

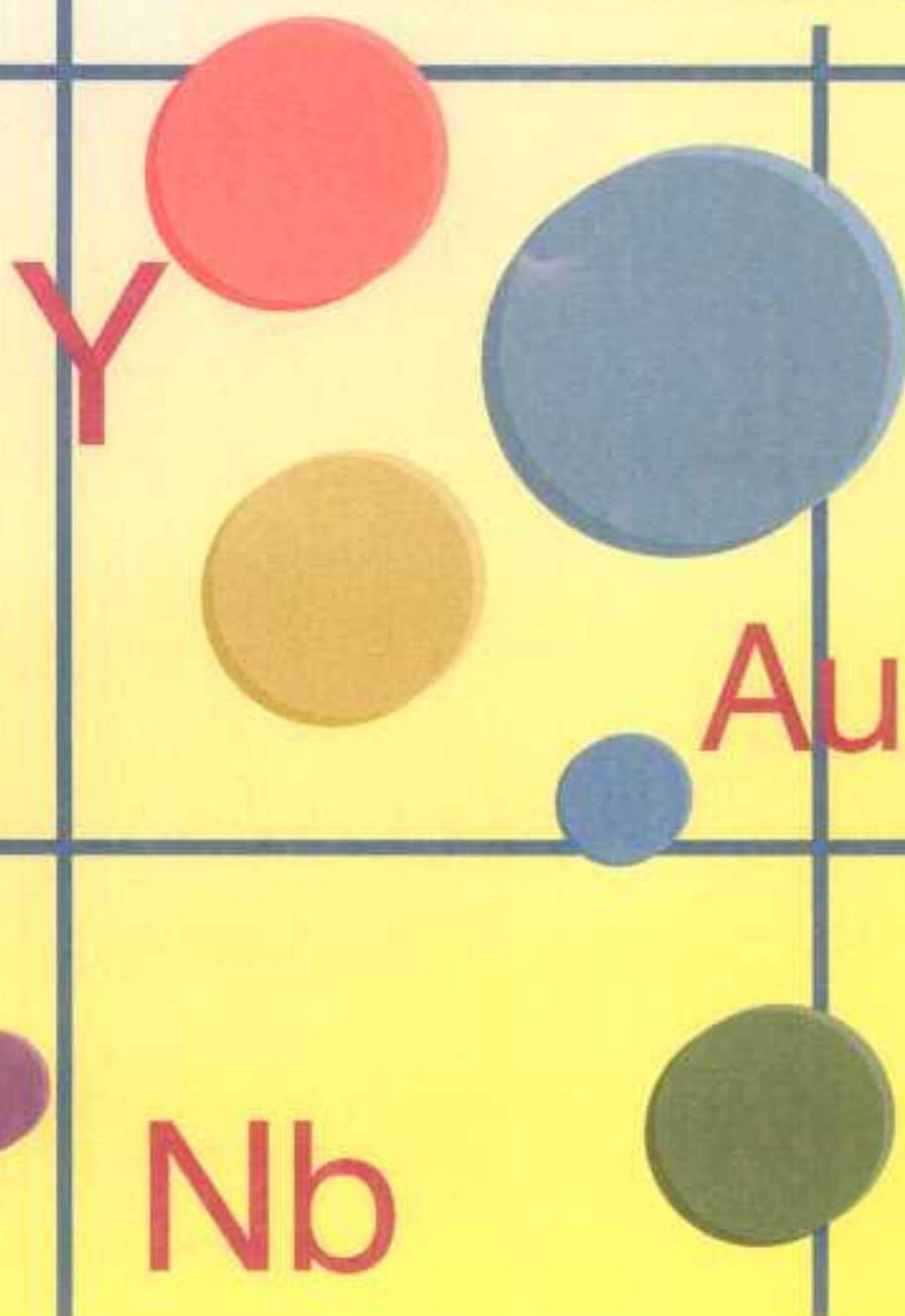
**EXPLANATORY
NOTES**



GEOCHEMICAL MAPPING OF THE FRASER RANGE REGION

by P. A. Morris, A. J. Sanders, S. A. McGuinness,
J. Coker, and J. D. King

1:250 000 REGOLITH GEOCHEMISTRY SERIES



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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Digital dataset (in pocket)

Located regolith geochemical data, Fraser Range region (fraser.csv)
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Geochemical mapping of the Fraser Range region

by

P. A. Morris, A. J. Sanders, S. A. McGuinness, J. Coker, and J. D. King

Abstract

Regolith and regolith geochemical mapping over part of the Proterozoic Albany–Fraser Orogen at 1:250 000 scale is based on regolith characteristics and sampling of regolith from 949 sites, at a nominal density of one sample per 16 km². These samples comprise 721 sheetwash samples, 145 lake sediments, 46 sandplain samples, and 37 stream sediments. This study, which covers six 1:100 000-scale map sheets over part of the ZANTHUS, WIDGIEMOOLTHA, NORSEMAN, and BALLADONIA 1:250 000 sheets, specifically targets metamorphosed igneous and sedimentary rocks of the Fraser Complex that forms part of the Albany–Fraser Orogen.

Each regolith sample was analysed for 47 components, pH, and conductivity. Forty-four components (excluding SiO₂, Cd, and Bi) are shown as spot-concentration maps. Statistical analysis of chemical data, including additive indices, was used to highlight areas of potential mineralization and delineate the extent of largely concealed bedrock. A regolith-distribution map was produced using the regolith characteristics recorded at each sample site, Landsat imagery, aerial photography, and published geology. Open-file company data dealing with surface geochemistry are tabulated.

The combined effects of a thick vegetation cover and low relief cause some difficulty in identifying regolith types, and delineating regolith boundaries. More than 60% of the project area is covered by a heterogeneous sandplain unit, which is shown to be largely of local derivation. The similarity in chemistry of different regolith types over individual bedrock units argues for local derivation and limited chemical weathering. Regolith chemistry suggests a greater extent of mafic and ultramafic volcanic rocks on the margin of the Yilgarn Craton, and chalcophile-related values in regolith are highest close to faults in this area, offering some potential for gold mineralization. Statistical analysis of regolith chemistry has shown that lakes of the Fraser Region contain locally derived detritus. Mineralization potential is seen in mafic lithologies of the Fraser Complex and greenstones of the Archaean Yilgarn Craton.

KEYWORDS: Fraser Complex, Albany–Fraser Orogen, Biranup Complex, Nornalup Complex, Zanthus, Norseman, Widgiemooltha, Balladonia, Coonana, Symons Hill, Harms, Yardilla, Fraser Range, Eucla Basin, regolith, geochemistry.

Introduction

The Fraser Range region regolith and geochemical Explanatory Notes are the sixteenth product from the Geological Survey of Western Australia's (GSWA's) regolith geochemistry mapping program, and the first collaborative regolith geochemistry project between GSWA and the Australian Geological Survey Organisation (AGSO), under the auspices of the National Geoscience Mapping Accord (NGMA). The broad objectives of the GSWA regolith geochemistry program are to provide data about the distribution and composition of regolith to the mineral exploration industry. More specifically, the program aims to:

- map the distribution of regolith (Plate 1);
- describe and chemically analyse regolith samples collected on a regular, broad-spaced grid;
- interpret the chemistry of regolith with respect to either bedrock or regolith type;
- collect gravity data at each sample site.

Data from the program are used to aid regional-scale geochemical exploration, indicate likely areas of mineralization, and assist in understanding the distribution of rock types as a complement to mapping of bedrock geology.

In these Explanatory Notes, regolith from six 1:100 000-scale maps covering the Fraser Complex and

adjacent geological units has been examined. Myers (1985) referred to the Fraser Complex as a 1100 km long by 200 km wide northeasterly trending belt of deformed gneiss, granite, and mafic dykes, which forms part of the Albany–Fraser Province (Gee, 1979), now termed the Albany–Fraser Orogen by Myers (1990a). The Fraser Range region was selected for the GSWA regional regolith and geochemical mapping program because it is an area of recent exploration interest. This is in part due to analogies being drawn between the Fraser Complex and the recently discovered nickel mineralization at Voisey's Bay (Li and Naldrett, 1999), and between the lithology and stratigraphy of parts of the Fraser Complex and the Bushveld Complex of South Africa.

The six 1:100 000-scale map sheets, collectively referred to here as the Fraser Range region, are COONANA*, ZANTHUS, YARDILLA, SYMONS HILL, FRASER RANGE, and HARMS (Fig. 1). The Fraser Range region is characterized by Archaean granite–greenstone of the Yilgarn Craton, Precambrian high-grade metamorphic and granitic rocks of the Fraser Complex, and Tertiary sedimentary rocks of the Eucla Basin (Wilson, 1969; Doepel and Lowry, 1970a,b; Myers, 1985, 1990a; Griffin, 1990; Hocking, 1990). Unconsolidated colluvium, alluvium, and sand deposits cover much of the bedrock. The western margin of the Bunda Plateau (Doepel and Lowry, 1970a,b), which is largely formed of Tertiary to Recent carbonate-rich sedimentary rocks of the Eucla Basin, dips gently to the southwest across the Fraser Range region.

Location and access

The Fraser Range region lies between latitudes 31°S and 32°30'S and longitudes 122°30'E and 124°E. Although most of the Fraser Range region is under pastoral lease, the only permanent settlements are at the Fraser Range and Coonana Homesteads (Fig. 2). The nearest town is Norseman, which is approximately 80 km west of the project area boundary.

The Eyre Highway affords access through the southern part of the project area, whereas access in the north is provided by a service road for the Trans-Australian Railway. Within the project area, access is afforded by a network of station and exploration tracks. A list of locations and their grid coordinates is presented in Appendix 1.

Climate

The climate of the Fraser Range region is semi-arid, with a mean annual rainfall of 280 mm, which generally decreases to the northeast. Streams are ephemeral, although scattered swamps and gnammas retain water through all but the driest months.

Geomorphology and vegetation

The Fraser Range, which trends northeastward across the central part of the Fraser Range region, consists of undulating hills and isolated low ridges. The highest peak (Mount Pleasant, 579 m) lies immediately northeast of the Fraser Range Homestead (Plate 2). Major easterly to southeasterly trending drainage channels are associated with Mesozoic palaeodrainage systems. Lake Harris, in the northern part of the Fraser Range region, lies within the Lefroy palaeodrainage, whereas Ponton Creek (Plate 1) forms the extension to the Rebecca–Raeside palaeodrainage. Chains of small salt lakes define palaeoriver courses. Elsewhere, streams are restricted to the flanks of larger hills.

Although bedrock exposure is poor, bedrock structural trends are clearly visible on both aerial photographs and satellite imagery, suggesting a thin regolith cover.

The Fraser Range region lies in the Eremaean Botanical Province of Diels (1906). Beard (1985) subdivided Western Australia into phytogeographic regions based on botanical provinces, regions, and districts or subdistricts, and the Fraser Range region covers part of the South Western Botanical Province and South Western Interzone of the Eremaean Province (Beard, 1975).

Fraser Range is covered by blackbutt woodland, with scrub at higher elevations. Sandy soil is present on some outcrops, with red loam filling depressions between hills. The vegetation east and west of Fraser Range is mainly mixed eucalypt woodland with patches of mallee and spinifex in the north. Soils become less calcareous towards the north and west according to Northcote et al. (1968). The lake systems in the north of the project area are fringed by mallee and gimlet, whereas gimlet and saltbush predominate in the south. South of Fraser Range is an area of *Dodena* scrub and woodland, which is unique in Western Australia (Beard, 1975).

Part of the South Western Botanical Province covers the southern boundary of the Fraser Range region, and is characterized by a mosaic of eucalypt woodland and mallee, with lakes surrounded by saltbush and greybush.

Topographic and remote-sensing datasets

The regolith-materials map of the Fraser Range region (Plate 1) was compiled using 1:100 000-scale false-colour composite Landsat Thematic Mapper (TM) images, using bands 7:4:1 (red, green, blue respectively). Images based on band ratios (5/7:4/7:4/2) were also used to reduce the effect of topographically induced reflectance variations, and to better discriminate between the reflectance of certain minerals and vegetation. However, the extent and density of vegetation severely reduced the effectiveness of all images in interpreting the nature and distribution of regolith. The 741 image proved the best image type for distinguishing areas of transported overburden and exposed rock. Black-and-white aerial photography at

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

1:50 000 and 1:81 500 scale was used to support the Landsat interpretation. Other data included 1:250 000 geological maps for ZANTHUS (Doepel and Lowry, 1970a), BALLADONIA (Doepel and Lowry, 1970b), NORSEMAN (Doepel, 1973), and WIDGIEMOOLTHA (Griffin, 1989).

Geology

The Fraser Range region includes granitic rocks and greenstones of the Archaean Yilgarn Craton (Griffin, 1990), high-grade Proterozoic metamorphic rocks of the Albany–Fraser Orogen (Myers, 1985, 1990a, 1995), and Tertiary sedimentary rocks of the Eucla Basin (Hocking, 1990). A summary of the geology of the Fraser Range region, as shown in Figure 3 and Plate 2, follows and reference should be made to the above publications for more detailed information.

Albany–Fraser Orogen

The Albany–Fraser Orogen truncates, at a high angle, granite–greenstones of the Yilgarn Craton (Gee, 1979; Myers, 1985). Rocks of this orogen represent the continent–continent collision of the Yilgarn Craton margin and east Antarctica between 1300 and 1100 Ma (Myers, 1993, 1995). Myers (1990a) divided the Albany–Fraser Orogen into the Northern Foreland and the Biranup and Nornalup Complexes, based on lithology and structure (Fig. 3). The Biranup Complex, which includes the Fraser Complex, is composed of high-grade quartzofeldspathic gneisses and layered basic intrusions that are isoclinally folded and tectonically interleaved. The Nornalup Complex comprises less intensely deformed, high-grade orthogneiss and paragneiss intruded by granitoids.

Northern Foreland

The southern and southeastern margin of the Yilgarn Craton forms the northern foreland of the Albany–Fraser Orogen (Myers, 1990a). This foreland separates the Yilgarn Craton from the Fraser Complex, and consists of enclaves of Archaean granite–greenstone, overprinted by cataclastic and gneissic fabrics, and dolerite dykes. Gee (1979) considered this transitional zone to be a reworked part of the adjacent Yilgarn Craton.

The Woodline beds outcrop poorly in the western part of the Fraser Range region, where they consist of mildly deformed and metamorphosed quartzite and less common phyllite. The rocks have undergone recrystallization under greenschist-facies metamorphic conditions, and rest unconformably on Archaean granite–greenstones (Griffin, 1989).

Archaean granite–greenstones

Archaean rocks of the Fraser Range region comprise a granite–greenstone association that is typical of the Eastern Goldfields Province (Griffin, 1990). Greenstones consist of metamorphosed mafic and ultramafic volcanic

rocks, felsic volcanic rocks, and associated volcanoclastic and clastic sedimentary rocks, with minor chemical sedimentary rocks (predominantly chert). The greenstones have been intruded by granitoid rocks, and both greenstones and granitoids have been subsequently folded.

Greenstones are multiply deformed, and range in metamorphic grade from greenschist to lower amphibolite facies. The resultant structure is usually dominated by strong north-northwesterly trends (Gee, 1979; Griffin, 1989).

Proterozoic intrusive rocks

Regional-scale Proterozoic intrusive rocks belong to the Widgiemooltha Dyke Swarm (Myers, 1990b), which, in the Fraser Range region, is restricted to the eastern part of the Jimberlana Dyke. The trace of the Jimberlana Dyke is shown by areas of more-mafic regolith in the western part of the project area (Plate 1). This 2411 Ma (Fletcher et al., 1987) feature is one of the largest east–west Proterozoic dykes found in the eastern part of the Yilgarn Craton. It is dominantly composed of cumulate-textured orthopyroxene, clinopyroxene, and plagioclase, although Fletcher et al. (1987) recorded more ultramafic-like material from west of the project area.

Numerous dolerite dykes of the Gnowangerup dyke swarm have been intruded subparallel to the margin of the Albany–Fraser Orogen, within 100 km of the margin of the Yilgarn Craton. Although dykes found in the Yilgarn Craton are usually undeformed and unmetamorphosed, those within the Albany–Fraser Orogen are intensely deformed, recrystallized and usually found as thin layers and lenses parallel to the main foliation within the gneisses (Myers, 1993).

Biranup Complex

Fraser Complex

The Fraser Complex, which lies southeast of the Northern Foreland, consists largely of mafic igneous rocks, derived from one or more layered igneous intrusions that are thrust sheets, 2–5 km thick and more than 100 km long (Myers, 1985, 1995). These highly deformed rocks have been tectonically interleaved with metasedimentary rocks (quartzite, banded iron-formation, and pelitic rocks) and intruded by granitoid gneiss. The whole sequence has been further metamorphosed and deformed to granulite facies. Along the northwestern margin, granulite-facies rocks have been overprinted by amphibolite- and then greenschist-facies metamorphism. The southeastern margin of the Fraser Complex is not exposed.

Fletcher et al. (1991), suggested that the Fraser Complex was tectonically emplaced into the upper crust at 1268 ± 20 Ma, shortly after crystallization of the complex under granulite-facies conditions at 1291 ± 21 Ma. Rapid uplift and emplacement of the complex and adjacent gneisses is supported by a variety of isotopic age data, including Sm–Nd (Fletcher et al., 1983, 1991), ion microprobe U–Pb (Nelson, 1995, Nelson

et al., 1995), whole-rock Rb–Sr (Arriens and Lambert, 1969; Bunting et al., 1976), and K–Ar (references contained within Nelson et al., 1995). Nelson et al. (1995) related the emplacement of the Fraser Complex to a major continent–continent collision event at c. 1300 Ma. Clark et al. (1999) reported four U–Pb zircon ages for granitoids and paragneisses of the Fraser Complex, and used these data to constrain structural and metamorphic events.

Myers (1985) divided the complex into five mappable tectonic units, which he termed units 1–5 (Fig. 4):

- unit 1: garnet amphibolite (metamorphosed garnet metagabbro), with thin lenses of Archaean rocks, including ultramafic igneous rocks, melanogabbro, and anorthosite;
- unit 2: pyroxene granulite, with relict igneous textures suggesting derivation from gabbro or norite;
- unit 3: metamorphosed leucogabbro, anorthosite, minor gabbro and melanogabbro, enclosed by quartzite and gneiss in the northeast;
- unit 4: mafic granulite, similar to unit 2;
- unit 5: mainly gabbro and metagabbro, possibly the precursor to units 2 and 4.

Nornalup Complex

The Nornalup Complex (Fig. 3) is dominated by quartzofeldspathic gneiss derived from granitoid and pelitic rocks (Myers, 1990a). Rocks of the Nornalup Complex outcrop poorly in the Fraser Range region, and are unconformably overlain by sedimentary rocks of the Eucla Basin. Two phases of granite emplacement are recognized in the Nornalup Complex. The earlier c. 1300 to 1280 Ma phase (Nelson et al., 1995), which also intruded the Biranup Complex, recrystallized at a later stage under granulite-facies conditions, mainly as gneiss. The second phase consists of granite sheets and plutons intruded into this gneiss between c. 1190 and 1130 Ma (Myers, 1993, Nelson et al., 1995).

The degree of deformation increases towards the Fraser Complex, whereas deformation intensity and metamorphic grade decreases to the southeast (Myers, 1990a, 1993).

Eucla Basin

The structure and stratigraphy of the Eucla Basin were discussed by Hocking (1990). Sedimentary rocks of the Eucla Basin unconformably overlie the eastern margin of the Fraser Complex in the Fraser Range region. These rocks range in age from Early Cretaceous to Holocene (Hocking, 1990), and consist mainly of marine and lacustrine deposits. In the Fraser Range region, most of these rocks consist of Eocene carbonate-rich sedimentary rocks and less common sandstone, lignite, and spongillite. Outcrops of quartz-rich siltstone and sandstone of the Eundynie Group, which contain abundant sponge spicules (Griffin, 1989), are found on the margins of some salt lakes in the Fraser Range region. This unit was deposited in drainage systems, now defined by major lakes, during a Tertiary marine transgression (Bunting et al., 1974).

Economic geology

Barite and building stone are the only commodities that have been produced from the Fraser Range region (Appendix 2). Two vermiculite prospects have been identified near Uraryie Rock. A demonstrated (measured plus indicated) resource of 250 000 t grading at 42% vermiculite (i.e. 105 000 t of vermiculite) has been estimated at the Fly Dam prospect.

Building stone

Fraser Range Granite NL has quarried 4840 t of building stone from the Albany–Fraser area since 1991. The building stones comprise a variety of metamorphosed rocks, including epidote–pyroxene magnetite augen gneiss (known as Verde Austral), garnetiferous gneissic granite (Garnet Ice), microgabbro (Gold Leaf Black), intercalated garnet–pyroxene augen gneiss and foliated pyroxene granulite (Fantasia), and fine-grained gabbro (Fraser Range Black). Proven reserves in excess of 1 million m³ have been determined for the Verde Austral type (Maritana Gold NL, 1991).

Barite

A total of 53.1 t of barite was mined from a barite vein in granite southwest of Coonana during 1946 and 1953. Quartz and accessory amounts of galena, chalcopyrite, and covellite are found with the barite (Doepel and Lowry, 1970b).

Geochemical surveys in open-file company reports

Appendix 3 and Plate 3 present a summary of open-file company reports containing surface and near-surface geochemical data (including surface sampling, and drilling information to 4 m depth). Projects with fewer than 30 samples have been omitted from this compilation. These data have been extracted from company reports lodged with the Department of Minerals and Energy in accordance with the Mining Act (1978). Projects in Appendix 3 are listed according to the M number, which is the project number assigned for the GSWA's Western Australian mineral exploration (WAMEX) database. When reports are released to open file, the M number is replaced by an I (or Item) number, with the highest I number denoting the most recent release. Gaps in reporting result from either the failure of tenement holders to lodge reports, or the lack of a requirement for mineral-claim holders to report all of their exploration results prior to 1978.

Company activity in the Fraser Range region is largely confined to the Fraser Complex and areas of Archaean greenstone to the west. Of the 6067 samples tabulated (5817 of which are surface samples), nickel, copper, cobalt, and gold are the most common elements that have been analysed.

Regolith sampling

Regolith sampling in the Fraser Range region was carried out over a two-week period during September 1998 by six two-person sampling teams (each comprising a field assistant and a geologist) using two Bell Jet-Ranger helicopters. At each sample site, characteristics of the regolith and surrounding geology were recorded on a standard form (Appendix 4, Fig. 4.1). The approach to regolith sampling is discussed in Appendix 4. A measurement of the earth's gravitational field was also made at each sample site (GSWA and AGSO, 1999).

Regolith-materials mapping

A regolith-materials map (Plate 1) has been produced for the Fraser Range region using Landsat TM imagery, 1:250 000 geological maps of ZANTHUS (Doepel and Lowry, 1970a), BALLADONIA (Doepel and Lowry, 1970b), NORSEMAN (Doepel, 1973), and WIDGIEMOOLTHA (Griffin, 1989), aerial photography, and field observations recorded at each sample site.

Relative to other areas covered by the GSWA's regional regolith geochemistry program (Morris et al., 1998; Fig. 1), regolith mapping in the Fraser Range region is particularly difficult due to a number of factors, including the following:

- dense vegetation cover, which limits the effectiveness of satellite imagery, ground observation, and aerial photograph interpretation in determining the nature and extent of different regolith-materials units;
- frequent small-scale changes in vegetation type or canopy density, limiting the accuracy of locating boundaries between regolith-materials units;
- modification of vegetation and destabilization of surficial cover by major bushfires, evident as fire scars;
- a lack of significant relief in the Fraser Range region, creating difficulties in determining changes in slope;
- an extensive residual and eolian loam cover that obscures bedrock and other regolith-materials units;
- lack of diagnostic features from remotely sensed data to adequately distinguish between some regolith-materials units (e.g. the heterogeneous sandplain unit).

These factors have resulted in a regolith-materials map with few subdivisions for the Fraser Range region (Plate 1), compared to maps produced in areas of Western Australia with greater relief and more scattered vegetation, such as the Hamersley Basin (Pye et al., 1999).

The regolith-materials maps of the Fraser Range region and AJANA (Sanders and McGuinness, in prep.) are the first to use a revised version of the GSWA's regolith-classification scheme (Hocking et al., in prep.). These revisions include the use of additional secondary (compositional) codes, and subscripts to further subdivide primary, secondary, and tertiary codes (Appendix 4). The area, percentage of total project area, and number of samples per regolith-materials unit are shown in Table 1.

Table 1. Regolith-materials unit area and number of samples

Regolith code	Area (km ²)	% of total area	No. of samples	% of all samples
Residual (R)				
Rf	28.19	0.18	0	—
Rz	35.94	0.23	0	—
Exposed (X)				
Xgm	49.39	0.31	12	—
Xgm _p	18.46	0.12	1	—
Xgp	113.25	0.72	17	—
Xls	40.90	0.26	3	—
Xmh	4.40	0.03	0	—
Xmm	699.01	4.44	90	—
Xqs	9.41	0.06	0	—
Xu	1.80	0.01	0	—
Total	—	6	123	13
Colluvial (C)				
Cl	2 430.40	15.44	152	—
Cf	5.72	0.04	1	—
Cg	86.22	0.55	12	—
Cgm	5.48	0.03	1	—
Cgp	24.90	0.16	5	—
Cmh	0.60	0.00	0	—
Cmm	142.28	0.90	33	—
Cqs	14.04	0.09	1	—
Cu	0.48	0.00	0	—
Total	—	17.2	205	22
Distal sheetwash (W)				
W	61.72	0.39	6	1
Alluvial (A)				
A	434.86	2.76	60	6
Lacustrine (L)				
L	310.44	1.97	74	—
L _m	1 057.36	6.72	65	—
Total	—	9	139	14
Sandplain (S)				
Sl	10 170.37	64.59	416	44
Total	15 745.60	100	949	100

The regolith codes for each sample are listed in the accompanying datafile (fraser.csv), and described in the legend for Plate 1 and in Appendix 4. A simplified version of the regolith-materials map is presented as Figure 5.

Regolith over the Fraser Range region is dominated by a unit of mixed residual and eolian sand, silt, and clay, with locally developed carbonate, that is termed a heterogeneous sandplain unit. In places, bedrock penetrates the regolith cover, and in other places, the cover has been dissected and reworked by water. Major features of the regolith in the Fraser Range region are:

- low scattered outcrop, subcrop, and bouldery lag, and locally derived colluvium over the Fraser Range;
- isolated low outcrop, subcrop, bouldery lag, and locally derived colluvium in areas of granite and granitic gneiss of the Biranup and Nornalup Complexes, west and east of the Fraser Range;
- weathered Archaean granitoid rock (exposed at breakaways in the central-northern part of the project area), capped by silcrete and ferruginous lag, with

locally derived colluvium on foot slopes. Archaean granite and greenstone are also exposed in the upland regions of the central-western part of the project area;

- the Woodline beds form prominent hills in the western part of the project area, locally surrounded by steep colluvium-covered slopes. Nearby, deeply weathered pelitic and psammitic rocks form subdued outcrop and are usually restricted to lower topographic positions in the landscape;
- in some areas, the mixed residual and eolian sand, silt, and clay cover has been reworked, along with locally derived colluvium and bedrock material;
- lake systems dominate the low-lying areas adjacent to the Fraser Range, particularly in the central-northern and southeastern parts of the project area. Other lake systems extend throughout the western part of the Fraser Range region, many of them bound on their western side by outcrops of marine and continental limestone.

Residual-regime regolith (R)

Residual-regime regolith accounts for less than 0.5% of regolith by area (about 64 km² in total) of the Fraser Range region, and no regolith samples have been collected over this regolith type (Table 1). The majority of this material (*Rf* and *Rz*) is found in the northern part of the project area between Coonana and Zanthus, where it consists of clay- to boulder-grade deposits with ferruginous and siliceous cement capping weathered Archaean granitoid rocks (Doepel and Lowry, 1970a). Southeast of Zanthus, iron-rich colluvium (*Cf*) has developed on slopes adjacent to iron-rich material residuum (*Rf*). In places, both residual units (*Rf*, *Rz*) grade into, or are covered by, heterogeneous sandplain (*Sl*). Where this sandplain unit covers iron-rich residual material (*Rf*), spectral characteristics from Landsat TM imagery indicate that the heterogeneous sandplain unit is more ferruginous, suggesting some input from the iron-rich residual material. Other more localized areas of residual iron-rich material (*Rf*) are found in the southwestern part of the Fraser Range.

Exposed-regime regolith (X) and spatially related colluvial regolith (C)

As there is an intimate spatial association of some exposed-regime regolith and colluvium, they are discussed together in this section. Areas of exposed rock, subcrop or bouldery lag (X) and locally derived colluvium (all C units except *Cl*, which is discussed below) comprise only 6% and 2% respectively of regolith by area in the Fraser Range region, and account for 13% and 5% of total samples. The dominant exposed regolith type is that derived from metamorphosed ferromagnesian igneous rocks of the Fraser Complex (*Xmm*), which outcrop as low hills and exhumed surfaces (Twidale, 1976), surrounded by the heterogeneous sandplain unit (*Sl*). The exposed-regime regolith (*Xmm*) is derived from a mixture of largely

metamorphosed igneous rocks, including pyroxene- and garnet-bearing granulite, amphibolite, and metagabbro with less common quartzite and gneiss.

The exposed-regime regolith (*Xmm*) is best exposed in the southwestern part of the project area, where it is flanked by locally derived colluvium (*Cmm*), which grades laterally into more heterogeneous colluvium (*Cl*). Heterogeneous sandplain (*Sl*) is found on some of the more elevated areas overlying exposed-regime regolith (*Xmm*), although it is probably only a thin cover, with bedrock close to the surface. Northeast of Symons Hill, the elevation of exposed-regime regolith (*Xmm*) above surrounding regolith decreases, and outcrops are locally exposed where heterogeneous sandplain (*Sl*) has been removed. In these areas, outcrop is either flat or even concave, with locally derived colluvium (*Cmm*) developed on top of, and in between, outcrops. The lack of slope in large parts of the central Fraser Range has limited the development of colluvium and alluvium. The heterogeneous sandplain unit (*Sl*) is thicker and less reworked in these areas than elsewhere in the Fraser Range, and it either abuts or overlies bedrock.

South of Coonana, weathered granitoid rocks, comprising variably degraded boulder and rubble material (*Xgp*), are exposed below breakaways. Locally developed, poorly sorted sandy colluvium (*Cgp*) abuts heterogeneous sandplain (*Sl*) or grades into heterogeneous colluvium (*Cl*). Southeast of Coonana, a northeasterly trending sliver of ultramafic schist (*Xu*) is found in Archaean granite, and west of Zanthus another small exposure of similar material is bordered by locally derived colluvium (*Cu*).

Between Coonana and the Fraser Range, isolated areas of regolith representing weathered quartzofeldspathic plutonic rocks (*Xgp*) and quartzofeldspathic gneissic rocks (*Xgm*) emerge above the heterogeneous sandplain unit (*Sl*). Immediately west of Uraryie Rock, dissection of heterogeneous sandplain (*Sl*) has revealed colluvial deposits of quartz- and feldspar-rich sand, silt, clay, and rock fragments (*Cg*), with outcrops locally developed (Doepel and Lowry, 1970a).

South of Lake Rivers, the sporadic occurrence of exposed-regime regolith derived from granitoid rocks (*Xgp*) within areas of colluvium, sheetwash, and alluvium (i.e. *Cl* and *A* units) suggests that granitoid bedrock is close to the surface. The thin nature of regolith cover is also apparent in the western part of the project area, where areas of exposed-regime regolith derived from granitoid rocks (*Xgp*) and greenstone (*Xmm*) are emergent through heterogeneous sandplain (*Sl*) between major north-south trending lake systems. As discussed below, regolith chemistry indicates that greenstones may be more extensively developed in this area than previously thought.

The exposed-regime regolith derived from the mafic hypabyssal rocks (*Xmh*) correlates with the trace of the Jimberlana Dyke. This regolith type is discontinuous and covered in places with heterogeneous sandplain (*Sl*) and colluvium (*Cmh* and *Cl*).

Between lake systems in the central-western part of the project area are exposures of regolith derived from

pelitic and psammitic metasedimentary rock (Xgm_p). This regolith type is poorly exposed and grades rapidly into heterogeneous colluvium (Cl) or lake-margin material (L_m). It is locally overlain by heterogeneous sandplain (Sl), which often contains fragments of metasedimentary rock, suggesting a thin regolith cover with bedrock close to the surface (Griffin, 1989).

Regolith derived from arenaceous and argillaceous metasedimentary rock of the Woodline beds (Xqs) forms prominent hills with relatively steep surrounding slopes covered by locally derived colluvium (Cqs) in the western part of the project area. The colluvial material becomes more heterogeneous (Cl) downslope towards the lake systems, incorporating granite- and greenstone-sourced detritus, and reworked heterogeneous sandplain (Sl).

Scarp retreat along the western margins of lakes has exposed Cainozoic sedimentary rocks, whose regolith (Xls) consists of quartz-rich siltstone, sandstone, and biogenic carbonate. This regolith type is exposed as low cliffs that are particularly well developed around Lake Rivers, Lake Harms, and other smaller lakes in the central-western part of the project area.

In the southeastern part of the Fraser Range region are areas of exposed-regime regolith derived from scattered low-aspect domes of granitoid rock (Xgp) and gneiss (Xgm) of the Nornalup Complex. The majority of these regolith types directly abut heterogeneous sandplain (Sl), although in some cases, locally sourced colluvium (Cgp and Cgm) has developed. Parts of the Nornalup Complex have been exposed by dissection of the heterogeneous sandplain unit (Sl), which appear as depressions consisting of scattered outcrops and locally derived colluvium (Cg).

Regolith derived from granitic gneiss of the Biranup Complex (Xgm) is found along the western and south-western margin of the Fraser Range, particularly in the southwestern part of the project area around Ten Mile Rocks. It includes regolith derived from garnetiferous gneiss and garnetiferous granodiorite (Xgm). These areas are commonly of low relief, surrounded by heterogeneous sandplain (Sl) or lacustrine material (L and L_m).

Heterogeneous colluvial regolith (Cl)

The difficulties in subdividing regolith of the Fraser Range region as discussed above are particularly pertinent to classifying the more-distal colluvial and sheetwash environments. The heterogeneous colluvial unit (Cl) is diverse, both in terms of its landform position and composition. It consists of colluvial, sheetwash, and alluvial deposits with a variety of compositions, including quartzofeldspathic, ferromagnesian, and quartz-rich material. It accounts for over 15% of regolith by area in the Fraser Range region, and 152 samples. Commonly, this unit occupies topographically lower areas (depressions) relative to the heterogeneous sandplain unit (Sl), and probably follows topographically lower areas in the undulating basement or Cainozoic limestone platform.

Heterogeneous colluvium (Cl) is most common in the southwestern part of the project area, surrounding the Fraser Range. Here, the unit is a mixture of colluvial and sheetwash deposits (probably including some reworked heterogeneous sandplain, Sl) on low slopes and plains between regolith derived from outcrop and subcrop of the Fraser Complex (Xmm).

In the northern part of the project area, the heterogeneous colluvial unit (Cl) consists of colluvium that rapidly grades into sheetwash, with units of alluvium in active stream channels. The heterogeneous colluvium includes degraded quartzofeldspathic material and, in places (e.g. around the Fly Dam quarry), some reworked heterogeneous sandplain (Sl).

In the western part of the project area, the undulating topography typical of the granite-greenstone terrane and metasedimentary rocks is conducive to the development of heterogeneous colluvium (Cl), which forms low-angle colluvial and sheetwash deposits.

The heterogeneous colluvial unit (Cl) in the north-eastern part of the Fraser Range region consists of reworked heterogeneous sandplain (Sl) as thin sheetwash deposits. The composition of this material is dominated by quartz sand, with less common ferromagnesian material, along the axis of the Fraser Range. In this part of the project area, the heterogeneous sandplain unit (Sl) is relatively thick, and has been deposited on bedrock showing only subdued relief; the associated heterogeneous colluvium (Cl) has been deposited in broad, shallow depressions in the sandplain (Sl) unit, from which it has been derived.

In the southeastern part of the project area, the heterogeneous colluvial unit (Cl) usually occupies topographically lower areas of the undulating granitic basement and contains reworked sandplain (Sl) and some quartzofeldspathic material derived from nearby outcrop or subcrop (Xgm and Xgp).

In most places, the heterogeneous colluvial unit (Cl) grades into distal sheetwash (W), active alluvial channels (A) or lacustrine regolith (L and L_m).

Distal sheetwash (W), alluvial (A), and lacustrine (L) regolith

In areas of scattered vegetation and more marked relief (e.g. WYLOO; Pye et al., 1999), regolith classification has closely followed an idealized landform profile. In these cases, regolith changes downslope from exposed through colluvial material and into distal sheetwash or diluvium (W), before merging with major drainage systems. The application of this approach to the Fraser Range region is not entirely appropriate, due to the significant vegetation cover and low level of relief. This more stable environment is conducive to widespread development of near-source regolith, rather than the generation of distinctive proximal versus distal deposits. Thus, distal sheetwash (W) in the parlance of Hocking et al. (in prep.) is of limited extent in the Fraser Range region, occupying less than 0.5% by area and accounting for only 6 samples. However, areas

of distal sheetwash may be greater than shown, as this unit is gradational to heterogeneous colluvium (*Cl*) and, in many cases, regolith has been classified as colluvium (*Cl*) rather than sheetwash (*W*) in order to convey the mixed nature of material, lack of thickness of slope deposits, and proximity of bedrock to the surface throughout the project area. Distal sheetwash (*W*) represents a less incised, thicker depositional sequence of commonly finer grained, better sorted material distal to outcrop. It is limited to the central-northern part of the project area, where material has been shed primarily from Archaean rocks into broad topographic lows.

Regolith in alluvial channels (*A*) is confined to poorly developed drainages, which are concentrated in areas of more significant relief, such as those near the Fraser Range, and in the northern part of the project area draining outcrops of Archaean granitoid. It accounts for almost 3% of regolith by area, and 6% of samples. Observations at sample sites indicate that active alluvial channels near areas of outcrop contain a mixed assemblage of cobbles, gravel, sand, and silt of various lithology. In northern areas, alluvium contains quartzofeldspathic and iron-rich lithic fragments, whereas along the Fraser Range, a significant number of mafic lithic clasts have been recorded. A number of drainages, particularly those incised into the heterogeneous sandplain unit (*Sl*) in the eastern part of the project area (e.g. Ponton Creek), contain quartz sand to the near exclusion of other components. Silt- and clay-sized fractions have probably been flushed out into downstream lake systems, whereas more coarse-grained material is lacking due to the lack of outcrop and low relief. In many cases, heterogeneous colluvium (*Cl*) found in depressions interfingers with alluvium in active alluvial channels, with both units terminating in claypans or lakes.

Areas of lacustrine regolith (*L*) and surrounding dune and playa terrain (*L_m*) occupy large areas of the Fraser Range region (almost 9% by area), and accounts for 14% of samples. These lakes represent a pre-Eocene drainage system that accumulated material of lacustrine, fluvial, and marine origin, the products of which are now exposed by scarp retreat along western lake margins (*Xls*). These lake systems now contain several tens of metres of saline and gypsiferous sand, silt, and clay (Doepel and Lowry, 1970a; Griffin, 1989). Calcrete and silcrete have also been observed in lake-margin material. The lakes (*L*) are commonly elongated east-west, parallel to the prevailing wind, with sand sheets, dunes (lunettes), and interstitial claypans developed largely on the eastern side (*L_m*). The lake-margin unit (*L_m*) interfingers with the heterogeneous sandplain unit (*Sl*) and heterogeneous colluvium (*Cl*), particularly in the north between Lake Rivers and Lake Harris, and extending in a southwesterly direction from Lake Harris along the western margin of the Fraser Range.

Sandplain regolith (*S*)

The most common regolith-materials type of the Fraser Range region is the dominantly residual and partly eolian blanket of sand, silt, and clay (*Sl*), which can loosely be viewed as a loam. This heterogeneous sandplain unit

occupies nearly 65% of regolith by area, and 416 samples (or 44% of all samples) come from this regolith type.

The widespread development of this unit reflects the significant vegetation cover and low relief (low energy) of the project area, both of which are conducive to near-source regolith development. Although classified with the primary '*S*' code (residual and mixed sandplain; Appendix 4, Table 4.6), the unit is not always a sand-dominated unit in that the sand content is variable throughout the project area — rather, the unit is a mixture of sand, silt, and clay in variable proportions with local intermixing of ferruginous and calcareous material. The unit has been classified using the *S* primary code as it is interpreted as largely being of residual origin with only local eolian reworking. It does not closely resemble sandplain deposits mapped on other regolith-landform maps of the GSWA program in terms of its Landsat TM characteristics, in that it is more of a loam-like deposit.

Areas of heterogeneous sandplain (*Sl*) underlain by relatively thick sequences of flat-lying Eucla Basin sedimentary rocks (*Czm* and *Czmr*) are characterized on the regolith-materials map (Plate 1) by a lack of exposed-regime regolith (*X*), alluvium (*A*), or heterogeneous colluvium (*Cl*). For example, in the northeast, the *Sl* unit appears to thicken and show less relief, as it does on either side of the Fraser Range (north and east of Symons Hill). Over Archaean and Proterozoic rocks, however, the undulatory nature of the unit suggests that it thins and follows the surface of the bedrock. In these areas the unit tends to have a greater level of dissection and reworking (producing heterogeneous colluvium *Cl*), well illustrated in the southwestern part of the Fraser Range and the central-western part of the project area.

The heterogeneous sandplain unit (*Sl*) varies widely in composition from quartzofeldspathic, through ferromagnesian, to quartz-rich, which suggests that its composition is strongly influenced by the underlying bedrock. However, these supposed compositional variations could not be confidently translated into discrete regolith-landform units, although an attempt is made to examine compositional differences in a later section dealing with the statistical treatment of regolith chemical data.

Eolian activity may influence the nature of the heterogeneous sandplain unit (*Sl*), as shown by the ubiquity of carbonate in this unit, which may have been derived as a type of loess from the Eucla Basin. Local areas of eolian activity in the northern and central-eastern parts of the project area have formed scattered low dunes in the heterogeneous sandplain. Observations at sample sites suggest that thin eolian sand deposits may have recently developed over this unit following destabilization of regolith due to loss of vegetation through bushfire activity.

Conclusions

The subdued relief and heavy vegetation cover have posed difficulties in identifying some regolith types, subdividing regolith according to slope position or composition, and

delineating areas of any one particular regolith type. The resulting regolith-materials map (Plate 1) suggests a close spatial relationship between exposed-regime regolith, colluvium, and more heterogeneous colluvium and sandplain (e.g. *Xmm*, *Cmm*, *Cl*, *Sl*), which implies a strong influence on regolith composition from underlying or nearby bedrock. This is consistent with the low relief in the project area, which prevents long-distance transportation of regolith.

The most extensively developed regolith unit of the Fraser Range region is a heterogeneous sandplain unit (*Sl*), which is found as a blanket cover in most areas, covering bedrock, and at a topographically higher level than heterogeneous colluvium (*Cl*). In areas of subdued bedrock relief, the latter unit appears to be derived largely by reworking of the sandplain (*Sl*) unit, whereas in areas of more pronounced bedrock relief, where bedrock is locally emergent, the heterogeneous colluvial unit is an admixture of regolith derived by the breakdown of bedrock, and reworked heterogeneous sandplain. The widespread occurrence of carbonate in regolith and localized evidence for eolian reworking of the heterogeneous sandplain unit suggest that it has a transported component, although the majority of evidence suggests that this, as well as most other regolith units, owe their composition largely to nearby bedrock. This will be further examined in relation to regolith chemistry.

Chemical analysis

The 949 regolith samples from the Fraser Range region were analysed in five separate batches by Amdel Laboratories, Wangara, Perth. The samples comprise 721 sheetwash samples, 145 lake sediment samples, 46 sandplain samples, and 37 stream-sediment samples. Nomination of sample medium type (i.e. stream, sandplain, lake, sheetwash) on Plate 2 and in the digital dataset (*fraser.csv*) is based on observations made at the site by the geologist. At a local scale, such as the sample site, a sample may be designated as sheetwash, but at the regional scale, this sample site may be found in a broad region of sandplain.

In addition to analysis of regolith samples, 15 analyses of three GSWA in-house standards were carried out (three per batch), along with analyses of standards, duplicates, and blanks by Amdel Laboratories. Thirteen samples with relatively high concentrations of one or more analytes were reanalysed by Genalysis Laboratory Services, Maddington, Perth. Sample preparation and analytical conditions for both laboratories are described in Appendix 4.

A discussion of sample preparation and analytical techniques are presented in Appendix 4. The results of quality control are presented as a series of digital tables (in .csv format) in Appendix 5, with an explanation in Appendix 4 (Table 4.7).

For the four analytical techniques (IC3E, IC3M, IC4, and IC4M) carried out at Amdel, a total of 50 blank analyses, 93 duplicate analyses, and 25 analyses each of

three Amdel standards (OREAS_42P, OREAS_43P, and OREAS_44P) were carried out, spread across the five batches. For the fire-assay procedure (FA3), 26 blank analyses were carried out, along with 50 duplicate analyses, 28 analyses each of two Amdel standards (PM7 and PM8), and 141 replicate analyses for gold. These data can be found as digital tables, along with analyses of the three GSWA standards, and the 13 reanalyses carried out by Genalysis on the accompanying disk.

Analyses of blanks, standards, and duplicates commonly complied with requirements (Appendix 4), apart from the cases mentioned below. For the IC3M technique, precision and accuracy were good. A replicate Bi analysis (101 ppm) of 73.9 ppm was reanalysed by Amdel, and returned 103 ppm. Seven Nb replicates (GSWA samples 163705, 163707, 163746, 163789, 163790, 161830, and 161870) showed poor agreement (i.e. greater than 20% difference between primary analysis and replicate) and were reanalysed by Amdel. Replication was improved in some cases, but not in others. Morris et al. (1998) discussed problems with Nb replication for regolith samples from MOUNT EGERTON and TUREE CREEK, attributing it to incomplete sample dissolution. Antimony gave relatively poor results for one analysis of each of two Amdel standards (OREAS_43P and OREAS_44P).

Gold, Pd, and Pt were analysed by lead-collection fire-assay fusion. Precision and accuracy for Au and Pt were acceptable, but the accuracy of Pd analysis in two Amdel standards (PM7 and PM8) was poor (Appendix 5). According to Amdel, it is possible that the suggested value of 40 ppb for Pd in the standard PM7 is too high. Of 13 samples reanalysed by Genalysis, as part of routine quality-control procedures, four had notable Pd concentrations according to Amdel. However, all four samples returned Pd values close to detection level according to Genalysis. Checking with Amdel revealed that a period of reduced sensitivity of their graphite furnace system, which was not detected by laboratory quality-control procedures, resulted in erroneously high values for a number of samples. These approximately 80 samples were reanalysed and returned lower Pd values. The revised data are included in the digital dataset (*fraser.csv*), and in the relevant quality-control tables.

Duplicate analyses of 144 samples for the precious metals Au, Pt, and Pd were carried out. Gold contents of standards and unknowns ranged from less than detection level (1 ppb) to >170 ppb, whereas Pt and Pd levels ranged from less than detection level (1 ppb) to 8 ppb respectively. Acceptable duplication was achieved for all samples.

Analysis of the three GSWA standards were acceptable in terms of precision and accuracy. This was determined by comparison with the average of 12 laterite and 11 gossan analyses carried out by Amdel on NABBERU (Morris et al., 1997), TUREE CREEK (Coker et al., 1998), and MOUNT EGERTON (Morris et al., 1998), and seven amphibolite analyses carried out by Amdel on the MOUNT EGERTON and TUREE CREEK map sheets. These can only be taken as working values. Precision and accuracy were generally acceptable apart from Cr in sample GSWA 160048 (gossan IQC45), which assayed 430 ppm compared to a

suggested value of 149 ppm. A reanalysis by Amdel produced a more acceptable value of 154 ppm. Of some concern were high W assays for the gossan (suggested 2.6 ppm), and laterite (1 ppm), which was up to 27 ppm for the gossan and up to 9 ppm for the laterite. As the three GSWA standards were analysed in sequence (amphibolite, gossan, then laterite), and the amphibolite contains a suggested W content of 1107 ppm, there is some evidence to support an analytical 'tail', where an essentially barren sample is contaminated by its proximity to a sample with a relatively high concentration of the analyte. Reanalysis of the gossan and laterite standards produced more acceptable results, which have been included in the accompanying digital table.

Thirteen samples with relatively high concentrations of one or more analytes were reanalysed by Genalysis Laboratory Services, and compared with Amdel data. The major-element oxide and loss on ignition (LOI) values show good agreement, apart from three lower LOI values from Genalysis. The high Ba (10 600 ppm) in sample GSWA 163757 produced an acceptable duplicate value of 9275 ppm at Genalysis. Of the 13 samples, Genalysis produced consistently higher results for Ce (4 samples), Co (3 samples), Cr (11 samples), Sc (4 samples), Zn (7 samples), and Zr (4 samples). Sample GSWA 163941 assayed 2453 ppm Cr at Genalysis, but 5210 ppm at Amdel. Lanthanum (4 samples), Nb (3 samples), and Pb (4 samples) were significantly different between laboratories, although there was no consistently high or low relationship. The issue of high Pd in a group of samples has been discussed previously.

The poor agreement between laboratories for some analytes could be attributed to incomplete sample dissolution, particularly as poor duplication is found for elements such as Ce, La, Cr, and Zr, which are commonly found in resistate minerals such as allanite (La and Ce), chromite (Cr), and zircon (Zr).

Element-distribution maps

The chemistry of regolith of the Fraser Range region is presented as a series of spot-concentration maps against simplified geology (Figs 6 to 49), which is the approach adopted in previously published sets of maps and Explanatory Notes for the GSWA regional regolith geochemistry program. The simplified geology is presented in Figure 3. The approach of presenting regolith chemistry in relation to bedrock attempts to highlight whether there are genetic relationships between regolith and proximal bedrock units. If a relationship is not apparent, this may be because the regolith has been transported, or has undergone sufficiently extensive weathering that the chemistry bears few hallmarks of the nearby parent bedrock. As will become clear in the following discussion, in some cases there is evidence for a strong relationship between regolith and underlying bedrock, whereas in other cases, regolith chemistry can be better explained by inclusion of some transported component. In their discussion of regolith on AJANA, Sanders and McGuinness (in prep.) show that regolith chemistry, in many cases, bears little resemblance to

underlying bedrock, and there is strong evidence for a significant transported component in regolith.

On Figures 6 to 49, the diameter of the circle is linearly related to the concentration of the analyte, unless the concentration is greater than 2.5 standard deviations above the mean. Regardless of concentration, analytes values above this level are termed 'anomalous', and shown as stars. In some cases where analyte concentrations are rarely above detection level (e.g. Ta; Fig. 42), anomalous values are those above detection level.

The spot-concentration maps are ordered in terms of major-element oxides and LOI, then trace elements and ultra-trace elements in alphabetical order, although they are discussed in terms of the categories outlined below. Silica has not been plotted as it shows a reasonably uniform distribution over the map sheet, and Bi and Cd have also not been plotted as there are few values above detection level. Many locations discussed below are not included on the cited figures, in order to avoid congestion — a comprehensive array of localities is included on Plate 2 and in Appendix 1.

Grouping of chemical components

Chemical components are grouped into seven categories, based on the scheme of Evans (1993). This approach has also been taken in Morris et al. (1997, 1998). The categories are:

- major-element oxides and loss on ignition: SiO₂, TiO₂, Al₂O₃, Fe₂O₃, MnO, MgO, CaO, Na₂O, K₂O, P₂O₅, LOI
- precious metals: Au, Ag, Pd, Pt
- anions: S
- base metals: Cu, Pb, Zn, Sn
- ferro-alloy metals: Ni, Cr, Mo, W, V, Co
- fissionable metals: U, Th
- minor metals and non-metals: As, Ba, Be, Bi, Cd, Ce, Ga, In, La, Li, Nb, Rb, Sb, Sc, Se, Sr, Ta, Y, Zr.

Major-element oxides and loss on ignition

The highest concentrations of TiO₂ in regolith are found over amphibolite and metagabbro of the Fraser Complex (Fig. 6), which includes all anomalous values up to a maximum of 3.72% (sample GSWA 161721, from approximately 31 km southwest of Lake Harms). Sample GSWA 161721 is spatially associated with other high-TiO₂ samples found in the southern part of the Fraser Complex, including several other lake-sediment samples. The remaining regolith samples of the Fraser Range region have relatively low TiO₂ contents.

There is no consistent pattern of Al₂O₃ content of regolith according to bedrock in the Fraser Range region (Fig. 7). Anomalous values (i.e. those greater than 22.7%) are found in regolith samples overlying Eucla Basin sedimentary rocks about 35 km east of Cullinia Rocks (lake sediment GSWA 163959), and three anomalous

values (including two samples of lake sediment) were found over granitic gneiss of the Biranup Complex. The majority of high- Al_2O_3 values in regolith are found in lake sediments, irrespective of bedrock type.

The maximum value of Fe_2O_3 in regolith (Fig. 8) is in sample GSWA 163132, from the junction of two regional faults south of the Claypan Fault in the western part of the Fraser Range region. High values are largely confined to two areas — in regolith over the Fraser Complex, and in regolith over Archaean metasedimentary rocks, mafic igneous rocks, and the Jimberlana Dyke southwest of the Claypan Fault in the western part of the Fraser Range region (Plate 2). Values are commonly low in regolith over Eucla Basin sedimentary rocks, Archaean granite, and granite gneiss, but slightly higher over granitic gneiss and granite of the Nornalup Complex.

All three anomalous MnO values (i.e. greater than 0.39%; Fig. 9) are found over the Fraser Complex, including the maximum value of 1.41% (GSWA 163767, about 13 km southwest of Yardilla Bore). Manganese in regolith is highest over the Fraser Complex, with values in sharp contrast to regolith over Eucla Basin sedimentary rocks and the Biranup Complex to the west, and regolith over the Nornalup Complex and Eucla Basin sedimentary rocks to the east. Within the Fraser Complex, MnO values in regolith appear to be highest over unit 2 of Myers (1985; Fig. 4). Because values are higher in regolith over this unit regardless of sample medium, there is compelling evidence for bedrock control on regolith composition.

Regolith MgO concentrations (Fig. 10) appear to be highest over the Fraser Complex, and show a strong accord with MnO (c.f. Fig. 9), with high values especially pronounced in the Mount Pleasant area. There are anomalous MgO values in lake-sediment samples from the western part of the Fraser Range region over Archaean granitic rocks (e.g. 9.4% MgO in GSWA 163538), and several higher values over Eucla Basin sedimentary rocks in the southeast. High values are also found in regolith over the Jimberlana Dyke south of the Claypan Fault (c.f. Fe_2O_3), such as 15.9% MgO in GSWA 163941. Higher values of MgO in regolith in the Lake Harms area could reflect easterly transport of regolith from the Fraser Complex.

Relatively high values of CaO in regolith are found in lake sediments in the southwestern part of the Fraser Range region (Fig. 11), and near Lake Harris. The highest value of 35.4% is in lake sediment GSWA 163967, 20 km east of Cullinia Rocks. There are relatively high CaO values in a group of sheetwash samples from the Cherternerlynyer Lagoon area in the central-northern part of the Fraser Range region. Values are low over the remainder of the project area, apart from a few scattered higher values over sedimentary rocks of the Eucla Basin.

Sodium in regolith over the Fraser Complex is commonly low, with the higher values in lake sediments southwest and southeast of Lake Harris, 15 km west of Uraryie Rock, and some scattered higher values on the western edge of the map area (Fig. 12). The maximum value of 8.2% Na_2O is found in GSWA 161766, from 25 km west of the Claypan Fault on the western edge of

the Fraser Range region. Several relatively high values are found in regolith over the central part of the Archaean granite southwest of the Claypan Fault.

Potassium in regolith is unevenly distributed over the Fraser Range region (Fig. 13). A group of elevated values (including an anomalous value of 4.2% in sample GSWA 161747) shows a similar distribution to Na_2O in the central part of the Archaean granitoid southwest of the Claypan Fault. High values are also found in the Uraryie Rock area over several media types, suggesting some bedrock control. Some lake samples have high K_2O contents, such as GSWA 163334 (3.7% K_2O) from 5 km east of the Harms Lake microwave repeater station. Potassium values in regolith over granite and gneiss of the Nornalup Complex appear to be slightly higher than over lithologically similar material in the Biranup Complex. Values are low in regolith over the Fraser Complex, as well as over Eucla Basin sedimentary rocks.

The maximum phosphorus content in regolith over the Fraser Range region is 0.25% in sample GSWA 163308, from 3 km southeast of Peters Hole in the southwestern part of the Fraser Complex (Fig. 14), although most samples have P_2O_5 contents that are close to or less than detection level (0.05%). Despite these low values, P_2O_5 values in regolith appear higher over unit 2 of the Fraser Complex (cf. MgO and MnO; Myers, 1985), with anomalous values of 0.20% (GSWA 163368) and 0.24% (GSWA 163901) near Mount Pleasant. Other relatively high values are found in lake sediments in the northeastern part of the Fraser Complex and to the west (e.g. southwest of Lake Harris). One anomalous value of 0.23% P_2O_5 (GSWA 163368) is found in lake sediment east of the Claypan Fault.

The highest LOI values appear to be over Eucla Basin sedimentary rocks regardless of sample medium (Fig. 15). The highest value of 32.5% is found in GSWA 163971, from 35 km northeast of Cullinia Rocks. A group of high values is found in regolith near Cherternerlynyer Lagoon in the northern part of the Fraser Range region. Elevated values are found in most samples of lake sediment.

Precious metals

Gold concentrations in regolith of the Fraser Range region are commonly low (Fig. 18) with a maximum of 26 ppb Au in GSWA 161753, from 20 km northwest of Fraser Range Homestead. Four hundred and fifty-seven samples (48%) have gold values below the detection level (1 ppb), and a further 154 (or 16%) have 1 ppb Au. The maximum value of 26 ppb Au is accompanied by three other anomalous values in the same area (18 ppb in GSWA 163932; 13 ppb in GSWA 163136; and 12 ppb in GSWA 163934), and three of these samples lie close to a major northeasterly trending fault. Several relatively high gold values are found further northeast near Cherternerlynyer Lagoon. Two other high values also plot close to regional fault traces (10 ppb Au in lake-sediment sample GSWA 163617, 10 km northeast of Lake Harris; and 10 ppb Au in sheetwash sample GSWA 163842, 7 km southwest of Yarrara Native Well). Gold values are commonly low in regolith over the Fraser Complex and Eucla Basin, with

a few scattered higher values in the southeastern part of the Fraser Range region. Higher values are found in regolith over the Woodline beds in the western part of the Fraser Range region compared to regolith over other Proterozoic rocks.

Seventy-five percent of samples have silver values below the detection level (0.1 ppm), with the maximum value only reaching 0.5 ppm (Fig. 16). Most values above detection level appear to be in regolith over Eucla Basin sedimentary rocks, although anomalous values of 0.4 ppm Ag are found in GSWA 163941 (over the trace of the Jimberlana Dyke), and 0.5 ppm Ag in GSWA 163950 (approximately 10 km east of Newman Rock over the Nornalup Complex).

Eight hundred and thirty-seven regolith samples from the Fraser Range region (89%) have below detection level (1 ppb) concentrations of palladium (Fig. 33). The maximum value is 4 ppb Pd in four samples (lake sediment GSWA 163443, lake sediment GSWA 161810, sheetwash GSWA 163751, and sheetwash GSWA 163747), which are on or close to the western margin of the Fraser Complex.

Ninety-two percent (or 872) regolith samples from the Fraser Range region have below detection level (1 ppb) values of platinum (Fig. 34). The distribution of platinum-bearing samples is similar to that for palladium, and one sample with 4 ppb Pt (lake sediment GSWA 163443) has 4 ppb Pd. The maximum value of 5 ppb Pt is found in GSWA 163941 (in regolith over part of the Jimberlana Dyke), which also has high MgO, Cr, and Ni.

Anions

There is a strong relationship between regolith type and sulfur content. The maximum sulfur concentration of 20.6% is found in lake sediment GSWA 163967, from 20 km east of Cullinia Rocks (Fig. 36). Although designated a sandplain sample at the collection site, GSWA 164045 (17.2% S), from 21 km west-southwest of Uraryie Rock, is in lacustrine regolith (Plate 1); all other high-sulfur samples are of lake sediments. Eighty-six percent of regolith samples from the Fraser Range region have sulfur values below detection level (0.1%).

Base metals

Copper values are commonly higher in regolith over the Fraser Complex compared to regolith over the adjacent Eucla Basin sedimentary rocks (Fig. 24). There are several higher values over Archaean greenstone south of the Claypan Fault, including one value of 195 ppm Cu (GSWA 163926, close to the Jimberlana Dyke). Isolated high copper values are found over parts of the Biranup Complex (including the maximum value of 234 ppm Cu in GSWA 163913), and in the Eucla Basin sedimentary rocks (233 ppm Cu in GSWA 161792, 35 km east-northeast of Symons Hill; 204 ppm Cu in GSWA 161861 near Uraryie Rock; 90 ppm Cu in GSWA 163201, 18 km east-northeast of Symons Hill). However, regolith copper concentrations are low over most geological units.

The maximum lead value of 186 ppm is found in a lake-sediment sample (GSWA 161822) 15 km northeast of Lake Harris (Fig. 32). Values are not noticeably higher in regolith over the Fraser Complex compared to regolith over other geological units. There are slightly higher values in a group of samples close to Uraryie Rock. Scattered anomalous lead values are found in samples over Eucla Basin sedimentary rocks (108 ppm in GSWA 161792), Archaean granitic rocks near the Jimberlana Dyke (86 ppm Pb in GSWA 163926), and the Biranup Complex (81 ppm Pb in GSWA 163913). Values are commonly low over sedimentary rocks of the Eucla Basin.

Zinc values are relatively high in regolith over the Fraser Complex, and higher over the Nornalup Complex compared to regolith over the Eucla Basin sedimentary rocks (Fig. 48). Several anomalous zinc concentrations are recorded in samples close to Archaean metasedimentary and metavolcanic rocks (104 ppm in GSWA 163558; 126 ppm in GSWA 163549; 191 ppm in GSWA 161737; 107 ppm in GSWA 163938), and in Eucla Basin sedimentary rocks west of the Fraser Complex, south of the Claypan Fault. An anomalous value of 145 ppm Zn is found in lake-sediment sample GSWA 161822 from about 15 km north of Lake Harris.

The maximum tin value of 19 ppm is found in lake sediment GSWA 163539 from the western edge of the Fraser Range region over Archaean granite, near the trace of the Jimberlana Dyke. Some higher values are found in regolith over the southern part of the Fraser Complex near the Southern Hills (Fig. 40), and a group of higher values from various sample media types are found at Cherternerlynyer Lagoon. An anomalous concentration of 15 ppm Sn is recorded in lake sediment GSWA 161822 from about 15 km north of Lake Harris, and sample GSWA 163705 (from northeast of Boingarng Rock over the Nornalup Complex) has 14 ppm Sn.

Ferro-alloy metals

Nickel values in regolith are commonly low over sedimentary rocks of the Eucla Basin, Archaean granitic rocks, and Proterozoic metasedimentary rocks, but relatively high in regolith over the Nornalup Complex (Fig. 31). The highest value of 614 ppm Ni is in GSWA 163941, in regolith over the Jimberlana Dyke south of the Claypan Fault. The sample also has elevated chromium and MgO contents. Other high values are in regolith samples from northeast of this anomalous sample, and near Cherternerlynyer Lagoon. Some anomalous nickel values are also found over the southern part of the Fraser Complex, including 165 ppm in GSWA 161713, and 194 ppm in GSWA 163112. A sheetwash sample (GSWA 163201) approximately 17 km east of Symons Hill has 271 ppm Ni, as well as elevated chromium and copper values.

Chromium in regolith (Fig. 23) picks out Fraser Complex mafic rocks relative to adjacent rocks of the Nornalup Complex, Biranup Complex, and Eucla Basin. The highest value of 5210 ppm Cr is in sheetwash sample GSWA 163941 in regolith over the Jimberlana Dyke, south of the Claypan Fault. This sample also has high Co,

Ni, and MgO. Some high values are also found in regolith over the Woodline beds to the west. Several high and anomalous values are recorded in regolith either overlying or close to the Fraser Complex, such as 1200 ppm Cr in GSWA 164006. Chromium values are typically low over Eucla Basin sedimentary rocks, Archaean granitic rocks, and rocks of the Nornalup Complex.

Molybdenum concentrations in regolith from the Fraser Range region are low, with only 30% of samples having concentrations above the detection level (1 ppm), and a further 19% having only 1 ppm Mo. The highest concentration is in colluvium sample GSWA 163757 in the northwestern part of the Fraser Range region (Fig. 29). Several lake samples have elevated or anomalous molybdenum values, irrespective of geology.

Tungsten values are commonly low across the Fraser Range region, with a maximum value of only 3 ppm W. Eighty-five percent of regolith samples have tungsten contents below the detection level (1 ppm; Fig. 46).

Higher concentrations of vanadium in regolith are found in two areas on the Fraser Range region: over rocks of the Fraser Complex (cf. TiO_2), and over Archaean metasedimentary and metavolcanic rocks south of the Claypan Fault. The highest value of 738 ppm V (GSWA 163132) is found near a fault trace east of Archaean metavolcanic rocks in the western part of the Fraser Range region, with a value of 607 ppm (GSWA 163352) nearby. Anomalous vanadium values of 482 ppm (GSWA 163385), 536 ppm (GSWA 163746), and 499 ppm (GSWA 163517) are found in regolith samples overlying unit 2 of the Fraser Complex (Fig. 45).

As with vanadium and TiO_2 , cobalt effectively highlights regolith overlying the Fraser Complex (Fig. 22), with high values near Mount Pleasant (cf. MnO and MgO). Cobalt values appear to be slightly higher in unit 2 compared to other units of the Fraser Complex. The highest cobalt value is in GSWA 163925 (76 ppm), a lake sediment from 12 km northwest of Ten Mile Rocks. Another elevated value is in regolith over the Jimberlana Dyke, south of the Claypan Fault (73 ppm in GSWA 163941). Cobalt values are commonly lower in regolith over Eucla Basin sedimentary rocks and Archaean granitic rocks, but slightly higher over the Nornalup Complex.

Fissionable metals

Both thorium (maximum 24.3 ppm) and uranium (maximum 7.0 ppm) are usually in higher concentrations in lake-sediment samples (Figs 43 and 44 respectively). High values for both elements are recorded in GSWA 163757 over the Woodline beds in the western part of the Fraser Range region (24.3 ppm Th and 5.8 ppm U). Concentrations of both elements are high in regolith over Eucla Basin sedimentary rocks compared to regolith over the Fraser Complex.

Minor metals and non-metals

Arsenic concentrations (Fig. 17) are commonly low in regolith over the Fraser Complex, Nornalup Complex, and

Eucla Basin sedimentary rocks east of the Fraser Complex. Several higher values, including anomalous values of 60 ppm As and the maximum value of 61 ppm As (GSWA 163757 and 163414 respectively), cannot be associated with any bedrock lithology, but either lie close to northeasterly trending fault traces or are subparallel to lithological contacts (cf. gold). These higher values are found in a variety of sample media. Several higher values are also found about 12 km north of Cullinia Rocks, and in several lake-sediment samples.

The highest barium value of 10 600 ppm is found in sheetwash sample GSWA 163757 west of the Claypan Fault on the western edge of the Fraser Range region (Fig. 19). A group of relatively high barium values is found in regolith samples at the centre of Archaean granitoid in the same general area, including anomalous values of 2480 ppm (GSWA 161747) and 2140 ppm (GSWA 163935). Another anomalously high barium concentration (4130 ppm) is found in lake-sediment sample GSWA 163334, from about 4 km east of Harms Lake microwave repeater station. Barium concentrations are commonly low in regolith over sedimentary rocks of the Eucla Basin.

Beryllium only reaches a maximum of 5 ppm, and 76% of samples have concentrations below detection level (1 ppm Be; Fig. 20). Most samples with detectable beryllium are of lake sediments, and high concentrations are probably due to relatively high clay contents in this type of medium. Beryllium is mostly below detection level in regolith over rocks of the Fraser Complex.

Most high cerium values are in lake sediments, irrespective of geology, including the maximum value of 258 ppm Ce in GSWA 163127 in the western part of the Fraser Range region. Cerium values are commonly low in regolith over the Fraser Complex, with scattered higher values near Cherternerlynyer Lagoon (Fig. 21).

High gallium values, like cerium, are usually found in lake sediments, particularly over the Biranup Complex about 6 km southwest of Ten Mile Rocks (Fig. 25). The highest value of 36 ppm Ga is also found in lake sediment (GSWA 163101 from 7 km southwest of Ten Mile Rocks). Gallium values are higher in regolith over the Fraser Complex compared to regolith over the Biranup Complex, Eucla Basin sedimentary rocks, and Archaean granitic rocks. Some higher values, for different sample media types, are in regolith close to greenstone south of the Claypan Fault, including anomalous values of 34 ppm Ga in lake sediment GSWA 163139.

Eighty-seven percent of regolith samples in the Fraser Range region have below detection level (0.1 ppm) concentrations of indium and, of the remainder, few have more than 0.1 ppm In. A group of slightly higher indium values are found close to a fault trace south of the Claypan Fault (Fig. 26).

High lanthanum concentrations, like cerium, are usually associated with lake sediments (Fig. 27), with the highest value of 171 ppm La in GSWA 161822 from about 15 km north of Lake Harris. Most values are much less than 40 ppm La.

The highest lithium value is 104 ppm in lake sediment GSWA 163303 from about 24 km southeast of Mount Malcolm (Fig. 28). Lake sediments have the highest lithium contents, and most samples have less than 30 ppm Li.

Several relatively high niobium values are found in regolith about 13 km north of the Fraser Range Homestead over the Fraser Complex (Fig. 30), including the maximum value of 45.9 ppm Nb in GSWA 163766. Several other anomalous values (i.e. more than 36.6 ppm Nb) are also found in unit 2 of the Fraser Complex (cf. MnO, MgO, and P₂O₅). High niobium values are also found in lake sediments over Eucla Basin sedimentary rocks and over parts of the Fraser Complex, but most other values are low.

Rubidium (Fig. 35) shows a broadly even distribution in regolith across the Fraser Range region, with a group of higher values in the central part of the Archaean granite (maximum 203 ppm Rb in GSWA 163928), south of the Claypan Fault (cf. Na₂O and K₂O). The maximum value of 694 ppm Rb is in lake sediment GSWA 161822 from about 13 km northeast of Lake Harris. Other high rubidium values are found in other lake sediments, and several higher values are observed in different sample media between Lake Harris and Uraryie Rock. Two high rubidium values in sheetwash (163 ppm in GSWA 163330, and 184 ppm in GSWA 163529) are located approximately 15 km southeast of Lake Harms, close to the contact of the Nornalup Complex and Eucla Basin sedimentary rocks.

Elevated concentrations of antimony in regolith (Fig. 37) are scattered over Eucla Basin sedimentary rocks west of the Fraser Complex. The maximum value of 17.0 ppm Sb is in a sheetwash sample (GSWA 163224) south of Coonana. Samples GSWA 163757 (1.5 ppm Sb, in regolith over the Woodline beds) and GSWA 163248 (1.4 ppm Sb, over Archaean granitoid, 20 km east-southeast of Coonana) also have anomalous antimony.

The highest concentrations of scandium in regolith (Fig. 38) are found over the Fraser Complex, regardless of sample medium, including two anomalous values of 34 ppm Sc (GSWA 163183 and 163141) and 39 ppm Sc (GSWA 163103). The highest value of 42 ppm Sc is in a lake-sediment sample over the Eucla Basin rocks about 5 km east of the Claypan Fault (GSWA 161770). There is a group of slightly high scandium values on or close to Archaean greenstone south of the Claypan Fault.

The maximum selenium value of 12.2 ppm is in sheetwash sample GSWA 163757 in the western part of the Fraser Range region (Fig. 39). Elevated values are found in regolith over the Fraser Complex (maximum 2.6 ppm Se in GSWA 161778). Two lake-sediment samples (GSWA 161786 and 163101) contain anomalous concentrations of 2.7 ppm Se.

High strontium values are found in lake-sediment samples, such as the maximum value of 1330 ppm Sr in GSWA 163503, approximately 9 km west of Ten Mile Rocks (Fig. 41). Other high values are in lake-sediment

samples from 30 km west-northwest of the Fraser Range Homestead (950 ppm in GSWA 163539) and 15 km northeast of Lake Harris (1040 ppm in GSWA 163407). Several localized high strontium values are found over Eucla Basin sedimentary rocks about 30 km east of Newman Rock. Some high strontium values are located in sheetwash samples over Archaean granitic rocks and greenstone, and Eucla Basin rocks on the western side of the Fraser Range region close to regional fault traces. Strontium values are commonly low in regolith over the Fraser Complex.

All but 12 samples have tantalum values below the detection level (2 ppm), and the maximum value is only 3 ppm. Most values above detection level are found in regolith over the Fraser Complex (Fig. 42).

The highest number of elevated yttrium values are found in regolith over the Fraser Complex, in particular over unit 2 (cf. MnO). Some high values are also found in lake sediments (Fig. 47), including the highest value of 94 ppm Y in GSWA 163127 from the western margin of the project area. An anomalous value of 71 ppm Y is found in sample GSWA 163938, over sedimentary rocks of the Eucla Basin west of the Fraser Complex. Two lake-sediment samples (GSWA 163148 and 163303) have anomalous concentrations of 62 and 50 ppm Y respectively.

Zirconium shows a relatively even distribution over the Fraser Range region, with values appearing to be slightly higher in regolith over the Fraser Complex (Fig. 49). Some anomalous zirconium values are observed in lake-sediment samples, including the highest concentration of 792 ppm Zr in GSWA 161721, from approximately 27 km south of Mount Malcolm. Another anomalous value of 447 ppm Zr (GSWA 163703) is found in a nearby sheetwash sample over the Biranup Complex.

Discussion

In general, spot-concentration maps highlight control on the chemistry of regolith according to sample medium and bedrock geology. In particular, there are some strong compositional contrasts between regolith over the Fraser Complex and over adjacent geological units. Components such as TiO₂, Fe₂O₃, MnO, Co, Cr, Cu, Nb, Pb, Sc, Se, Ta, V, Y, and Zn have high values (despite low concentrations of Se and Ta from the Fraser Range region), and Na₂O, K₂O, and LOI have low values in regolith over the Fraser Complex, compared to regolith over Eucla Basin sedimentary rocks. Higher contents of TiO₂, Fe₂O₃, and MgO in regolith over Eucla Basin rocks immediately adjacent to the Fraser Complex could result from some eastward transport of regolith derived from the Fraser Complex regolith. Another example of bedrock control is the higher concentration of components such as Fe₂O₃, MgO, Co, Cr, Cu, Ga, Ni, Sc, V, and Zn in regolith on or close to Archaean greenstone south of the Claypan Fault in the western part of the Fraser Range region. The extent of these relatively high values is suggestive of a greater extent of greenstone than previously mapped. Many of these elements are also

concentrated in one sample of regolith over the Jimberlana Dyke in this area (GSWA 163941). In this western part of the project area, Na₂O, K₂O, Ba, and Rb concentrations are higher in a group of regolith samples at the centre of Archaean granitoid on the western margin of the Fraser Range region. This is compelling evidence for some compositional zonation of this granitoid body. Several components essentially identify unit 2 (pyroxene granulite) of the Fraser Complex. These include MnO, MgO, P₂O₅, Nb, V, and Y. Of the Proterozoic rocks, the Fraser Complex has the most distinctive regolith chemistry, with few discernible differences in regolith chemistry between other Proterozoic units, although K₂O differs slightly between regolith over the Nornalup and Biranup Complexes respectively.

Most elevated gold and arsenic values in regolith are also found in the western part of the Fraser Range region, although in the case of gold, in particular, most samples with higher concentrations lie close to north-easterly trending regional faults, extending to the vicinity of Cherternerlynyer Lagoon (Fig. 18). The strong coincidence of higher gold and arsenic in these samples is indicative of some structural control on gold distribution, a facet of gold mineralization in the eastern Yilgarn region (Witt, 1993). Gold concentrations appear to be slightly higher in regolith over the Woodline beds (Fig. 18) compared to other Proterozoic-derived regolith.

One of the most marked associations on the Fraser Range region is the high concentration of several elements in lake sediments. These include high concentrations of TiO₂, Al₂O₃, MgO, CaO, Na₂O, K₂O (some samples), P₂O₅, LOI, Ba, Be, Ga, Li, Mo (some samples), Rb, S, Se, Sn (locally), Sr, Y, Zn (some samples), and Zr. The relatively high concentrations of some of these components can be accounted for by the common occurrence of evaporite deposits (Na₂O, LOI), calcrete (CaO, Sr, LOI), and clay minerals (Al₂O₃, Be, Rb) in lake systems, but this cannot explain the elevated concentrations of species such as TiO₂, Ga, Mo, Sn, Y, Zn, and Zr. The regolith-materials map (Plate 1) shows a close spatial relationship between areas of exposed-regime regolith and lacustrine regolith; the implication is that lakes on the Fraser Range region are acting as drainage sumps in which locally derived regolith is deposited.

A group of dominantly sheetwash samples near Cherternerlynyer Lagoon has relatively high LOI, CaO, Au, and, occasionally, Sn and Ni values. This association is consistent with the local development of calcrete.

Table 2 is a compilation of samples, according to medium, that have anomalous concentrations of three or more components. A striking feature of this table is that of the 16 samples listed, nine (56%) are lake sediments. As discussed above, some elements in these samples (Al, Be, Mg) can be associated with common minerals in lacustrine systems, whereas others (Ce, La, Nb, Ta, Th, U, Zr) may be related to concentrations of resistate phases such as monazite, zircon, and rutile. However, components such as Mo, Ni, Pb, TiO₂, and Zn suggest some sort of bedrock control. A strong relationship between regolith

Table 2. Samples with three or more anomalous analyte concentrations

GSWA no.	Sample medium	Geological unit	Anomalous components
161737	Lake	Archaean granite	Li, Ni, Zn
163127	Lake	Archaean granite	Mg, Ce, La, Li, Y
163541	Lake	Archaean granite	Ce, La, Li, U
161813	Lake	Eucla Basin	La, Th, U, W
161822	Lake	Eucla Basin	Be, Ce, La, Mo, Pb, Rb, Sn, Zn
163427	Lake	Eucla Basin	Be, Ce, U
163101	Lake	Biranup Complex	Al, Ga, Mo, Se
163902	Lake	Biranup Complex	Ce, La, Li
161721	Lake	Fraser Complex	Ti, Nb, Ta, Zr
163757	Sheetwash	Woodline beds	Fe, As, Ba, Mo, Sb, Se, Th, U
161747	Sheetwash	Archaean granite	K, Ba, Sr
163941	Sheetwash	Archaean granite	Mg, Ag, Co, Cr, Ni, Pt
163132	Sheetwash	Eucla Basin	Fe, Th, V
163747	Sheetwash	Biranup Complex	Al, Ga, Pd, Th
163201	Sheetwash	Fraser Complex	Cr, Cu, Ni
163366	Stream	Fraser Complex	Ti, Ta, Zr

and bedrock is shown by sample GSWA 161747, which has anomalous K₂O, Ba, and Sr and is found over Archaean granitoid of the Fraser Range region. However, sheetwash sample GSWA 163941, overlying part of the Jimberlana Dyke, has a combination of anomalous elements (Mg, Co, Cr, Ni, and Pt) that are strongly indicative of an ultramafic parentage.

Bedrock control is also shown by samples GSWA 161721, 163594, 163308, and 163366, all sourced from the Fraser Complex. All have anomalous concentrations of TiO₂, and two have anomalous Zr, yet they represent three different sample media.

GSWA 163757 is a sheetwash sample over the Woodline beds in the western part of the project area. It has anomalous concentrations of several components, including Fe₂O₃, As, Ba, Mo, Sb, Se, Th, and U. The sample form for this site (YAR15) records abundant saprolite, saprock, and bedrock fragments, along with vein quartz. Bedrock fragments include intercalated iron-rich and felsic siliciclastic horizons. Mention is made of the potential for mineralization associated with quartz veining and iron-staining.

Table 3 shows the chemistry of two samples (GSWA 161813 and 163377) collected from site SYM2, approximately 20 km southeast of Cherternerlynyer Lagoon (Plate 2). Both are lake samples and show similarity to other lake samples in having high Al₂O₃ and LOI contents. Most analytes are in a similar range, but SiO₂, V, and Nb are at quite different concentrations in the two samples (Table 4).

Statistical treatment of regolith chemical data

Although spot-concentration maps (Figs 6 to 49) facilitate a rapid comparison of regolith chemistry and bedrock geology, it is necessary to statistically assess groups of regolith analyses in order to determine differences in the chemistry of regolith according to criteria such as sample media, bedrock unit or regolith materials. The 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 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 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 on two (Student's *t*-test) or more (Tukey's Honestly Significant Difference, HSD) sample populations, as discussed by Morris et al. (1997, 1998). One major assumption of this approach is that the addition of a constant and log normalization produces a sufficiently normally distributed dataset to allow the use of such parametric statistical tests. However, for small datasets or where data are not normally distributed, non-parametric tests may be more appropriate. Amongst these is the non-parametric equivalent of the Student's *t*-test for independent samples, known as either the Mann-Whitney U test or the Wilcoxon rank-sum test (Swan and Sandilands, 1995). Whereas the Student's *t*-test deals with the equality of population means, the Mann-Whitney U test examines the equality of medians (i.e. the middle value in a set of ranked data). As the Mann-Whitney U test is calculated on ranked data, rather than data in its raw form, it is less sensitive to outliers, and is therefore more robust than statistical tests comparing population means (e.g. Student's *t*-test). However, caution should be exercised in using the Mann-Whitney U test where there are many similar values in both populations, such as zero in exploration geochemical datasets. In this case, the computed rank sums may unrealistically highlight the importance of values that are only just above detection level.

The Mann-Whitney test has been used in a statistical analysis of regolith chemical data from the Fraser Range region. The probability of medians being statistically different is assessed at the 99% or higher level for median analyte values that are greater than ten times the detection level. For most statistical tests carried out, the medians for 18 analytes (MnO, P₂O₅, Ag, As, Au, Be, Bi, Cd, In, Mo, Pd, Pt, S, Sb, Se, Ta, U, and W) are excluded from discussion on the basis of detection level.

• Statistical comparison of regolith chemistry according to sample medium

Of the 949 samples collected, 721 consist of sheetwash, 145 comprise lake sediments, 46 are sandplain samples, and 37 are stream sediments. Sampling procedures for these media types are described in Appendix 4, and it is

Table 3. Chemistry of samples from site SYM2

GSWA no.		161813	163377
Easting		526124	526186
Northing		6514470	6514387
Medium		Lake	Lake
	DL	Batch 5	Batch 3
Percentage			
SiO ₂	0.1	46.3	59.6
TiO ₂	0.05	0.75	0.47
Al ₂ O ₃	0.1	22.7	15.7
Fe ₂ O ₃	0.1	6.7	4.5
MnO	0.05	0.07	0
MgO	0.1	0.9	0.3
CaO	0.1	0.2	1.9
Na ₂ O	0.1	1.9	1.3
K ₂ O	0.1	2.6	2.3
P ₂ O ₅	0.05	0.12	0.06
LOI	0.1	15.8	12.7
Total	0.01	98.05	98.91
Parts per million			
Ag	0.1	0.2	0
As	1	19	10
Au (ppb)	1	0	1
Ba	5	385	399
Be	1	2	2
Bi	0.5	0	0
Cd	1	0	0
Ce	0.5	128	81.1
Co	1	32	10
Cr	2	67	42
Cu	1	25	15
Ga	1	30	15
In	0.1	0.1	0
La	0.2	80.7	47.6
Li	3	58	36
Mo	1	1	0
Nb	0.5	27.7	5.3
Ni	2	43	24
Pb	1	28	20
Pd (ppb)	1	1	0
Pt (ppb)	1	0	0
Rb	0.5	109	89.1
S (%)	0.1	1.4	2
Sb	0.5	0	0
Sc	1	16	10
Se	0.5	2.2	0
Sn	1	4	3
Sr	1	253	184
Ta	2	0	0
Th	0.1	23.3	10.6
U	0.1	5.2	3.3
V	2	108	72
W	1	3	0
Y	1	39	12
Zn	2	36	18
Zr	5	103	115

NOTE: DL: Detection limit

clear from the nature of these samples that many of them are found at different levels in the landform profile. For example, lakes are found at topographically high and low levels within the Fraser Complex, and sheetwash samples similarly encompass a wide range of elevations, as well as including both proximal and distal deposits.

Table 4. Median values for regolith according to sample medium

	Sheetwash (n=721)	Stream (n=37)	Sandplain (n=46)	Lakes (n=145)
Percentage				
SiO ₂	69.7	81.4	82.05	62.2
TiO ₂	0.58	0.45	0.34	0.55
Al ₂ O ₃	7.7	5.4	4	9.1
Fe ₂ O ₃	4.9	3	2.4	4.6
MgO	1.2	0.5	0.5	0.8
CaO	2.3	0.9	1.1	0.7
Na ₂ O	0.4	0.5	0.2	1.1
K ₂ O	0.9	0.9	0.5	1.2
LOI	7.4	3.1	4.05	9.9
Parts per million				
Ba	225	312	131.5	247
Ce	22.9	17.4	13.2	26.3
Co	9	7	4	8
Cr	56	29	28.5	50
Cu	21	16	15	18
Ga	10	8	5.5	10
La	14.3	9.8	7.85	14.3
Li	14	11	10.5	14
Nb	5.7	4.2	5.6	6.5
Ni	32	20	18.5	24
Pb	11	9	6.5	11
Rb	36.1	27.2	19	35.6
Sc	8	5	4	7
Sr	102	63	60	113
Th	6	3.9	3.4	6.2
V	76	50	38	72
Y	8	6	5	7
Zn	22	16	12.5	19
Zr	107	84	77.5	102

NOTE: n: number of samples

The aim of statistically comparing the chemistry of samples according to sample medium is to examine how variable each sampling medium is, and what causes this variability. Population medians for the three media types are shown in Table 4.

Relative to other sample media, sheetwash samples have the highest median values for MgO, CaO, Cr, Cu, and Ni. Compared to stream sediments, sheetwash samples have higher median values for Al₂O₃, LOI, La, Nb, Sr, Th, Y, and Zn, and lower SiO₂. The median values for sheetwash samples and stream sediments are statistically similar for TiO₂, Fe₂O₃, Na₂O, K₂O, Ba, Ce, Co, Ga, Pb, Rb, Sc, V, and Zr. In addition to MgO, CaO, Cr, Cu, and Ni, sheetwash samples have higher median values for SiO₂, TiO₂, Fe₂O₃ compared to lake-sediment samples. Compared to sandplain samples, sheetwash samples have higher median values for most analytes, apart from SiO₂.

Lake-sediment samples have the highest median values for Al₂O₃, Na₂O, K₂O, and LOI, and the lowest SiO₂ of all media types. Compared to stream sediments, median values for lake-sediment samples are statistically higher for Ce, La, Li, Nb, and Th. Relative to sandplain samples, lake sediments have higher median values for TiO₂, Fe₂O₃, Ba, Ce, Co, Cr, Cu, Ga, La, Li, Rb, Sc, Th, V, Zn, and Zr.

Sandplain samples have the lowest median values for Na₂O and Ba of all media types. As discussed above, they have lower median values for most analytes (apart from SiO₂) compared to sheetwash and lake-sediment samples, but statistically similar median values to stream sediments for all analytes except for Na₂O and Ba. Site observations have shown that many streams over Eucla Basin sedimentary rocks have a high sand content.

These statistical results highlight features of regolith chemistry according to sample media in the Fraser Range region. Lake-sediment samples on other 1:250 000 map sheets completed for the GSWA regional regolith geochemistry program (e.g. NABBERU: Morris et al., 1997; and SIR SAMUEL, Kojan et al., 1997) are dominated by elevated CaO, Na₂O, LOI, and Sr and strong depletion in other analytes. In contrast, lake sediments of the Fraser Range region are compositionally more similar to other sample media. The high Al₂O₃, K₂O, and Sr content of lake sediments compared to other sample media is consistent with a high clay content, and it is likely that lake sediments have been deposited from standing water in shallow depressions. The higher median values for Ce, La, Nb, and Th in lake sediments compared to stream sediments indicates that lakes may have higher concentrations of resistate phases. Furthermore, examination of spot-concentration maps shows that lake-sediment chemistry is strongly influenced by bedrock, indicating that lakes act as local sumps.

A surprising aspect of this statistical comparison is the overall similarity in median values for sandplain samples and stream sediments, which are only statistically different in terms of Na₂O and Ba. Commonly, sandplain samples have significantly higher SiO₂ contents than other sample media, which tends to dilute the concentration of other analytes. Two explanations for the similarity of sandplain and stream-sediment samples in the Fraser Range region are: (a) that stream sediments have undergone more protracted chemical weathering than many other media types due to the limited movement of stream sediment because of low stream gradient — this is consistent with a high proportion of streams cutting Eucla Basin sedimentary rocks, where there is a lack of relief; and (b) that sandplain samples represent a mixture of locally derived and eolian material, rather than a purely eolian product. A contributing factor to sandplain chemistry could be that 20 of the 46 sandplain samples are from bushfire areas. It is possible that destruction of vegetation by bushfires could destabilize sandy areas, resulting in the winnowing of fine material leaving a depleted residuum.

The relatively high content of MgO, CaO, Cr, and Ni in sheetwash samples relative to other sample media is consistent with a higher ferromagnesian mineral content, indicative of a relatively low degree of chemical weathering. This is consistent with sheetwash units being found relatively close to areas of outcrop or subcrop. Higher median values for Al₂O₃ and Sr in sheetwash samples relative to stream sediments, and lower SiO₂ are consistent with lower feldspar contents in stream sediments and a higher degree of chemical weathering producing more clay in sheetwash material.

• Statistical comparison of regolith chemistry over five lithological associations in the Fraser Complex

Myers (1985) divided the Fraser Complex into five tectono-stratigraphic units (Fig. 4). Unit 1, forming the western part of the Fraser Complex, consists of garnet amphibolite and thin layers of metamorphosed ultramafic rocks, melanogabbro, and anorthosite. Unit 2 consists of basic pyroxene granulite. Unit 3 consists of metamorphosed leucogabbro, anorthosite, and subordinate gabbro and melanogabbro. Unit 4 is lithologically similar to unit 2 (i.e. basic pyroxene granulite). Unit 5 consists largely of gabbro and metagabbro with relatively well preserved igneous textures.

Several spot-concentration maps (e.g. MnO, Fig. 9; MgO, Fig. 10) indicate that there is some compositional difference between these units of the Fraser Complex. A statistical assessment of regolith chemistry according to Myers' (1985) subdivision has been carried out by comparing population medians using the Mann-Whitney U test. The population groupings compared here examine: (a) Myers' (1985) assertion that units 2 and 4 are lithologically similar; and (b) if lithological association 2 is statistically different to other lithological associations, as suggested by some spot-concentration maps.

The median values for regolith populations over each of the five lithological associations are shown in Table 5. Apart from CaO, LOI, Cu, Nb, Sr, and Th, the median values of all analytes in unit 2 have a 99% probability of being higher than those in unit 1, apart from SiO₂, which is statistically higher in unit 1. Units 3, 4, and 5 have higher median values for TiO₂, Al₂O₃, K₂O, Ba, Ce, Co, Cr, Ga, La, Li, Nb, Ni, and Rb, and lower SiO₂ than unit 1. In addition, unit 3 has higher median values for Fe₂O₃, Na₂O, Pb, Sc, V, Y, Zn, and Zr compared to unit 1, and unit 4 has higher median values for Na₂O, Sc, Y, Zn, and Zr compared to unit 1.

There are fewer statistical differences in median values for regolith over units 2, 3, 4, and 5. Relative to unit 3, unit 2 has higher MgO, Y, and Zn, whereas relative to unit 4, unit 2 has lower TiO₂, Al₂O₃, Ba, and Zn. Unit 2 has higher median values for MgO, Ce, Sr, Y, and Zn and lower LOI compared to unit 5. Unit 4 has higher TiO₂, Al₂O₃, Na₂O, and Ba than unit 3, and there are no statistical differences for median values of analytes between units 3 and 5.

This statistical comparison of regolith over the five lithological associations identified by Myers (1985) in the Fraser Complex shows wide disparities in median values between garnet amphibolite of unit 1 and other units. Unit 1 has lower median values for most analytes, apart from SiO₂, which suggests that it is more leucocratic. Although it could be argued that differences in regolith chemistry could be due in part to variable weathering of regolith, this is unlikely, as all five lithological associations have similar regolith-landform types, largely consisting of erosional-regime regolith (*Xmm*) derived from mafic metamorphic rocks, a colluvial analogue (*Cmm*), and heterogeneous colluvium (*Cl*) and sandplain (*Sl*).

Table 5. Median values for regolith according to lithological units (Myers, 1985) of the Fraser Complex

Unit	1 (n=26)	2 (n=49)	3 (n=52)	4 (n=28)	5 (n=27)
Percentage					
SiO ₂	64.25	55	55.75	56.2	56.9
TiO ₂	0.745	1.46	1.44	1.94	1.44
Al ₂ O ₃	7.9	12	12.7	14.2	12.2
Fe ₂ O ₃	9.45	12.5	11.3	10.65	11.6
MgO	1.65	2.2	1.8	1.85	1.9
CaO	3.35	3.1	3.05	3.05	3.1
Na ₂ O	0.4	0.9	0.8	1	0.6
K ₂ O	0.7	1.2	1.2	1.3	1
LOI	6.45	6.8	8.45	7.6	10.7
Parts per million					
Ba	182	340	346	441	352
Ce	19	36	32	31	31
Co	14	27	22	29	22
Cr	75	148	167	170	170
Cu	23	27	26	24	29
Ga	11	18	18	18	18
La	13	19	19	18	19
Li	11	15	13	14	17
Nb	5	8	11	8	11
Ni	32	53	50	57	55
Pb	10	14	13	14	13
Rb	27	41	43	44	39
Sc	12	20	19	20	18
Sn	1	1	2	1	2
Sr	106	143	124	127	105
Th	5	6	6	6	7
V	141	174	169	170	176
Y	12	21	16	18	15
Zn	30	52	42	39	41
Zr	114	169	170	186	160

NOTE: n: number of samples

Further evidence for strong bedrock compositional control on the chemistry of regolith is provided by the mafic nature of regolith over unit 2 — this association has the highest median values of all five associations for MgO and Fe₂O₃. Differences in regolith composition between units 2 to 5 are less marked than between unit 1 and the other four units, and can be largely explained in terms of variations in the proportions of ferromagnesian and feldspar minerals. Myers (1985) assertion that units 2 and 4 are lithologically similar is supported by the small number of differences in median concentrations of analytes between these two associations (TiO₂, Al₂O₃, Ba, Zn), but regolith chemistry also indicates few compositional variations between units 2 to 5 in total, especially units 3 and 5, for which there are no statistically significant differences in the median values for regolith (Table 5). It is clear from this statistical comparison that regolith over unit 1 is more distinctive, with the higher median value for SiO₂ and lower median values for several other analytes indicating a more leucocratic protolith. In addition, the comparison highlights the mafic nature of unit 2 compared to other units. In terms of Myers' (1985) observations about the compositions of the five lithological associations of the Fraser Complex,

comparison of their regolith chemistry does confirm his assertion that unit 2 is compositionally different (in being more mafic), but it is unit 1 that is distinctive from the other four units, which show few compositional differences between them.

• Statistical comparison of regolith-materials types over part of the Fraser Complex

The discussion above about the variations in regolith chemistry over five lithological associations of the Fraser Complex highlights the influence of bedrock on regolith chemistry. In particular, this approach shows the compositional differences between garnet amphibolite of unit 1 and the remaining 4 units, and emphasizes the possible chemical similarity of units 2 to 5. The apparent influence of bedrock on the chemistry of regolith, and the similarity of regolith chemistry between units 2 to 5 of the Fraser Complex offers a good opportunity to examine any differences in regolith chemistry according to regolith-materials type over these four units. In particular, the relationship of proximal and more-distal regolith derived from mafic metamorphic rocks (*Xmm* and *Cmm* respectively) is examined, as well as the relationship of colluvium derived from mafic metamorphic rocks (*Cmm*) and heterogeneous colluvium (*Cl*), and the relationship of heterogeneous colluvium (*Cl*) and heterogeneous sandplain (*Sl*). Suppositions made in mapping the distribution of regolith in the Fraser Range region include the derivation of some part of the heterogeneous colluvial unit (*Cl*) by the reworking of heterogeneous sandplain (*Sl*).

Median values for erosional-regime regolith derived from mafic metamorphic rocks (*Xmm*), analogous colluvium (*Cmm*), heterogeneous colluvium (*Cl*), and sandplain (*Sl*) over units 2 to 5 of the Fraser Complex are shown in Table 6. A statistical comparison of median values for erosional-regime regolith (*Xmm*) and colluvium (*Cmm*) shows no significant difference in analyte concentrations at or above the 99% level (and only Na_2O shows a significant difference at the 95% level or above). This is compelling evidence that both regolith types are locally derived, and any differences between them can be attributed to physical rather than chemical processes. This close compositional relationship between exposed-regime regolith and colluvium is also consistent with the thin regolith cover in the Fraser Range area, and the near-surface occurrence of bedrock in areas of colluvium and sheetwash.

Colluvium derived from mafic metamorphic rocks (*Cmm*) and heterogeneous colluvium (*Cl*) over units 2 to 5 of the Fraser Complex also show a limited number of differences in the median values of analytes (Table 6), with only higher Sr in the heterogeneous colluvium (*Cl*) unit. A similar situation exists for heterogeneous colluvium (*Cl*) and sandplain (*Sl*), with only lower median MgO in the latter. The few statistical differences in median values for this depositional-regime regolith over these four lithological associations of the Fraser Complex indicates that there is strong bedrock control on all regolith types, regardless of whether the regolith belongs to the exposed or depositional regimes.

Table 6. Median values for regolith over units 2–5 of the Fraser Complex

Regolith code	<i>Xmm</i> (n=71)	<i>Cmm</i> (n=19)	<i>Cl</i> (n=21)	<i>Sl</i> (n=33)
Percentage				
SiO_2	56.00	55.10	55.00	56.80
TiO_2	1.68	1.64	1.56	1.26
Al_2O_3	13.60	12.30	11.80	11.90
Fe_2O_3	11.60	12.00	12.30	10.70
MgO	2.20	1.80	2.10	1.50
CaO	3.10	3.10	4.30	2.90
Na_2O	1.00	0.70	0.80	0.60
K_2O	1.20	1.20	1.10	1.10
LOI	6.80	8.70	10.50	10.80
Parts per million				
Ba	382	354	383	331
Ce	33	36	29	33
Co	28	25	25	20
Cr	167	151	183	145
Cu	25	26	27	26
Ga	18	18	17	16
La	18	20	18	19
Li	15	15	15	15
Nb	10	10	9	9
Ni	53	50	57	50
Pb	13	13	14	14
Rb	42	43	37	42
Sc	21	21	19	17
Sn	1	2	2	1
Sr	126	110	144	113
Th	5	5	7	7
V	176	174	196	154
Y	20	21	17	14
Zn	49	48	42	41
Zr	169	177	172	160

NOTE: n: number of samples

• Statistical comparison of medians and cluster analysis of heterogeneous sandplain (*Sl*) over contrasting bedrock lithologies

Statistical comparison of medians

Heterogeneous sandplain (*Sl*) accounts for approximately 65% by area of the regolith cover of the Fraser Range region. Its diverse nature, both in terms of its geomorphology and composition, mean that it is not easy to assign an unequivocal origin, although there is some evidence that it is in part locally derived, and in part resulting from eolian transport. If regolith is to be considered as a viable sampling medium in any regional geochemical survey, it is important to understand how effectively the various regolith units mirror the composition of the underlying bedrock. Evidence from four lithological associations of the Fraser Complex indicates a strong contribution from the bedrock to adjacent regolith units. In order to further test the significance of local derivation, population medians (Table 7) for this regolith unit over two lithologically contrasting bedrock units (Nornalup Complex and Eucla Basin sedimentary rocks) have been statistically compared. Twenty analytes (TiO_2 , Al_2O_3 , Fe_2O_3 , K_2O , Ba,

Table 7. Median values for heterogeneous sandplain regolith (SI) over Eucla Basin sedimentary rocks, and the Nornalup Complex.

Unit	Eucla Basin (n=210)	Nornalup Complex (n=39)
Percentage		
SiO ₂	75.75	70.80
TiO ₂	0.43	0.82
Al ₂ O ₃	5.30	6.50
Fe ₂ O ₃	3.05	5.00
MgO	0.90	1.30
CaO	2.20	2.40
Na ₂ O	0.30	0.30
K ₂ O	0.70	0.90
LOI	7.10	8.10
Parts per million		
Ba	174	217
Ce	17	20
Co	6	9
Cr	35	55
Cu	17	21
Ga	7	9
La	11	13
Li	12	14
Nb	5	7
Ni	23	33
Pb	8	12
Rb	27	32
Sc	5	8
Sr	83	103
Th	5	7
V	48	80
Y	6	8
Zn	14	20
Zr	97	130

NOTE: n: number of samples

Ce, Co, Cr, Cu, Ga, Li, Nb, Ni, Pb, Rb, Sc, Th, V, Zn, and Zr) have a 99% or more probability of being higher in heterogeneous sandplain (SI) regolith over the Nornalup Complex compared to the same regolith-landform unit over the Eucla Basin sedimentary rocks. If this regolith unit resulted from significant eolian input, it would be fair to expect a more uniform composition over the Fraser Range region. However, the number of analyte median values that are significantly different between these two regolith groupings is indicative of local bedrock control on composition, consistent with findings from the four lithological units of the Fraser Complex discussed above. Eolian input cannot be totally discounted, as dune forms over the heterogeneous sandplain unit in the northeastern part of the project area support eolian action, and the wide distribution of carbonate in regolith of the Fraser Range region is thought to result from eolian processes (Myers, J. S., 1998, pers. comm.).

In order to further examine the factors that control the composition of extensively developed regolith-materials units in the Fraser Range region, median values for heterogeneous sandplain regolith (SI) of the Fraser Complex, from east and west, have been statistically compared (Table 8). Median values for Fe₂O₃, Na₂O, Cr,

Cu, Ni, Pb, Th, V, and Zn are statistically higher in this regolith-materials unit from west of the Fraser Complex compared to the same unit to the east, whereas TiO₂ and Zr are lower. It is clear from this comparison that there is a stronger mafic influence on the composition of heterogeneous sandplain (SI) regolith west of the Fraser Complex, which may indicate input from the Fraser Range area or Yilgarn Craton or both.

Cluster analysis

Cluster analysis can be used to subdivide regolith units according to chemistry. Discussion so far has indicated significant bedrock control on the composition of the heterogeneous sandplain unit (SI), and cluster analysis of this unit has been carried out to further examine this assertion. Cluster analysis aims to divide a series of observations into several discrete or overlapping groups (Rock, 1988). Based on geology (Fig. 3) and regolith (Plate 1), there are four possible compositional groupings of the heterogeneous sandplain unit (SI):

- quartzofeldspathic plutonic, metamorphic rocks;
- ferromagnesian metamorphic rocks;

Table 8. Median values for heterogeneous sandplain regolith (SI) east and west of the Fraser Complex

Position	West (n=205)	East (n=211)
Percentage		
SiO ₂	72.7	73.6
TiO ₂	0.41	0.61
Al ₂ O ₃	6.5	5.6
Fe ₂ O ₃	4.2	3.3
MgO	1	1
CaO	2.2	2.1
Na ₂ O	0.4	0.3
K ₂ O	0.8	0.8
LOI	7.4	7.3
Parts per million		
Ba	193	191
Ce	20	18
Co	8	6
Cr	48	36
Cu	21	18
Ga	8	7
La	12	12
Li	13	12
Nb	5	5
Ni	29	24
Pb	10	9
Rb	32	29
Sc	7	6
Sn	1	1
Sr	97	83
Th	6	5
V	66	51
Y	7	7
Zn	19	15
Zr	93	112

NOTE: n: number of samples

- carbonate- and quartz-rich marine and continental sedimentary rocks;
- other sources or chemical overprints (limestone and sandstone).

As the number of clusters is pre-determined, the k-means clustering approach has been used to subdivide this regolith unit. This technique produces exactly four clusters of greatest possible distinction, based on chemistry. Thirty-four analytes were used in clustering the samples. The mean values for each group are shown in Table 9. The results of k-means clustering of heterogeneous sandplain (*SI*) are displayed in Figure 50, where the four clusters are identified by coloured symbols relative to simplified geology. Cluster 1 groups samples of a quartzofeldspathic nature, and these samples are largely found over the Nornalup Complex, although a number of samples extend beyond the known outcrop area, suggesting a greater extent of these rocks. Other members of this group are found in parts of the Fraser Complex, and in areas of the Eucla Basin sedimentary rocks — the latter could mean that these Cainozoic rocks are providing only a thin cover in some parts of the Fraser Range region.

Cluster 2 are heterogeneous sandplain samples that show a ferromagnesian character. These samples are largely found in the western part of the project area, over and beyond areas of Archaean greenstone, and provide more evidence for a greater extent of this bedrock unit. They are also found along the Fraser Range, northeast of Symons Hill. A few scattered samples over the Nornalup Complex could mean that this unit has some minor mafic component. Cluster 3 is a small group of 27 samples that are mainly found in small clumps over Eucla Basin sedimentary rocks in the eastern part of the Fraser Range region. These small groups of samples do not correspond to known drainages — one possibility is that these are areas where groundwater carbonate has been precipitated in topographic depressions in the heterogeneous sandplain unit.

Cluster 4 has the highest population (239 samples), and these samples are mainly found over Eucla Basin sedimentary rocks. The encroachment of these samples onto areas of the Fraser Complex in the northeastern part of the project area (south of Spy Hill) provides some evidence for transportation of this unit, which is consistent with dune-like features evident on Landsat TM imagery in this area. Scattered samples from this cluster are also found over granitoid rocks in the southern part of the project area, and the Eucla Basin sedimentary rocks may be more common here than shown on the simplified geology in Figure 50.

Cluster analysis has largely confirmed the strong bedrock control on the heterogeneous sandplain unit, as well as supporting the wider extent of Archaean greenstone in the western part of the project area. This approach has also shown that the Nornalup Complex may be of greater extent than previously thought, and it may locally penetrate Eucla Basin sedimentary rocks, and contain a minor mafic component. The encroachment of the heterogeneous sandplain unit on the Fraser Complex in the northeastern part of the project area is consistent

Table 9. Average values after k-means cluster analysis of heterogeneous sandplain regolith (*SI*)

	Cluster 1 Quartzofeldspathic (n=61)	Cluster 2 Ferro-magnesian (n=87)	Cluster 3 Carbonate (n=27)	Cluster 4 Limestone and sandstone (n=239)
Percentage				
SiO ₂	70.59	59.80	56.96	79.74
TiO ₂	0.80	0.98	0.46	0.42
Al ₂ O ₃	9.16	10.30	5.97	5.22
Fe ₂ O ₃	5.29	11.17	3.15	3.51
MnO	0.05	0.09	0.01	0.01
MgO	1.18	1.76	4.53	0.81
CaO	2.74	3.72	9.76	2.50
Na ₂ O	0.68	0.54	0.71	0.25
K ₂ O	1.62	1.07	0.90	0.66
P ₂ O ₅	0.01	0.02	0.01	0.00
Parts per million				
Ba	516.97	259.28	204.37	155.51
Be	0.34	0.40	0.22	0.08
Ce	30.13	32.89	20.62	16.38
Co	10.54	17.52	7.22	6.15
Cr	55.36	156.77	38.15	38.08
Cu	23.33	32.79	20.52	18.85
Ga	11.44	14.97	6.19	6.88
La	17.26	19.14	13.17	9.84
Li	14.95	19.17	15.44	11.87
Mo	0.28	0.60	0.30	0.24
Nb	7.32	9.39	4.87	4.92
Ni	29.46	60.37	27.22	24.21
Pb	16.48	15.03	6.81	8.85
Rb	59.52	44.12	27.32	26.47
S	0.02	0.04	0.29	0.00
Sb	0.03	0.19	0.04	0.04
Sc	8.87	13.55	5.26	5.31
Sr	148.34	140.74	489.85	72.42
Th	6.94	9.27	5.32	5.21
U	0.85	1.06	1.25	0.57
V	79.56	179.18	58.33	51.34
Y	10.13	12.33	7.37	5.90
Zn	22.77	41.60	15.52	14.64
Zr	128.20	142.23	98.22	87.22

NOTE: n: number of samples

with Landsat TM observations that this unit has an eolian (i.e. transported) component in this area.

Conclusions

Regardless of the approach taken, all statistical tests have underlined the strong influence of bedrock on the composition of regolith. This extends even to lake sediments, which have been viewed in previous GSWA regional regolith geochemistry programs as an unreliable indicator of the underlying bedrock. In contrast, lake sediments of the Fraser Range region appear to have acted as local sumps for fine-grained sediment, and as such could be useful sampling media.

The similarity in chemistry of exposed-regime regolith (*Xmm*), colluvium (*Cmm*), heterogeneous colluvium (*CI*), and heterogeneous sandplain (*SI*) over part of the Fraser

Complex indicates that physical rather than chemical processes are more important in the formation of regolith in the Fraser Range region. The chemical similarity of colluvium and exposed-regime regolith is also consistent with the close proximity of bedrock to the surface and the general thin regolith cover in the project area. In contrast, chemical as well as physical weathering appears to be important in the case of stream sediments. They are compositionally similar to sandplain samples of the Fraser Range region, which could be explained by the low gradient of streams leading to in situ weathering of stream sediments rather than downslope transport and deposition.

Extensive statistical tests have shown that the heterogeneous sandplain unit (*SI*), which is widely developed in the Fraser Range region, is largely of local derivation. This has major implications for regional regolith sampling programs, in that some confidence can be expressed in the unit being indicative of the underlying bedrock. However, there is local evidence for eolian input, and it is possible that carbonate, which is found throughout regolith in the project area, could have been transported into the area by eolian processes.

Speciality maps

Additive-index maps, such as those used to identify areas of chalcophile-element abundance in ferricrete of the northern Yilgarn Craton (Smith et al., 1989) have been used successfully in the GSWA's regional regolith geochemistry program to highlight areas of potential mineralization (Morris et al., 1998; Pye et al., 1998). This approach, which combines elements indicative of certain mineralization styles in an additive fashion (e.g. chalcophile index = As + Sb + Bi + Mo + Ag + Sn + W + Se; Smith et al., 1989) is not the mere addition of analyte concentrations, but requires some data transformation to ensure that an element showing anomalous concentrations even at low abundances is given equal importance as an element showing anomalous concentrations at a higher level of concentration — that is, higher concentration elements do not negate the importance of other elements that may be found at lower concentrations. The transformation involves the addition of a constant to each analyte value to remove zero data, followed by calculating the logarithmic value, which reduces the effects of extremely high or low values. These values are then expressed as standard deviations relative to the overall distribution (standard normal deviates), which allows direct comparison of analytes regardless of absolute concentration. These values are then summed to calculate the standard score.

Chalcophile-index map

Standard scores for a chalcophile index (modified from Smith et al., 1989) are shown in Figure 51. This index sums the standard scores for As, Ag, Bi, Cd, Sb, and Mo. As expected, values are low in regolith over Eucla Basin sedimentary rocks, and most high values are found west of the Fraser Complex. In particular, there appears to be a high concentration of samples with relatively high

chalcophile standard scores on or close to regional faults, especially in the central-western part of the project area near Archaean greenstone. This strong association of elevated index values and regional faults in this area could indicate zones of fault-controlled gold mineralization in the western part of the project area. Regolith-materials mapping (Plate 1) and regolith geochemistry indicate a greater extent of greenstones in this area than previously mapped, and elevated chalcophile standard scores clearly extend beyond these areas of greenstone — in fact, they curve around from the greenstone, along regional faults, and extend along the synclinal structure in the Woodline beds, with only low chalcophile-index values over the intervening Archaean granitoid rocks. Groves et al. (1988) and Witt (1993) discussed the controlling factors on the location of major gold deposits in the Eastern Goldfields Province, noting that structure and lithology are the two main factors, involving regional-scale faults and mafic lithologies (basalt and dolerite).

A few higher chalcophile-index values are also found near faults in the Fraser Complex and adjacent Nornalup Complex. Several higher values over Eucla Basin sedimentary rocks west of the Fraser Complex in the central part of the project area are subparallel to regional fault trends.

Ferro-alloy index map

Figure 52 shows the distribution of summed ferro-alloy index scores (Ni + Cr + Mo + Co + V) against simplified geology. The majority of elevated scores are found over all of the Fraser Complex, with the other area of higher summed standard scores in the region of Archaean greenstone (in the central-western part of the project area), and over the Woodline beds. Other, more scattered areas of higher scores are found northeast of Archaean greenstone towards the northern areas of the Fraser Range region, and over Eucla Basin sedimentary rocks between the Fraser Complex and the Yilgarn Craton. The latter samples may indicate either transport of regolith derived from the Fraser Range over the Eucla Basin rocks, or local areas of more mafic material emergent through this Cainozoic succession. The regolith-materials map indicates that the latter is more important. This plot provides more support for a greater extent of Archaean greenstones in the western part of the project area, and provides some evidence for areas of possible nickel mineralization.

Calcrete abundance plots

Lintern and Butt (1993) discussed the potential for the use of calcrete as a sampling medium in gold exploration. In order to further examine this for the Fraser Range region, maps have been constructed using data recorded at each sample site. Figures 53 and 54 show the locations of sample sites where calcrete is recorded as a component of the clast population or as a secondary unit nearby respectively. Of the 949 sites sampled in the Fraser Range region, 332 (35% of all sites) have carbonate clasts recorded, but as is evident from Figure 53, there is no

clear correlation of clast population with bedrock type. There are only 35 sites (<4% of all sites) where calcrete is recorded as a secondary unit nearby, and again there is no correlation with bedrock, although some calcrete units are found either close to or coincident with lake systems.

Conductivity

Figure 55 shows the conductivity or total dissolved solids (TDS; in mS/cm) for each regolith sample in relation to drainage and lake systems. Most conductivity values are low (<4 mS/cm) and there appears to be no discernible correlation with particular drainages or lake systems.

Acidity-alkalinity (pH)

The pH of regolith samples is largely in the neutral range (6–8) with only a few isolated lower values (3–4) in the southern part of the project area (Fig. 56). There is no apparent correlation with particular drainage systems or lakes.

Mineralization potential

The Fraser Range region has been explored for a variety of commodities, including gold, nickel, uranium, barite, and base metals, but to date, the area has only produced building stone and a small amount of barite, with a known resource of vermiculite. There has been a renewed focus on the Fraser Complex as an exploration target due to analogies being drawn between its age, lithology, and presumed tectonic evolution and that of the Voisey's Bay nickel deposit in Canada (Li and Naldrett, 1999; Register of Australian Mining, 1999/2000b). Gibson (1989) discussed the platinum-group element (PGE) potential of the Fraser Complex by drawing analogies with the Bushveld Complex of South Africa.

Gold exploration in the Fraser Complex has focused on areas of deformation, where several gold, molybdenum, and arsenic anomalies have been reported (Register of Australian Mining, 1999/2000a). Several exploration approaches have been used, including the use of calcrete as a sampling medium (Australian Gold Annual, 1998/99), although some results from the present study indicate that calcrete may not be an effective sampling medium, as there is evidence that the ubiquity of calcrete may result from eolian input. Groves et al. (1998) and Witt (1993) discussed the controls on gold mineralization in the Eastern Goldfields area of the Archaean Yilgarn Craton. They underlined the importance of structure in controlling areas of significant gold mineralization, noting in particular that large gold deposits show a high correlation with regional-scale lineaments, which are often tens to hundreds of kilometres long; the actual gold deposits, however, were usually localized in smaller brittle structures spatially related to these major faults. The importance of lithology is shown by the predominance of tholeiitic basalt or dolerite host rocks, underlining the importance of greenstone belts.

The GSWA's regional regolith geochemistry program in the Fraser Range region has shown that greenstones are probably more extensively developed in the western part of the project area than previously thought. This, combined with the coincidence of elevated chalcophile-index values and regional-scale faults in the area, indicates possible areas of structurally controlled gold mineralization.

Several areas of small-scale mineralization have been reported in the Fraser Range region. A kaolinized, iron-stained rock found east of Buningtonia contained 22% graphite in veins (Doepel and Lowry, 1970b). A sample of massive psilomelane was found about 50 km northwest of Balladonia (Griffin, 1989), and low-grade manganese mineralization was found over weathered garnet gneiss of the Fraser Complex (de la Hunty, 1963; Doepel and Lowry, 1970a). All anomalous MnO values in regolith are found over the Fraser Complex, reaching a maximum of 0.39%. High MnO in regolith is especially noteworthy over unit 2. Simpson (1948) reported the occurrence of allanite and hydroallanite in pegmatite intruding rocks of the Fraser Complex. Regolith abundances of Th and U are commonly low, reaching 24.3 and 7 ppm respectively. The highest values are found in lake sediments. Simpson (1951) reported minor euxenite (YNbTi_2O_8 and $\text{Y}_2\text{Nb}_2\text{O}_8$) in pegmatite veins found in granite gneiss of the Fraser Range.

Doepel and Lowry (1970b) argued that the Fraser Complex could host base metal deposits. Despite extensive exploration for nickel and other base metals during the 1970s, no significant deposits were discovered, but sparsely disseminated copper sulfide was reported in migmatites containing hornblende and epidote within areas of faulting (Doepel, 1973). Copper and zinc values tend to be higher in regolith over greenstone-related regolith on the margin of the Yilgarn Craton, and higher lead values have been reported in lake sediments throughout the project area.

Minor disseminated chalcopyrite was found in garnet amphibolite of the Fraser Complex during nickel exploration activity in the 1970s (Griffin, 1989). Tyrwhitt and Orridge (1975) reported on Newmont's exploration activities in the Fraser Range area in the late 1960s, which included subeconomic disseminated copper-nickel sulfide mineralization associated with three mafic-ultramafic associations in the southwestern part of the Fraser Range. In the Mount Malcolm area, diamond drilling of a mafic-ultramafic association encountered <1% disseminated pyrrhotite-pentlandite and chalcopyrite. The rock association was up to 500 m thick and extended along strike for more than 1500 m. Mineralization was reported to be best developed in more highly sheared zones, where it reached 15% sulfides. The best drill intersection had 0.44% Ni and 0.12% Cu over 6 m.

Gibson (1989) discussed the PGE potential of the Fraser Complex, arguing that it bears strong lithological and chronological similarities to the Bushveld Complex of Africa. Chrome-rich rocks (i.e. >5% Cr_2O_3) associated with pyroxenite, gabbro, and anorthosite near Buningtonia Spring (approximately 100 km east of Fraser Range Homestead) returned values between 58 and 800 ppb Pt. Taking into account the mobility of platinoids under arid

conditions, Gibson (1989) argued that the relative abundances of PGEs in these rocks was similar to those of the Bushveld Complex. Gibson (1989) extended the analogy with the Bushveld Complex to include work carried out by Newmont in the Gnamma South and Talbot areas near Mount Malcolm, where he equated differentiated rocks (with zones of copper and nickel mineralization, as discussed above) as equivalent to the critical zone of the Bushveld Complex. Soil sampling by Pancontinental Mining in the Gnamma South area (reported by Gibson, 1989) returned values of 40 ppb Pt and 250 ppb Pd, along with elevated nickel and copper values.

Platinum-group element values are commonly low in regolith from the Fraser Range region, with 89% of samples returning 1 ppb Pd and 92% of samples returning <1 ppb Pt. Higher PGE values are found in regolith with high Cr, Ni, and MgO near the Jimberlana Dyke in the western part of the project area. Elevated chromium and nickel values are found over parts of the Fraser Complex, and extending northeastward from areas of known greenstone occurrences near the Claypan Fault.

Summary and conclusions

Regional-scale regolith and geochemical mapping of the Fraser Range region has involved the collection of 949 regolith samples, including 721 sheetwash, 145 lake, 46 sandplain, and 37 stream-sediment samples. This represents a nominal sampling density of 1 sample per 16 km². Each sample has been analysed for 47 components (major-element oxides and trace elements), acidity-alkalinity (pH), and total dissolved solids. These data are presented as either spot-concentration or contour maps.

A comprehensive quality-control program, using GSWA and laboratory procedures, has been carried out during the analysis of regolith samples, including the analysis of three GSWA reference standards with each batch of samples (15 in all). Laboratory standards, blanks, and repeat assays were also carried out in each batch. Thirteen samples with relatively high concentrations of various analytes were submitted to a second laboratory for repeat analysis. Precision and accuracy fell within acceptable limits for most analyses, although in some cases Nb, Cr, Bi, and Pd showed disagreement between replicate analyses, or in relation to accepted analyses for standards. This can in part be attributed to getting such elements as Nb and Cr into solution for inductively coupled plasma (ICP) analysis, and the lack of well-constrained values for precious-metal standards.

Chemical data are presented as a series of spot-concentration maps (Figs 6–49) against a background of simplified bedrock geology. Regolith chemistry is strongly influenced by the composition of the underlying bedrock, with a strong lithological contrast apparent between regolith over the Fraser Complex and the adjacent sedimentary rocks of the Eucla Basin. Regolith chemistry has indicated a larger extent of greenstones in the western part of the project area, and one sample coincident with the Proterozoic Jimberlana Dyke has the expected high

MgO, Cr, and Ni values. Variations in Na₂O and K₂O in granitoid-derived regolith in the same area suggest some compositional zonation of granitoids.

Statistical examination of regolith over the Fraser Complex partly confirms Myers' (1985) assertion about the lithological equivalence of units 2 and 4, although the regolith chemistry indicates that the westernmost unit (unit 1) is the more distinctive in having notably higher SiO₂ and lower median values for several other analytes. The remaining four lithological associations show limited variability in their regolith chemistry, although the mafic signature of unit 2 is noteworthy. Regolith derived from lithologically restricted bedrock of units 2–5 of the Fraser Complex shows little variability between different regolith landform types (*Xmm*, *Cmm*, *Cl*, and *Sl*) indicating that bedrock exerts a strong control on regolith, and downslope processes are physical rather than chemical. Bedrock control is emphasized by statistical examination of the heterogeneous sandplain unit over two different bedrock units, and east and west of the Fraser Complex.

The regolith-materials map of the Fraser Range region has used an expanded version of the GSWA's regolith-classification scheme (Hocking et al., in prep.) to account for local geomorphological and compositional conditions. Delineation of regolith types and regolith-materials boundaries was hindered by the dense and often continuous vegetation cover, and the lack of relief. More than 65% of the map area is covered by a heterogeneous sandplain unit, which has been shown to be largely of local derivation using a series of statistical tests on regolith chemistry in conjunction with interpretation of remotely sensed data. The local derivation of this unit makes it a useful sampling medium in any regional-scale geochemical program.

Major conclusions from the GSWA's regional regolith geochemistry program in the Fraser Range region are:

- Despite its nature and extensive cover, a heterogeneous sandplain unit (sandy loam) is shown to be largely of local derivation, with localized eolian input or reworking. The carbonate fraction of this and other units throughout the Fraser Range region may be of eolian input.
- Greenstone units on the margin of the Archaean Yilgarn Craton in the western part of the project area may be of greater extent than previously thought. Their proximity to regional-scale faults, and the coincidence of gold-mineralization index values with these faults presents some potential for structurally controlled gold mineralization.
- Regolith chemistry is an effective tool in characterizing the nature of underlying bedrock. The similarity in chemistry of different regolith types over areas of relatively homogeneous bedrock indicates the predominance of physical rather than chemical processes in regolith formation, and confirms field observations and deductions from remotely sensed data that the regolith cover is commonly thin throughout the project area.
- The preponderance of vegetation and the lack of relief in the Fraser Range region posed problems in

identifying regolith-materials types and delineating their boundaries. The project area also offered the first evidence for anthropomorphic effects on regolith chemistry, where the destruction of vegetation by major bushfires has destabilized the regolith, possibly leading to the winnowing of the finer fraction.

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Appendix 1

Gazetteer of localities

Locality	AMG coordinate	
	Easting	Northing
Blackbutt quarry	531234	6550637
Buningonia	551299	6521368
Chertermerlynnyer Lagoon	512575	6531374
Coonana settlement	514547	6567578
Coonana Hill	506519	6566581
Coonana prospect	506836	6564536
Cullinia Rocks	513937	6459186
Fly Dam quarry	528818	6557848
Fraser Range Homestead	481169	6455756
Fraser range 138 quarry	509300	6469200
Garnet Ice quarry	468540	6451190
Harms Lake microwave repeater station	523300	6434225
Lake Harms	507199	6434278
Lake Harris	553807	6540417
Lake Rivers	505194	6550418
Manners Flat	585593	6516279
Mount Malcolm quarry	484740	6435339
Mount Malcolm	484364	6434153
Mount Pleasant	481850	6456150
Newman Rock	516079	6446720
Peters Hole	476027	6442777
Southern Hills	483790	6437607
Spy Hill	567786	6536002
Symons Hill	502615	6477702
Ten Mile Rocks	468519	6448758
Ten Mile quarry	468385	6450321
Uraryie Rocks	539733	6549815
Wyrallinu Hill	480948	6453859
Yardilla Bore	494608	6466656
Yarrara Native Well	573120	6558225
Zanthus	554248	6566292

Appendix 2

Mines and prospects in the Fraser Range region prior to February 1999

Commodity	Mineral Field	Years mined	Mine/prospect	Tenements	Location (AMG)		Production (t)
					Easting	Northing	
Barite	Northeast Coolgardie	1946	Coonana	ML 1k	nd	nd	10.2
		1953	Coonana	MC 2k	506830	6564530	42.9
Granite	Dundas	1991–99	Fraser Range Granite	M63/234–235	484740	6435339	4 840.0

SOURCE: Department of Minerals and Energy's (DME's) unpublished records
Location information from TENGGRAPH (DME's electronic tenement graphics system)

NOTES: nd: not determined

Appendix 3

Open-file surface geochemistry for the Fraser Range region as at February 1999

Key	
ID No.:	Project reference number allocated for these notes (see Plate 3)
M No.:	GSWA project reference number An asterisk beside the M number indicates that not all the samples for the listed activities fall within the Fraser Range region; that is, the total number of samples includes some taken on adjacent sheets
I No.:	The Item number, or the Department of Minerals and Energy's (DME's) library reference number for a group of related open-file reports on microfiche. This number replaces the M number for project identification
A No.:	GSWA report reference number
Year:	The year that the report was written
Activity type:	The geochemical exploration activity (drilling details are only included if analytical samples are taken within 0–4 m depth): NGRD: Includes rock-chip, lag, costean (up to 4 m depth), and grab samples RAB: Rotary air blast drilling RC: Reverse circulation drilling SOIL: Surface or shallow soil samples SSED: Stream sediment
No.:	The number of analytical samples
Method:	The analytical method used to determine the elements listed: AAS: Atomic absorption spectroscopy BCL: Bulk cyanide leach ETA: Electron thermal atomization FA: Fire assay ICP: Inductively coupled plasma MS: Mass spectrometry NAA: Neutron activation OES: Optical emission spectrometry XRF: X-ray fluorescence
Activity elements:	The elements for which analyses were carried out
Analyst:	AAL: Australian Assay Laboratories ALS: Australian Laboratory Services CRAE: CRA Exploration Pty Ltd
DD:	A 'Y' in this column indicates deep drilling has taken place in the activity area
Comment:	Various sample details such as the sieve size fraction, sample density, detection limit (Au only), and so on, depending on the information provided in the report

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

Appendix 3. Open-file surface geochemistry

ID no.	M no.	Item no.	A no.	Year	Activity type	No.	Method	Activity elements
1	157	1429	392, 393	1966	NGRD	68		Ag,Co,Cr,Cu,Mn,Mo,Ni,Pb,V,W,Zn,Sn,Sr,Ba,P,Be,La,Y,Ce
			396-399, 400-401, 2412, 10352, 10359, 10361, 10363, 10364, 10369	1966-72	SOIL			Co,Cu,Ni,Zn
2	2692/2	1609	9914	1981	SOIL	325	AAS ICP	Ag,Co,Cu,Ni,Pb,Zn,Sn Ta,W,Nb
3	4679	3551	21138	1987	SSED	17	FA/ICP-MS	Au,Pt,Pd,Ba
				"	"		AAS	Ag,Co,Cu,Mn,Ni,Pb,Zn
				"	"		ICP	As,Cr
				NGRD	"	9	FA/ICP-MS	Au,Pt,Pd
				"	"		AAS	Ag,Co,Cu,Mn,Ni,Pb,Zn
				"	"		ICP	As,Cr
				"	"		ICP-MS	Ta,W,Ba,Nb,Be,Sn
				NGRD	"	8	FA/ICP-MS	Au,Pt,Pd
				"	"		AAS	Ag,Co,Cu,Mn,Ni,Pb,Zn
				"	"		ICP	As,Cr
				"	"		ICP-MS	Ba
4	5478/1	3727	25286	1988	SOIL	30	BCL	Au
					RAB	37	AAS	Ag,Au
5	5478/2	3730	25468/25465	1988	SOIL/SSED	228	BCL	Au
6	6069/2	6401	26429	1988	NGRD	152	FA	Au
				"	"		AAS	Ag,As,Cr,Cu,Mn,Ni,Pb,V,Zn,Ce,Nb,Sn,Ti,La,Y,Pt,Pd,Rh,Zr
				"	"		XRF	Ta,W
				RAB	"	8	ICP	Ag,As,Cr,Cu,Mn,Ni,Pb,Zn,Zr
				"	"		XRF	Bi,W,Nb,Sn,Ta,Ti,Ce,Dy,Er,Eu,Gd,La,Nd,Pr,Sm,Y
				"	"		AAS	V
				"	"		FA	Au,Pt,Pd,Rh
6a			32011	1990	SOIL	896	FA/MS	Au,Pt,Pd
				"	"		AAS/OES	Cr,Cu,Ni
				NGRD	"	23	AAS	Cr,Cu,Ni
6b			32033	1990	NGRD	3	AAS	Au
				SOIL	"	24	AAS	Au
				SSED	"	8	AAS	Au
7	6069/4	9428	52073	1997	SOIL	101	FA/ETA/AAS	As,Au,Cu,Ni
				NGRD	"	3	ETA	Au
				"	"		AAS	As,Cu,Ni
8	6158	4972	27134	1988	SOIL	112	XRF/ETA/BCL	As,Au
8a			33015	1991	SOIL	635	FA/ETA/AAS/XRF	As,Au
9	6438	3940	29243	1989	SOIL	137	BCL	Au,Ti,Sn,Nb,Ba,La,Ce,Nd,Sm,Y,Zr
				"	"		ICP-MS	As,Co,Cr,Cu,Fe,Mn,Ni,Pb,Ta,Th,V,W,Zn
				SSED	"	24	FA/AAS	Au
				"	"		AAS	Ag,Bi,Co,Cu,Fe,Mn,Mo,Ni,Pb,Zn
*10	6632	6068	20586	1989	SSED	19	FA/MS	Au,Pt,Pd
				"	"		AAS	Cu,Ni,Zn
				"	"		OES	Cr,V,Ti
				NGRD	"	33	FA/OES/NAA/MS/AAS	As,Au,Cr,Cu,Ni,V,Zn,Pt,Pd,Ir,Os,Ru,Rh,Ti
			20588	1988	NGRD	16	FA/MS/AAS/OES	Au,Cr,Cu,Ni,V,Zn,Pd,Pt,Ti
				SSED	"	22	FA/MS/AAS/OES	Au,Cr,Cu,Ni,V,Zn

survey for the Fraser Range region as at February 1999

Analyst	DD	Comment on samples
		Rock chip samples
	Y	Results of Cu and Ni analyses reported as profiles along grid lines, samples analysed for a further 21 elements, but these results not reported
Pilbara Laboratories Pty Ltd	Y	
Analytical Services Pty Ltd		DL: 1 ppb, Mesh: -80#, heavy mineral fraction S.G. > 2.9
"		
"		Rock chip samples, DL: 1 ppb
"		
"		Pisolite, DL: 1 ppb, W: 50 g
"		
"		
Analytical Services Pty Ltd	Y	DL: 1 ppb
Genalysis		DL: 0.01 ppm, D: 0-5 m
Analytical Services Pty Ltd		DL: 0.1 ppb
ALS	Y	Rock chip, DL: 0.01 ppm, W: 1-3 kg
"		
"		
"		
Genalysis		DL: 1 ppb, D: 0.2 m, Mesh: -80#
ALS / Genalysis		Rock chip samples
ALS		Rock chip samples, DL: 1 ppb, 0.1 ppm
"		Mesh: -1 mm, DL: 1 ppb and 1 ppm, 200 m interval along baseline, assay results given in the form of profiles along sampling lines
"		Mesh: -80#, DL: 1 ppb and 1 ppm
Genalysis		DL: 1 ppb, Mesh: -80#, -6 mm + 2 mm, W: 0.5 kg
"		Rock chip, DL: 1 ppb
"		
Analabs / Genalysis / ALS	Y	DL: 1 ppb, D: 0.5-1.0 m, W: 1.5 kg
ALS / AAL		DL: 1 ppb
Sheen Analytical Services (WA) Pty Ltd		DL: 1 ppb, Grid: 2.5 x 1.0 km and 1000 x 500 m
"		
Genalysis		Mesh: +2.0 mm, 2.0 - 0.4 mm, 0.4 - 177.0 mm, +177.0 mm
"		
Genalysis		DL: 1 ppb, Mesh: -80#
"		
"		
Beckeral / Analabs / Genalysis		Rock chip samples, DL: 2 ppb, repeat analyses for Pt, Pd, Rh
Genalysis	Y	Rock chip, DL: 1 ppb
"		Mesh: -80# and -2 mm, Poor sample location

ID no.	M no.	Item no.	A no.	Year	Medium	No.	Method	Activity elements
11	6881/3	7757	35611	1992	SSED	6	BCL	Au
					SOIL	60	FA	Au
					"		ICP	Ag,As,Bi,Cu,Pb,Sb,Zn
					NGRD	6	FA	Au
					"		ICP	Ag,As,Bi,Cu,Pb,Zn
11a			38397	1993	SOIL	155	BCL	Au
					"		XRF	As
			41702	1994	SOIL	1138	AAS	As,Au
					RAB	148	AAS	Au
12	6881/4	8082	44852	1995	SOIL	45	FA	Au
					NGRD	7	FA	Au
			43604	1995	SOIL	45	FA	Au
13	8564	7864	43351	1994	SOIL	25		Ag,As,Au,Bi,Co,Cr,Cu,Fe,Mn,Mo,Ni,Pb,Sb,Ta,U,V,W,Zn, P,Ti,Zr,Nb,Sn,Ba,Pt,Pd
					SOIL	25		
					RC	7		Ag,As,Au,Bi,Co,Cr,Cu,Fe,Mn,Mo,Ni,Pb,Sb,Ta,U,V,W,Zn, P,Ti,Zr,Nb,Sn,Ba,Pt,Pd
14	9614	8622	45202	1995	SOIL	71	ICP	Ag,As,Au,Bi,Co,Cr,Cu,Fe,Mn,Mo,Ni,Pb,Ta,V,W,Zn,K,Li, Na,P,Sc,Sn,Pt,Pd,Nb,Be,Ba,Ca,La,Ti, Al,Y,Sr,Ga,Mg,Zr,Cd
15	9652/2	9379	51681	1997	SOIL	949	ICP-MS	Ag,As,Au,Cu,Mo,Ni,Pb,Zn,Sn,Ba,Cd
					RAB	50	ICP-MS/OES	Ag,As,Au,Cu,Mn,Pb,Zn
16	9968	8493	46918	1996	SOIL	392	FA	Au
					"		ICP	Ag,As,Bi,Cu,Fe,Mn,Mo,Ni,Pb,Sb,Zn,Mg,Ca

(continued)

Analyst	DD	Comment on samples
ALS	Y	DL: 50 ppt, W: 3–4 kg
"		DL: 1 ppb, 59 samples from 10 sites, Mesh: +2 mm, -2 mm, 2 mm + 0.5 mm, -0.5 mm + 0.25 mm, and -0.25 mm
"		Rock chip, DL: 0.01 ppm
"		
Classic Laboratories		DL: 0.05 ppb, Mesh -2 mm + 0.5 mm, Grid: 400 × 200 m
"		
Analabs	Y	DL: 1 ppb, D: 0–1 m, Grid: 200 × 50 m, W: 500–750 g, Results as profile
"		DL: 1 ppb
Amdel		DL: 1 ppb, Mesh: -2 mm, Sample location by GPS, Some infill sampling
Amdel		Rock chip, DL: 0.1 ppm
Amdel		Mesh: -2 mm, Grid: 500 × 500 m (triangular), DL: 1 ppb
Analabs	Y	DL: 1 ppb, W: 1 kg
CRAE		W: 18 kg, Mesh: -2 mm, Loam samples observed to +0.25 mm for pyrope and chromite.
Analabs		DL: 1 ppb, D: 0–4 m
AAL		DL: 1 ppb, D: 0.1 – 1.0 m, Grid: 100 m intervals along 3 baselines 1 km apart
Ultra Trace	Y	DL: 1 ppb, Mesh: -2mm, Grid: 800 × 100 m
"		DL: 1 ppb, D: 0–4 m
ALS		DL: 1 ppb, Grid: 1000 × 400 m
"		

Appendix 4

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

In areas of active sand dunes, sandplain samples are taken from 3 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 4.1. At each sampling site, the sample's AMG coordinates (Ausgeo84 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. Abundant: >30%; Common: 5–30%; Rare: 1–5%; Trace: <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 according to its position in an idealized landform profile as relict (R), erosional (E), or depositional (D). Relict-regime regolith is usually found 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

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

Sheet <u>AFB</u>	Zone <u>51</u>	Loc/n No _____	GSWA No _____	Date _____
Site Ref _____	_____ E		_____ N	
Photo Y/N (Describe) _____				
<div style="display: flex; justify-content: space-between;"> Gravity G1 G2 </div>				
Channel <input type="checkbox"/>	Pit/Hole <input type="checkbox"/>	Single point <input type="checkbox"/>	Multipoint <input type="checkbox"/>	Shtwsh Creek Soil Lake Sand
Site Description:				
CLASTS	Gravel (2-5 mm) <input type="checkbox"/>	Stones (5-64 mm) <input type="checkbox"/>	Surrounding Regolith Code: Left _____ Right _____	
	cobbles (64-256 mm) <input type="checkbox"/>	Boulders (>256 mm) <input type="checkbox"/>		
Abundant : >30%		Common : 5-30%	Rare : 1-5%	Trace : <1%
Iron-rich Abnt/Comm/Rare/Tr <input type="checkbox"/>		Lithic Abnt/Comm/Rare/Tr <input type="checkbox"/>		Regolith Description:
<input type="checkbox"/> Pisoliths		<input type="checkbox"/> Saprolite fragments		
<input type="checkbox"/> Nodules <input type="checkbox"/> Ferrig/ granules		<input type="checkbox"/> Ferruginous Saprolite fragments		
<input type="checkbox"/> Ferrug. duricrust		<input type="checkbox"/> Saprock fragments		
<input checked="" type="checkbox"/> Gossan fragments		<input type="checkbox"/> Fresh b'rock fragments (below)		
<input type="checkbox"/> Ferrug. Lithic fragments		<input type="checkbox"/> Vein quartz <input type="checkbox"/> Other silica		
Non-lith Abnt/Comm/Rare/Tr <input type="checkbox"/>		Clast lithology		
<input type="checkbox"/> Quartz (sand) <input type="checkbox"/> Feldspar		<input type="checkbox"/> Mafic	<input type="checkbox"/> BIF	<input type="checkbox"/>
<input type="checkbox"/> Calcrete		<input type="checkbox"/> Ultramafic	<input type="checkbox"/> Sandstone	<input type="checkbox"/>
<input type="checkbox"/> Hardpan		<input type="checkbox"/> Felsic	<input type="checkbox"/> Ark / Gwk	
<input type="checkbox"/> MnO ₂		<input type="checkbox"/> Granite	<input type="checkbox"/> Shale/Siltstone	
<input type="checkbox"/> Silcrete <input type="checkbox"/> Other _____		<input type="checkbox"/> Quartzite	<input type="checkbox"/> Chert	
Secondary coating		<input type="checkbox"/> Fe / Mn	<input type="checkbox"/> Siliceous	<input type="checkbox"/> Calcareous <input type="checkbox"/> Clay
-2 mm Material <input type="checkbox"/> Sand (0.1-2 mm) <input type="checkbox"/> Clay <input type="checkbox"/> Other _____ Colour _____				
Rock O/c	Dist.	Dir.	Secondary Units Nearby	
1. _____ m	_____ m	_____	Hardpan <input type="checkbox"/> Consolidated colluvium <input type="checkbox"/>	Heading _____ Width _____ m
2. _____ m	_____ m	_____	Calcrete <input type="checkbox"/> Duricrust <input type="checkbox"/>	<input type="checkbox"/> Single <input type="checkbox"/> Braided <input type="checkbox"/> Incised
3. _____ m	_____ m	_____	Mot zone <input type="checkbox"/> Saprolite <input type="checkbox"/> Saprock <input type="checkbox"/>	Sieved to size: Y/N Depth: _____
4. _____ m	_____ m	_____	Gyps dune <input type="checkbox"/> Sand dune <input type="checkbox"/> Salt <input type="checkbox"/>	0size: _____ % Usize: _____ %

REMARKS: _____

Figure 4.1. Sample-recording form Albany-Fraser belt

Table 4.1. 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	

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's 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 had drawbacks, in that it only worked well for lithologically simple map sheets, relied on a qualitative determination of slope position, and required identification of the parent rock type to indicate the composition of regolith — the latter was often 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 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 4.1). 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 4.1)

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 implemented 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_gmv_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 4.2 to 4.5. The regolith codes used for the Fraser Range region regolith map are summarized in Table 4.6.

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,

Table 4.2. Revised primary regolith codes

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

Table 4.3. Examples of primary code qualifiers

Primary landform/process	Landform element or pattern	Suggested primary code	Suggested subscript code
Colluvial (proximal slope)	Landslide	C	C _l
Wash (sheet-flood, distal slope)	Playa, pan	W	W _p
Floodplain	Delta	F	F _d
	Alluvial plain		F _p
Alluvial	Stream channel	A	A _c
	Delta		A _d
	Alluvial fan		A _f
	Gravel bar		A _g
Lacustrine	Fringing dunes	L	L _d
	Fringing bedded deposits		L _g
	Dune and playa terrain		L _m
	Lake, excluding fringing deposits		L _l
	Playa, pan		L _p
Eolian	Dunefield	E	E _d
	Dune		E _e
	Longitudinal dunefield		E _l
	Mobile dune		E _m
	Interdune pavements		E _p
	Lunette		E _u
Sandplain, residual, uncertain, and mixed	Gravel deflation pavement	S	S _p
Wave-dominated coastal (beach)	Beach (foreshore)	B	B _f
	Mobile dunes		B _m
Tide-dominated coastal	Tidal bar, in channel	T	T _b
	Tidal delta		T _d
	Estuary		T _e
	Lagoon		T _l
Marine	Coral reef	M	M _r

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 consensus or recommended values. In the GSWA regional regolith and geochemical mapping program, precision is deemed acceptable if the percent relative standard deviation ($RSD\% = (\text{standard deviation}/\text{mean}) \times 100$) 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 will be used to assess replication, with a value of 10% deemed acceptable. The HRD factor = $((\text{assay \#1} - \text{assay \#2}) / (\text{assay \#1} + \text{assay \#2}) \times 100$; Shaw et al., 1998).

Accuracy is assessed using GSWA and laboratory standard analyses, with acceptable accuracy being 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.

Table 4.4. Revised secondary codes and qualifiers

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

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 SiO₂ 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 SiO₂ range of 7% to 96% for regolith on the NABBERU 1:250 000 sheet — and the concentration of resistate phases (e.g. rutile, chromite, and zircon) lower in the landform profile, it is unlikely that one preparation or analytical technique is suitable for all samples. Morris et al. (1998) discussed this

problem with regard to analysis of niobium on the MOUNT EGERTON and TUREE CREEK 1:250 000 sheets. They concluded that precise and accurate analysis of high field strength elements such as niobium was difficult, as these elements were often found in resistate phases, such as rutile, which were 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 <100 ppm, data are reported after mixed acid digestion and inductively coupled plasma mass spectrometric (ICP-MS) analysis; for values of >100 ppm, data are reported following fusion and mixed acid digest and inductively coupled plasma

Table 4.5. Revised tertiary codes and qualifiers for parent rock or cement type

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

Table 4.6. Summary of regolith-landform classification codes, Fraser Range region

<i>Regolith code</i>	<i>Description</i>
Residual (R)	Includes duricrust, proximal, and reworked material
<i>Rf</i>	ferricrete and ferruginous lag
<i>Rz</i>	silcrete
Exposed (E)	Includes saprock, bedrock, and subcrop with locally derived sand, silt, clay, and rubble
<i>Xgm</i>	derived from quartzofeldspathic metamorphic rock
<i>Xgm_p</i>	derived from quartzofeldspathic metamorphic rock (dominantly pelitic)
<i>Xgp</i>	derived from quartzofeldspathic plutonic rock
<i>Xls</i>	derived from various sedimentary rocks
<i>Xmh</i>	derived from ferromagnesian hyperbyssal rock (dykes)
<i>Xmm</i>	derived from ferromagnesian metamorphic rock
<i>Xqs</i>	derived from quartz-rich siliciclastic sedimentary rock
<i>Xu</i>	derived from ultramafic rock
Colluvial (C)	Includes unconsolidated and semiconsolidated clay, silt, sand, gravel, and rubble; small rock outcrops locally present
<i>Cf</i>	iron rich
<i>Cg</i>	derived from quartzofeldspathic material
<i>Cgm</i>	derived from quartzofeldspathic metamorphic rock (dominantly pelitic)
<i>Cgp</i>	derived from quartzofeldspathic plutonic rock
<i>Cmh</i>	derived from ferromagnesian hyperbyssal rock (dykes)
<i>Cmm</i>	derived from ferromagnesian metamorphic rock
<i>Cqs</i>	derived from quartz-rich siliciclastic sedimentary rock
<i>Cu</i>	derived from ultramafic rock
<i>Cl</i>	dominated by transported residual and eolian sand, silt, and clay in colluvial/sheetwash or alluvial deposits (various sources) (referred to in Explanatory notes as heterogeneous colluvium)
Distal sheetwash	
<i>W</i>	Sand- and clay-dominated colluvium or sheetwash
Fluvial	
<i>A</i>	Cobbles, gravel, sand and silt active alluvial channels
Lacustrine	
<i>L</i>	Sand, silt, clay and evaporitic material in playas; saline and gypsiferous locally
<i>L_m</i>	Sand, silt, clay and evaporitic material in mixed playa and dune terrain; saline and gypsiferous locally; may include areas of residual sand, silt, and clay
Sandplain (S)	
<i>Sl</i>	Residual and eolian sand, silt, and clay in variable proportion with local areas of colluvium; includes ferruginous and calcareous soil

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 the EDMUND (Pye et al., 1998) and GLENBURGH (Sanders et al., 1998) 1:250 000 sheets. In both cases, gold at levels of <4 ppb (detection level of 1 ppb) were subject to batch control.

Quality-control data for regolith of the Fraser Range region are presented as a series of digital datafiles on the accompanying floppy disk. A guide to this list of datafiles is shown in Table 4.7. For GSWA standards, the consensus values are taken as averages of analyses carried out at individual laboratories during the course of the GSWA regolith program. Consensus values for laboratory standards have been provided by the respective laboratories.

Typical analytical schemes from two commercial laboratories are outlined below.

Genalysis Laboratory Services

All regolith samples were oven dried at GSWA's Carlisle base in Perth. 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 SiO₂, TiO₂, Fe₂O₃, Al₂O₃, MnO, MgO, K₂O, and Cr), or a chrome-steel jumbo ring mill (for analysis of CaO, Na₂O, P₂O₅, 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).

Forty-eight components were measured for each sample, comprising 10 oxides in percent (SiO₂, TiO₂, Fe₂O₃, Al₂O₃, MnO, MgO, CaO, Na₂O, K₂O, P₂O₅), 33 trace elements as parts per million (Ag, As, Ba, Be, Bi, Cd, Ce, Co, Cr, Cu, Ga, In, La, Li, Mo, Nb, Ni, Pb, Rb,

Table 4.7. Index to quality-control data

<i>.CSV file</i>	<i>Folder</i>	<i>Description</i>
Fablk	fire assay	fire assay blank data, method FA3
Farep		fire assay replicate data, method FA3
Farpt		fire assay repeat analysis data, method FA3
Fapm7		fire assay standard data, PM7, method FA3
Fapm8		fire assay standard data, PM8, method FA3
Ic3ebk	ic3e	blank data, method IC3E
Ic3edup		duplicate data, method IC3E
Ic3e42p		OREAS_42P standard data, method IC3E
Ic3e43p		OREAS_43P standard data, method IC3E
Ic3e44p		OREAS_44P standard data, method IC3E
Ic3mbk	ic3m	blank data, method IC3M
Ic3mdup		duplicate data, method IC3M
Ic3m42p		OREAS_42P standard data, method IC3M
Ic3m43p		OREAS_43P standard data, method IC3M
Ic3m44p		OREAS_44P standard data, method IC3M
Ic4bk	ic4	blank data, method IC4
Ic4dup		duplicate data, method IC4
Ic442p		OREAS_42P standard data, method IC4
Ic443p		OREAS_43P standard data, method IC4
Ic444p		OREAS_44P standard data, method IC4
Ic4mbk	ic4m	blank data, method IC4M
Ic4mdup		duplicate data, method IC4M
Ic442p		OREAS_42P standard data, method IC4M
Ic443p		OREAS_43P standard data, method IC4M
Ic444p		OREAS_44P standard data, method IC4M
Gswastd	gswa standards	analyses of three GSWA standard materials
Labcomp	amdel–genalysis comparison	comparison of analyses, Amdel and Genalysis

Sb, Sc, Se, Sn, Sr, Ta, Te, Th, U, V, W, Y, Zn, and Zr), three ultra-trace elements as parts per billion (Au, Pd, and Pt), one anion as percent (S), and loss on ignition (LOI) as percent.

Seven different analytical methods were used:

1. Ag, 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 hydrofluoric–multi-acid digestion (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. MnO, Na₂O, P₂O₅, Cr, Cu, Ni, Sc, V, and Zn were analysed by ICP-OES using a combined hydrofluoric–multi-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 dilute hydrochloric acid.
3. SiO₂, TiO₂, Al₂O₃, Fe₂O₃, MgO, CaO, K₂O, 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 to dissolve the melt (Genalysis code DX/OES).

4. Nb, 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 to dissolve the melt (Genalysis code DX/MS).
5. The precious metals Au, Pd, and Pt were analysed by fire-assay lead collection and ICP-MS analysis (Genalysis code FA*MS).
6. Se was analysed by precipitation of selenium metal followed by aqua-regia digestion and ICP-MS analysis (Genalysis code A*MS).
7. Loss on ignition was determined by gravimetric means (Genalysis code GRAV).

Amdel Laboratories

All regolith samples were oven dried at GSWA's Carlisle base in Perth. Approximately 2 kg of each sample (either sieved to <2 mm or to <6 mm) was supplied to the laboratory. Following oven drying, an aliquot of each sample was sieved to between 2 and 0.45 mm. This material was pulverized to <75 mm 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 Cu, Pb, Zn, Ni, Mo, Co, or V.

Forty-eight components were measured for each sample, comprising 11 oxides in percent (SiO_2 , TiO_2 , Al_2O_3 , Fe_2O_3 , FeO , MnO , MgO , CaO , Na_2O , K_2O , and P_2O_5), 32 trace elements as parts per million (Ag, As, Ba, Be, Bi, Cd, Ce, Co, Cr, Cu, Ga, In, La, Li, Mo, Nb, Ni, Pb, Rb, Sb, Sc, Se, Sn, Sr, Ta, Th, U, V, W, Y, Zn, and Zr), three ultra-trace elements as parts per billion (Au, Pd, and Pt), one anion as percent (S), and loss on ignition (LOI) as percent.

Six analytical methods were used:

1. SiO_2 , TiO_2 , Al_2O_3 , Fe_2O_3 , FeO , 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, Sb, Se, Sn, Sr, Th, U, W, Y, and Zr 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). Chromium values of <100 ppm are reported using this method, whereas concentrations of >100 ppm are reported from ICP-OES analysis (Amdel code IC4).
3. Barium, Be, Li, S, 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, then analysed by graphite furnace atomic absorption spectroscopy (AAS; Amdel code FA3).
6. Loss on ignition 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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4. Geology of the Fraser Complex
5. Generalized regolith interpretation

Element-distribution and other maps

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8. Fe_2O_3
9. MnO
10. MgO
11. CaO
12. Na_2O
13. K_2O
14. P_2O_5
15. LOI
16. Ag
17. As
18. Au
19. Ba
20. Be
21. Ce
22. Co
23. Cr
24. Cu
25. Ga
26. In
27. La
28. Li
29. Mo
30. Nb
31. Ni
32. Pb
33. Pd
34. Pt
35. Rb
36. S
37. Sb
38. Sc
39. Se
40. Sn
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54. Distribution of sample sites with calcrete as a secondary unit nearby
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56. Regolith acidity-alkalinity (pH)

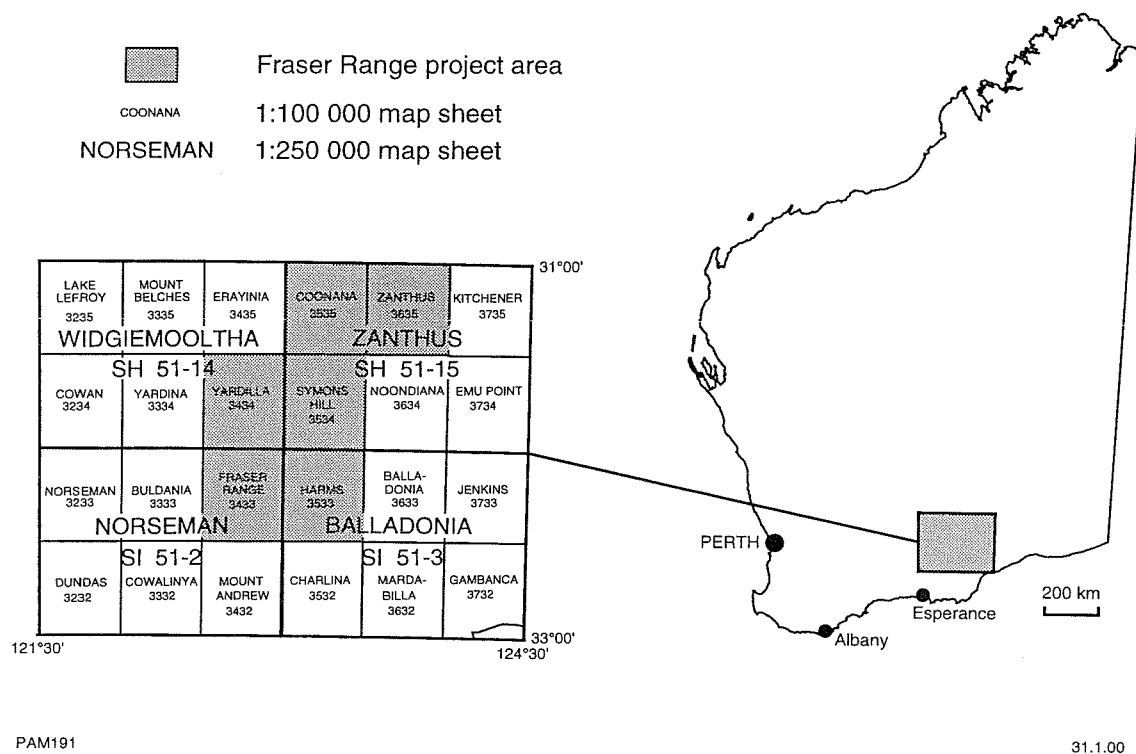
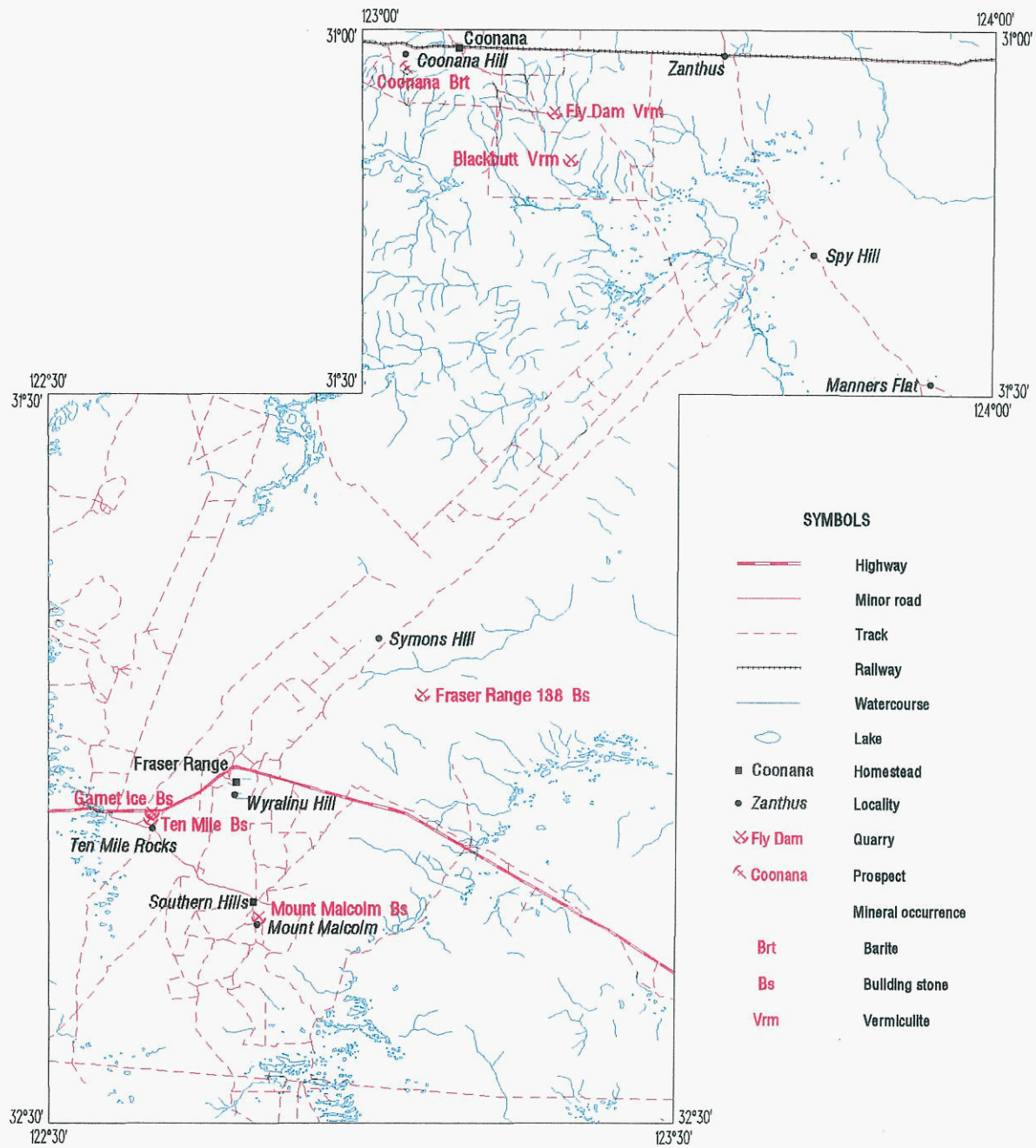


Figure 1. Location of the Fraser Range project area in Western Australia

SIMPLIFIED LOCALITY PLAN



FRASER RANGE REGION

First Edition 2000

Figure 2

GENERALIZED GEOLOGICAL INTERPRETATION

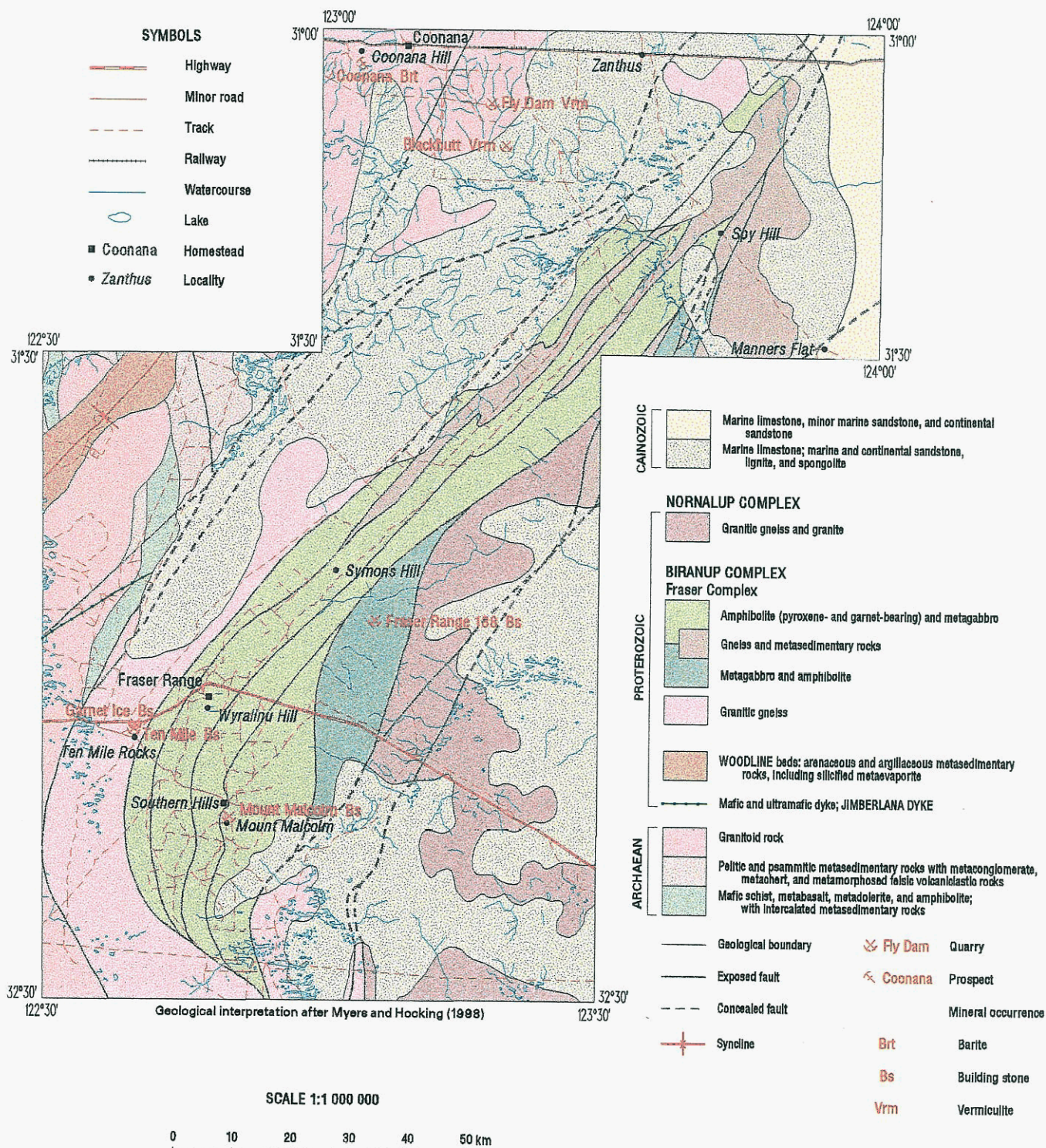


Figure 3

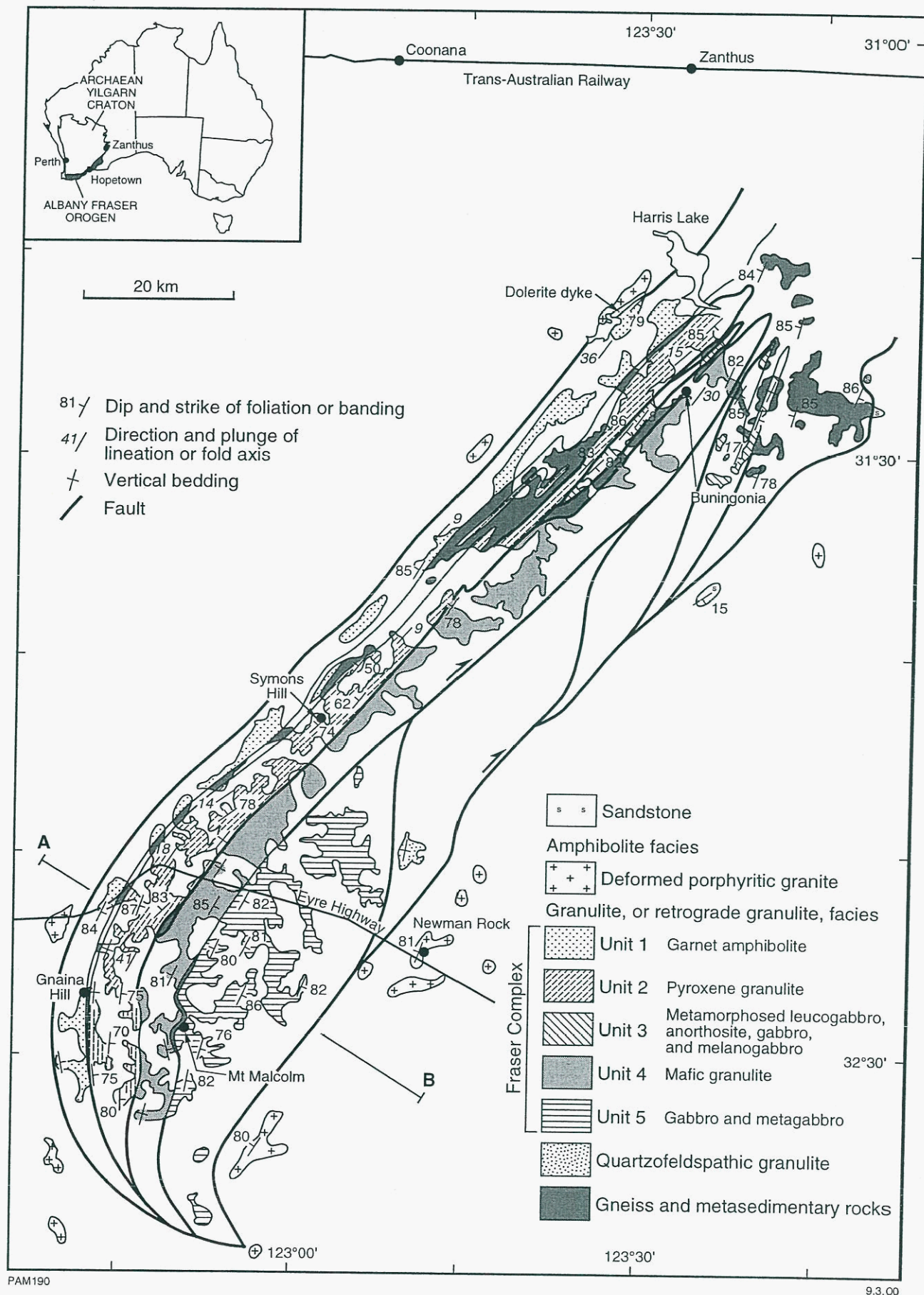
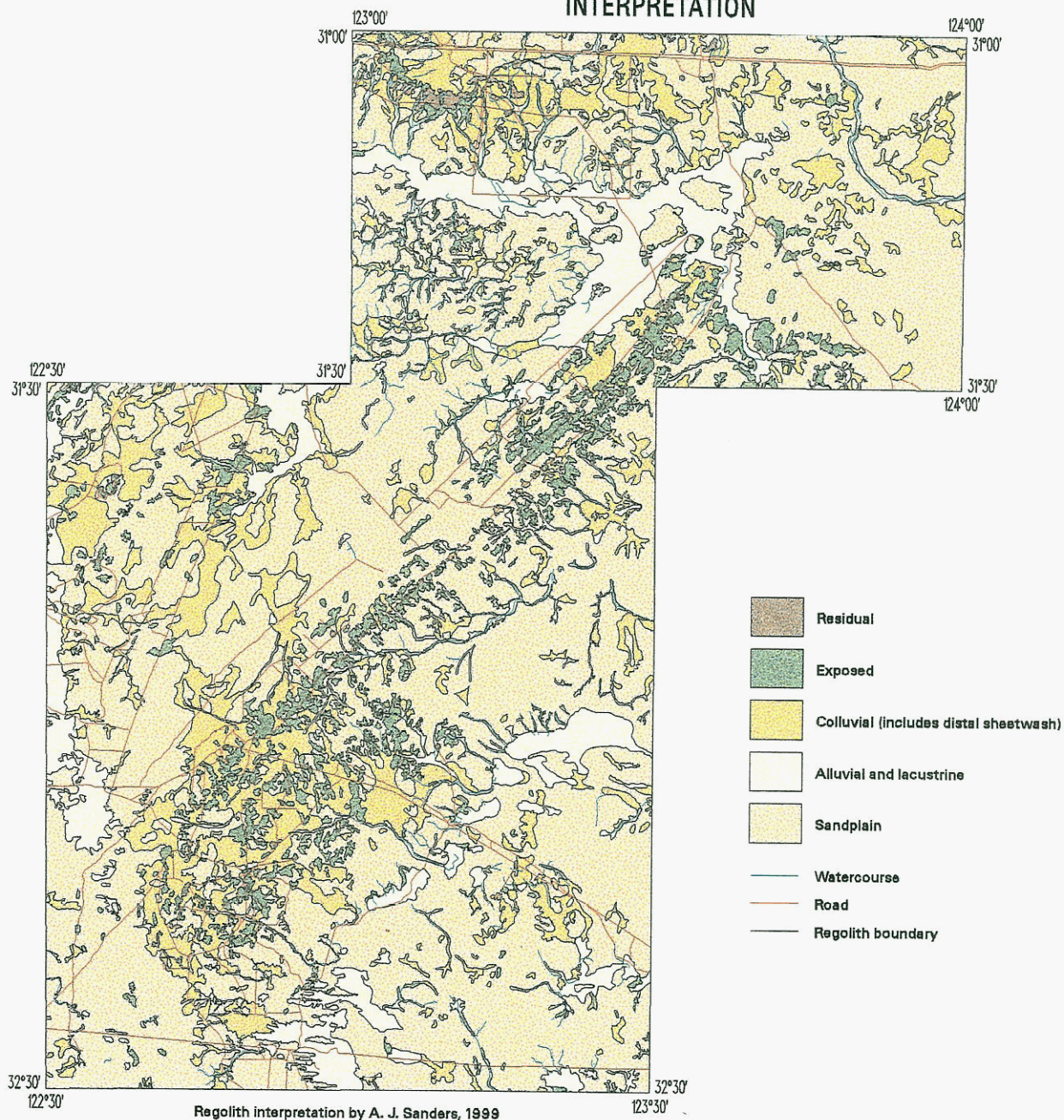


Figure 4. Geology of the Fraser Complex, after Myers (1985)

GENERALIZED REGOLITH INTERPRETATION



SCALE 1:1 000 000

0 10 20 30 40 50 km

FRASER RANGE REGION

First Edition 2000

Figure 5

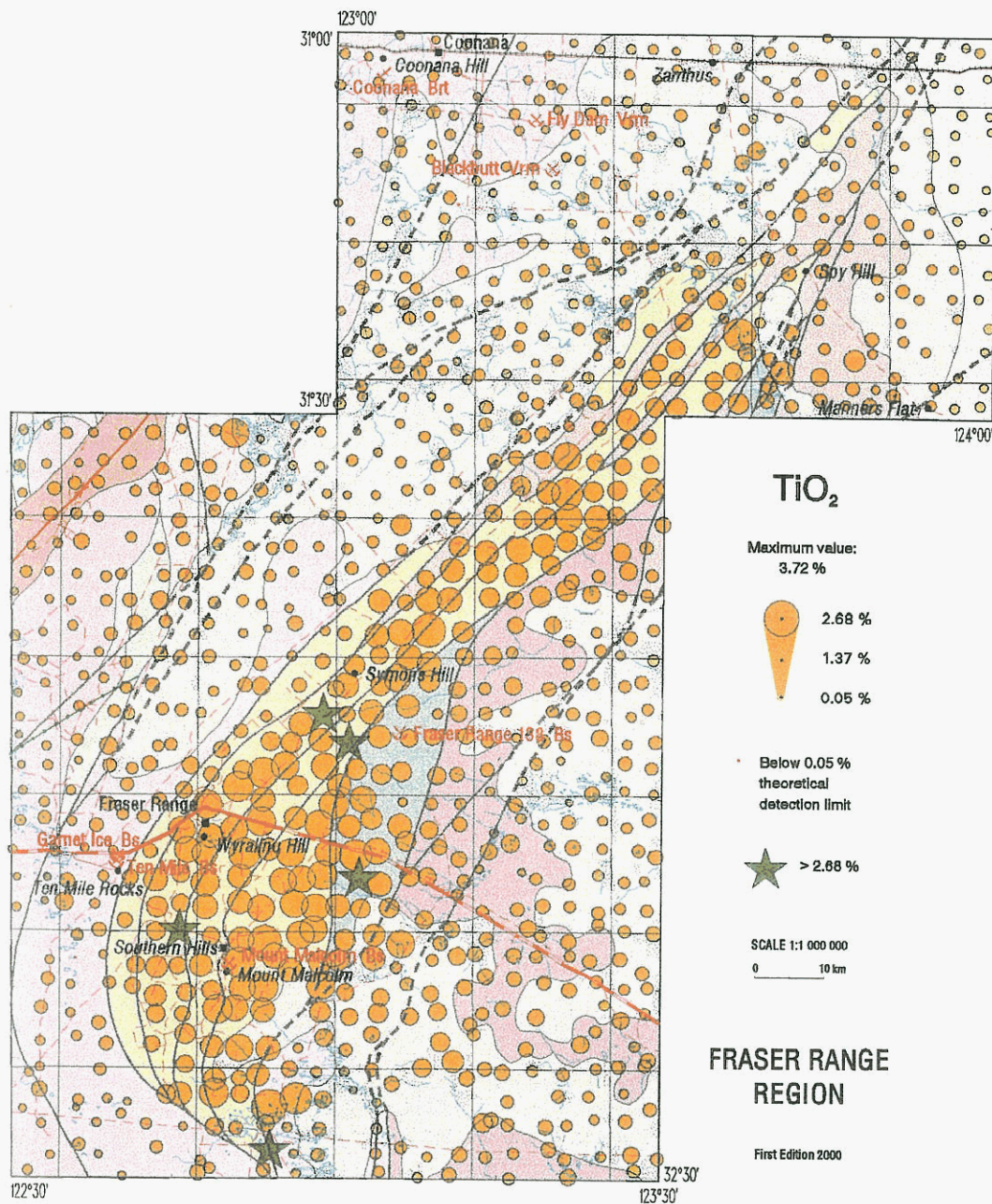


Figure 6

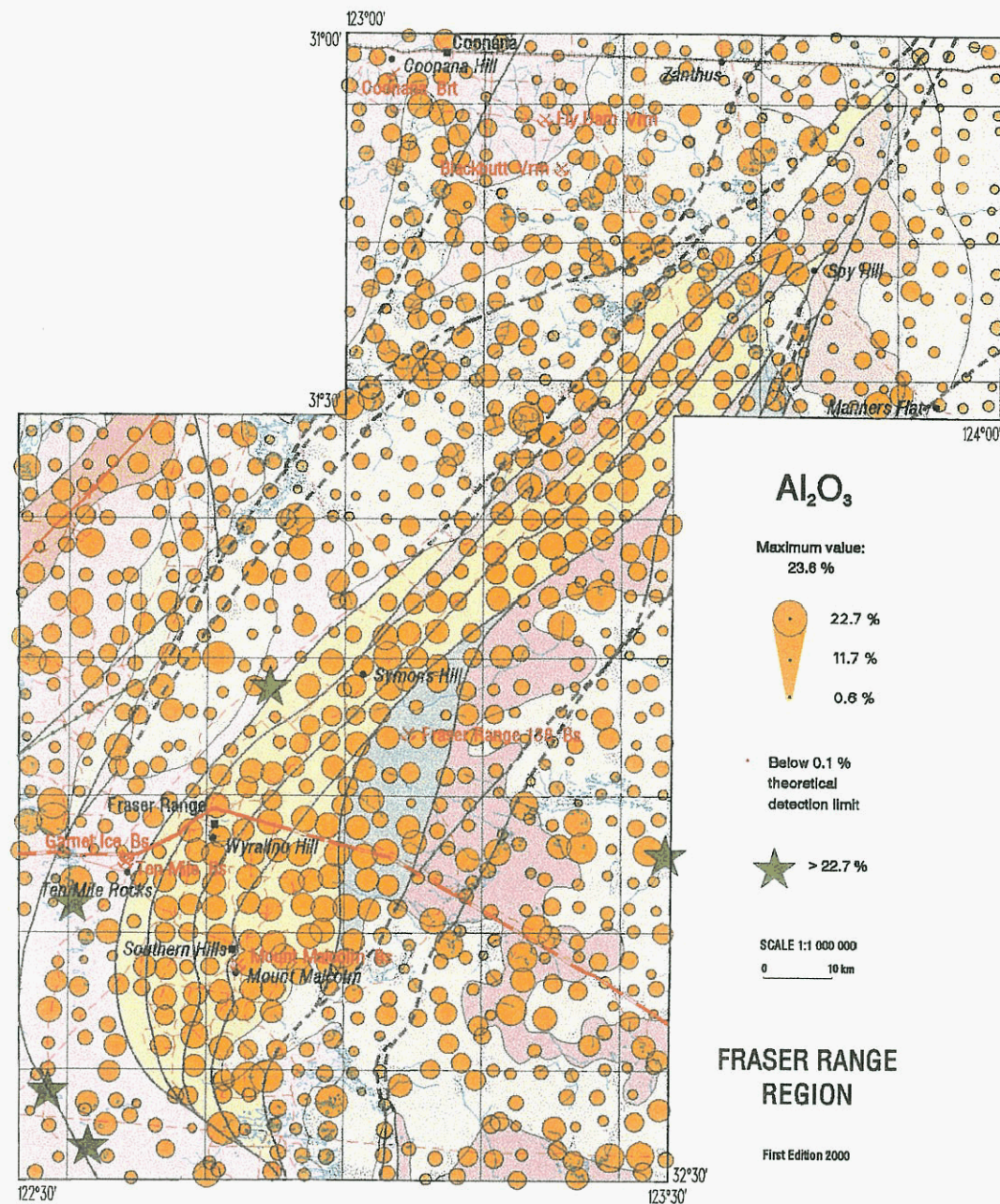


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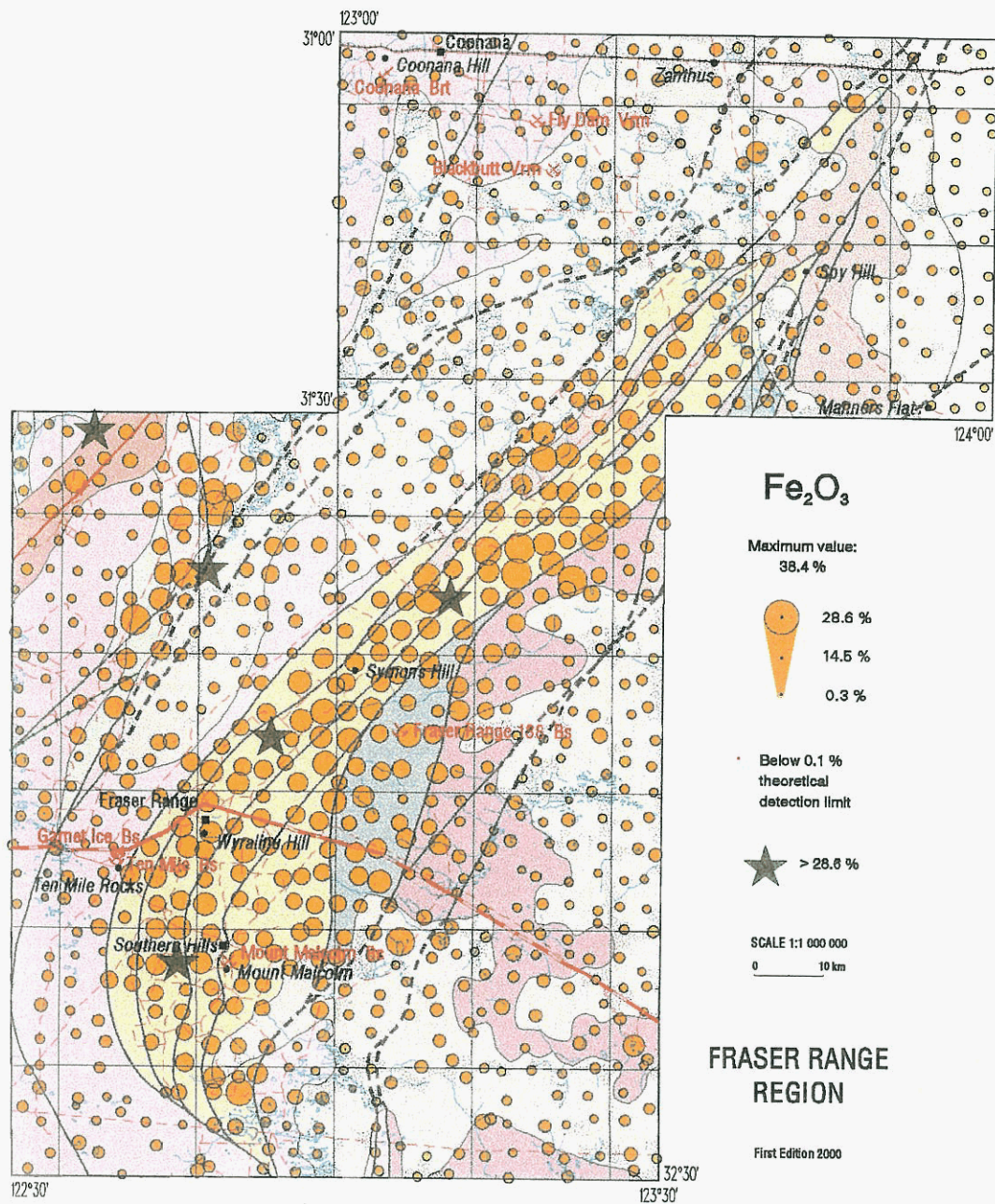


Figure 8

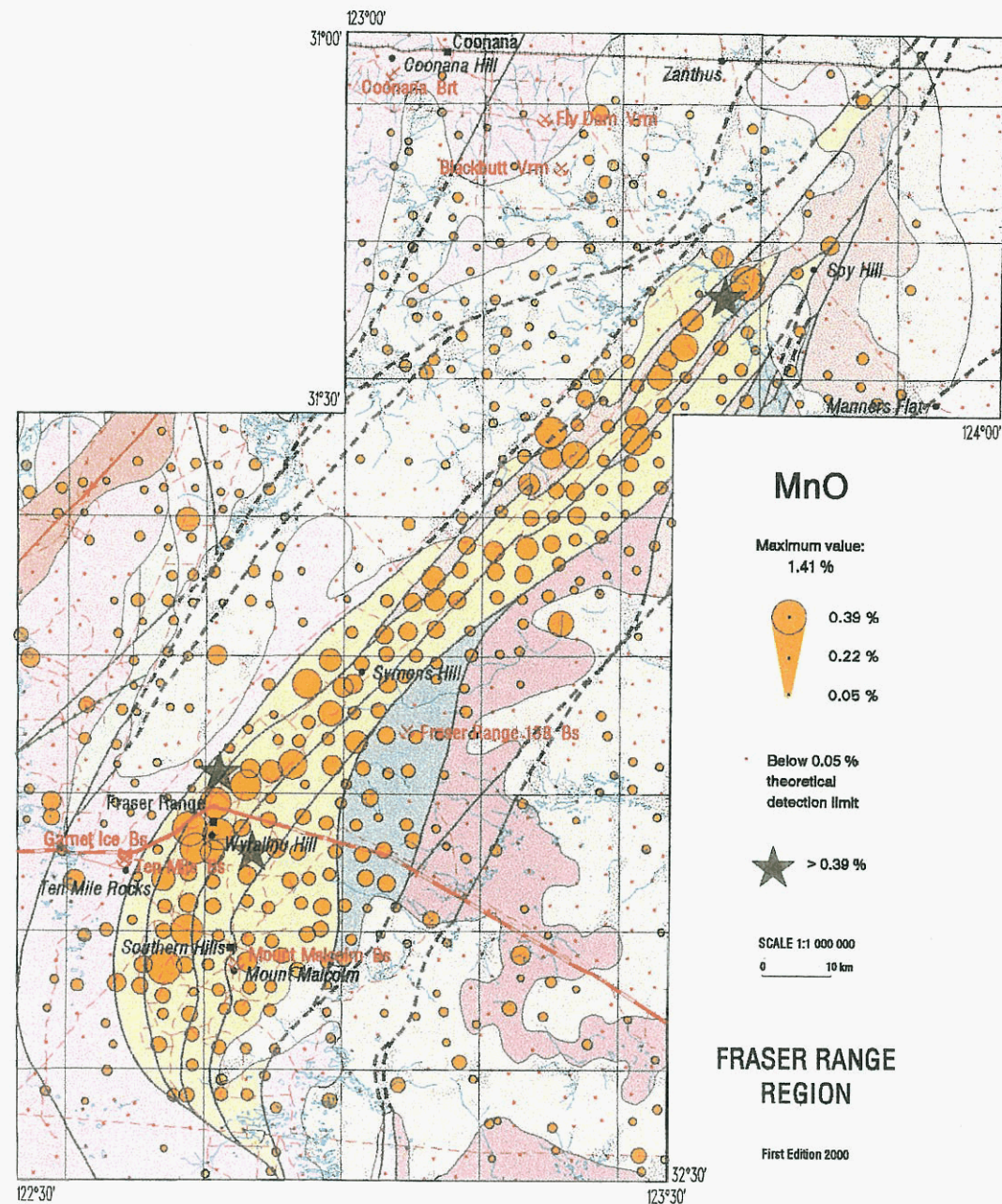


Figure 9

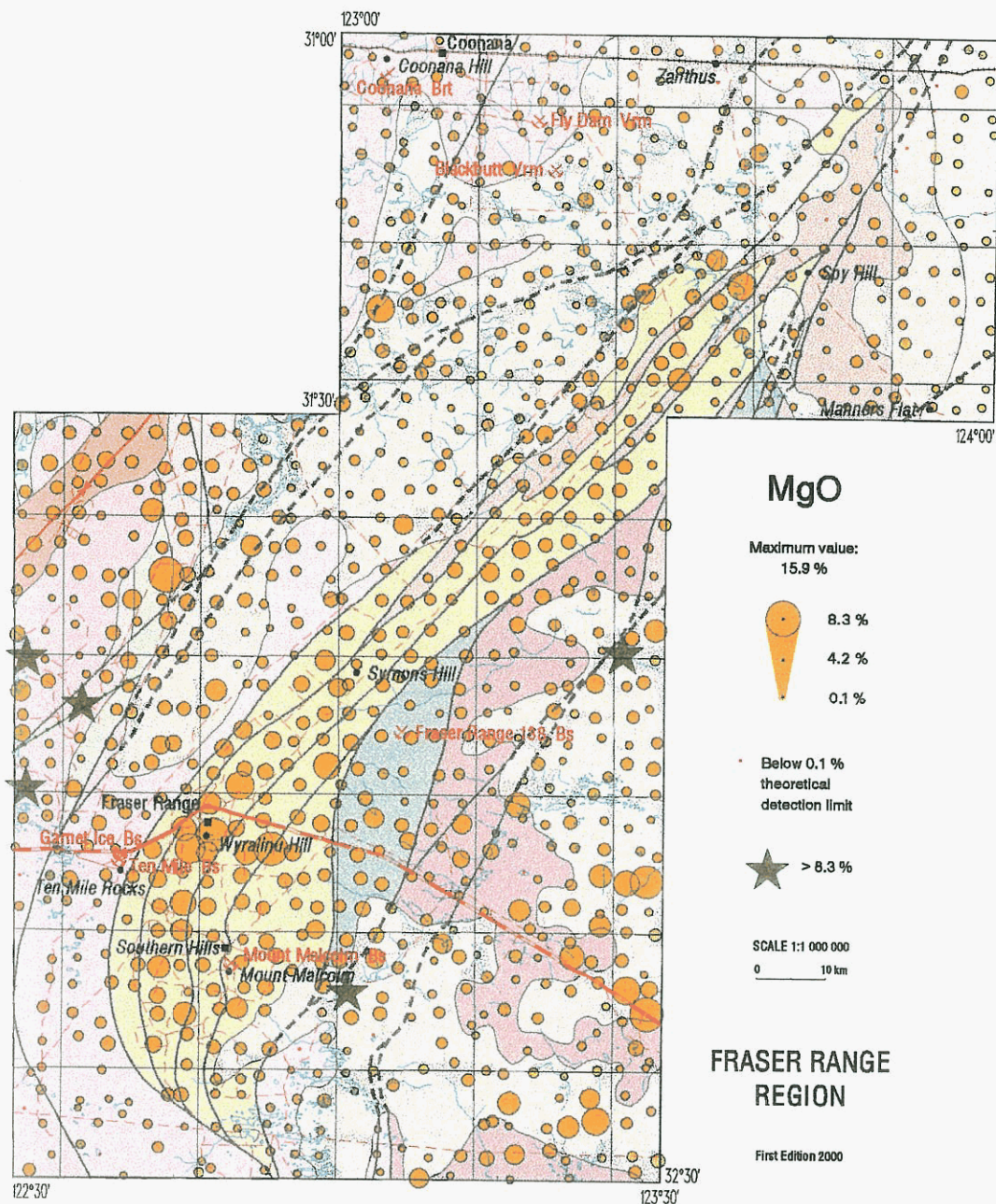


Figure 10

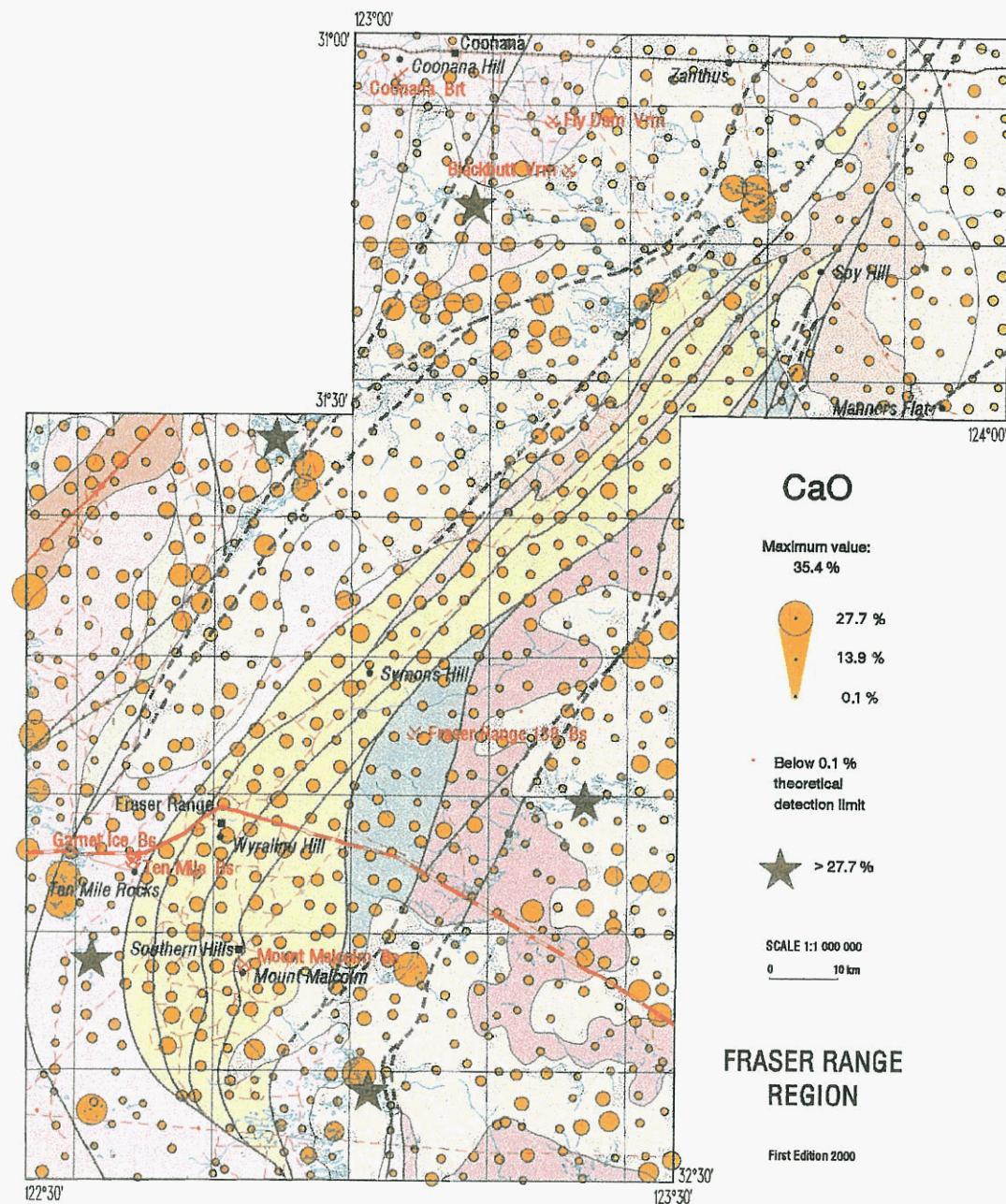


Figure 11

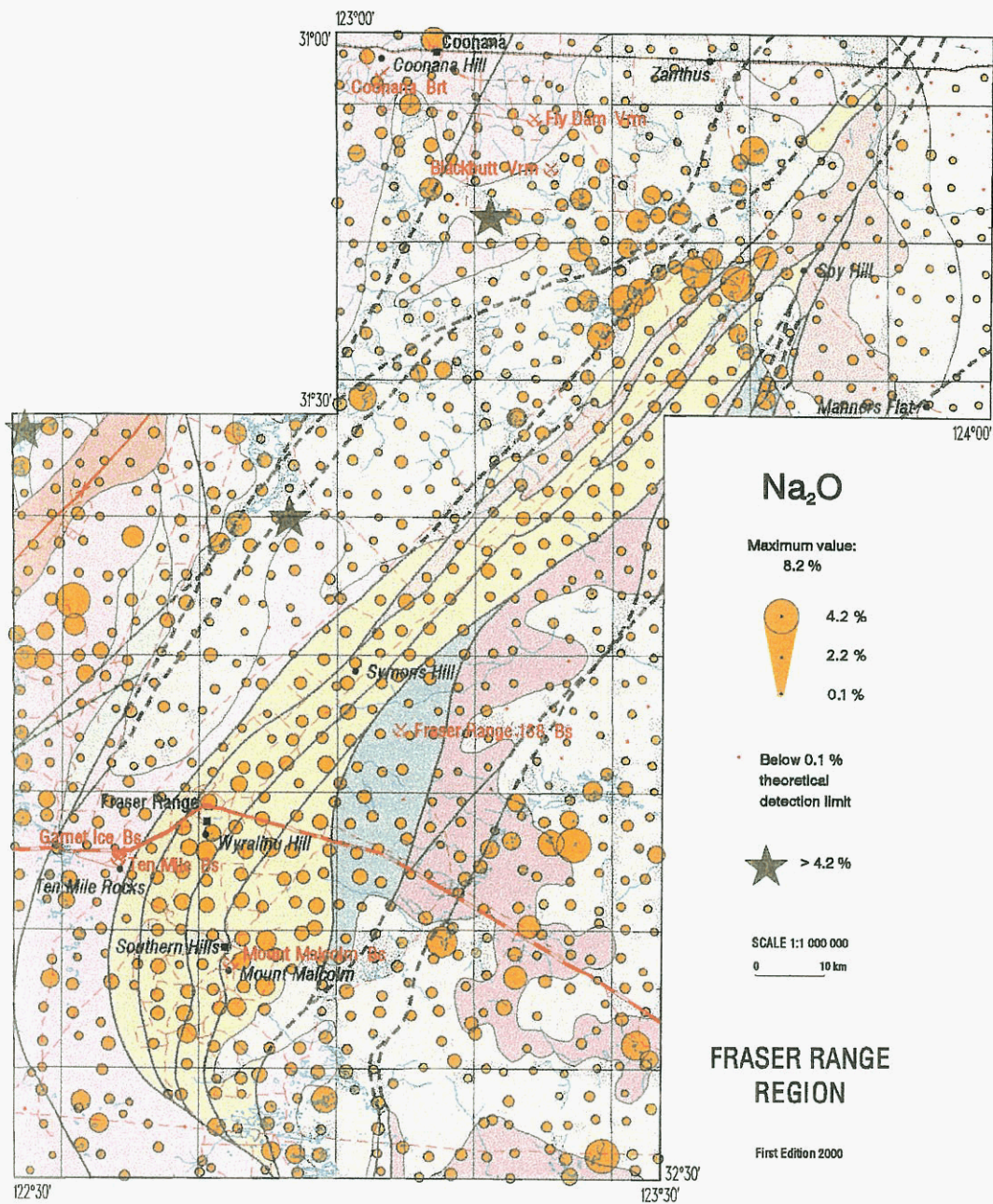


Figure 12

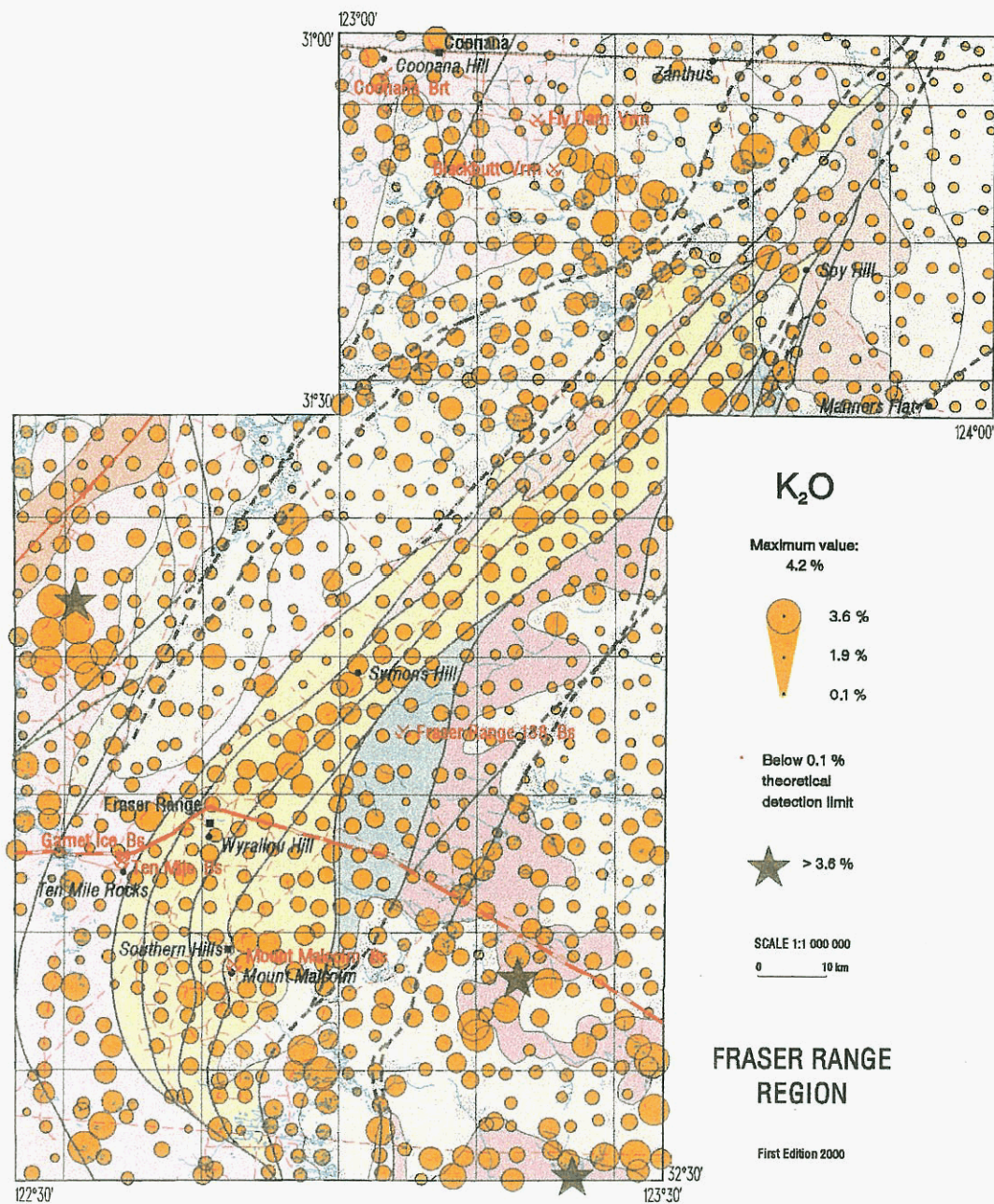


Figure 13

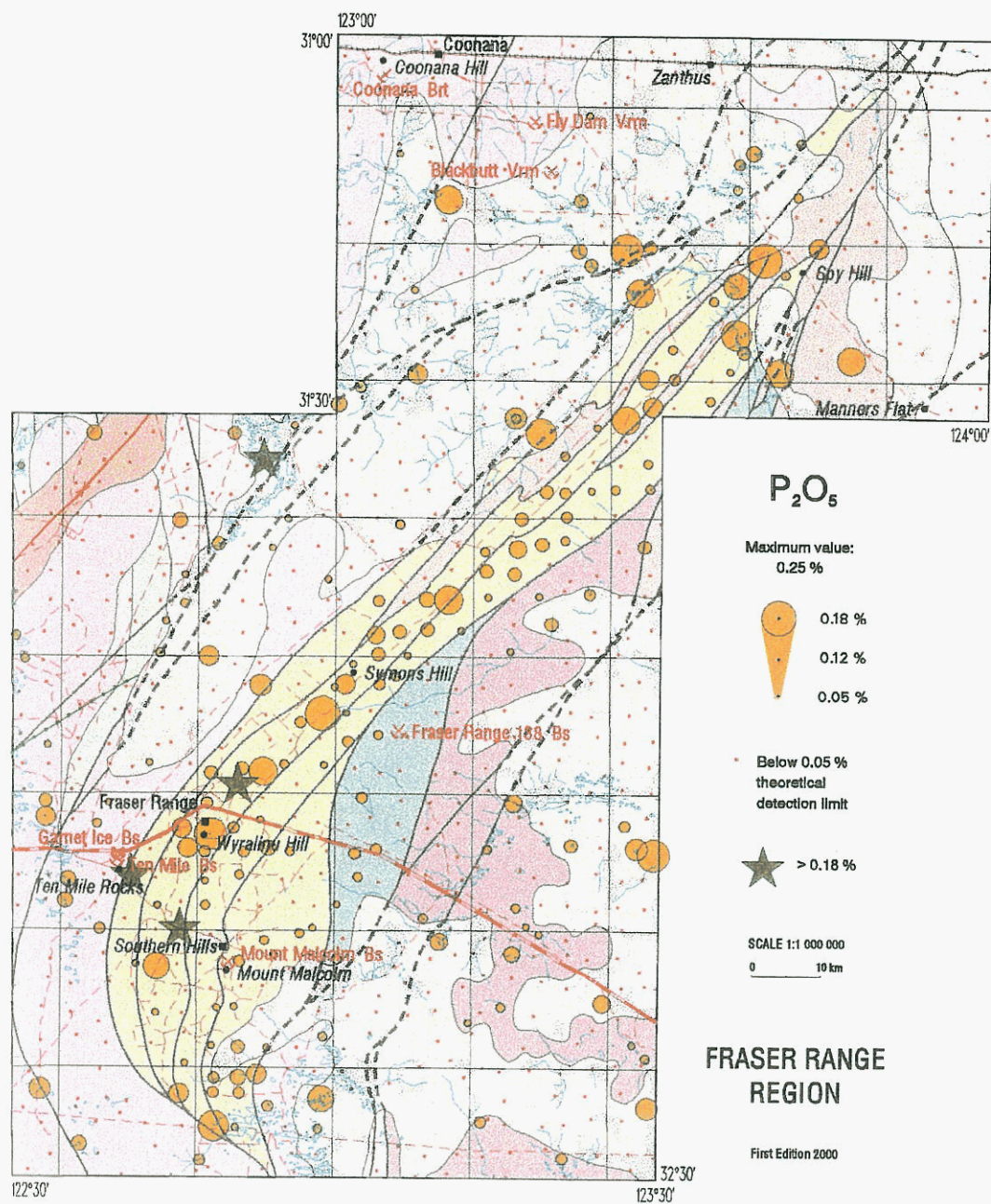


Figure 14

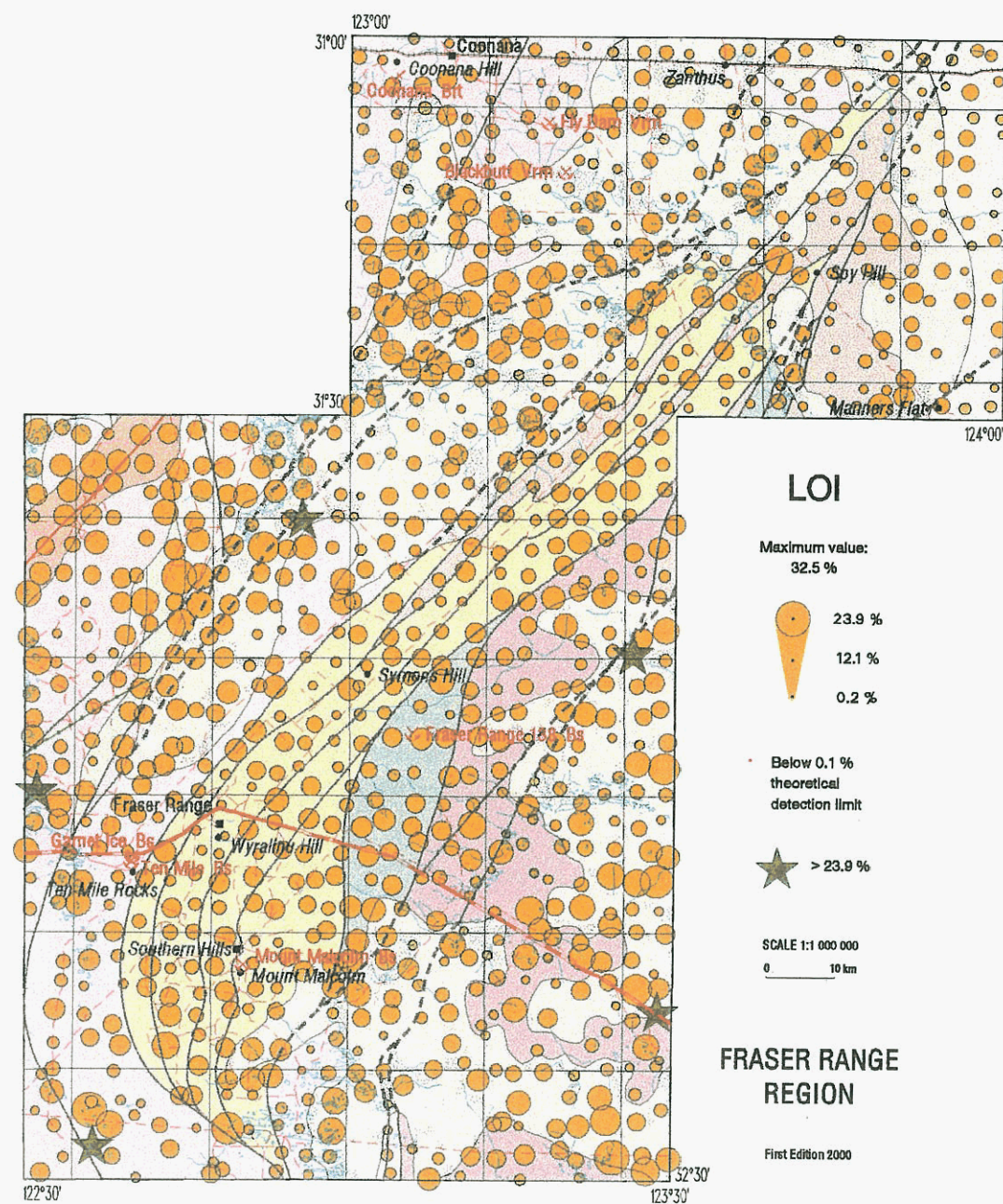


Figure 15

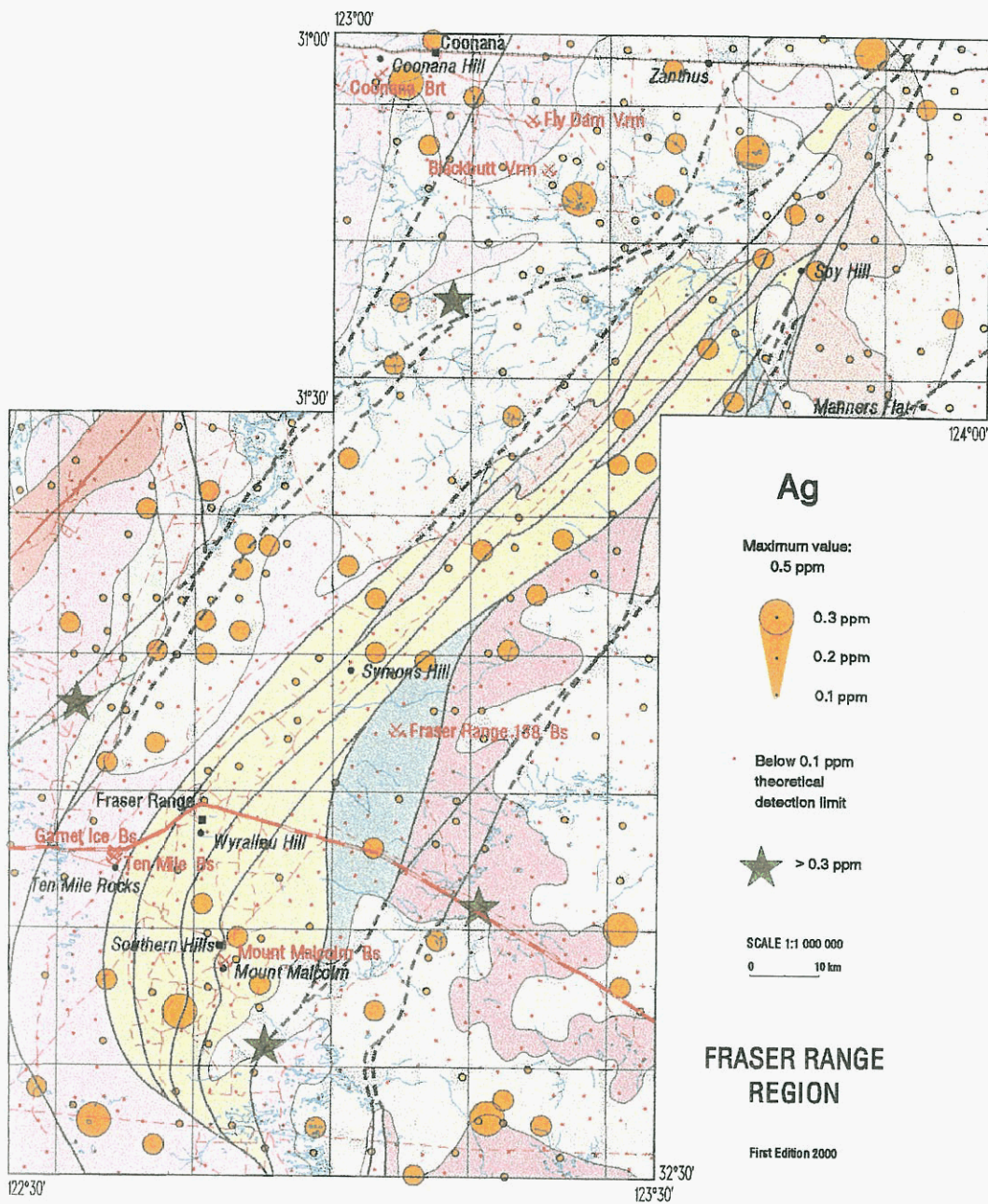


Figure 16

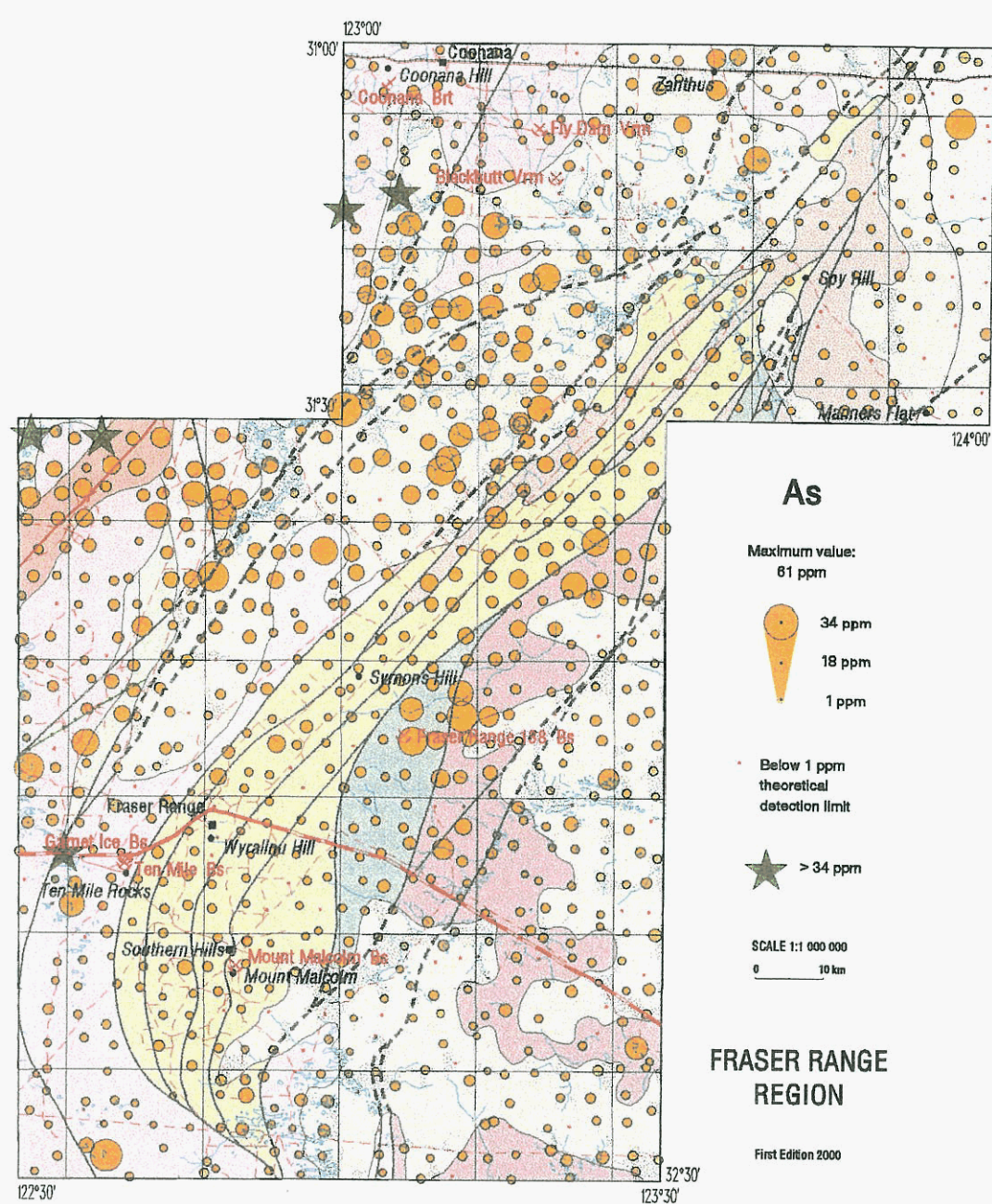


Figure 17

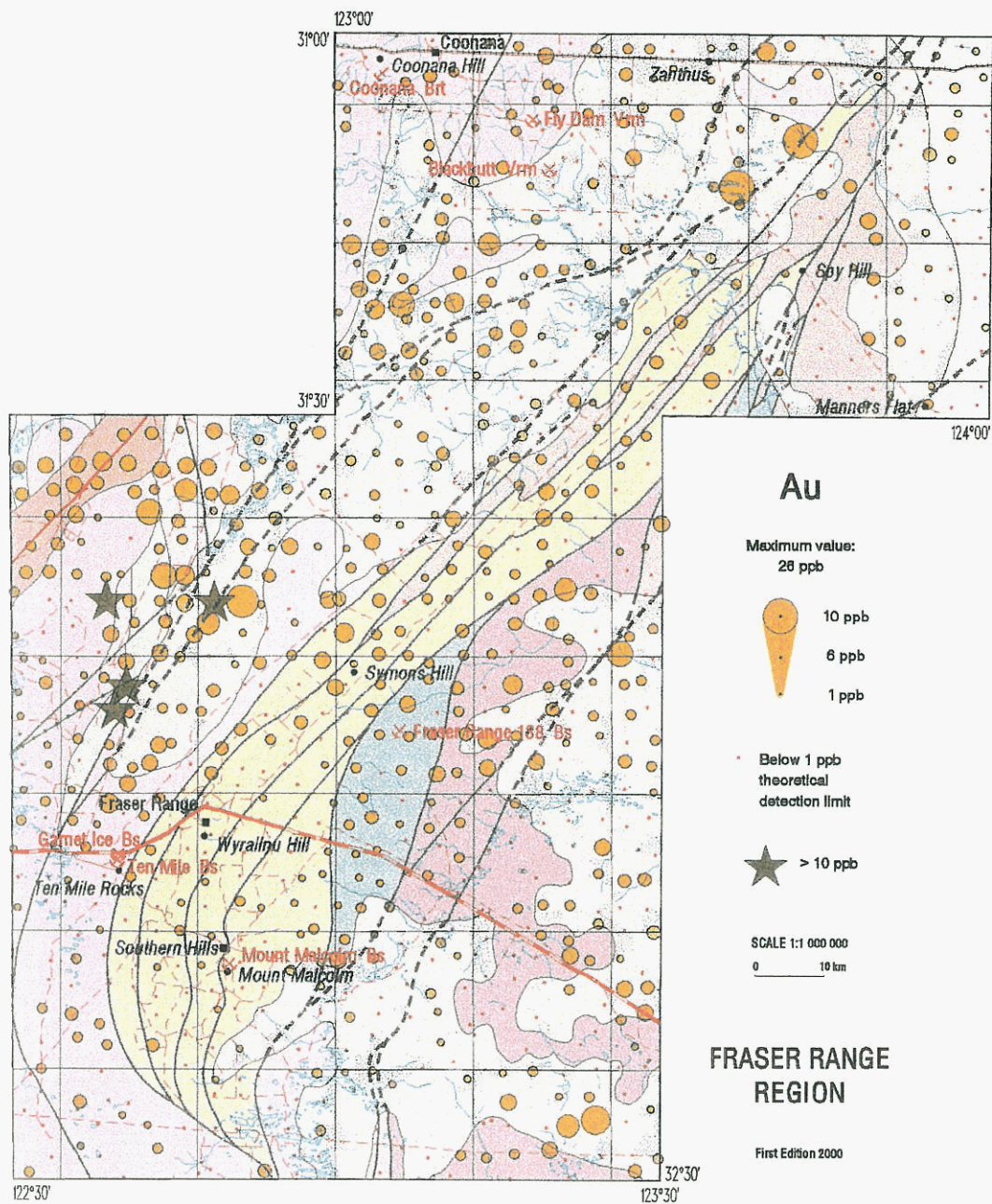


Figure 18

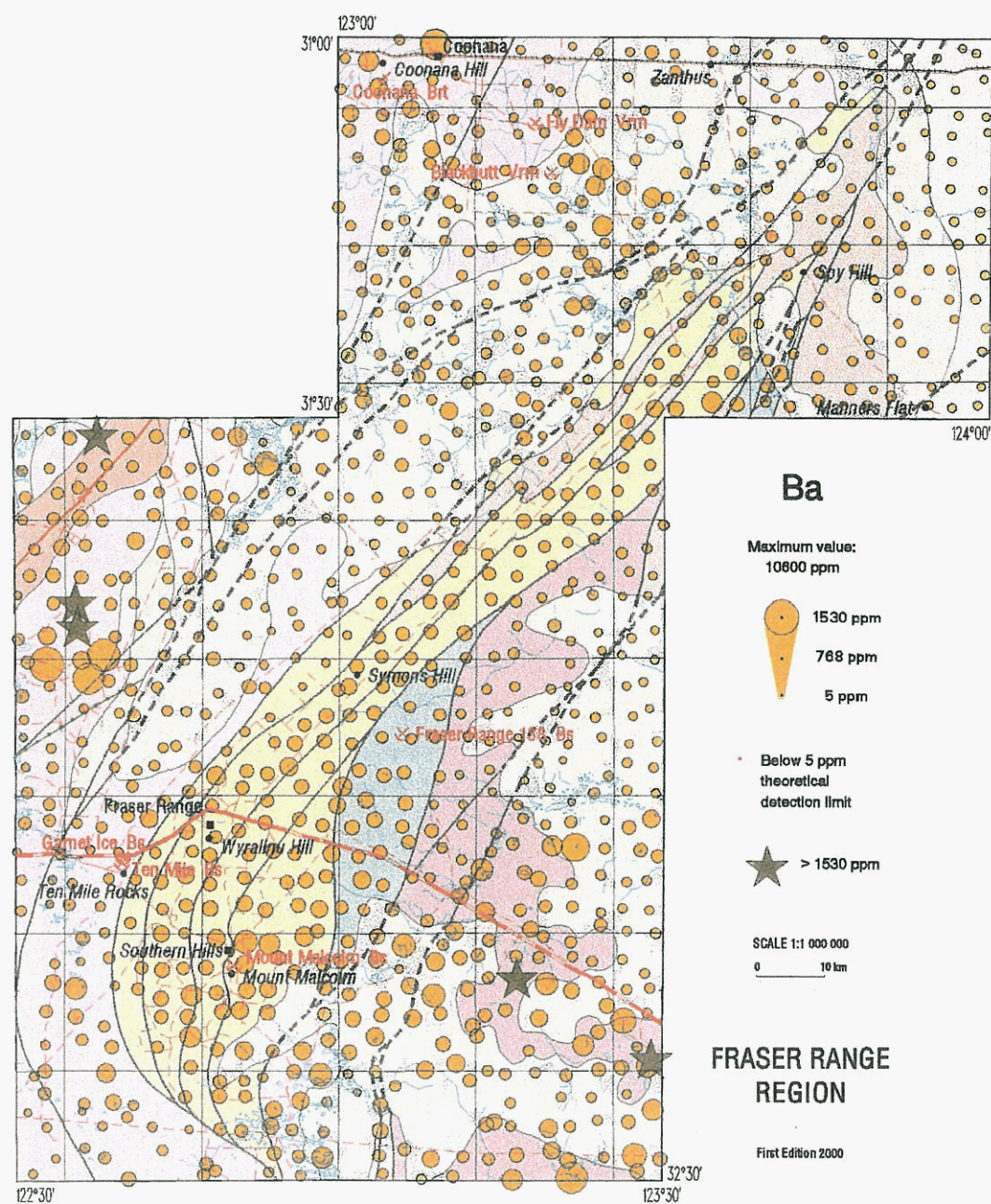


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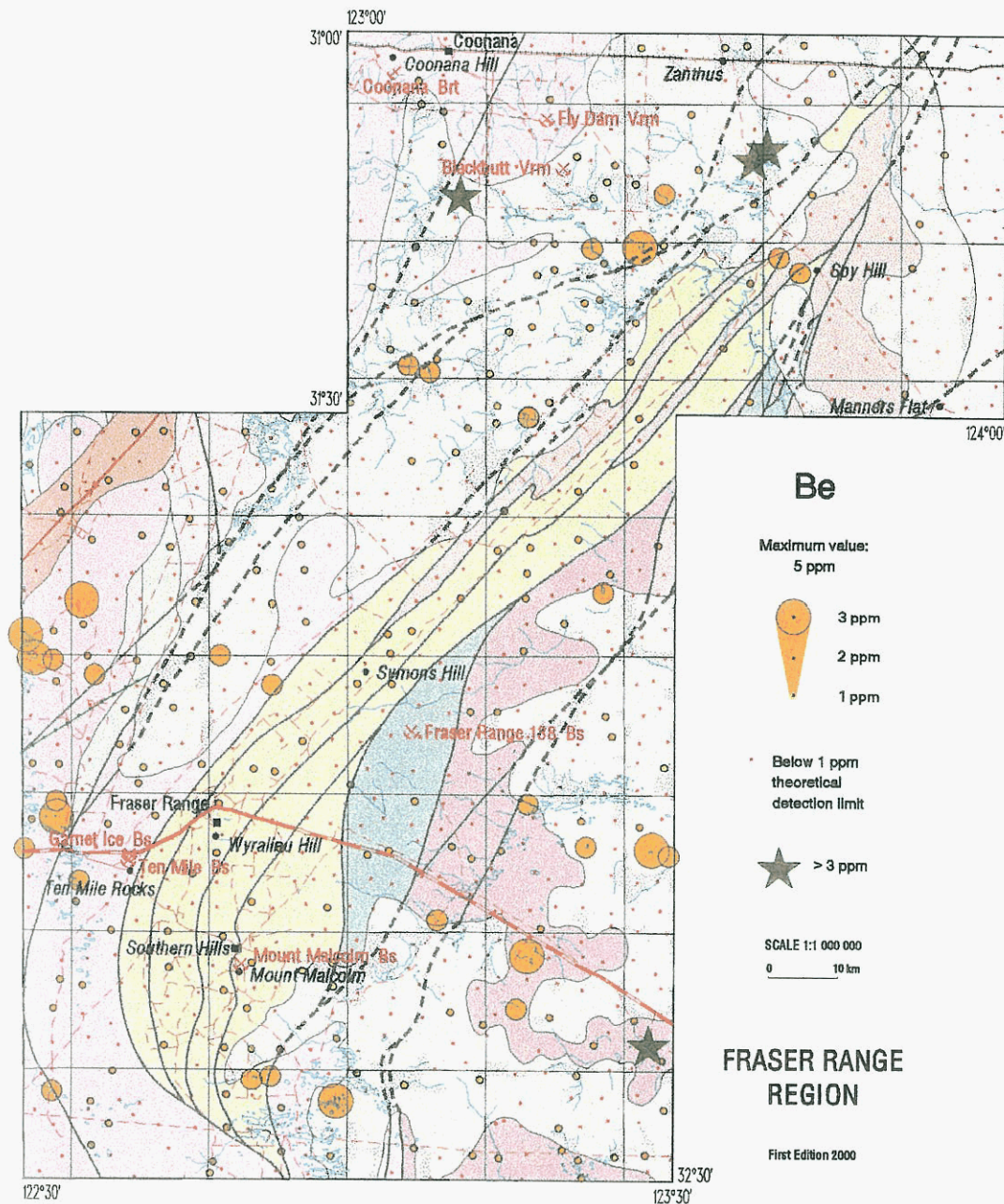


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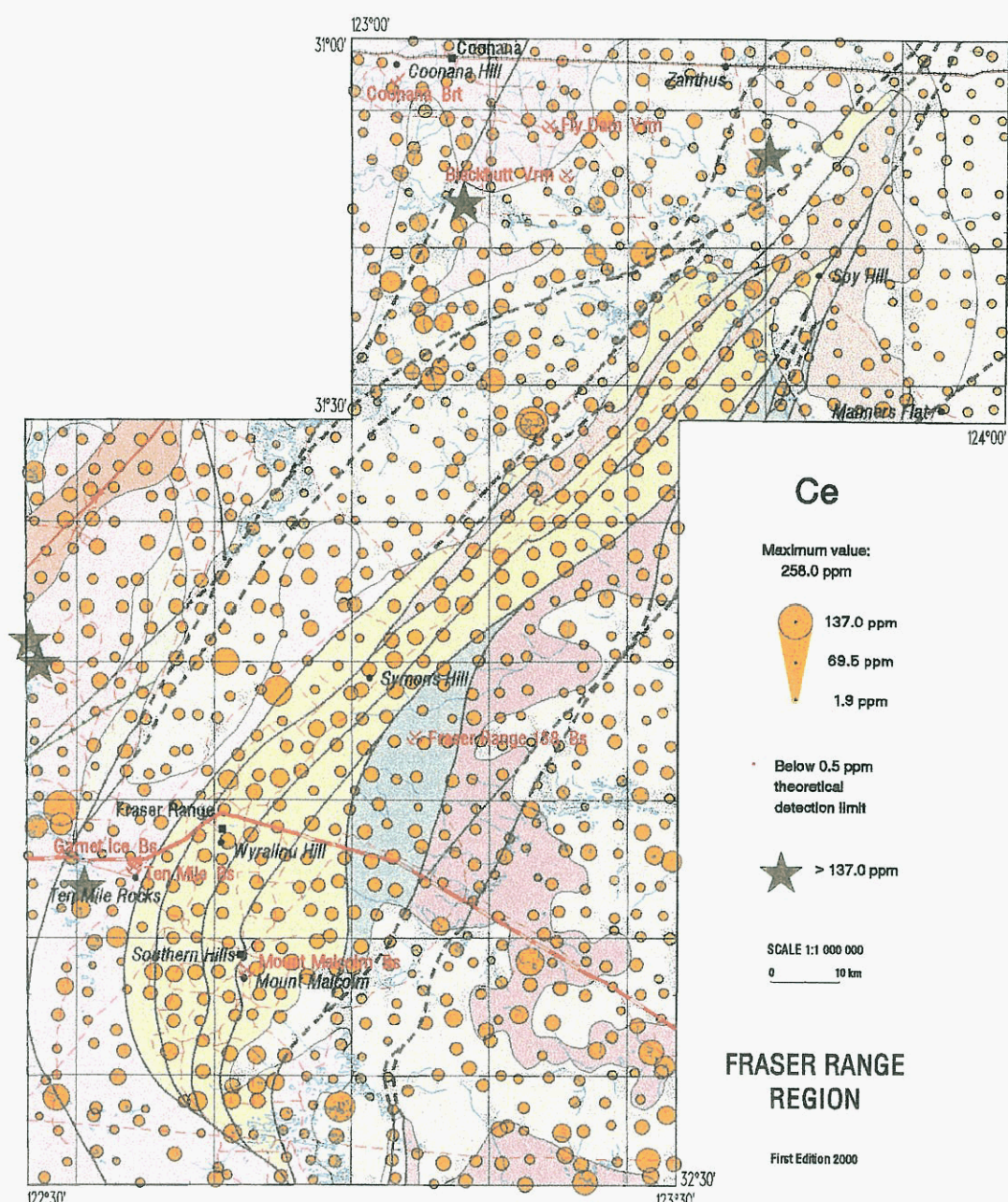


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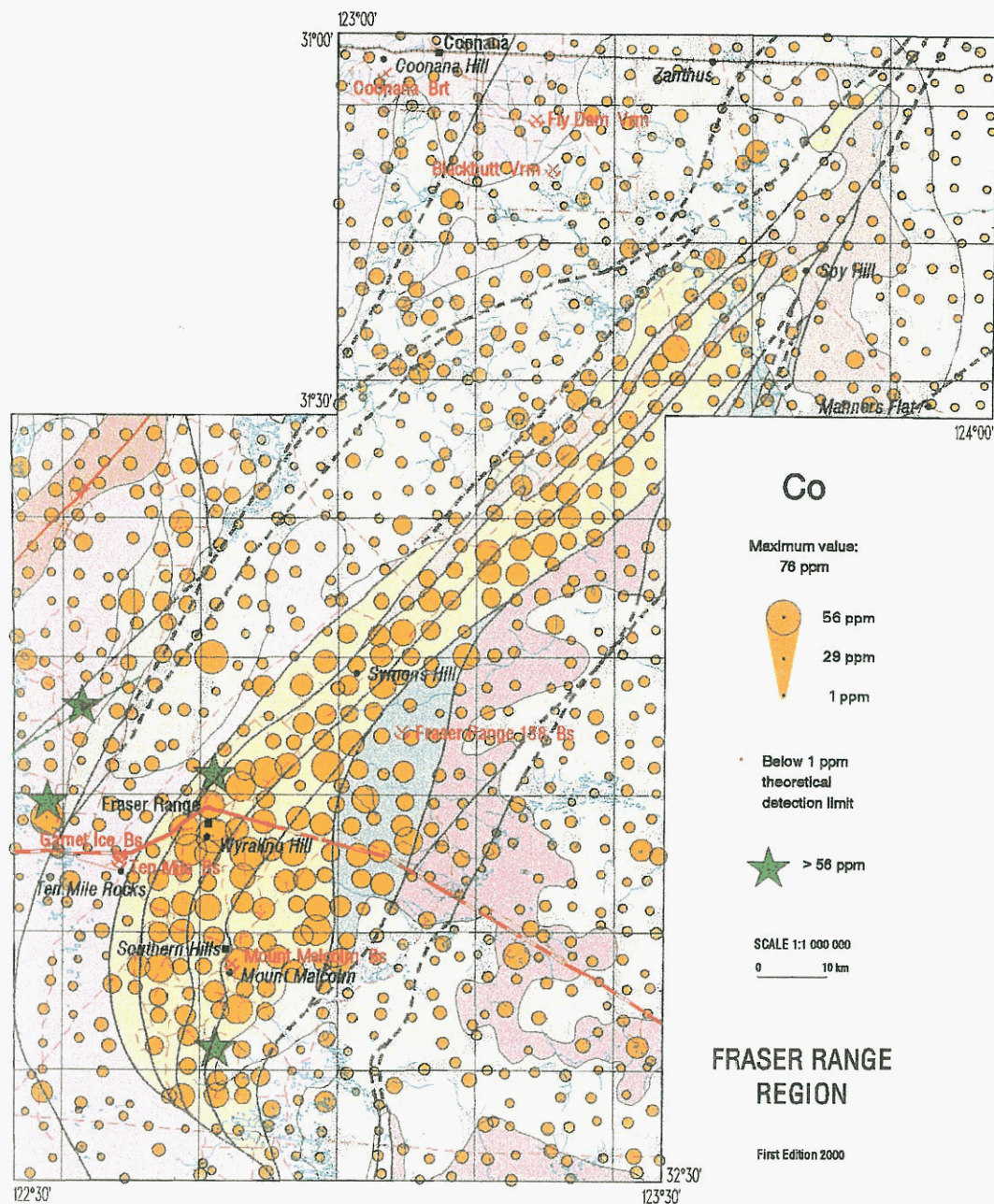


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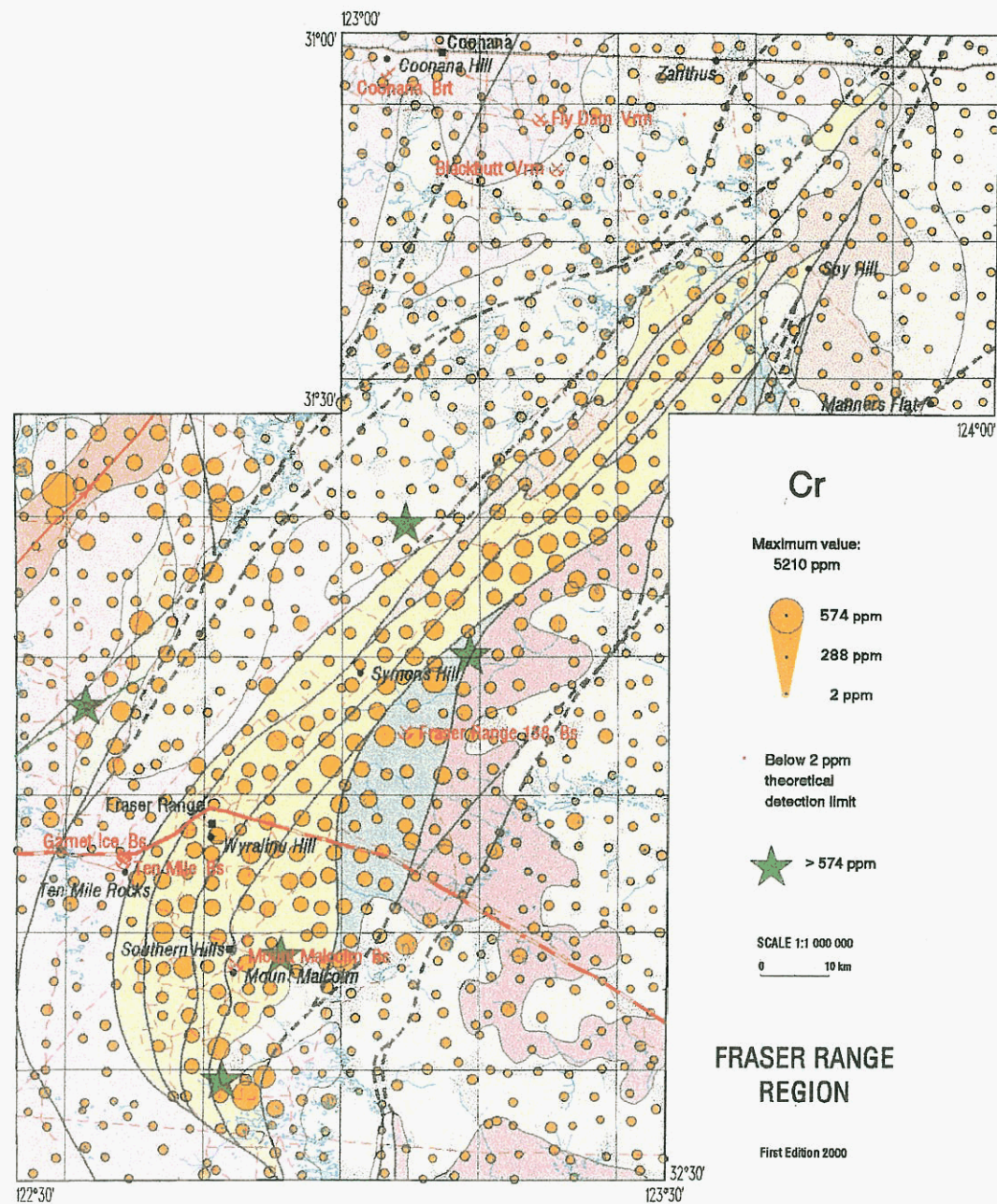


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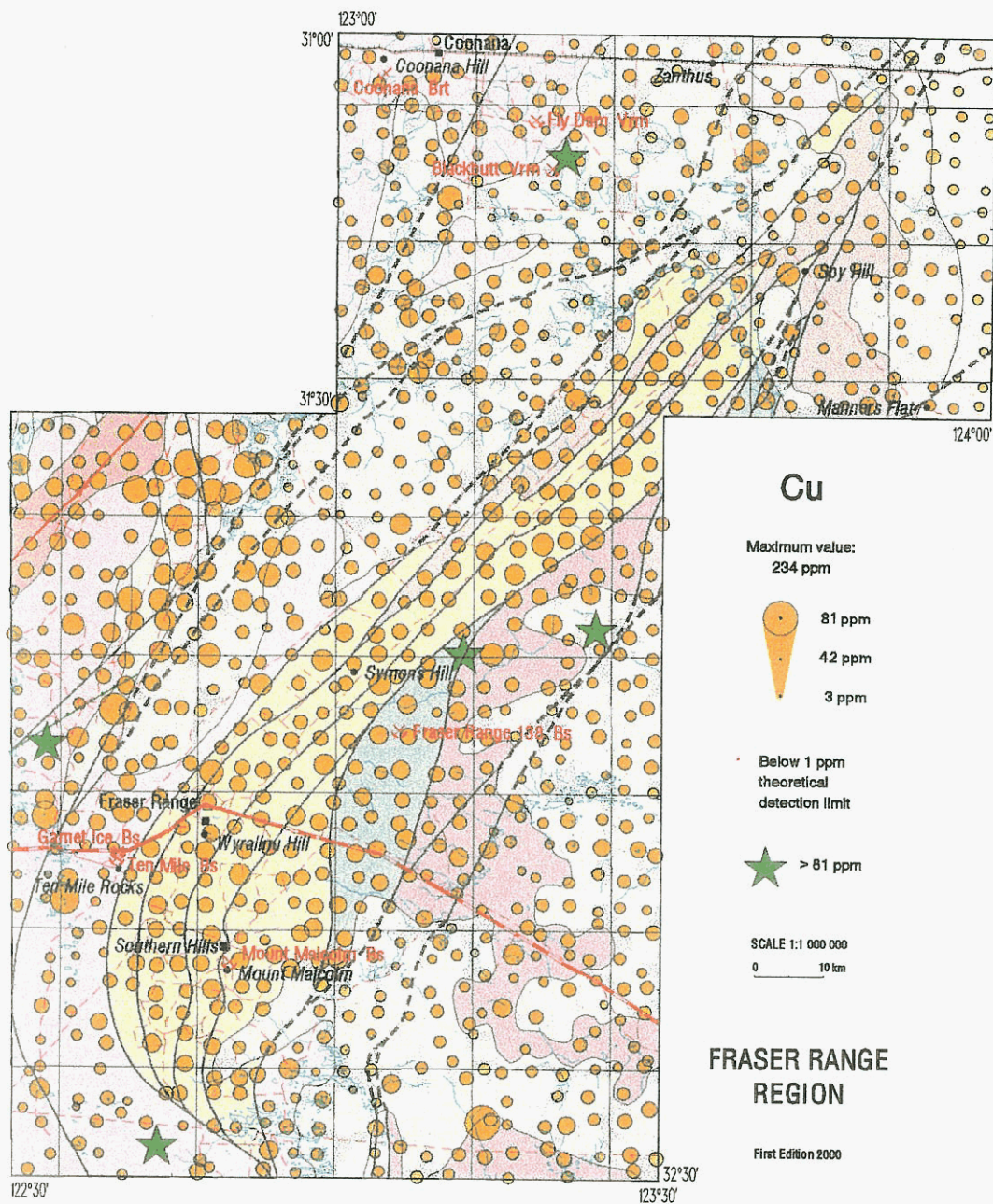


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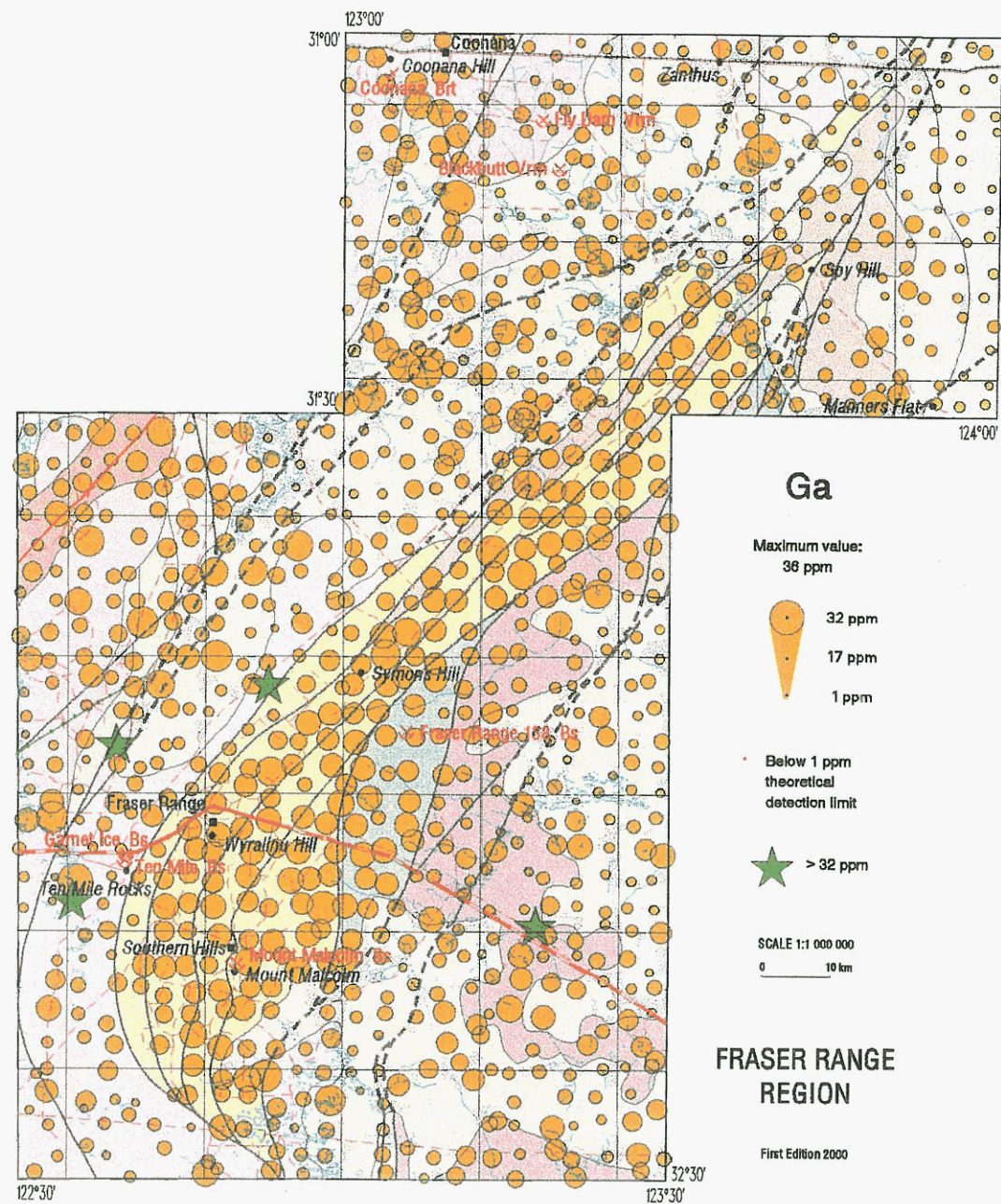


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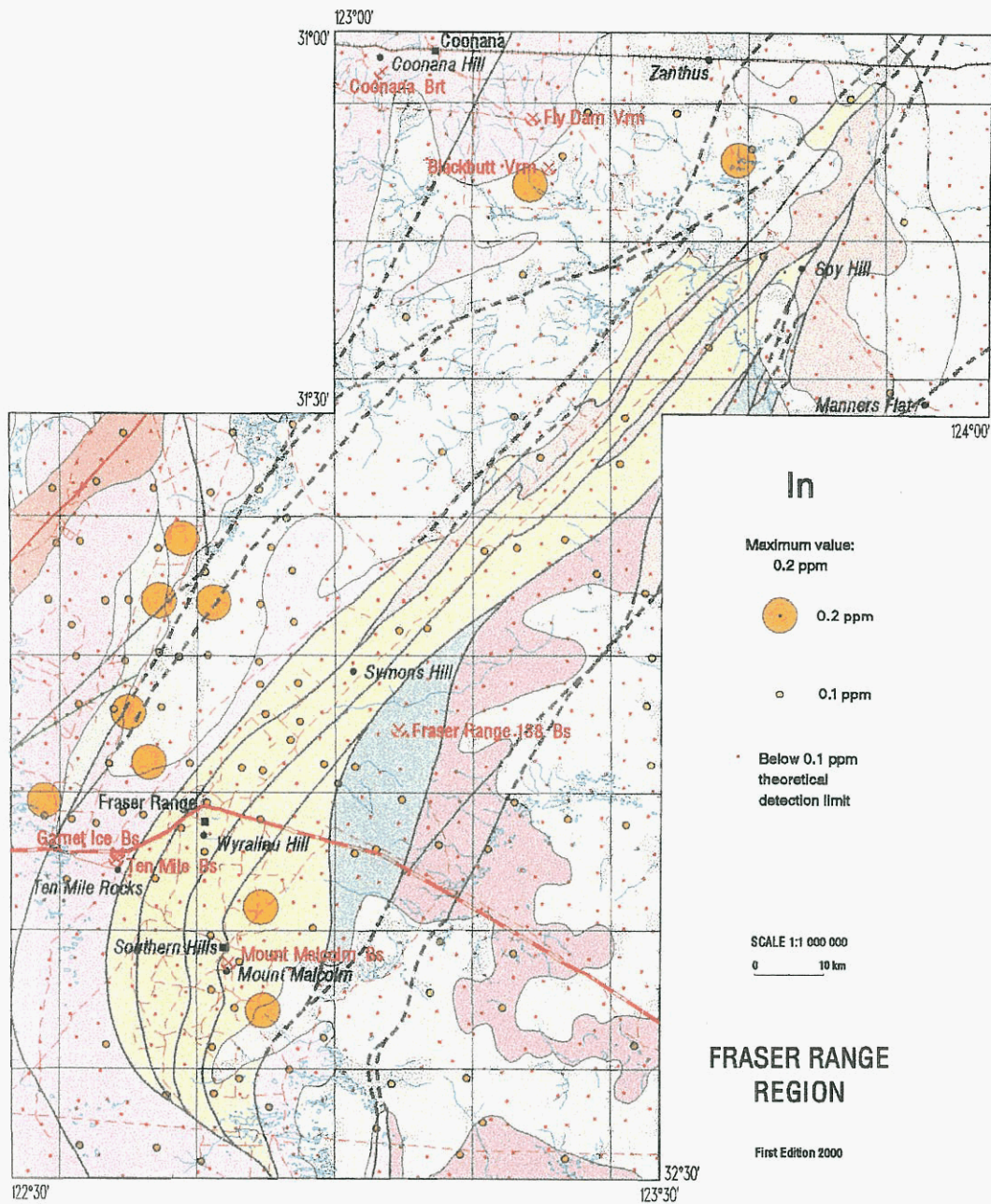


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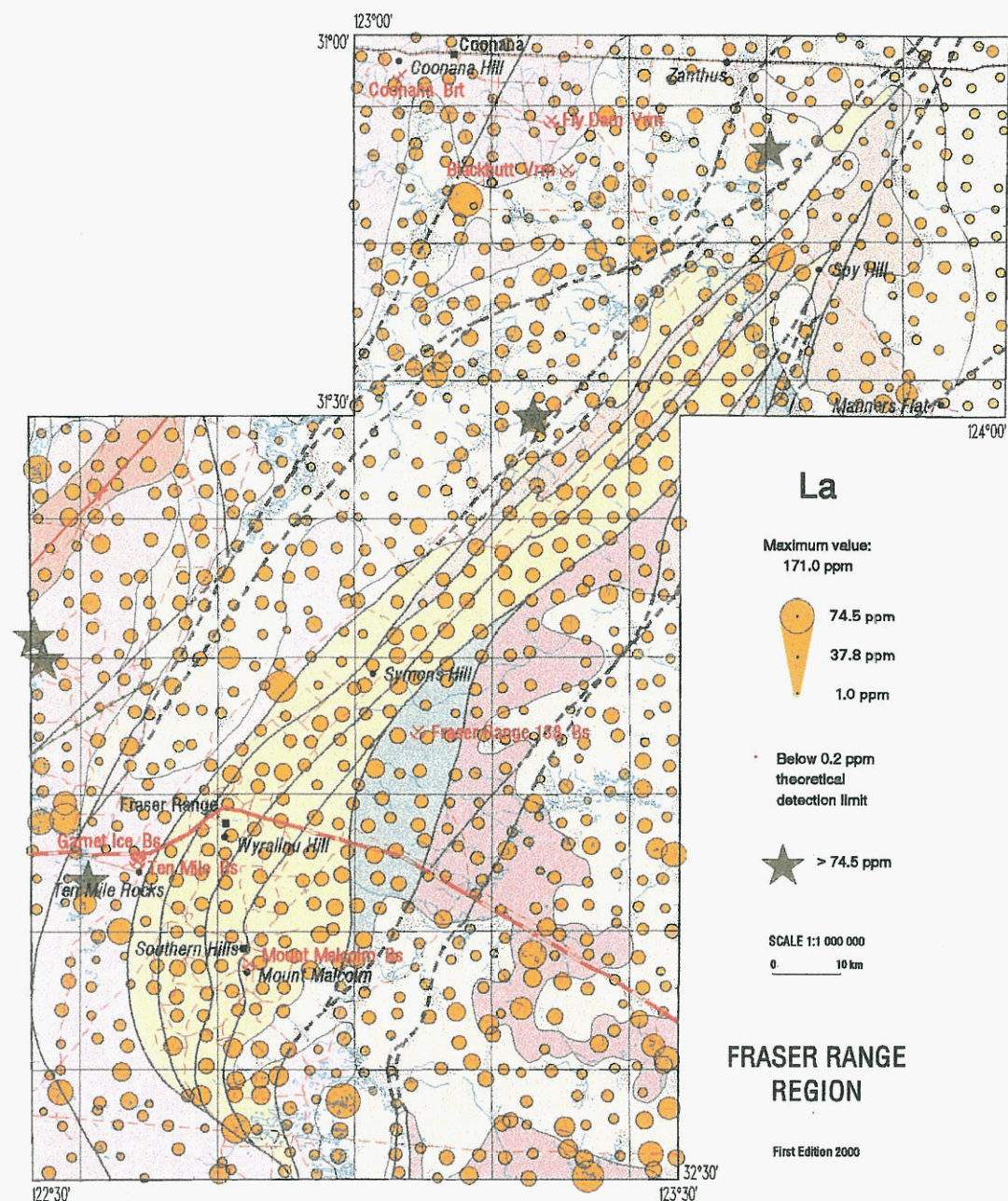


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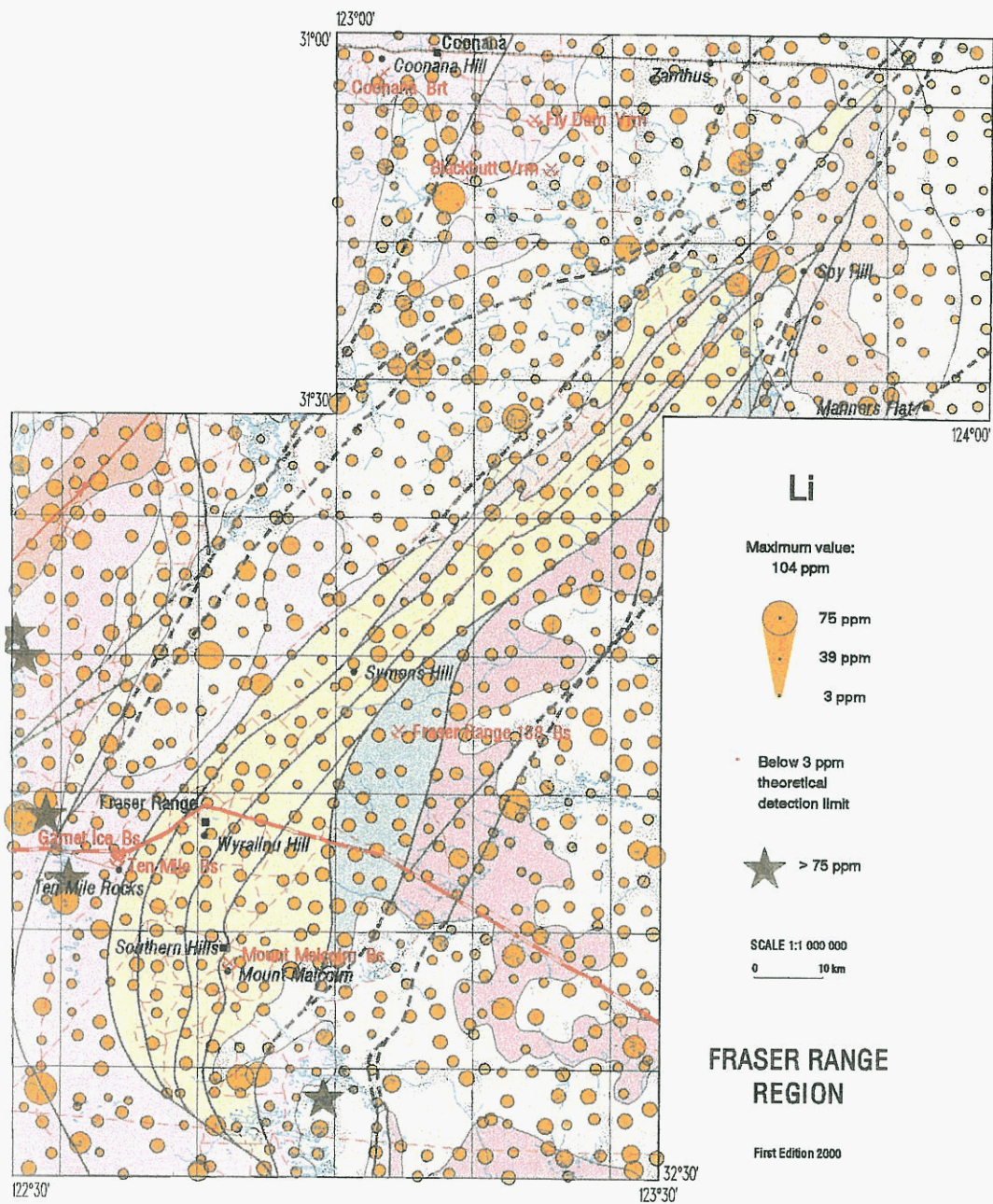


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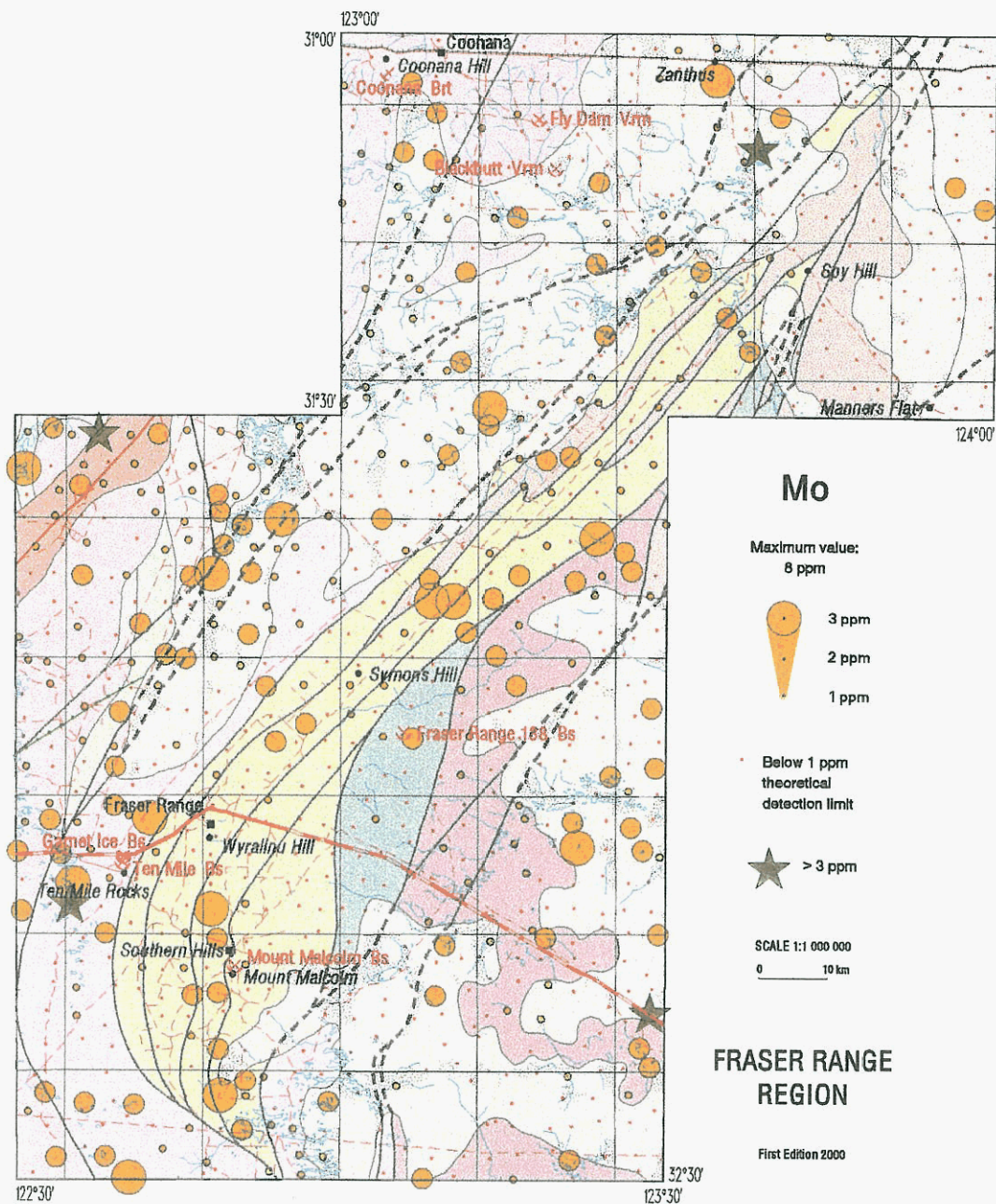


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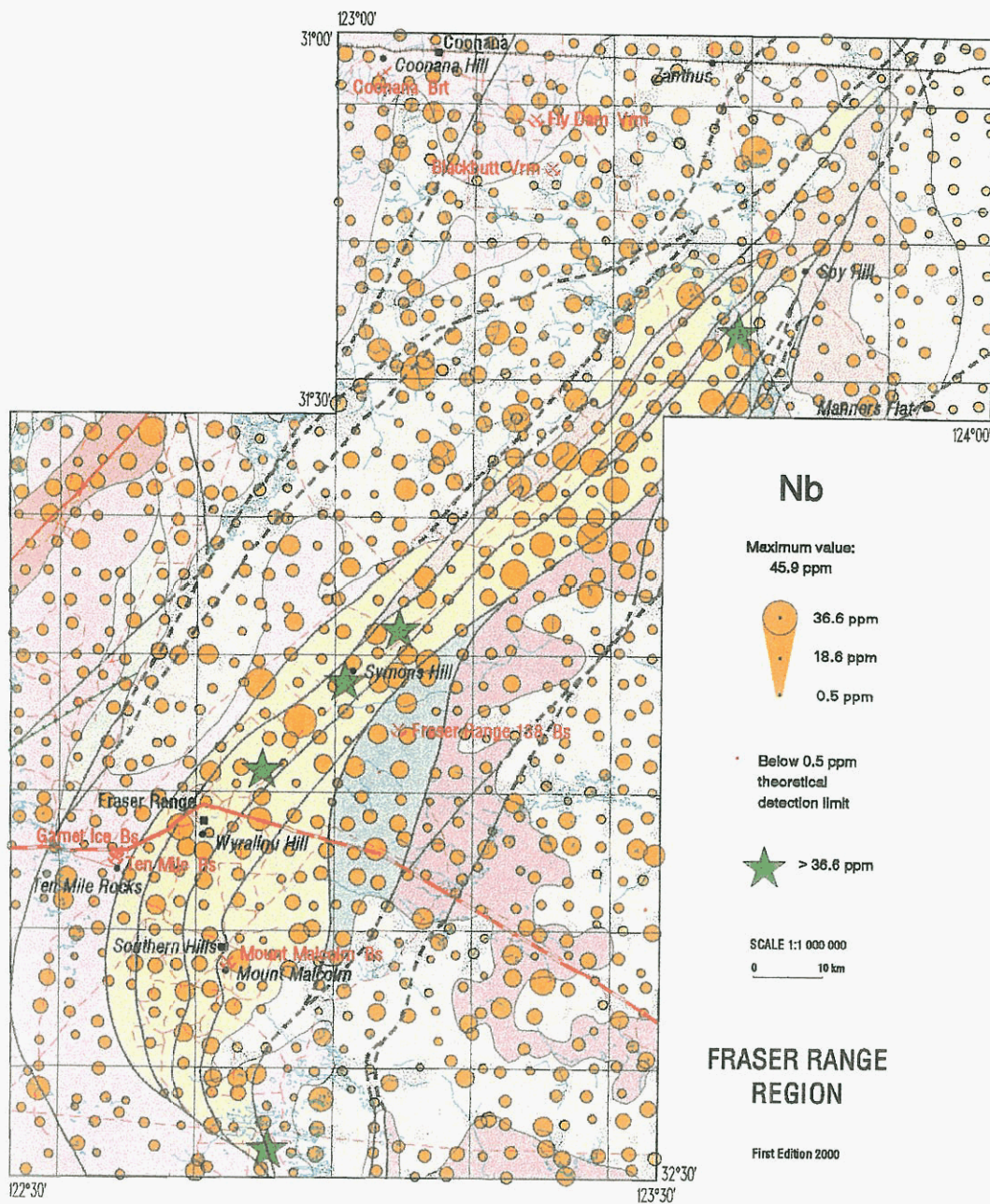


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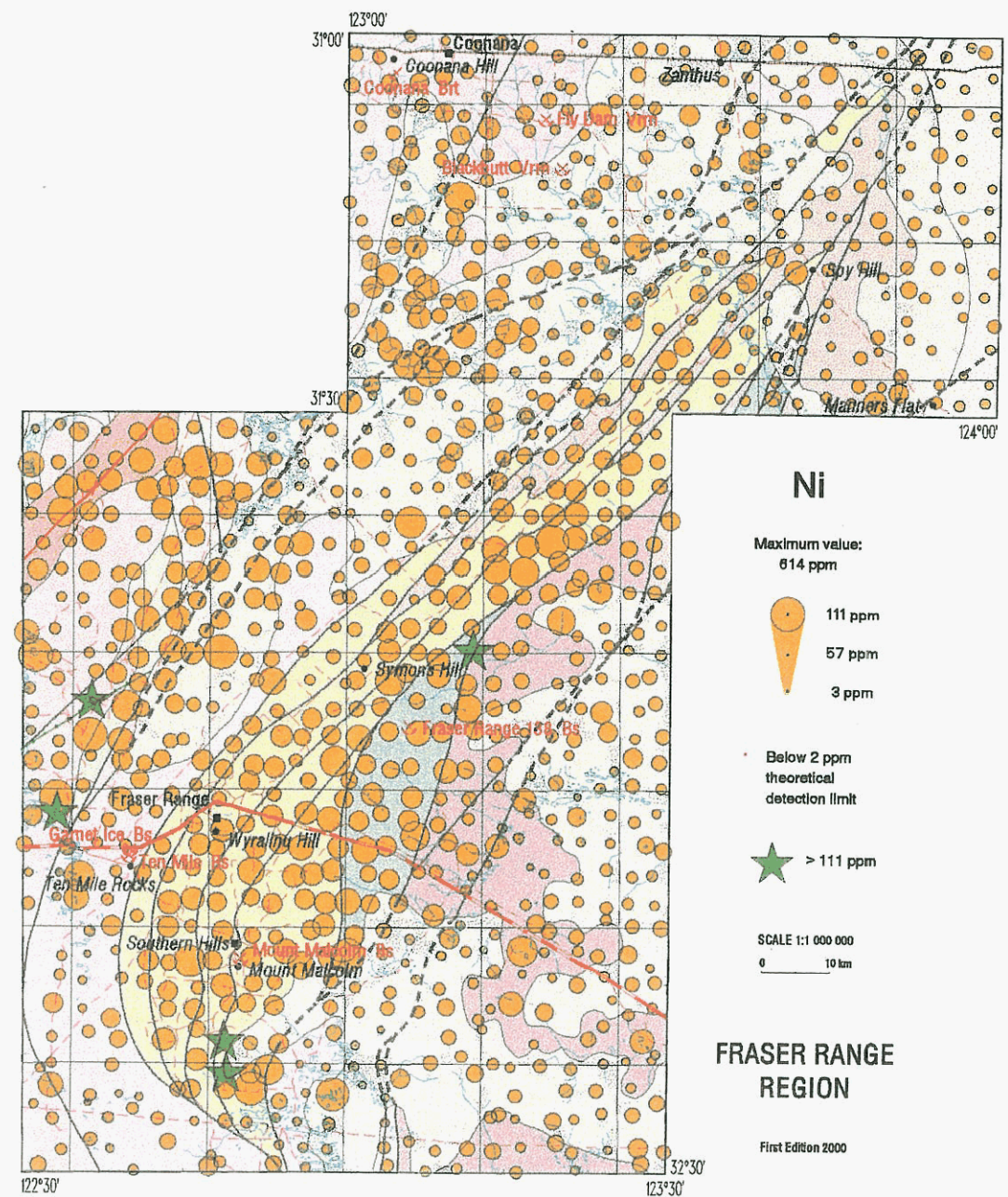


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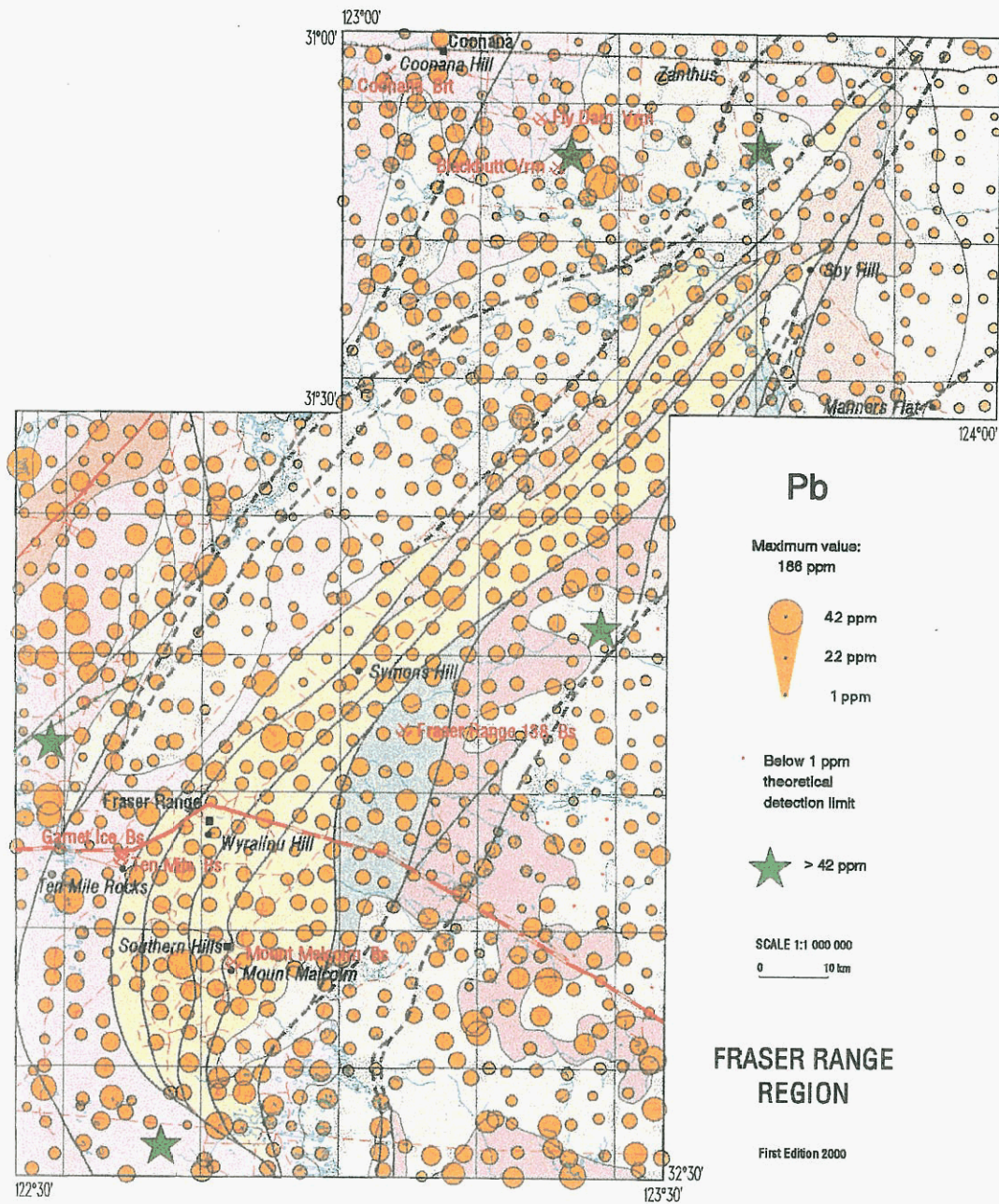


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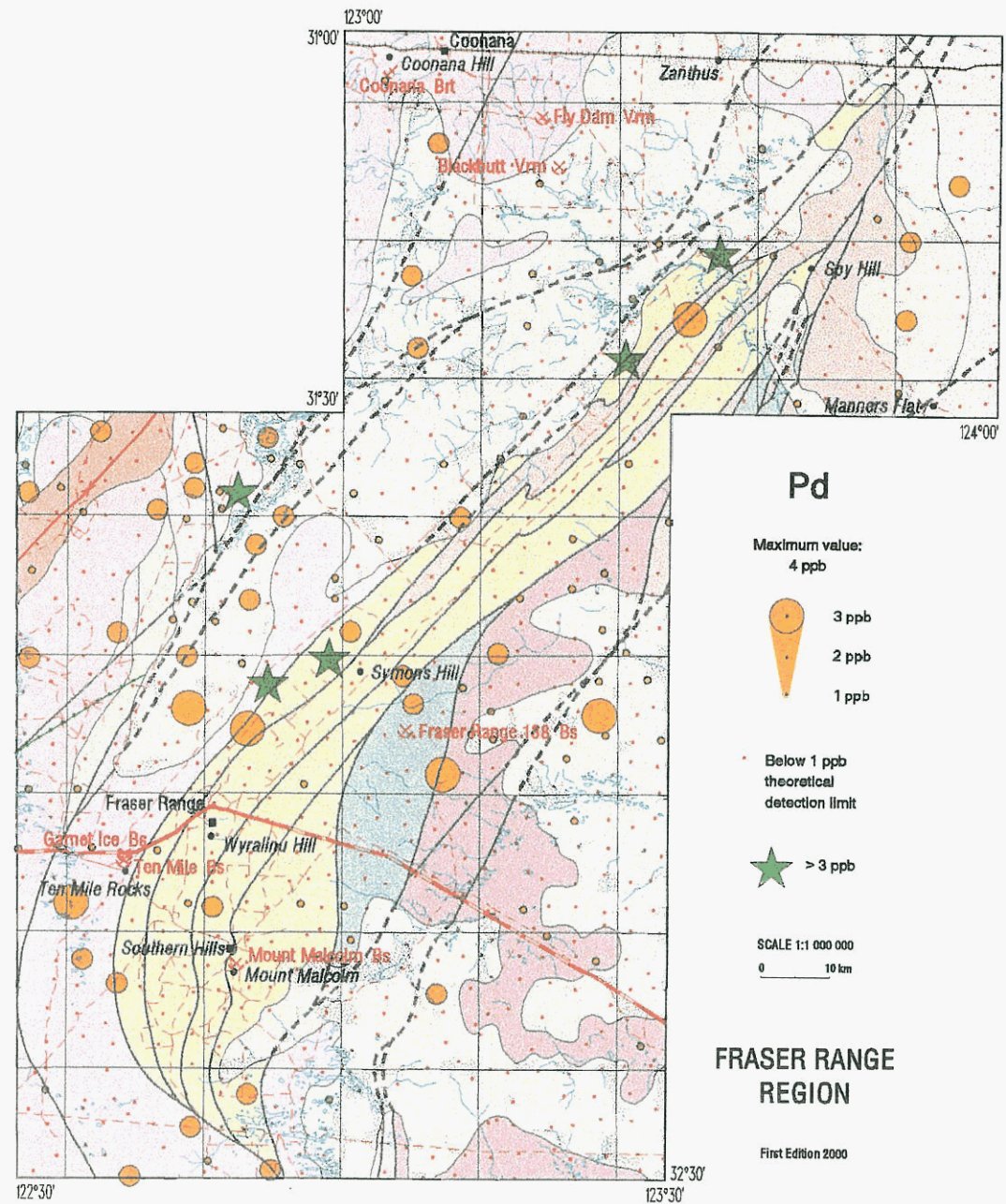


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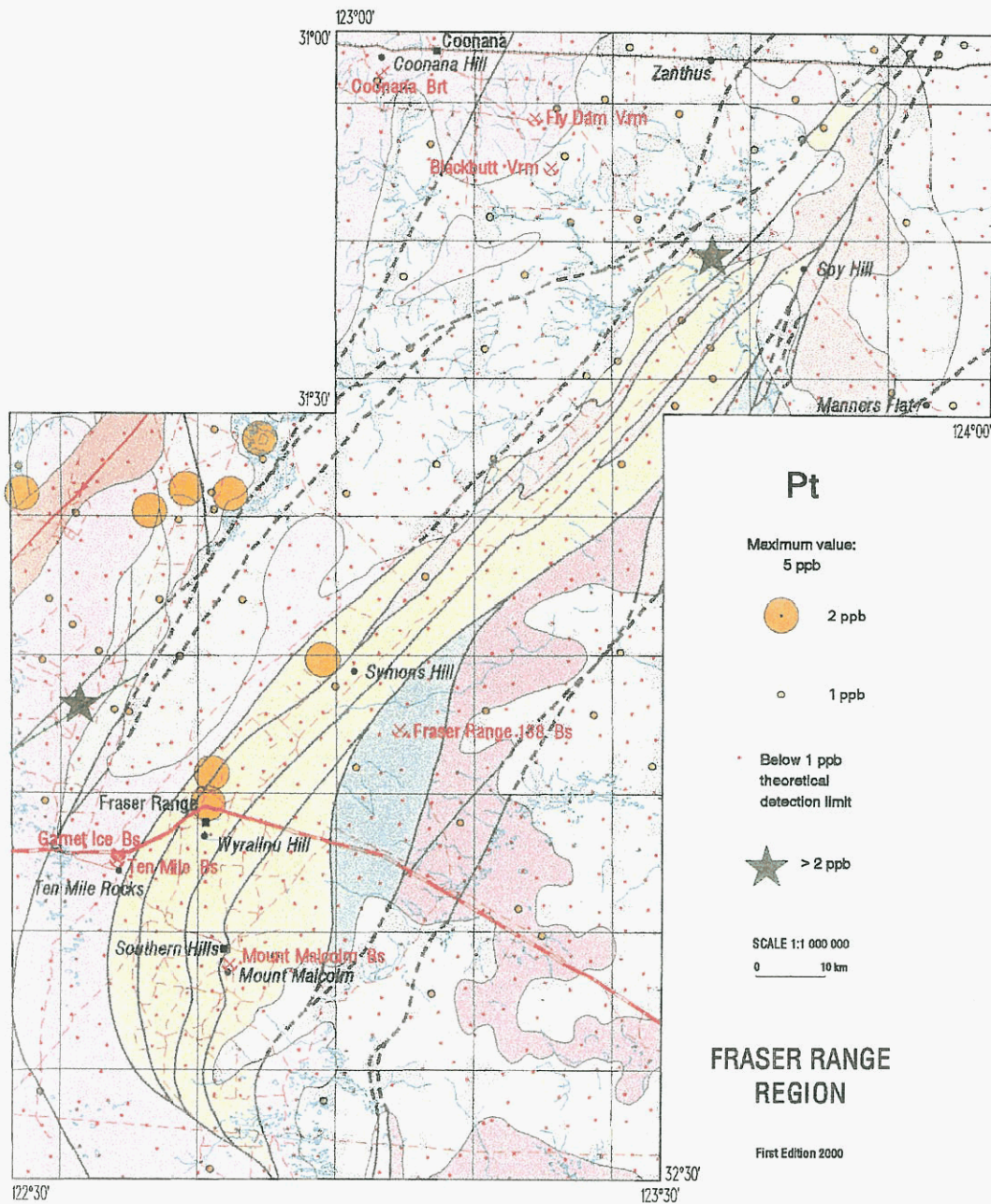


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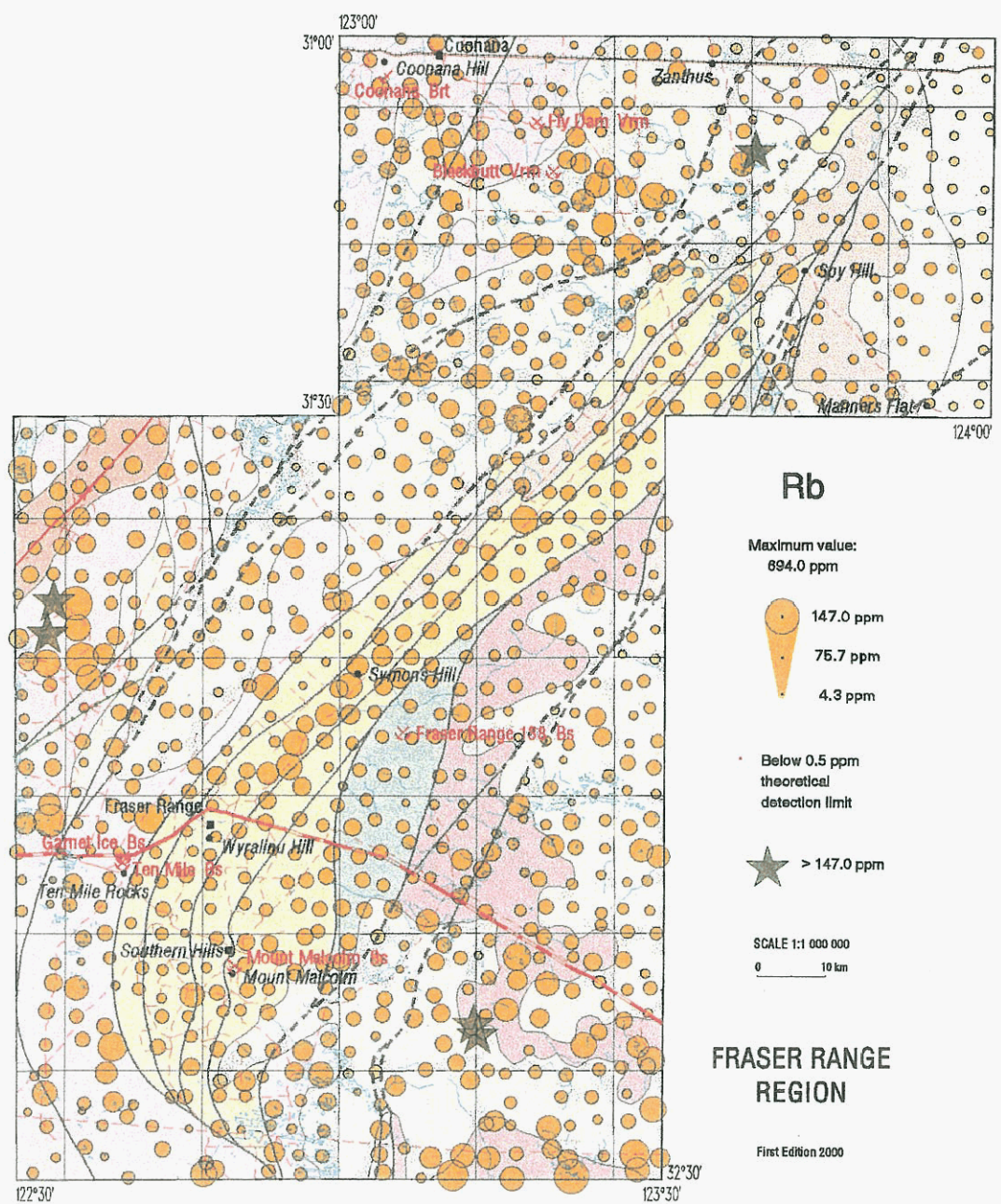


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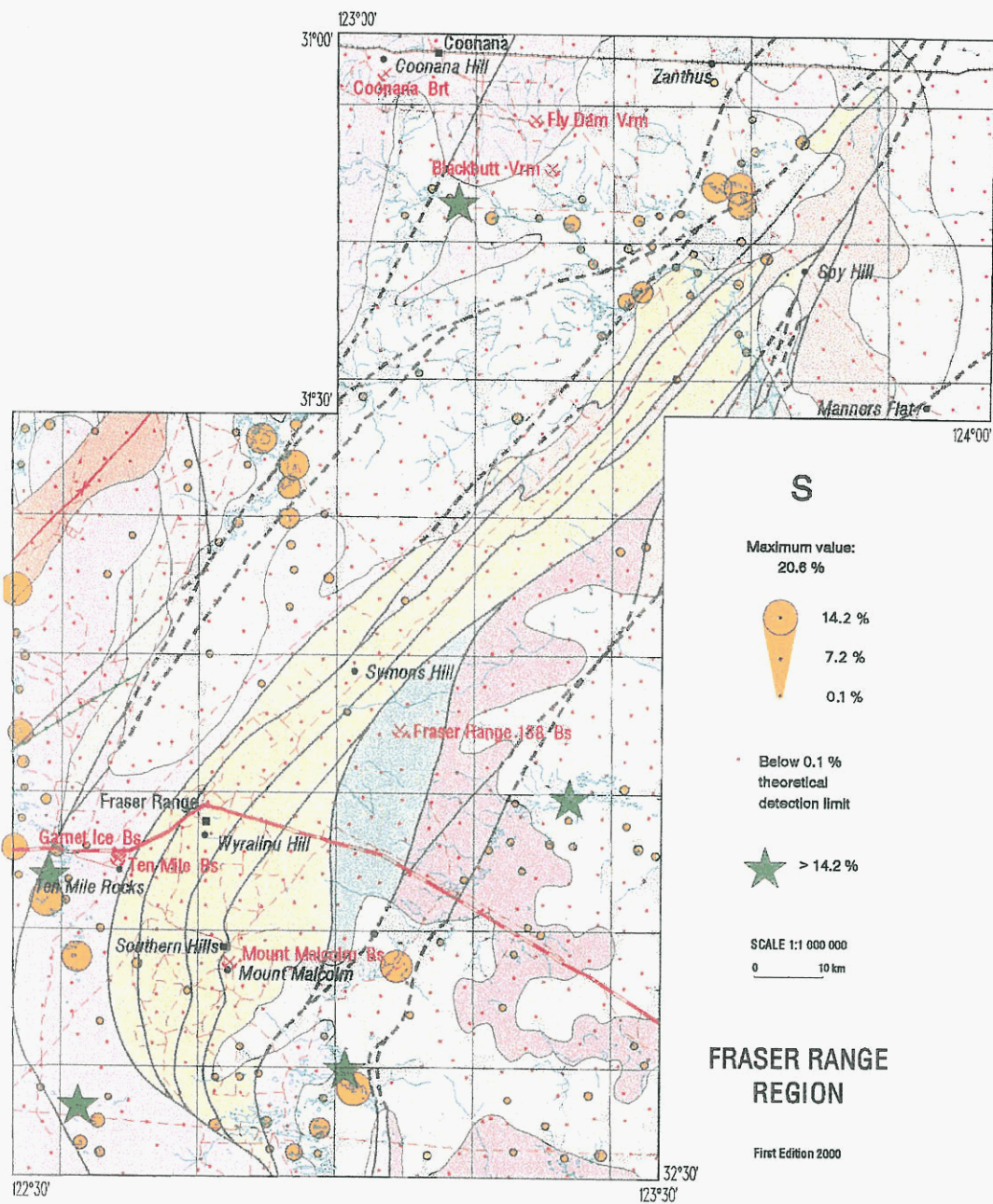


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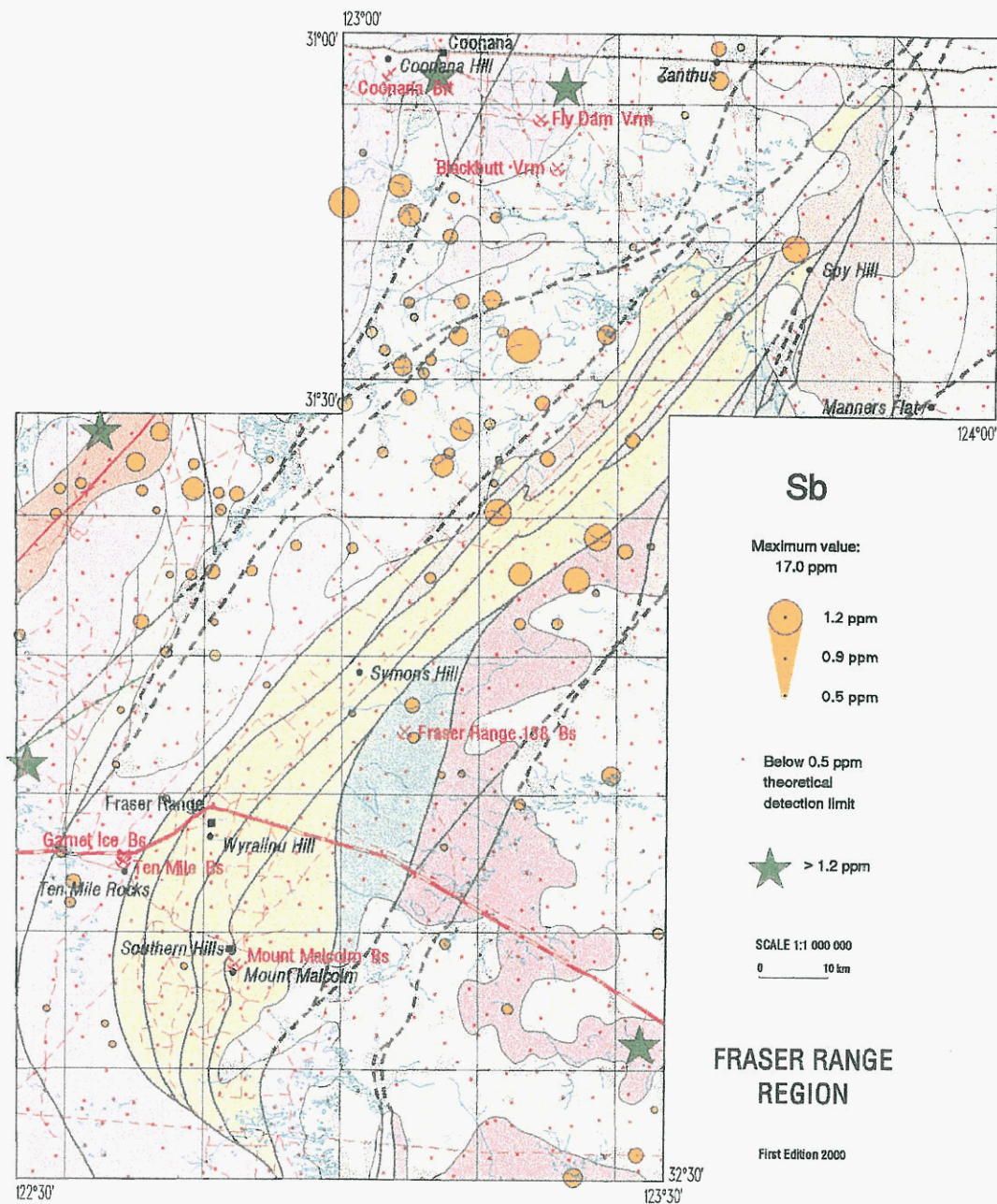


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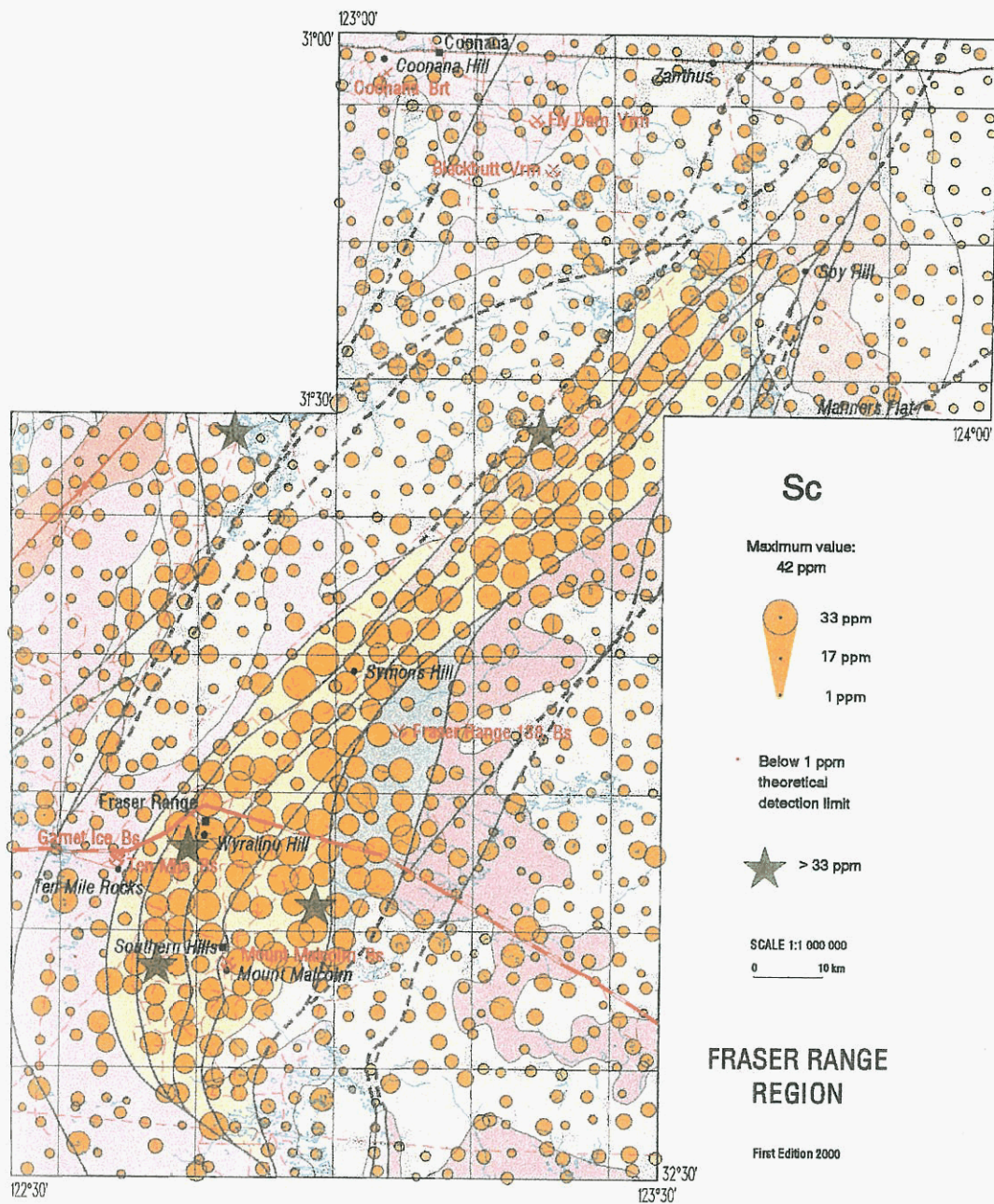


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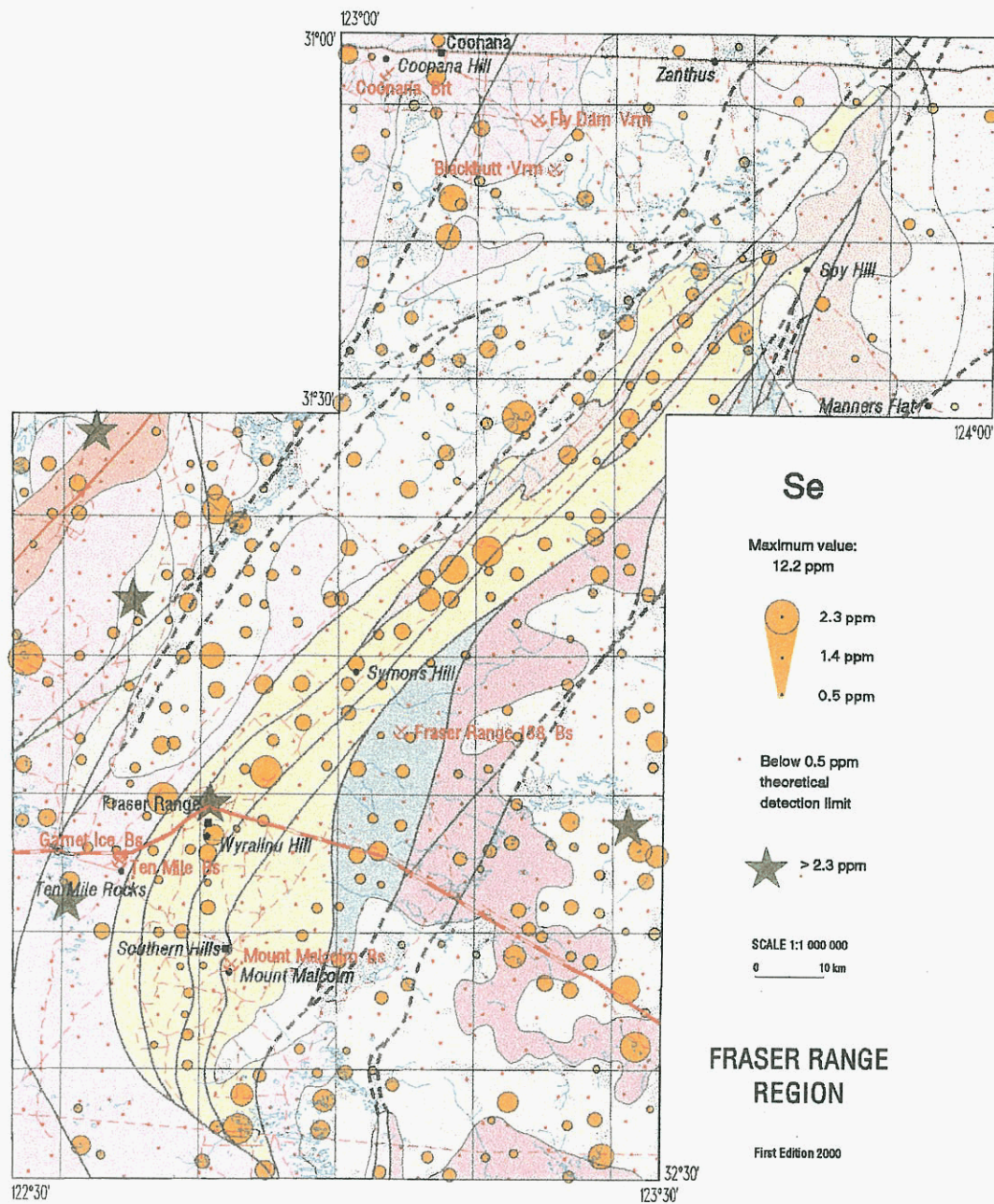


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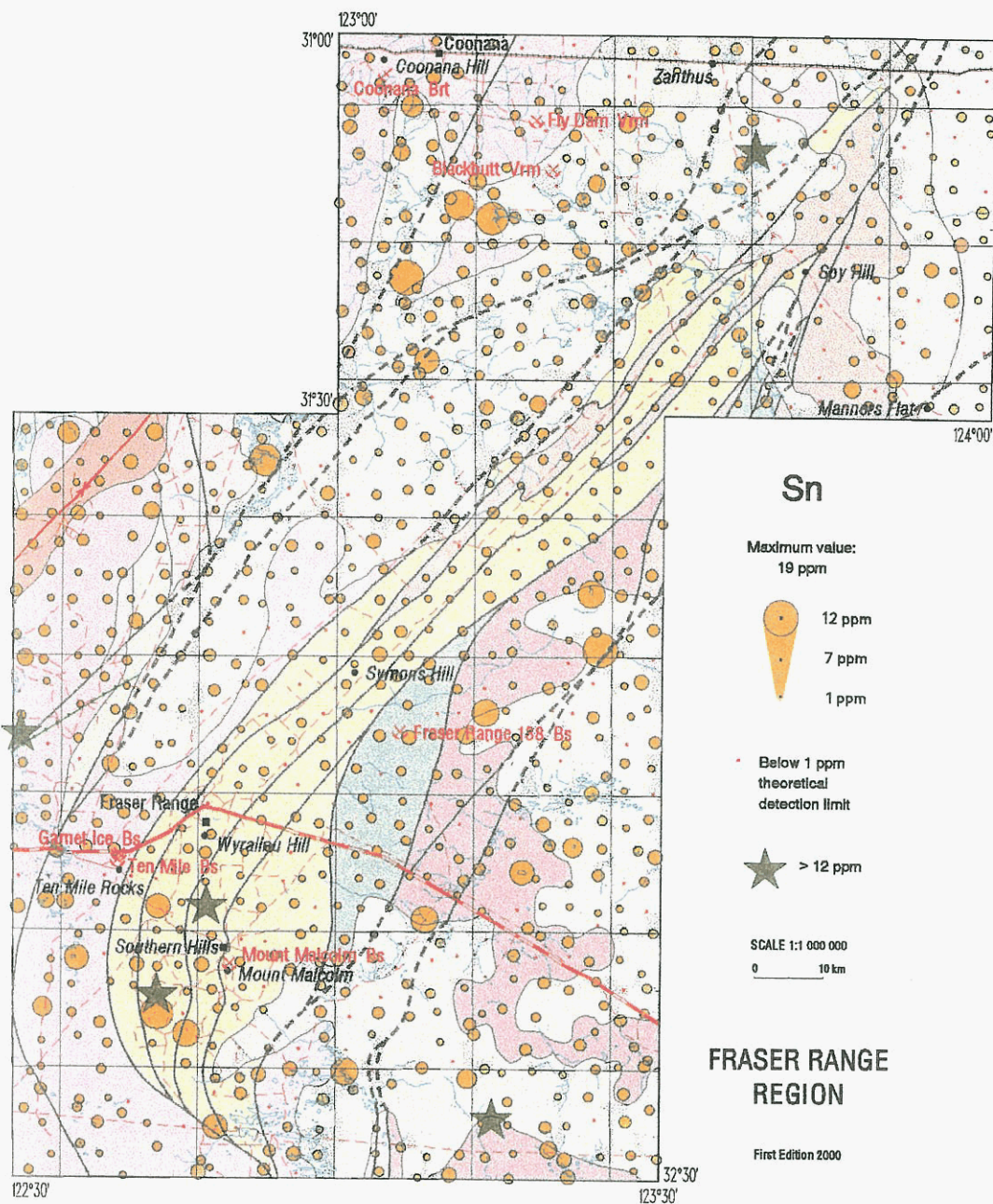


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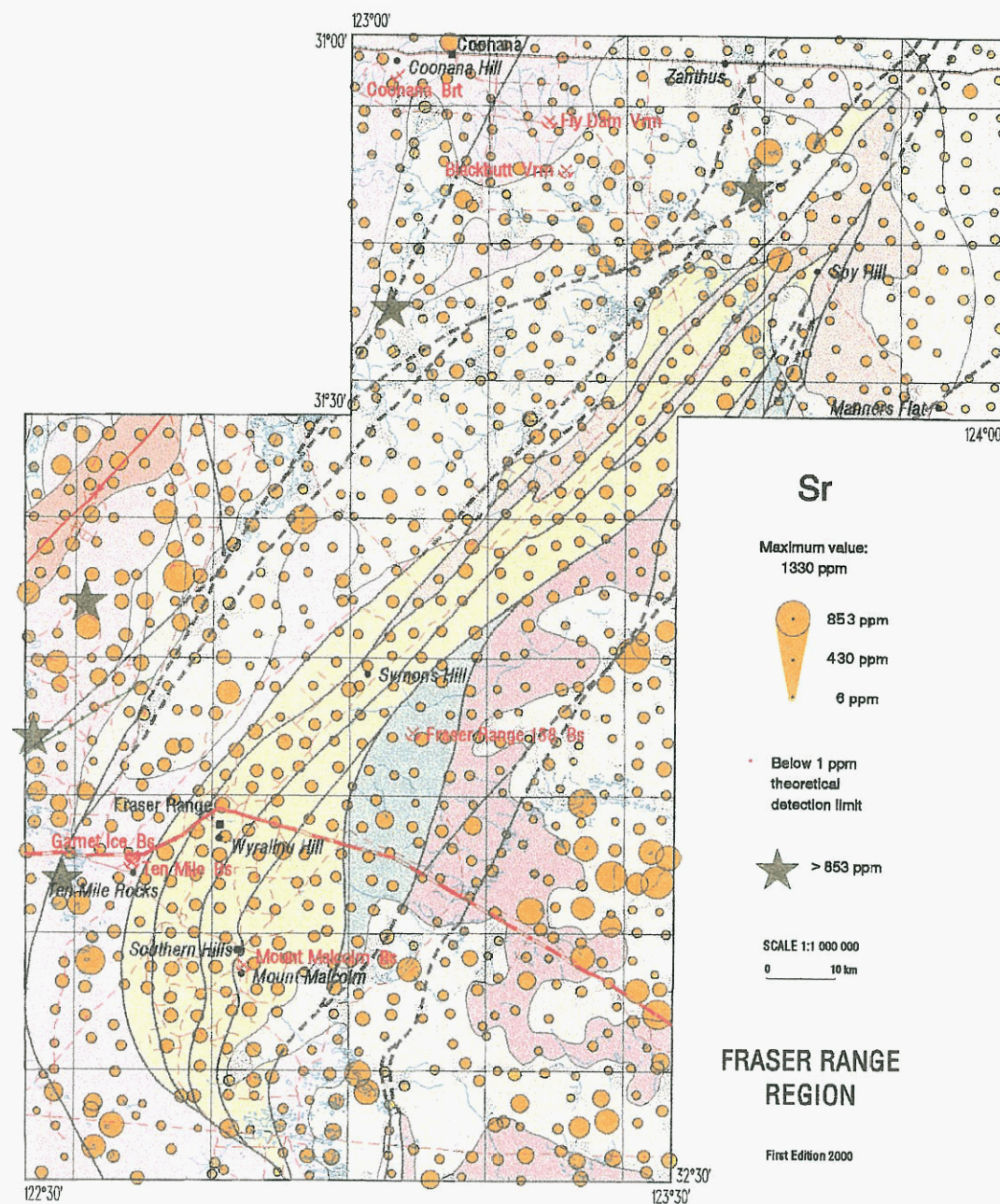


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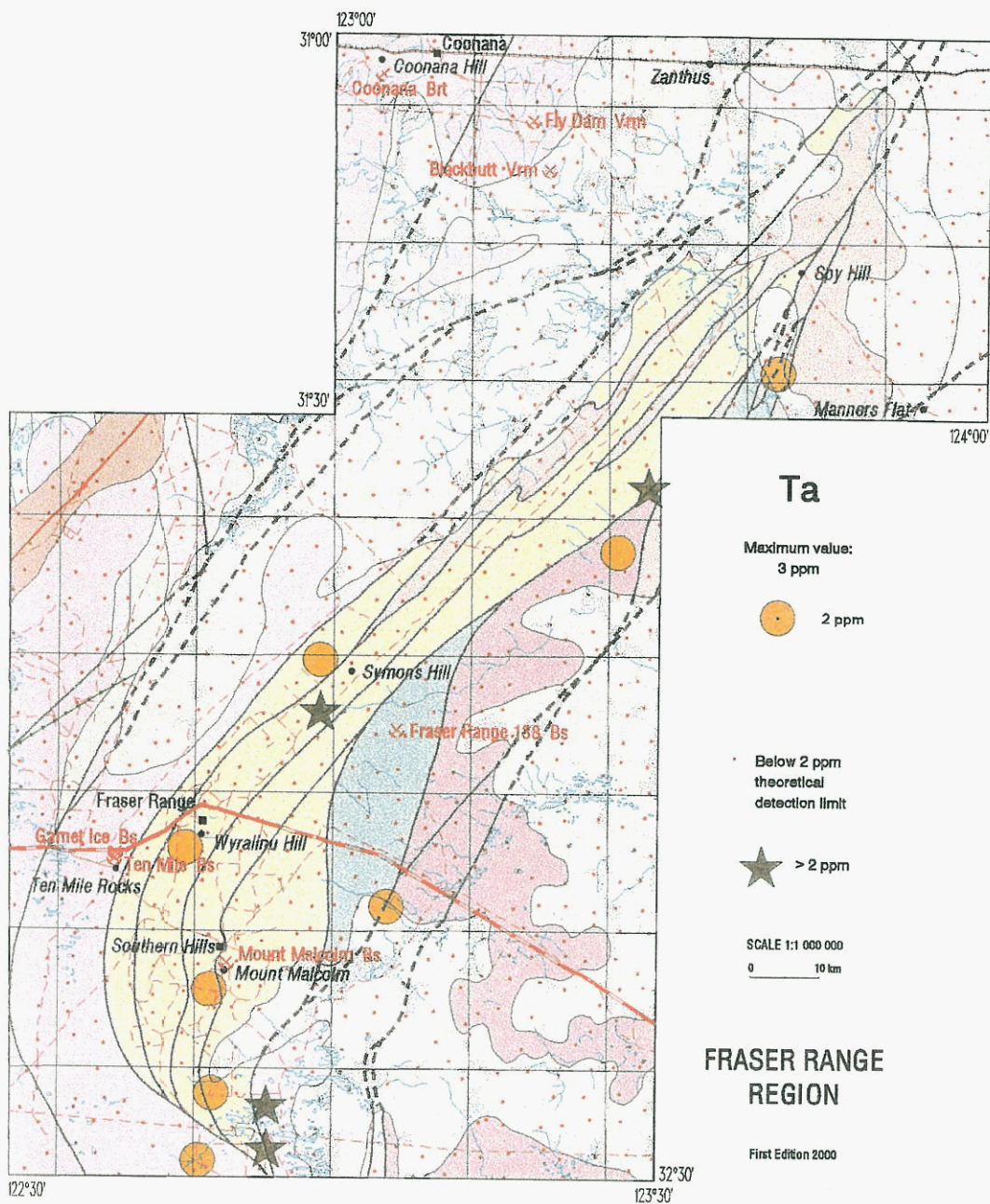


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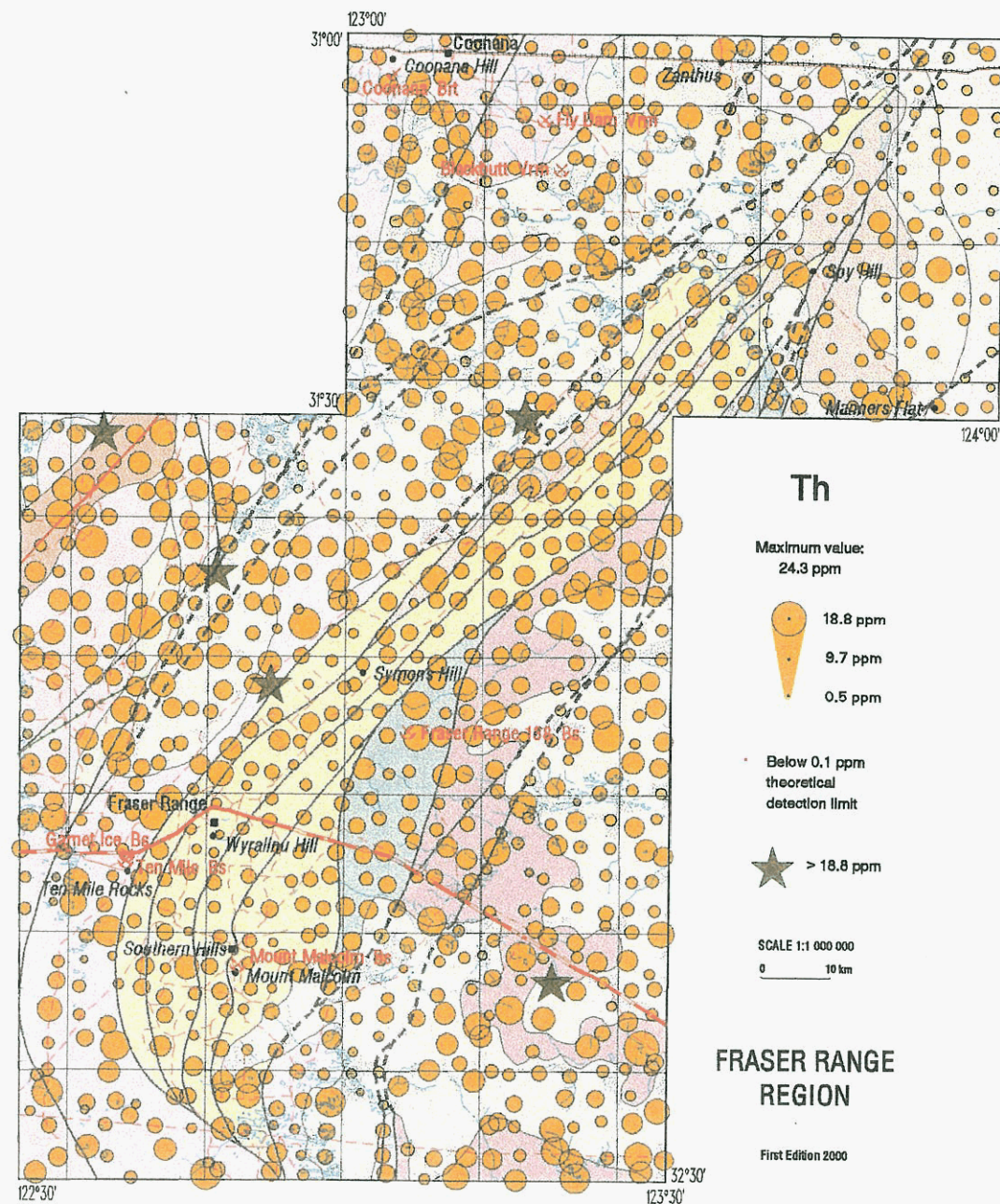


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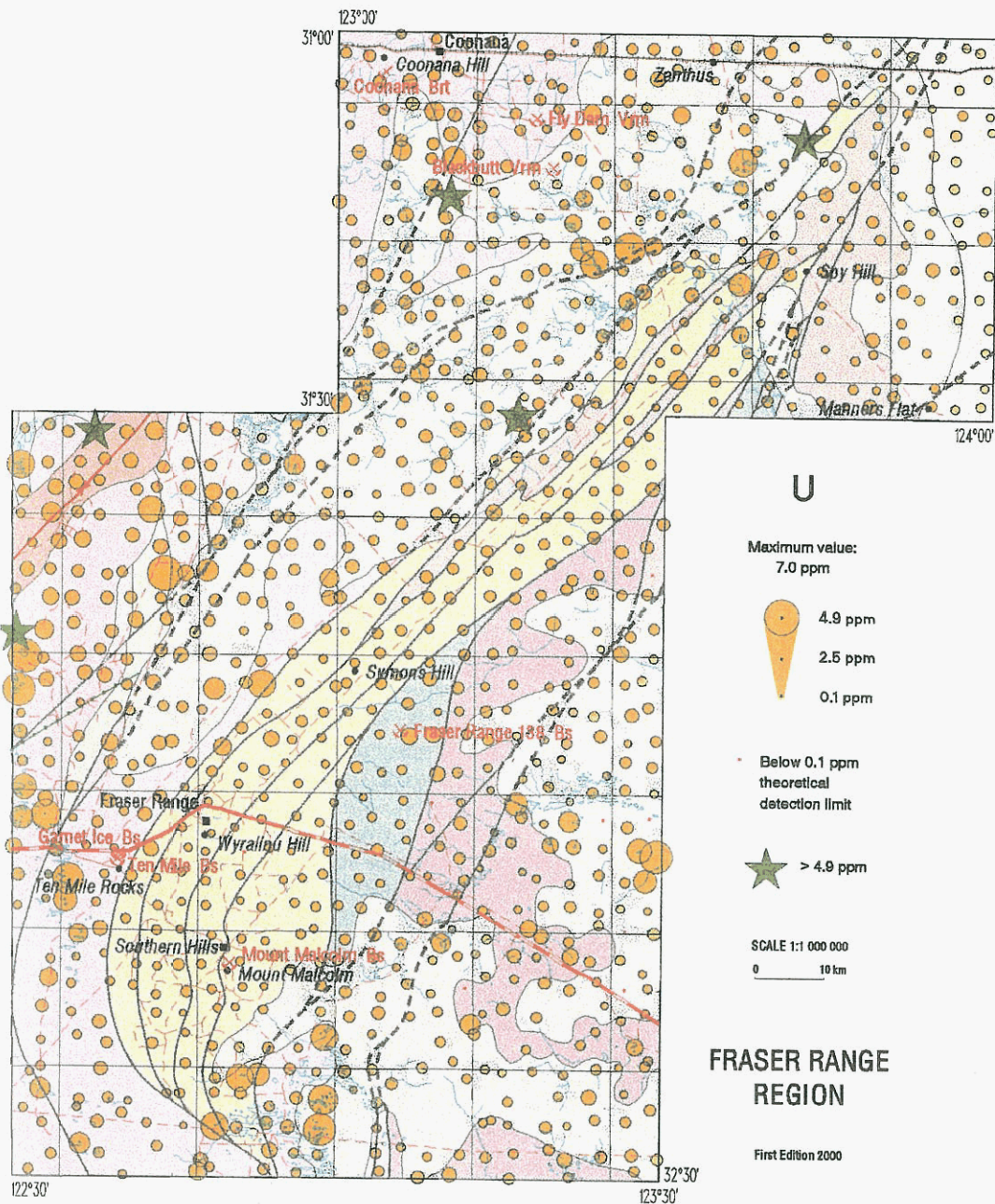


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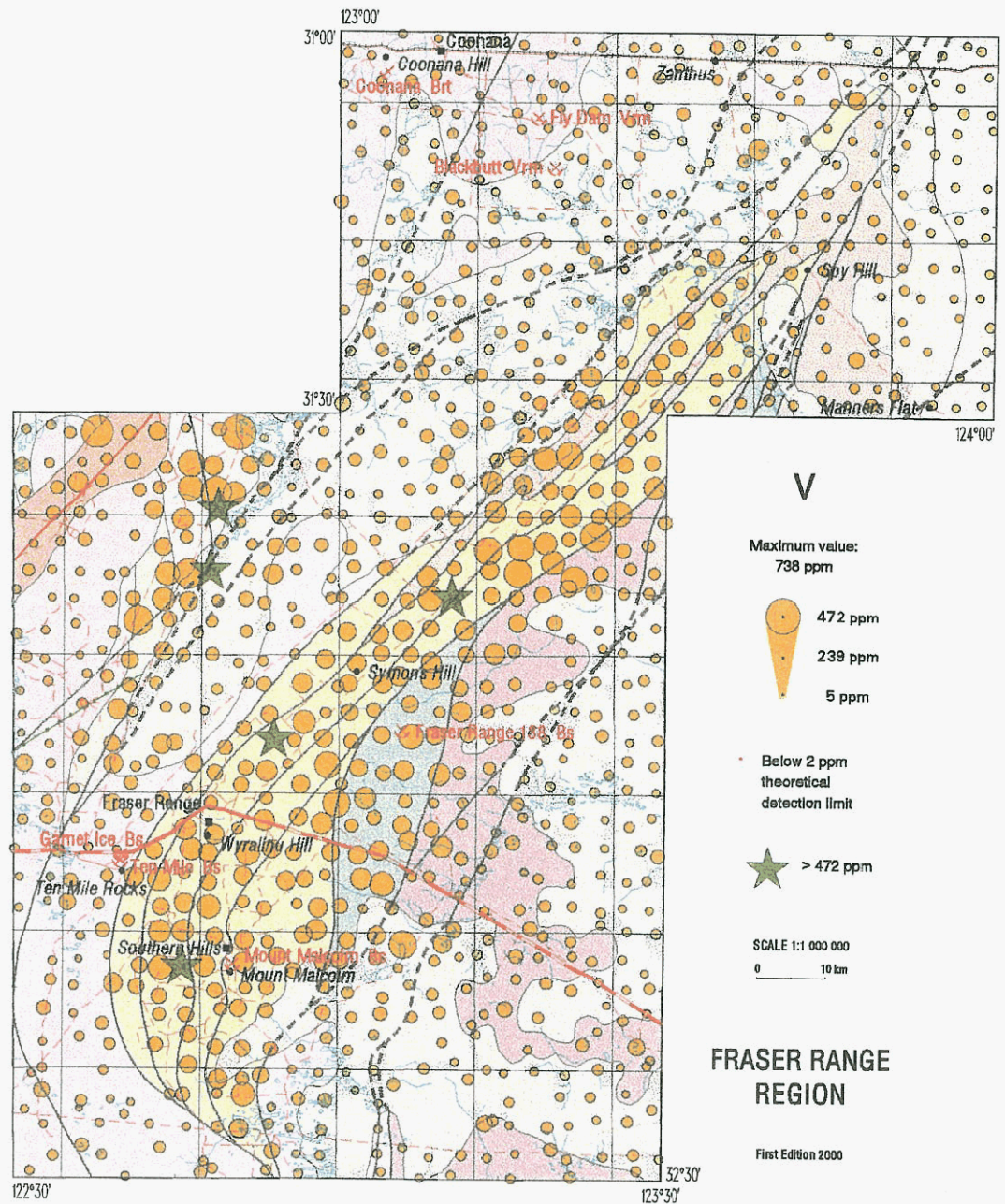


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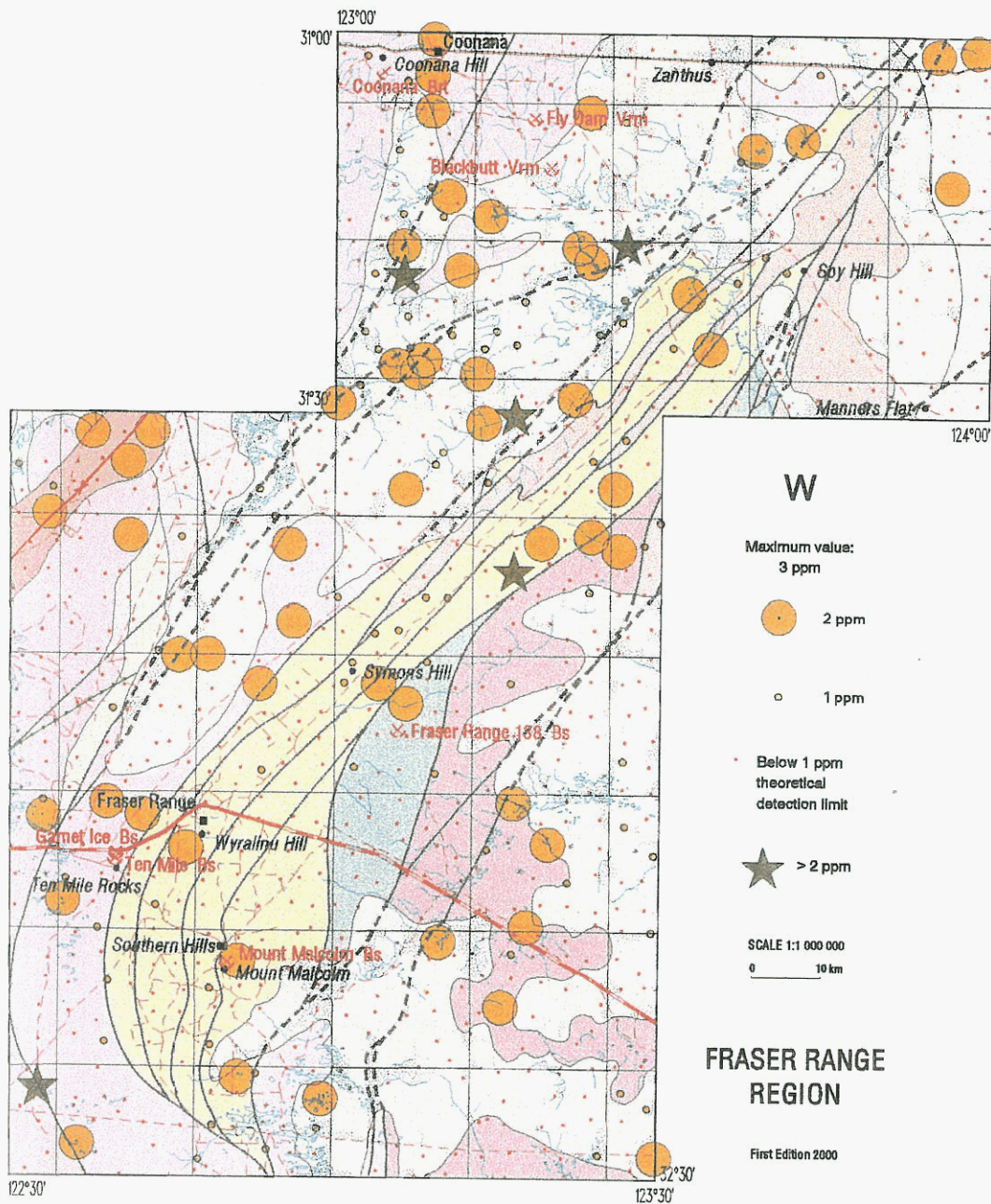


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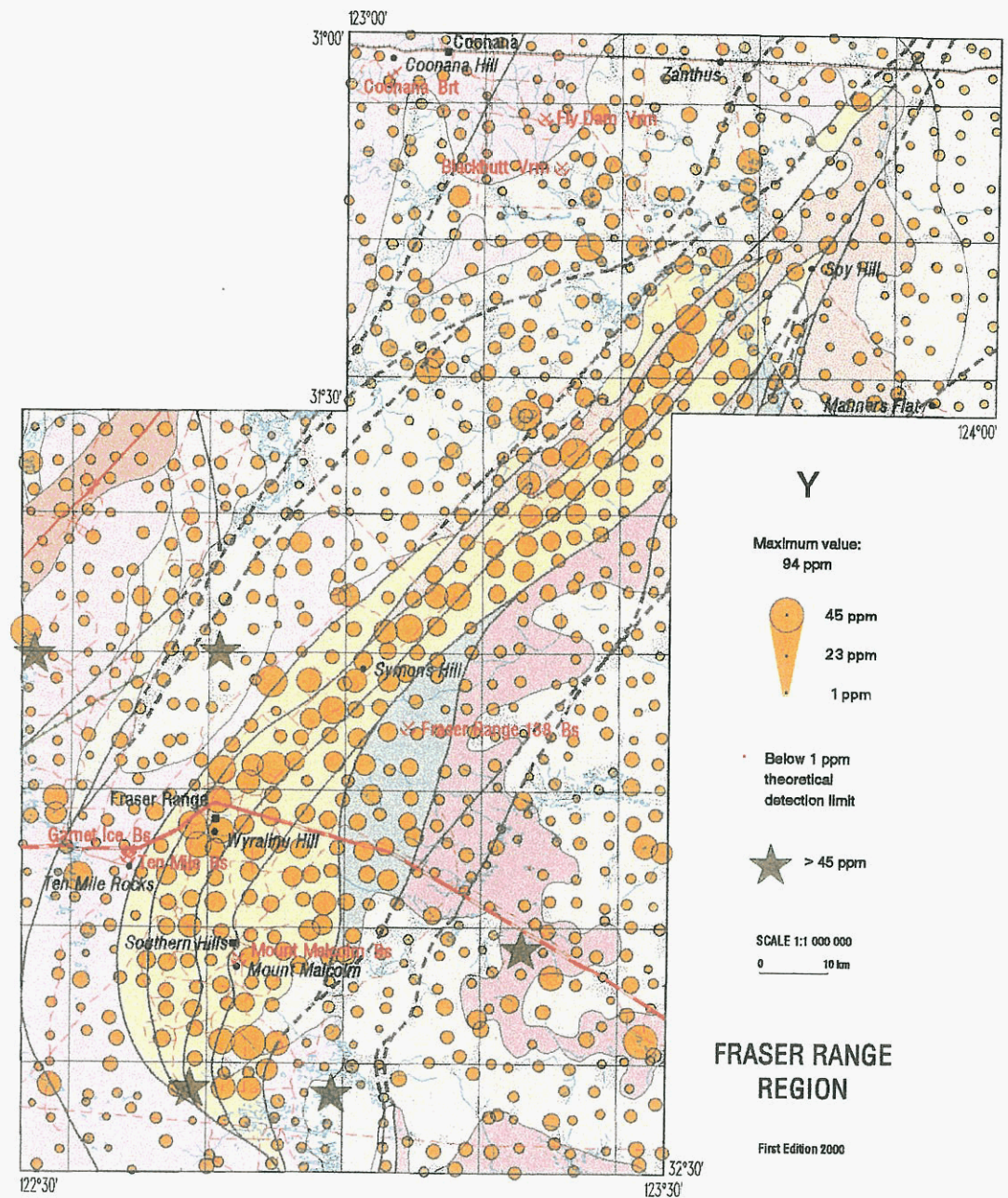


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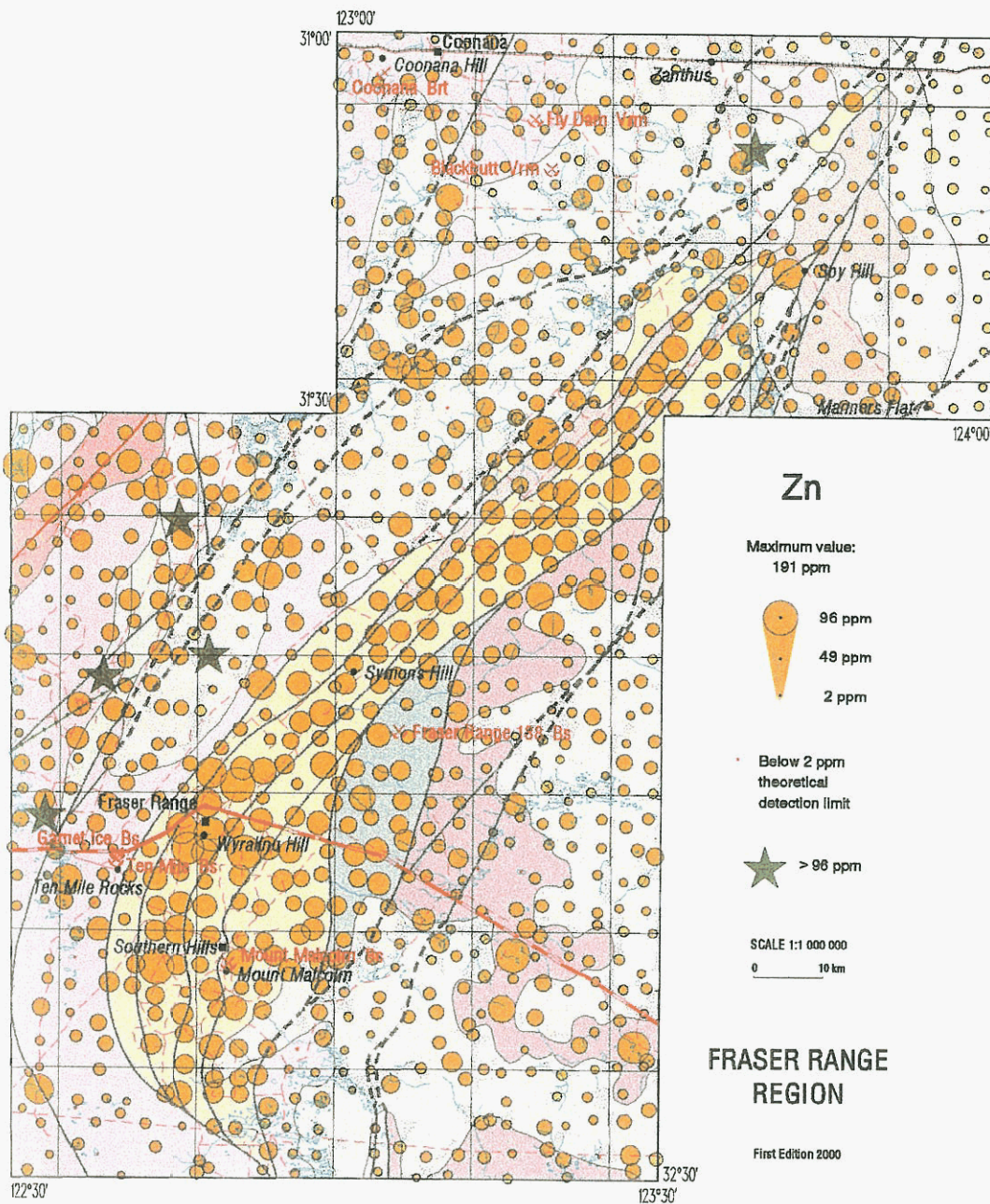


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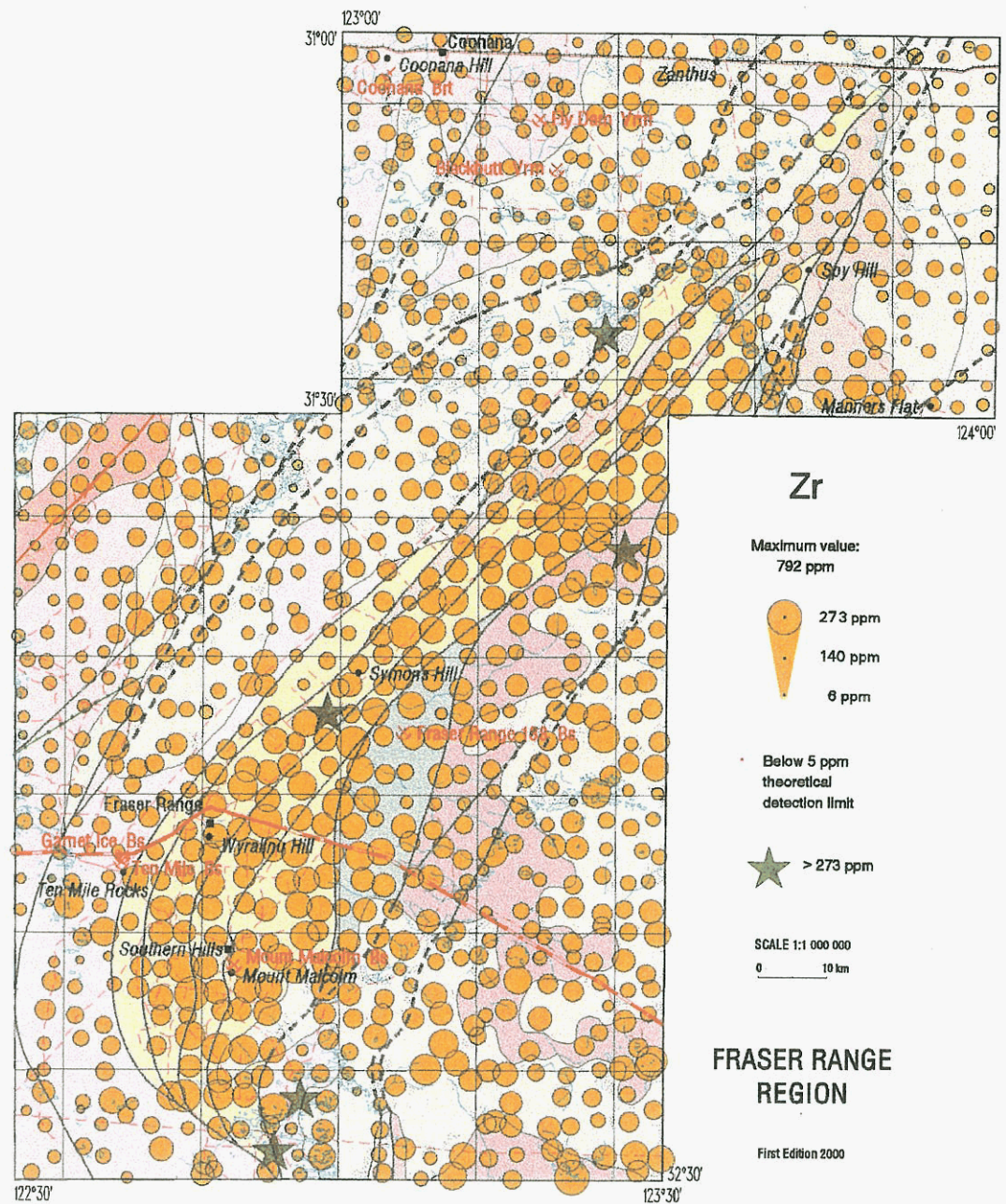
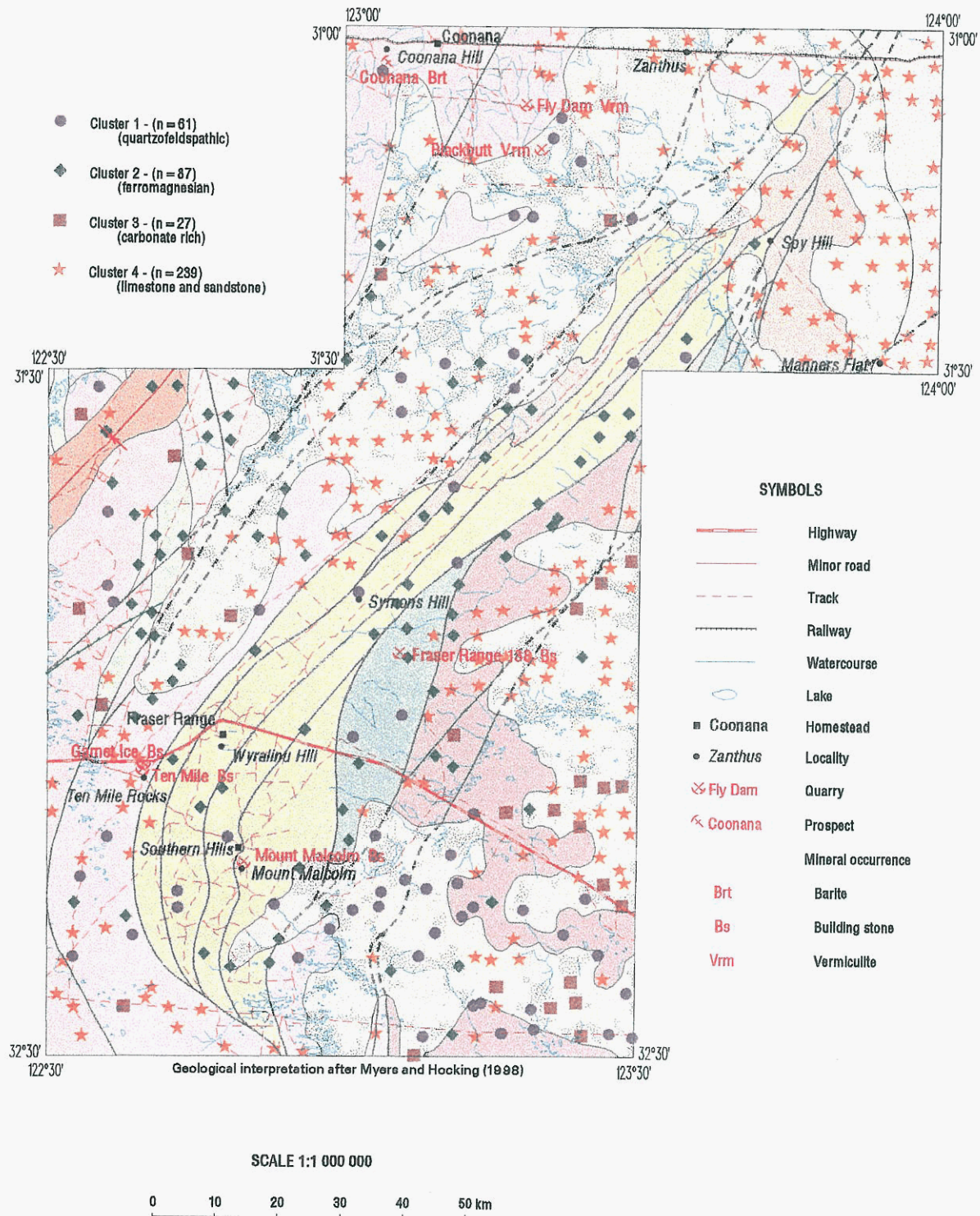


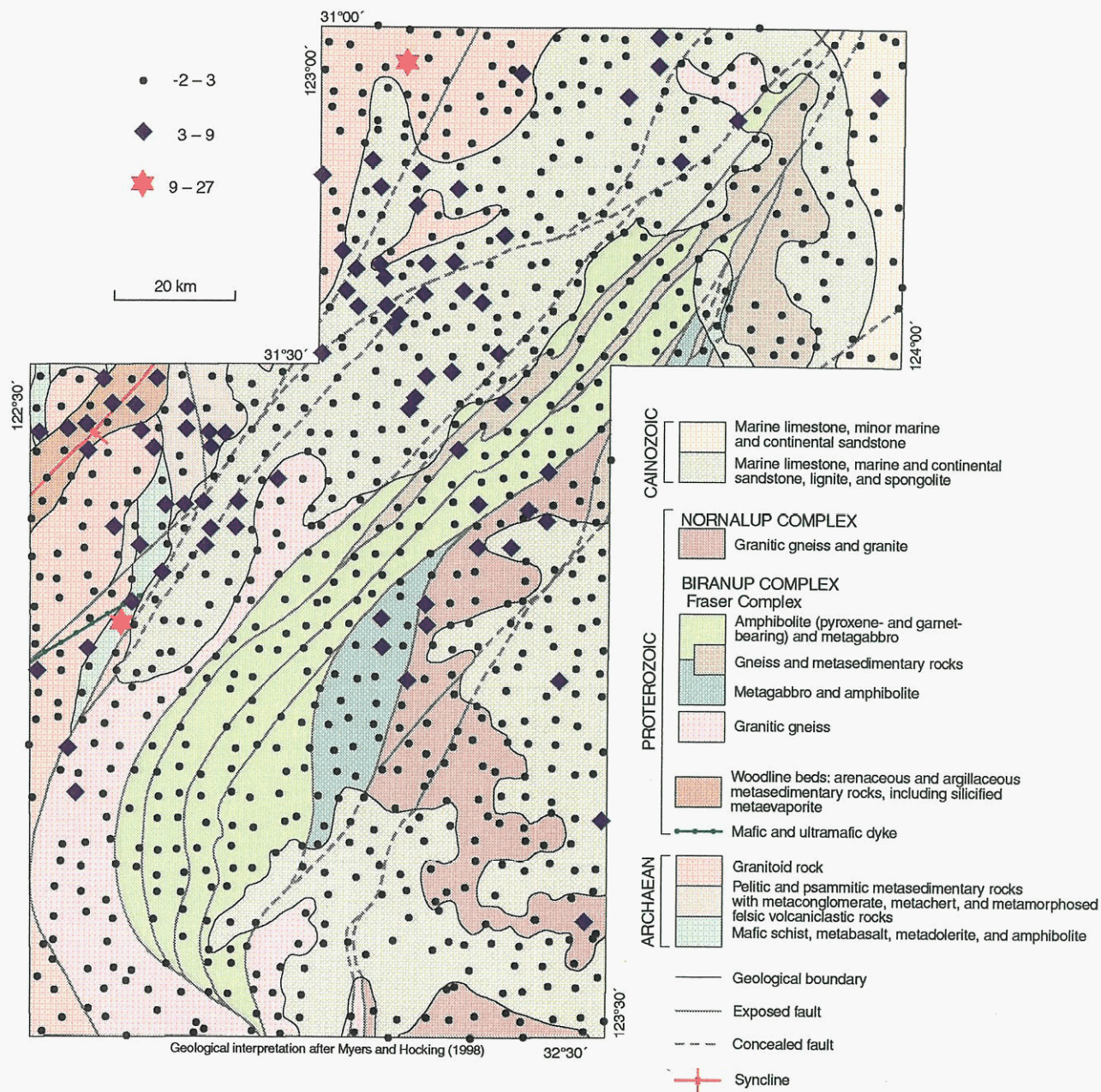
Figure 49

CLUSTER ANALYSIS OF HETEROGENEOUS SANDPLAIN (S) IN THE FRASER RANGE REGION



FRASER RANGE REGION

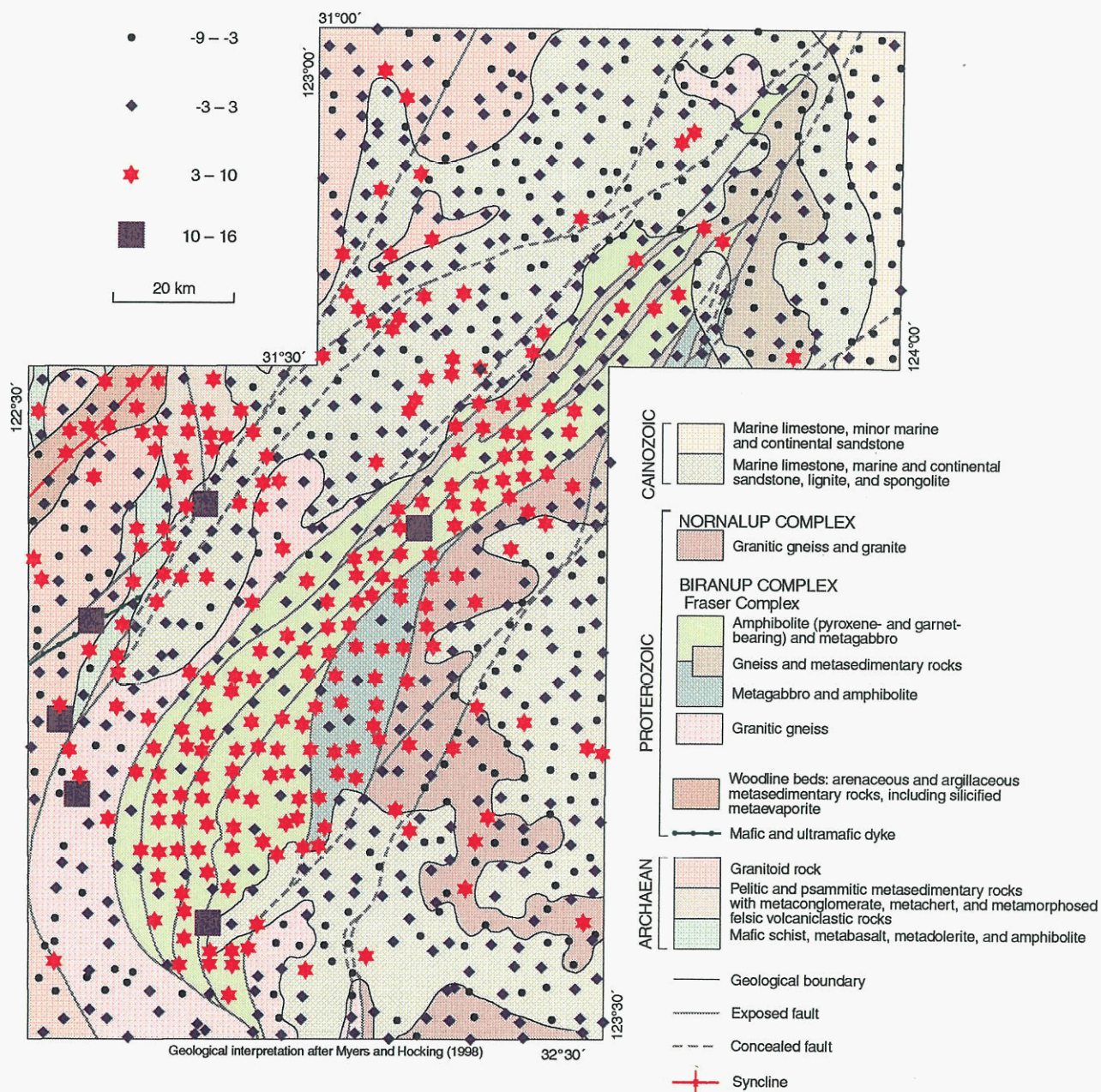
First Edition 2000



PAM192

2.3.00

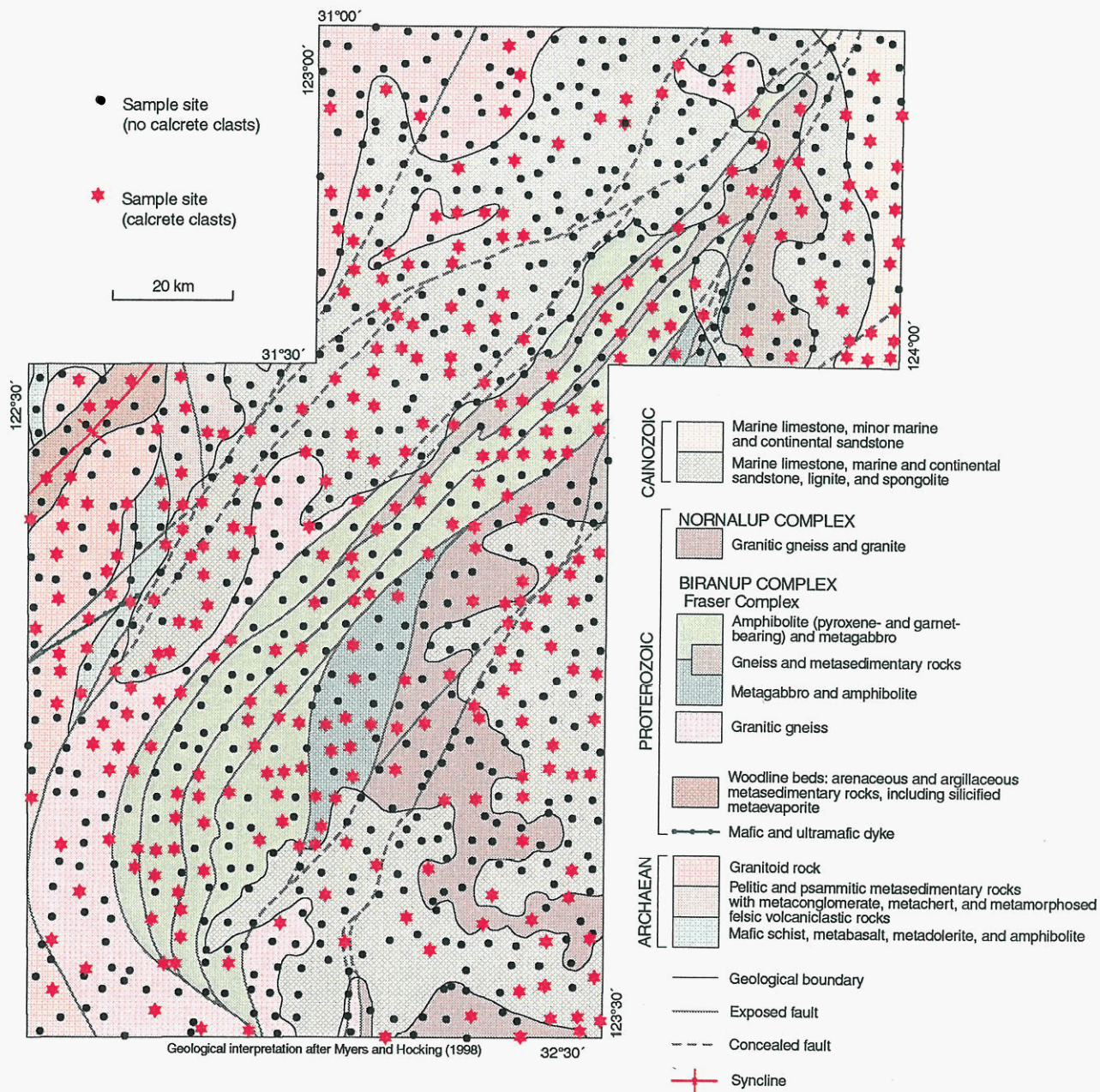
Figure 51. Chalcophile-index scores (As + Ag + Bi + Cd + Sb + Mo)



PAM193

2.3.00

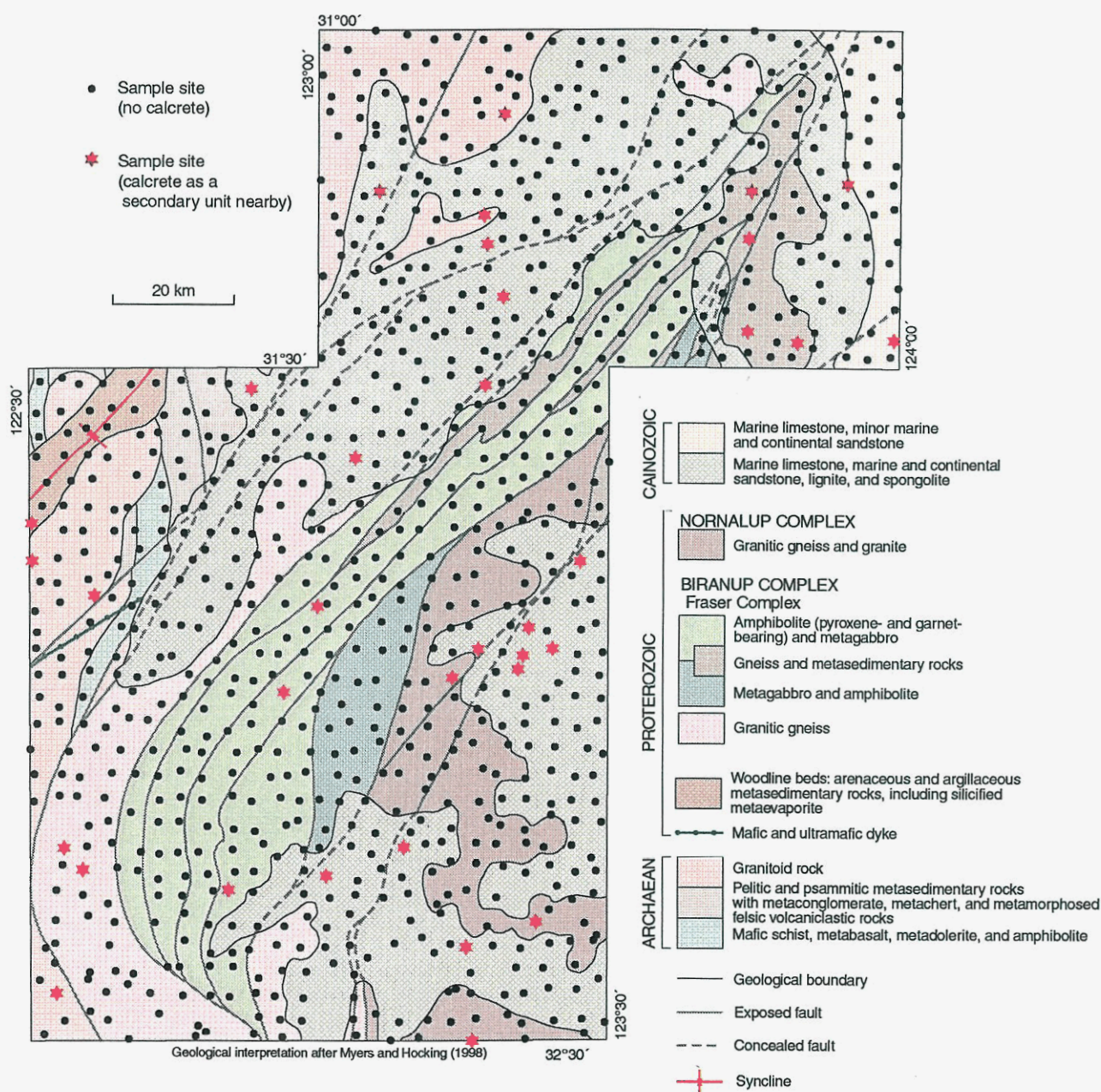
Figure 52. Ferro-alloy index (Ni + Cr + Mo + Co + V)



PAM198

2.3.00

Figure 53. Distribution of sample sites with calcrete clasts



PAM195

2.3.00

Figure 54. Distribution of sample sites with calcrete as a secondary unit nearby

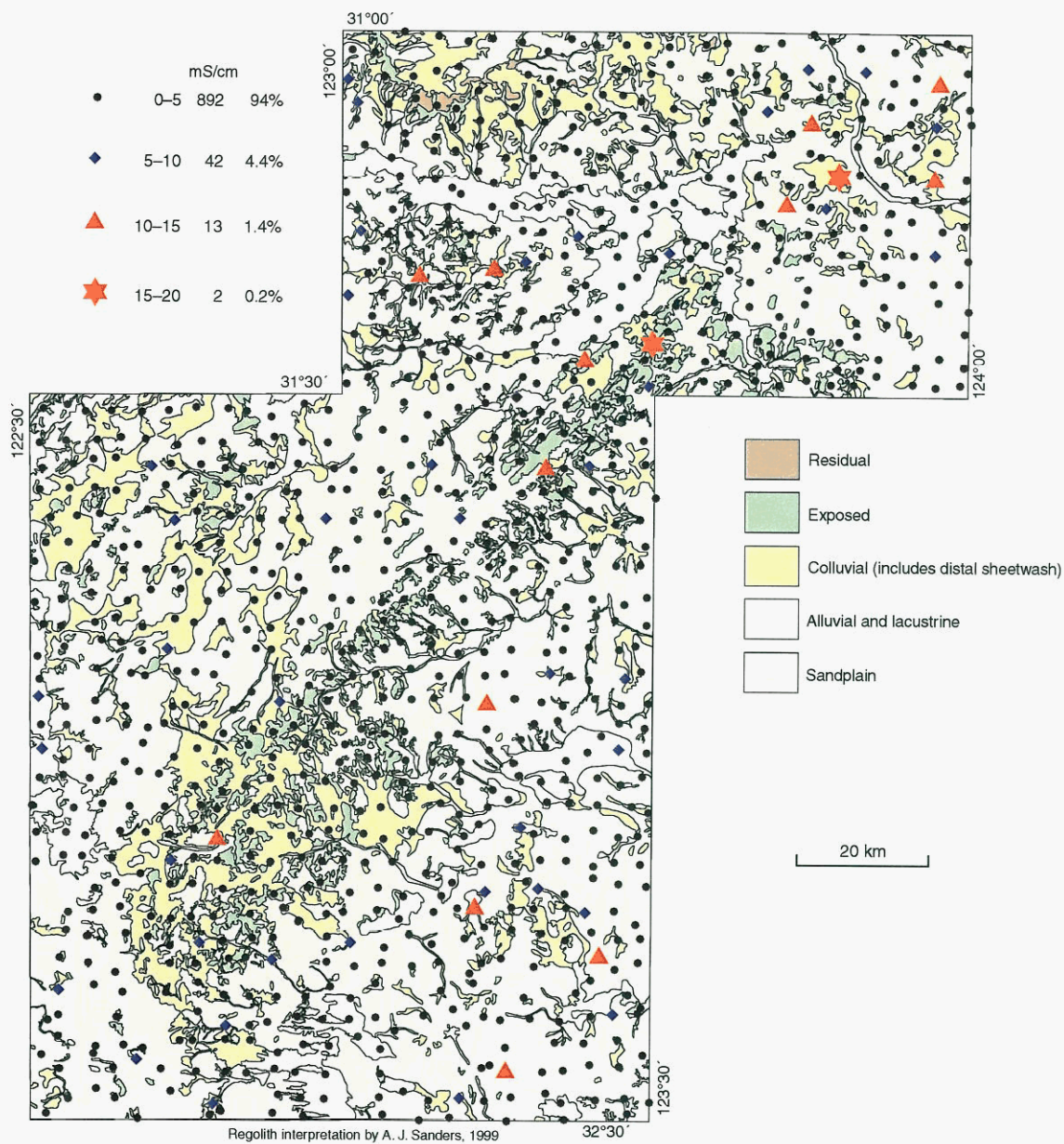


Figure 55. Regolith conductivity (TDS)

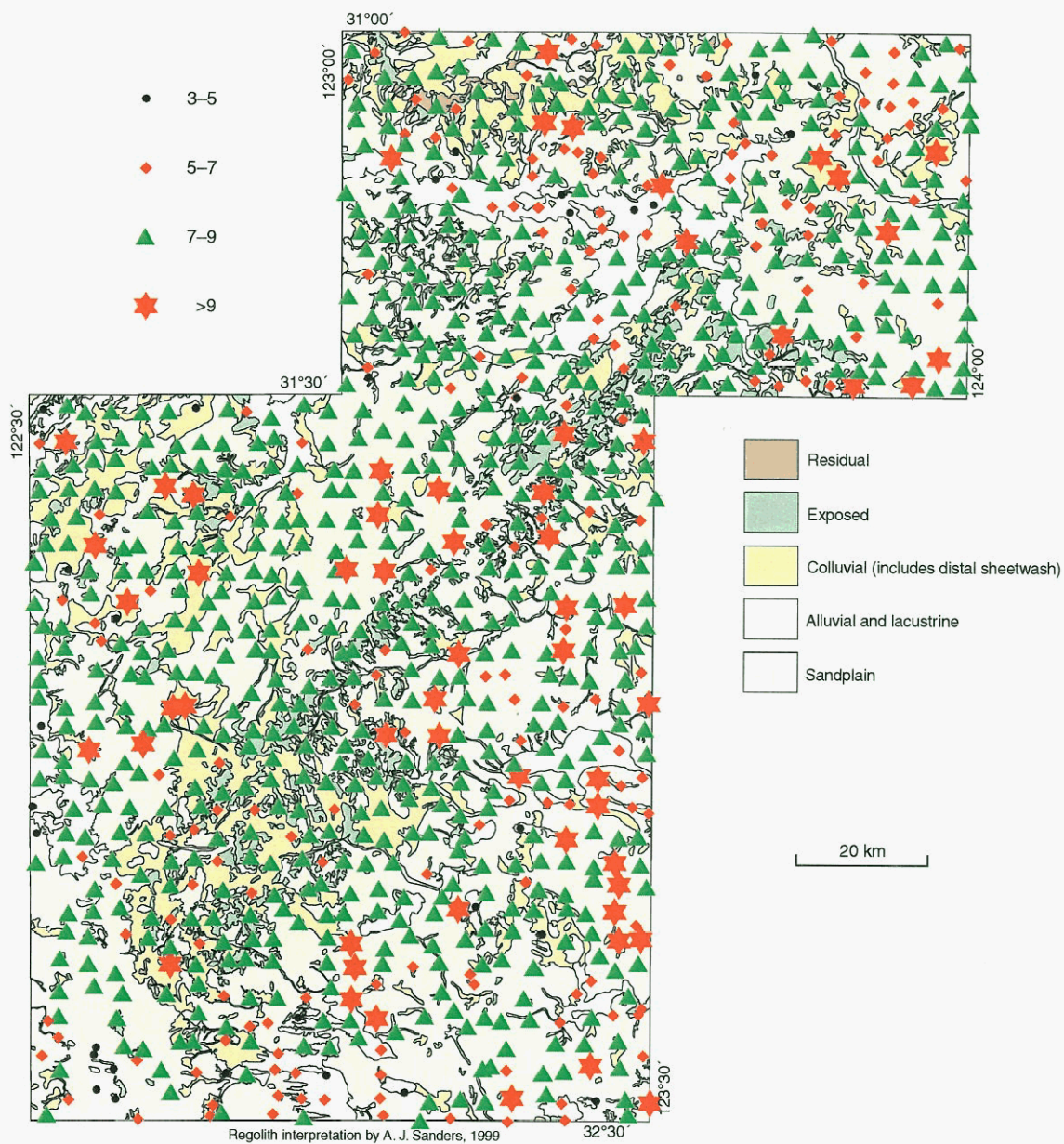
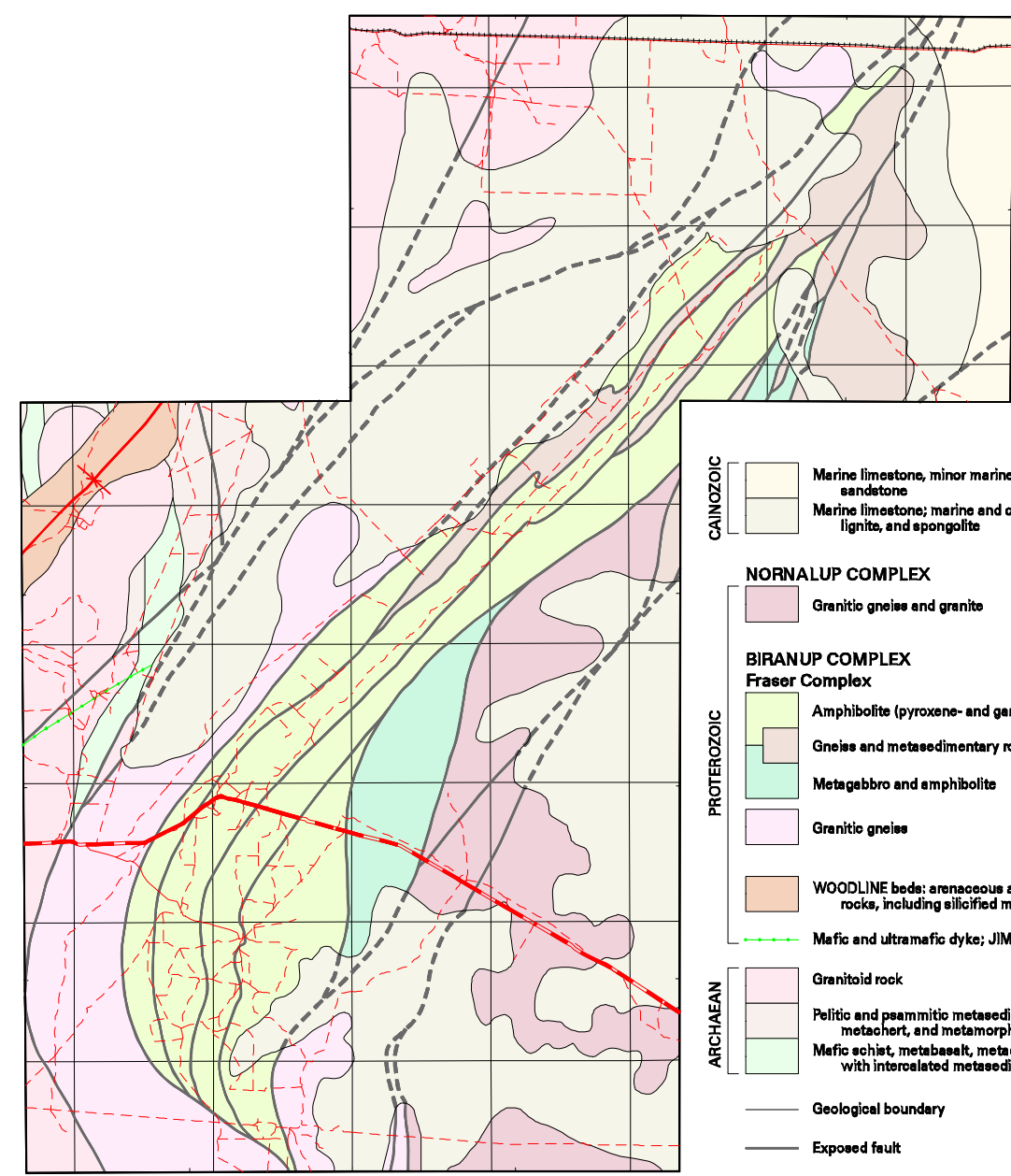


Figure 56. Regolith acidity-alkalinity (pH)

FRASER RANGE REGION

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SIMPLIFIED GEOLOGICAL INTERPRETATION



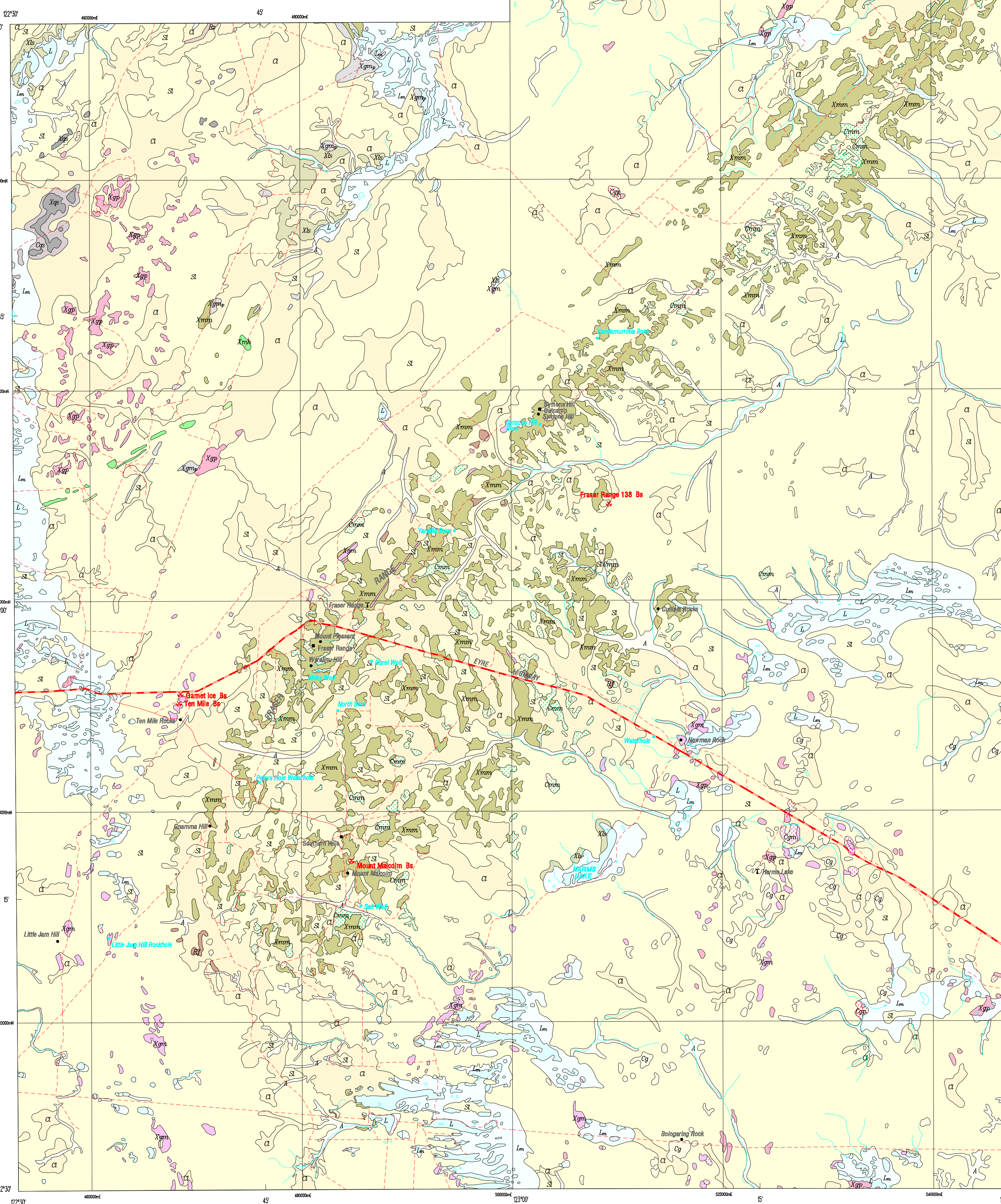
REGOLITH MATERIALS

REFERENCE

- RESIDUAL (R)** - Residual surface, proximal and reworked material derived by in situ weathering
- Rf** comprising mainly iron-rich material (ferric and ferruginous lag)
 - Rt** comprising mainly silica-rich material (silicite)
- EXPOSED (X)** - Outcrop of saprock, bedrock, and subcrop with locally derived sand, silt, clay, and rubble
- Xgrs** derived from quartzite/diopside metamorphic rock (granitic gneiss, gneissiferous gneiss, and felsic schist)
 - Xgrm** derived from quartzite/diopside metamorphic rock (pyroxene- and garnet-bearing gneiss, amphibolite, and metagabbro) and minor quartzite and gneiss
 - Xgp** derived from quartzite/diopside plutonic rock (granite and granitic gneiss)
 - Xls** derived from sedimentary rocks (sandstone, siltstone, shale, and spongiolite)
 - Xmh** derived from ferromagnesian hypabyssal rock (mafic and ultramafic dykes)
 - Xmms** derived from ferromagnesian metamorphic rock (pyroxene- and garnet-bearing gneiss, amphibolite, and metagabbro) and minor quartzite and gneiss
 - Xqs** derived from quartz-rich silicified rock (sandstone and mudstone)
 - Xu** derived from ultramafic metamorphic rock (magnesian-serpentine schist)
- COLLUVIAL (C)** - Unconsolidated and semi-consolidated clay, silt, sand, gravel, and rubble, small rock outcrops locally present
- Cf** dominated by transported residual and silt and sand, silt, and clay in colluvial, sheetwash, or alluvial deposits
 - Cg** comprising strongly ferruginised material
 - Cgrs** derived mainly from quartzite/diopside metamorphic rock (granitic gneiss, gneissiferous gneiss, and felsic schist)
 - Cgrm** derived from quartzite/diopside metamorphic rock (pyroxene- and garnet-bearing gneiss, amphibolite, and metagabbro) and minor quartzite and gneiss
 - Cgp** derived from quartzite/diopside plutonic rock (granite and granitic gneiss)
 - Cmh** derived mainly from ferromagnesian hypabyssal rock (mafic and ultramafic dykes)
 - Cmms** derived mainly from ferromagnesian metamorphic rock (pyroxene- and garnet-bearing gneiss, amphibolite, and metagabbro) and minor quartzite and gneiss
 - Cqs** derived from quartz-rich silicified rock (sandstone and mudstone)
 - Cu** derived mainly from ultramafic metamorphic rock (magnesian-serpentine schist)
- DISTAL SHEETWASH (W)**
- Wf** Sand- and clay-dominated colluvium or sheetwash with indistinct alluvial channels
- ALLUVIAL (A)**
- A** Cobbles, gravel, sand and silt in active alluvial channels
- LACUSTRINE (L)**
- L** Sand, silt, clay, and evaporite material in playas, saline and gypsumiferous locally
 - Lm** Sand, silt, and evaporite material in mixed plays and dune terrain; saline and gypsumiferous locally; may include areas of residual sand, silt, and clay
- SANDPLAIN (S)**
- Sf** Residual and silt and sand, silt, and clay in variable proportions with local areas of colluvium; indistinct blanket cover, includes ferruginous and calcareous soil

SYMBOLS

- Regolith boundary
- Highway
- Minor road
- Railway
- Watercourse
- Lake
- Coonanna
- Zanthus
- Harris Lake
- Fly Dam
- Coonanna
- Homestead
- Locality
- Microwave repeater station
- Quarry
- Prospect
- Mineral occurrence
- Bt
- Bs
- Vrm
- Bedite
- Bedstone
- Vermiculite



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



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



ACSO
AUSTRALIAN COASTAL SURVEY ORGANISATION



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
DAVID BLIGHT, DIRECTOR

SCALE 1:250 000

TRANSVERSE MERCATOR PROJECTION
HORIZONTAL DATUM: AUSTRALIAN GEODETIC DATUM 1984
VERTICAL DATUM: AUSTRALIAN HEIGHT DATUM
Grid lines indicate 20 000 metre interval of the Australian Map Grid Zone 51

REGOLITH MATERIALS

REGOLITH GEOCHEMISTRY SERIES

FRASER RANGE REGION

FIRST EDITION 2000
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Edited by N. Telford and G. Loan
Cartography by G. Jose

Topography from Australian Land Information Group
and modified from geological field survey (1980)

This map was compiled and produced using a Geographic Information System (ARC/INFO),
and the data are available in digital form
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the data, are available from the Information Centre, Department of Minerals and Energy,
100 Plain Street, East Perth, W.A. 6004. Phone (08) 9222 3459, Fax (08) 9222 3444

Compiled by A. J. Sanders, S. Sheehan, M. Painter, A. Ripatti, J. Watt, and
B. Greenwood (from GSWA), S. Baege, J. Hansen, A. Lee, S. McGuinness, 1998

Compiled using Landsat TM images (1986 data), black and white aerial photography,
Cartograph 1984, Delandina 1992, Nemmen 1974, Wiggamoocha 1980, published
GSWA 1:250 000 Geological Series maps (see sheet index), and field observations 1998

The recommended reference for this map is:
SANDERS, A. J., 2000, Regolith materials, Fraser Range region,
in: Geological mapping of the Fraser Range region by
P. A. MORRIS, A. J. SANDERS, S. A. MCGUINNESS, J. COOPER, and J. D. KING,
Western Australia Geological Survey, 1:250 000 Regolith Geochemistry Series Explanatory Notes, Plate 1



SHEET INDEX

KALGOORNEY SH 61-4	KIMBERLEY SH 61-10	CUNDEELEE SH 61-11	SEMORE SH 61-12
BONNARIN SH 61-13	WIDEMOUTH SH 61-14	ZANTHUS SH 61-15	HARTHA SH 61-16
LAKE JOHNSON SH 61-17	NORSEMAN SH 61-18	BALADONIA SH 61-19	CULVER SH 61-20
HAVERSTOCK SH 61-21	ESPERANCE SH 61-22	MALCOLM SH 61-23	BALLY SH 61-24

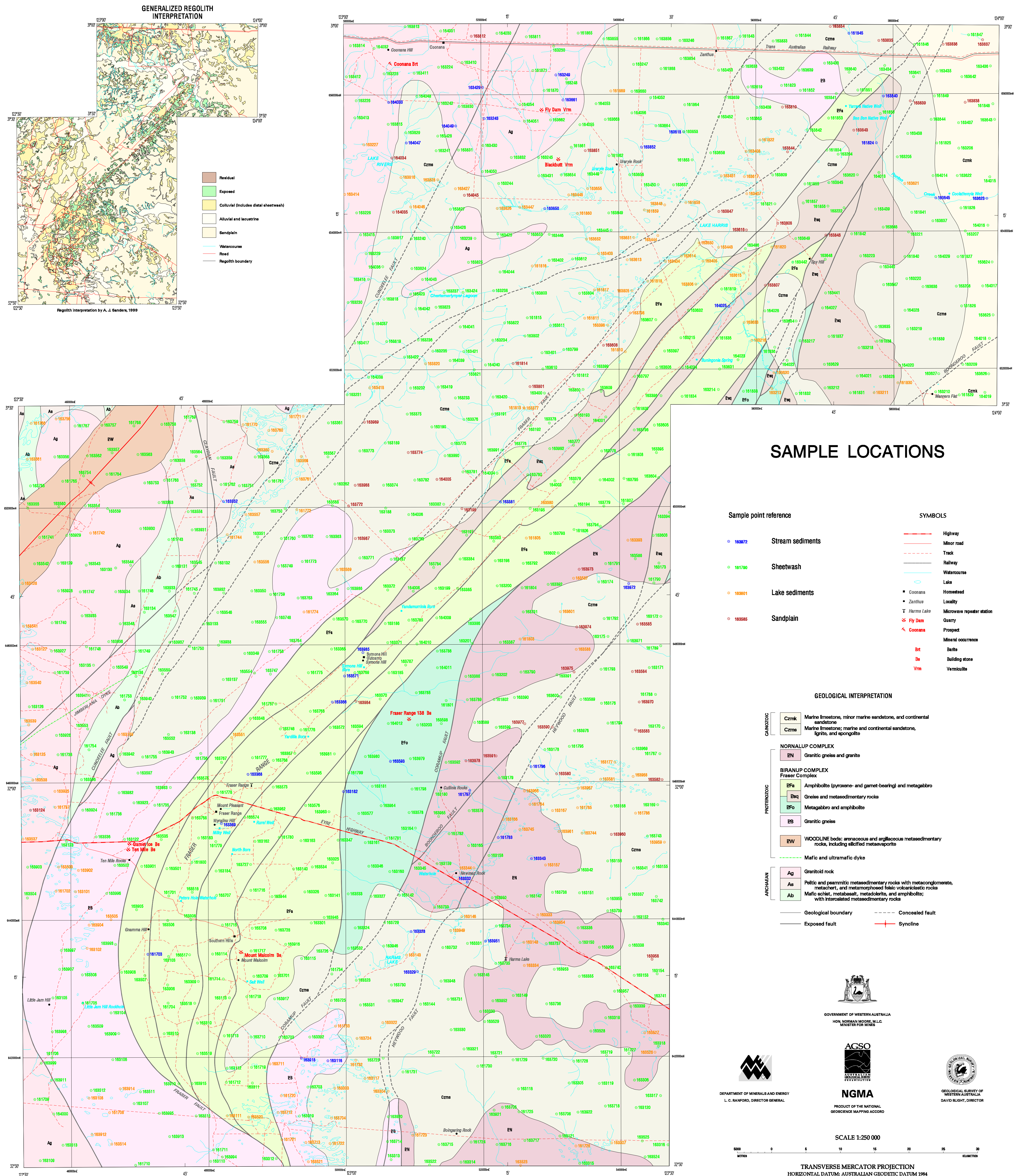
INDEX TO 1:100 000 MAP SHEETS WITHIN FRASER RANGE REGION

COONANNA 3638	ZANTHUS 3635
YARULLA 3424	BYRON HILL 3634
FRASER RANGE 3423	HARRIS 3633

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

FRASER RANGE REGION

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA



Edited by N. Telford and G. Loan
Cartography by G. Jones

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

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Sampling by: K. Pys, S. Sheehy, M. Painter, A. Rignall, J. Watt, and B. Greenwald (from GSMA), S. Baeleou, J. Hanson, A. Lee, S. McGuinness, 1998

Analysed by: Amel Laboratories. Minimum sample size: 1.5 kg.
Fraction of sample analysed: > 0.45mm < 2mm

Geological interpretation after Myers and Hemmings (1998).

The recommended reference for this map is:
MORRIS, P. A., SANDERS, A. J., MCGUINNESS, S. A., COKER, J. and KING, J. D., 2000.
Sample locations, Fraser Range region. In: Geological mapping of the Fraser Range region by P. A. MORRIS, A. J. SANDERS, S. A. MCGUINNESS, J. COKER, and J. D. KING. Western Australia Geological Survey, 1:250 000 Regolith Geochemistry Series Explanatory Notes, Plate 2



SHEET INDEX			
KALGOORNEY SH 51-4	KIMBERLEY SH 51-5	CUNDEELEE SH 51-11	SEWING SH 51-12
BOONAHIN SH 51-13	WIDEMOUTH SH 51-14	ZANTHUS SH 51-15	HARTHA SH 51-16
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NAVEMOUTH SH 51-21	ESPERANCE SH 51-22	MALCOLM SH 51-23	BALLY SH 51-24

INDEX TO 1:250 000 MAP SHEETS WITHIN FRASER RANGE REGION	
COONANA 3635	ZANTHUS 3635
YANDALLA 3635	BYRON HILL 3635
FRASER RANGE 3635	HARTHA 3635

SAMPLE LOCATIONS

REGOLITH GEOCHEMISTRY SERIES FRASER RANGE REGION

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