerals

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Weight: 5–10 kg. -2 mm clay and silt overbank material. Average density of 1 sample/2 km^2

Appendix 2.

ID no.	**M. no**	**I. no.**	**A. no.**	**Year**	**Activity *type***	**No.**	**Method**	**Activity elements**	**Analyst**	**DD**
25a	10438*	10368	53134	1997	SSED/SOIL	1127	?		?	
25b			58219	1998	SSED/SOIL	494				
						2	?	Ni,Cu,Ce,La,Co,Mo,U,Ba, Cr,Nb,Pb,Y,Rb,V,Zr,As, Au,Zn,Cs,Sr,Th,Pr,Er,Eu, Gd,Lu,Nd,Sm,Tb,Yb,Cd, Hf,Sc,Ga,Sb,Ho	?	
						2	?	Al_2O_3,SiO_2,TiO_2,Fe_2O_3, MnO,CaO,K_2O,MgO, P_2O_5,SO_3,Na_2O,LOI	?	
26a	10595	9983	54903	1998	SSED	170				
					SOIL	78				
26b			55004	1998	SSED	190				
					SOIL	59				
26c			57016	1998	NGRD	6	XRF	Ba,Ce,Cr,La,Nb,Ti,V,Zr	ANA	
							ICP-OES	P,Zn,Ca,Co,Cu,Fe,K,Mg, Mn,Na,Ni,	ANA	
							ICP-MS	Ag,As,Bi,Cd,Mo,Pb,Sb	ANA	
					SOIL	1	XRF	Ba,Ce,Cr,La,Nb,Ti,V,Zr	ANA	
							ICP-OES	P,Zn,Ca,Co,Cu,Fe,K,Mg, Mn,Na,Ni,	ANA	
							ICP-MS	Ag,As,Bi,Cd,Mo,Pb,Sb	ANA	
					SSED	3	ICP-MS	Au,Pt,Pd,Nb,La,Rb,Th,U	UT	
							ICP-OES	P,Sr,V,Ni,Cu,Co,Cr,Mn, Fe,Mg,Pb,Zn,As,Ag,Ca,K	UT	
					NGRD	7	ICP-MS	Au,Pt,Pd,Nb,La,Rb,Th,U	UT	
							ICP-OES	P,Sr,V,Ni,Cu,Co,Cr,Mn, Fe,Mg,Pb,Zn,As,Ag,Ca,K	UT	

NOTE: # mesh size

(continued)

Description

Numbers of stream and loam samples undifferentiated. Mineralogical examination of heavy mineral concentrates for kimberlitic indicator minerals
Microprobe data available

Weight: 50–60 kg. -2 mm material processed and examined for kimberlitic indicator minerals. -25 + 40# geochemical samples collected but not analysed
Weight: 50–60 kg. -2 mm material processed and examined for kimberlitic indicator minerals. -25 + 40# geochemical samples collected but not analysed
Weight: 50–60 kg. -2 mm material processed and examined for kimberlitic indicator minerals. -25 + 40# geochemical samples collected but not analysed
Weight: 50–60 kg. -2 mm material processed and examined for kimberlitic indicator minerals. -25 + 40# geochemical samples collected but not analysed
Analyses to determine kimberlitic affinities of altered ultramafic float

Orientation stream and duricrust samples to test areas potential for nickel mineralization

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.

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 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

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

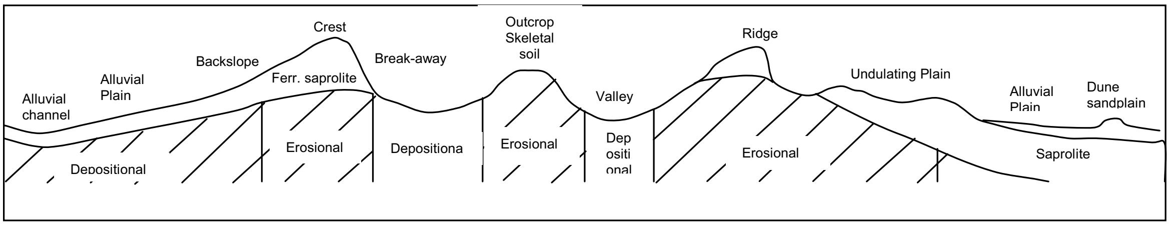
Sheet SG 50-10_**Zone** 50 | **Loc/n No**____________ | **GSWA No**____________ | **Date**__________

Site Ref__________________ | __________________ **E** | ___________________ **N** | **Sampler**_______

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

Site description

Drainage heading________ Width ______m
☐ Single ☐ Braided ☐ Incised



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

<u>Surface</u> regolith material: ___%clasts ___%Sand ___%Clay ___%Other____________ Colour ________________

<u>Downhole</u> 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 **A**bnt/**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	☐ *A*rk / *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)

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____
____

Figure 3.1. Sample recording form for Byro

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 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

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	

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 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

Table 3.2. Primary regolith codes for GSWA maps

Primary landform code	*Environment and process*	*Notes*
R	Residual or Relict	Remnant material overlying an ancient land surface. Residual material is derived by in situ weathering and shows no evidence of having undergone significant transport. Relict material comprises deposits of uncertain origin, either transported or residual, or a combination of both. The term relict should not be used if the original depositional process can be determined. In such cases the appropriate primary code (e.g. A, C, W), together with a relative age qualifier, should be used instead
X	Exposed	Used for rock (optional) and weathered rock. Includes subcrop and bouldery lag
C	Colluvial	Proximal mass wasting deposits grading into sheetwash with a significant to perceptible slope
W	Low-gradient slope	Distal slope deposits (sheetwash and sheet flood) where the gradient is minimal, and drainage is not clearly defined
A	Alluvial / fluvial	Alluvium in channels and floodplains. Includes deltaic deposits
L	Lacustrine	Inland lakes, dune and playa terrain, and some coastal lakes. 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 mixed origin, including residual, sheetwash and eolian sands
B	Coastal (wave-dominated)	Beaches, beach ridges, barrier bars and lagoons, and back-beach dunes, coastal cliffs and other erosional features e.g. blowouts
T	Coastal (tide-dominated)	Intertidal and supratidal flats and channels, estuaries, and mangrove flats
M	Marine	Subtidal, shoreface, and offshore marine deposits such as coralgal reefs, shell banks, and sea-grass banks
V	Valley	Higher level category; includes lacustrine, alluvial, floodplain, sheetwash, and colluvial
K	Coastal	Higher level category; includes wave- and tide-dominated coastal, and marine
D	Depositional	Includes all depositional systems

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) reported 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 BYRO are presented as a series of digital datafiles on the accompanying compact 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.

Table 3.3. Landform (primary) code qualifiers

Primary landform /process	*Landform element or pattern*	*Suggested primary code*	*Suggested subscript code*
Residual or relict		R	
	In situ weathered (residual)		R_I
	Duricrust (residual or relict)		R_r
	Sand (residual or relict)		R_s
	Transported (relict)		R_t
Exposed		X	
	Deeply weathered		X_w
Colluvial (proximal slope)		C	
	Cliff-foot slope		C_c
	Footslope		C_f
	Landslide		C_l
	Scarp-foot slope		C_s
	Talus		C_t
Low gradient slope (sheet-flood, distal slope)		W	
	Sheet-flood fan		W_f
	Playa, pan		W_p
	Scarp-foot slope		W_s
Alluvial		A	
	Alluvial plain		A_a
	Stream bed		A_b
	Stream channel		A_c
	Drainage depression /swale		A_d
	Delta		A_e
	Floodplain		A_f
	Gravel bar		A_g
	Channel bench		A_h
	Stream bank		A_k
	Levee		A_l
	Meander plain		A_m
	Backplain		A_n
	Playa, pan		A_p
	Stream bar		A_r
	Sand bar		A_s
	Terrace		A_t
	Superficial channel		A_u
	Fan/ flood-out		A_v
	Swamp		A_w
	Ox-bow		A_x
Lacustrine		L	
	Fringing dunes		L_d
	Fringing bedded deposits		L_g
	Lake, excluding fringing deposits		L_l
	Dune and playa terrain		L_m
	Playa		L_p
	Saline lake		L_s
	Subcropping bedrock in lake		L_x
Eolian		E	
	Parabolic dunefield		E_a
	Blow-out		E_b
	Dunefield		E_d
	Dune		E_e
	Longitudinal dunefield		E_l
	Mobile dune		E_m
	Net-like dunefield		E_n
	Sand and playa terrain		E_p
	Lunette		E_u
	Interdune pavements		E_v
	Swampy swale		E_w
Sandplain; residual, uncertain, and mixed origin		S	
	Blow-out		S_b
	Dune		S_d
	Gravel deflation pavement		S_g
	Longitudinal dunefield		S_l

Table 3.3. (continued)

Primary landform /process	*Landform element or pattern*	*Suggested primary code*	*Suggested subscript code*
Sandplain; residual, uncertain, and mixed origin (cont.)	Net-like dunefield		S_n
	Sand and playa terrain		S_p
	Undulating		S_u
Coastal (wave-dominated)		*B*	
	Beach (foreshore and backshore)		B_b
	Cliffs		B_c
	Foredune		B_d
	Foreshore		B_f
	Backshore		B_k
	Back-barrier lagoon		B_l
	Mobile dunes		B_m
	Boulder beach		B_o
	Beach ridge plain		B_r
	Storm beach gravels		B_s
Tide-dominated		*T*	
	Tidal bar, in channel		T_b
	Tidal channel (subtidal base)		T_c
	Tidal delta		T_d
	Estuary		T_e
	Tidal flat (intertidal and supratidal)		T_f
	Chenier plain		T_h
	Intertidal flat		T_I
	Lagoon		T_l
	Mangrove flats		T_m
	Superficial channel (intertidal)		T_s
	Supratidal flat		T_u
Marine		*M*	
	Coral reef		M_c
	Shell bank		M_k
	Plain, nearshore		M_n
	Plain, offshore		M_p
	Reef flat / backreef/rock flat		M_r
	Shoreface		M_s
	Relict channel		M_v

NOTES: These combinations should be followed where possible, however, the list is not exhaustive. Landform elements and patterns largely follow McDonald et al. (1990)

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).

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).

Table 3.4. Secondary codes and qualifiers for regolith composition

Code	*Composition*	*Qualifier*	*Composition*
c	clay	c_b	black soil/ gilgai
		c_c	chlorite
		c_g	glauconite
		c_k	kaolin
		c_i	illite
		c_m	montmorillonite
		c_s	smectite
d	undivided		
e	evaporite	e_a	anhydrite
		e_g	gypsum
		e_h	halite
f	ferruginous	f_g	gossan
		f_h	hematite
		f_l	limonite
		f_o	goethite
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
k	carbonate	k_a	aragonite
		k_c	calcite
		k_d	dolomite
		k_m	magnesite
l	heterogeneous		
m	ferromagnesian		
q	quartz		
r	carbonaceous/organic	r_c	coal
		r_h	humus
		r_p	peat
		r_y	pyritic
t	lithic (rock fragments)		
u	ultramafic		
x	other mineral	x_a	aluminous/bauxitic
		$\mathrm{x_i}$	mica
		x_m	manganese
z	siliceous		

Table 3.5. 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
h	hypabyssal	h_d	dolerite
		h_p	porphyry
i	iron cement		
k	carbonate cement		
m	metamorphic	m_n	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_r	gabbro
		p_d	diorite
		p_g	granite
		p_m	monzogranite/monzonite
		p_o	granodiorite
		p_s	syenogranite/syenite
		p_t	tonalite
r	duricrust		
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_r	rhyolite
		v_t	trachyte
		v_v	volcaniclastic
z	silica cement		

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 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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Figures

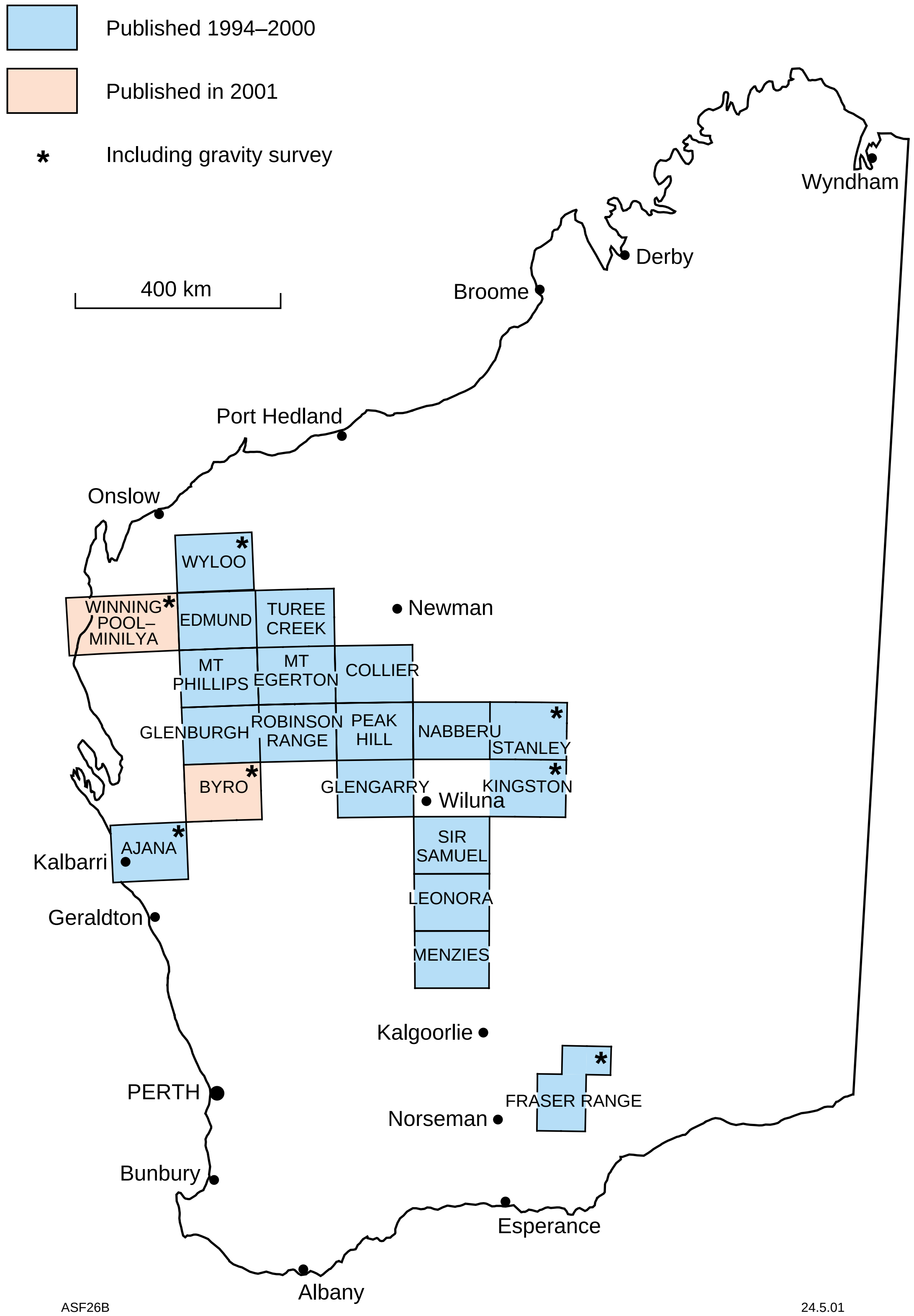
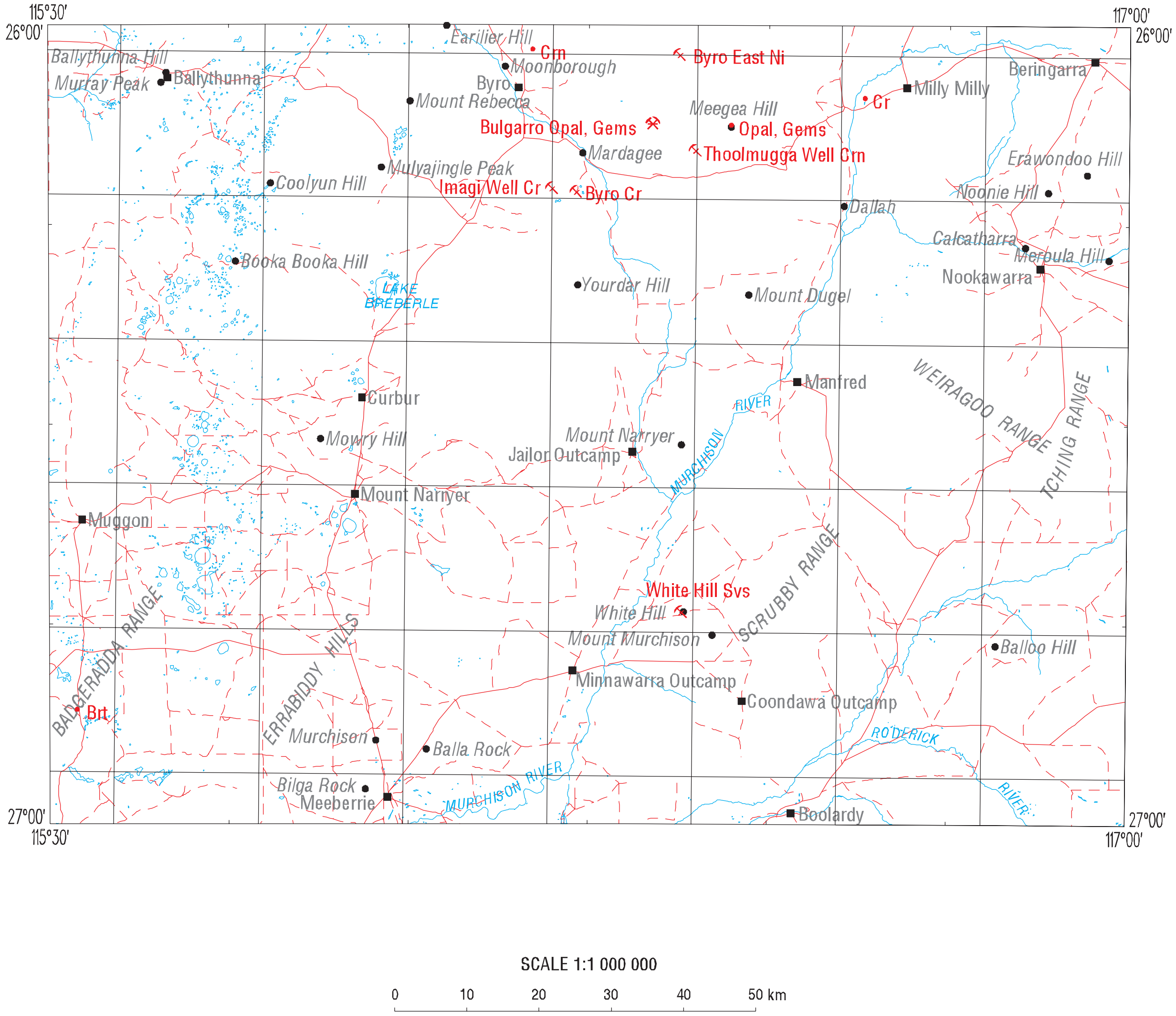


Figure 1. Status of GSWA regional regolith and geochemical mapping program.

SIMPLIFIED LOCALITY PLAN



SYMBOLS

(red line)	Formed road
(red dashed line)	Track
(blue line)	Watercourse
(blue outline)	Lake
■ Byro	Homestead
● *Mount Rebecca*	Locality
Bulgarro	Opencut, abandoned
Byro East	Prospect
●	Mineral occurrence
Brt	Barite
Cr	Chromium
Crn	Corundum
Gems	Gemstones
Ni	Nickel
Opal	Opal
Svs	Silica

BYRO

SHEET SG 50-10

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Figure 2

14 Jun 01 08:59:16

INTERPRETED BEDROCK GEOLOGY

PHANEROZOIC — EARLY PERMIAN

Byro Group

Bioturbated siltstone and fine-grained sandstone

Wooramel Group

Siltstone, quartzose or feldspathic sandstone, carbonaceous shale, and minor claystone

Lyons Group

Immature sandstone, siltstone, shale, micaceous claystone, and tillite; numerous glacial erratics

PROTEROZOIC

Badgeradda Group

Siltstone, silty sandstone, feldspathic and quartzose sandstone, and minor pebble-conglomerate lenses

ARCHAEAN — YILGARN CRATON

Narryer Terrane

YARRA YARRA GRANITE: coarse-grained, equigranular, leucocratic monzogranite; metamorphosed at granulite facies

CHURLA GRANITE: coarse-grained, equigranular, leucocratic monzogranite; metamorphosed at granulite facies

BALLA GRANITE: coarse-grained, porphyritic to equigranular monzogranite, with inclusions of **EURADA GNEISS**; metamorphosed at amphibolite facies

IMPEY GRANITE: heterogeneous, coarse-grained, porphyritic to equigranular monzogranite; metamorphosed at amphibolite facies

Coarse-grained, equigranular to porphyritic granite, locally with inclusions of amphibolite, ultramafic rock, metasedimentary rock, or gneiss

YALLALONG GRANITE: coarse-grained, equigranular, leucocratic monzogranite; metamorphosed at granulite facies

WANDARRIE GRANITE: coarse-grained, equigranular, leucocratic monzogranite

Undivided metasedimentary rocks, including banded iron-formation, quartz-magnetite rock, pelite, quartzite, conglomerate, sandstone, silicic schist, mylonite, quartz-mica schist, and micaceous quartzite; subordinate metagabbro, ultramafic schist, and amphibolite

MILGA GNEISS: granodioritic gneiss

DUGEL GNEISS: monzogranitic and syenogranitic gneiss

EURADA GNEISS: monzogranitic to tonalitic gneiss, with inclusions of **MEEBERRIE GNEISS** and veined by **DUGEL GNEISS**

MEEBERRIE GNEISS: monzogranitic to tonalitic gneiss, veined by **EURADA GNEISS** and **DUGEL GNEISS**

Murchison Granite-Greenstone Terrane

WEIRAGOO GRANITE: porphyritic to equigranular monzogranite; metamorphosed at amphibolite facies

CUNDARRA GRANITE: coarse-grained, equigranular to porphyritic monzogranite; metamorphosed at amphibolite facies

TCHING GRANITE: monzogranite with inclusions of **BEARRA GNEISS**; metamorphosed at amphibolite facies

BEARRA GNEISS: dioritic and leucogranitic gneiss, possibly an earlier phase of the **TCHING GRANITE**

Geological boundary

Fault

Anticline

Syncline

BYRO

SHEET SG 50-10

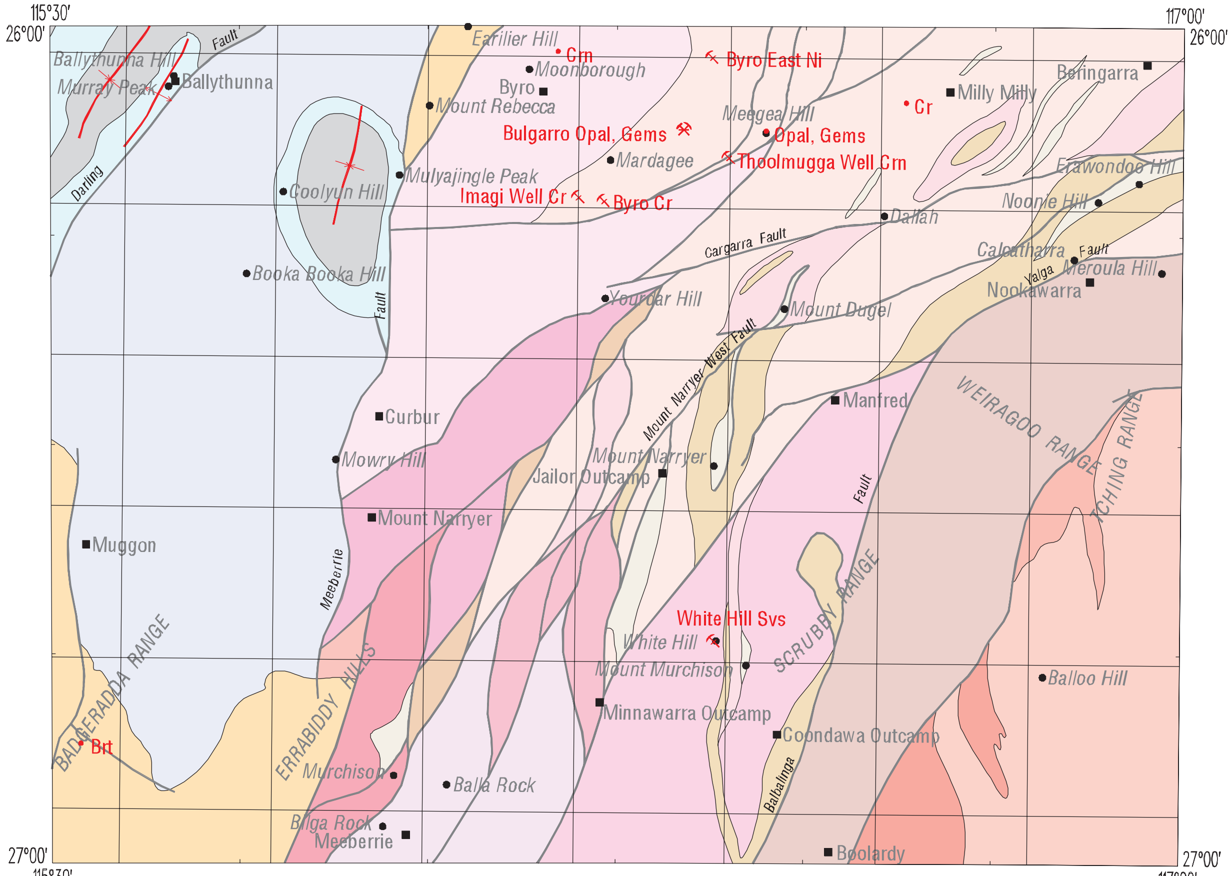
First Edition 2001

Figure 3

14 Jun 01 09.01.17

INTERPRETED BEDROCK GEOLOGY

See Figure 3 for geology reference



Geological interpretation after Myers (1997), Myers and Hocking (1998)

SCALE 1:1 000 000

0 10 20 30 40 50 km

SYMBOLS

■	Byro	Homestead
●	*Mount Rebecca*	Locality
⚒	Bulgarro	Opencut, abandoned
⛏	Byro East	Prospect
●		Mineral occurrence
	Brt	Barite
	Cr	Chromium
	Crn	Corundum
	Gems	Gemstones
	Ni	Nickel
	Opal	Opal
	Svs	Silica

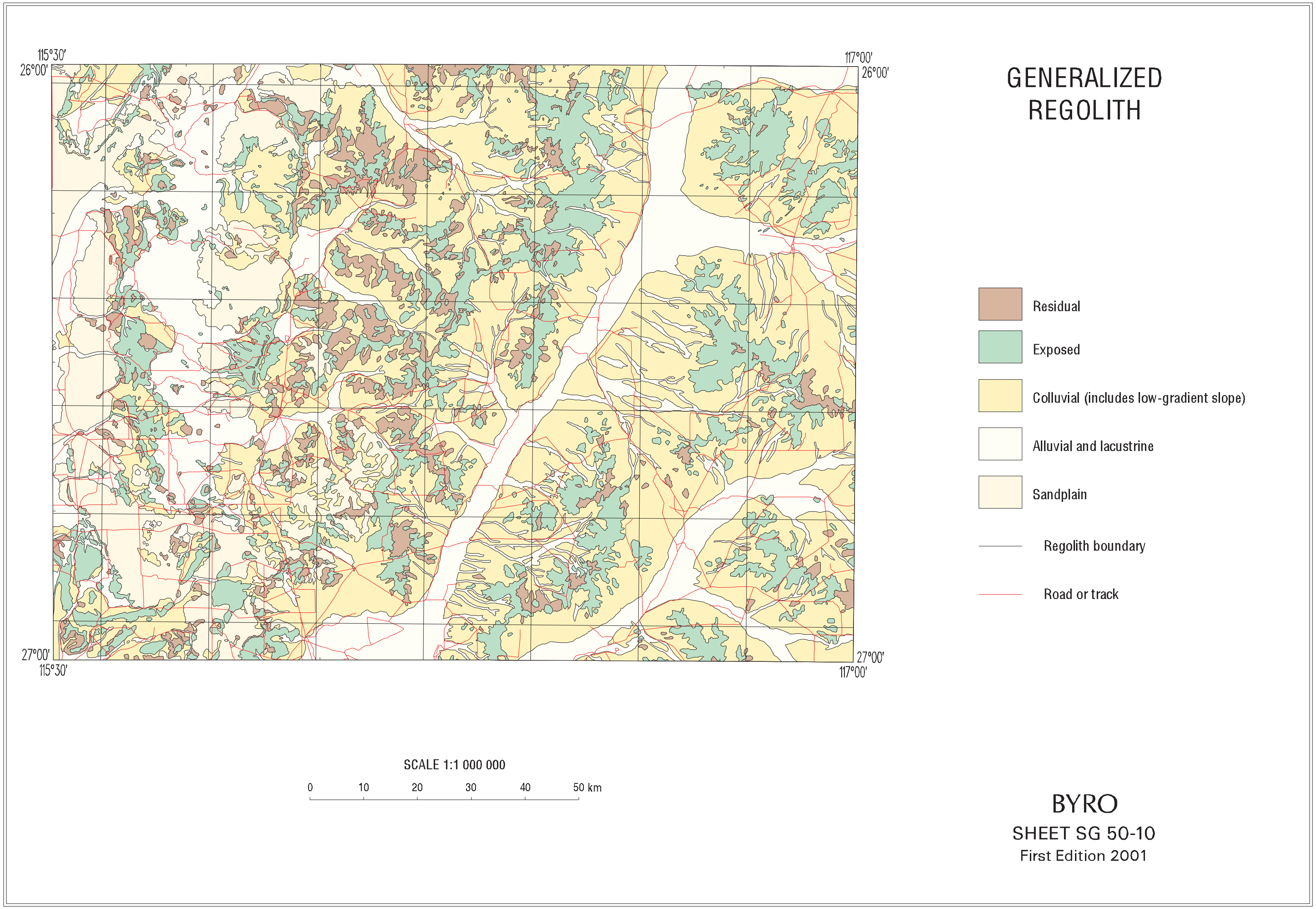
BYRO

SHEET SG 50-10

First Edition 2001

Figure 4

14 Jun 01 09.00.49



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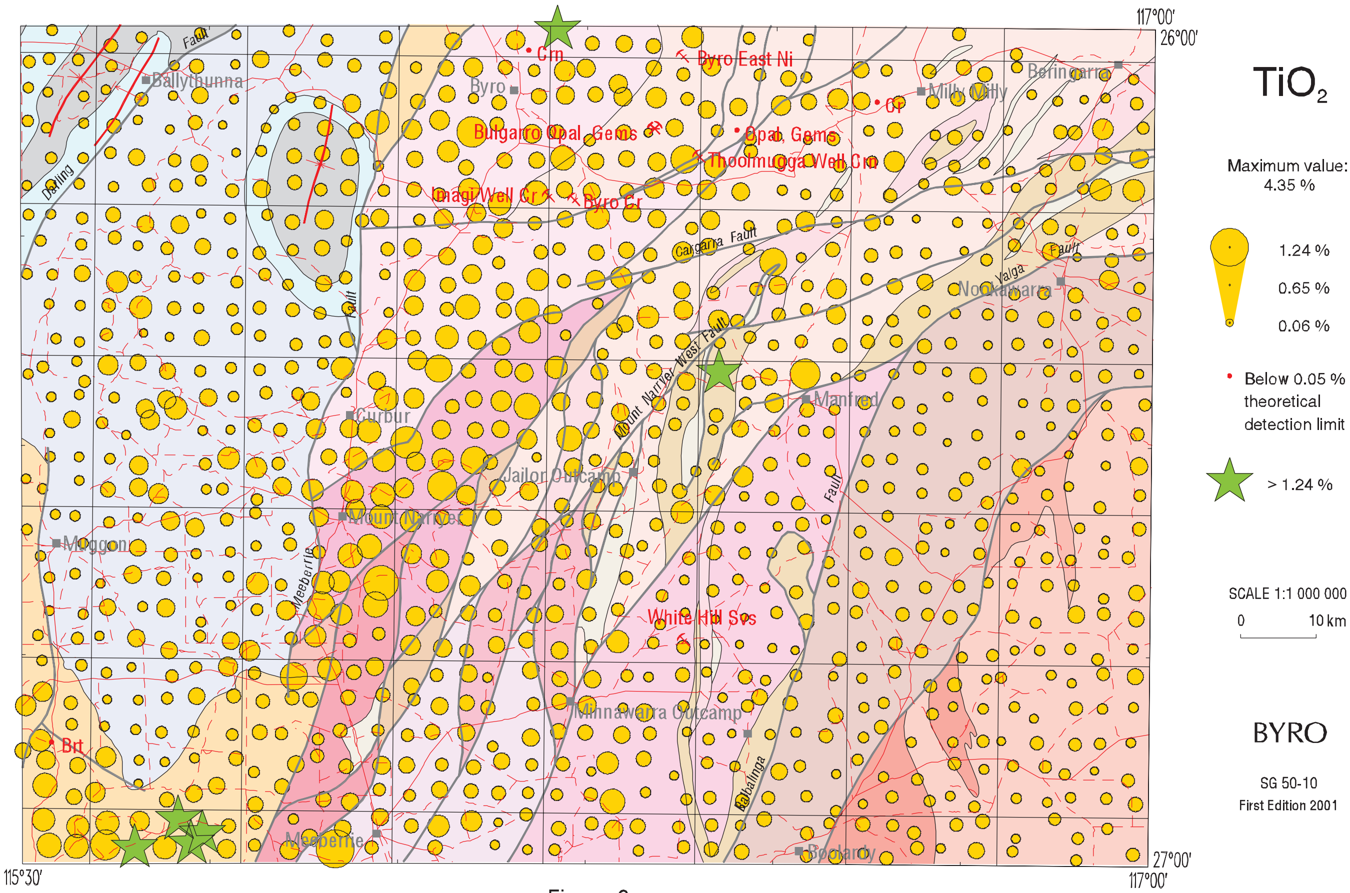

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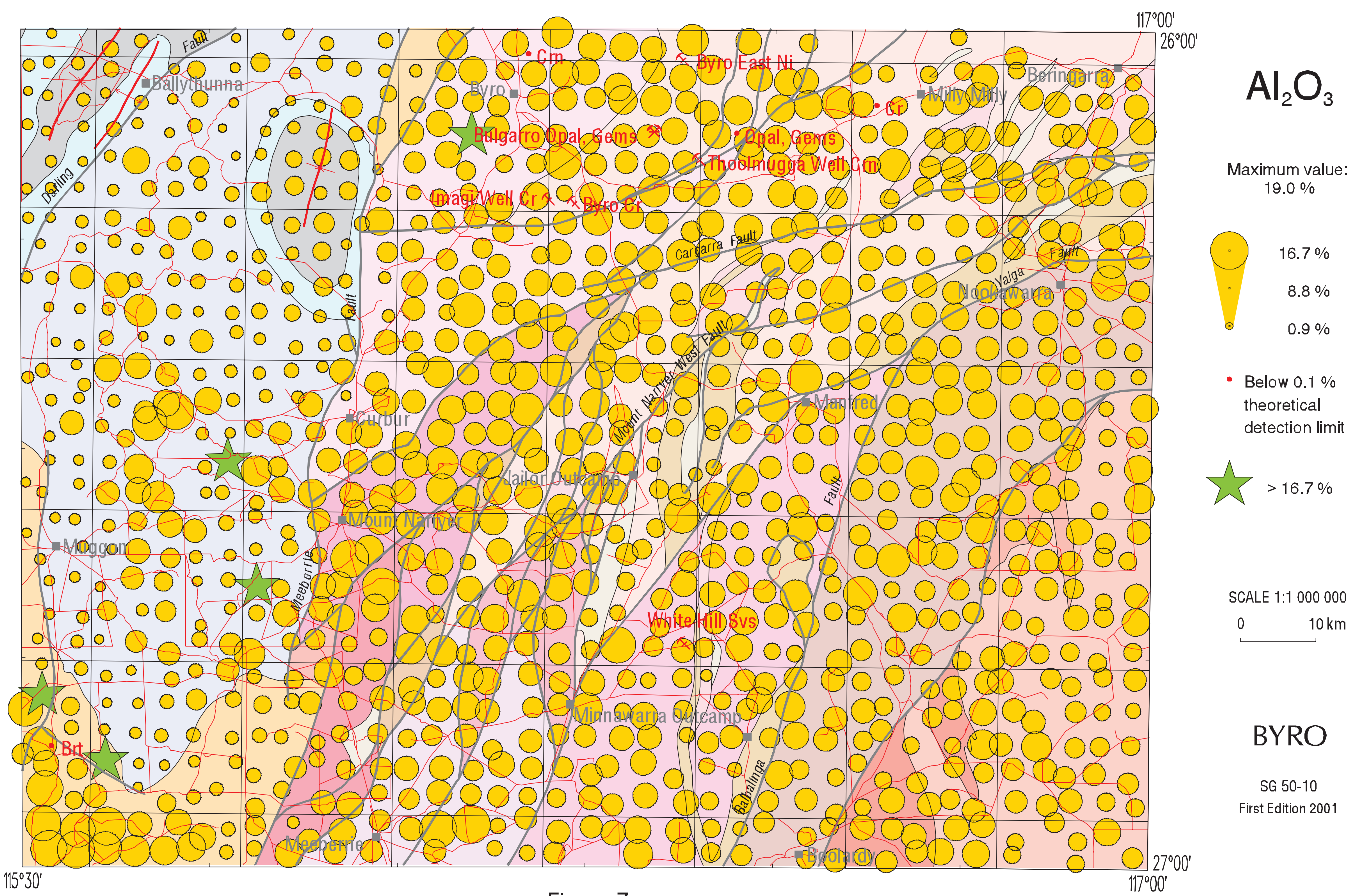

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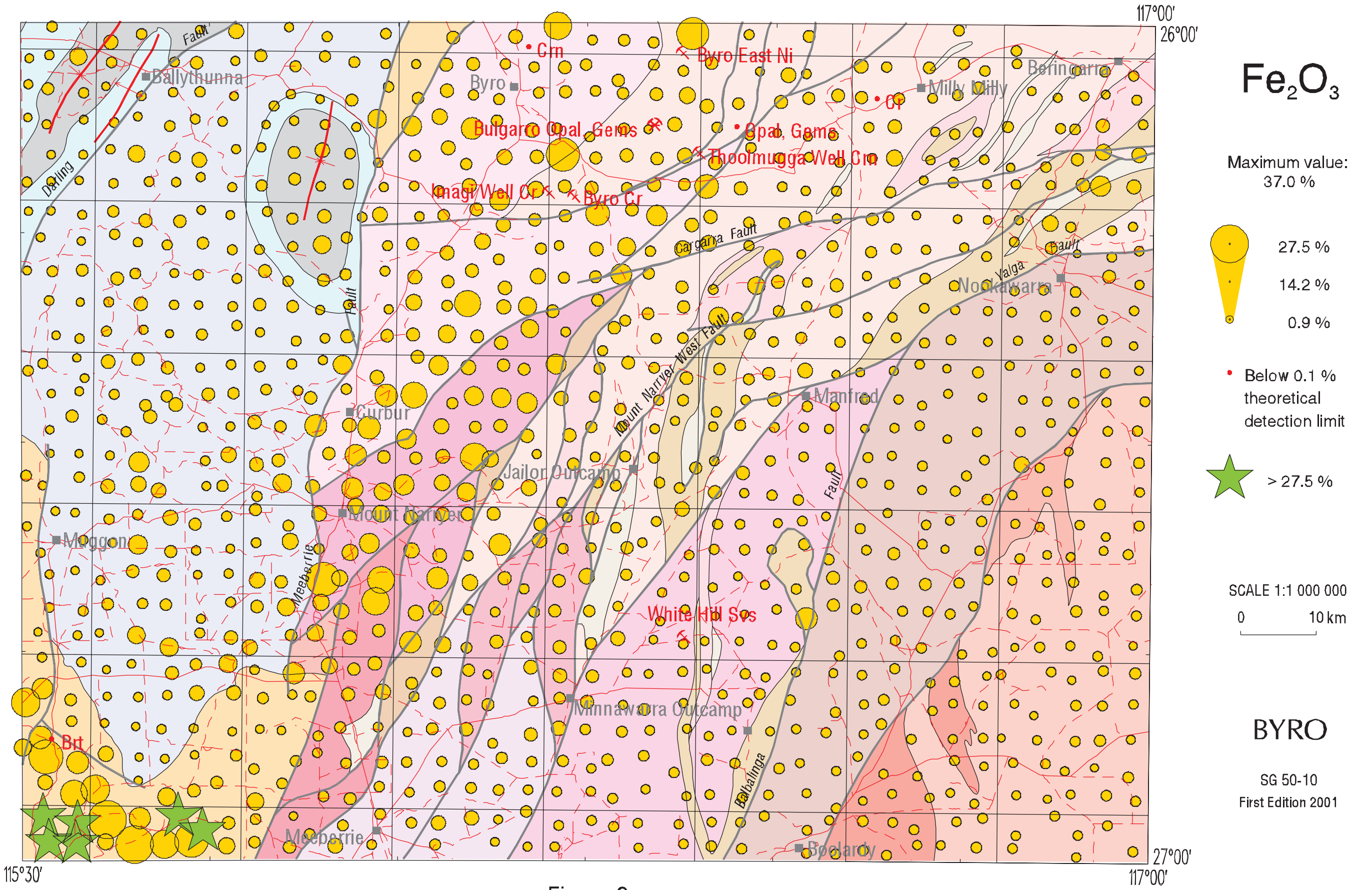
13 Jun 01 09.57.01



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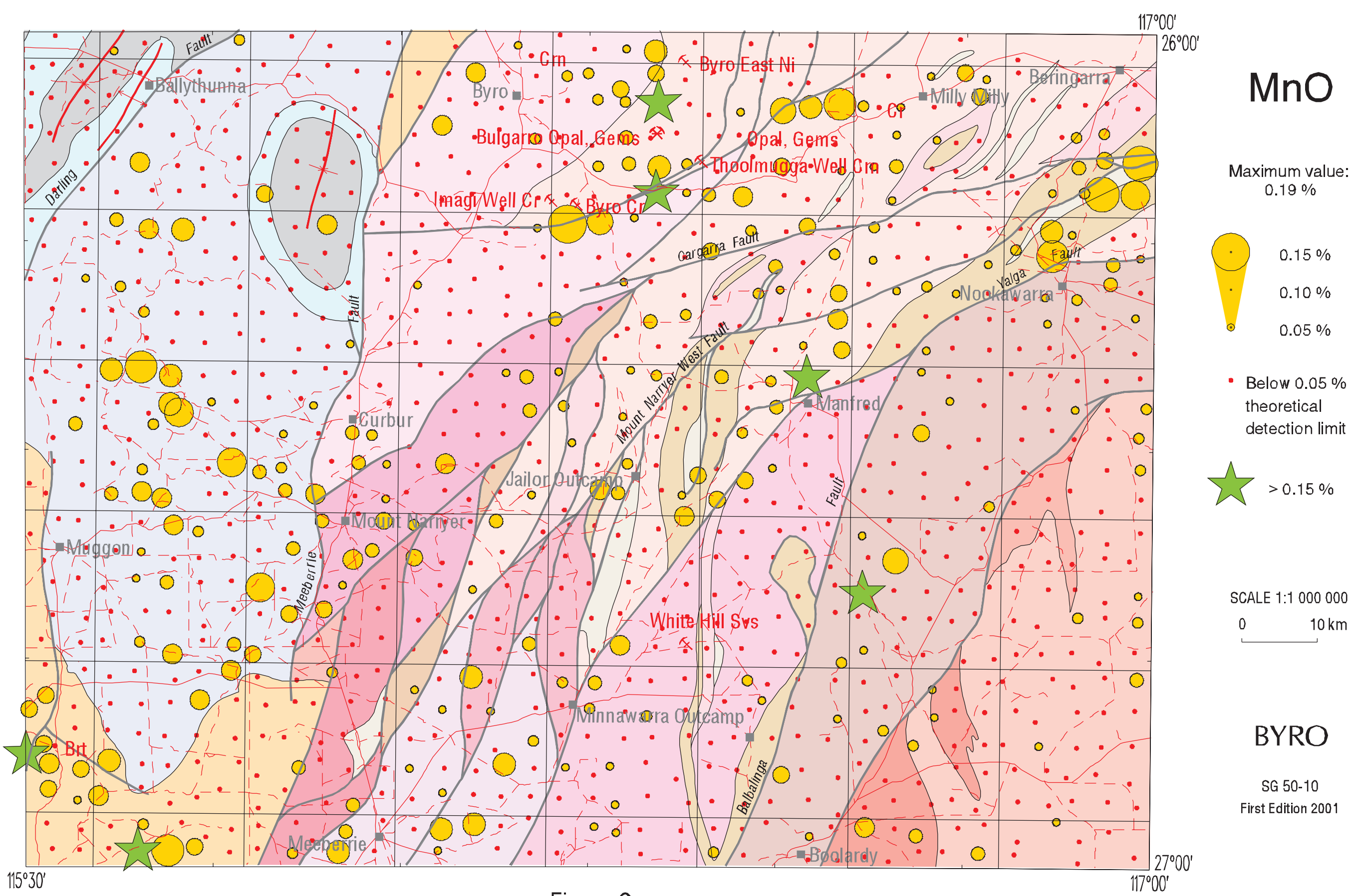

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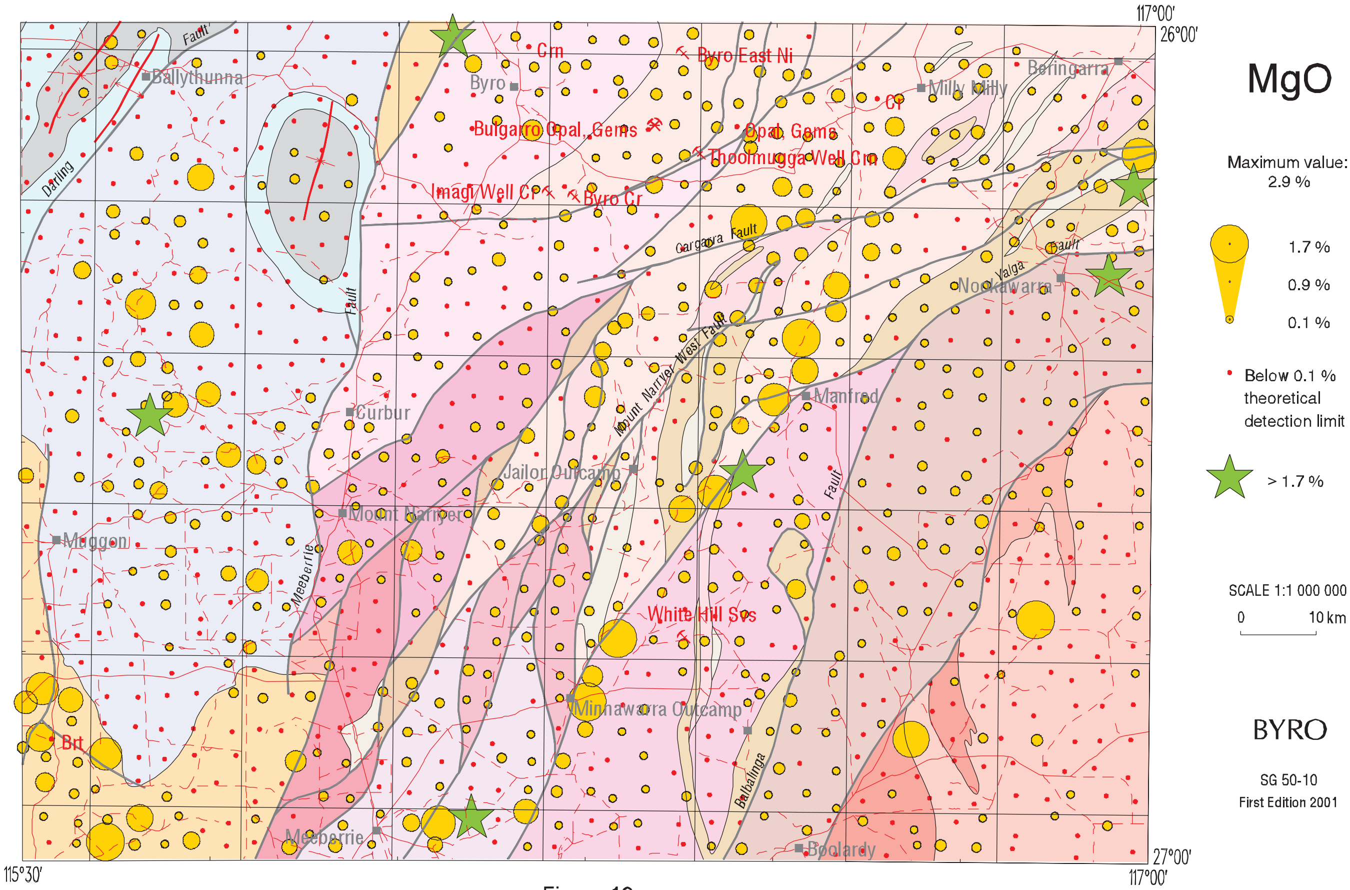

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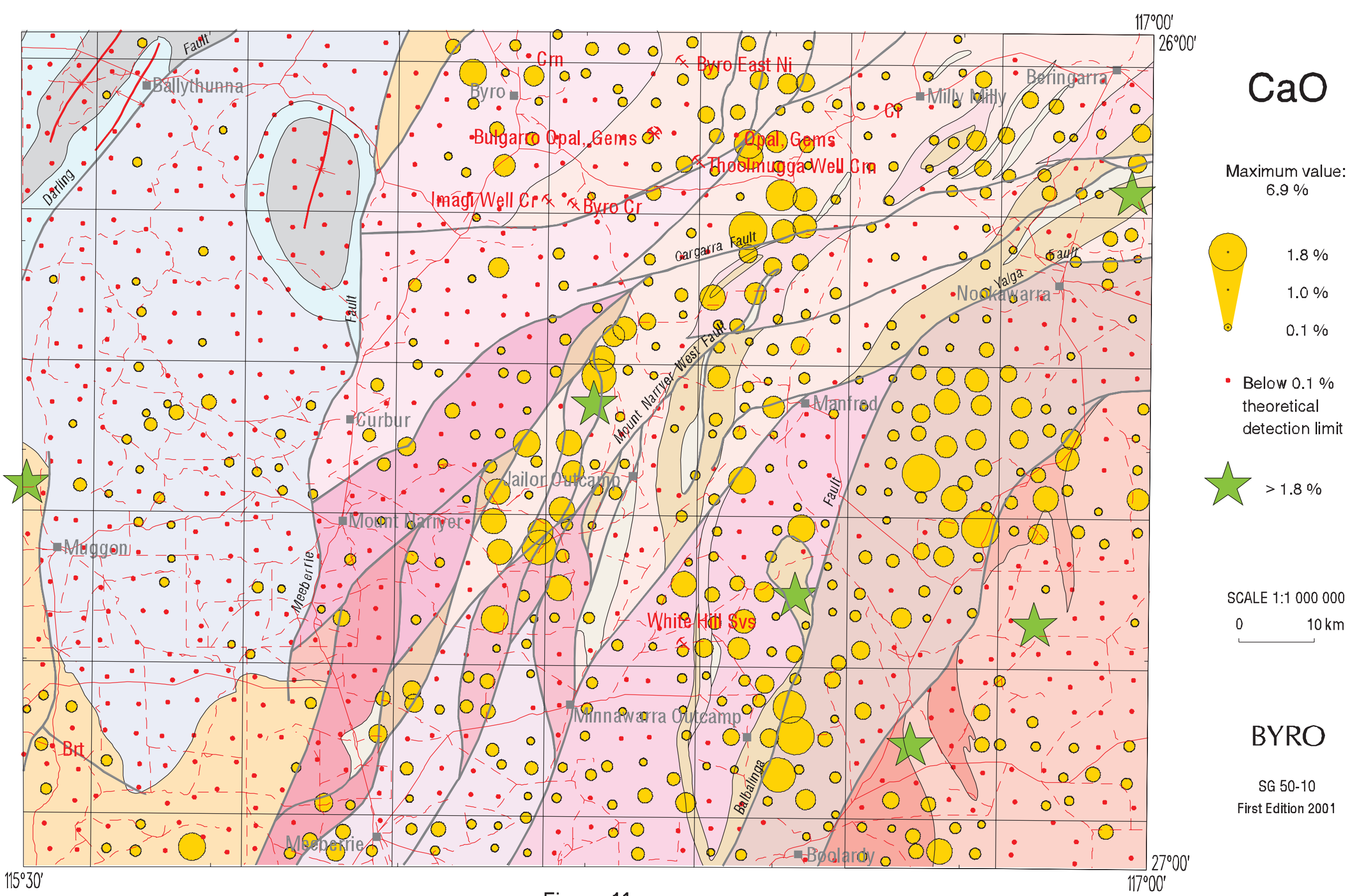

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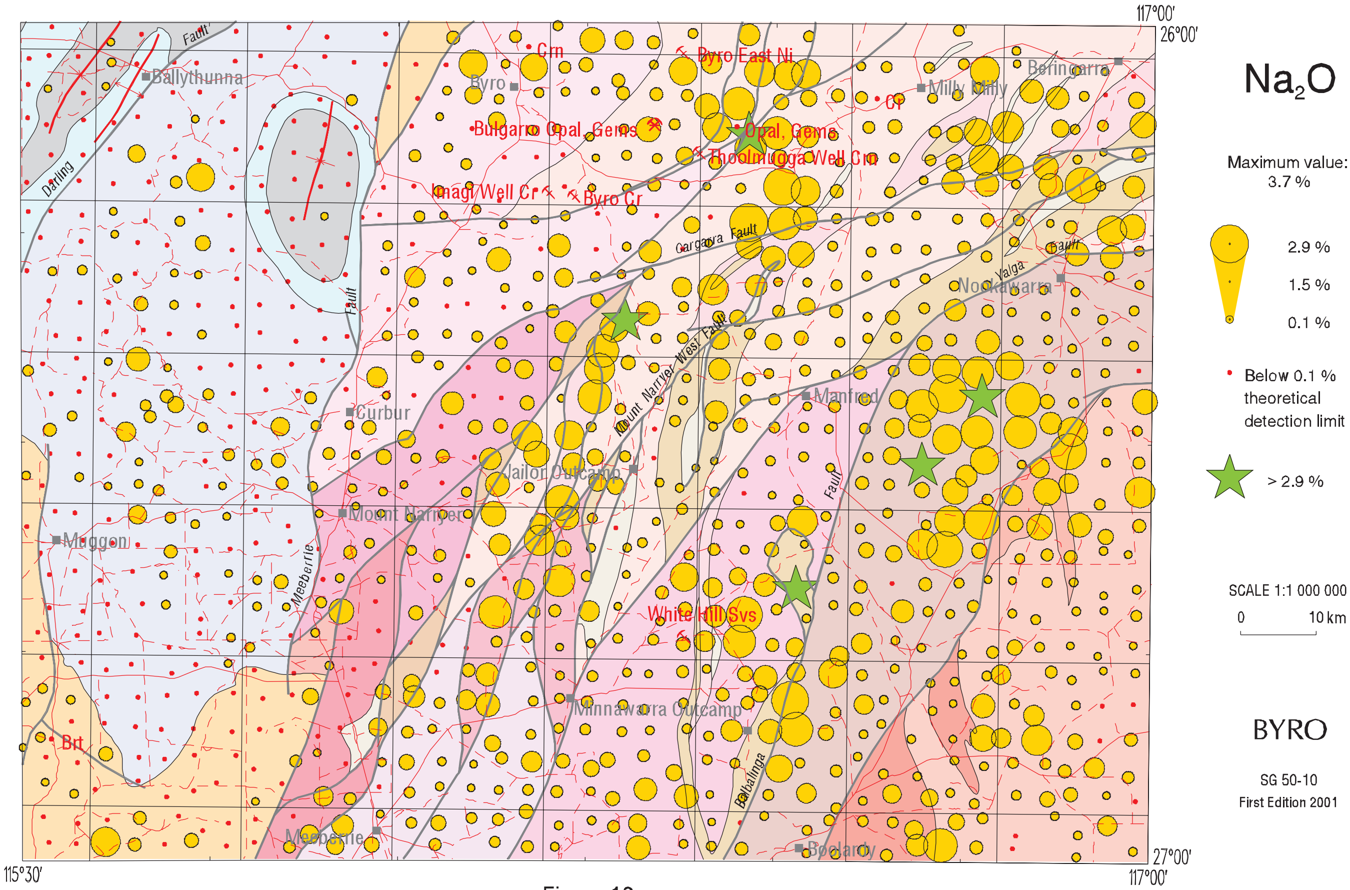

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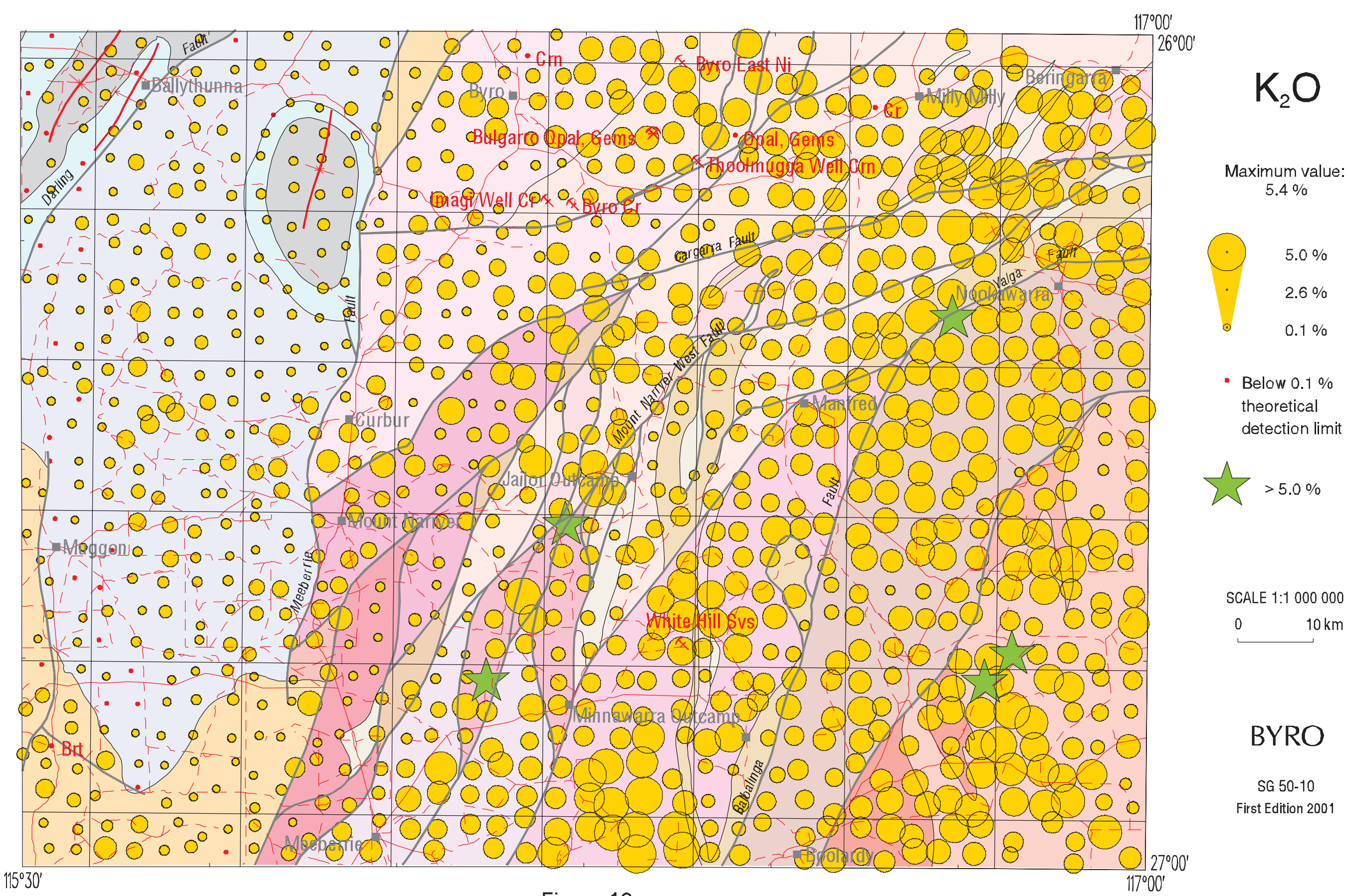

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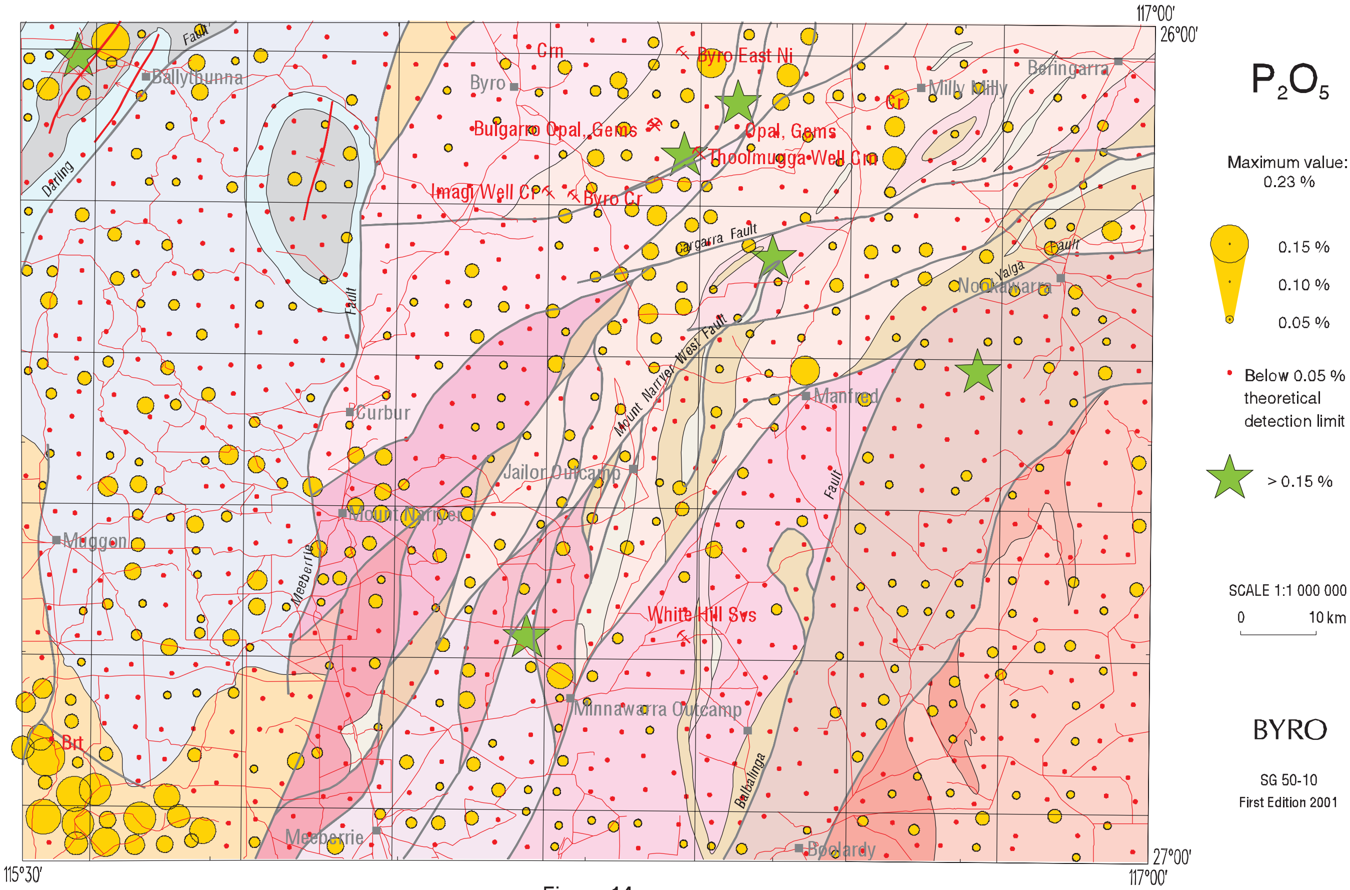

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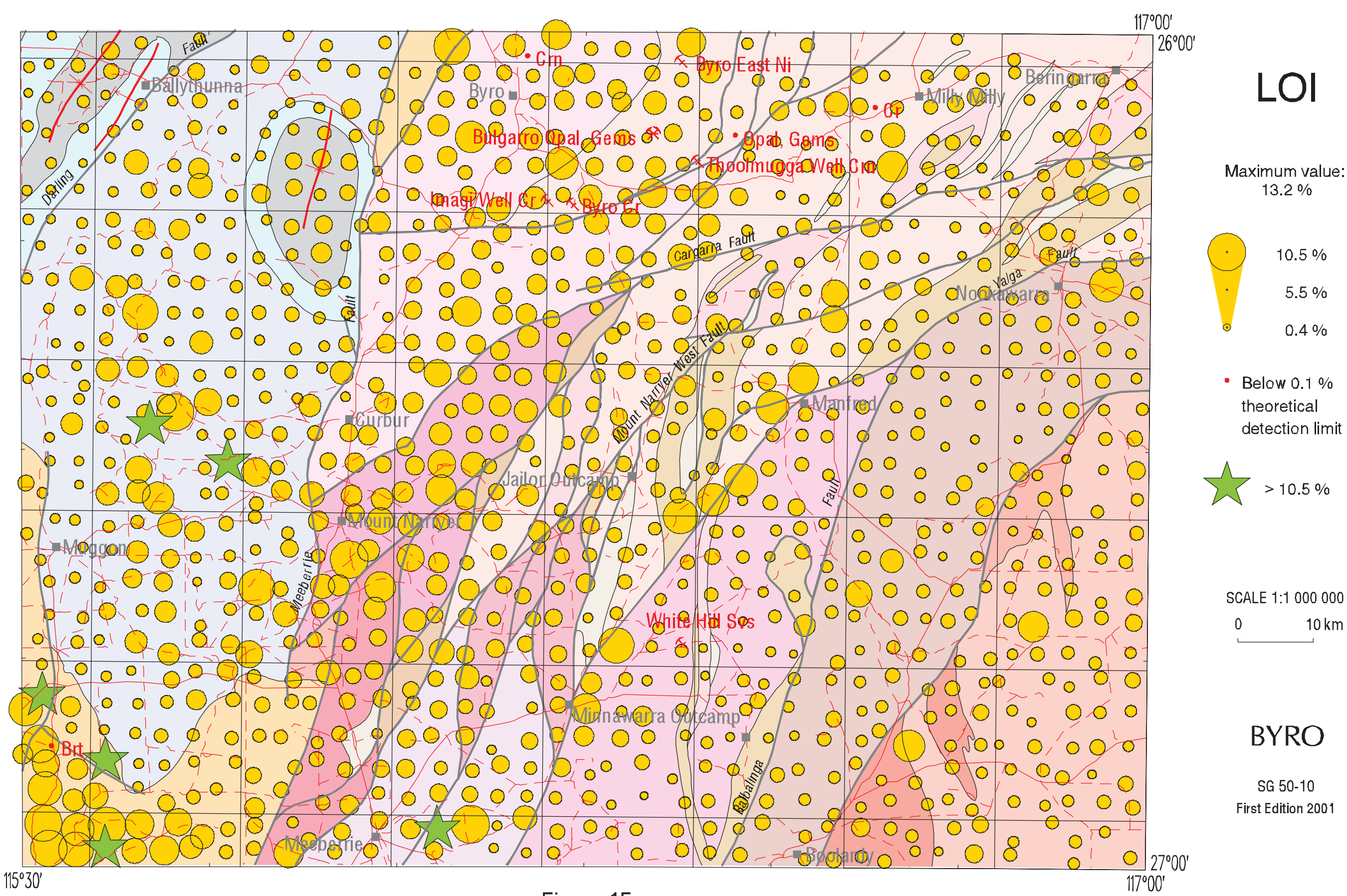

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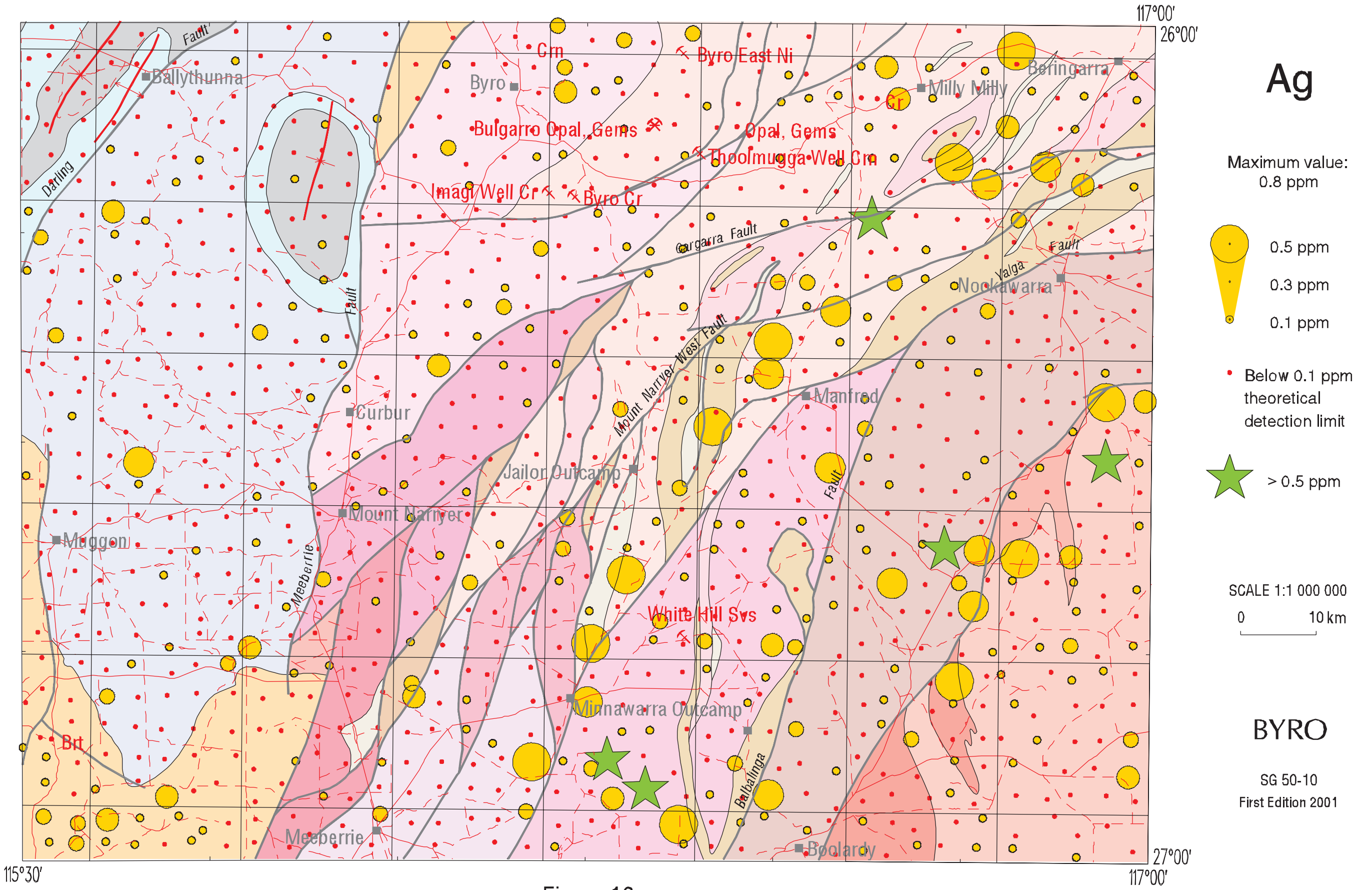

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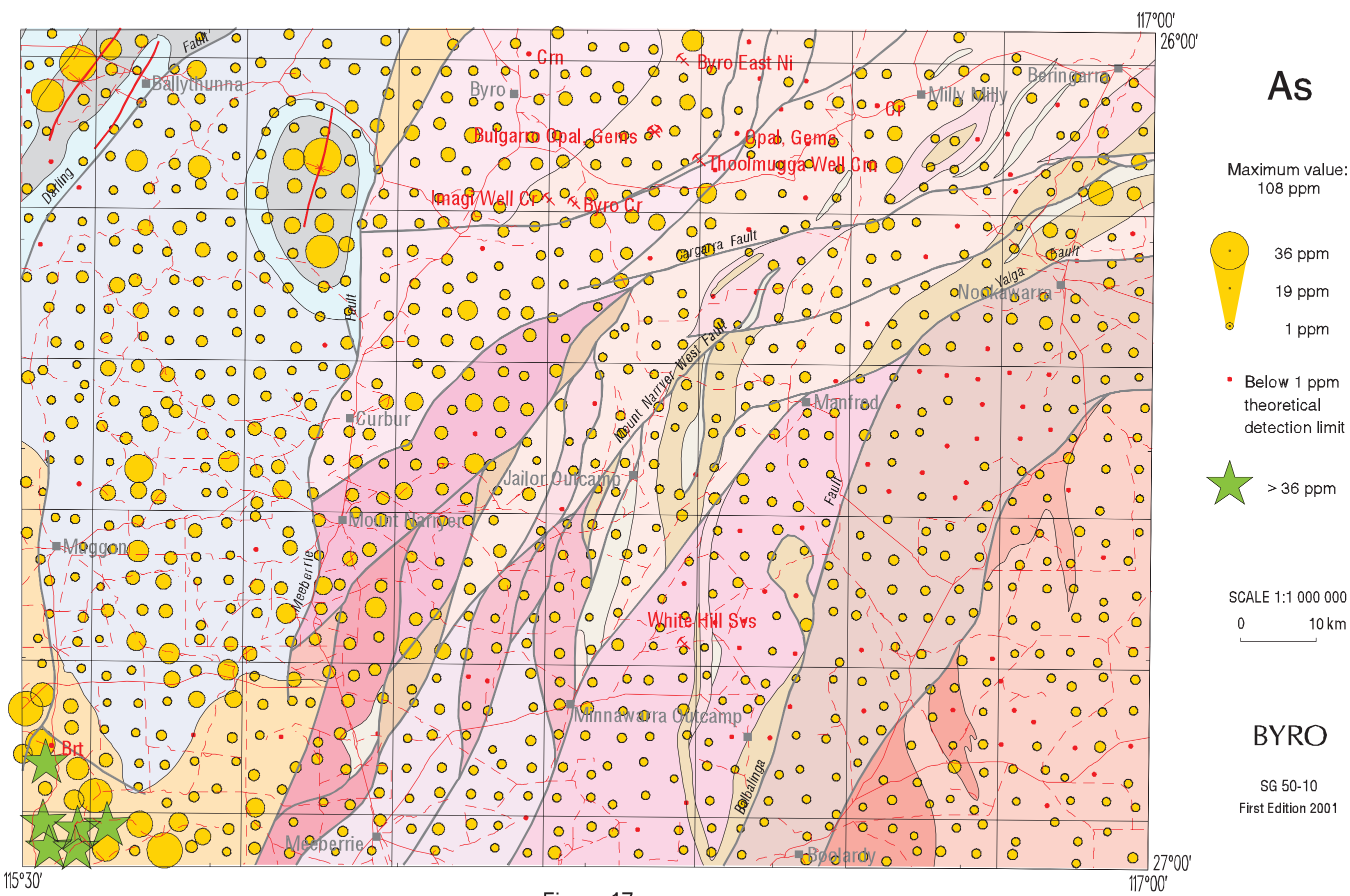

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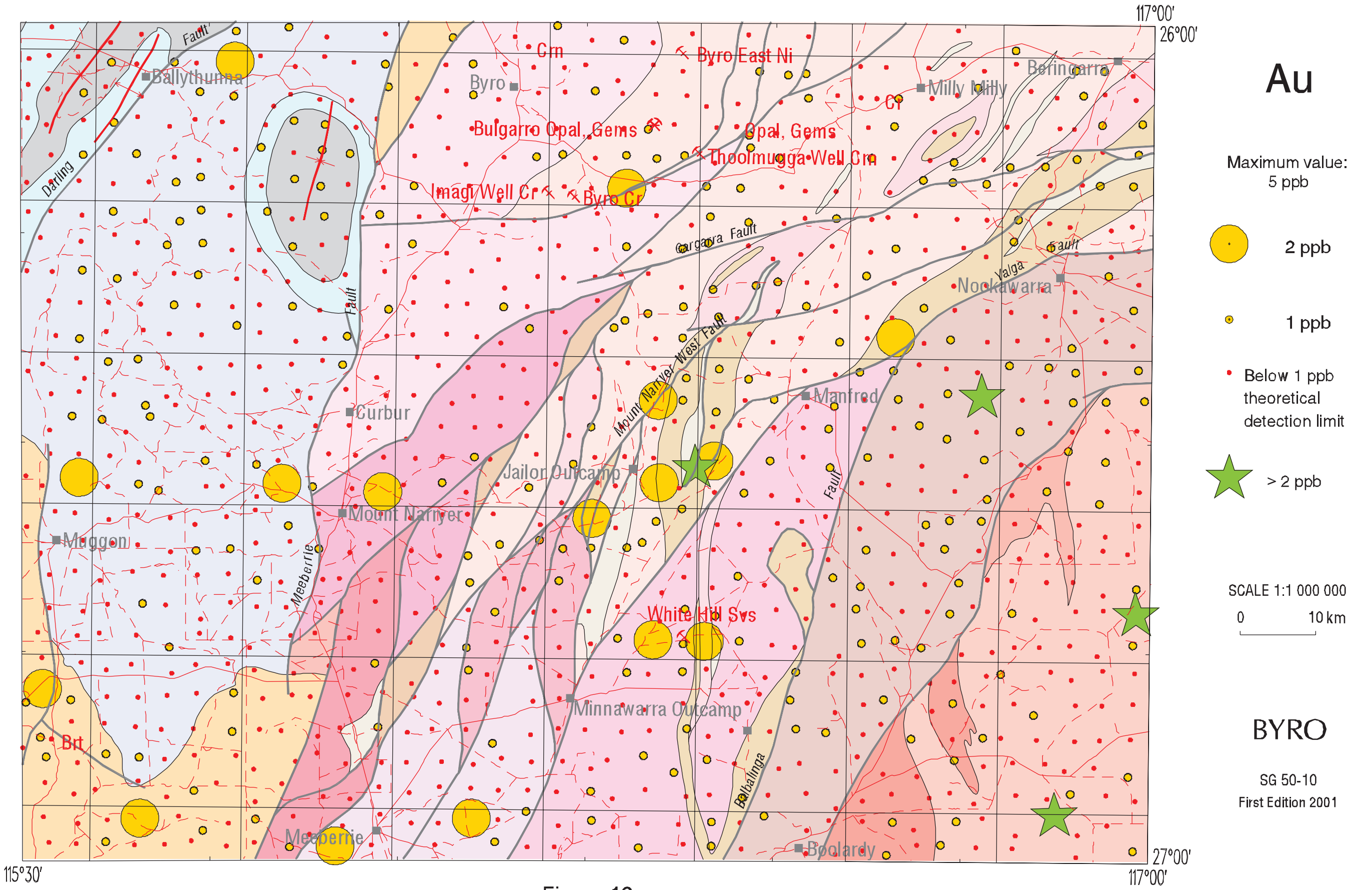

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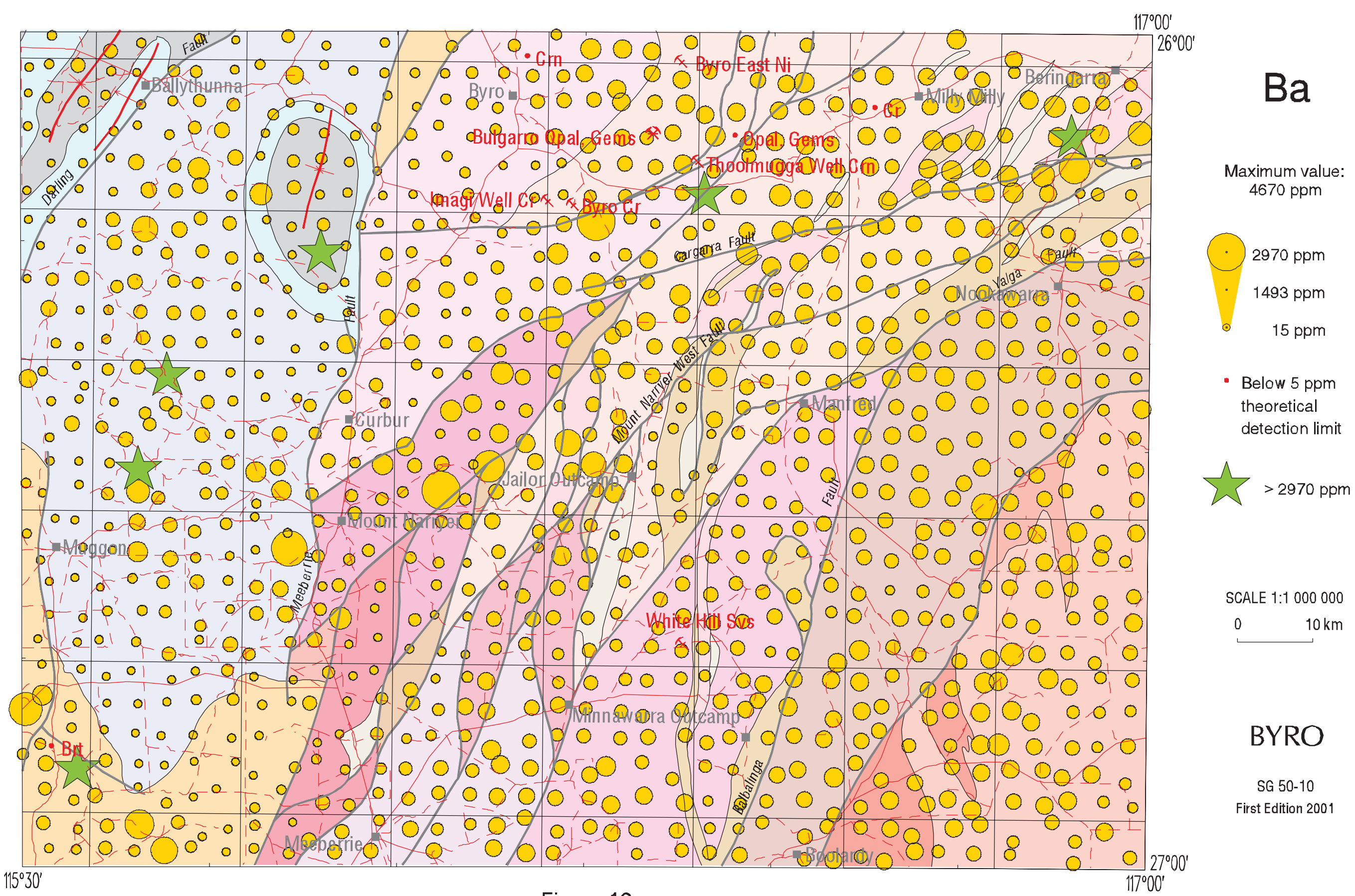

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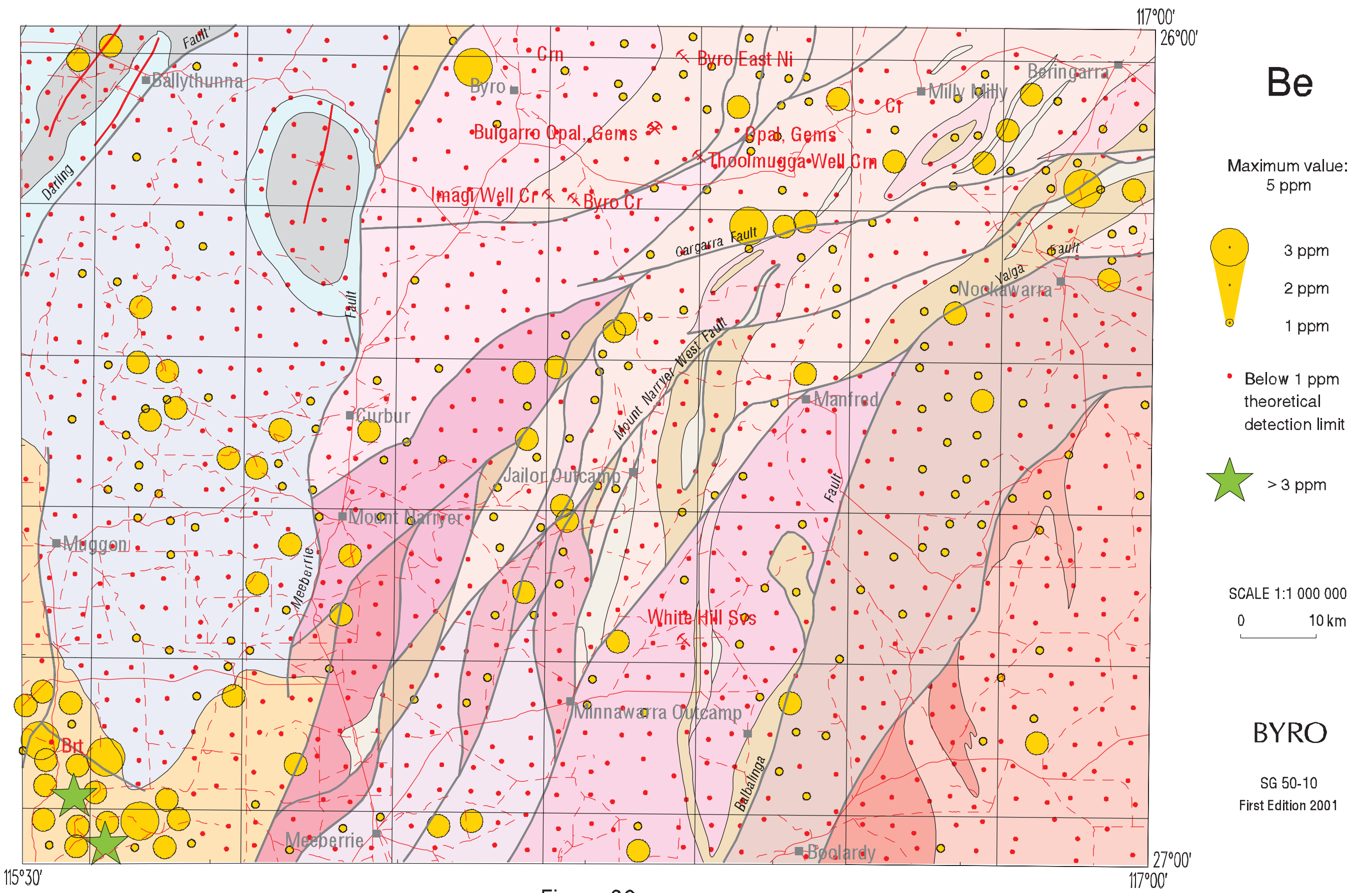

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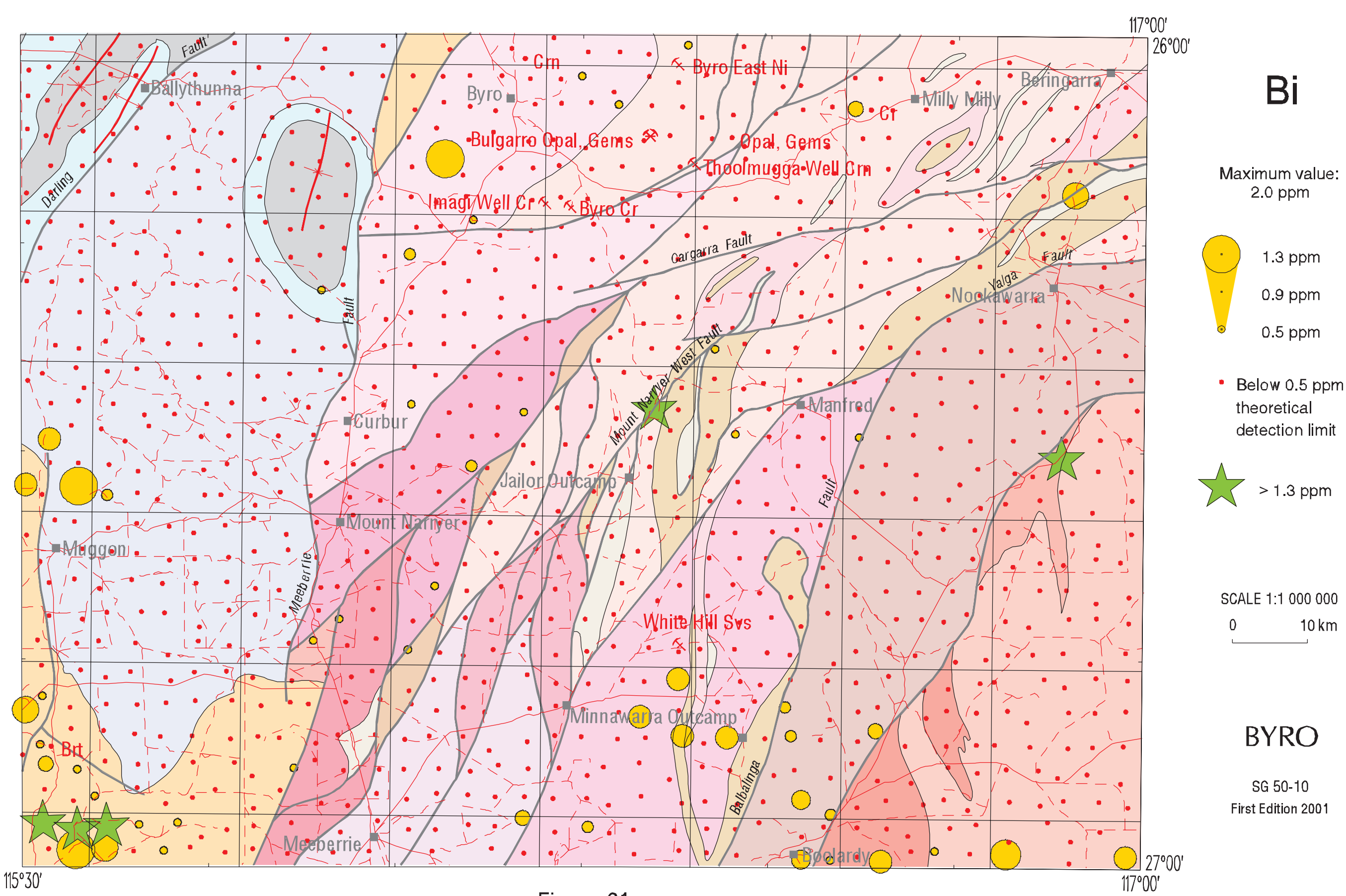

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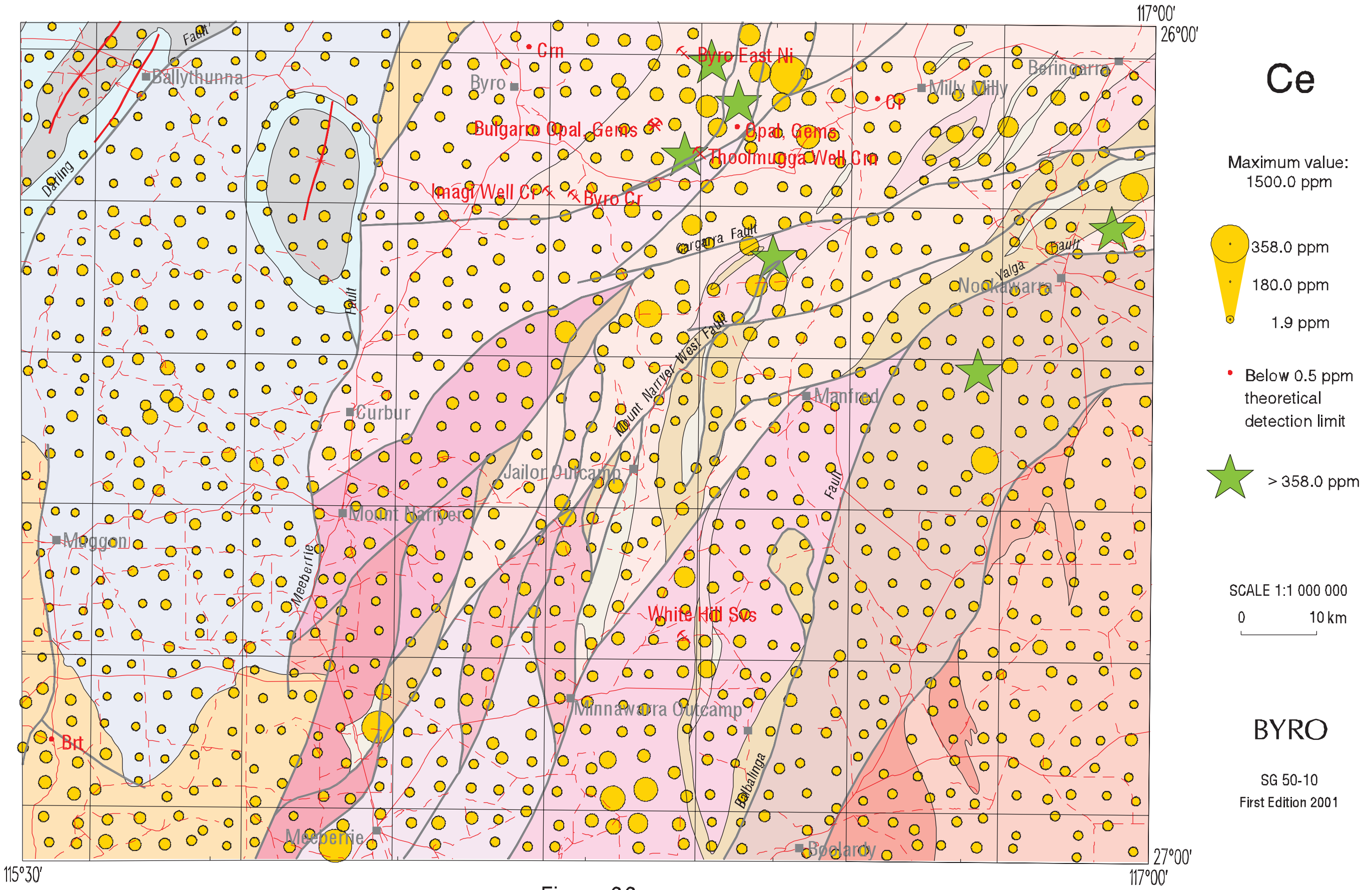

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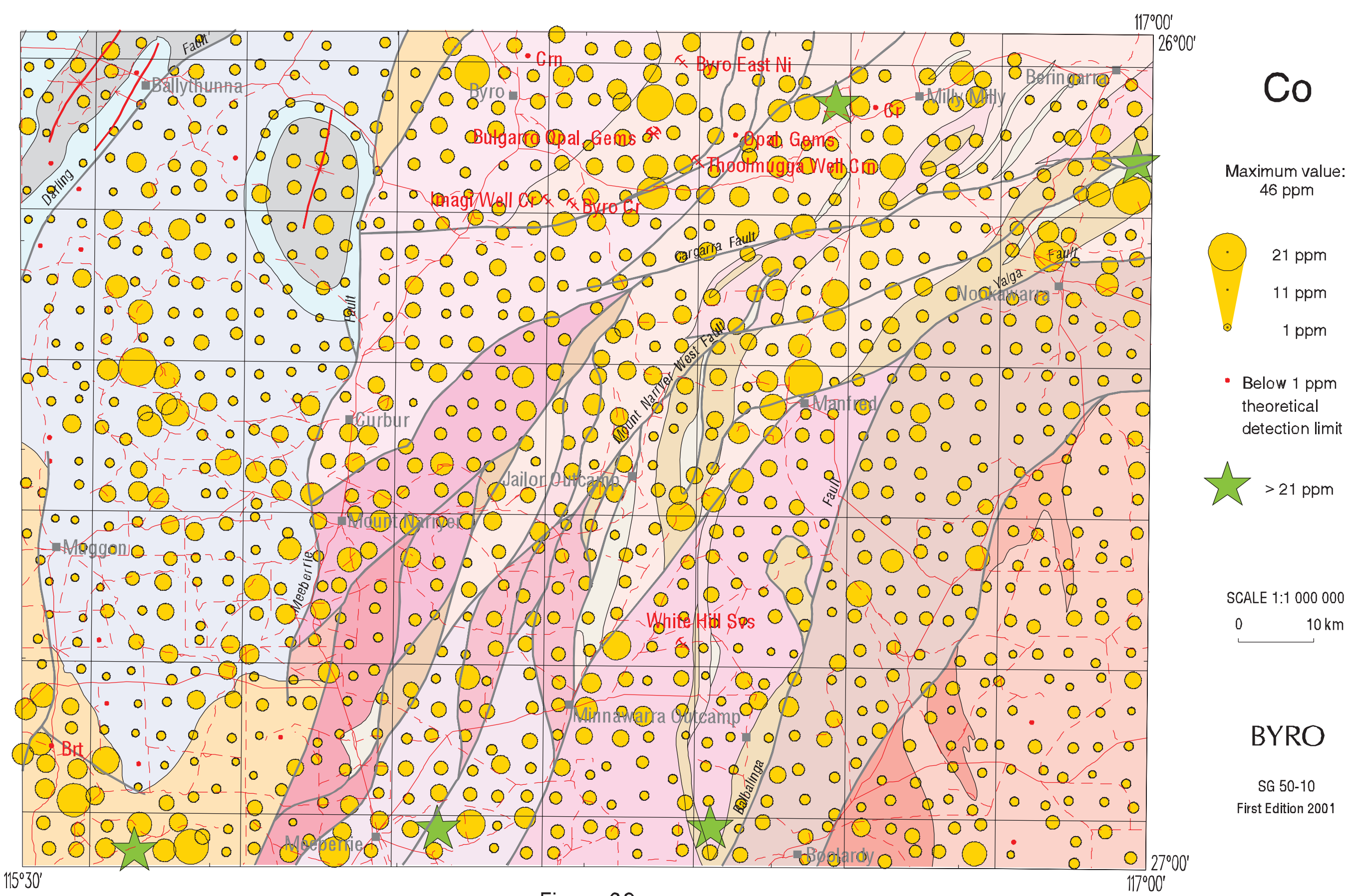

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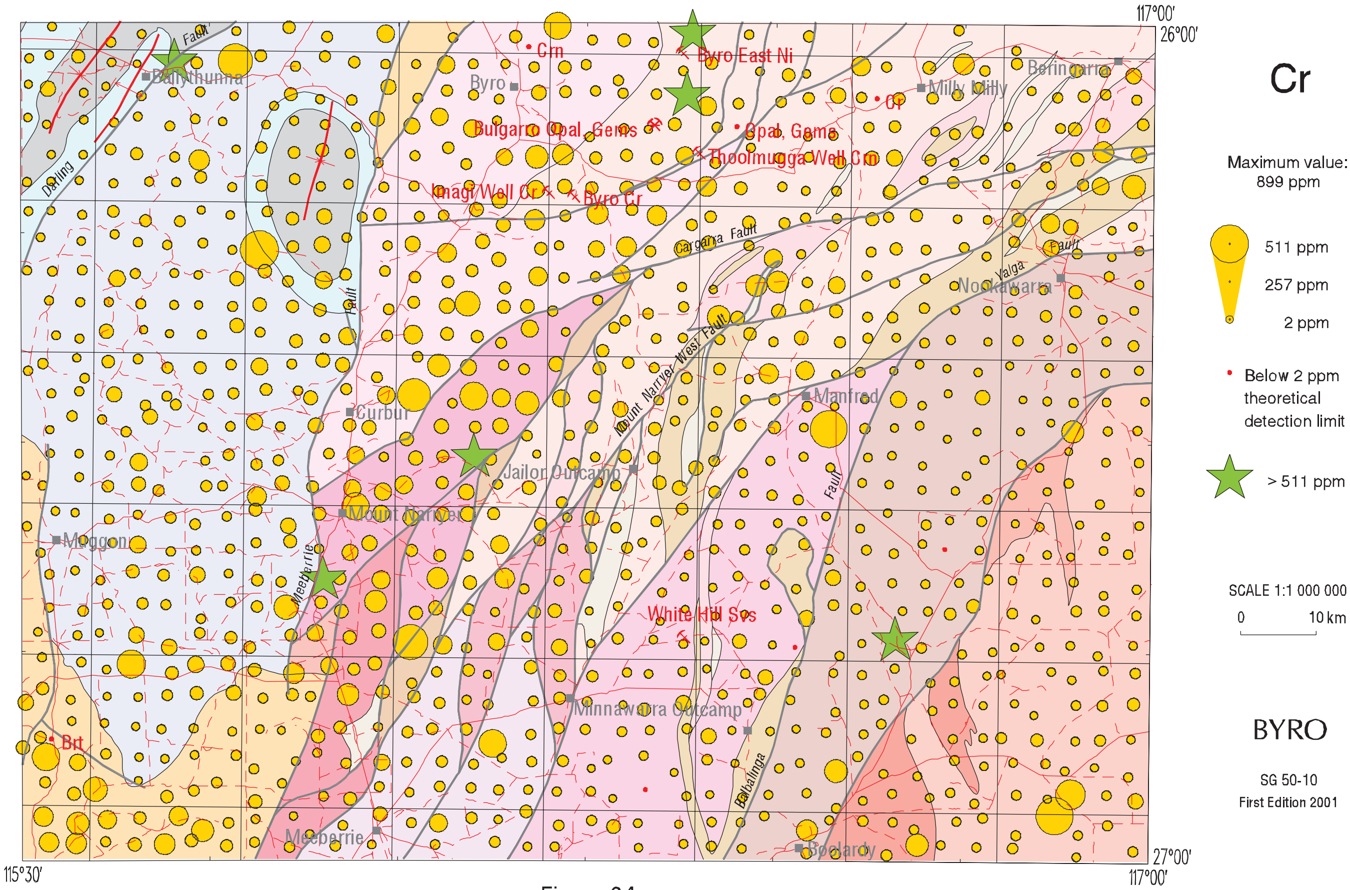

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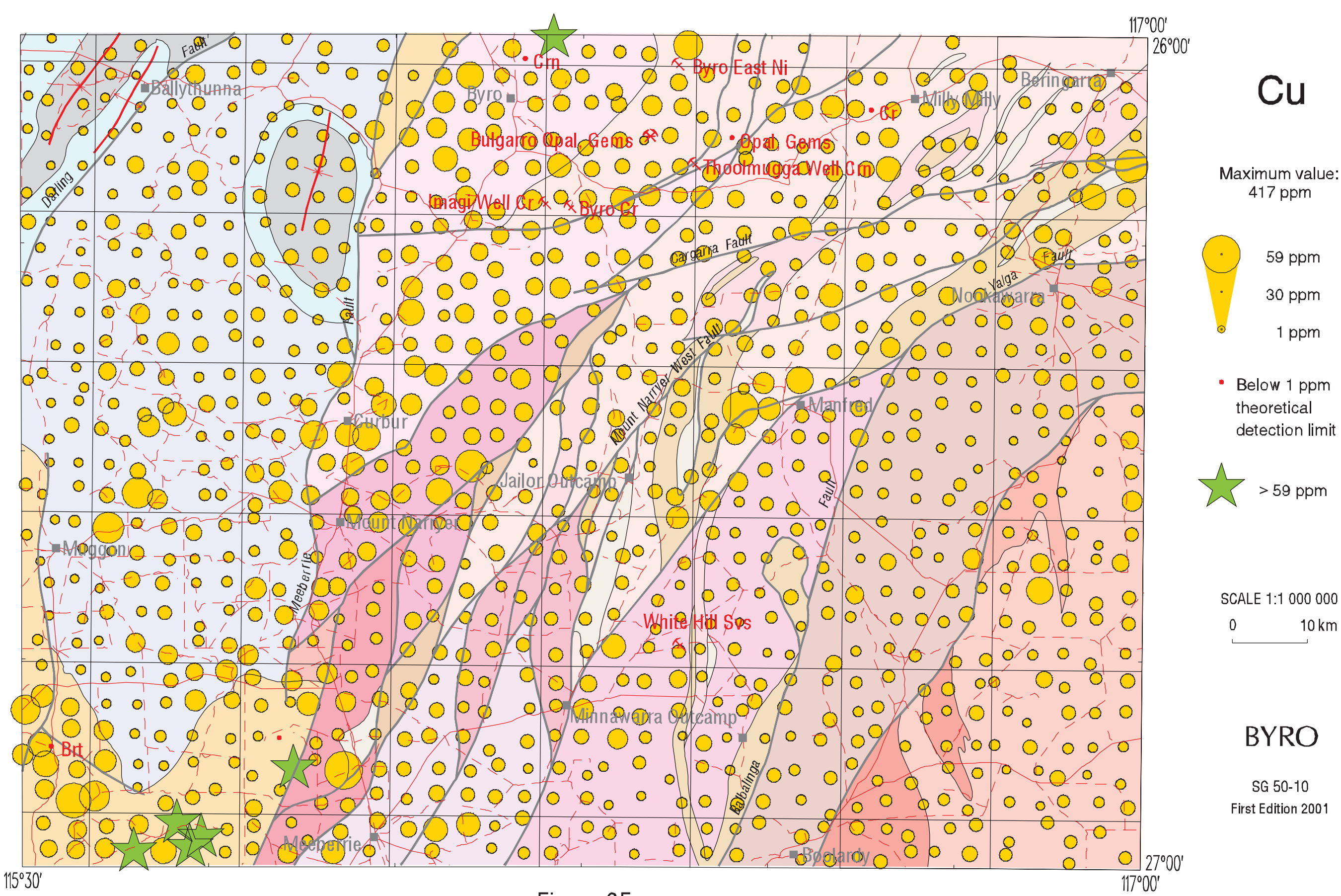

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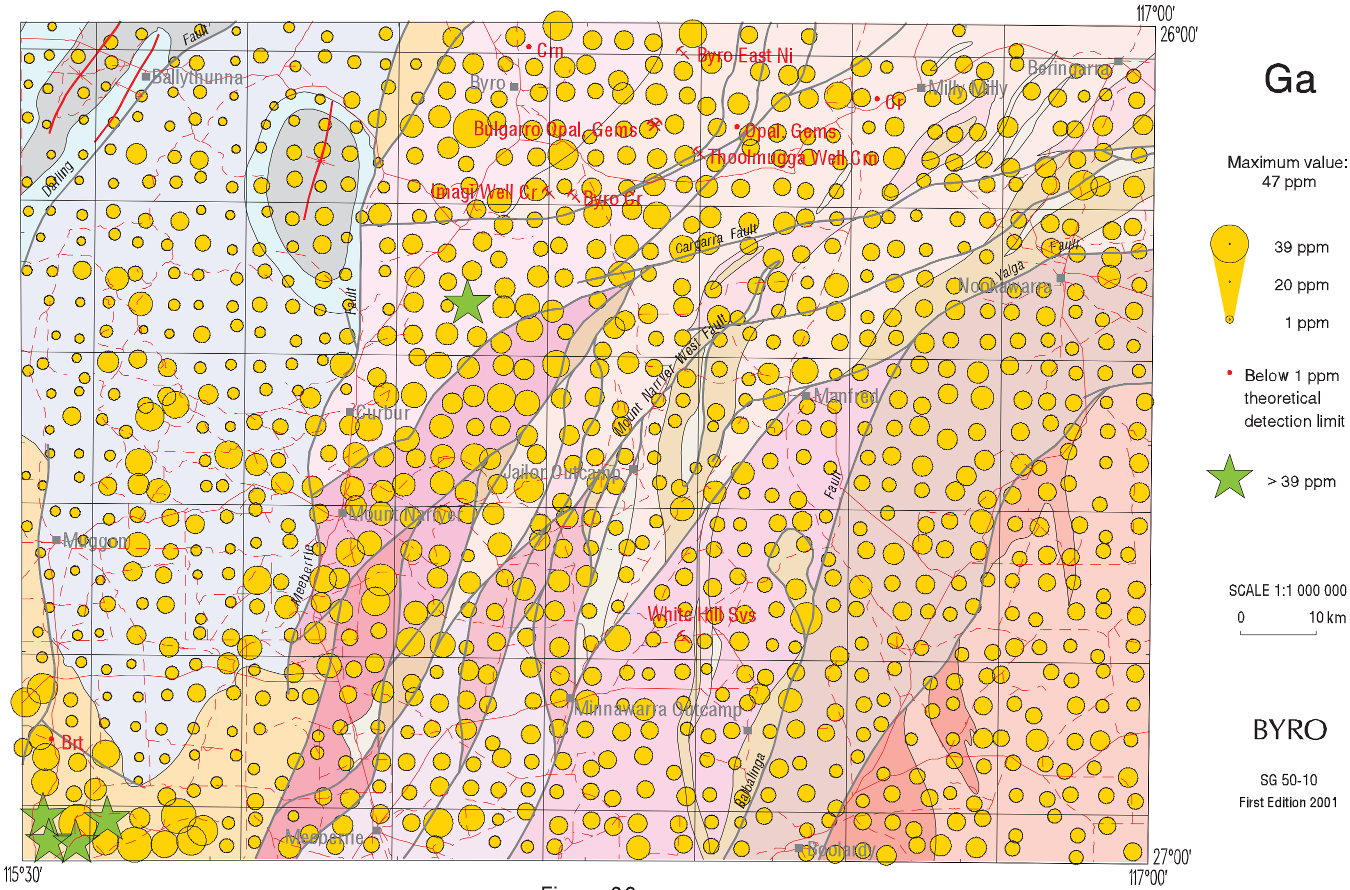

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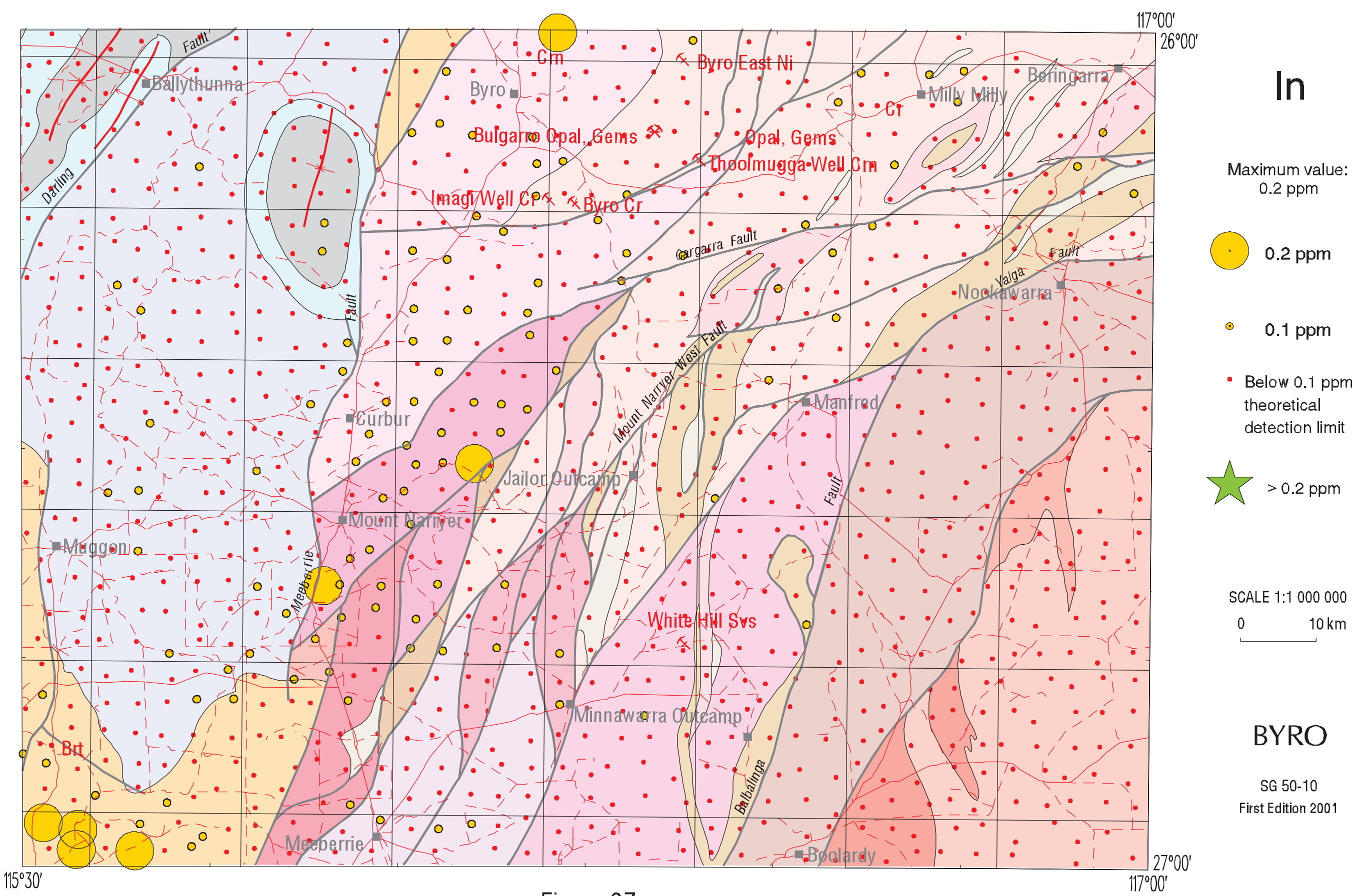

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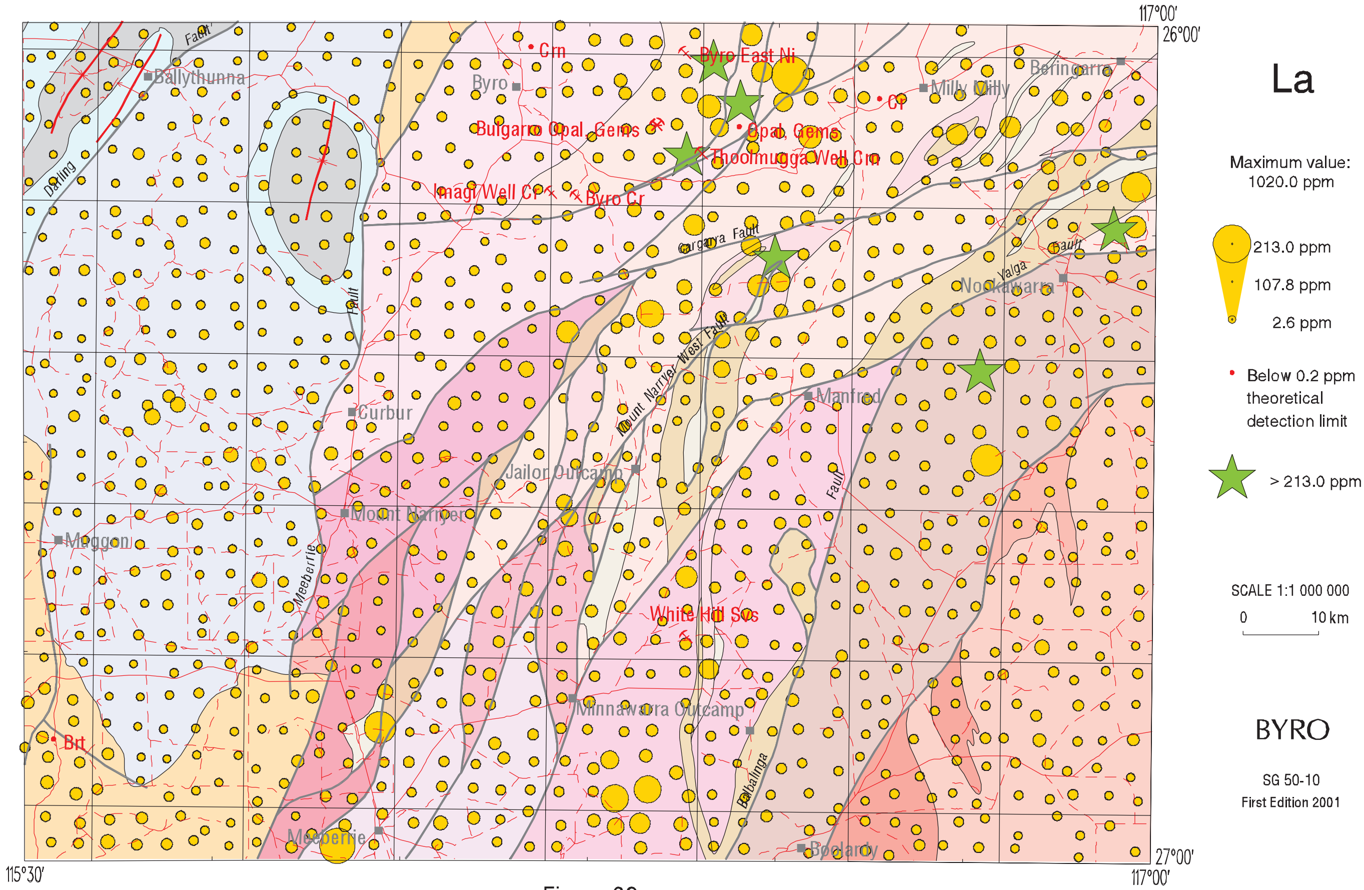

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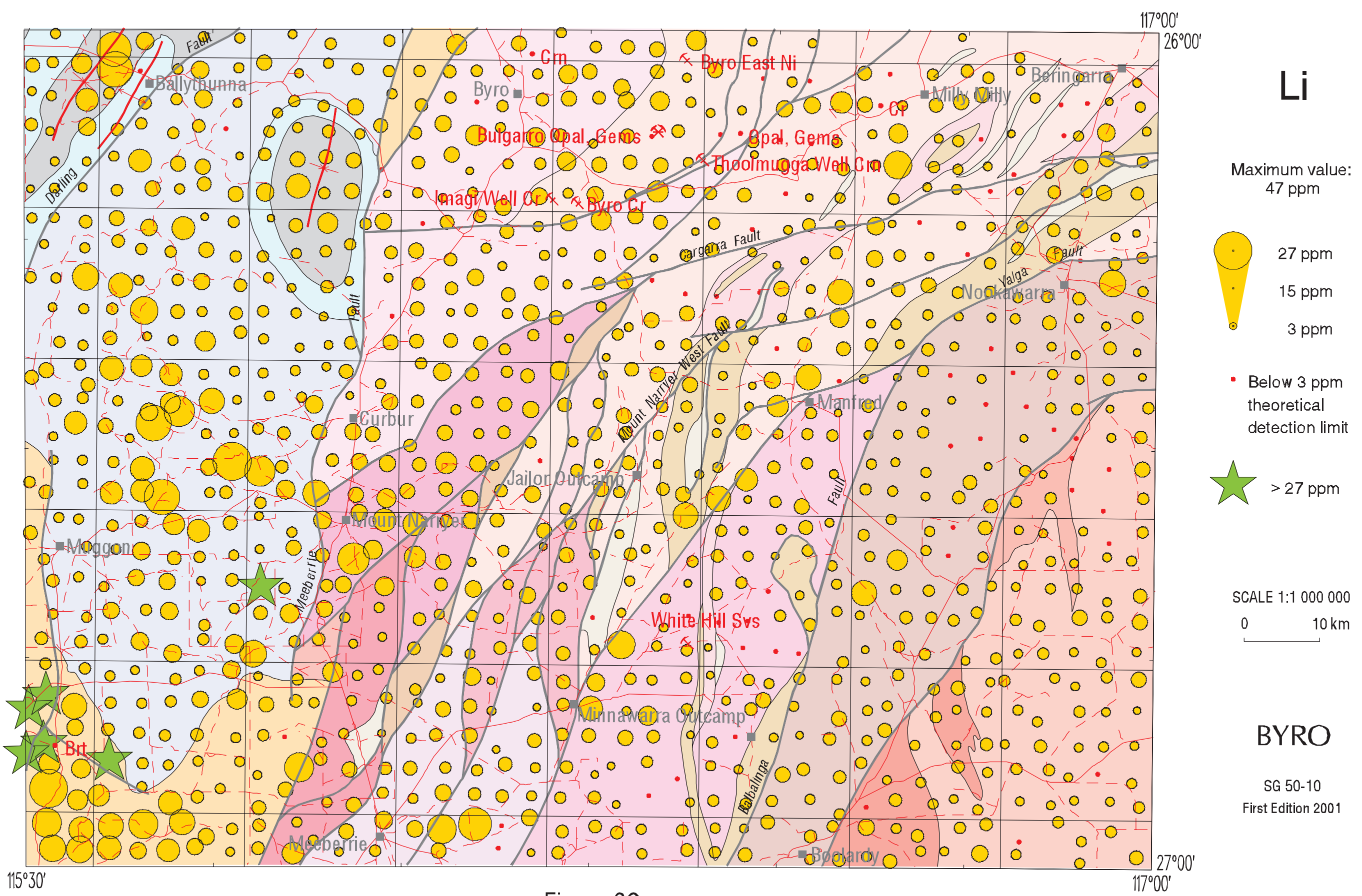

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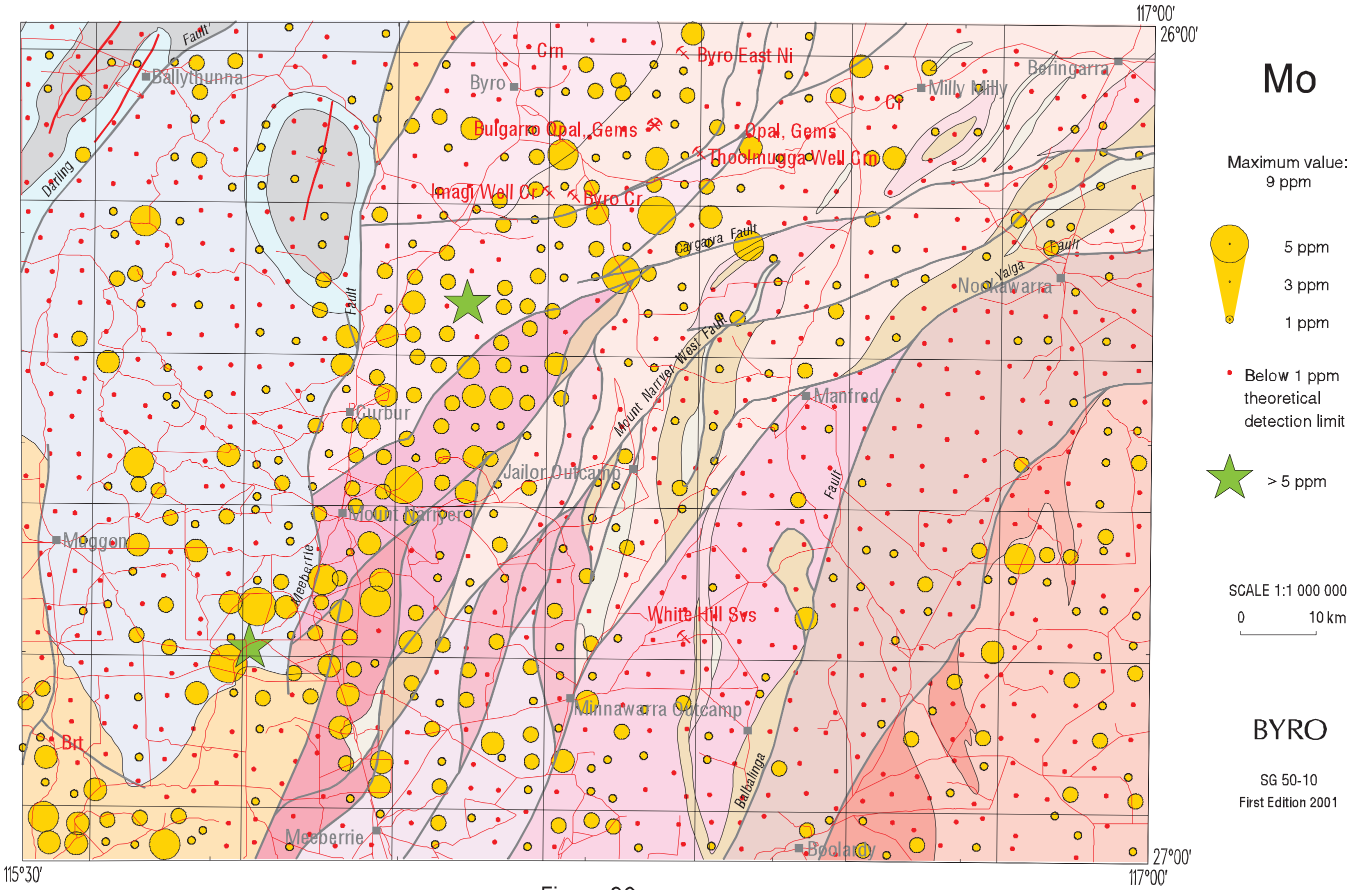

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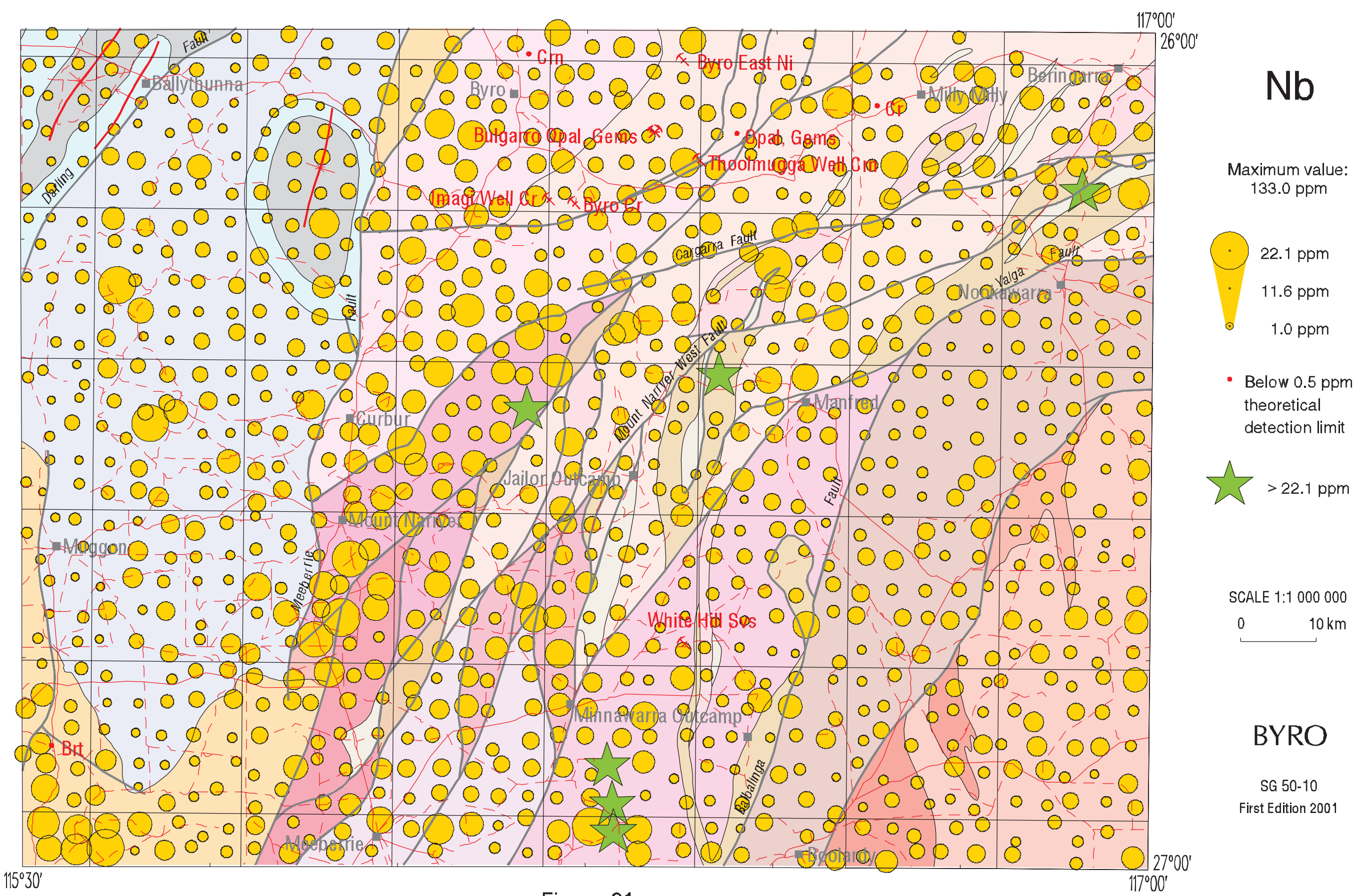

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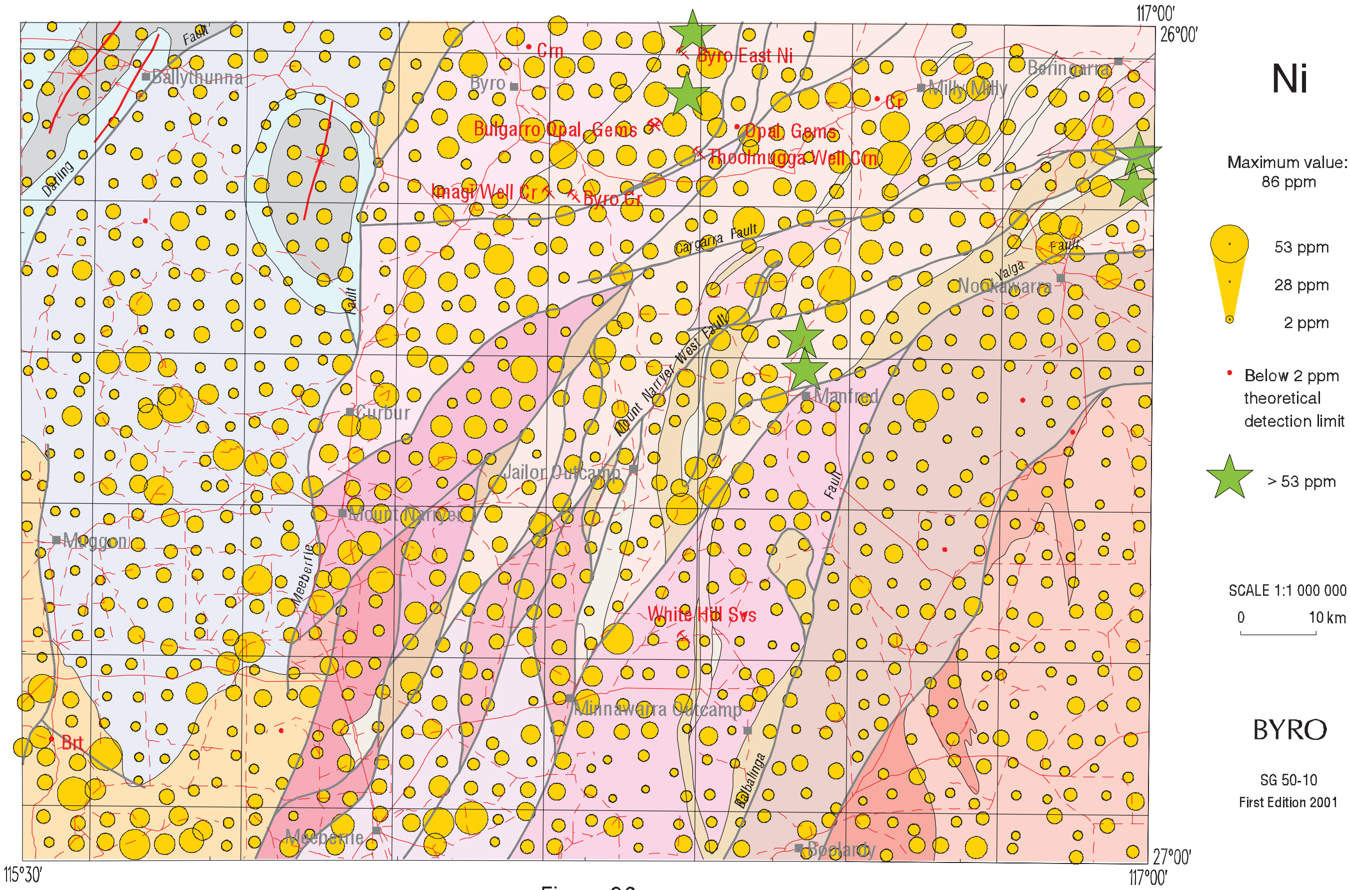

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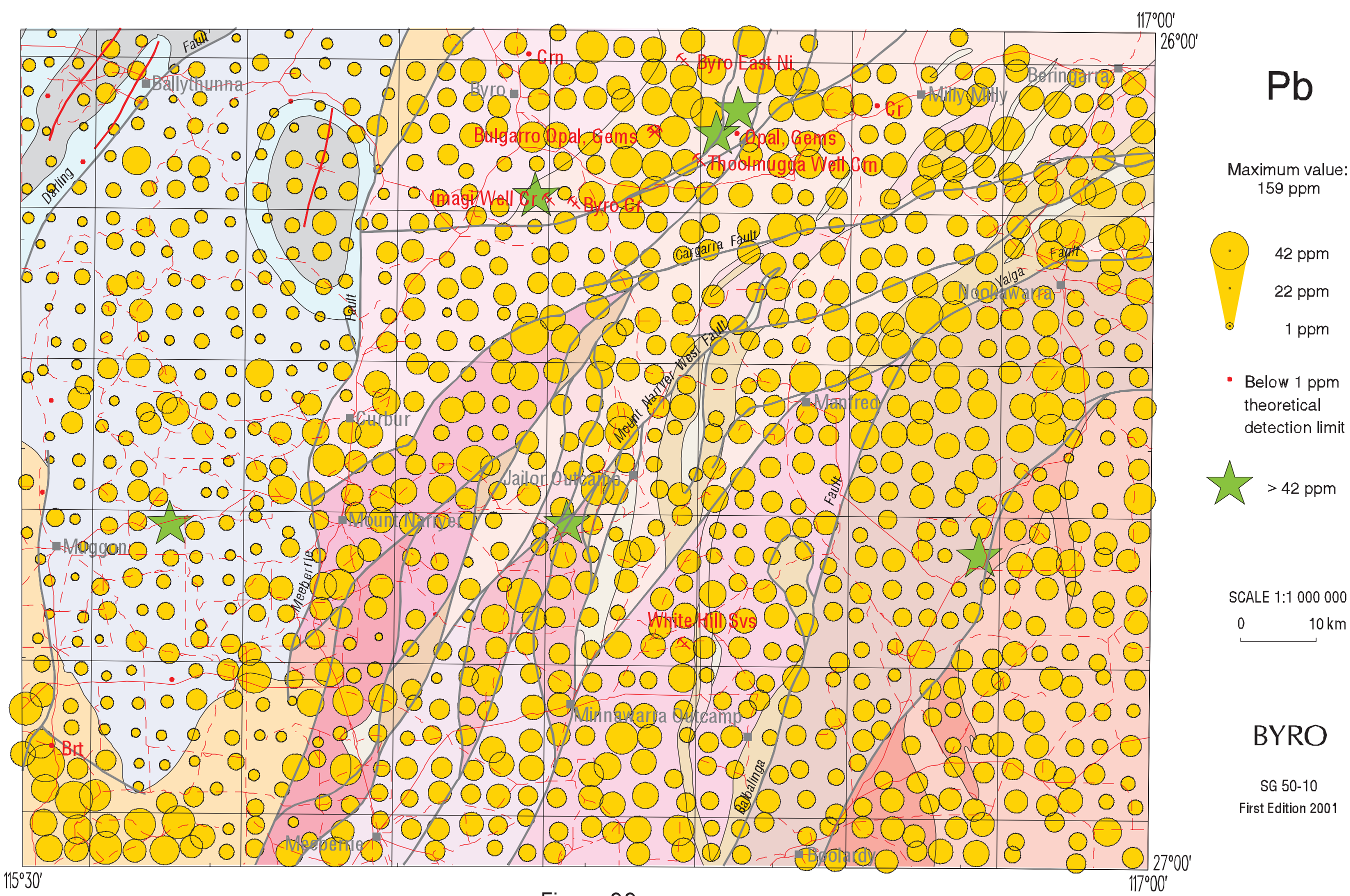

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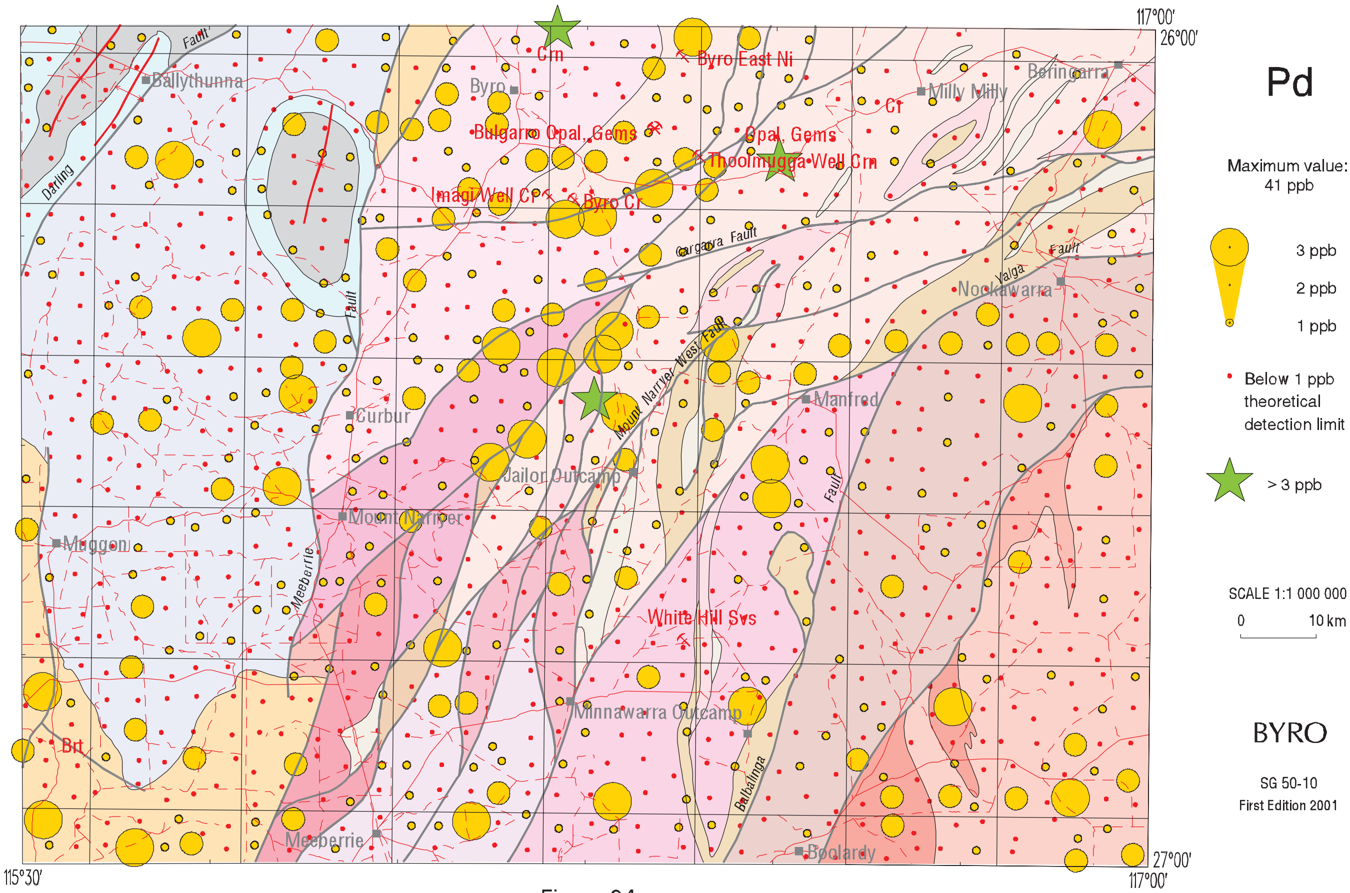

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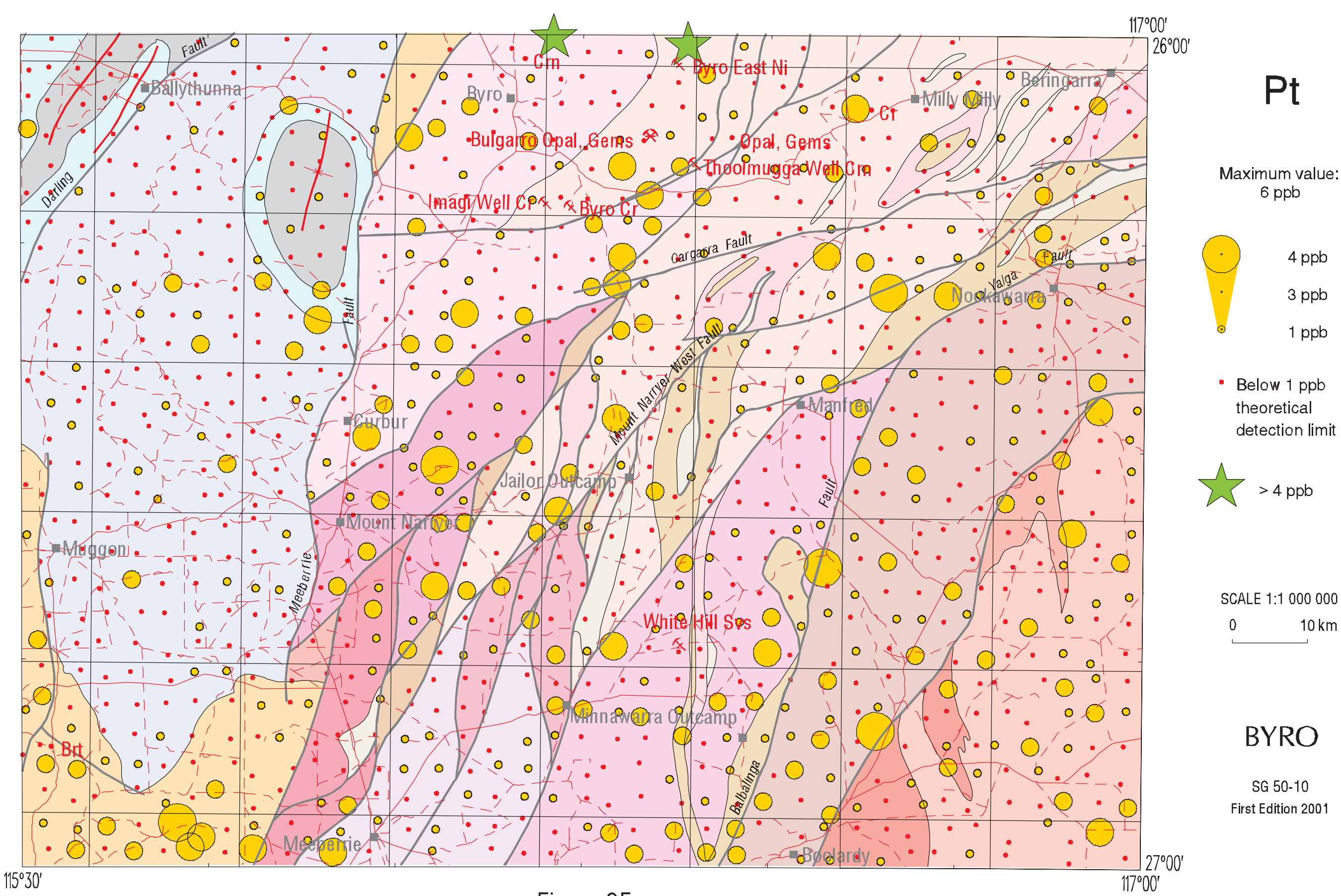

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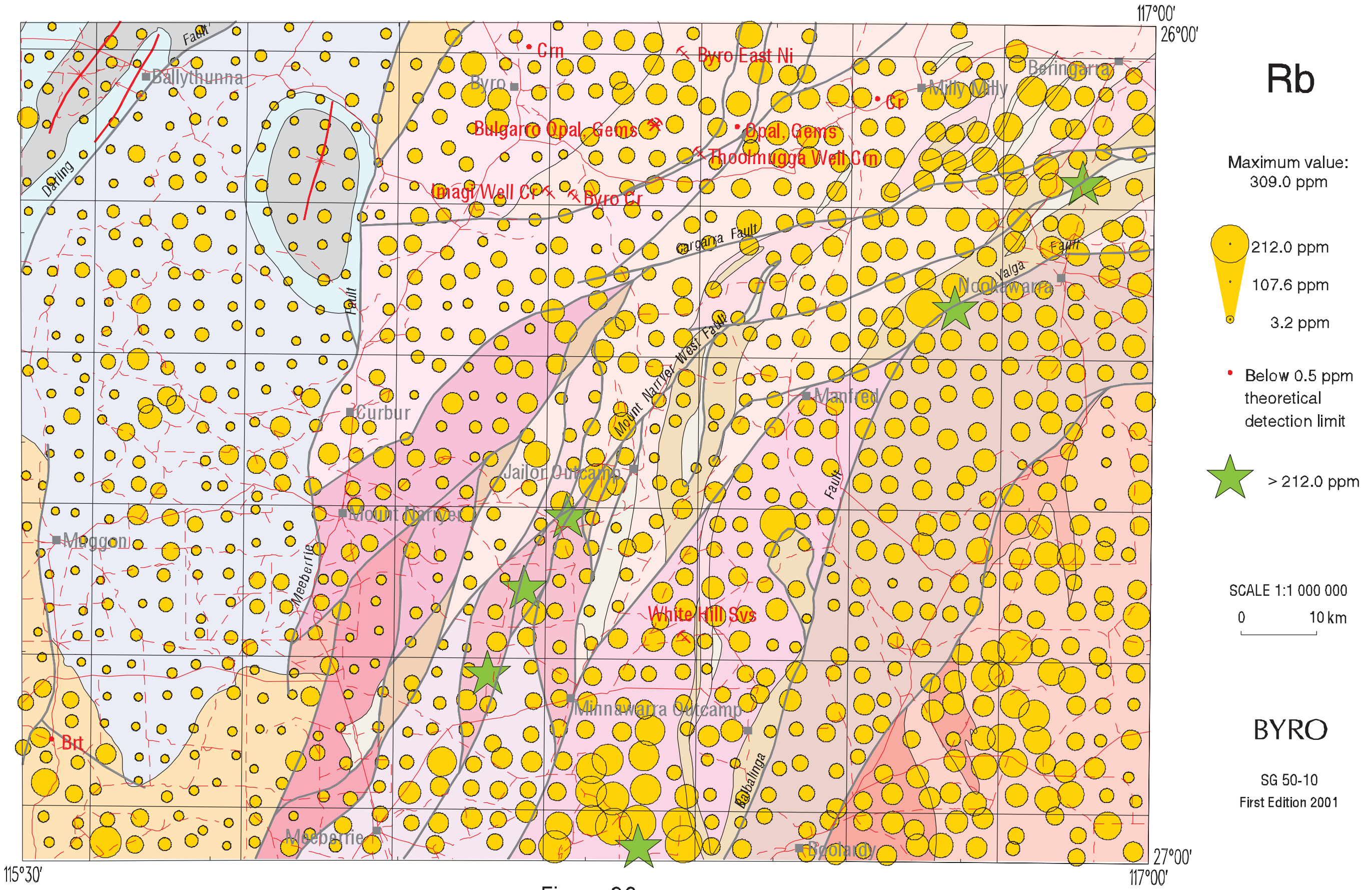

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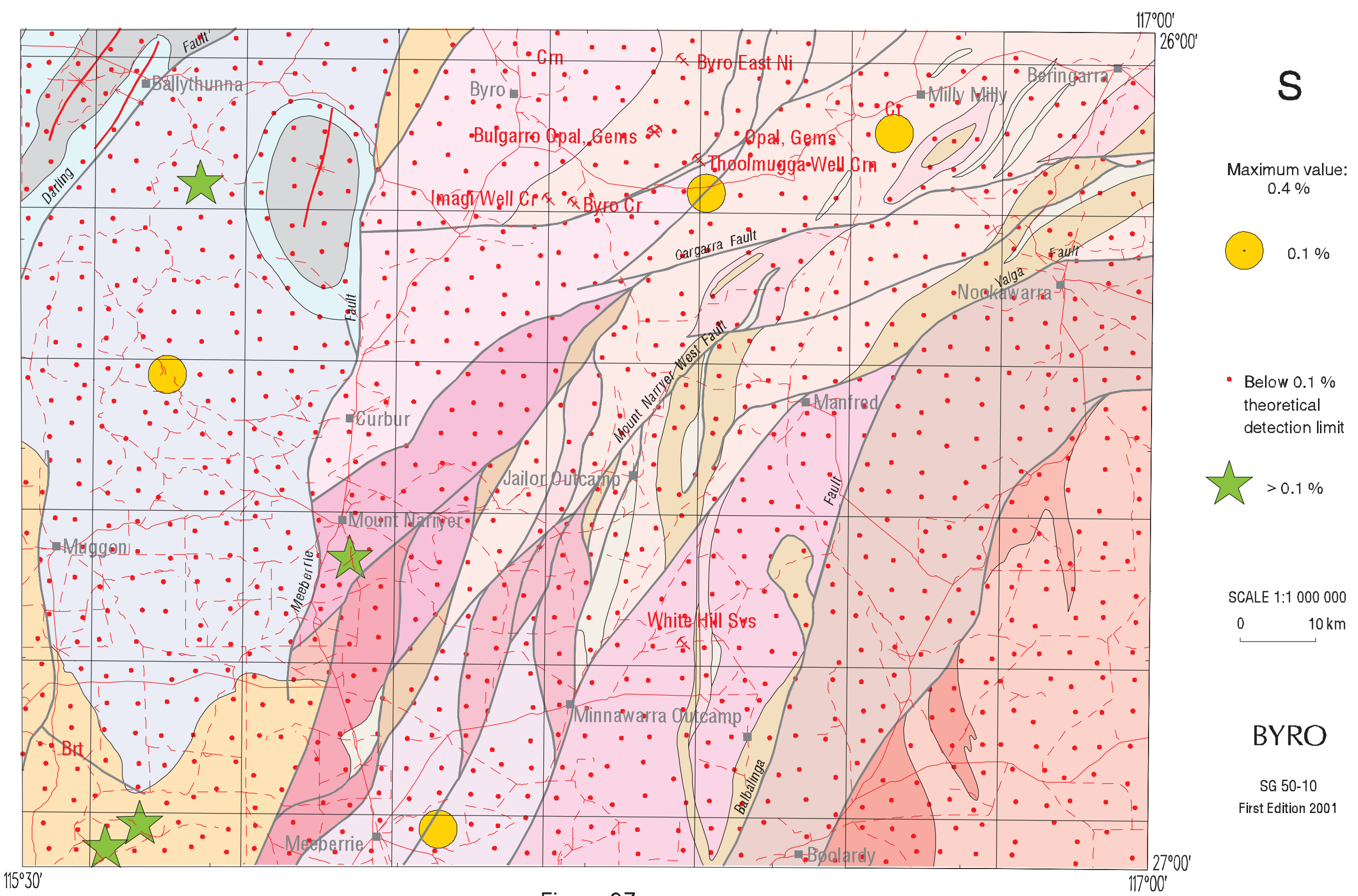

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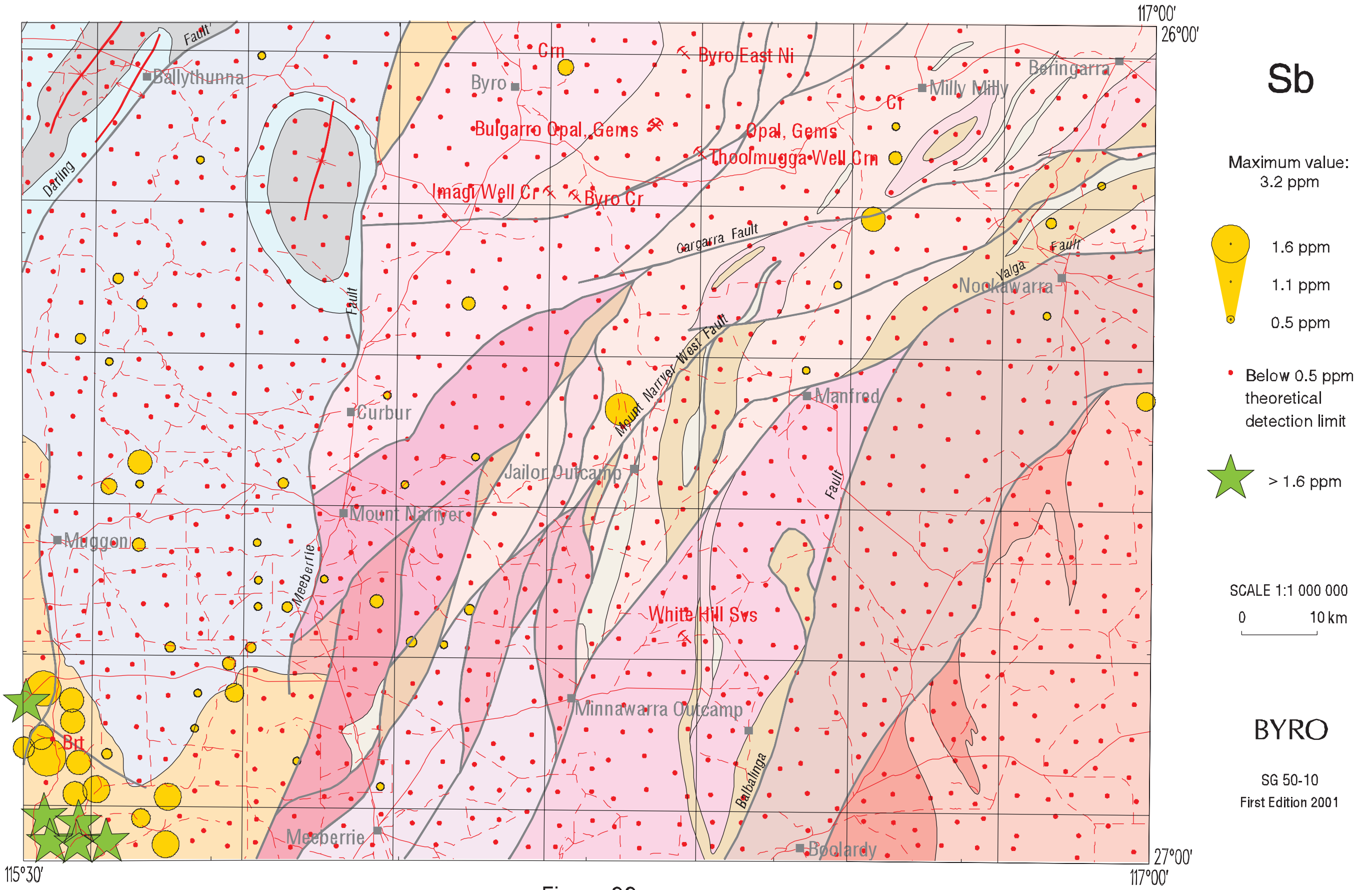

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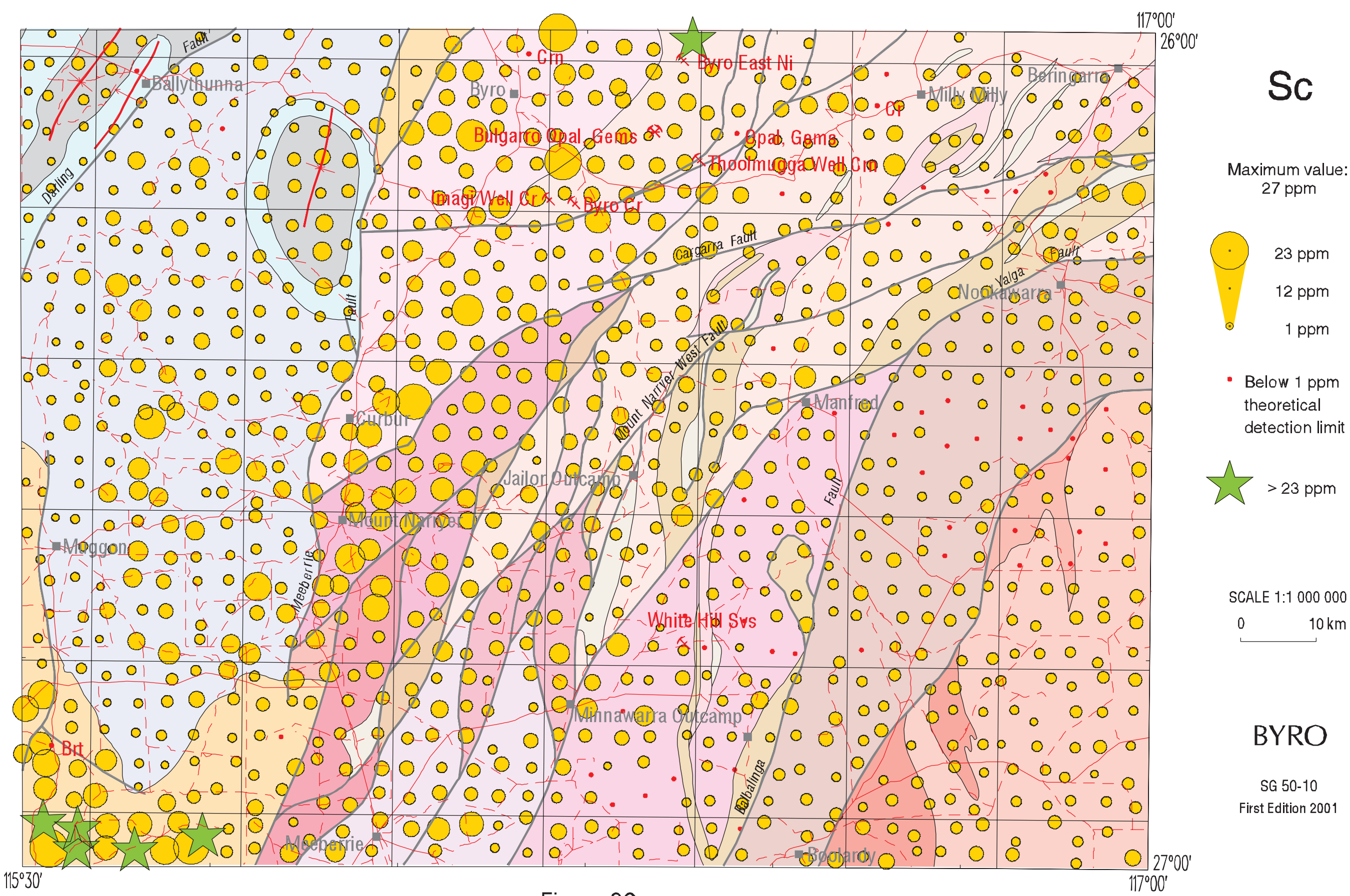

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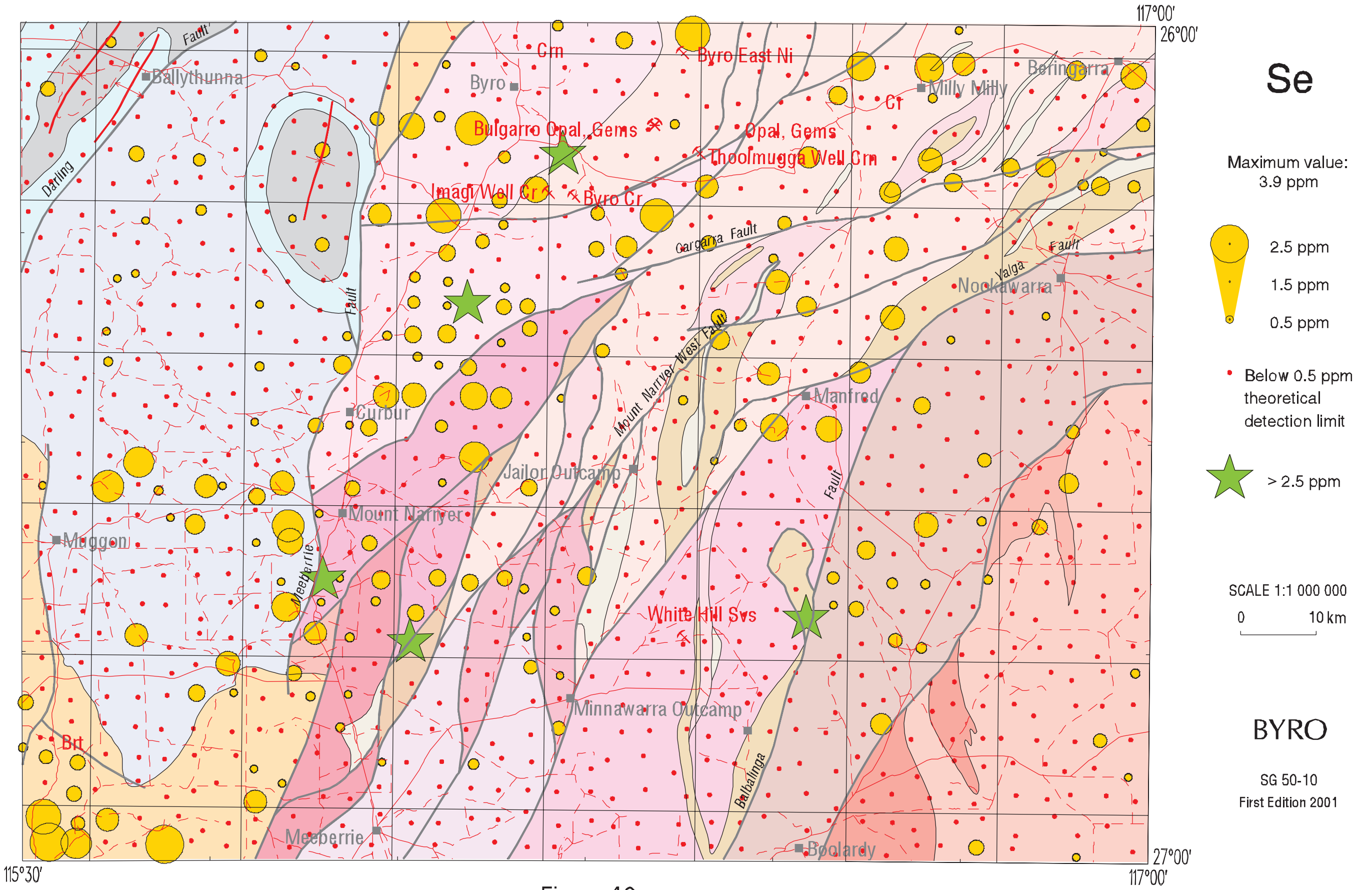

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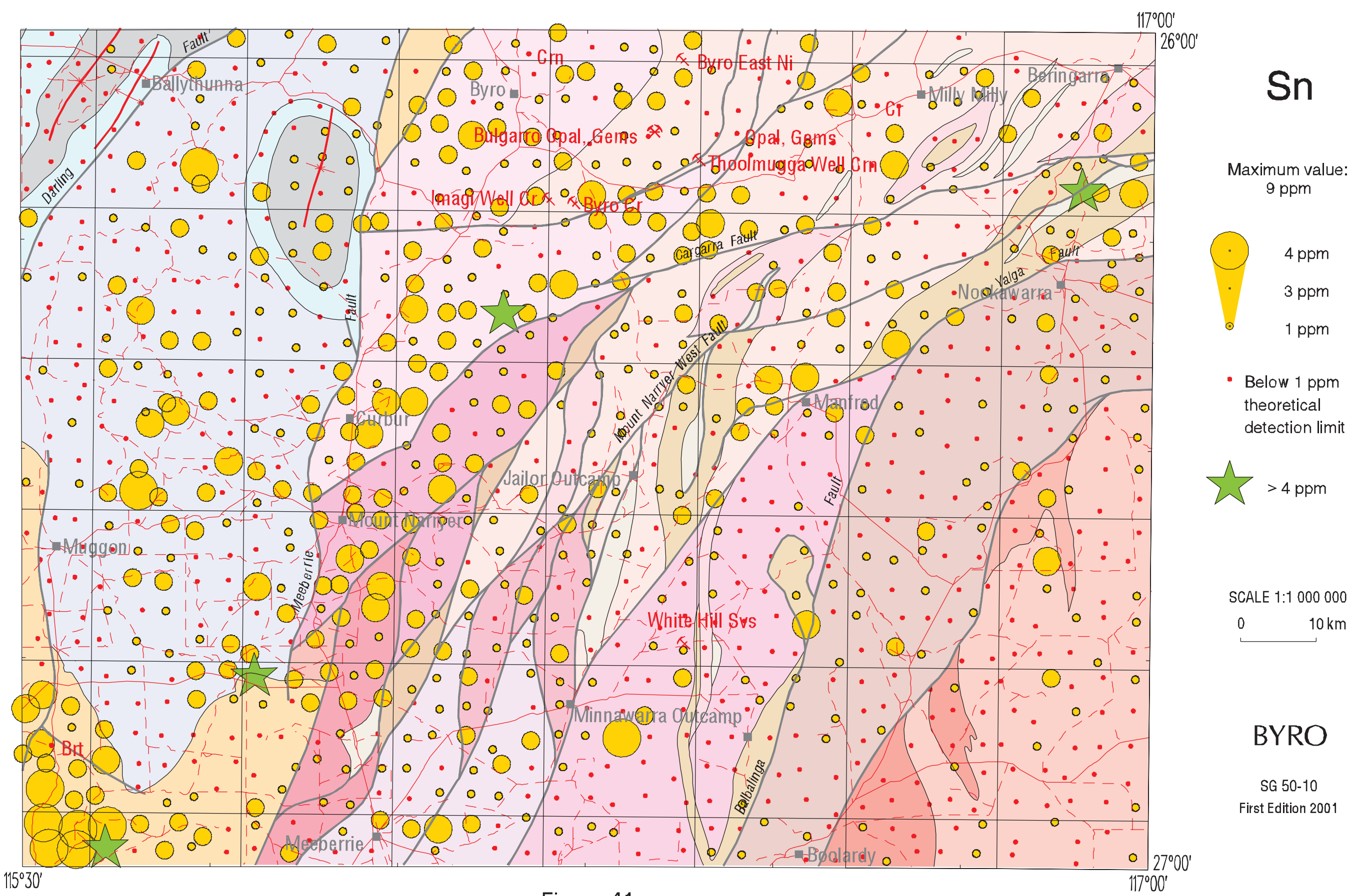

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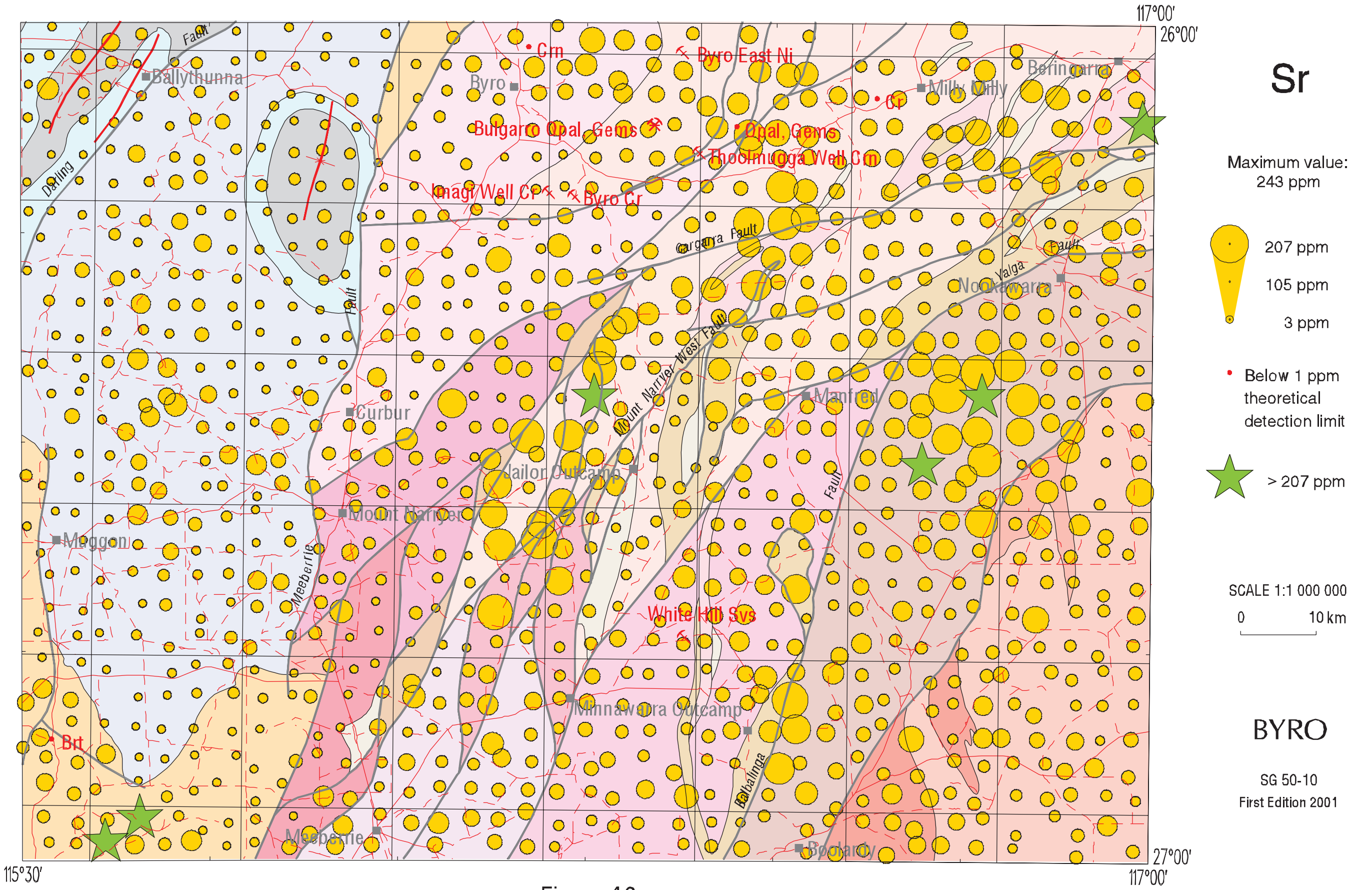

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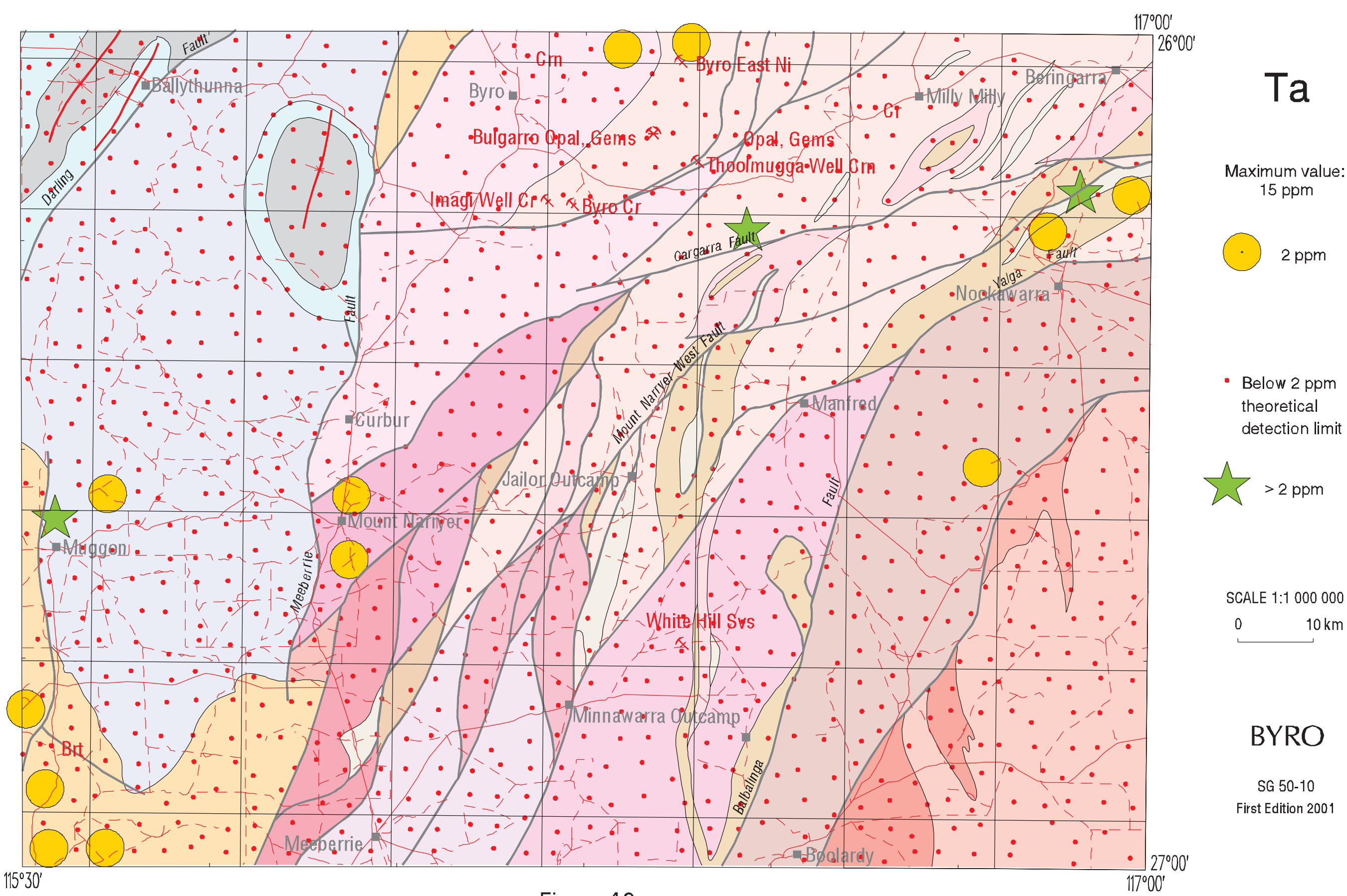

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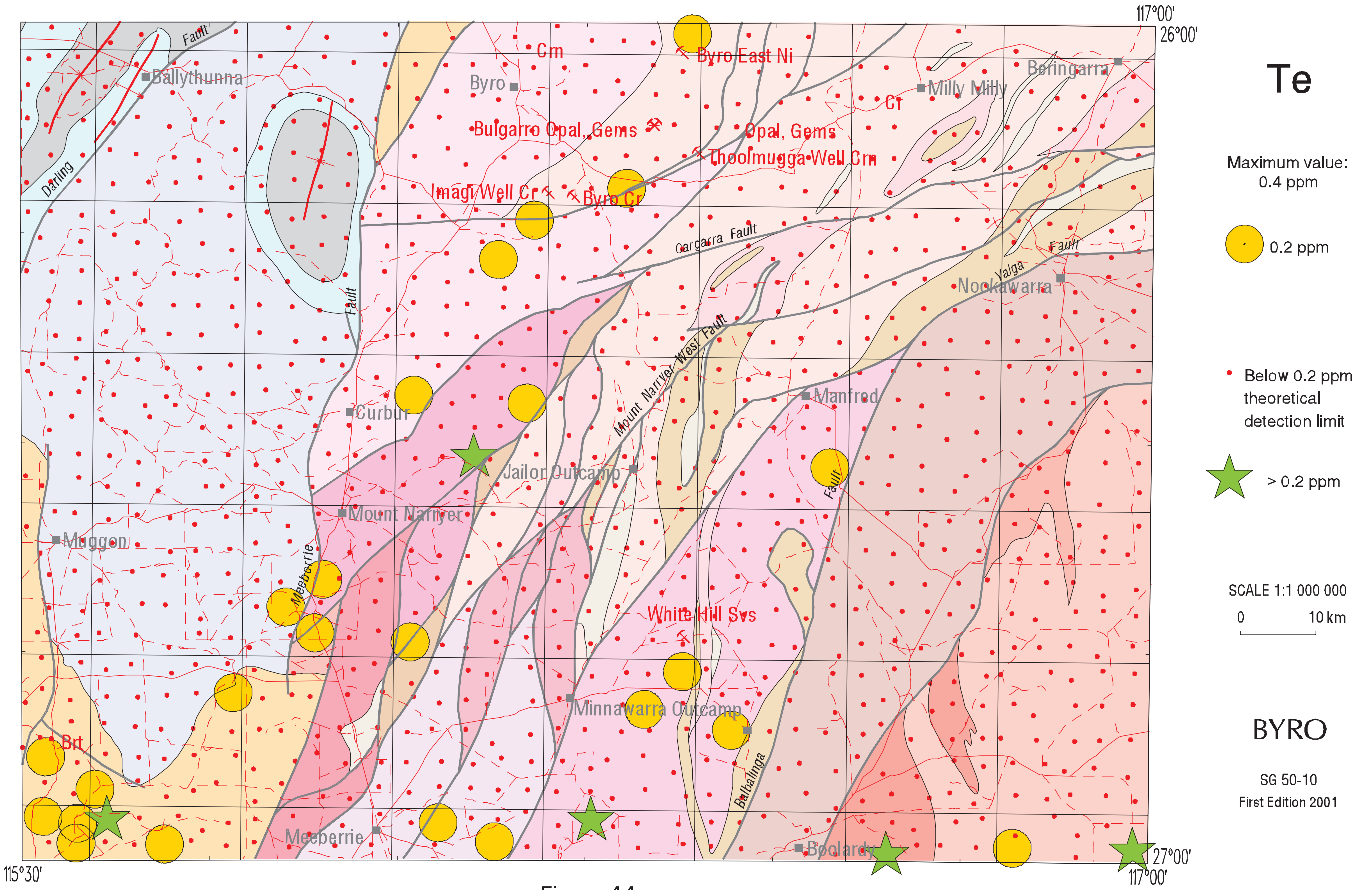

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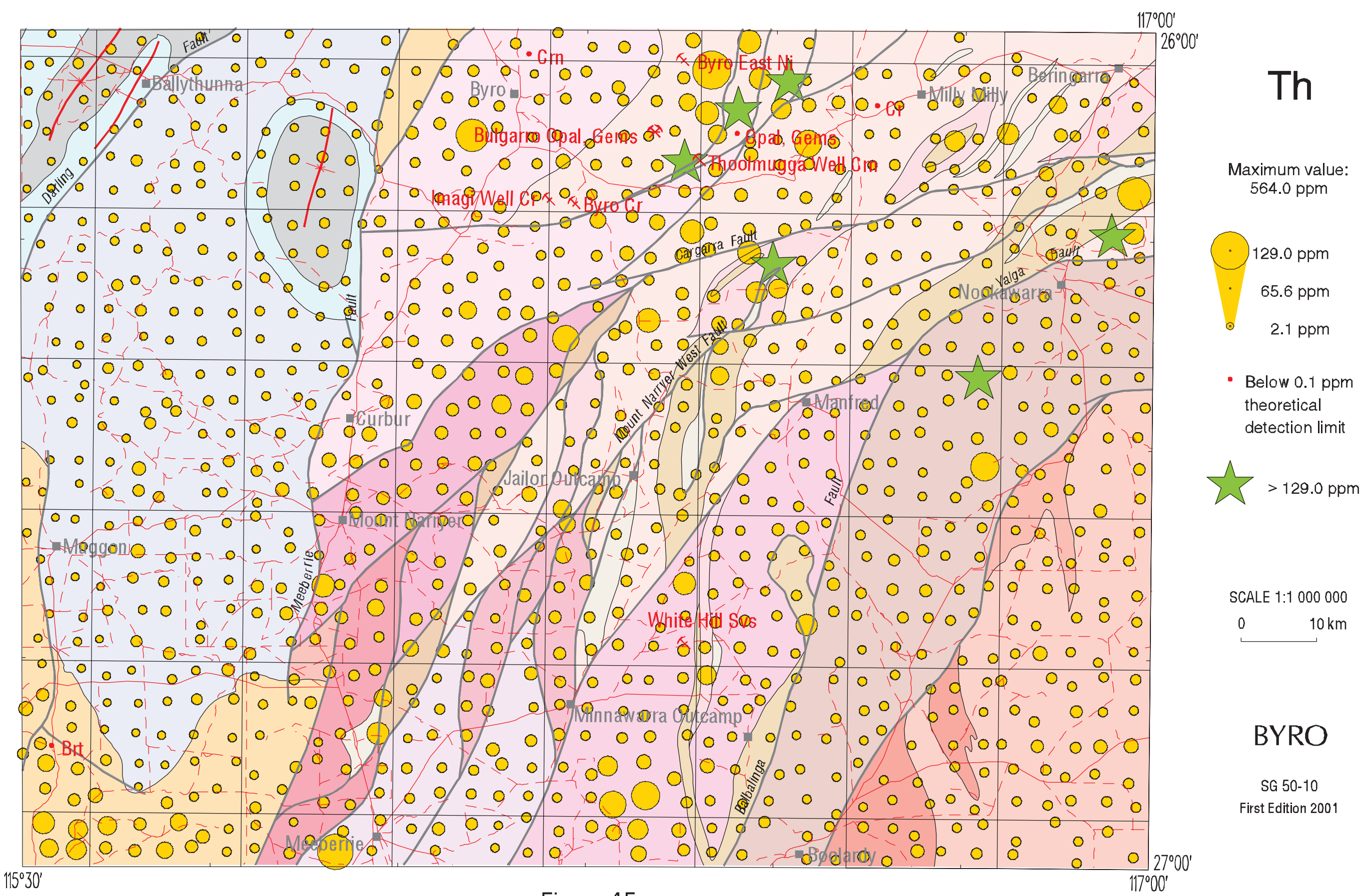

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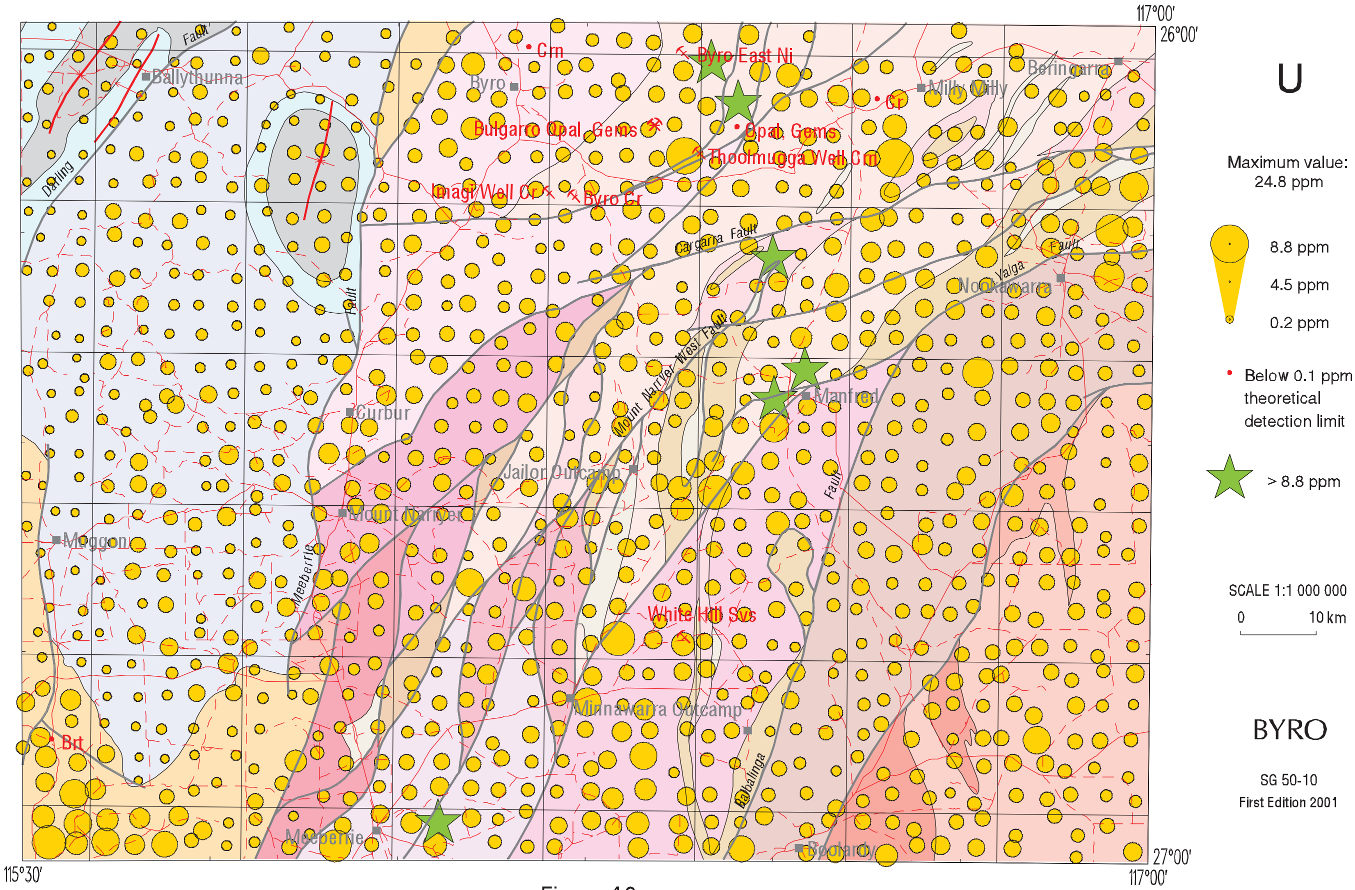

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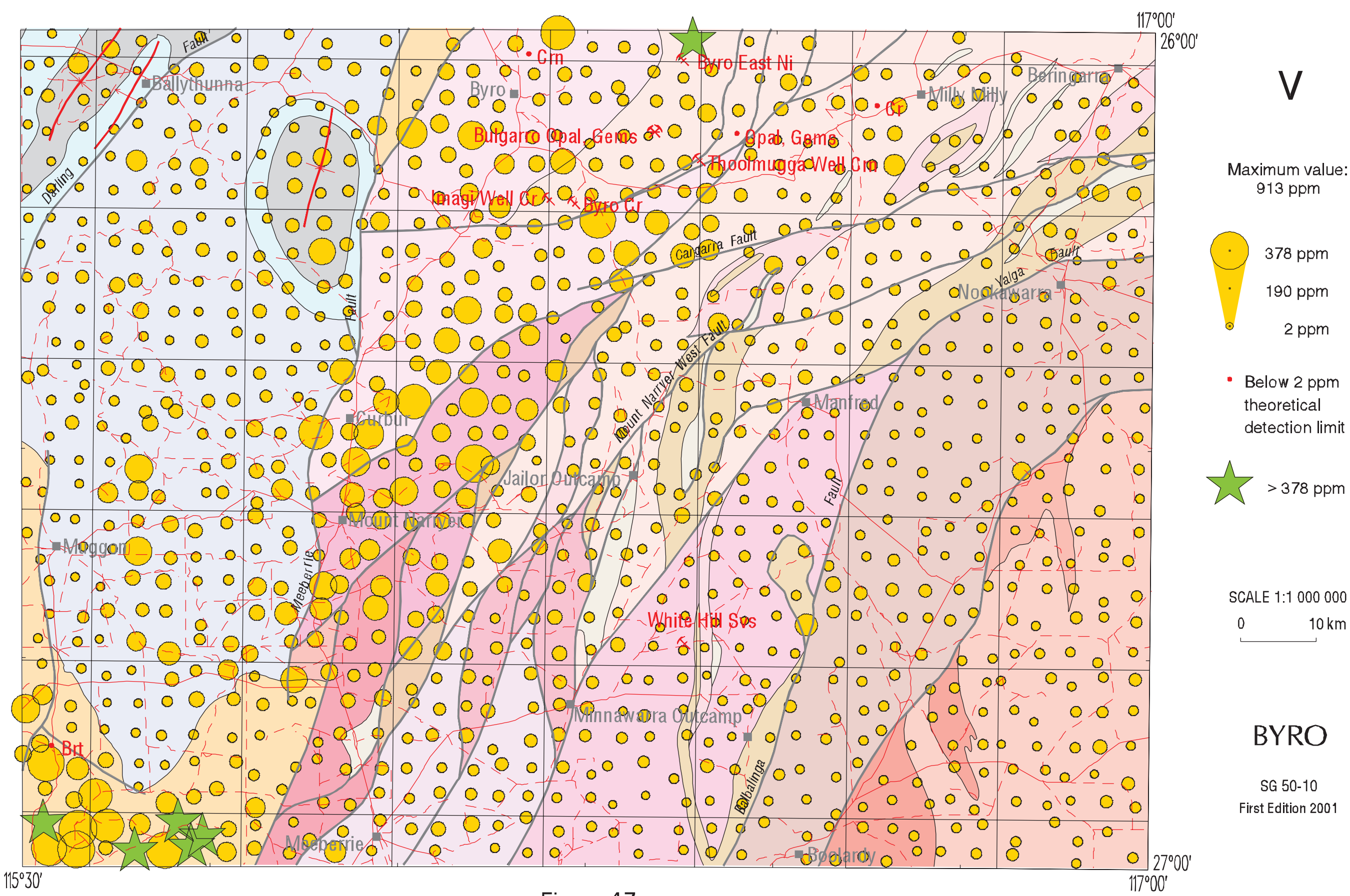

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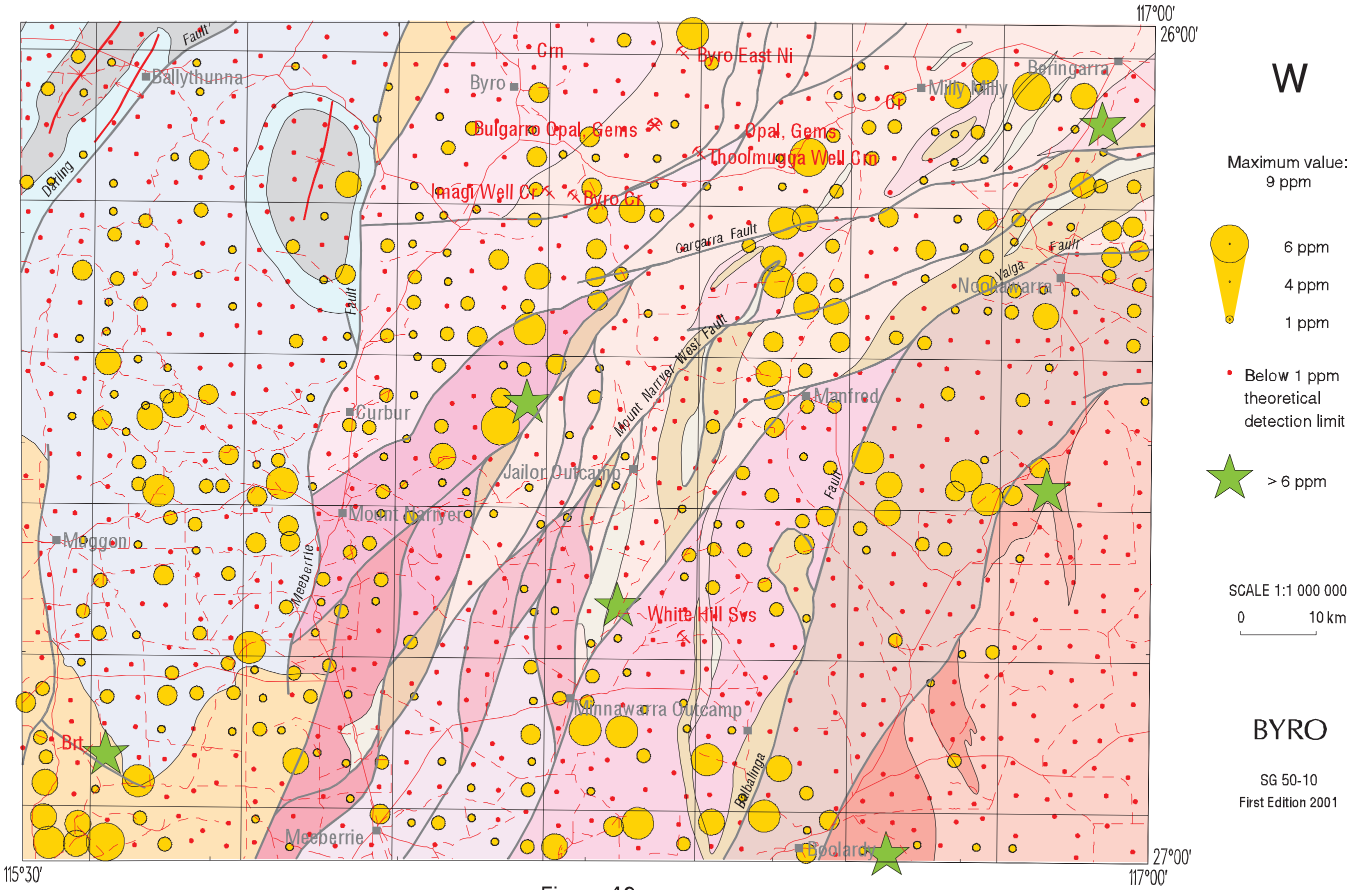

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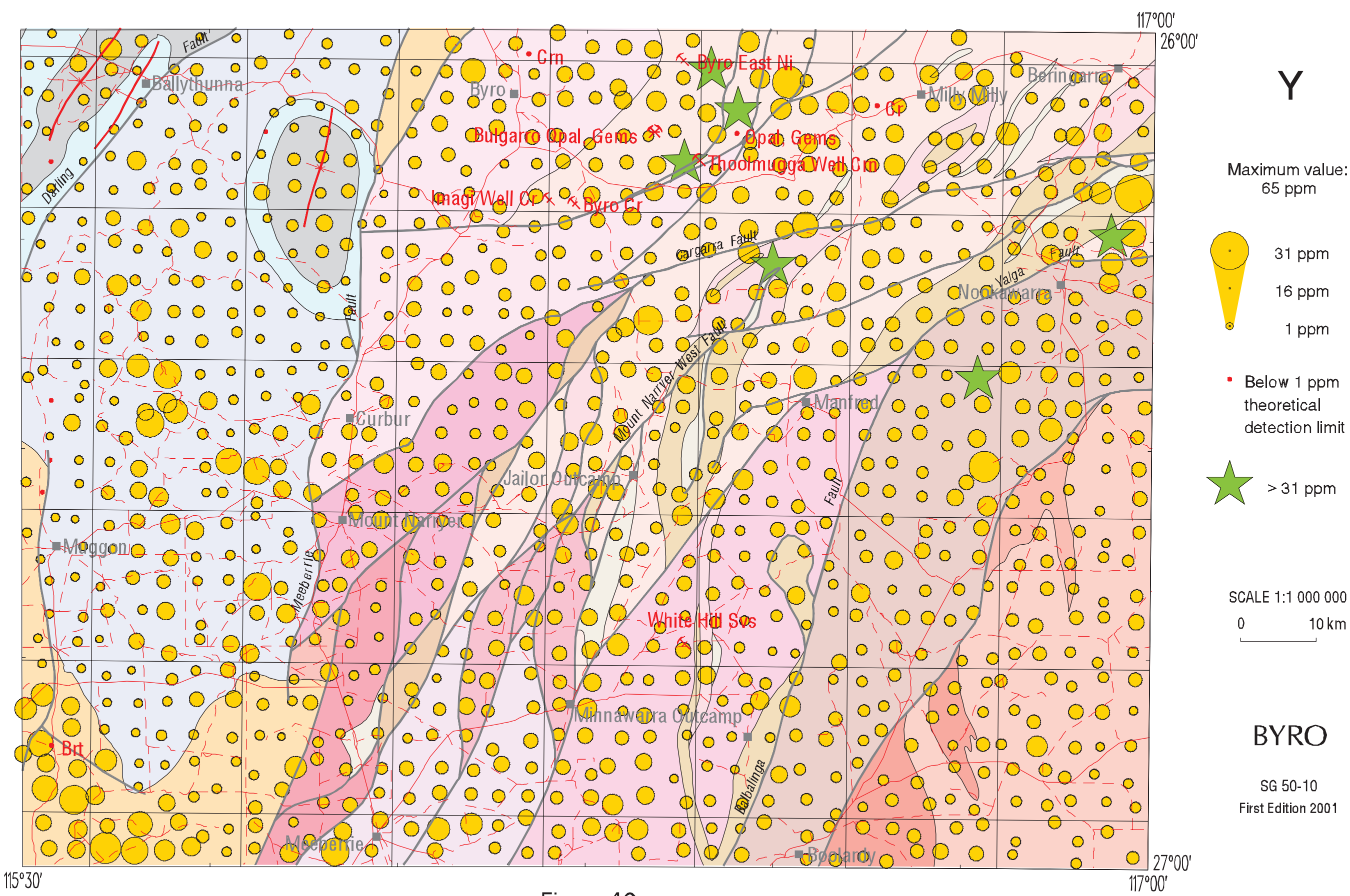

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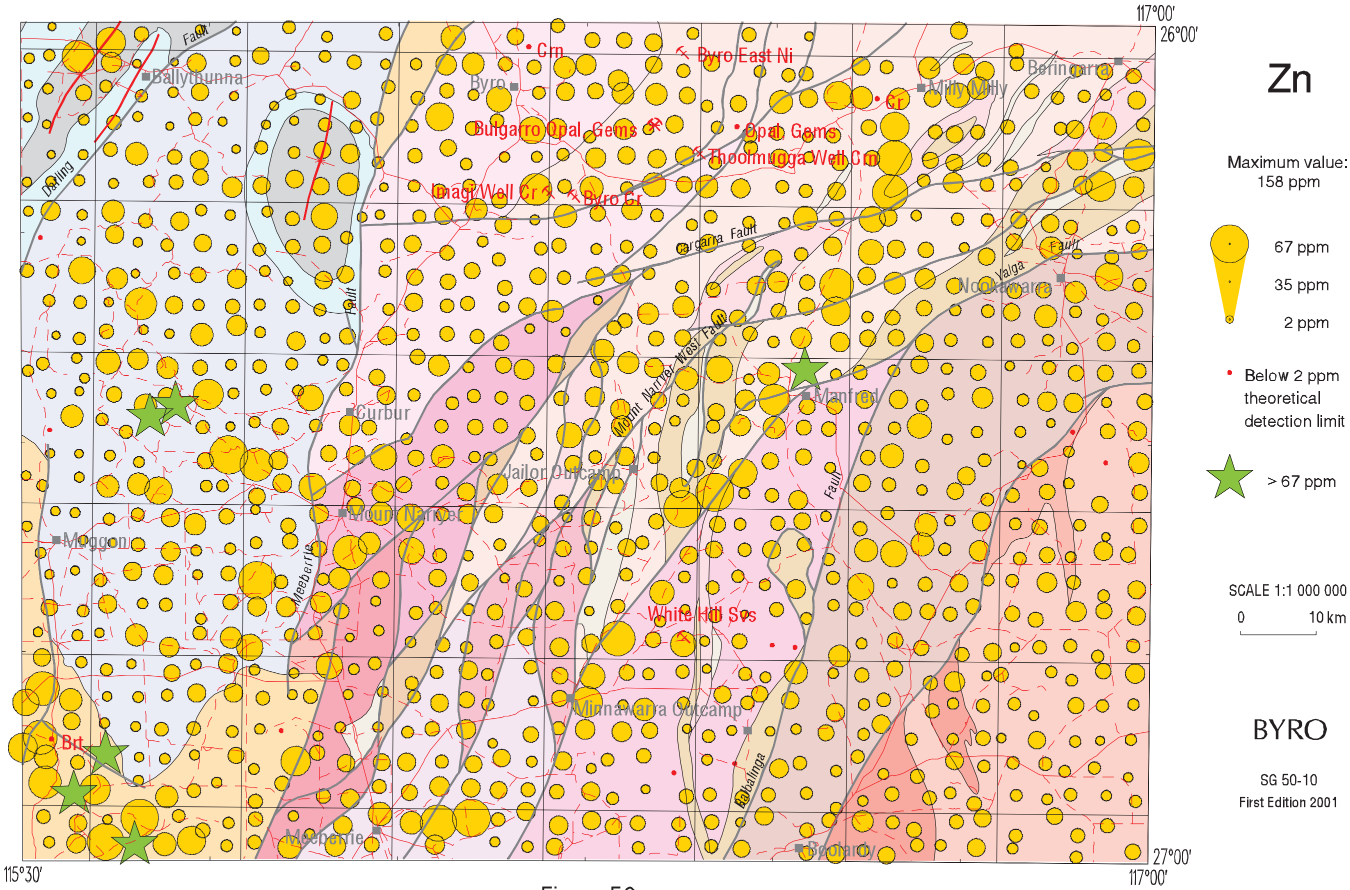

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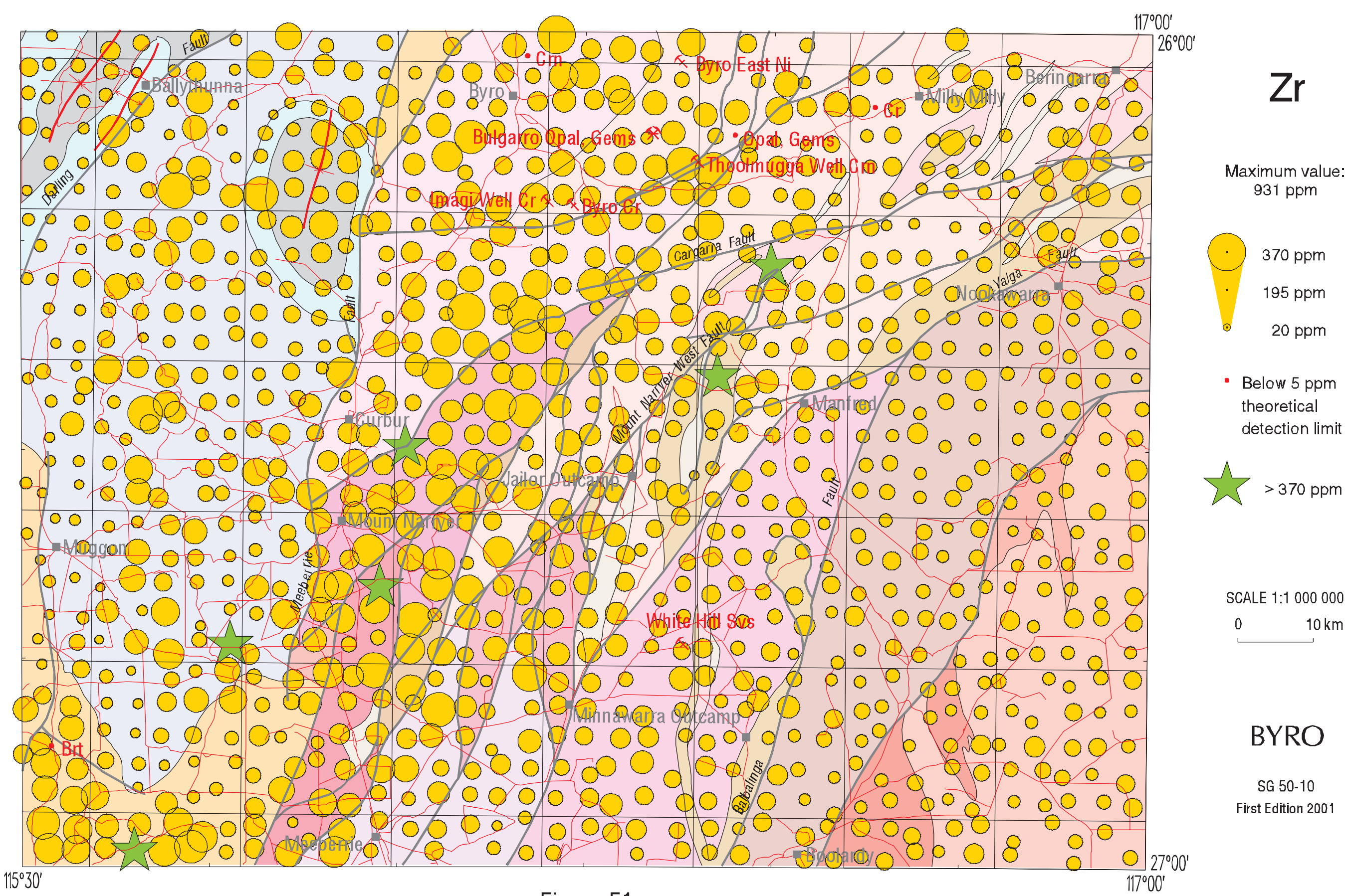

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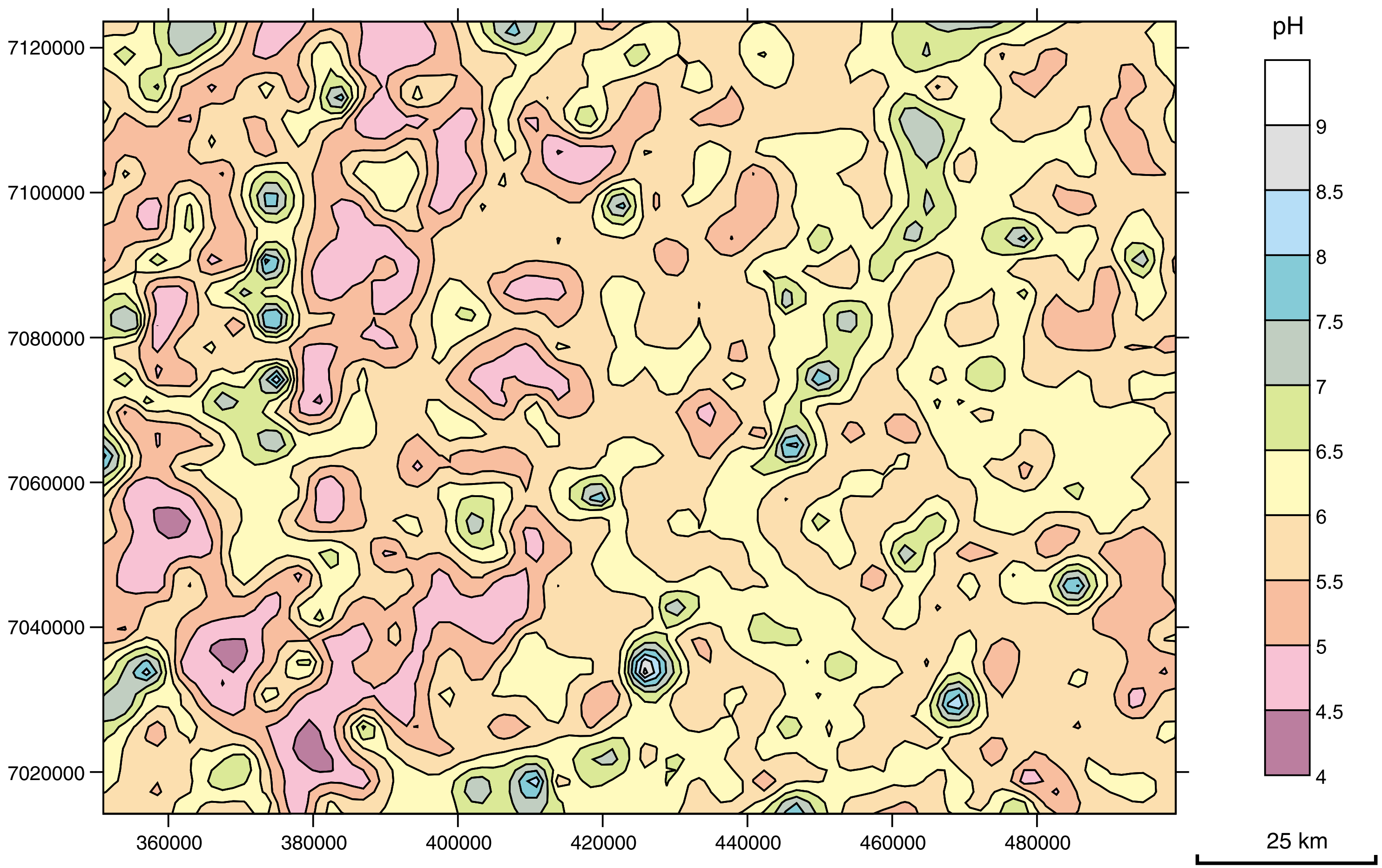


Figure 52. pH in regolith

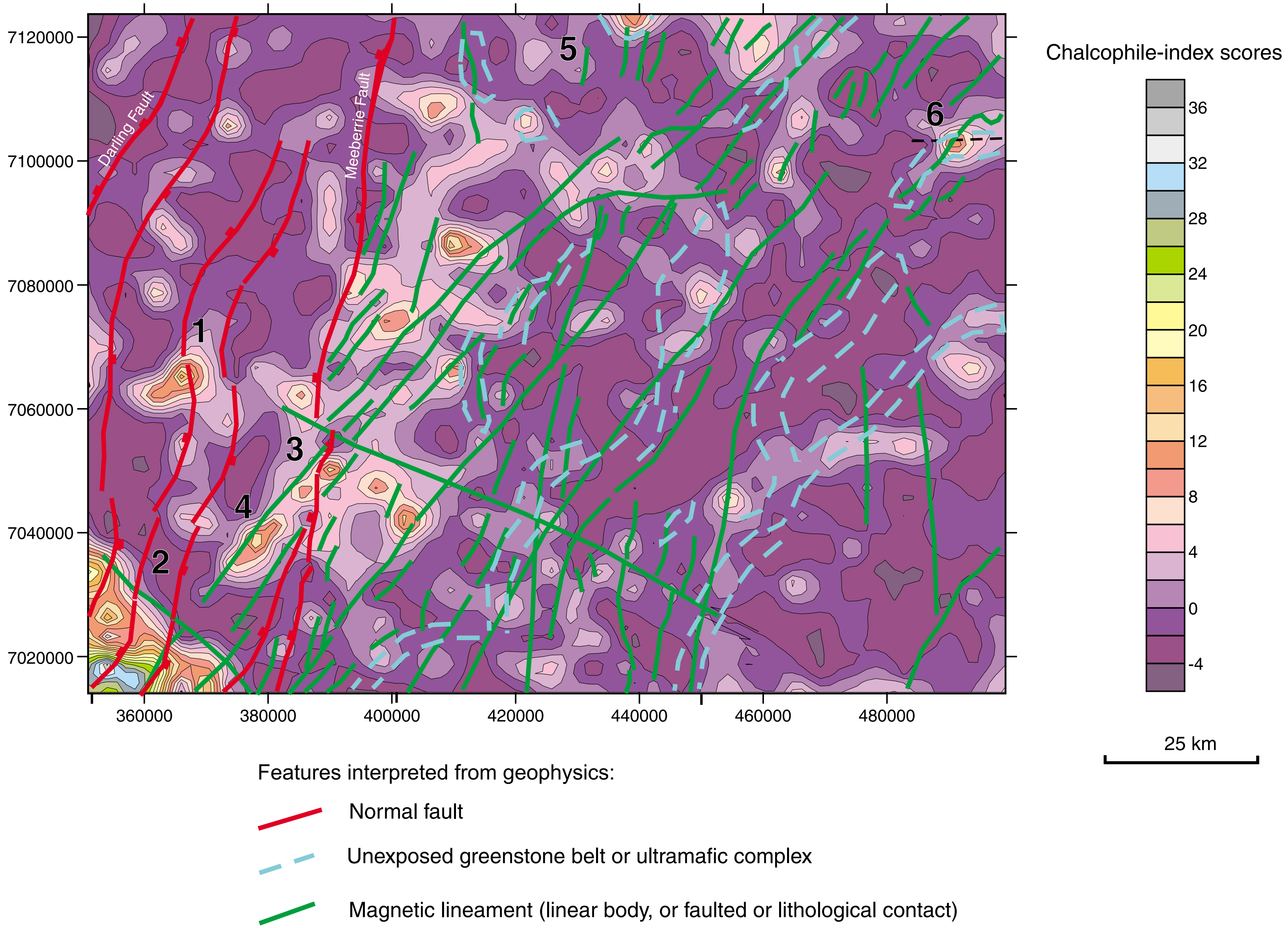
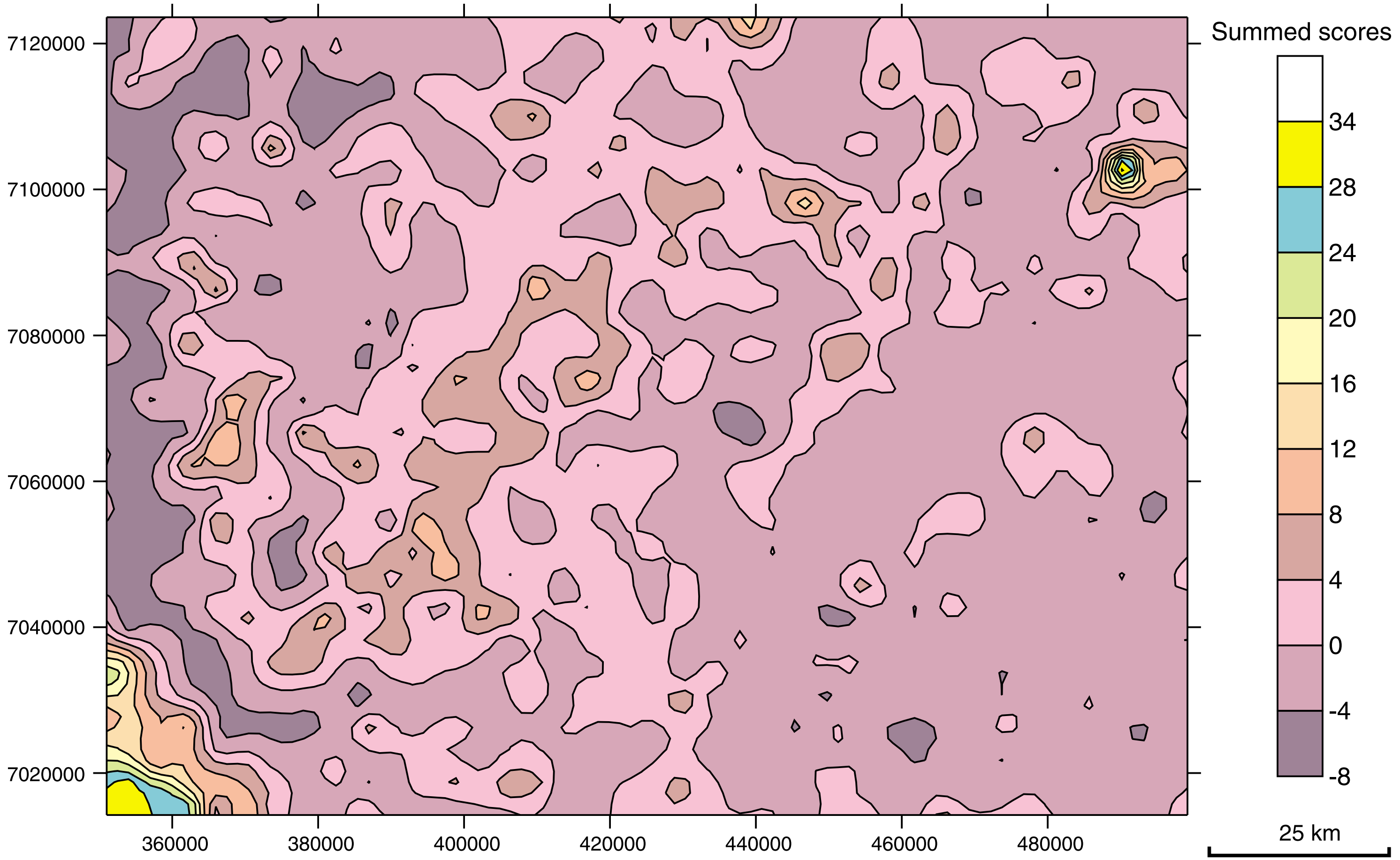


Figure 53. Contoured chalcophile-index scores and structure interpreted from geophysics (after Blundell et al., in prep.)

PAM228

11.5.01



PAM229

Figure 54. Contoured pegmatite index scores (As + Sb + Sn + Ga + W + Nb + Ta) in regolith

23.5.01

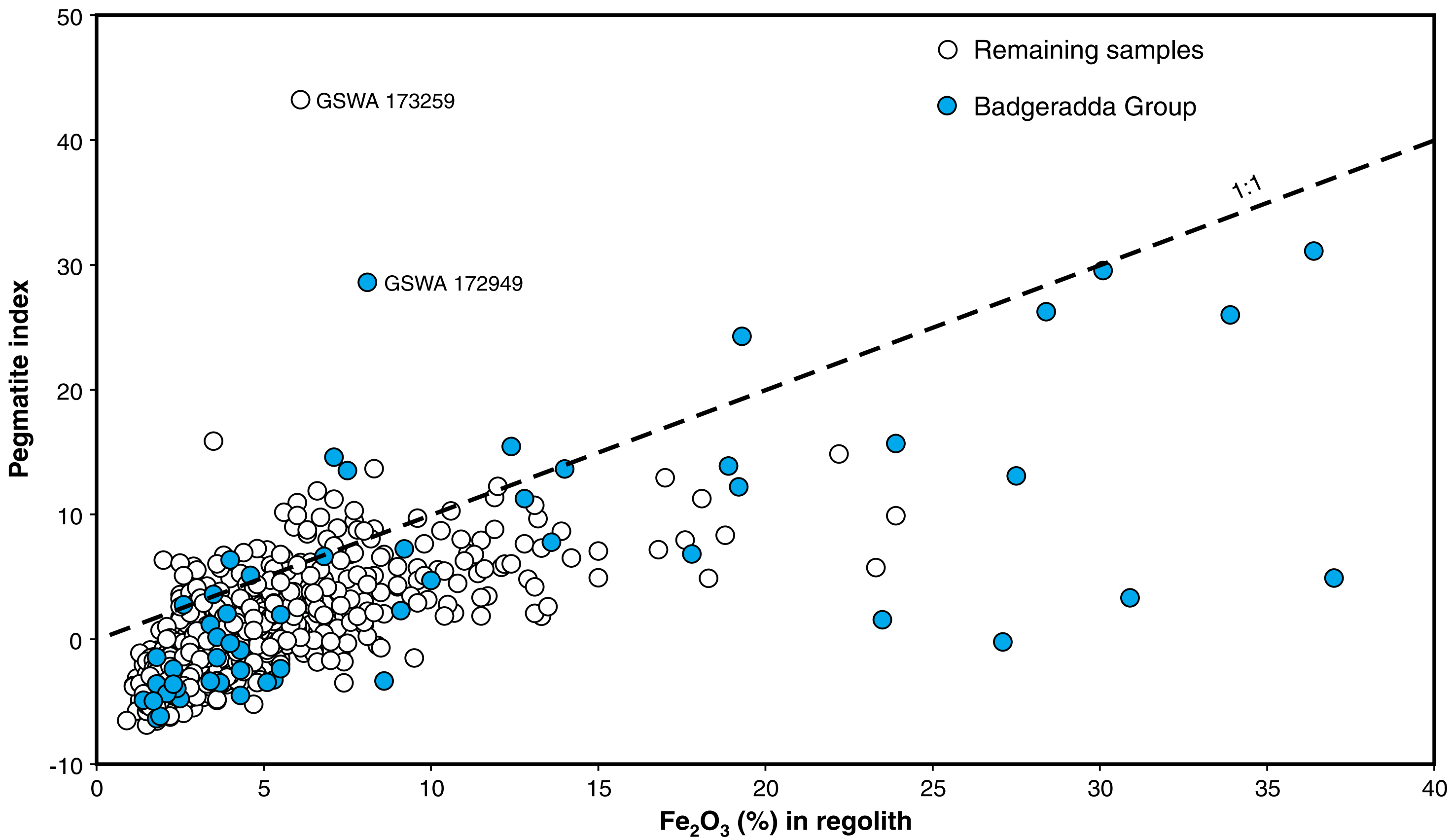


Figure 55. Pegmatite index versus Fe_2O_3 (%) in regolith (see text for discussion)

PAM230

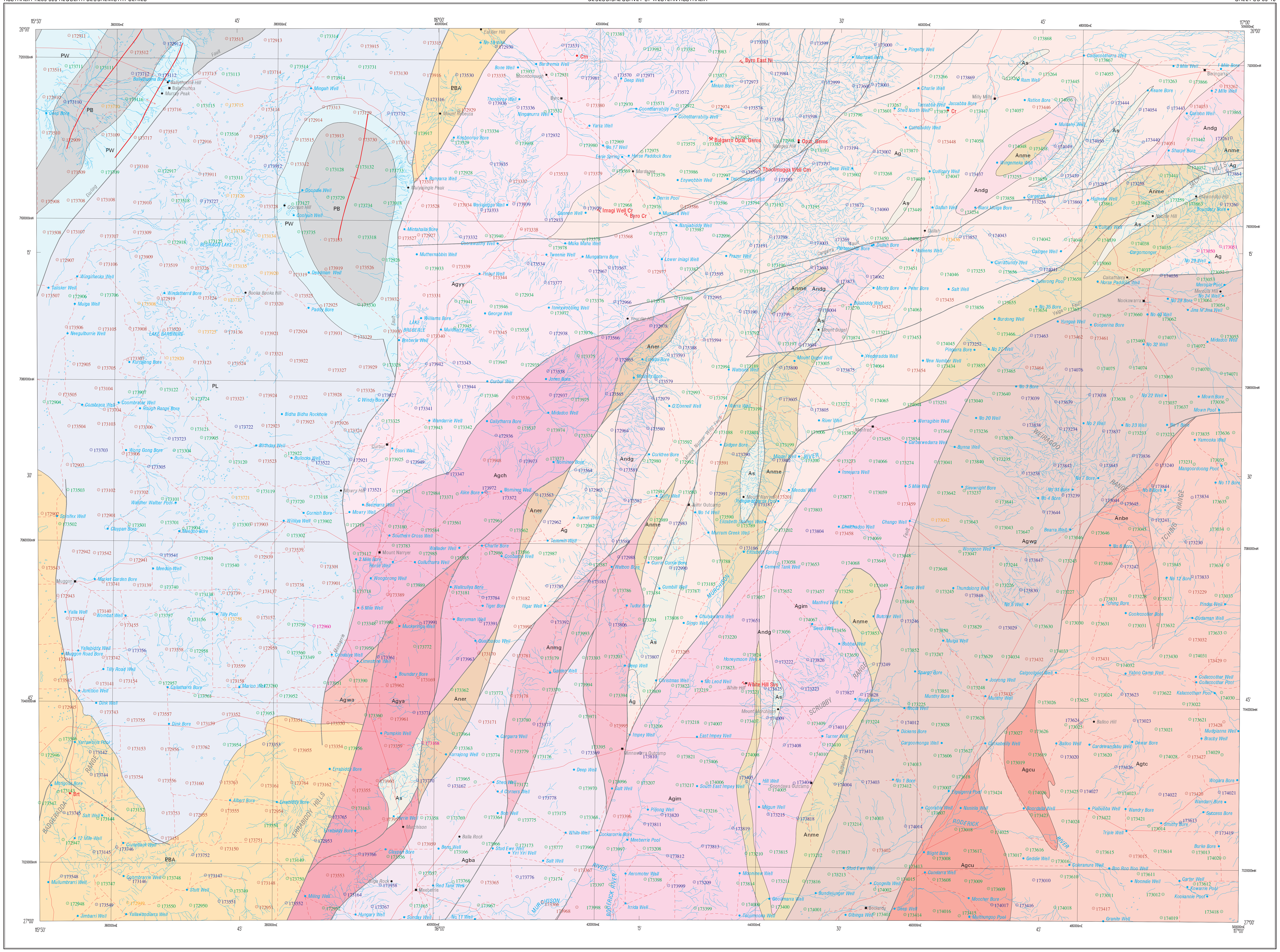
23.5.01

AUSTRALIA 1:250 000 REGOLITH GEOCHEMISTRY SERIES

BYRO

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

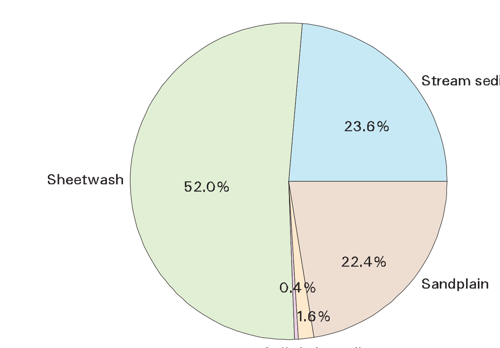
SHEET SG 50-10



SAMPLE LOCATIONS

Sample point reference

172912	Stream sediment
172904	Sheetwash
172960	Soil
172920	Lake sediment
172901	Sandplain



Total sample sites 1016

INTERPRETED BEDROCK GEOLOGY

PHANEROZOIC — EARLY PERMIAN

Byro Group

PB	Bioturbated siltstone and fine-grained sandstone

Wooramel Group

PW	Siltstone, quartzose or feldspathic sandstone, carbonaceous shale, and minor claystone

Lyons Group

PL	Immature sandstone, siltstone, shale, micaceous claystone, and tillite; numerous glacial erratics

PROTEROZOIC

Badgeradda Group

ĿBA	Siltstone, silty sandstone, feldspathic and quartzose sandstone, and minor pebble-conglomerate lenses

ARCHAEAN — YILGARN CRATON

Narryer Terrane

Agyy	YARRA YARRA GRANITE: coarse-grained, equigranular, leucocratic monzogranite; metamorphosed at granulite facies
Agch	CHURLA GRANITE: coarse-grained, equigranular, leucocratic monzogranite; metamorphosed at granulite facies
Agba	BALLA GRANITE: coarse-grained, porphyritic to equigranular monzogranite, with inclusions of **EURADA GNEISS**; metamorphosed at amphibolite facies
Agim	IMPEY GRANITE: heterogeneous, coarse-grained, porphyritic to equigranular monzogranite; metamorphosed at amphibolite facies
Ag	Coarse-grained, equigranular to porphyritic granite, locally with inclusions of amphibolite, ultramafic rock, metasedimentary rock, or gneiss
Agya	YALLALONG GRANITE: coarse-grained, equigranular, leucocratic monzogranite; metamorphosed at granulite facies
Agwa	WANDARRIE GRANITE: coarse-grained, equigranular, leucocratic monzogranite
As	Undivided metasedimentary rocks, including banded iron-formation, quartz-magnetite rock, pelite, quartzite, conglomerate, sandstone, silicic schist, mylonite, quartz-mica schist, and micaceous quartzite; subordinate metagabbro, ultramafic schist, and amphibolite
Anmg	MILGA GNEISS: granodioritic gneiss
Andg	DUGEL GNEISS: monzogranitic and syenogranitic gneiss
Aner	EURADA GNEISS: monzogranitic to tonalitic gneiss, with inclusions of **MEEBERRIE GNEISS** and veined by **DUGEL GNEISS**
Anme	MEEBERRIE GNEISS: monzogranitic to tonalitic gneiss, veined by **EURADA GNEISS** and **DUGEL GNEISS**

Murchison Granite-Greenstone Terrane

Agwg	WEIRAGOO GRANITE: porphyritic to equigranular monzogranite; metamorphosed at amphibolite facies
Agcu	CUNDARRA GRANITE: coarse-grained, equigranular to porphyritic monzogranite; metamorphosed at amphibolite facies
Agtc	TCHING GRANITE: monzogranite with inclusions of **BEARRA GNEISS**; metamorphosed at amphibolite facies
Anbe	BEARRA GNEISS: dioritic and leucogranitic gneiss, possibly an earlier phase of the **TCHING GRANITE**

Geological boundary — Anticline

Fault — Syncline

SYMBOLS

Formed road		Bulgarro	Opencut, abandoned
Track		Byro East	Prospect
Watercourse			Mineral occurrence
Lake		Brt	Barite
Pool, rockhole, spring, bore, well		Cr	Chromium
Byro	Homestead	Crn	Corundum
Mount Rebecca	Locality	Gems	Gemstones
		Ni	Nickel
		Opal	Opal
		Svs	Silica

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 SG 50-10

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Compiled by P. A. Morris 2000

Sampling by S. Brindle, M. Gallen, R. Hackney, S. McGuinness, D. O'Farrel, A. L. Verren, G. White, and P. A. Morris (GSWA)

Total sample sites: 1016; 240 stream sediment, 528 sheetwash, 16 lake sediment, 228 sandplain, and 4 soil

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

Geological interpretation after: MYERS, J. S., 1997, Byro, W.A. Sheet SG 50-10 (second edition): Western Australia Geological Survey, 1:250 000 Geological Series; MYERS, J. S., and HOCKING, R. M., 1998, Geological map of Western Australia 1: 2 500 000 (13th edition): Western Australia Geological Survey

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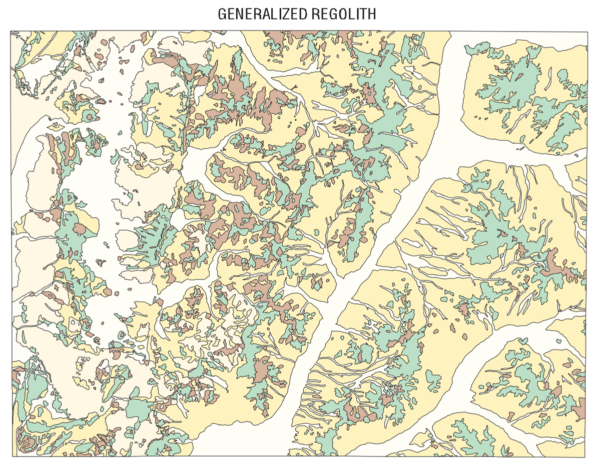
GENERALIZED REGOLITH



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

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

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YARINGA SG 50-9	BYRO SG 50-10	BELELE SG 50-11
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BADGERADDA 2044	CHULYAWARRA 2144	BOOLARDY 2244

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GOVERNMENT OF WESTERN AUSTRALIA
CLIVE BROWN, M.L.A.
MINISTER FOR STATE DEVELOPMENT; TOURISM; SMALL BUSINESS; GOLDFIELDS-ESPERANCE

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
TIM GRIFFIN, DIRECTOR

SAMPLE LOCATIONS

REGOLITH GEOCHEMISTRY SERIES

BYRO

SHEET SG 50-10

FIRST EDITION 2001

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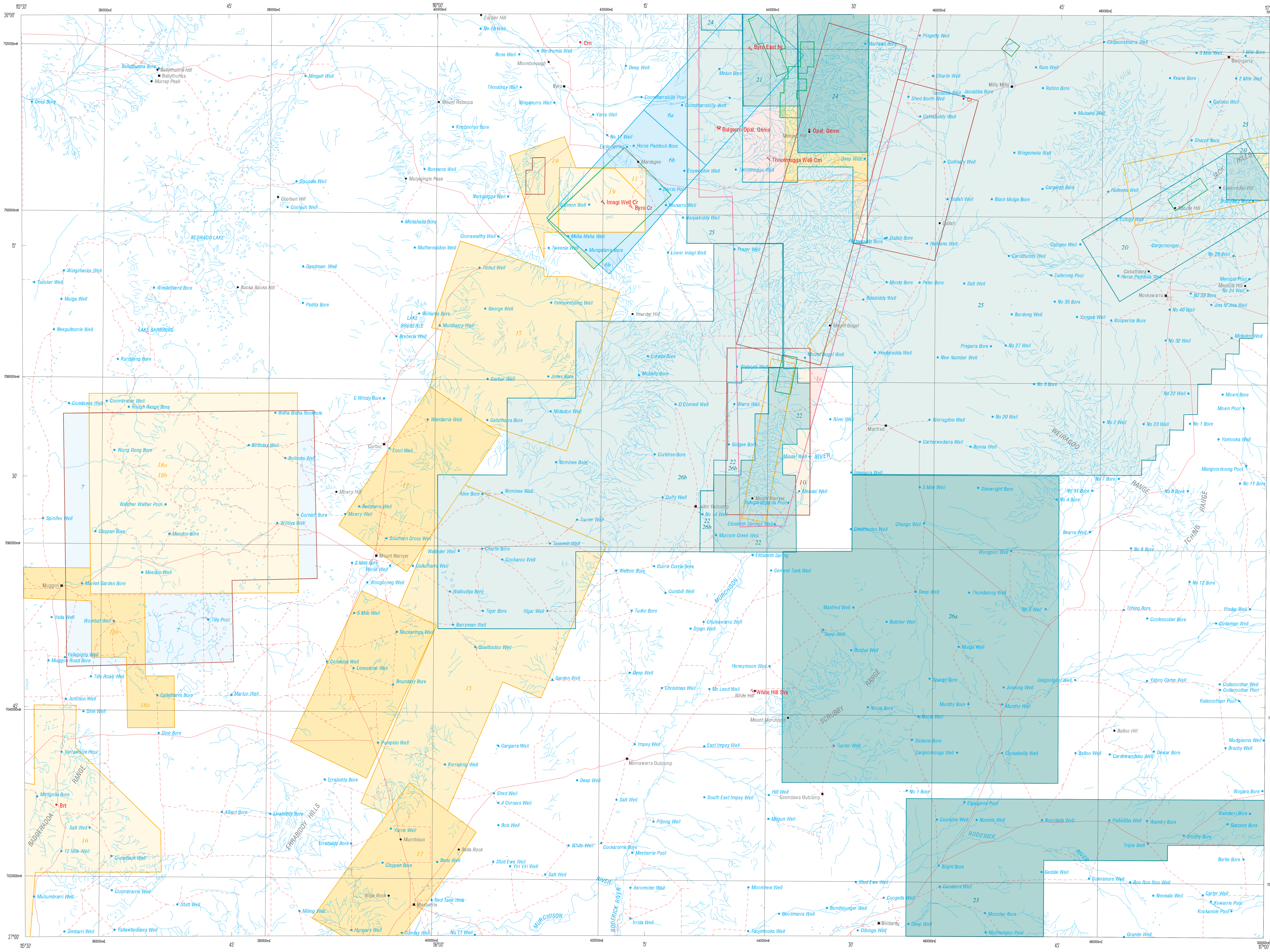
BYRO

AUSTRALIA 1:250 000 REGOLITH GEOCHEMISTRY SERIES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET SG 50-10



COMPANY PROJECTS WITH SURFACE GEOCHEMISTRY DATA IN OPEN-FILE REPORTS (at August 2000)

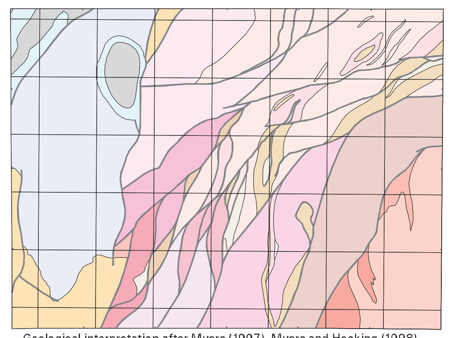
Project period reported within

(Various colour shades used for ease of project identification)

- 1966 - 1970
- 1971 - 1975
- 1976 - 1980
- 1981 - 1985
- 1986 - 1990
- 1991 - 1998

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

INTERPRETED BEDROCK GEOLOGY



Geological interpretation after Myers (1997), Myers and Hocking (1998)

Scale 1:2 000 000

- Geological boundary
- Fault

PHANEROZOIC — EARLY PERMIAN

Byro Group

- Bioturbated siltstone and fine-grained sandstone

Wooramel Group

- Siltstone, quartzose or feldspathic sandstone, carbonaceous shale, and minor claystone

Lyons Group

- Immature sandstone, siltstone, shale, micaceous claystone, and tillite; numerous glacial erratics

PROTEROZOIC

Badgeradda Group

- Siltstone, silty sandstone, feldspathic and quartzose sandstone, and minor pebble-conglomerate lenses

ARCHAEAN — YILGARN CRATON

Narryer Terrane

- YARRA YARRA GRANITE: coarse-grained, equigranular, leucocratic monzogranite; metamorphosed at granulite facies
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- YALLALONG GRANITE: coarse-grained, equigranular, leucocratic monzogranite; metamorphosed at granulite facies
- WANDARRIE GRANITE: coarse-grained, equigranular, leucocratic monzogranite
- Undivided metasedimentary rocks, including banded iron-formation, quartz-magnetite rock, pelite, quartzite, conglomerate, sandstone, silicic schist, mylonite, quartz-mica schist, and micaceous quartzite; subordinate metagabbro, ultramafic schist, and amphibolite
- MILGA GNEISS: granodioritic gneiss
- DUGEL GNEISS: monzogranitic and syenogranitic gneiss
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Murchison Granite-Greenstone Terrane

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- CUNDARRA GRANITE: coarse-grained, equigranular to porphyritic monzogranite; metamorphosed at amphibolite facies
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- BEARRA GNEISS: dioritic and leucogranitic gneiss, possibly an earlier phase of the **TCHING GRANITE**

SYMBOLS

Formed road	Bulgarro — Opencut, abandoned
Track	Byro East — Prospect
Watercourse	Mineral occurrence
Lake	Brt — Barite
Pool, rockhole, spring, bore, well	Cr — Chromium
Byro — Homestead	Crn — Corundum
Mount Rebecca — Locality	Gems — Gemstones
	Ni — Nickel
	Opal — Opal
	Svs — Silica

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

Cartography by M. Vicentic

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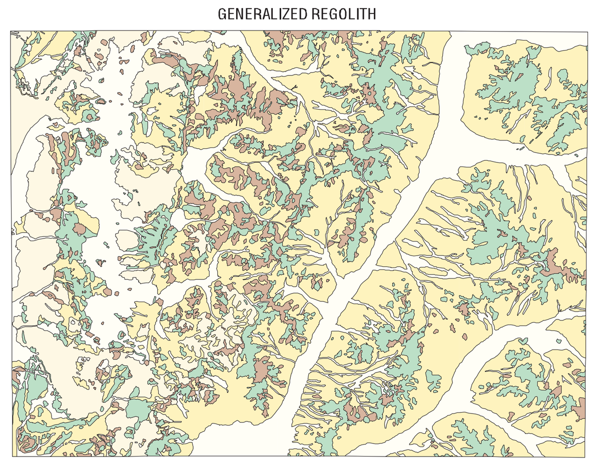
GENERALIZED REGOLITH



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

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

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Compiled by A. L. Verren 2000

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

The recommended reference for this map is:
VERREN, A. L., 2001, Company projects with surface geochemistry data in open-file reports (at August 2000), Byro, W.A. Sheet SG 50-10, *in* Geochemical mapping of the Byro 1:250 000 sheet *by* P.A. Morris and A. L. Verren: Western Australia Geological Survey, 1:250 000 Regolith Geochemistry Series Explanatory Notes, Plate 2

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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
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COMPANY PROJECTS WITH SURFACE GEOCHEMISTRY DATA IN OPEN-FILE REPORTS (at August 2000)

REGOLITH GEOCHEMISTRY SERIES

BYRO

SHEET SG 50-10

FIRST EDITION 2001

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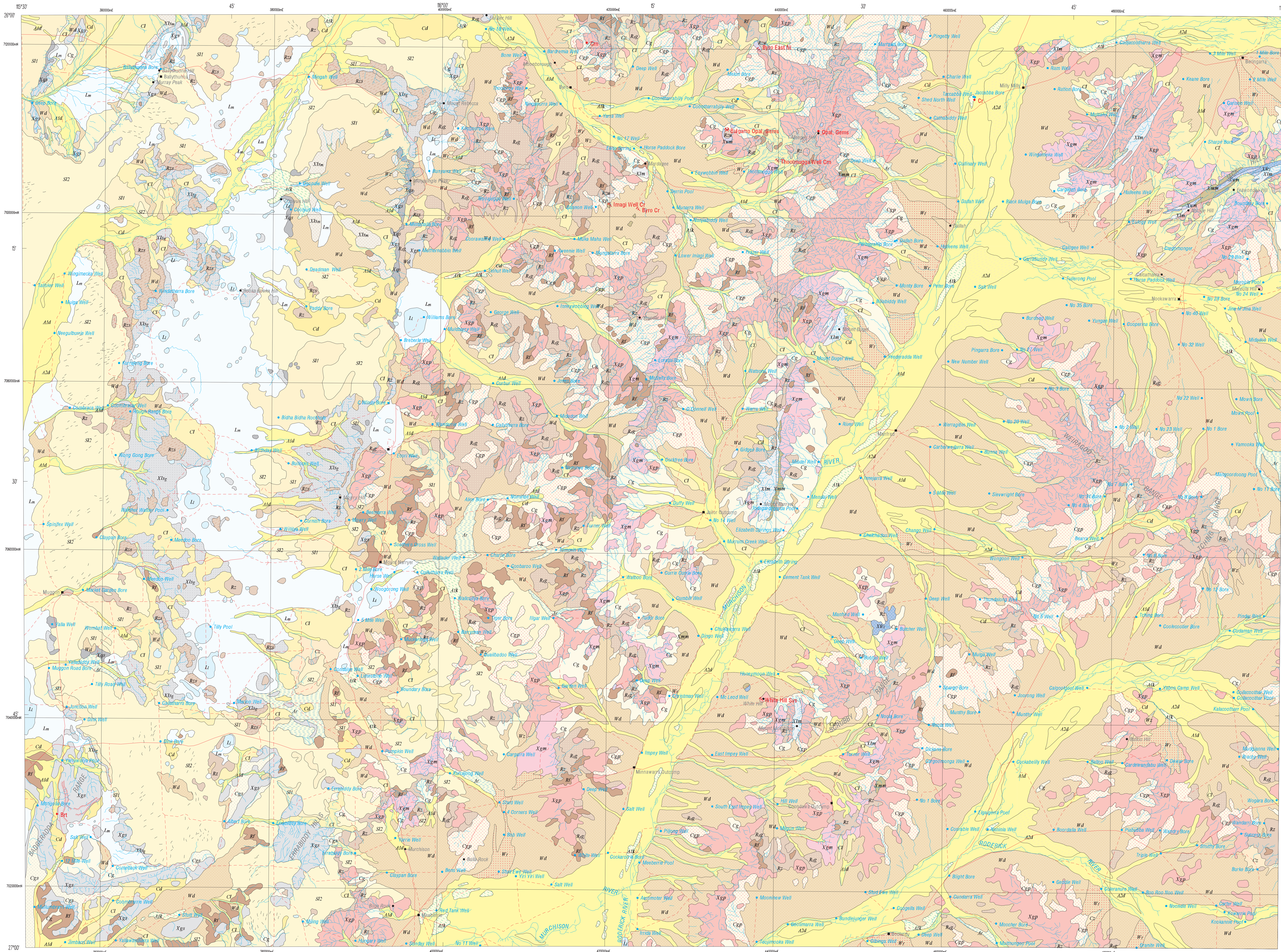
BYRO

AUSTRALIA 1:250 000 REGOLITH GEOCHEMISTRY SERIES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET SG 50-10



REGOLITH MATERIALS

REFERENCE

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

Rf	comprising mainly iron-rich material (ferricrete)
Rsg	comprising sand derived from quartzofeldspathic rock
Rz	comprising mainly silica-rich material (silcrete)
Rzs	comprising mainly silica-rich material (silcrete) developed over sedimentary rock
Rzu	comprising mainly silica-rich material (silcrete) developed over ultramafic rock

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

Xfci	derived from ferruginous chemical sedimentary rock (banded iron-formation and quartz-magnetite rock)
Xgm	derived from quartzofeldspathic metamorphic rock (granodiorite, monzogranite, syenite, and tonalite protoliths)
Xgp	derived from quartzofeldspathic plutonic rock (monzogranite and granite)
Xgs	derived from quartzofeldspathic sedimentary rock
Xlm	derived from heterogeneous metamorphic rock (quartzite, metaconglomerate, metasandstone, silicic schist, and mylonite)
Xlsg	derived from glacigene rock
Xlsm	derived from fine-grained sedimentary rock (mudstone, siltstone, and shale)
Xmm	derived from ferromagnesian metamorphic rock (mafic schist, amphibolite, and metamorphosed dolerite and gabbro)
Xqs	derived from quartz-rich siliciclastic sedimentary rock (conglomerate, sandstone, and siltstone)
Xum	derived from metamorphosed ultramafic rock (serpentinized peridotite and pyroxenite)

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

Cd	undivided
Cg	derived mainly from quartzofeldspathic rock
Cgp	derived mainly from quartzofeldspathic plutonic rock (monzogranite and granite)
Cgs	derived from quartzofeldspathic sedimentary rock
Cl	derived from mixed rock types
Cz	containing abundant silica-rich material

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

Wd	undivided
Wf	sheet-flood or fan deposits
Wz	containing abundant silica-rich material

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

A1d	alluvium in active drainages
A2d	consolidated alluvium, locally incised
Af	floodplain deposits
A1k	carbonate-rich alluvium in active drainages

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

Ll	in lakes and large playas
Lm	in mixed dune and playa terrain

SANDPLAIN *(S)* - Eolian and residual sand

Sl1	in mixed sandplain, colluvium, and sheetwash terrain, with local eolian reworking; weakly incised
Sl2	in mixed sandplain, colluvium, and sheetwash terrain, with local eolian reworking; typically vegetated

SYMBOLS

Regolith boundary		Bulgarro	Opencut, abandoned
Breakaway		Byro East	Prospect
Sand dune			Mineral occurrence
Formed road		Brt	Barite
Track		Cr	Chromium
Watercourse		Crn	Corundum
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Field observations 2000 by S. Brindle, M. Gallen, R. Hackney, D. O'Farrel, S. McGuinness, P. Morris, G. White, and A. Verren

Compiled using: Landsat TM images (1998 data); 1995 1:50 000 scale black and white aerial photography; MYERS, J. S., 1997, Byro, W.A. Sheet SG 50-10 (second edition): Western Australia Geological Survey, 1:250 000 Geological Series; MYERS, J. S., and HOCKING, R. M., 1998, Geological map of Western Australia 1: 2 500 000 (13th edition): Western Australia Geological Survey; and field observations 2000

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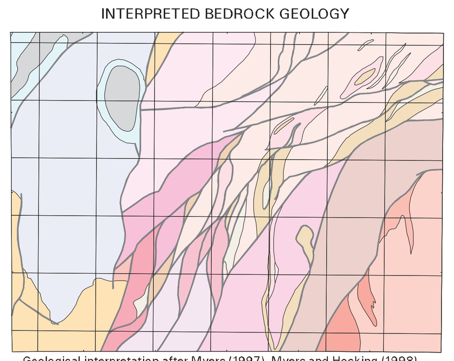

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Scale 1:2 000 000

Geological boundary

Fault

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REGOLITH MATERIALS

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BYRO

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