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MINERAL OCCURRENCES AND EXPLORATION POTENTIAL OF THE WEST KIMBERLEY

By L. Y. Hassan

Geological Survey of Western Australia

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

REPORT 88

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Perth 2004

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Cover photograph:
Ore from the Goongewa mine: sphalerite and galena with marcasite and sparry calcite surrounding a limestone fragment in a solution cavity

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Mineral occurrences and exploration potential of the west Kimberley

by

L. Y. Hassan

Abstract

The west Kimberley area in the north of Western Australia is an important producer of zinc, lead, iron ore, and diamonds and it is prospective for these minerals and a variety of other minerals, including gold, bauxite, coal, copper, tungsten, tin, beryl, mica, corundum, uranium, and clays. The first significant production in the area was high-grade iron ore at Yampi Sound in 1951. Very large resources of bauxite were delineated at Mitchell Plateau in the late 1960s, but these remain undeveloped. Major zinc–lead production commenced from the Lennard Shelf Project in 1987 following a period of substantial exploration for Mississsippi Valley-type (MVT) deposits in the 1970s and 1980s. The Lennard Shelf Project was the largest producer of zinc and lead in the State and the sixth largest zinc–lead mining complex in the world until it was placed on care and maintenance in 2003. Diamonds were discovered in the Ellendale area in 1976, and diamond production commenced in May 2002. There has also been minor production of copper, gold, tungsten, tin, corundum, mica, beryl, and dimension stone from the area. A large low-grade coal resource at Liveringa is currently being re-examined.

The oldest tectonic unit in the west Kimberley is the King Leopold Orogen, which consists of Palaeoproterozoic metasedimentary and igneous rocks of the Hooper Complex and the deformed margins of the Palaeoproterozoic Speewah and Kimberley Basins. The western part of the Speewah and Kimberley Basins occupy the northern part of the study area; these basins are overlain in places by Mesoproterozoic to Neoproterozoic sedimentary rocks. The Phanerozoic Canning Basin unconformably overlies the Hooper Complex in the southern part of the area.

The most prospective unit of the Hooper Complex is the Marboo Formation in which black slates and phyllites host possible sedimentary–exhalative (SEDEX) and vein-style copper mineralization. Volcanogenic massive sulfide (VMS) base metal mineralization has also been recognized in the Marboo Formation. There is potential for the industrial minerals kyanite, corundum, and garnet where argillic rocks of the Marboo Formation have been strongly metamorphosed. Other prospective units of the Hooper Complex are the Whitewater Volcanics and Ruins Dolerite. The Whitewater Volcanics have potential to host hydrothermal and volcanogenic gold mineralization but only minor mineralization has been found to date. The Ruins Dolerite has potential for copper and nickel mineralization. Granitoids and dolerite in the Hooper Complex have demonstrated potential for further production of dimension stone.

The Kimberley Basin has potential for additional stratabound sedimentary iron ore production from the Yampi Formation at Cockatoo and Koolan Islands and other islands in Yampi Sound. The Yampi Formation is also prospective for uranium. Copper mineralization has been reported from the Wotjulum Porphyry, Carson Volcanics, Jap Bay Member of the Warton Sandstone, the middle section of the Pentecost Sandstone, and the Teronis Member of the Elgee Siltstone. Gold-bearing reefs were reported from the Carson Volcanics in 1907 but never followed up. The discovery in 2002 of a new epithermal gold province to the east of the study area has awakened interest in the gold prospectivity of the entire Kimberley Basin, including the west Kimberley.

The Devonian reef complexes of the Lennard Shelf in the Canning Basin are highly prospective for further discoveries of MVT zinc–lead mineralization. Faults have played a major role in channelling solutions. There is also strong stratigraphic control. In the southeastern part of the Lennard Shelf, the lower part of the platform facies Pillara Formation and the pre-reef Cadjebut Formation are the most prospective units. Further north, the upper-platform facies and marginal-slope facies of the Pillara Formation and, to a lesser extent, marginal-slope Sadler Formation, host the known zinc–lead mineralization. Still further north, the most prospective units for zinc–lead mineralization are reef-slope and fore-reef limestone of the Napier Formation and, to a lesser extent, the Windjana Limestone.

Extensive deposits of low-grade coal have been found in the Permian of the Canning Basin. The Lightjack Formation of the Liveringa Group appears to be the most prospective unit but coal has also been found in the Permian Condren Sandstone and Hardman Formation, in the Carboniferous Anderson Formation, and in the Late Jurassic to Early Cretaceous Jarlemai Siltstone. Thin beds of phosphate and oolitic iron formation have also been recorded from the Canning Basin.

If the Cambrian Milliwindi dyke is the feeder zone for the Antrim Plateau Volcanics in the east Kimberley, then it has potential for Voiseys Bay-style nickel–copper mineralization.

Miocene lamproites intrude rocks ranging in age from Palaeoproterozoic to Triassic. Economic resources of diamond have been defined in two of the lamproites at Ellendale and many others contain traces of diamond. There is potential for the discovery of economic diamond concentrations in the known lamproites and for new lamproite discoveries. There is also potential for diamonds in c. 820 Ma kimberlites in the Kimberley Basin.

KEYWORDS: mining, mineralization, exploration, King Leopold Orogen, Hooper Complex, Speewah Basin, Kimberley Basin, Canning Basin, Lennard Shelf, lamproites, regolith, lead, zinc, diamonds, iron, bauxite, coal, copper, gold, tungsten, tin, beryl, mica, corundum, uranium, dimension stone.

Introduction

Although the west Kimberley was Western Australia's largest producer of lead and zinc, and has significant resources of diamonds, bauxite, iron ore, uranium, and coal, as well as occurrences of many other commodities, much of the area is rugged and remote terrain and has only been sparsely explored. The aim of this study is to show the distribution of reported mineralization and exploration activity in a Geographic Information System (GIS) database, to relate the mineralization to the geological setting, and to highlight the prospectivity of the west Kimberley area for a range of mineral commodities and mineralization styles.

Details of mineral exploration, mineral occurrences, and other geoscientific information for the study have been compiled from the following sources:

- the large dataset of open-file statutory mineral exploration reports held in the Western Australian mineral exploration (WAMEX) database at the Department of Industry and Resources (DoIR);
- the database of Western Australia's mines and mineral deposits information (MINEDEX) held at DoIR;
- information published in books, journals, magazines, newspapers, company reports to shareholders and the Australian Stock Exchange (ASX), and on the internet; and
- regional geological surveys, airborne geophysical datasets, and remote-sensing datasets.

This mineral prospectivity study of the west Kimberley has three main parts: this report, Plate 1 of this Report, and a digital dataset on CD-ROM. The Report reviews the regional geology of the area and the history of mining and exploration, and gives examples of mineral occurrences for each style of mineralization, mineralization controls, and potential for further discoveries.

Plate 1 shows the mineral occurrences, indicating commodity and mineralization style, on a geological map showing interpreted geology at 1:500 000 scale. Enlargements of densely mineralized areas on Plate 1 are included as Plate 1a. A listing of the mineral occurrences is also included in Appendix 1 of the Report.

The accompanying CD-ROM includes all the data used to compile the map and Report, and it also includes files of geophysical, remote sensing, and topographic data. The CD-ROM contains the files necessary for viewing the data in the ArcView GIS environment, and a self-loading version of the ArcExplorer software package modified to suit this particular dataset. Metadata statements on the geological, geophysical, and topographic datasets are also provided.

Appendix 2 defines the terms used in the Geological Survey of Western Australia (GSWA) Western Australian mineral occurrence database (WAMIN) and the database of Western Australian mineral exploration activities (EXACT). Appendix 3 gives a description of the digital datasets included on the CD-ROM.

Location, land access, and physiography

The Report covers the west Kimberley area of Western Australia, in the far northwest of the State, and includes the NOONKANBAH*, LENNARD RIVER, CHARNLEY, PRINCE REGENT – CAMDEN SOUND, MONTAGUE SOUND, YAMPI, DERBY, and MOUNT ANDERSON 1:250 000 map sheets (Fig. 1).

The west Kimberley is serviced by the port and town of Derby; the other significant settlement is Fitzroy Crossing (Fig. 2). Road access to the area is gained via the sealed Great Northern Highway, which connects Derby to Broome in the west, and Fitzroy Crossing and Halls Creek in the east. Station tracks also provide access to many parts of the area but may be impassable during the wet season.

Pastoral stations, conservation reserves, and reserves for the use and benefit of Aboriginal inhabitants occupy a large percentage of the area of the west Kimberley (Fig. 2). Standard guidelines have been developed to cover mineral exploration and mining in the different types of conservation reserves, proposed conservation reserves, and other environmentally sensitive areas. These guidelines are summarized in the Department of Minerals and Energy Information Series No. 11 pamphlet (Department of Minerals and Energy, 1998a). Guidelines for the management of declared rare flora are summarized in the Department of Minerals and Energy Information Series No. 16 pamphlet (Department of Minerals and Energy, 1998b). Guidelines for prospecting, exploration, and mining on pastoral leases are summarized in the Department of Minerals and Energy Information Series No. 5 pamphlet (Department of Minerals and Energy, 1996).

All tenements are subject to the Western Australian Mining Act 1978. In addition, all new tenements and exploration licence renewals are subject to the legislation and procedures of the Commonwealth Native Title Act 1993, except where it is determined that the applications cover land where native title has been extinguished.

The physiography of the west Kimberley is shown on Figure 2. The area was divided into two major physiographic divisions by Jutson (1934): Fitzroyland and the North Kimberley Division. The North Kimberley Division was further subdivided by Wright (1964) into the Kimberley Plateaux Province and the Kimberley Foreland Province. The area also includes a small portion of the Dampierland Province of Brunnschweiler (1957) on the western margin.

In the west Kimberley, the Kimberley Plateaux Province is underlain by Palaeoproterozoic rocks and has been subdivided into the Prince Regent Plateau, the Gibb Hills, and the Harding Plateau (Gellatly and Halligan, 1971). The Prince Regent Plateau is underlain by the King Leopold Sandstone and is a gently undulating plateau with deeply incised drainage (Gellatly and Halligan, 1971). The

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

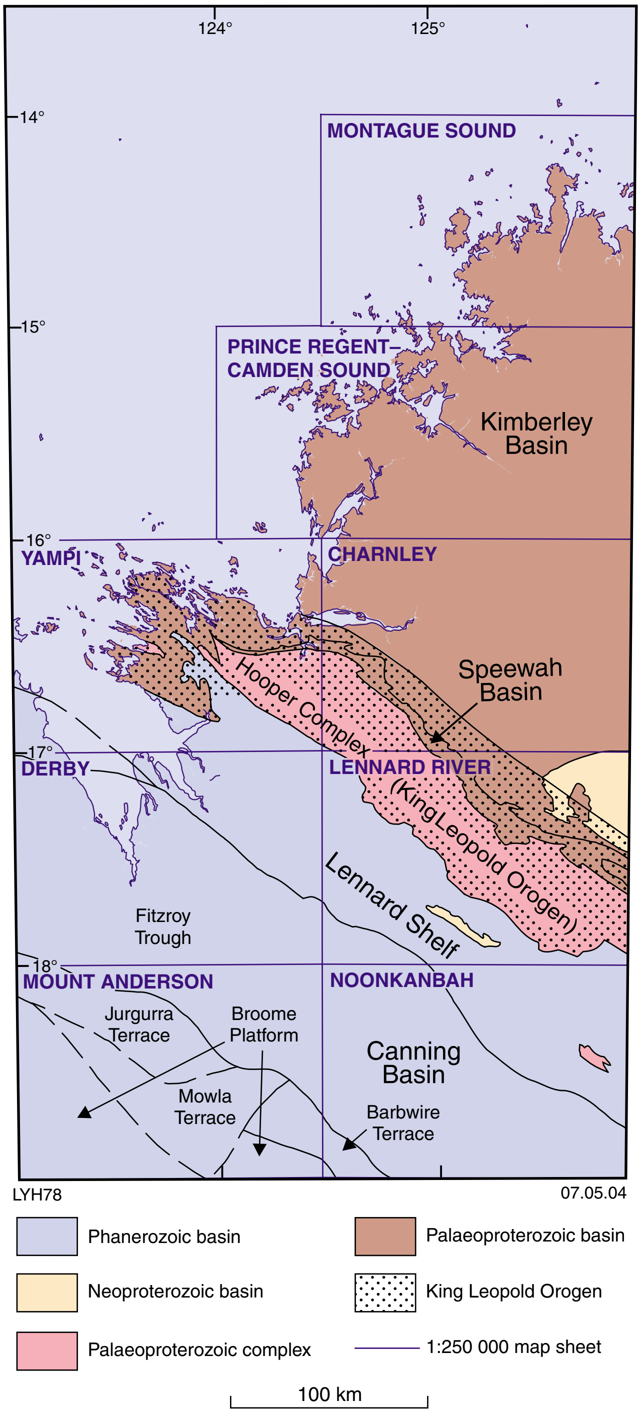


Figure 1. Tectonic sketch of the west Kimberley area, showing boundaries of the published 1:250 000 geological sheets (modified from Tyler and Hocking, 2002)

Gibb Hills are a series of low rounded hills formed on Carson Volcanics (Gellatly and Halligan, 1971). The Harding Plateau is characterized by escarpment-bounded plateaus of Warton Sandstone in which cuestas are a dominant feature of the topography. The Harding Plateau is geologically and physiographically similar to the Karunjie Plateau in the eastern part of the north Kimberley (Gellatly and Halligan, 1971). The Kimberley Foreland Province forms the southern and western margins of the Kimberley Plateaux Province. In the King Leopold Ranges, the Kimberley Foreland Province consists of strike ridges of Proterozoic quartzite and sandstone (Wright, 1964; Gellatly and Halligan, 1971). On the Yampi Peninsula, the Kimberley Foreland Province consists of rocky plateaus along the axes of anticlines and synclines with intervening cuestas (Wright, 1964; Gellatly and Halligan, 1971).

The Fitzroyland Division includes the Fitzroy Uplands Province, the Fitzroy Plains Province and the Sand Plain Province (Wright, 1964). The Fitzroy Uplands Province includes granite domes, gneiss hills, and schist ridges developed over the Palaeoproterozoic Hooper Complex, and is equivalent to the Lamboo Hills in the east Kimberley (Dow and Gemuts, 1969). The Fitzroy Plains Province includes the Fitzroy Ranges, North Fitzroy Plains, South Fitzroy Plains, and Fitzroy–Lennard Flood-plains (Wright, 1964). The Fitzroy Ranges consist of rocky ranges and plateaus developed over Devonian limestone and rounded conglomerate hills (Wright, 1964). The North Fitzroy Plains consist of sandplain and dunefields developed on interbedded sandstone and shale of Permian and Triassic age. The King Sound Lowlands consist of extensive coastal mudflats. The South Fitzroy Plains is an area of low undulating gravel plains with poorly outcropping Permian rocks and local dunefields. There are also plateaus and hills formed on areas of more resistant Permian sandstone and conglomerate at Grant Range (Wright, 1964; Gibson and Crowe, 1982). The Fitzroy–Lennard Flood-plains have developed along the Fitzroy and Lennard Rivers and their tributaries. The Sand Plain Province includes the Western Sand Plains and Dune Fields (Wright, 1964). The Western Sand Plains are extensive sandplains with little or no surface drainage. The Dune Fields consist of sand dunes covering plains overlying Jurassic–Cretaceous conglomerate, sandstone, and siltstone, and Permian and Triassic sandstone and siltstone of the Canning Basin (Wright, 1964). The Edgar Ranges is an area of dissected Mesozoic sandstone and mudstone characterized by steep-sided mesas within the Dune Fields (Wright 1964; Gibson and Crowe, 1982).

The Lombadina Plateau of the Dampierland Province is a sand-covered plateau bounded on the south by a low escarpment of Mesozoic sandstone cliffs (Gellatly and Sofoulis, 1973).

Previous work

The first geological investigation of the west Kimberley area was carried out by Hardman (1884), who also produced the first geological map and reported on the potential for gold and other minerals. Further geological reconnaissance was undertaken by Maitland in 1901 (Maitland, 1902), Fitzgerald in 1905–06 (Fitzgerald, 1907), and the Freney Kimberley Oil Company during the search for petroleum (Wade, 1924, 1936). The first detailed maps of mineralized areas were made by the Aerial Geological and Geophysical Survey of Northern Australia (AGGSNA) in the late 1930s (Finucane, 1938a,b; Finucane, 1939a,b; Finucane and Jones, 1939).

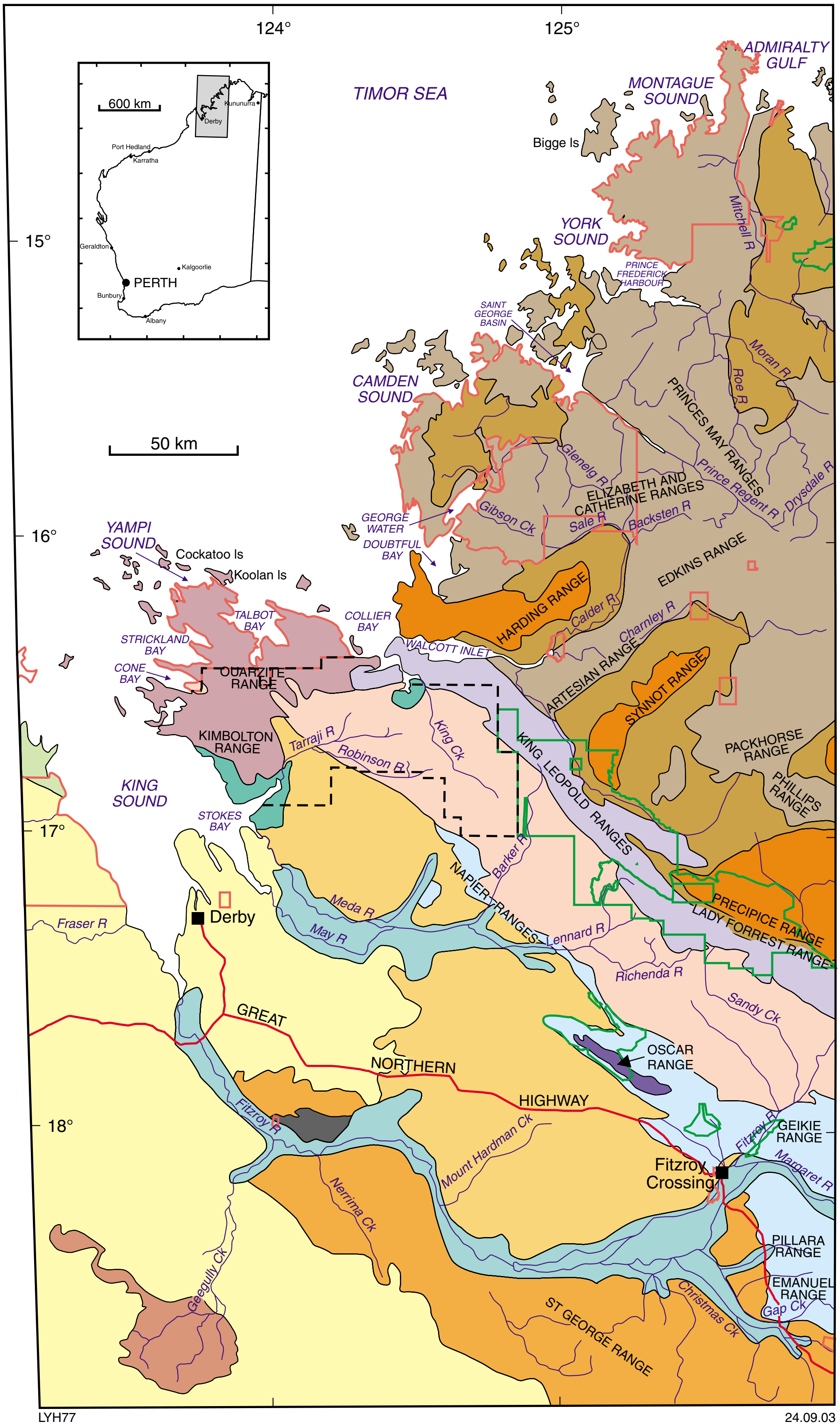
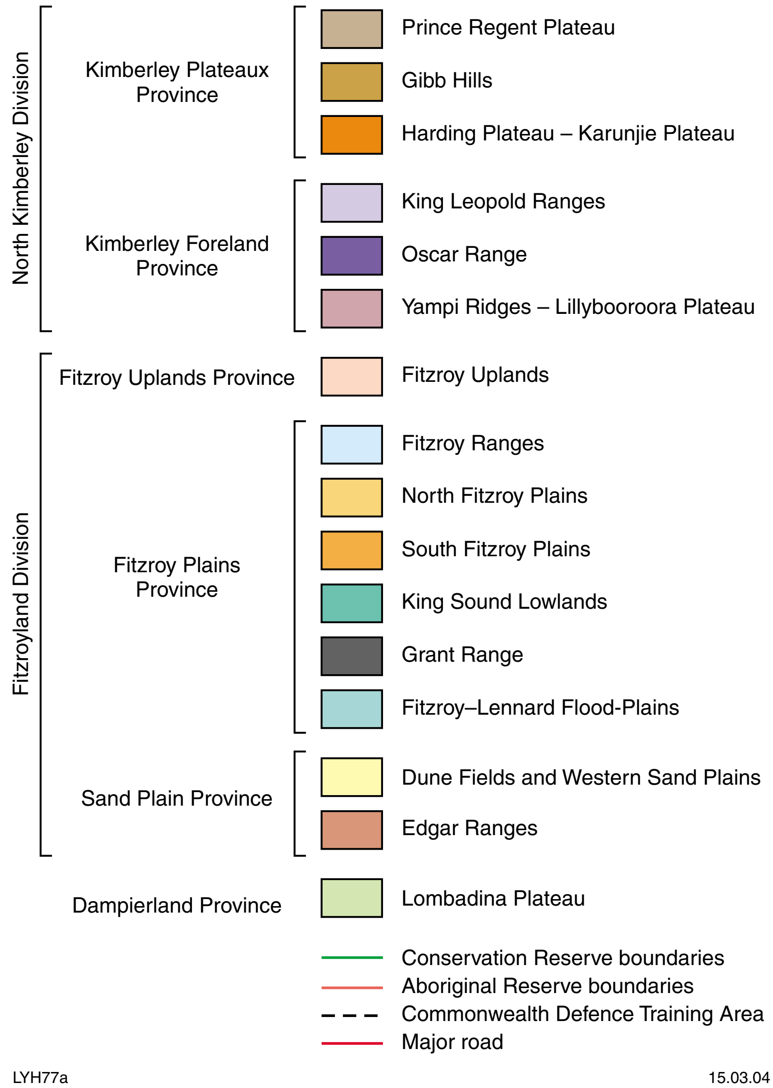


Figure 2. Physiographic sketch of the west Kimberley showing Conservation Reserve and Aboriginal Reserve boundaries, and the Commonwealth Defence Training Area



Systematic mapping of the DERBY (Casey, 1958), LENNARD RIVER, MOUNT ANDERSON, and NOONKANBAH 1:250 000-scale sheets was carried out by the former Bureau of Mineral Resources (BMR)* between 1947 and 1952 and the results from this work are discussed in Guppy et al. (1952, 1958). Harms (1959, 1965) gave descriptions of the gold, iron ore, uranium, base metals, tin, tungsten, and other mineral occurrences of the Kimberley Division.

Remapping and additional mapping of the west Kimberley, at a scale of 1:250 000, was carried out jointly by GSWA and BMR between 1966 and 1977 as part of a Proterozoic Orogen–Basin project. Maps and Explanatory Notes were published on LENNARD RIVER (Gellatly et al., 1968; Gellatly, Sofoulis et al., 1974; Derrick and Playford, 1973), CHARNLEY (Gellatly et al., 1969; Gellatly and Halligan, 1971; Gellatly, Derrick et al., 1974), PRINCE REGENT – CAMDEN SOUND (Williams and Sofoulis, 1971), MONTAGUE SOUND (Allen, 1971) and YAMPI (Gellatly and Sofoulis, 1973). NOONKANBAH (Crowe and Towner, 1981), DERBY (Casey, 1958; Towner, 1981), and MOUNT ANDERSON (Gibson and Crowe, 1982) were mapped separately.

A third edition of the 1:250 000-scale LENNARD RIVER sheet and Explanatory Notes (Griffin et al., 1993) and a second edition of YAMPI (Tyler and Griffin, 1993) have also been published. The King Leopold Orogen has been mapped at a scale of 1:500 000 (Griffin and Tyler, 1995) and a structural and metamorphic interpretation of this area at the same scale has also been produced (Tyler and Griffin, 1995). The Devonian reef complexes of the Canning Basin have also been mapped at a scale of 1:250 000 (Playford and Hocking, 1999), and in part at 1:100 000 scale (Hocking and Playford, 1998a,b,c,d), at 1:50 000 scale (Playford and Hocking, 1998a), and 1:25 000 scale (Playford and Hocking, 1998b). Whole-rock geochemical data were published in Sheppard et al. (1997a).

Aeromagnetic and gravity data at a scale of 1:250 000 have been published by GA and are also available in digital format.

Blockley (1971), Ringrose (1989), and Ferguson (1999) have summarized the lead–zinc mineralization of

* Later known as the Australian Geological Survey Organisation (AGSO), and now called Geoscience Australia (GA)

the area. The Department of Resources Development and the Department of Minerals and Energy (1997) reported on the prospectivity of the entire Kimberley as part of a joint study.

Regional geology

The west Kimberley area includes most of the King Leopold Orogen, and parts of the Palaeoproterozoic Speewah and Kimberley Basins, and the Phanerozoic Canning Basin (Fig. 1). The King Leopold Orogen includes the Palaeoproterozoic metasedimentary and igneous rocks of the Hooper Complex and the deformed margins of the Speewah and Kimberley Basins (Griffin and Grey, 1990). Tyler et al. (in prep.) are compiling the results of GSWA mapping of the King Leopold Orogen and the Halls Creek Orogen.

The interpreted geology on Plate 1 of this Report, and the digital interpreted geology map on the CD-ROM accompanying this Report, are based on the 1:250 000-scale geological sheets and the 1:500 000-scale map of the King Leopold Orogen (Griffin and Tyler, 1995) except on the Lennard Shelf of the Canning Basin where 1:100 000-scale mapping was utilized. The regolith layer is based on the 1:250 000-scale geological maps.

Palaeoproterozoic Hooper Complex

The Hooper Complex trends in a northwesterly direction across the central part of the project area and outcrops on LENNARD RIVER, YAMPI, and CHARNLEY. It includes the Marboo Formation, the Whitewater Volcanics, the Ruins Dolerite, and granitoids of the Paperbark Supersuite. The Hooper Complex is a continuation of the Western Zone of the Lamboo Complex (Tyler et al., 1995, 1999; Griffin et al., 2000).

The oldest rocks exposed are those of the Marboo Formation and Mount Joseph Migmatite. The Marboo Formation consists predominantly of metamorphosed turbiditic sandstone, siltstone, and mudstone, and felsic volcanic rocks (Griffin et al., 1993; Tyler et al., 1999). Hancock and Rutland (1984) described dacitic and rhyolitic tuff beds near the top of the sequence, which they interpreted as a precursor to the extensive volcanism that produced the Whitewater Volcanics. However, these tuffs were not observed during remapping of the Hooper Complex (Tyler and Griffin, 1993; Griffin et al., 1993; Tyler et al., 1999). Tyler et al. (1999) suggested that the tuffs described by Hancock and Rutland (1984) were deformed and metamorphosed turbiditic metasedimentary rocks that had a significant felsic igneous component. However, the presence of altered andesite and rhyolite fragments in a volcanic breccia intersected at the Chianti prospect in the northwestern part of the Hooper Complex (Jessup and Yeaman, 1972) would appear to support the conclusion of Hancock and Rutland (1984). The maximum age of deposition of the Marboo Formation is c. 1870 Ma, based on SHRIMP U–Pb dating of detrital zircon (Tyler et al., 1995; Tyler et al., 1999); the minimum age is given by a high-level intrusive stock in the Marboo Formation dated at 1858 ± 5 Ma (Tyler et al., 1999). The Mount Joseph Migmatite includes high-grade, well-bedded sillimanite–muscovite–K-feldspar–garnet–biotite–quartz–cordierite metasedimentary rocks, and anatectic gneiss and migmatite that have been interpreted by Griffin et al. (1993) to have been metamorphosed at a deeper crustal level than most of the Marboo Formation.

The Whitewater Volcanics unconformably overlie the Marboo Formation, and consist of dacitic to rhyolitic ignimbrites, minor lava flows, lapilli tuff, and volcanogenic sedimentary rocks (Griffin et al., 1993; Thorne et al., 1999). Two samples of Whitewater Volcanics have been dated at c. 1855 Ma using SHRIMP U–Pb geochronology (Griffin et al., 2000). The volcanic rocks have been intruded by high-level porphyry intrusions, and granitoid and gabbro of the Paperbark Supersuite dated at 1865–1850 Ma. The volcanic rocks, porphyries, and granites are all co-genetic (Griffin et al., 2000).

The Ruins Dolerite consists of steeply dipping layered mafic sills that intrude the Marboo Formation. There are up to seven sills averaging 270 m thick (Derrick and Playford, 1973; Gellatly, Sofoulis et al., 1974).

Hooper Orogeny

The Hooper Orogeny affected the Marboo Formation, Ruins Dolerite, and Whitewater Volcanics of the Hooper Complex (Tyler and Griffin, 1993; Griffin et al., 1993). The Marboo Formation was deformed and metamorphosed (D_1/M_1) between c. 1870 Ma and c. 1865 Ma before being unconformably overlain by the Whitewater Volcanics (Tyler et al., 1995; Tyler et al., 1999). This deformation resulted in layer parallel foliation (S_1) and greenschist facies metamorphism (Griffin et al., 1993). A second period of deformation and metamorphism (D_2/M_2) occurred either prior to, or contemporaneously with, intrusion of the Paperbark Supersuite between 1865 and 1850 Ma (Griffin et al., 1993; Tyler et al., 1995; Tyler et al., 1999). The second deformation resulted in upright open to tight folds at all scales. The metamorphic grade varied from greenschist facies to granulite facies (Griffin et al., 1993). The Hooper Orogeny is interpreted to correspond to the accretion of island arc basalts of the Central Zone of the Halls Creek Orogen to the Kimberley Craton (Myers et al., 1996; Sheppard et al., 1997b; Sheppard et al., 1999).

Palaeoproterozoic basins

Palaeoproterozoic sedimentary and volcanic rocks of the Speewah and Kimberley Basins unconformably overlie the Hooper Complex. The Kimberley Basin covers an area of about 160 000 km^2 (Plumb et al., 1981) and underlies most of the Kimberley Plateaux Province. The Speewah Basin is only exposed along the edge of the Halls Creek and King Leopold Orogens.

Speewah Basin

The Speewah Group is considered to have been deposited in a separate basin from the Kimberley Group, on the basis of a significant unconformity between the Speewah Group and the overlying Kimberley Group and different palaeogeographies (Griffin et al., 1993; Thorne et al., 1999). The Speewah Group includes the O'Donnell Formation, Tunganary Formation, Valentine Siltstone, Lansdowne Arkose, Luman Siltstone, and Bedford Sandstone. These formations form part of a transgressive–regressive cycle with fluvial sands passing into or alternating with shallow-marine facies and then back into fluvial sands (Plumb et al., 1981). Palaeocurrent measurements suggest that sediment was transported from the northeast and east (Gellatly et al., 1970). Zircons from a felsic volcanic unit in the Valentine Siltstone gave a SHRIMP U–Pb date of 1834 ± 3 Ma (Geoscience Australia's OZCHRON database).

Kimberley Basin

The Kimberley Group unconformably and disconformably overlies the Speewah Group (Griffin et al., 1993; Thorne et al., 1999). The group is interpreted to have been deposited within a broad, semi-enclosed, shallow-marine basin (Plumb et al., 1981). Palaeocurrent directions in the Kimberley Group indicate sediment transport from the north and north-northwest (Gellatly et al., 1970).

The King Leopold Sandstone forms the base of the Kimberley Group and lies unconformably to disconformably on the Bedford Sandstone or Lansdowne Arkose of the Speewah Group. The King Leopold Sandstone typically consists of medium- to coarse-grained quartz sandstone with medium- to large-scale trough cross-stratification, and forms prominent ridges and cliffs (Dow et al., 1964; Gellatly and Sofoulis, 1973; Derrick and Playford, 1973; Griffin et al., 1993). On Sunday Island, it consists of coarse-grained tourmaline-rich, muscovite-bearing quartzite (Gellatly and Sofoulis, 1973). A thin basal conglomerate is present on LENNARD RIVER (Derrick and Playford, 1973; Griffin et al., 1993).

The Carson Volcanics conformably overlie the King Leopold Sandstone, and consist of interlayered massive to amygdaloidal basalt, quartz sandstone, feldspathic sandstone, siltstone, tuff, agglomerate, and chert (Dow et al., 1964; Derrick and Playford, 1973; Griffin et al., 1993; Thorne et al., 1999). Edwards (1942) noted that the basalts were chemically and mineralogically intermediate between tholeiitic basalt and calc-alkaline andesite. The Carson Volcanics are areally extensive and typically vary in thickness between 200 and 700 m, although they are locally up to 1140 m thick north of Mount Nellie, where there has been a thick accumulation of pyroclastic rocks (Gellatly and Sofoulis, 1973). Ruddock (2003) suggested that the Carson Volcanics formed during a phase of intracratonic rifting that may be related to mantle-plume activity below the Kimberley Craton.

The Warton Sandstone conformably overlies the Carson Volcanics and consists principally of coarse-grained quartz sandstone with minor feldspathic sandstone. The sandstone has medium- to large-scale trough cross-stratification and horizontal planar stratification (Dow et al., 1964; Thorne et al., 1999). In the McLarty Range area, low-grade copper mineralization is associated with banded ferruginous chert and siltstone, which is possibly tuffaceous, within the Jap Bay Member of the Warton Sandstone (Gellatly, 1972a).

The Elgee Siltstone conformably overlies the Warton Sandstone and consists predominantly of red-brown siltstone with thin interbedded quartz sandstone (Dow et al., 1964; Plumb, 1968). Bruinsma (1970) subdivided the Teronis Member, at the base of the Elgee Siltstone, into four units: Teronis I consisting of grey-green sandstone with minor siltstone and shale; Teronis II consisting of grey-green shale and siltstone with minor fine-grained sandstone and oolitic and algal dolomite; Teronis III consisting of red-brown siltstone and minor shale; and Teronis IV consisting of green shale, siltstone, sandstone, calcareous sandstone and siltstone, and algal dolomite. Subeconomic syngenetic copper mineralization is widespread in the Teronis IV unit. Owen (1970) suggested that the Teronis Member was deposited on a tidal flat, or open shallow lagoon.

The Pentecost Sandstone, conformably overlying the Elgee Siltstone, has been subdivided into three units. The lower unit consists of thinly bedded to laminated quartz sandstone; the middle unit consists of planar-stratified or cross-stratified quartz sandstone and siltstone, with glauconitic sandstone and shale at the base; and the upper unit consists of massive, trough cross-bedded quartz sandstone and pebbly sandstone (Dow et al., 1964; Thorne et al., 1999).

The Yampi Formation was originally described as the Yampi Member in the upper part of the Pentecost Sandstone (Sofoulis et al., 1971) but was later raised to formation status (Tyler and Griffin, 1993). The formation consists of quartz sandstone, hematitic sandstone, feldspathic sandstone, siltstone, and quartz-pebble conglomerate. Where the Yampi Formation overlies the Pentecost Sandstone, its base is defined by the first appearance of abundant hematite. On Koolan Island, where the Yampi Formation unconformably overlies the Elgee Siltstone, it is up to 900 m thick (Tyler and Griffin, 1993). Gellatly (1972b) interpreted the formation to have been deposited near a shoreline.

Hart Dolerite

The Hart Dolerite consists of a series of massive dolerite sills and less extensive granophyre that intrude the Speewah and Kimberley Groups. The dolerite has been dated at c. 1790 Ma using SHRIMP U–Pb geochronology (Thorne et al., 1999). Alvin (1993) proposed the term Yilingbun Granophyre for the granophyric phase, which intrudes the dolerite in the Speewah Valley in the east Kimberley.

Mesoproterozoic Yampi Orogeny

The Yampi Orogeny produced large-scale northwest-trending, southwest-dipping ductile thrusts in the crystalline rocks of the Hooper Complex, and northeasterly trending folding and thrusting (D_5) in the Kimberley Basin on YAMPI and LENNARD RIVER (Tyler and

Griffin, 1990; Griffin et al., 1993). The Yampi Orogeny post-dates the Hart Dolerite and pre-dates the deposition of the Mount House glacigene rocks (Griffin et al., 1993). K–Ar ages from sheared granitoid rocks from the Hooper Complex place age limits of between 1475 ± 12 Ma and 999 ± 9 Ma on the Yampi Orogeny (Shaw et al., 1992). Low- to medium-grade metamorphism (M_5) accompanied deformation during the Yampi Orogeny (Griffin et al., 1993).

?Mesoproterozoic to Neoproterozoic sedimentary sequences

Oscar Range Group

The Oscar Range Group is a succession of low-grade metasedimentary rocks of uncertain age. The succession has been unaffected by the Yampi Orogeny and pre-dates the Neoproterozoic Elimberrie and Ninety Seven Mile Formations, suggesting that it is of Mesoproterozoic or Neoproterozoic age (Griffin et al., 1993). Five different formations have been defined in the Oscar Range Group but the stratigraphic relationships between the three lower formations (Mount Wilson Sandstone, Christopher Formation, and Le Lievre Formation) are not exposed. Therefore, it is possible that they are tectonically separated parts of the same formation (Griffin et al., 1993).

Neoproterozoic glacigene rocks

Oscar Range Inlier

The Elimberrie Formation unconformably overlies the Ellendale Formation of the Oscar Range Group. The Elimberrie Formation consists of carbonate, sandstone, siltstone, chert, ironstone, and diamictite. The Ninety Seven Mile Formation, which outcrops in the northwestern part of the Oscar Range Inlier, is probably a lateral equivalent of the Elimberrie Formation (Griffin et al., 1993). It consists of quartzite, diamictite, phyllite, amygdaloidal basalt, and felsic tuff or volcanic rock (Griffin et al., 1993).

Mount House Group

The Mount House Group unconformably overlies the Kimberley Group in the vicinity of Mount House in the western side of the study area. The basal Walsh Tillite, which consists of a basal diamictite overlain by tillite with scattered pebbles in a shaly matrix, overlies striated glacial pavements that indicate ice movements from the north and northeast (Griffin et al., 1993). The Walsh Tillite is conformably overlain by the Traine Formation, which consists of massive lithic sandstone with scattered glacial erratics. The Throssell Shale overlaps the Traine Formation and Walshe Tillite. It consists of siltstone with minor shale and sandstone (Griffin et al., 1993). A Rb–Sr date of 670 ± 84 Ma on the Throssell Shale (Bofinger, 1967) suggests that the glaciation is correlated with the Marinoan glaciation in central and southern Australia (Coats and Preiss, 1980). There is a gradational contact between the Throssell Shale and the overlying Estaughs Formation, which consists of micaceous sandstone and siltstone (Griffin et al., 1993).

Neoproterozoic King Leopold Orogeny

The King Leopold Orogeny (D_6) produced extensive west-northwesterly trending folding and thrusting in the King Leopold Ranges along the southwestern margin of the Kimberley and Speewah Basins (Griffin and Myers, 1988; Tyler and Griffin, 1990), together with the reactivation of shear zones in the Hooper Complex (Tyler et al., 1991; Shaw et al., 1992). Reactivated shear zones have given K–Ar ages of c. 560 Ma (Shaw et al., 1992).

Phanerozoic (Cambrian) dolerite

The Milliwindi dolerite dyke, which intrudes the Palaeoproterozoic King Leopold Orogen and Kimberley Basin, has a SHRIMP date of 513 ± 12 Ma (Hanley and Wingate, 2000). The dolerite is geochemically identical to basalts of the Antrim Plateau Volcanics and has been interpreted by Hanley and Wingate (2000) to be a feeder zone for the Antrim Plateau Volcanics, which have subsequently been eroded away in the west Kimberley. The Milliwindi dyke is positively magnetized similar to a number of other northwesterly trending dykes cutting sedimentary rocks of the Kimberley Group (Gunn and Meixner, 1998).

Phanerozoic Canning Basin

The study area includes the northeastern portion of the Canning Basin, a large intracratonic basin covering northwestern and central Australia (Purcell, 1984). The Canning Basin has had a long and complex tectonic history commencing in the Early Ordovician and continuing through to the Jurassic and Cretaceous (Kennard et al., 1994). The geology of the basin is described by Forman and Wales (1981), Towner and Gibson (1983), and Yeates et al. (1984). A more recent interpretation of the tectonic and stratigraphic framework is given in Kennard et al. (1994) and is illustrated in Figure 3. The main tectonic elements within the study area are: the northwest-trending Fitzroy Trough, which contains in excess of 10 km of sedimentary rock and was formed by extension and rifting in the Givetian (Kennard et al., 1994); the Lennard Shelf, which flanks the Fitzroy Trough to the north; and the Broome Platform, which flanks the Lennard Shelf to the south (Fig. 1). Reef complexes rimmed the trough on the Lennard Shelf.

Palaeozoic

Ordovician

On the Lennard Shelf, Early Ordovician rocks of the Prices Creek Group outcrop near Prices Creek along the southwest scarp of the Emanuel Range. The Prices Creek Group includes limestone, siltstone, and sandstone of the Emanuel Formation, and dolomite, dolomitic sandstone,

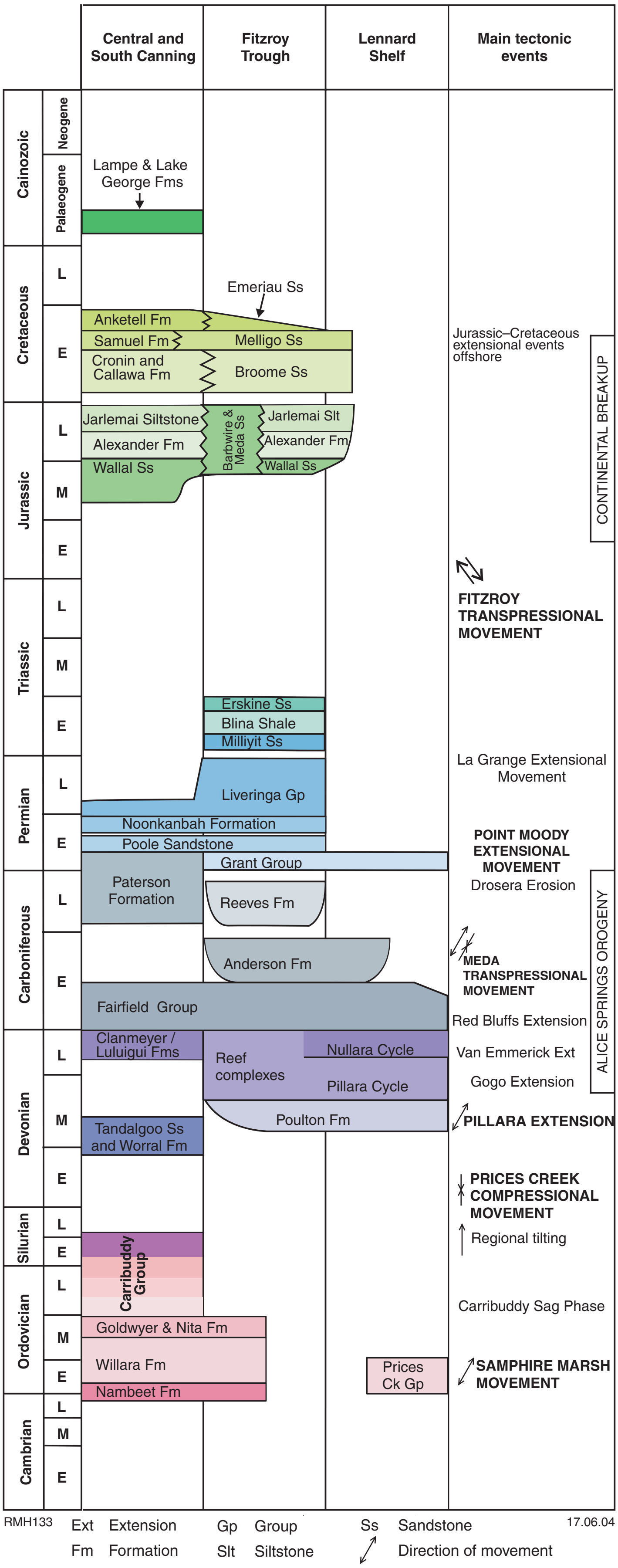


Figure 3. **Stratigraphic column for the northern part of the Canning Basin showing lithostratigraphy and main tectonic events (modified from Kennard et al., 1994)**

and siltstone of the overlying Gap Creek Formation. An angular unconformity separates the Prices Creek Group from the overlying Devonian sedimentary rocks (Guppy et al., 1958). Possible correlatives of the Prices Creek Group, conformably overlain by Middle Ordovician carbonate rocks and shale, and unconformably underlain by Precambrian rocks, have been intersected in oil wells in the Fitzroy Trough (Gibson and Crowe, 1982).

Middle Ordovician to Early Devonian

The Carribuddy Group (Lehmann, 1984) is a thick dolomite and evaporite unit of Middle Ordovician and Silurian age (Kennard et al., 1994) that conformably overlies Middle Ordovician sedimentary rocks and is overlain unconformably by cross-bedded red sandstone of the Tandalgoo Formation (Koop, 1966; Kennard et al., 1994) and the stratigraphically equivalent Worral Formation (Kennard et al., 1994) . A salt dome intersected in Frome Rocks 1 well, drilled by West Australian Petroleum Pty Limited (WAPET), may have been mobilized from evaporites of the Carribuddy Group (West Australian Petroleum Pty Limited, 1962) or from evaporites deposited in the proto-Fitzroy Trough (Brown et al., 1984).

Devonian

Devonian limestone forms part of the Devonian ‘Great Barrier Reef’ on the Lennard Shelf (Wade, 1936; Playford, 1980). Two main cycles of reef development have been recognized by Playford (1980, 1984) and Playford et al. (1989) — the Givetian–Frasnian Pillara Cycle characterized by essentially vertical platform growth followed by drowning and backstepping, and the Famennian Nullara Cycle, characterized by a strongly advancing platform (Fig. 4). The boundary between the two cycles was marked by a short period of transgression corresponding with a drop in sea level and worldwide mass extinction at the end of the Frasnian. Stromatoporoids and corals dominated the platforms of the Pillara Cycle but were almost absent in the platforms of the Nullara Cycle, which were dominated by cyanobacteria (Playford, 1980, 1984; Playford et al., 1989).

On the basis of subsurface analysis, Copp (2000) further subdivided the Pillara Cycle into three associations: Pillara Cycle association 1 represents the initial stages of carbonate build-up on the southeastern Lennard Shelf. During this period, there was an overall retreating pattern of platform-margin growth with periodic upright scarp-margin development indicating that much of the platform could not keep up with the rising sea level. Pillara Cycle association 2 represents keep-up growth of the initial carbonate buildups and is characterized by aggradational growth and near-vertical upright scarp reef margin. The keep-up growth was terminated by a platform-drowning event (give-up stage) that resulted in the development of patch reefs and pinnacle reefs with basinal sediments deposited in the surrounding areas. Pillara Cycle association 3 in the Fossil Downs and Brooking Gorge areas, represents give-up (backstepped margin) growth followed by keep-up (upright and advancing margins) reef growth.

The Cadjebut Formation probably pre-dated reef formation, although it may be contemporaneous with the oldest part of the Pillara Limestone (Copp, 2000). Hocking et al. (1996) recognized four broad lithofacies within the Cadjebut Formation: a basal lag consisting of grey siltstone, lithic wacke, and conglomerate; dolomitic grainstone interpreted as bank or shoal accumulation; siltstone and dololutite interpreted as a back-barrier, restricted circulation, lagoonal deposit; and an evaporitic facies interpreted to have formed in a supratidal sabkha to hypersaline lagoon setting.

The Pillara Cycle includes the Pillara Limestone (platform facies), Sadler Limestone (marginal-slope and basin facies), Gogo Formation (basin facies and lower fore-reef facies), the lower part of the Virgin Hills Formation (marginal-slope and basin facies), and the lower part of the Napier Formation (reef-slope and fore-reef subfacies). The Pillara Limestone consists of back-reef deposits fringed by reef-flat and reef-margin subfacies. The back-reef deposits are well bedded and consist of stromatoporoid biostromes, fenestral limestone, oolite, and peloidal limestone, interbedded in places with terrigenous deposits of sandstone, siltstone, and conglomerate. The bedded reef-flat and massive reef-margin limestones were constructed by frame-building stromatoporoids, cyanobacteria, and minor corals (Griffin et al., 1993). The Sadler Limestone consists of thick- to thin-bedded limestone with scattered allochthonous blocks of reef limestone and some debris-flow deposits (Hocking and Playford, 1998d). The basin facies of the Gogo Formation consists of siltstone and shale with minor silty limestone, and horizons with abundant cannonball (calcareous) concretions (Hocking and Playford, 1998d). The lower fore-reef facies of the Gogo Formation consist of siltstone and shale with thin interbeds of silty limestone containing some platform-derived debris (Hocking and Playford, 1998d). Mounds of stromatolitic limestone, commonly intergrown with barite, have developed where the Gogo Formation adjoins marginal-slope facies Sadler Formation and where the Gogo Formation is cut by synsedimentary faults (Playford and Wallace, 2001). The Virgin Hills Formation consists of limestone, thick- to thin-bedded siltstone and sandstone with some allochthonous blocks of reef limestone (Hocking and Playford, 1998d). The Napier Formation consists of crudely bedded to well-bedded limestone with some dolomite and terrigenous interbeds (Griffin et al., 1993). The fore-reef facies consists principally of debris eroded from the reef platform and includes large allochthonous reef blocks and massive debris-flow deposits. The reefal-slope facies resulted from the growth of layers of cyanobacteria and sponges and has a range of dips from horizontal to vertical. In places, the sponges and cyanobacteria built up large biohermal mounds on the marginal slopes or on top of drowned pinnacle reefs (Griffin et al., 1993).

The Nullara Cycle includes the Nullara Limestone (reef-margin subfacies), Windjana Limestone (reef-margin subfacies), upper part of the Napier Formation (reef-slope and fore-reef subfacies), Bugle Gap Limestone (fore-reef subfacies), upper part of the Virgin Hills Formation (marginal slope and basin facies), and Piker Hills Formation (marginal-slope and basin facies), described by Playford and Hocking (1999). The Nullara Limestone

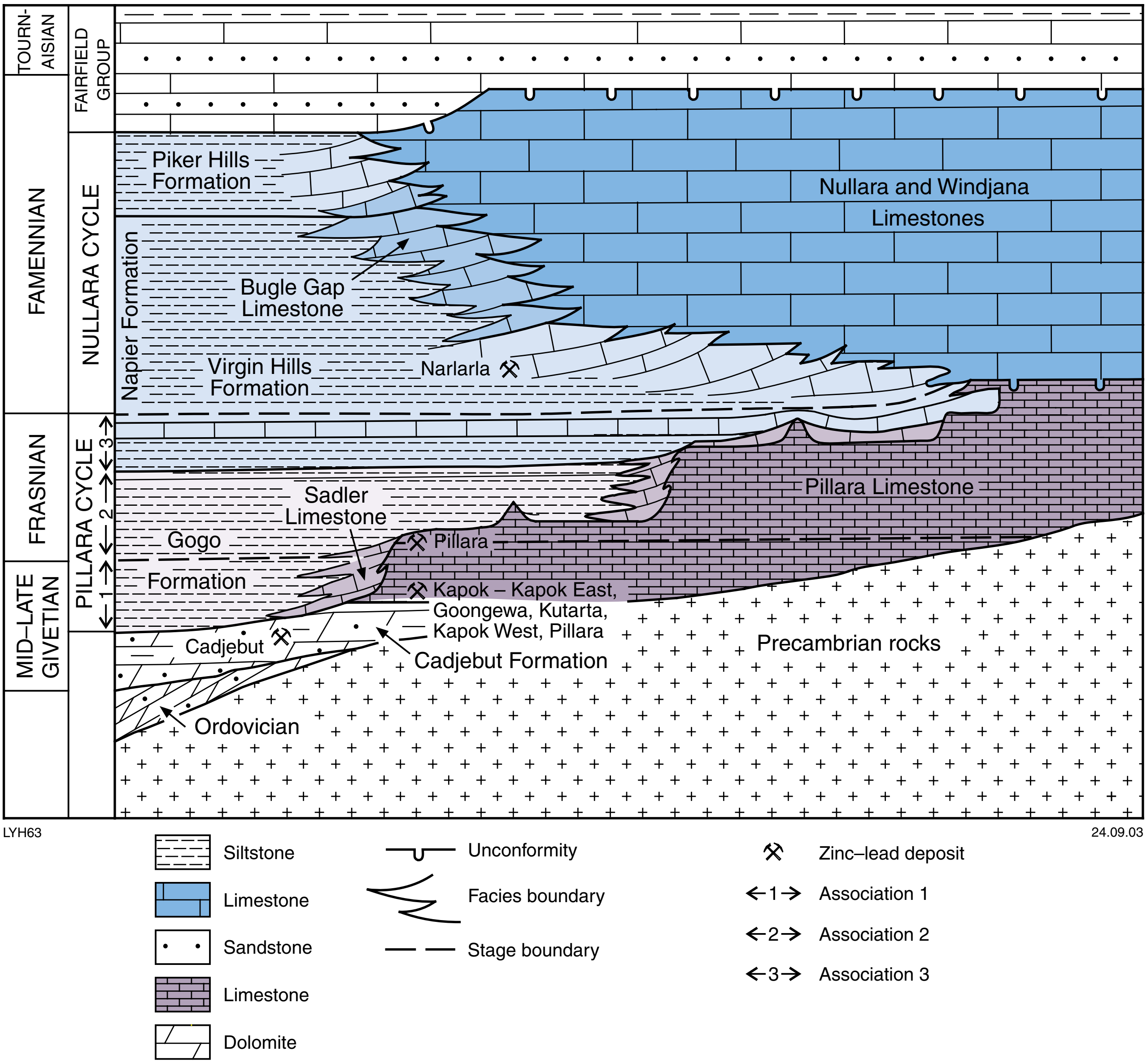


Figure 4. Stratigraphic nomenclature and development of the reef complexes through time, showing the two major reef cycles and stratigraphic positions of Mississippi Valley-type deposits on the Lennard Shelf (after Playford, 1984; Copp, 2000)

consists of fenestral limestone and oolite that have been partially dolomitized in places (Griffin et al., 1993). The Windjana Limestone consists of massive to crudely bedded reef limestone and minor dolomite built primarily by cyanobacteria (Griffin et al., 1993). The Bugle Gap Limestone consists of crudely bedded limestone with some allochthonous blocks of reef limestone (Hocking and Playford, 1998d). The Piker Hills Formation consists of limestone, siltstone, and sandstone, and is locally conglomeratic (Hocking and Playford, 1998c).

Devonian boulder, cobble, and pebble conglomerates and sandstones have complex interfingering and unconformable relationships with the reef limestones (Playford, 1980; Botten, 1984). Botten (1984) interpreted the conglomerates as fanglomerates and the finer grained units as fluviatile and deltaic deposits. The units in the west Kimberley include the Stoney Creek Conglomerate, Big Spring Formation, Bobs Bore Conglomerate, Behn Conglomerate, and Van Emmerick Conglomerate (Playford and Hocking, 1999).

Late Devonian to Early Carboniferous

The Late Devonian to Early Carboniferous Fairfield Group conformably overlies the reef complex carbonates and consists of limestone, sandstone, siltstone, and shale deposited in a shallow-marine environment (Griffin et al., 1993).

Palaeozoic Alice Springs Orogeny

The 400–300 Ma Alice Springs Orogeny (D_7) reflects a period of north-northeasterly sinistral strike-slip faulting in the Pillara Range in the Canning Basin (Thorne and

Tyler, 1996). The Permian sedimentary rocks of the Fitzroy Trough have been folded, whereas the overlying Triassic Blina Shale is unfolded (Brunnschweiler, 1954).

Carboniferous to Early Permian

Massive fluvioglacial silty sandstone, conglomeratic sandstone, tillite, siltstone, shale, and varved rocks of the Grant Group unconformably overlie the Devonian sedimentary rocks at the margin of the Fitzroy Trough (Derrick and Playford, 1973). The Grant Group gradually thickens in the subsurface from the margins of the Lennard Shelf into the Fitzroy Trough (Griffin et al., 1993). The Anderson Formation (Campbell, 1956; Towner, 1981), consisting of sandstone, siltstone, shale, minor limestone, dolomite, and anhydrite, was intersected beneath the Grant Group in the WAPET oil well Grant Range 1 on MOUNT ANDERSON (Gibson and Crowe, 1982), and WAPET oil well Fraser River 1 on DERBY.

Permian

Marine and non-marine silty sandstone and quartz sandstone of the Poole Sandstone disconformably (unconformably in places) overlie the Grant Group (Guppy et al., 1958; Derrick and Playford, 1973).

The Noonkanbah Formation overlies the Poole Sandstone with minor disconformity. At the margin of the Fitzroy Trough the Noonkanbah Formation consists of a basal conglomerate followed by a shallow-water sequence of sandy siltstone, calcareous siltstone with minor shale, sandstone, and sandy limestone. Further into the trough there is a deeper water marine assemblage consisting of alternating mudstone and sandstone (Guppy et al., 1958). The Noonkanbah Formation has a rich fossil assemblage including brachiopods, bryozoa, corals, crinoids, foraminifera, and molluscs (Guppy et al., 1958).

The Liveringa Group, which conformably overlies the Noonkanbah Formation, consists of three formations: the Lightjack Formation, the Condren Sandstone, and the Hardman Formation (Guppy et al., 1958; Yeates et al., 1975; 1984). At the base of the Lightjack Formation, there is greywacke and fossiliferous quartz sandstone with lenses of limonitic oolites. These are followed by micaceous olive-green sandstone and ripple-marked yellow-brown sandstone with plant fragments (Guppy et al., 1958). Galloway and Howell (1975) concluded that the basal Lightjack Formation consisted of a succession of distributary mouth-bar sands overlain by point-bar or spit sandstone with coal at the top of the uppermost cycles generated by the equivalent of present-day mangroves. The upper part of the Lightjack Formation has been interpreted as a lacustrine, bay, or overbank deposit overlain by a point-bar sequence (Galloway and Howell, 1975).

The lower part of the Condren Formation consists of sandstone overlain by siltstone with traces of coal, and it possibly formed during progradation into a tidal bay (Galloway and Howell, 1975). The upper part of the Condren Formation varies from fine siltstone with sandstone interbeds and thin coal seams at the base, to sandstone with thin coal seams at the top; it has been interpreted to have formed in a tidal bay (Galloway and Howell, 1975).

The Hardman Formation consists predominantly of fine- to medium-grained micaceous silty sandstone with some interbedded medium- to coarse-grained sandstone and contains a rich assemblage of marine fossils including brachiopods, pelecypods, gastropods, and bryozoa indicating a Late Permian age (Guppy et al., 1958). Yeates et al. (1975) subdivided the Hardman Formation into three members: the Kirby Range Member, the Hicks Range Sandstone Member, and the Cherrabun Member. These three members are equivalent to Liveringa Formation units B, C, and D of Galloway and Howell (1975). Galloway and Howell (1975) suggested that the basal part of the formation is lacustrine and that marine influence increased with time as a result of subsidence. Coal seams at the top of the Hardman Formation are interpreted to have formed at the distal ends of a delta, under brackish or saline conditions, from plant material that was the Permian equivalent of mangroves (Galloway and Howell, 1975).

Mesozoic

Triassic

The Millyit Sandstone unconformably overlies the Hardman Formation in the McLarty Syncline (Yeates et al., 1975; Gibson and Crowe, 1982). The Blina Shale overlaps the Millyit Sandstone and overlies the Permian Liveringa Group with angular unconformity (Gibson and Crowe, 1982). The Blina Shale consists principally of ferruginous shale but around the margins of the synclinal deposition basins there are beds of phosphatic crustaceans and a fish-bone bed (Brunnschweiler, 1954). The presence of lingulid species indicates that the Blina Shale is marine and is interpreted to be lagoonal or estuarine (Brunnschweiler, 1954).

The Erskine Sandstone disconformably overlies the Blina Shale in places, and elsewhere unconformably overlies Permian units (Brunnschweiler, 1954; Guppy et al., 1958). The Erskine Sandstone consists of sandy shale in the lower part and ferruginous, cross-bedded sandstone and quartz-pebble conglomerates in the upper part and was deposited under estuarine, and probably fluviatile, conditions (Brunnschweiler, 1954). The Erskine Sandstone is conformably overlain by the Munkayarra Shale on DERBY (Smith, 1992).

Jurassic – Early Cretaceous

Lindner and McWhae (West Australian Petroleum Pty Limited, 1961a, Appendix C) noted that the Wallal Sandstone consists of sandstone with minor siltstone, conglomerate, and lignite beds unconformably overlying Permian and Triassic rocks and conformably overlain by the Alexander Formation. The Alexander Formation, which consists of impure quartz sandstone with inter-bedded shale, is disconformably overlain by the marine Jarlemai Siltstone, which consists of poorly bedded silt-stone with minor intercalated mudstone (Brunnschweiler, 1954). There is a nodular phosphate bed at the base of the Jarlemai Siltstone (described as the Langey Shale by

Brunnschweiler, 1954), and the formation also contains phosphatic ironstones suggesting periods of very slow clastic deposition (Yeates et al., 1984). The fluviatile to deltaic Mowla Sandstone, consisting of a basal conglomerate and cross-bedded sandstones with interbedded siltstone, overlies the Jarlemai Siltstone disconformably in places (Guppy et al., 1958; Yeates et al., 1984). The Broome Sandstone of Brunnschweiler (1957) includes the Jowlaenga Formation and the Leveque Sandstone (after Yeates et al., 1984). It is the most widespread unit overlying the Jarlemai Siltstone and is interpreted to have been deposited in a shallow marine (tidal) environment (Yeates et al., 1984).

Intrusions associated with late Phanerozoic or Mesozoic rifting

A tholeiitic dolerite, intruding siltstones of the Carboniferous Anderson Formation, was intersected at a depth of between 3063 and 3093 m (10 045–10 144 feet*) in WAPET petroleum well Fraser River 1 (Fig. 5) on DERBY (Campbell, 1956; Glover, 1956). The dolerite was interpreted by Glover (1956) to be possibly of Triassic age and to be related to the break-up of Gondwana. Glover (West Australian Petroleum Pty Limited, 1961b, Appendix 1) noted a similar dolerite intruding the Anderson Formation in WAPET petroleum well Barlee 1 (Fig. 5), on BROOME, to the east of the study area that is possibly comagmatic. K–Ar dating of the dolerite in Barlee 1 gave an age of 196 Ma (Harding, 1966). However, fission-track dating of a thick dolerite intersected in oil well Perindi 1 in the offshore Canning Basin gave a minimum age of 266 ± 25 Ma (Gleadow and Duddy, 1984). Fission-track studies of annealed apatites from sedimentary rocks surrounding the dolerite in Fraser River 1 suggest that the intrusion is also of Permian age (Gleadow and Duddy, 1984). Petrologically, the dolerites in Perindi 1, Fraser River 1, Barlee 1, and three other oil wells (Fig. 5) in the northwestern Canning Basin are similar, and they were interpreted by Reekmann and Mebberson (1984) to be comagmatic and related to the initiation of tensional tectonics and the beginning of rifting.

To the north of the study area (Fig. 6), a series of magnetic anomalies lie at the intersection between northeast-trending faults and a major northwest-trending rift, between the Browse and Bonaparte Basins, known as NW1 (O'Brien et al., 1999), The magnetic anomalies were interpreted by O'Brien et al. (1999) as mafic igneous intrusions that could be Permian or Mesozoic in age and possibly related to continental break-up. They could, however, be interpreted as volcanic rocks: Burmah Oil Company of Australia Ltd (1968) reported an intersection of Upper Jurassic volcanic rocks in petroleum well Ashmore Reef 1 (Fig.6). A small magnetic anomaly beneath the Osborne Islands on the northwestern boundary of the area and a large magnetic anomaly in the northeast Kimberley to the east of the study area (Gunn and Meixner, 1998) are along the same trend (Fig. 6) and have

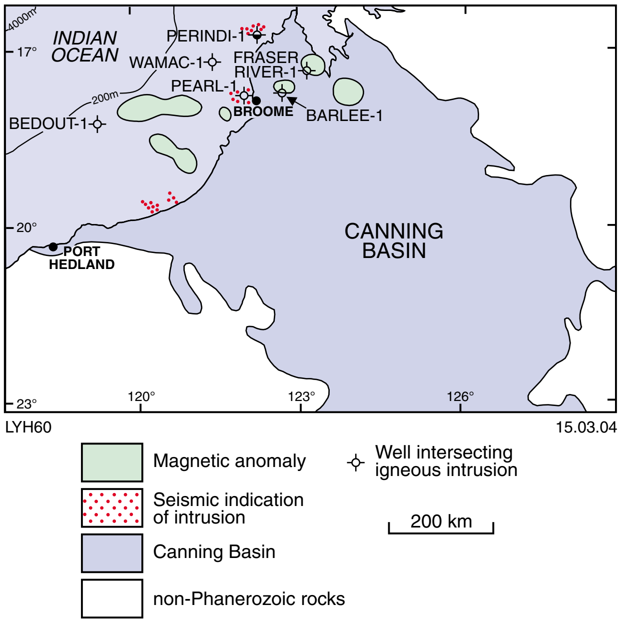


Figure 5. Map of the Canning Basin showing distribution of petroleum wells that intersected igneous intrusions and the location of magnetic and seismic anomalies possibly associated with subsurface igneous rocks (after Reekmann and Mebberson, 1984)

been interpreted by Napier Minerals to be magnetic granitoids of similar age (Garlick, 2003). However, Garlick (2003) noted that the large anomaly could alternatively represent a magnetic granitoid in the underlying Archaean basement. The modelling of Gunn and Meixner (1998) indicated that the large magnetic anomaly is a very deep-seated feature (approximately 6 km deep) in the basement beneath the Kimberley Basin. It may be just coincidence that it lies on the same trend as NW1.

A conjugate set of northeast- and northwest-trending dyke-filled fractures cutting the Kimberley Group and clearly visible on aeromagnetic images and maps of the region (Fig. 6.) has been interpreted by Gunn and Meixner (1998) to possibly be the result of a stress-couple applied to the Kimberley Craton by simultaneous rift-related crustal extensions on its northeastern and southwestern borders during the Devonian–Carboniferous. Alternatively, the northwesterly trending dyke-filled fractures could have been initiated in the Palaeoproterozoic, and the northeasterly trending dykes could be filling Mesozoic extensional fractures (O'Brien et al., 1999).

Miocene Fitzroy Volcanics (lamproites)

Several clusters of lamproite volcanic vents in the west Kimberley were collectively referred to as the Fitzroy Lamproite by Thomas (1958) and, more recently, as the Fitzroy Volcanics by Lewis (Griffin et al., 1993). The lamproites intrude Palaeozoic and Triassic sedimentary

* Imperial measurements in the WAPET report have been converted to S.I. units

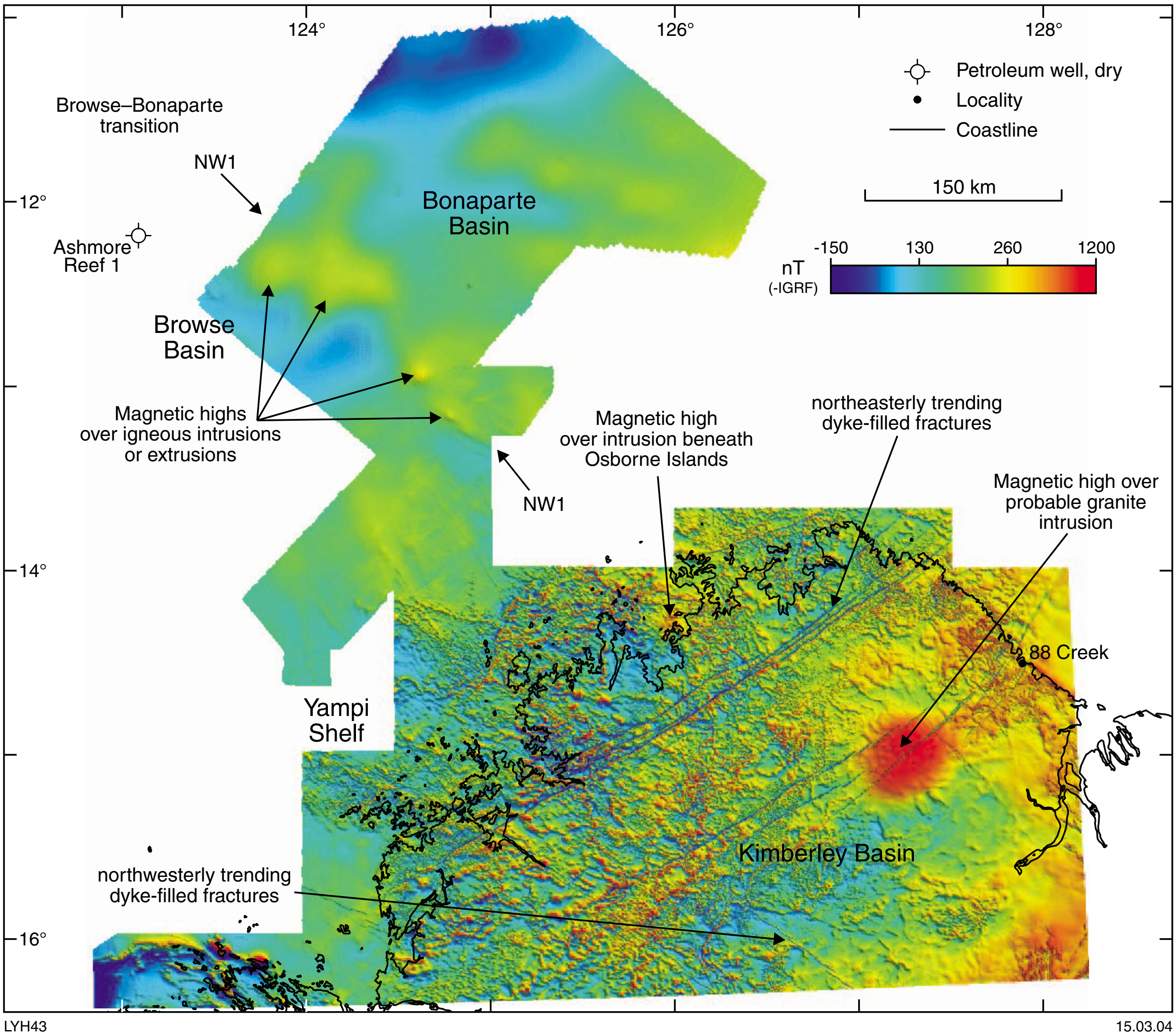


Figure 6. Total magnetic intensity image of the Kimberley and Bonaparte Basin showing intrusions along the Browse–Bonaparte transition zone (NW1) and intrusions along a possible extension into the north Kimberley; note also the northwesterly and northeasterly trending dyke-filled fractures (modified from O'Brien et al., 1999 and Gunn and Meixner, 1998)

rocks of the Canning Basin and, in places, Proterozoic granites of the Hooper Complex (Prider, 1960; Derrick and Gellatly, 1972). The lamproites have been dated as Miocene (18–22 Ma) by K–Ar and Rb–Sr methods (Wellman, 1972; Jaques et al., 1984). There is an overall decrease in age to the south suggesting a southward migration of volcanism with time, possibly related to the northward drift of the Australian continent over a hot spot (Smith, 1984).

The lamproites range in composition from leucite lamproites to olivine lamproites (Atkinson et al., 1984). The leucite lamproites were subdivided by Wade and Prider (1940) and Prider (1960) into five varieties according to their mineral composition: fitzroyite (phlogopite–leucite lamproite); cedricite (diopside–leucite lamproite); wyomingite (phlogopite–diopside–leucite lamproite); mamilite (potassic richterite – leucite lamproite); and wolgidite (phlogopite – diopside – potassic richterite – leucite lamproite). The olivine lamproites contain large rounded xenocrysts of olivine up to 4 mm in diameter, fine-grained euhedral olivine averaging 0.3 mm across, variable proportions of diopside and phlogopite, and accessory chrome spinel, apatite, potassic richterite, priderite, and diamonds in a fine-grained groundmass (Atkinson et al., 1984). The olivine lamproites differ from kimberlite by the absence of picroilmenite and the presence of potassic richterite and priderite (Atkinson et al., 1984; Lewis, 1987).

Most of the lamproites show evidence of an early explosive phase, which formed tuffs and breccias, followed by quiet intrusion of a central stock or a complex of sills and stocks. The overall shape of most of the intrusions is that of a champagne glass with the stem representing the narrow conduit (Jaques et al., 1986).

Regolith

A veneer of unconsolidated or partly consolidated sediments including windblown sand, black soil, colluvium, slope deposits, valley-fill deposits, and alluvium covers much of the Canning Basin and is locally developed in the vicinity of rivers and creeks in the remainder of the area. There are also areas of laterite (duricrust), travertine and tufa, and calcrete (Crowe and Towner, 1981; Griffin et al., 1993). Along the coast there are dune sands and coastal mud, silt, and sand with a thin salt crust developed in places (Tyler and Griffin, 1993).

Exploration and mining

Gold

A convict named Wildman claimed that he found eight nuggets in the country near Camden Sound, 220 km northeast of Derby, in 1856. When it was confirmed that he had sold nuggets in Liverpool for £416, an expedition was sent to search for gold in 1864 but none was found (Battye, 1915). Sholl is reported to have found indications of gold whilst exploring the country between Camden Harbour and the Leopold Ranges in 1865 (Battye, 1915). Hardman (1884) noted the presence of quartz veins in the Mount Broome – Richenda River area and suggested that this area was prospective. It is not certain when gold was first worked in the Mount Broome area but diggers were obtaining gold from the creeks and a quartz reef when Frank Hann visited the area in 1898 (Hann 1901; Donaldson and Elliot, 1998). Recorded production from Mount Broome Creek was only 14.6 oz (454 g) and from Richenda River 2.5 oz (78 g) but the production may have been significantly higher as most finds went unreported (de Havelland, 1986).

Maitland examined the Kimberley Basin when he accompanied the survey of Brockman and Crossland in 1901 (Brockman, 1902). Maitland (1902) noted that there were large quartz veins cutting the sedimentary and mafic igneous rocks, but concluded that they were of no economic importance. However, Fitzgerald discovered auriferous reefs within Carson Volcanics near Plover Hill*, Manning Creek, Mount Synnot, and Mount Brennan during the Crossland expedition of 1905 (Fitzgerald, 1905, 1907) but his reports of these appear to have been ignored by later prospectors and geologists. Furthermore, Maitland (1919a) made no mention of gold in the west Kimberley. Harms (1959) dismissed persistent reports of gold in the Kimberley Basin as being due to pyrite in the Carson Volcanics and appears unaware of the high assays obtained by Fitzgerald. There is also no mention of Fitzgerald's discoveries in the explanatory notes for CHARNLEY (Gellatly and Halligan, 1971; Gellatly, Derrick et al., 1974). Prospector Charlie James reported the discovery of quartz reefs and alluvial gold north of Mount Heytesbury (south of Yampi Sound) in 1909 (*Sunday Times*, 1909a,b,c) and alluvial gold is reputed to have been won from a gully on Oobagooma Station (*Sunday Times*, 1914). These discoveries also do not appear to have been followed up.

There was limited gold exploration from the 1970s to the 1990s, and this was concentrated on the Mount Broome Creek – Richenda River area; the only discoveries being at Turtle Creek (McConnell, 1973) and in the vicinity of the Robinson River (Barnes, 1990). No further gold production from the west Kimberley has been recorded, although Barnes (1990) noted that rich surface leaders in the Robinson River area had been dollied for gold, and nuggets had been collected intermittently for most of the 20th century with the production going unrecorded.

In 2001, a program of Airborne Multispectral Scanning undertaken by De Beers Australia Exploration Ltd in joint venture with Striker Resources outlined a broad area of argillic alteration in the north Kimberley (Striker Resources NL, 2002a). Interest in the gold prospectivity of the Kimberley Basin has been awakened by the recent discovery of alluvial gold in association with alteration and epithermal quartz veins. The discovery was made by Striker Resources in the Oombulgurri area in the north Kimberley in January 2002 (Striker Resources NL, 2002a,b,c; Ruddock, 2003). Striker Resources later announced soil assays up to 16.7 g/t gold (Striker Resources NL, 2002d).

Base metals

Copper

Copper mineralization was discovered in the vicinity of Camden Harbour and Brecknock Harbour by Sholl, who led a party to the Glenelg River in 1863–64, and attempted to establish a government settlement (*Sunday Times*, 1908a; Battye, 1915). During his survey of the west Kimberley in 1883, Hardman (1884) noted the presence of minor copper mineralization in limestone of the Napier Range at Devils Pass (Windjana Gorge), Oscar Range near Brooking Creek, Geikie Range, and near Mount Pierre. A. W. Sergison alleged that he found rich copper–silver lodes in a steep valley in the west Kimberley in 1897, and also copper ore in a cave on an island connected to the mainland by a ridge of rock, but he failed to give a location for either occurrence (*Sunday Times*, 1908b). Tenements for copper were pegged at Mount Lyell, 40 km southeast of Brecknock Harbour, by B. James (PA 3H)* and J. Osmond (PA 6H), and 13.3 km south of Brecknock Harbour by C. Caddew (PA 4H) and R. F. Moore (PA 5H) in 1901. PA 10H (Maura Reward copper mine) was pegged near Limestone Spring in 1902. Numerous tenements were pegged in the Little Tarraji River – Robinson River area during 1906, including Grants Find, Wilsons Reward, Monarch, and Mondooma, but the only recorded copper production from this area was from the Monarch Group of workings during 1915: 8.97 t at 1.82% Cu from the Obagama lease (ML228H)** and 4.22 t at 0.94% Cu from the Holbrook lease (ML227H). The Yampi

* In the bed of the Isdell River, between 5 and 11 km north of Plover Hill, according to Fitzgerald (1905)

* Mining tenement known as a Prospecting authority

** Mining tenement known as a Mineral lease

Sound copper mine reward lease (ML221H; ML1/04) was pegged by Bonnar and Menzies in 1914. It is probable that the Norah reward lease pegged by J. King (ML153H) in 1908 was over the same mineralization, as the datum description for the Norah lease states that it is on a beach, but the tenement map shows it further west. A total of 94.35 t at 24.55% Cu was produced from the Yampi Sound copper mine between 1914 and 1915. The production from this mine led to the proclamation of the West Kimberley Mineral Field.

Western Mining Corporation explored the Little Tarraji River – Robinson River area between 1957 and 1959. The company carried out geological mapping, stream-sediment sampling, ground magnetic and self potential surveys, and diamond drilling. An inferred resource of 400 000 t at 1.5–2% Cu to 120 m depth at Grants Find was estimated (Reid, 1959).

Between 1963 and 1966, Pickands Mather and Company International carried out regional stream-sediment sampling and geological reconnaissance over most of the west Kimberley area. Several areas with anomalous copper were defined (Pickands Mather and Company International, 1967a). Anomalous copper values in the Yampi Sound area were followed up in the hope of finding porphyry copper mineralization in the Wotjulum Porphyry, but no mineralization was found other than that of the shear-hosted Yampi Sound copper mine (Pickands Mather and Company International, 1967b). Gossans in the Ruins Dolerite at Limestone Spring were tested by diamond drilling and weak copper and nickel mineralization was intersected (Masham, 1970).

Volcanogenic massive sulfide-style (VMS) copper–lead–zinc mineralization was discovered within the Marboo Formation at Chianti in 1971 (Jessup and Yeaman, 1972). Massive sulfide mineralization was also found in the Marboo Formation at the Turtle Creek prospect in the Richenda River area by Prospector Jim Stuart and tested by Western Mining Corporation in 1973, but was considered uneconomic (McConnell, 1973).

Lead–zinc

Lead–zinc mineralization in carbonate rocks was first pegged at Narlarla by Pettigrew in 1900–01 but the lease was relinquished (Woodward, 1907). Leases over Narlarla No. 1 (ML61H) and Narlarla No. 2 (ML66H) were taken out by the Narlarla Hills Silver–Lead Mining Co in 1906.

Small parcels of ore were mined but even the high silver content of the ore did not cover the cost of mining, transport, and treatment of the ore from such a remote area (Woodward, 1907). The deposits were taken up by Devonian Proprietary Limited in 1948. Production between 1948 and 1966 was 2115 t lead, 2867 t zinc and 1162 kg* of silver from 11 033 t of ore, principally from the Narlarla No. 2 orebody (Blockley, 1971).

Matheson and Guppy (1949) noted small veinlets of galena within Devonian limestone 1.5 km northeast of the current Pillara mine at Galena Hill during regional mapping, but it was not until the 1970s that there was intensive exploration for carbonate-hosted base metal mineralization of Mississippi Valley-type (MVT) and Irish-type. Geological mapping, soil sampling, stream-sediment sampling, rock-chip sampling, IP surveys, resistivity surveys, gravity surveys, seismic surveys, magnetic surveys, EM surveys, soil-gas mercury surveys, rotary drilling, percussion drilling and diamond drilling are some of the techniques that have been used in exploration.

Serem Aust. Pty Ltd and Aquitaine Aust. Minerals Pty Ltd reported high levels of lead and zinc from gossans near the current Pillara mine in 1971 (Sylvain, 1971) and also near the Cadjebut mine (Sustrac, 1971). High-grade zinc–lead mineralization was first intersected in a diamond drill-hole at Pillara (then called Blendevale) by a joint venture between BHP, Shell Minerals, and Trend Exploration Pty Ltd during a grid-drilling program in 1978 (Murphy et al., 1990). Mining commenced at Pillara in 1997 (Western Metals Limited, 1998a). The indicated resource at end of June 2000 was 15.91 Mt at 7.64% Zn and 2.6% Pb, including a reserve of 12.92 Mt at 7.8% Zn and 2.7% Pb (Western Metals Limited, 2001). Production to end June 2000 was 3.04 Mt (Western Metals Limited, 2001).

The Wagon Pass deposit was discovered by Shell Australia Ltd in 1980, and was followed up with the discovery of the Cadjebut deposit by BHP in 1984, Twelve Mile Bore (later named Goongewa) by BHP in 1985, and Kapok (to the east of the study area) by BHP in 1989; all of these discoveries resulted from grid drilling (Copp, 2000). The Wagon Pass deposit has an inferred resource of 0.59 Mt at 8.5% Zn, 8.0% Pb, 0.5% Cu and 75 g/t Ag (Western Metals Limited, 1999a). Cadjebut had a pre-mining reserve of 4.4 Mt at 11.3% Zn and 3.3% Pb (Tompkins et al., 1997). BHP commenced development at Cadjebut in 1987 but sold the mine in 1994 — with its other interests in the Lennard Shelf area — to Western Metals (Wilkinson, 1994); mining continued until 1998 (Western Metals Limited, 1999a). The Goongewa mine produced 2.51 Mt grading 7.54% Zn and 2.36% Pb between 1995 and its closure in March 2001 (Western Metals Limited, 2002).

Production from the Lennard Shelf during 2001 was 313 000 t of zinc concentrate and 101 000 t of lead concentrate (Western Metals Limited, 2002), and this made it the largest producer of zinc and lead in the State. The Lennard Shelf operation was also the sixth biggest zinc–lead mining complex in the world (Hamilton, 2000). In 2003, the Lennard Shelf operation was shut down and placed on care and maintenance after the Western Metals Group of companies was placed in receivership (Western Metals Limited, 2003). Teck Cominco Limited, a Canadian-based corporation, purchased the operation in October 2003 (Price Waterhouse Coopers, 2003) and the company is currently assessing the resources and exploration potential of the area (Teck Cominco Limited, 2004).

Iron

The iron ores of Yampi Sound were discovered around 1880 by pearlers, and boulders of iron ore from the beach

* Silver production is incorrectly quoted as 162 kg in Ringrose (1989)

were used in the pearl luggers as ballast (Harms, 1959). Leases for iron ore were first taken up on Koolan Island in 1907 by the Australian Prospecting Association with the intention of mining the ore for flux purposes (Campbell, 1909b). During the 1920s and 1930s, there were a number of attempts to develop the deposits (Finucane, 1939b). However, production did not commence on Cockatoo Island until 1951 and on Koolan Island until 1964 (BHP staff, 1975). Production from Koolan Island between 1964 and 1993 was 63.8 Mt grading 66–67% Fe, and from Cockatoo Island between 1951 and 1987 was 29.9 Mt (DoIR production statistics). An additional 0.9 Mt of ore was mined by Portman Limited between 1998 and 2000 (Portman Limited, 2000). Portman (in a 50/50 joint venture with Henry Walker Eltin) plans to build an offshore engineered embankment to enable the mining of an extra 4 Mt of high-grade ore lying below sea level on Cockatoo Island (Portman Limited, 2002). Aztec Resources Limited has commenced drilling on Koolan Island as part of a feasibility study to recommence mining (Aztec Resources Limited, 2004).

Tungsten and tin

J. F. Taylor pegged ML146H over the King Sound tungsten–tin deposit in 1907 (DoIR historical tenement register; Campbell, 1909a) but A. W. Sergison allegedly found ‘a mountain of tin’ in this area in 1897 (*Sunday Times*, 1908b). The only recorded production from the King Sound mine is 27.4 t ore and concentrates totalling 2.03 t WO_3, between 1911 and 1913. There is no recorded production of tin from this mine, but some of the tin production ascribed to Patterson Range may have come from here (Blockley, 1980).

Diamonds

Wade and Prider (1940) first suggested a possible genetic connection between the lamproites of the west Kimberley and the kimberlites of South Africa: both rock types are derived from mica–peridotite magma. Earlier than this, a specimen of leucite lamproite collected by W. V. Fitzgerald from the Lennard River near Mount Eliza in 1905 was described by Farquharson (1920a,b), but he expressed some doubt about whether the sample had really come from the west Kimberley. Several other leucite lamproites were discovered by the Freney Oil Company during their search for petroleum in the 1920s and 1930s (Farquharson, 1922; Wade, 1924, 1936). By 1984, over 100 intrusions and vents of lamproite had been recognized in the west Kimberley (Smith, 1984) and 31 more have recently been discovered (Kimberley Diamond Company NL, 2001a,b, 2002a,c,d,f,g).

It was not until 1969 that the first diamonds were found in the west Kimberley in the Lennard River area. Nine diamonds with a total weight of 1.65 carats (ct), an average of 12 ct/t, were obtained from five sites in the Lennard River by the Exoil NL – Petromin NL – Transoil NL joint venture (Australian Mineral Development Laboratories, 1970; Haynes, 1971). Since the sampling results could not be repeated, and the diamonds were small and full of inclusions, the joint venture partners did no further work in the area (Haynes, 1971). Even earlier, Jeppe (1968) reported that Stellar Minerals Pty Ltd had identified indicator minerals, including pyrope with a kimberlitic composition, picroilmenite, picrochromite, and green diopside at Mount Abbott, and pyrope at The Sisters (Kalyeeda Hills). Stellar also reported anomalous Nb (150 ppm), P (10 000 ppm), and Be (60 pm) from lamproite and lamproitic breccia at Mount Percy in the Ellendale area (Noonkanbah field), but was unsuccessful in finding diamonds (Jeppe, 1968). Exploration for diamonds during the mid-1970s spread to other areas and has continued to the present day.

Indicator minerals and diamonds were located at Big Spring during 1976 (Hughes and Smith, 1977, 1978), during regional stream-sediment sampling by the Ashton Joint Venture in the vicinity of a possible lamproite that had been found during regional mapping by the former BMR and GSWA in 1966–67 (Derrick and Gellatly, 1972). A combination of stream-sediment sampling, auger drilling, magnetic surveys, and Turam (electro-magnetic) surveys assisted in delineating five olivine lamproites (Hughes and Smith, 1977). Bulk samples totalling 355 t taken from two of the olivine lamproites at Big Spring in 1977 contained 27 small diamonds totalling 0.37 ct, proving that diamonds were associated with the lamproites (Hughes and Smith, 1978) and highlighting the significance of chromite as an indicator mineral (Smith et al., 1990). The diamondiferous Ellendale 4 lamproite pipe was discovered by the Ashton Joint Venture in November 1976 as a result of regional stream-gravel sampling in which pyrope garnet was found. Follow-up sampling led to a trail of indicator minerals including diamond, which led back to the vent — visible as a composite circular structure on aerial photographs — some 12 km upstream (Atkinson et al., 1985; Jaques et al., 1986). Many additional lamproites were delineated in the Ellendale area soon afterwards by flying an airborne magnetic survey (Atkinson et al., 1985). Bulk samples of the Ellendale lamproites taken from surface pits and drill sampling were evaluated in a test plant between 1977 and 1980. A total of 92 000 diamonds weighing 13 000 ct were recovered from 230 000 t, including 6600 ct from Ellendale 4 and 6100 ct from Ellendale 9 (Atkinson et al., 1985). Sixty per cent of the diamonds from the Ellendale pipes were gem quality but it was concluded that the pipes were subeconomic (Atkinson et al., 1985). Kimberley Diamond Company NL acquired the tenements over Ellendale in 2001 and carried out bulk sampling programs at Ellendale 4 and 9. At Ellendale 9, individual diamonds up to 11.47 ct have been recovered (Kimberley Diamond Company NL, 2002a). Combined measured, indicated, and inferred resources were initially estimated at 23 Mt at 8.8 ct/100 t for Ellendale 4, and 10.9 Mt at 5.4 ct/100 t for Ellendale 9 (Kimberley Diamond Company NL, 2001b, 2002b). These resources have been substantially increased as a result of further bulk sampling, with combined resources estimated at 40.70 Mt at 7.0 ct/100 t for Ellendale 4, 17.80 Mt at 5.7 ct/100 t for Ellendale 4 satellite pipe, and 31.92 Mt at 5.5 ct/100 t for Ellendale 9 (Kimberley Diamond Company NL, 2004). Mining of the Ellendale 9 pipe commenced in May 2002 (Weir, 2002) and mining of Ellendale 4 is planned to commence in 2005 (Kimberley Diamond Company NL, 2003). Kimberley

Diamond Company has also been exploring for new lamproites using termite mounds as a sampling medium (Mason, 2000; Weir, 2002), detailed aeromagnetic surveys (Kimberley Diamond Company NL, 2002f), and the Falcon airborne gravity system. Newly discovered lamproite pipes and fissures in the catchment area of the Terrace 5 palaeochannel, in which large diamonds have been found, were tested (Kimberley Diamond Company NL 2001c, 2002c,d,e,f,g, 2003) but only small diamonds were recovered and the source of the large diamonds has yet to be found (Kimberley Diamond Company NL, 2003).

Coal

Coal seams were first discovered during well sinking on Lower Liveringa Station in 1909 (Simpson, 1910; Woodward, 1915). A prospecting authority for coal (PA1/04) was pegged by P. F. (Fred) King in 1921 near Barrongan Tower on MOUNT ANDERSON (DoIR historical tenement register; *Murchison Times*, 1921). There was considerable exploration for coal in the Fitzroy Sub-basin between 1965 and 1975 as a result of the need for coal to smelt the Pilbara iron ores and the demand for coal from overseas (Lord, 1975). Extensive but low-grade deposits were drill-tested at Audreys Bore by Premier Mining Co. (Baada, 1966); at Myroodah by Thiess Brothers (Pickering, 1968); at Liveringa Ridge by Australian Inland Exploration Company and Texasgulf Australia (Gair, 1972; Lee et al., 1980); and at Mount Fenton (Broken Hill Proprietary Company Limited, 1978). BHP Billiton has recently signed an agreement with Customers Limited to re-examine the Liveringa Ridge deposit and to explore for higher grade coal deposits (Customers Limited, 2002).

Bauxite

Bauxite was discovered at Cape Bougainville (to the east of the study area) by Reynolds Pacific Mines Proprietary Limited (a subsidiary of Reynolds Metal Company of USA) in 1958, but the company considered the deposit to be too low grade to be of interest and relinquished its temporary reserves (Ruddock, 2003). Higher grade bauxite was discovered on the Mitchell Plateau by the United States Metals Refining Co. (a subsidiary of AMAX — American Metal Climax Inc.) in 1965 (Joklik et al., 1975). This discovery was followed by a major evaluation program, involving vacuum drilling and pitting, undertaken between 1965 and 1971 that led to the establishment of a resource of 230 Mt at 47% total alumina and 2.6% total silica at Mitchell Plateau and 980 Mt at 36% total alumina and 1.9% total silica at Cape Bougainville (Joklik et al., 1975). In 1971 AMAX entered into a State Agreement, The Alumina Refinery (Mitchell Plateau) Agreement Act 1971, to develop the Mitchell Plateau deposits within its existing TRs 5610H to 5614H and to construct an alumina refinery, a port, and a townsite nearby. This envisaged that development of the deposits would take place in the mid-1970s, opening up the remote north Kimberley area and providing substantial economic benefit to the State. However, the project was curtailed because of a dramatic fall in alumina and aluminium prices in 1972 (Smurthwaite, 1990; Ruddock, 2003).

AMAX merged its aluminium and bauxite interests with Mitsui & Co. Ltd in 1973 to form Alumax, and for the next few years this company negotiated with other companies around the world to develop the Kimberley bauxites. In 1979 CRA (Comalco Ltd from 1982) took up an interest in the project, and managed it through its wholly-owned subsidiary Mitchell Plateau Bauxite Co. Proprietary Limited (MPBC). In 1980 Alumax disposed of its entire interests to MPBC, Alcoa of Australia Limited, Billiton, Sumitomo, and Marubeni (Ruddock, 2003). During the period from 1980 to 1983, MPBC undertook further drilling, bulk sampling, and beneficiation testing at Mitchell Plateau as part of a major reappraisal of the economic viability of the bauxite deposits (Parker and Sadleir, 1984; Bardossy and Aleva, 1990). From this work, revised bauxite reserves for the Mitchell Plateau (after beneficiation) were reported as 457 Mt at 46.6% Al_2O_3 and 4.6% SiO_2 (total silica), of which 277 Mt were considered as proven and 180 Mt as probable (Bardossy and Aleva, 1990). As well, zones of refractory-grade bauxite (with low TiO_2 and Fe_2O_3) within the deposits were assessed. In 1984, Comalco Ltd announced that it planned to ship bauxite from Mitchell Plateau to a proposed alumina refinery near Geraldton, because of the much higher costs involved in constructing a refinery on site. However, once again, project development was postponed because of declining world prices for aluminium and high costs of mining and beneficiation in this remote area (Smurthwaite, 1990; Ruddock, 2003).

Uranium

There was active exploration for uranium in the Canning, Kimberley, and Speewah Basins between 1968 and 1987. Sandstone-hosted uranium deposits (including roll-front, fluviodeltaic, and conglomerate-hosted deposits) were the exploration targets. Detailed assessments of environments of deposition and structure were used by Afmeco Proprietary Limited in their search for uranium (Botten, 1984). A resource of 4640 t U metal was outlined by Afmeco Proprietary Limited (1983) at Oobagooma.

Other minerals

Hardman (1884) noted the presence of red and yellow ochre and precious and semiprecious stones (agate, carnelian, amethyst, opal, catseye, sapphire, and emerald or green beryl) but he did not provide locations for the precious and semiprecious stones.

Rock phosphate, overlain by guano, was reported from White Island in 1910 (Simpson, 1911). Phosphatic beds in the Triassic Blina Shale and the Late Jurassic to Early Cretaceous Jarlemai Siltstone were noted by Brunnschweiler (1954). Utah Development Company carried out Australia-wide exploration for phosphate between 1962 and 1966, but concluded that the Canning Basin had unfavourable palaeogeography (Howard, 1972). Following exploration between 1965 and 1967, Mines Exploration Proprietary Limited concluded that phosphate in the Blina Shale and Jarlemai Siltstone was uneconomic. However, later metallurgical testing of the phosphate in the Jarlemai Siltstone at Langey Crossing indicated that the phosphate was relatively unreactive and could be suitable for direct application as a fertilizer (Mines Exploration Proprietary Limited, 1976).

Kyanite was first reported from the west Kimberley by Campbell (1909b), and the Hawkstone kyanite deposit was mapped and described in detail by Derrick and Morgan (1966). The deposit has been briefly assessed by exploration companies but there has been no production. Corundum (emery) was reported from the Richenda River area in 1918 (Simpson, 1919). Mica and beryl have been produced from a pegmatite at Stewarts and mica from Gussys mine (Harms, 1959).

A salt diapir was intersected in petroleum well Frome Rocks 1 drilled by WAPET in 1959. Offshore Diamond Mines NL (1991) estimated a resource of 55 billion tonnes of salt in the diapir based on the intersection in Frome Rocks 1 and seismic data.

Petroleum

Traces of petroleum were first noted in the west Kimberley by Mr Harry Price whilst sinking a water bore at Rough Range (now known as Pillara Range) in 1919 (Blatchford, 1922, 1927). Commercial oil was discovered in oilwell Blina 1 in 1981. Discussion of petroleum exploration is not within the scope of this report; however, a detailed review of petroleum exploration activities can be found in D'Ercole et al. (2003).

Mineralization

The 819 mineral occurrences in the west Kimberley are shown on Figure 7 and on Plate 1. The mineral occurrences on Plate 1 are grouped by mineral commodity and by mineralization style (see Table 2.1 and Table 2.3 in Appendix 2). Symbol colours on the plate are used to distinguish commodity groups and symbol shapes are used to distinguish mineralization styles. For the convenience of description in the section below, mineralization style is used as a main heading, with each of the commodity groups as a subheading. Mineral occurrences referred to below are also identified by the WAMIN deposit number shown thus: Ellendale 4 (***8410***). The WAMIN database for the west Kimberley is included on the accompanying CD-ROM and is described in Appendix 2.

Mineralization in kimberlite and lamproite

The distribution of mineralization classified as 'Kimberlite and lamproite' is shown in Figure 8. With the exception of two industrial mineral occurrences (bentonite and potassium feldspar), these are all diamond occurrences within lamproites of the Fitzroy Volcanics.

Precious mineral — diamond

The diamondiferous lamproites tend to be clustered together within discrete areas or lamproite fields. The Ellendale lamproite field, Eastern Lennard Shelf lamproite field, Calwynyardah lamproite field, and Noonkanbah lamproite field fall within the west Kimberley lamproite province (Jaques et al., 1986). The main diamond fields and other occurrences are described below.

Ellendale lamproite field

As at 2002, 79 lamproites have been found in the Ellendale field (Fig. 8) and new lamproites continue to be found (Kimberley Diamond Company NL, 2001a,b; 2002a,c,d, f,g). Most of the lamproites are volcanic craters and diatremes, which have been referred to as pipes, but dykes and sills have also been recorded (Smith et al., 1990; Kimberley Diamond Company NL, 2003). The lamproites vary in surface area from less than a hectare to 106 ha (Atkinson et al., 1984). Most of the lamproites lie on a postulated subsurface extension of the northwesterly trending fault along the base of the Oscar Range, although three are located at the edge of the northwesterly trending Napier Range (Smith, 1984). Ellendale 4 (***8410***) and Ellendale 9 (***8411***) contain significant quantities of diamonds with about 60% being of gem quality (Jaques et al., 1986). These two pipes are discussed in more detail below. Ellendale 7 (***8417***) and Ellendale 11 (***8418***) have a diamond content of about 1 ct/t, and traces of diamond are present in many of the other Ellendale lamproites, in particular the olivine lamproites (Atkinson et al., 1984).

Ellendale 4

Ellendale 4 (***8410***) is concealed beneath a cover of sand and soil but geophysical surveys and drilling results indicate that it has a surface area of 76 ha; the Ellendale 4 satellite pipe (***15606***), located to the east of the main pipe has a surface area of 11 ha (Kimberley Diamond Company NL, 2003). The pipes intrude sandstone of the Permian Grant Group and Devonian Nullara Limestone. The Ellendale 4 lamproite is a complex body consisting of two coalescing eruptive centres each with a core of olivine lamproite and a marginal zone of pyroclastic rocks. The pyroclastic rocks make up about 50% of the vent and range from pale-green sandy tuff to dark olivine lamproite lapilli tuffs (Fig. 9; Jacques et al., 1986). The diamonds are concentrated in the pyroclastic rocks (Jacques et al., 1986). Most of the stones are of dodecahedral habit, although stones less than 1 mm across have a planar octahedral form (Hall and Smith, 1984). About 65% of the stones are yellow, 22% brown, 11% colourless, and 2% grey (Hall and Smith, 1984). Ellendale 4 is estimated to contain a combined measured, indicated, and inferred diamond resource of 40.70 Mt at 7.0 ct/100 t (Kimberley Diamond Company NL, 2004), with an additional inferred resource of 17.80 Mt at 5.7 ct/100 t in the Ellendale 4 satellite pipe. Mining is planned to commence in 2005 (Kimberley Diamond Company NL, 2003).

Ellendale 9

Ellendale 9 (***8411***) has a surface area of 46.9 ha and is concealed beneath between 1 and 6 m of sand, laterite (duricrust), calcrete, and clay. Ellendale 9 consists of two coalescing vents each having a core of olivine lamproite with a central zone of phlogopite–olivine lamproite, and a marginal zone of pyroclastic rocks composed of 'sandy'

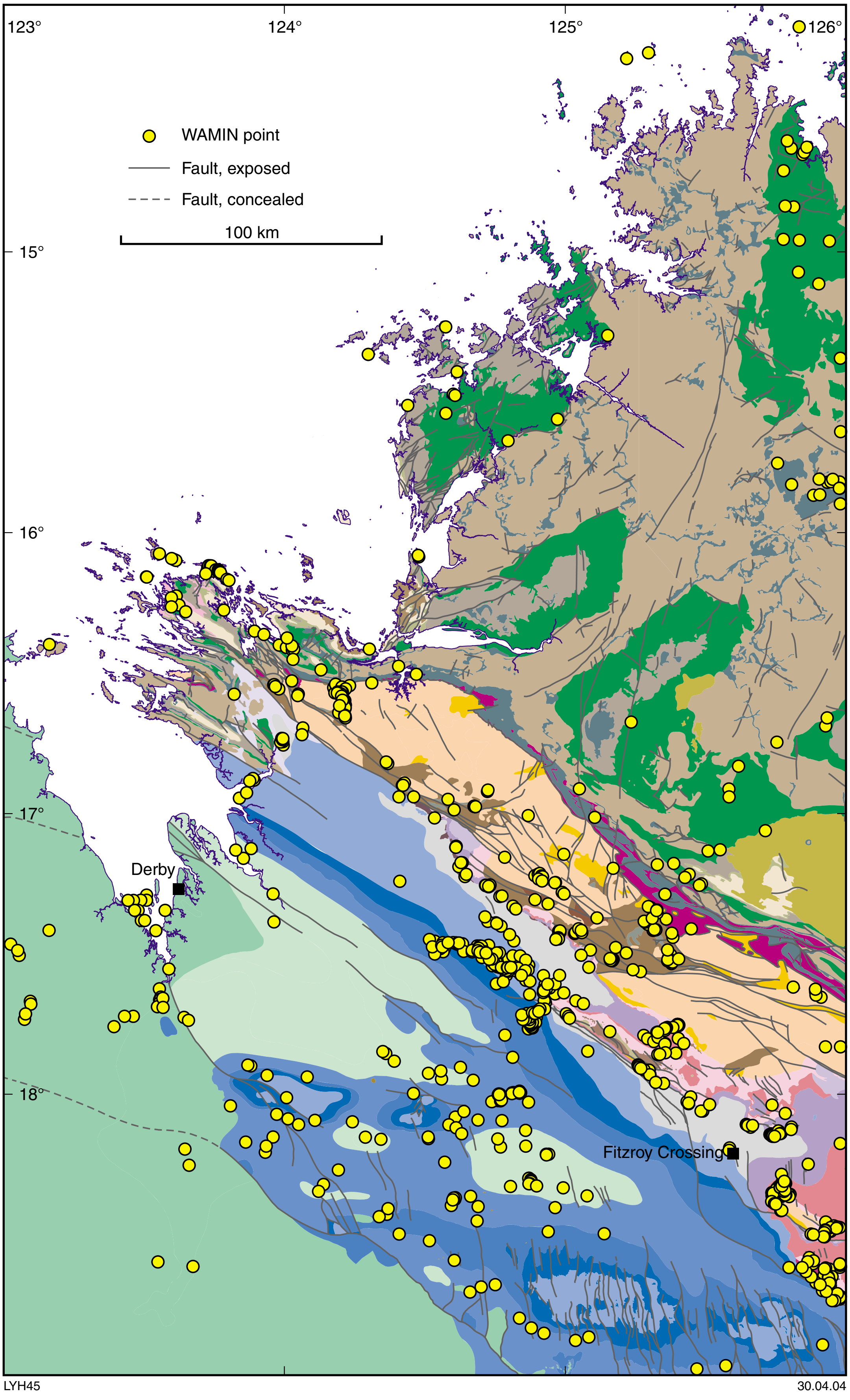
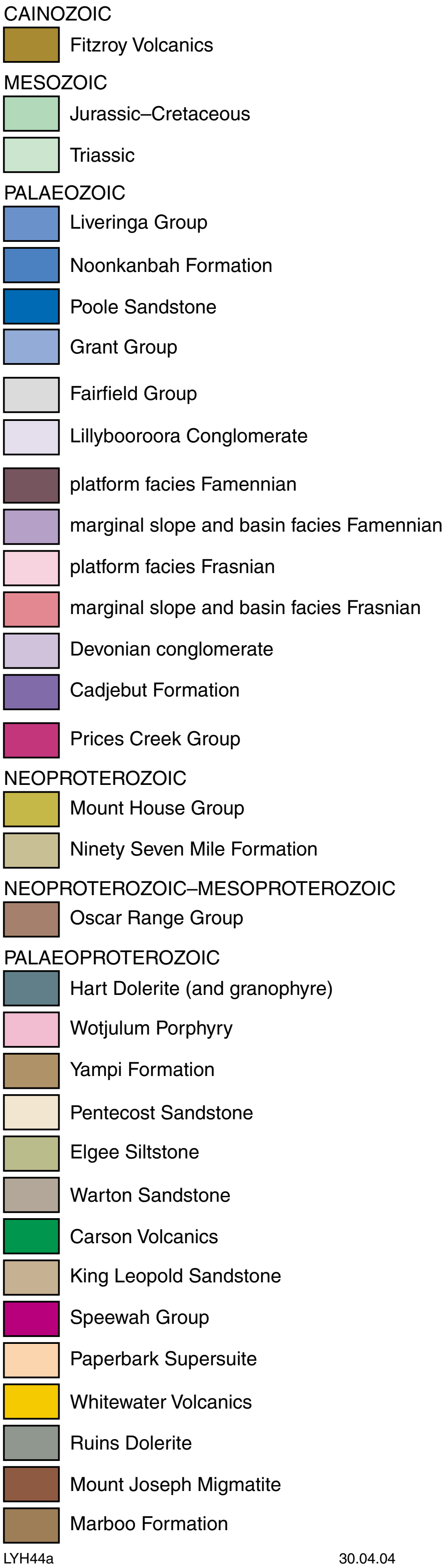


Figure 7. Simplified geological map showing distribution of mineral occurrences in the west Kimberley



lapilli tuff and olivine lamproite lapilli tuff (Fig. 10; Jacques et al., 1986). The highest diamond grades are in the marginal pyroclastic zones, but diamonds are also present in the olivine lamproite of the western lobe (Jacques et al., 1986). As at Ellendale 4, most of the diamonds have a dodecahedral habit (Hall and Smith, 1984). About 55% of the stones are yellow, 23% brown, 20% colourless, and 2% grey (Hall and Smith, 1984). A combined measured, indicated and inferred resource of 31.92 Mt at 5.5 ct/100 t to a depth of 120 m has been announced (Kimberley Diamond Company NL, 2004). The average grade at Ellendale 9 is lower than that at Ellendale 4, but the average size and value is greater, with diamonds up to 9.5 ct being recovered (Kimberley Diamond Company NL, 2002a). Mining commenced at Ellendale 9 in May 2002 (Weir, 2002).

Eastern Lennard Shelf lamproite field

Jaques et al. (1986) used the term Eastern Lennard Shelf field for 15 widely scattered lamproites to the east of the Ellendale area. Most of these intrude Devonian carbonate rocks of the Lennard Shelf, but some intrude granites of the Hooper Complex (Jaques et al., 1986). At Big Spring (***8391–95***), small diamonds and microdiamonds have been reported from five olivine lamproite pipes (Hughes and Smith, 1977, 1978; Haebig, 1979, 1983a).

Calwynyardah lamproite field

Several lamproites form a cluster between the Ellendale lamproite field and the Noonkanbah lamproite field. The largest of these is Calwynyardah (***8678, 8689–90, 8692–93***), with a surface area of 124 ha. The Calwynyardah vent is almost entirely filled with olivine lamproite lapilli tuff. There is a small olivine–leucite lampriote plug on the southeastern margin. Reworked lacustrine tuff occupies the central area of the vent (Fig. 11; Jaques et al., 1986). One small diamond (0.015 ct) was obtained from a 26 m^3 sample at Calwynyardah 1 (***8678***), and microdiamonds were obtained from drillhole samples at other locations within the intrusion (Haebig, 1983b). Boxer and Haebig (1980a) reported that small diamonds and microdiamonds have also been recovered from Laymans Bore East (***8658–63***). The Laymans Bore East lamproite has a surface area of 103 ha and is similar to the Calwynyardah vent in that it is filled with olivine lamproite tuff and has reworked lacustrine tuff in the central part of the area (Jaques et al., 1986). Small diamonds and microdiamonds have also been reported (Boxer and Haebig, 1980a,b) from Laymans Bore West A (***8667–68***) and Laymans Bore West B (***8669, 8660***), and microdiamonds have been found (Boxer and Haebig, 1980a,b) at Metters Bore no. 1 (***8650***), Metters Bore no. 3 (***8651***), Metters Bore no. 6 (***8652***), Merrilees Bore (***8696***), and Billys Bore West (***8695***).

Noonkanbah lamproite field

Seventeen lamproites have been described in the Noonkanbah lamproite field in the central part of the Fitzroy Trough by Wade and Prider (1940), Prider (1960), and Jacques et al. (1986). Many of the intrusions are large and form prominent landmarks. The largest lamproite is Walgidee Hills, which is a roughly circular intrusion 3 km across intruding the Triassic Blina Shale. The Walgidee

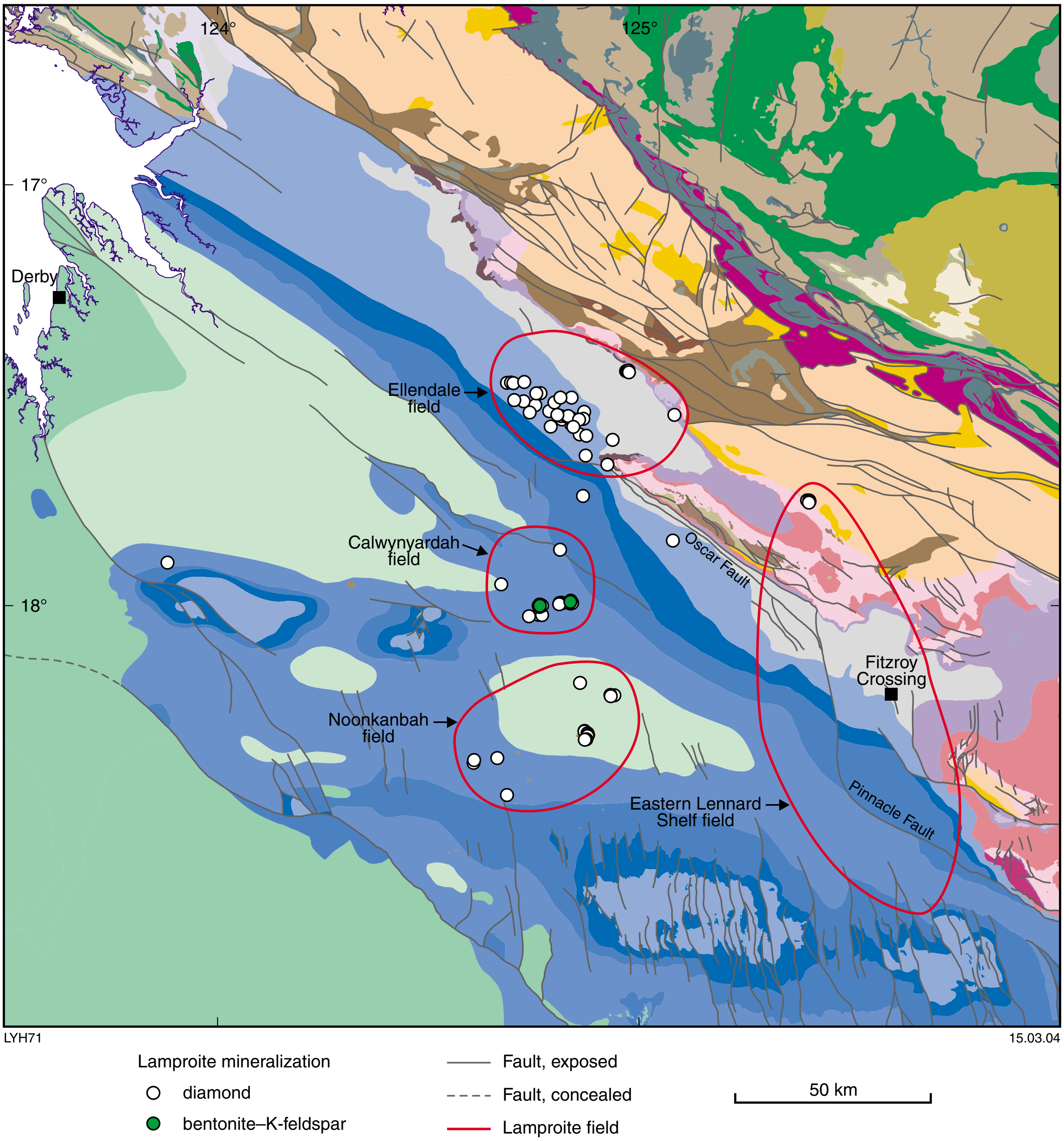


Figure 8. Simplified geological map showing distribution of lamproite fields and mineralization in the west Kimberley. See Figure 7 for geological legend

Hills intrusion consists predominantly of magmatic lamproite (diopside–K-richterite–sanidine lamproite, phlogopite–diopside–K-richterite–sanidine lamproite, and, around the margins, olivine–leucite lamproite) with a thin marginal zone of lamproite breccia and tuff breccia (Fig. 12; Jaques et al., 1986). Microdiamonds and a few small diamonds have been obtained from samples of pyroclastic rocks from around the eastern margin of the Walgidee Hills intrusion (***8854–63***), reported in Smith and Haebig (1990). Small diamonds and microdiamonds have also been found at Mount Abbott (***8637, 8640, 8643***), reported in Boxer and Haebig (1980a) and Haebig (1983b); Mount Noreen (***8634***), reported in Boxer and Haebig (1980a); 20 Bore no. 2 (***8694***), reported in Boxer and Haebig (1980a); no. 33 Bore (***8646–48***), reported in Haebig (1983b); and at Mount Ibis (***8705***), reported by Gregory (1982). To date, no economic concentrations of diamonds have been reported from this area.

Fitzroy Valley area

There are some lamproites scattered throughout the Fitzroy Valley that do not fall within the lamproite fields previously described (Jaques et al., 1986). To date,

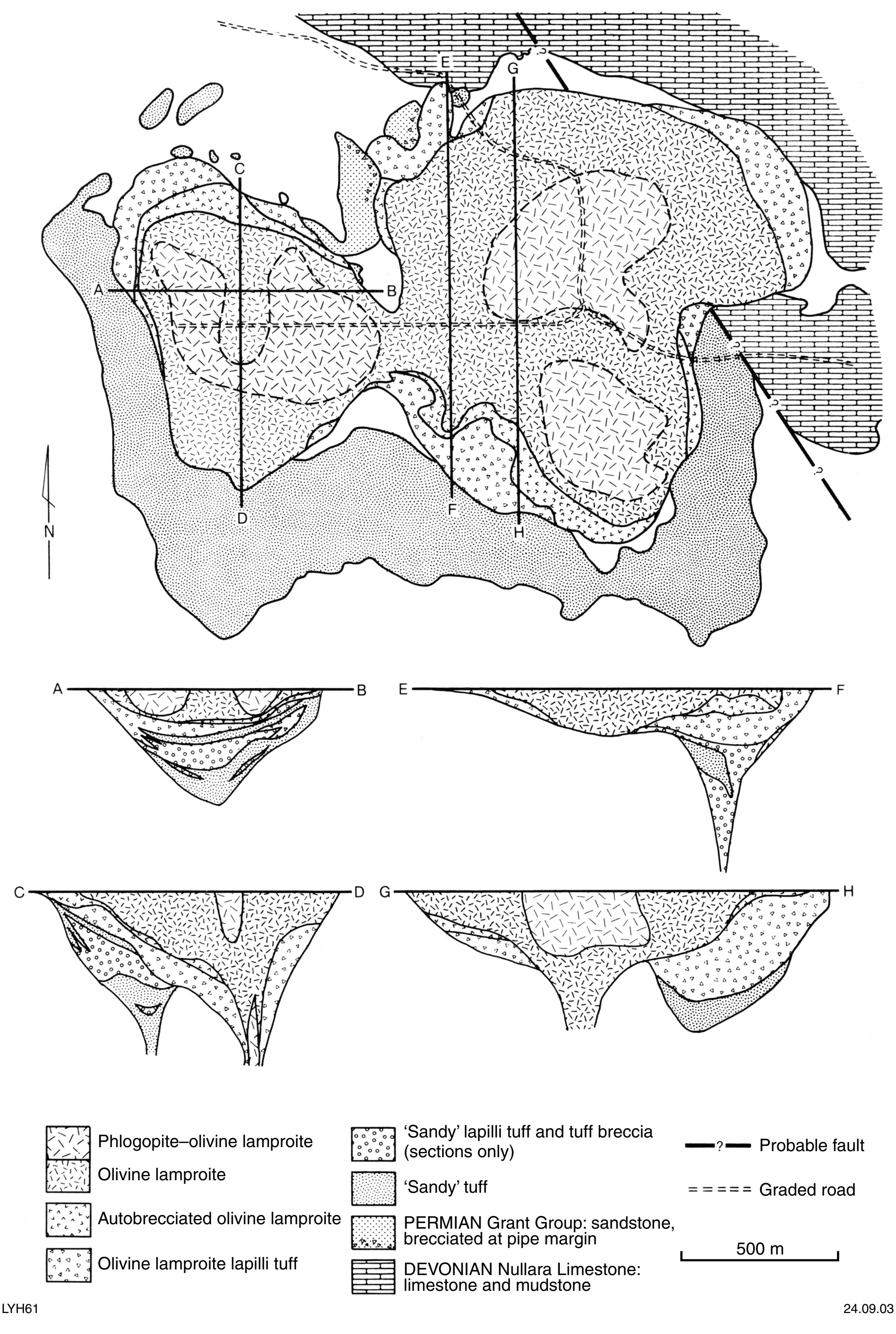


Figure 9. Geological map of Ellendale 4, with four cross sections of the vents (after Jaques et al., 1986)

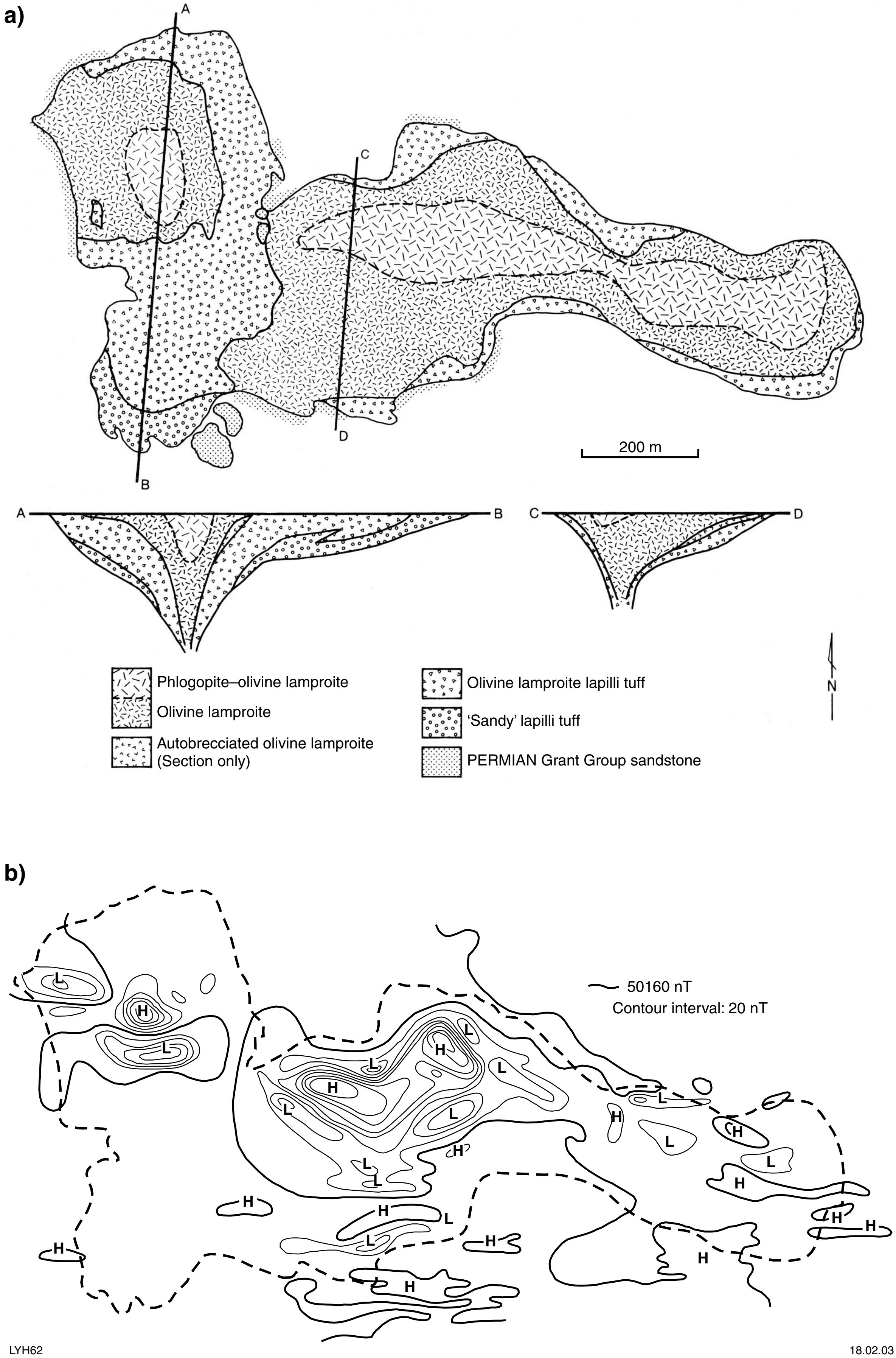


Figure 10. Ellendale 9 lamproite: a) geology, with two cross sections; b) ground magnetic contours (Jaques et al., 1986)

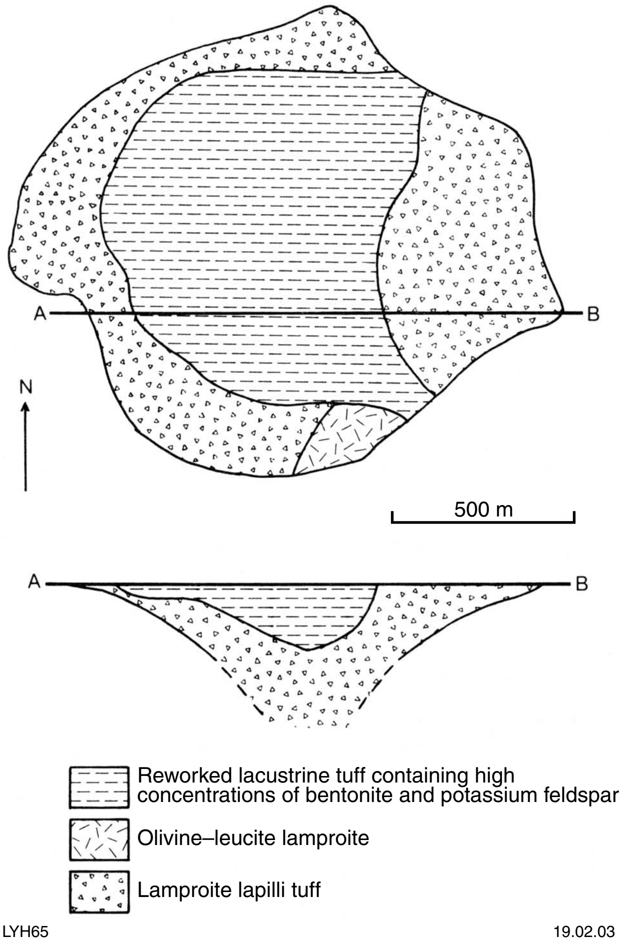


Figure 11. Geological map of Calwynyardah pipe and accompanying cross section (modified after Boxer and Haebig, 1980a; Jaques et al., 1986)

diamonds have only been reported from one of these. One diamond (0.0785 ct) and six microdiamonds were recovered from Camarotoechia Creek (***9126***), a pipe with a surface area of approximately 3.5 ha intruding Permian quartzite and calcareous limestone (Gregory, 1981; Pacific Exploration Consultants Proprietary Limited, 1991). This pipe consists of two varieties of olivine–leucite lamproite and bedded lapilli tuffs (Gregory, 1981).

Other areas

One microdiamond (0.275 × 0.275 mm) was recovered by CRA Exploration from a drillhole at Liveringa Diamond (***9125***), more than 80 km to the west of the other west Kimberley occurrences (Manning and Haebig, 1986). The host rock was interpreted as basalt by Manning and Haebig (1986), but as lamproite by Juka Mine Management Proprietary Limited (1991) during follow-up work for Australian Consolidated Minerals Ltd. Lamproitic chromite was also found in the area and confirmed by microprobe analysis, but no diamonds were found in the 1–12 mm fraction of a bulk sample taken from two pipes (Juka Mine Management Proprietary Limited, 1991).

Fielding and Thomas (1984a,b) reported alluvial diamonds in the northern part of the area, e.g. Mount Fyfe 1 (***8765***) and Mount Hann 1 (***8763***). The source of

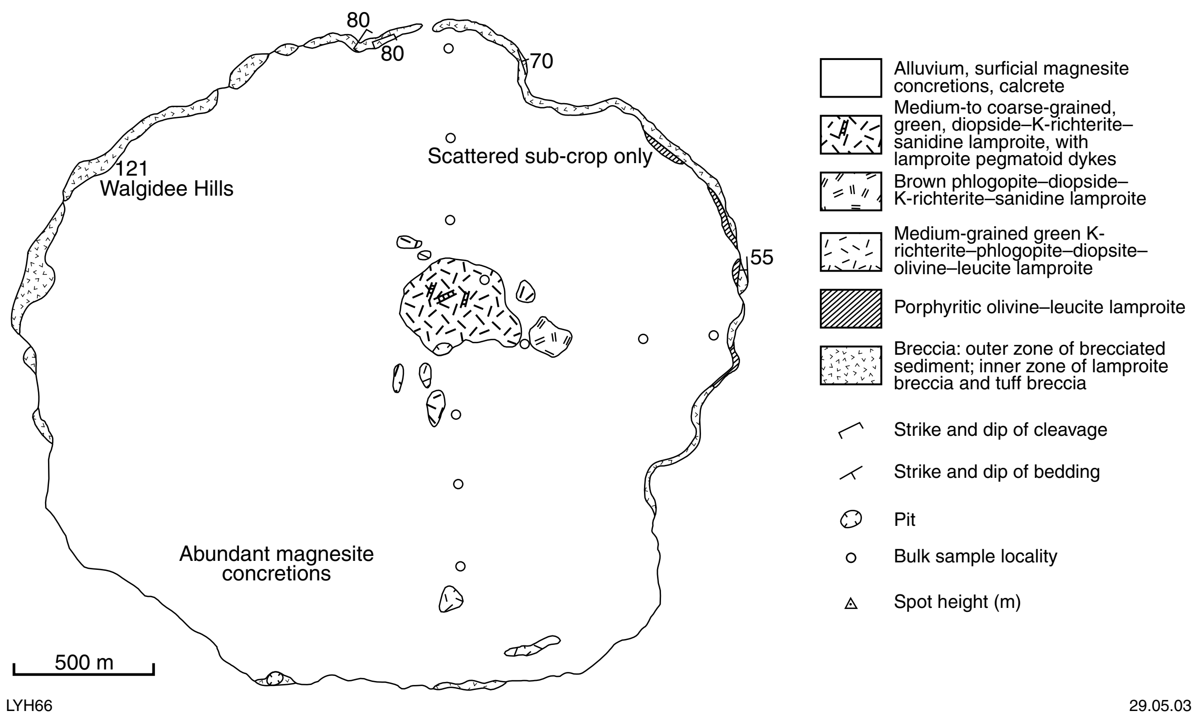


Figure 12. Geological map of the Walgidee Hills lamproite (after Jaques et al., 1986)

these diamonds is not known but may be related to kimberlite intrusions in the north Kimberley region.

Industrial mineral — bentonite and potassium feldspar

At Calwynyardah Bentonite (***10224***) and Laymans Bore East Bentonite (***10225***), high concentrations of bentonite (smectite) and potassium feldspar (orthoclase) were found in the crater-lake sediments overlying the lamproites (Fig. 11) during diamond exploration (Kimberley Diamond Company NL, 1996; Kimberley Resources NL, 1998). The estimated tonnage of sediments in the Calwynyardah crater lake is about 19.8 Mt at an average grade of 22% smectite clay, predominantly saponite (Jones, 1997; Abeysinghe, 2002).

Orthomagmatic mafic and ultramafic mineralization — undivided

The distribution of occurrences classified as 'Orthomagmatic mafic and ultramafic — undivided' is shown on Figure 13. They are base metal (copper, nickel) occurrences.

Base metal — copper (nickel)

At Limestone Springs (***340***), copper–nickel gossans and malachite, chalcocite, cuprite, and relict chalcopyrite are exposed in a shallow shaft and trenches over a distance of 90 m (Pickands Mather and Company International, 1967a). The mineralization was pegged as PA 10H (Maura Reward copper mine) in 1902 but there is no recorded production. The gossans with the highest base metal values are in the Ruins Dolerite where rock-chip samples assayed up to 30% Cu and 1.4% Ni (Pickands Mather and Company International, 1967a). There is also gossanous sericite–chlorite schist within the dolerite, which is interpreted by Harris (1968) as country rock caught up in the sill and partly replaced by sulfides derived from the cooling magma. Pickands Mather drilled two diamond drillholes in 1969 to test the gossans. One failed to intersect the dolerite but the other intersected weak disseminated mineralization within the dolerite with the best intersection being 7.6 m at 0.39% Ni and 0.2% Cu in DDH 1002 (Masham, 1970).

Malachite and chalcocite reported from weathered rock at Camden Sound (***10069***) by Simpson (1952) is possibly an orthomagmatic occurrence in the Hart Dolerite (Marston, 1979).

Steel industry metal — nickel

See Limestone Springs (***340***) in section above.

Greisen mineralization

Speciality metal — tin

At Silent Valley 1 (***10076***), there are thin seams of cassiterite in greisen, and coarse-grained cassiterite in quartz veins hosted by granite; about 1 t of cassiterite was recovered by J. Stewart (Harms, 1959). No other greisen occurrences have been recorded.

Pegmatitic mineralization

The distribution of pegmatitic mineralization is shown on Figure 14. This classification includes speciality metal (tin) and industrial mineral (beryl, mica).

Speciality metal — tin

Cassiterite-bearing pegmatites intruding the McSherrys Granodiorite at Dysons Creek (***7711***) were reported by Finucane (1939a) and Harms (1959). Nine samples taken from the main pegmatite at 12-m intervals assayed 0.09% Sn over 35 cm (Finucane, 1939a). Kalganu Island (***10101***) may also be a pegmatitic cassiterite occurrence (Blockley, 1980).

Industrial mineral — beryl, mica

Beryl and muscovite-bearing pegmatites intrude Marboo Formation and Ruins Dolerite at Stewarts (***353***) and Stewarts East (***8811***). Production from Stewarts reported by Harms (1959) was 3.56 t beryl and 68 kg mica. At Gussys (***2921***), a muscovite-bearing pegmatite intrudes gneissic granite of the Kongorow Granite. Reputed production of mica is 0.5 t (Harms, 1959). Sofoulis (1967a) also reported a few crystals and lumps of beryl on a dump at Gussys. Harms (1959) reported muscovite sheets up to 7.5 × 7.5 cm in pegmatites at Mount Joseph (***10080***), but there has been no recorded production.

Stratabound volcanic and sedimentary — volcanic-hosted sulfide mineralization

The distribution of mineral occurrences classified as 'Stratabound volcanic and sedimentary — volcanic-hosted sulfide' is shown on Figure 15. They include base metal (copper, lead, zinc, silver) and precious metal (gold).

Base metal — copper, lead, zinc (silver)

At Chianti 1 (***8380***), gossans within the Marboo Formation outcrop over a strike length of 150 m. Australian Consolidated Minerals NL drilled three diamond drillholes beneath the gossans. Diamond drillhole DDH3 intersected massive sulfides and a sulfide-bearing breccia. The sulfides consisted principally of pyrrhotite with chalcopyrite, sphalerite, and galena. The fragments in the breccia consisted of approximately 50% altered andesite, 15% rhyolite, 20% altered kaolinitic and sericitic rock, 10% chloritized fragments, and 5% quartz. The altered kaolinitic and sericitic rock fragments are rimmed by sphalerite and the chlorite fragments are preferentially rimmed and replaced by chalcopyrite. The best intersection in the massive sulfides is 6.55 m at 2.85% Zn, 1.96% Cu, 0.93% Pb, and 29.2 g/t Ag. Massive pyrrhotite within black shale was intersected in drillhole DDH2, but

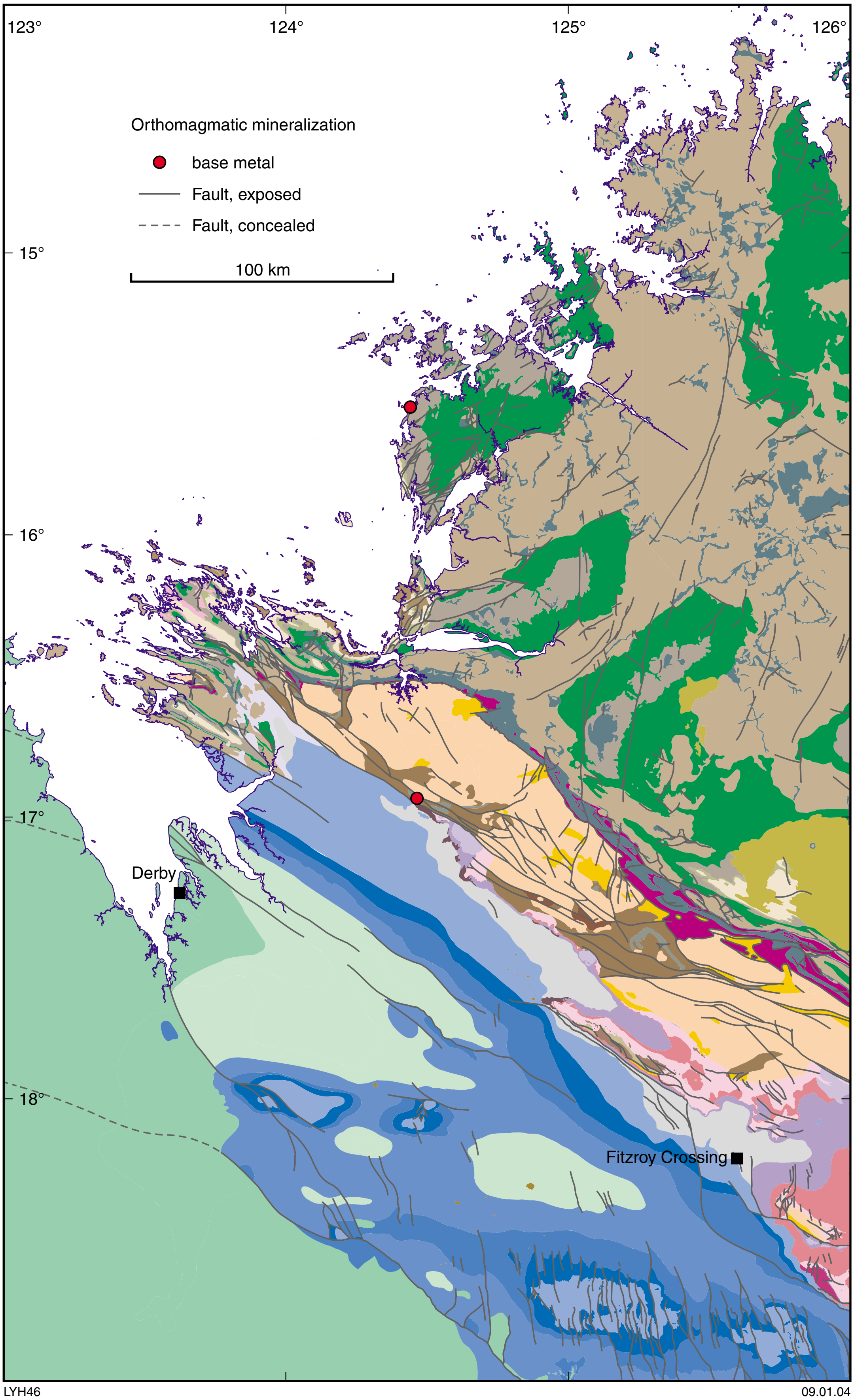


Figure 13. Simplified geological map showing distribution of orthomagmatic mineralization in the west Kimberley. See Figure 7 for geological legend

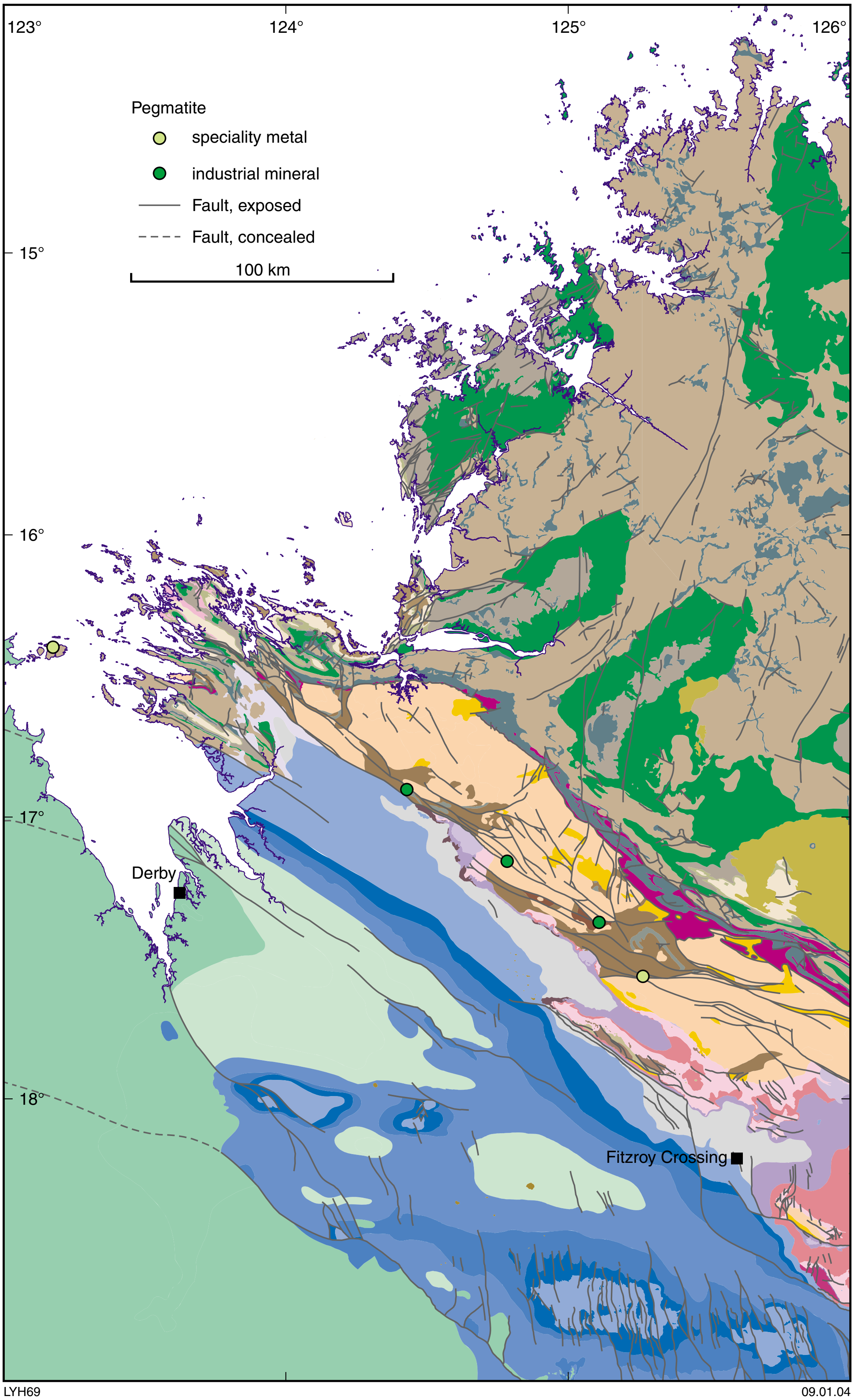


Figure 14. Simplified geological map showing distribution of pegmatitic mineralization in the west Kimberley. See Figure 7 for geological legend

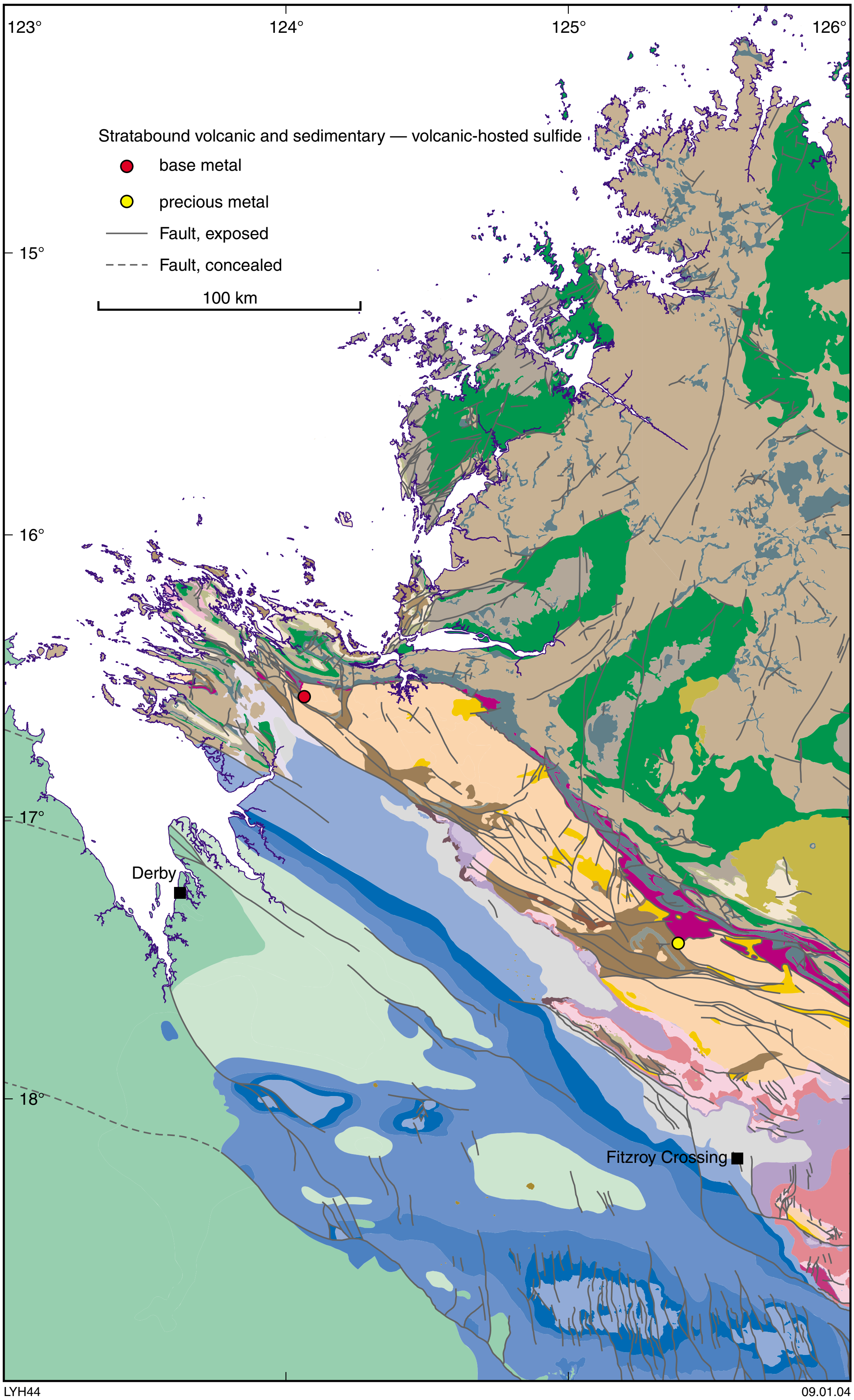


Figure 15. Simplified geological map showing distribution of stratabound volcanic and sedimentary — volcanic-hosted sulfide mineralization in the west Kimberley. See Figure 7 for geological legend

with a low base metal content. There are also disseminated sulfides in post-ore dolerite but the grade is negligible (Jessup and Yeaman, 1972).

Precious metal — gold

Small gold workings containing specks of free gold in association with arsenopyrite and stibnite were worked by Jim Stewart at Richenda River 7 (***7707***). Pickands Mather and Company International (1967a) interpreted the mineralization in the workings to be in small areas of metavolcanic rocks.

Stratabound volcanic and sedimentary — sedimentary-hosted sulfide mineralization

The distribution of mineral occurrences classified as 'Stratabound volcanic and sedimentary — sedimentary-hosted sulfide' is shown on Figure 16. They include base metal (copper, lead, zinc, silver, gold, arsenic) and precious metal (gold).

Base metal — copper, lead, zinc (silver, gold, arsenic)

In the central part of the Hooper Complex, stratiform massive sulfides were intersected in holes drilled by Western Mining Corporation in 1973, beneath a gossan zone 270 m long at Turtle Creek 1 (***8321***). The sulfides are hosted by laminated graphitic siltstones (with minor tuffaceous bands) within the Marboo Formation. The massive sulfides have a complex mineralogy consisting of variable amounts of pyrite, pyrrhotite, chalcopyrite, sphalerite, bournonite, galena, tetrahedrite–tennantite, jamesonite, tetradymite, arsenopyrite, boulangerite, jordanite, and stibnite. The best intersection was 2.38 m (true width) at 4.2% Zn, 3.5% Pb, 2.1% Cu, 162 g/t Ag, 2.7 g/t Au, and 4.24% As from 103.16 to 105.77 m in drillhole RDH2 (McConnell, 1973).

Precious metal — gold

At Turtle Creek 2 (***8322***), there are discontinuous gossanous lenses, from 20 to 30 cm thick, within a carbonaceous chlorite phyllite about 7 m wide. Gossan samples assayed up to 21.8 ppm Au, 11.6% Pb, 7.4% As (McConnell, 1973). McConnell (1973) reported minor tuffs within carbonaceous siltstones of the Marboo Formation at the nearby Turtle Creek 1 prospect (***8321***), and for this reason the deposit is classified as 'stratabound volcanic and sedimentary — sedimentary-hosted sulfide' rather than 'stratabound sedimentary — clastic-hosted'.

Stratabound volcanic and sedimentary mineralization — undivided

The distribution of mineral occurrences classified as 'Stratabound volcanic and sedimentary — undivided' is shown on Figure 17 and includes base metal (copper, lead).

Base metal — copper (lead)

Copper mineralization has been reported from the Carson Volcanics in the Camden Harbour – Brecknock Harbour area and minor occurrences of copper and lead mineralization have been reported from the Precipice Range. Weathered mafic rock with disseminated malachite and chalcocite obtained from Brecknock Harbour (***10065***), assayed 12% Cu, a trace of gold, and 1.5 ppm Ag (Simpson, 1952). Slugs of native copper are also said to have been found in this area (*Sunday Times*, 1908a). At Precipice Range 1 (***7934***), there is chalcopyrite and minor galena in a shear zone. Serem (Australia) Proprietary Limited (1969) concluded that the sulfides had been remobilized from the Carson Volcanics. The mode of occurrence of the other copper mineralization in the Carson Volcanics is unknown. The deposits have been classified as 'Stratabound volcanic and sedimentary — undivided' by analogy with the mineralization in the Carson Volcanics in the vicinity of the Durack Range (in the east Kimberley) where copper mineralization is associated with chert, tuffaceous flow-top breccias, and interflow sedimentary rocks (Planet Management and Research Proprietary Limited, 1971; Hassan, 2000).

Stratabound sedimentary — carbonate-hosted mineralization

The distribution of mineral occurrences classified as 'Stratabound sedimentary — carbonate-hosted' is shown on Figure 18. Apart from three industrial mineral occurrences (one barite and two high-grade limestone), they are all base metal. The base metal occurrences are predominantly lead–zinc, but some of them also contain copper and silver, and there are minor copper-only occurrences.

Base metal — lead, zinc, copper (silver, gold)

Significant MVT lead–zinc mineralization is hosted by Devonian carbonate rocks of the Lennard Shelf. At the end of June 2001, ore resources for Western Metals' Lennard Shelf Project were 23.63 Mt grading 7.7% Zn and 3.7% Pb; reserves were 16.29 Mt grading 7.5% Zn and 2.9% Pb (Western Metals Limited, 2002). Western Metals Limited (2002) reported that the largest resource (14.27 Mt) is at Pillara (***7747, 7750–53, 7755, 7757***), and there are smaller resources at Kapok and Kapok East (in the east Kimberley), Kutarta (***8312***), Kapok West (***7801***), Fossil Downs (***8315***), and Wagon Pass (***8057***). The Cadjebut (***7798–800***) and Goongewa (***7769***) deposits have been essentially worked out, as have the historic Narlarla no. 1 (***2915***) and Narlarla no. 2 deposits (***343***). There is a large number of base metal occurrences, in a variety of host rocks. The distribution of the deposits according to host formation is shown in Figure 19 and is discussed below. Approximately 7% of occurrences are hosted by pre-reef carbonate rocks, 59% by Pillara Cycle rocks, 33.5% by Nullara Cycle rocks, and 0.5% by the post-reef Carboniferous Fairfield Group.

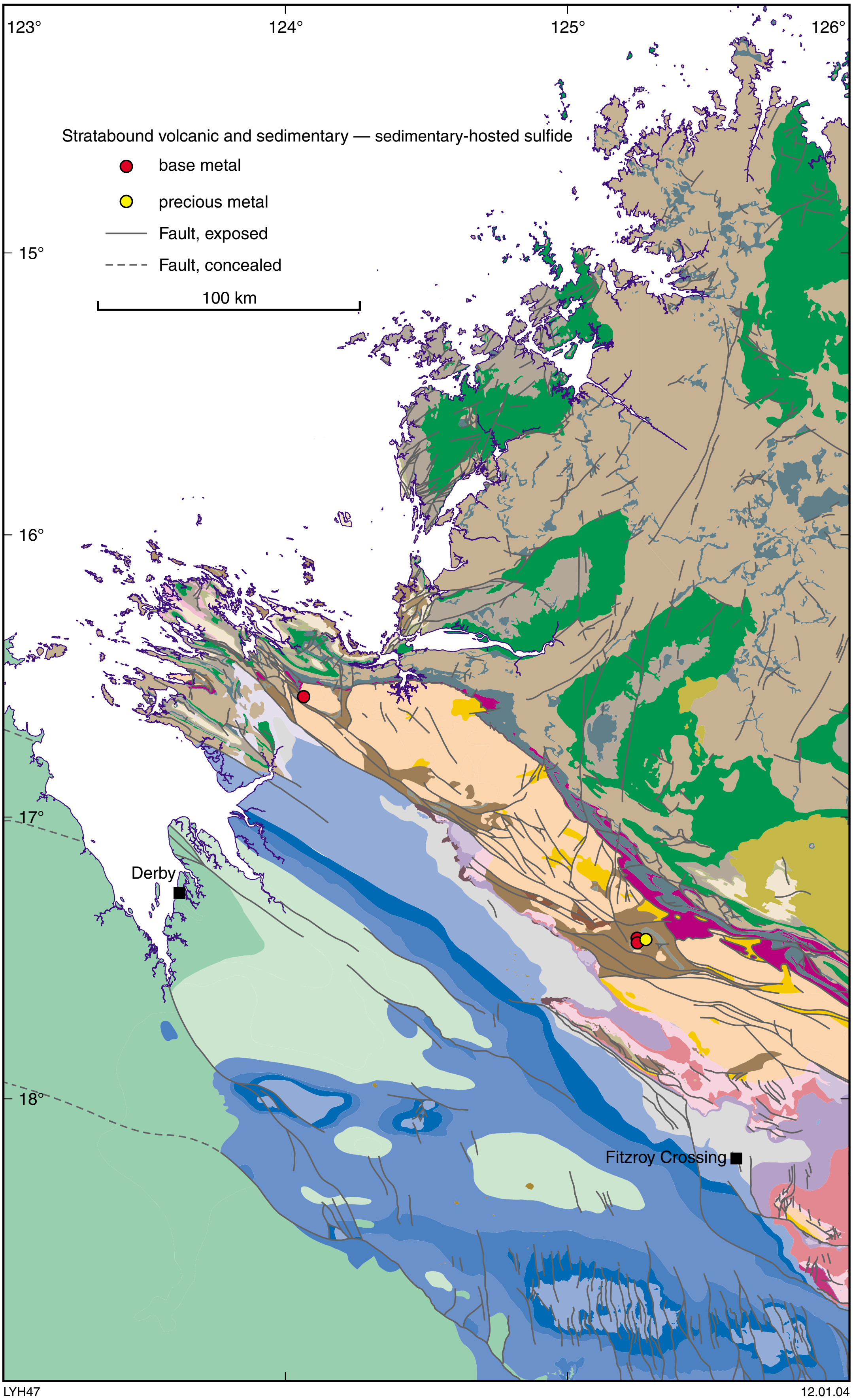


Figure 16. Simplified geological map showing distribution of stratabound volcanic and sedimentary — sedimentary-hosted sulfide mineralization in the west Kimberley. See Figure 7 for legend

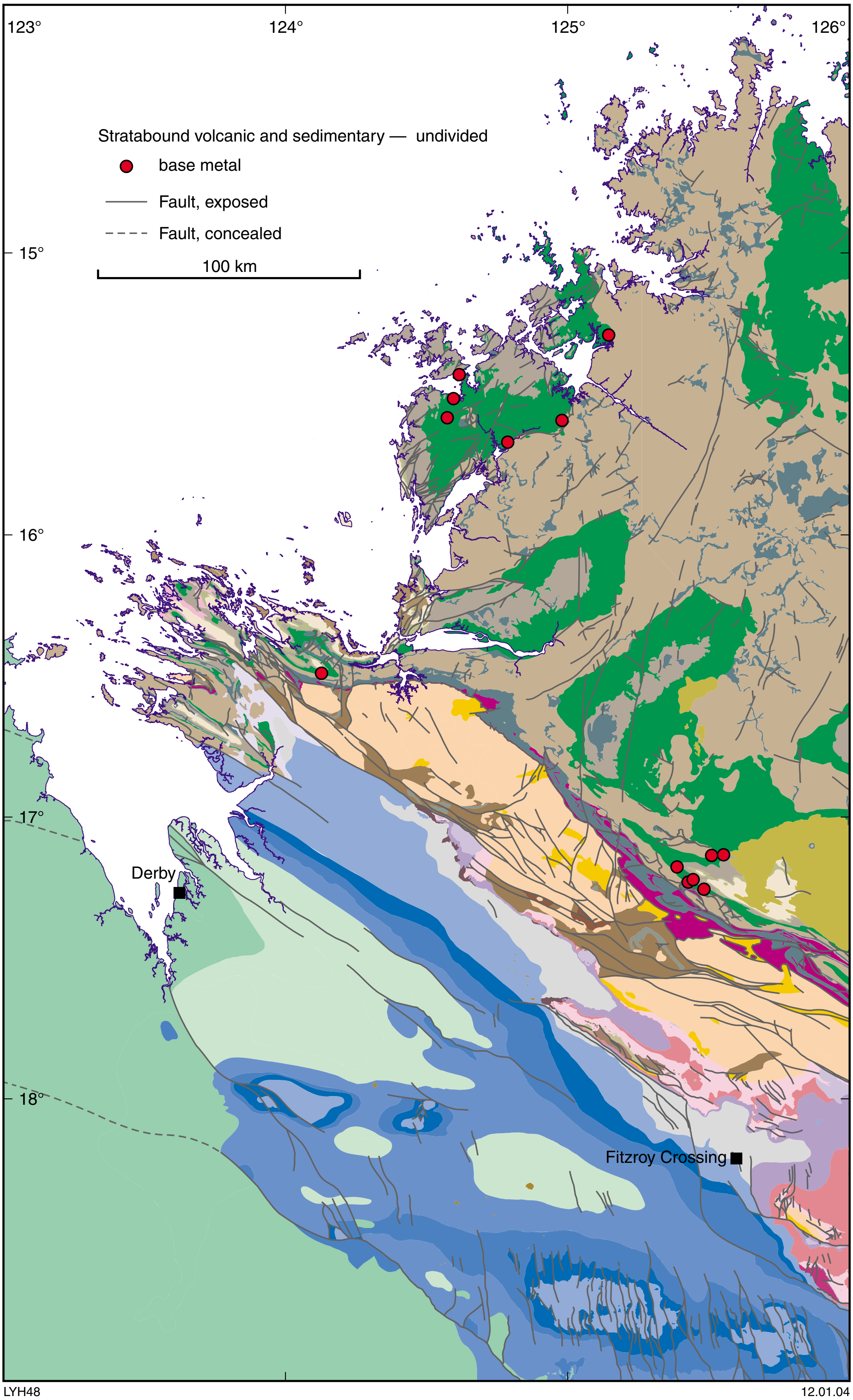


Figure 17. Simplified geological map showing distribution of stratabound volcanic and sedimentary — undivided mineralization in the west Kimberley. See Figure 7 for geological legend

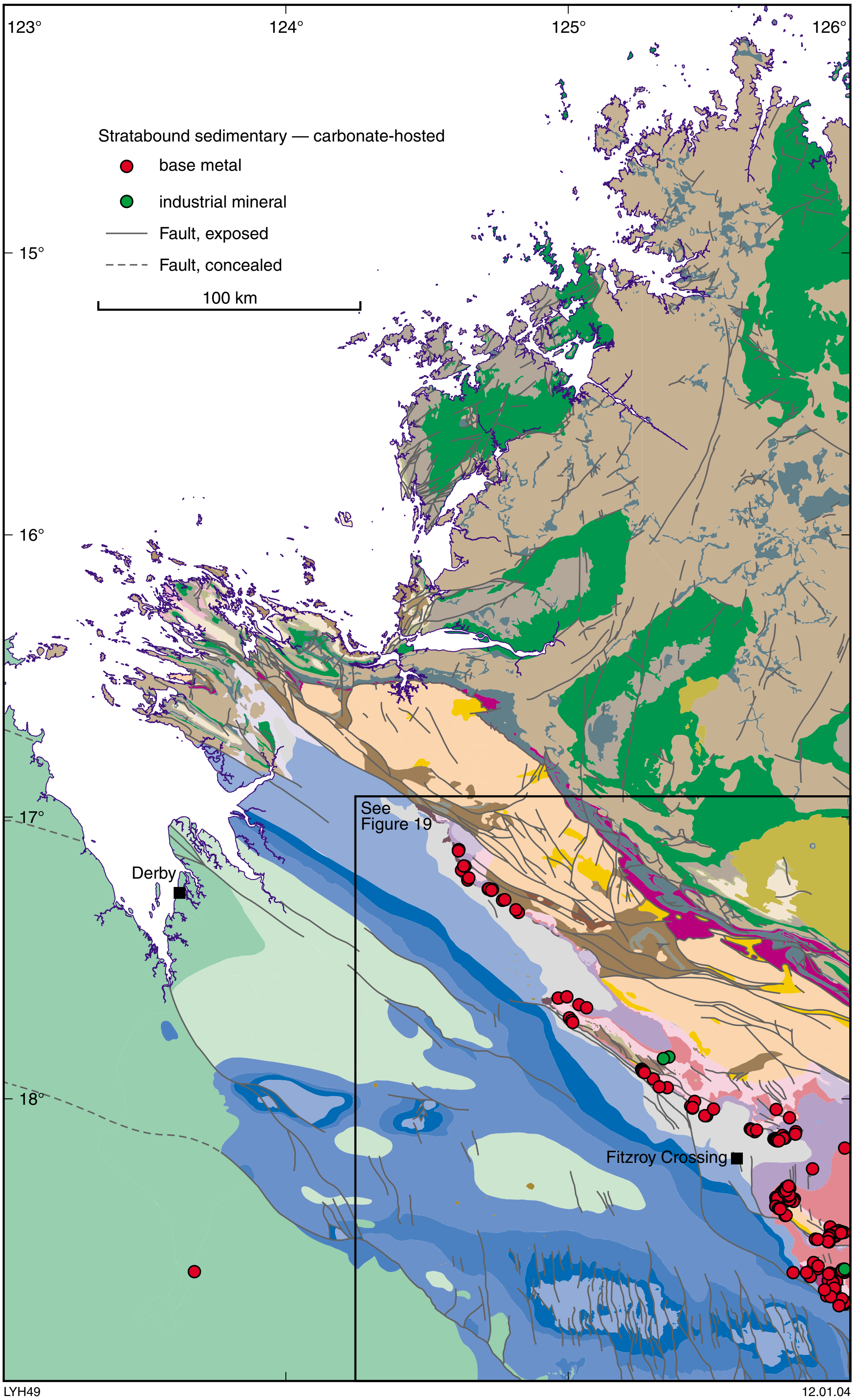


Figure 18. Simplified geological map showing distribution of stratabound sedimentary — carbonate-hosted mineralization in the west Kimberley. See Figure 7 for geological legend

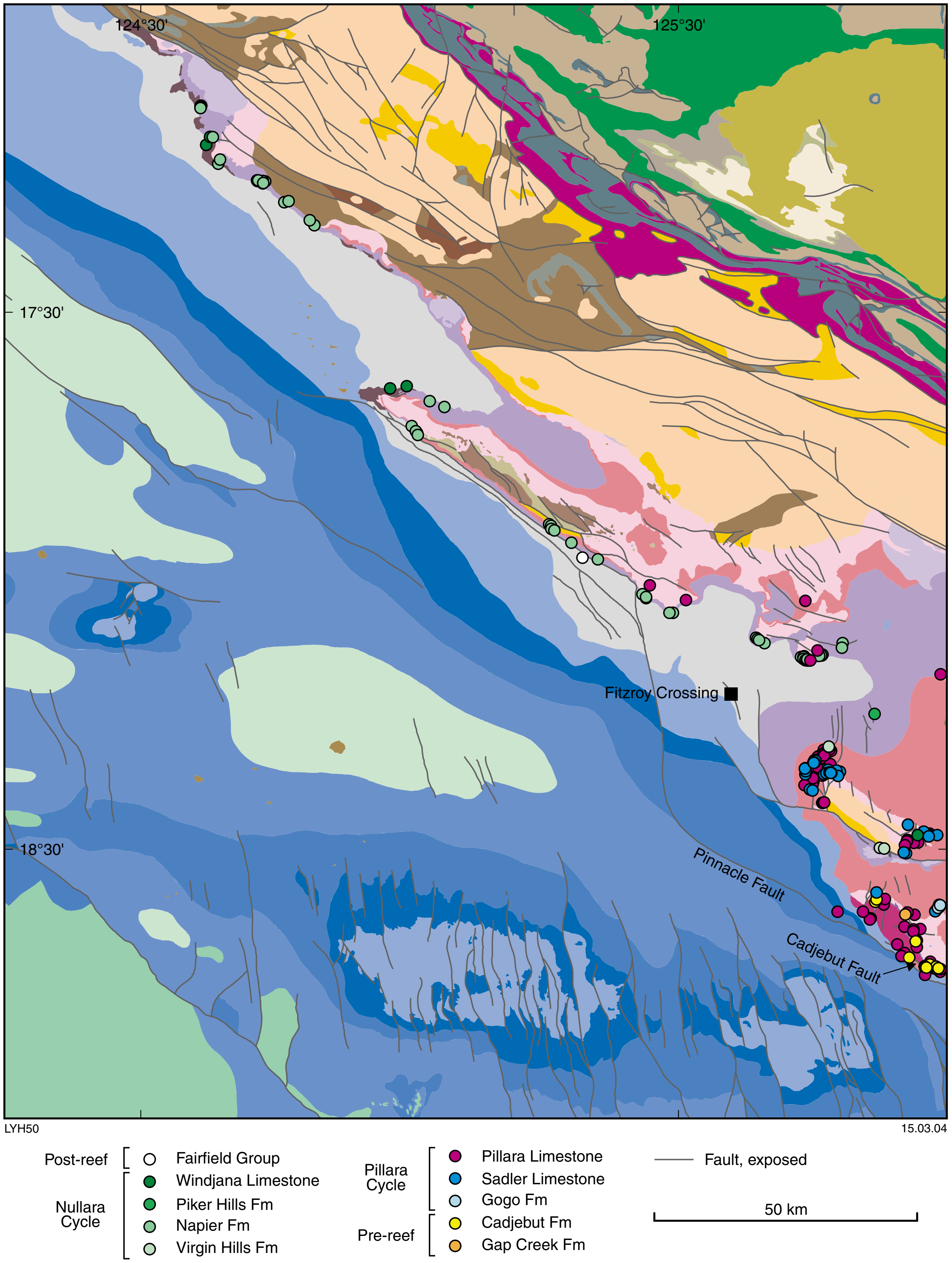


Figure 19. Host formations of stratabound sedimentary — carbonate-hosted mineralization in the west Kimberley. See Figure 7 for geological legend

Mineralization hosted by pre-reef carbonate rocks

At Emanuel Creek 1 (***8156***), there is disseminated fine-grained sphalerite and galena in sparry calcite cement in vuggy dolomite of the Gap Creek Formation beneath the Ordovician–Devonian unconformity. The best intersection is 3.24% Zn from 54 to 55 m, in diamond drillhole ECD1 (Wynne, 1988).

The Cadjebut deposit (***7798–7800***) is hosted by the Givetian Cadjebut Formation (Hocking et al., 1996). The orebody is located just to the north of, and subparallel to, the northwesterly trending Cadjebut Fault, which is probably a splay of the Pinnacle Fault (Tompkins et al., 1994b). Most of the high-grade zinc concentrate was produced from the stratiform, rhythmically banded ore (Fig. 20), whereas most of the lead concentrate was produced from the younger cross-cutting breccia ore (Tompkins et al., 1997). The rhythmically banded ore zone consists of a high-grade zinc core, 20 to 30 m wide, surrounded by rhythmically banded iron sulfides, barite, and/or calcite (Tompkins et al., 1997). Within the high-grade zone, rhythmically banded ore horizons vary from 0.1 m to 1 m in thickness and consist of repetitive layers, between 5 and 15 mm thick, of sphalerite, galena, and marcasite (Tompkins et al., 1994b). The breccia ore is more massive than the rhythmically banded ore and was deposited in open spaces during three cyclic hydrothermal stages (Tompkins et al., 1994b, 1997). The breccia ore is characterized by abundant dark-purple sphalerite, euhedral crystals of galena, marcasite, calcite, and barite that crystallized on top of colloform sphalerite (Tompkins et al., 1994b, 1997).

Other occurrences hosted by the Cadjebut Formation include Area 7 (***10571***), where drillholes intersected up to 2.28 m at 5.22% Zn, 0.38% Pb, and 56.4 g/t Ag from 80 m (Western Metals Limited, 1998b,c); Prices Hill 1 (***8097***), where there was an intersection of 6.1 m at 0.41% Zn and 0.04% Pb from 9 m (Gellatly and Cary, 1973); and Gindi (***10561***), where highly anomalous gossans have been found (Western Metals Limited, 1999a).

Mineralization hosted by Pillara Cycle rocks

In the southeastern part of the Lennard Shelf, in the Pillara Range and Emanuel Range area, many base metal occurrences are hosted by the platform facies of the Pillara Limestone (Fig. 19). These include the Pillara, Goongewa, Kutarta, and Kapok West deposits, which are hosted by Pillara Cycle association 1 platform facies (Copp, 2000).

At Pillara (***7747, 7750–53, 7755, 7757***), formerly known as Blendevale, most mineralization is in fault-controlled breccias on the easterly dipping Western Fault and F10 Fault and on the westerly dipping Eastern Fault, which form a north-northeasterly trending graben structure (Murphy et al., 1986). Along the faults, mineralization is developed preferentially in a fenestral Amphipora limestone unit, referred to by Murphy et al. (1986) as unit 5 (Fig. 21). The paragenetic sequence within the breccia ore is typically marcasite with or without colloform sphalerite, followed by sphalerite with subordinate fine-grained galena intergrowths, followed by coarse subhedral galena and sparry calcite, as shown on Figure 22 (Murphy et al., 1986; Ringrose, 1989). There is

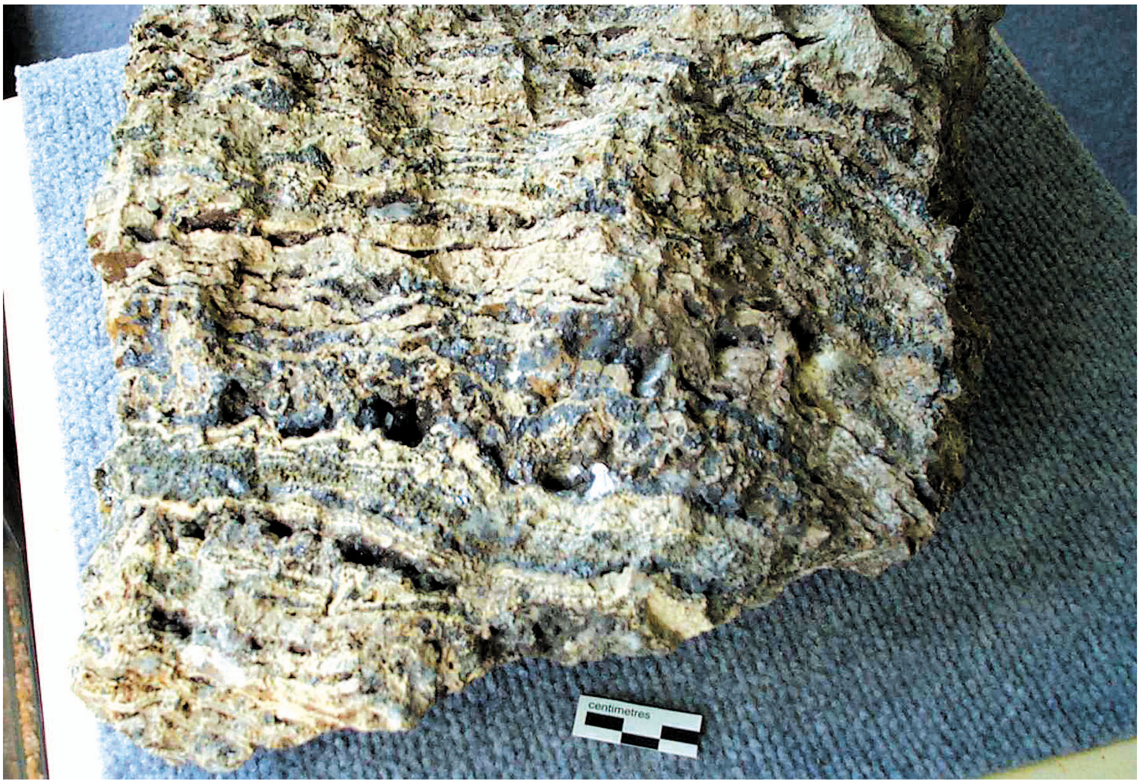


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Figure 20. Rhythmically banded ore from Cadjebut

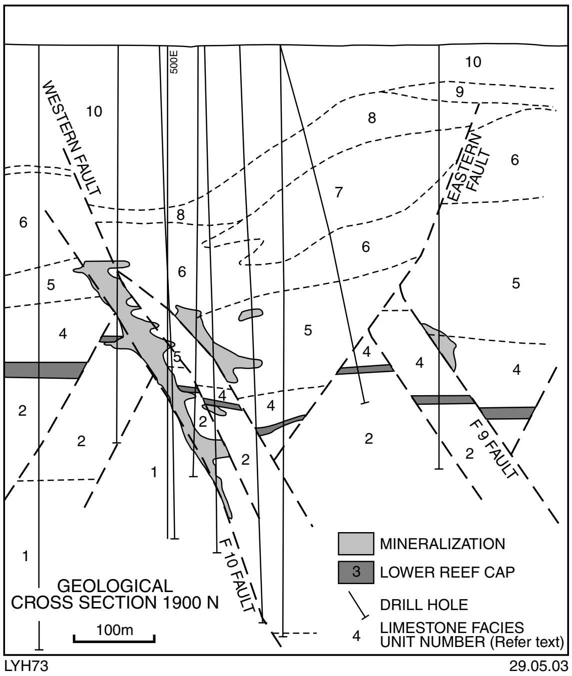

Figure 21. Geological cross section showing location of main mineralized bodies at Pillara (after Murphy et al., 1986)

no evidence of dolomitization or other alteration at Pillara (Murphy et al., 1990).

Mineralization at Goongewa (***7769***) occupied irregular solution cavities (Fig. 23) close to the Cadjebut Fault. A series of 13 separate pods were delineated by drilling, each consisting of sphalerite and galena together with sparry calcite and marcasite with or without pyrite within selectively dolomitized limestone (Western Metals Limited, 1994). At Kapok West (formerly Bloodwood), high-grade breccia zones are related to a dilational roll in the Cadjebut Fault (Western Metals Limited, 1997a,b). Mineralization at Kapok West is also related to near-vertical splays of the Cadjebut Fault (Western Metals Limited, 1997c). At Kutarta (formerly known as Prices Creek), fine-grained sphalerite is hosted by dolomitized limestone of the Pillara Limestone close to the Cadjebut Fault. Higher grade zones are associated with breccias (Western Metals Limited, 1997c).

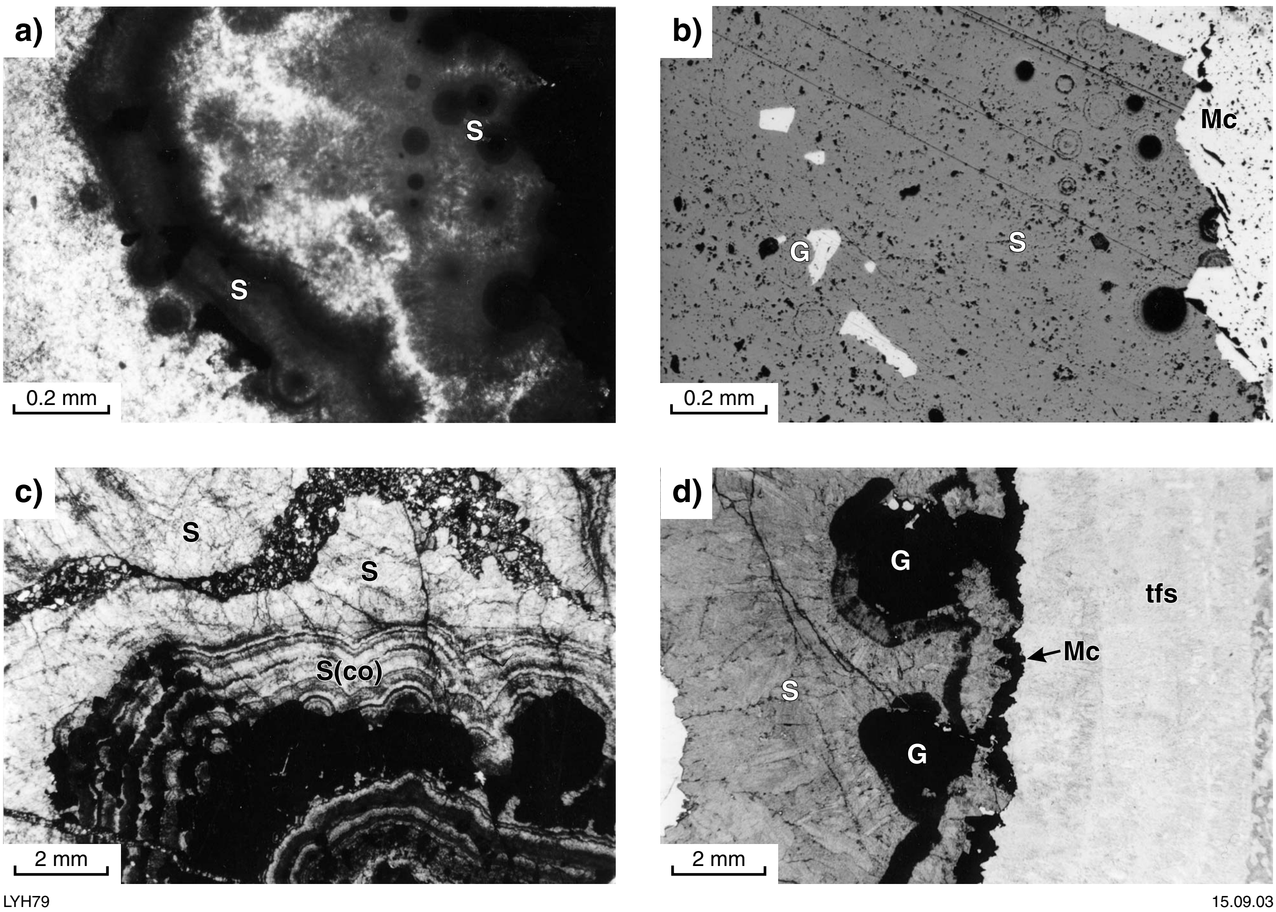

Figure 22. Photomicrographs of ore from Pillara:
a) banded spherulitic growth of sphalerite upon a marcasite lamina (under transmitted light); b) same sample as a), but with irregularly shaped inclusions of galena visible (under reflected light); c) finely banded or 'colloform' sphalerite overgrown by coarsely banded sphalerite; d) fibrous calcite overgrown by marcasite and banded sphalerite. Two opaque granules of galena are enclosed and have been rimmed by later sphalerite growth (after Ringrose, 1989). Abbreviations: S — sphalerite, S(co) — colloform sphalerite, G — galena, Mc — marcasite, tfs — turbid fibrous spar

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Figure 23. Photograph of Goongewa ore: sphalerite and galena with marcasite and sparry calcite surrounding a limestone fragment in a solution cavity

The main zones of mineralization at Fossil Downs (***8315***) are in platform-facies stromatoporoid limestone and marginal-slope facies of Pillara Cycle association 3 (Fig. 24; Copp, 2000). Copp (2000) also noted that the limestone has been extensively dolomitized.

There are a few other minor base metal occurrences in the Pillara Limestone in the Geikie Range area (e.g. Royal Gossan (***7965***); Ross and Cooper, 1983) and in the southeastern part of the Oscar Range near Brooking Gorge (e.g. Replacement Gossan (***8300***); Clifford and Amann, 1990). Further west in the Oscar Range and in the Napier Range, no base metal occurrences have been recorded in the Pillara Limestone (Fig. 19).

The Sadler Limestone (marginal-slope and basin facies), in the southeastern part of the Lennard Shelf, also hosts a significant number of base metal occurrences. An example is Snake Bore 1 (***8075***), on the western edge of Limestone Billy Hills, where minor disseminated sphalerite and galena is associated with pyrite over widths up to 32 m in an interbedded sequence of limestone and shale that was interpreted by Gellatly and Cary (1973) as inter-reef (basin) facies.

Minor lead–zinc mineralization at Longs Well (***5448, 9137, 9678***) is hosted within a stromatolite–barite–sulfide mound in the Gogo Formation and in breccias in the adjoining Sadler Limestone; this mineralization is interpreted to be exhalative in origin (De Kever, 1998; Mason, 1998; Playford and Wallace, 2001).

Mineralization hosted by Nullara Cycle rocks

Most occurrences in the Napier Range and Oscar Range areas, including the historical Narlarla no. 1 and Narlarla no. 2 mines and the Wagon Pass deposit, are hosted by the late Famennian part of the Napier Formation (massive reef-slope and fore-reef limestone) as shown on Figure 19.

The mineralization at Narlarla no. 2 (***343***) is localized along an east-southeasterly trending fault in dolomitized marginal-slope packstones and grainstones close to their contact with a stromatolitic buildup, which may mark stromatolitic colonization of a debris flow (Ringrose, 1989). The mineralization forms pods, lenses, and beds of primary sulfides surrounded by an envelope of smithsonite–chamosite below the watertable, and oxidized gossanous ore containing smithsonite, cerussite, and hydrozincite above the watertable (Ringrose, 1989). Sphalerite in the pods and lenses forms botryoidal masses of spherulitic, concentrically banded, colloform grains (up to 8 mm in diameter), whereas galena forms coarse, generally skeletal, cubic grains or laths within the sphalerite spherules. In the bedded-ore zones, sphalerite predominantly forms closely packed euhedral crystals (up to 0.5 mm across) in laminae up to 1 cm thick; some of the laminae of the euhedral crystals are capped by a layer of colloform sphalerite (Fig. 25; Ringrose, 1989). Pb-isotope studies indicated a heterogeneous source of Pb (Vaasjoki and Gulson, 1986).

The Wagon Pass deposit (***8057***) is hosted by pervasively dolomitized reefal-slope packstones and

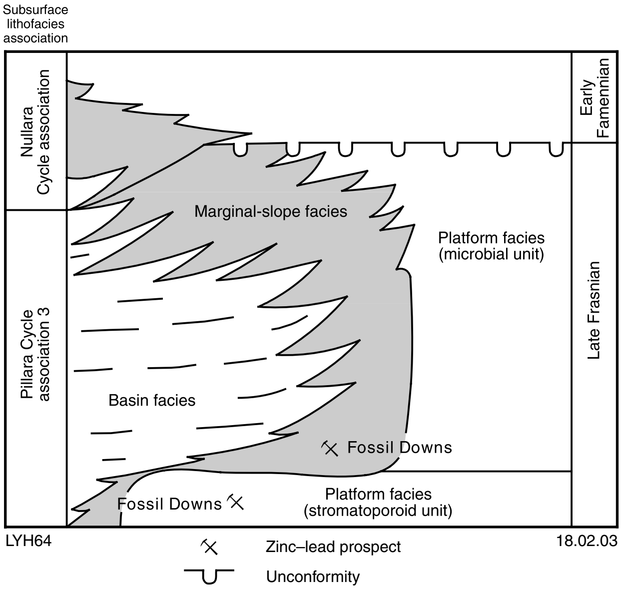


Figure 24. Relationships between Pillara Cycle association 3, Nullara Cycle association, and the main zones of mineralization in the central Lennard Shelf (from Copp, 2000)

intraclast breccias (Buchhorn, 1986; Ringrose, 1989). The mineralization lies in a north-northwesterly trending stratabound lens with a strike length of 300 m, a width of between 30 and 80 m, and a thickness from 3 to 36 m (Buchhorn, 1986). The mineralization consists of complex intergrowths of sphalerite and galena, with subordinate pyrite, marcasite, chalcopyrite, bornite, digenite, covellite, and bravoite (Buchhorn, 1986). Sphalerite commonly forms disseminated grains (0.05–0.4 mm) that coalesce into concentrated laminae interbedded with ?gypsum pseudomorphs in more heavily mineralized areas (Ringrose, 1989). Galena is typically coarser grained euhedral to subhedral crystals from 0.5 to 4 mm (Ringrose, 1989). Both galena and sphalerite also have colloform textures (Buchhorn, 1986; Ringrose, 1989). Chlorite alteration is associated with the highest grade mineralization (Buchhorn, 1986; Ringrose, 1989).

Further east, in the Geikie Range area, many occurrences are hosted by the late Famennian part of the Napier Formation. These include many gossans such as at Brooking Springs 1 (***8161***) reported by Miguel (1982), and gossans in the Fossil Downs area, e.g. Fossil Downs 3 (***7961***) noted by Crawford (1984), although the main mineralization at Fossil Downs is at depth in the Pillara Limestone (see **Mineralization hosted by Pillara Cycle rocks**, above). At Margaret River 7 (***8224***), there is disseminated fresh galena, with minor limonite after pyrite, and sphalerite along bedding planes in slope-facies grainstone and breccia bands about 20 cm thick (Sewell, 1993).

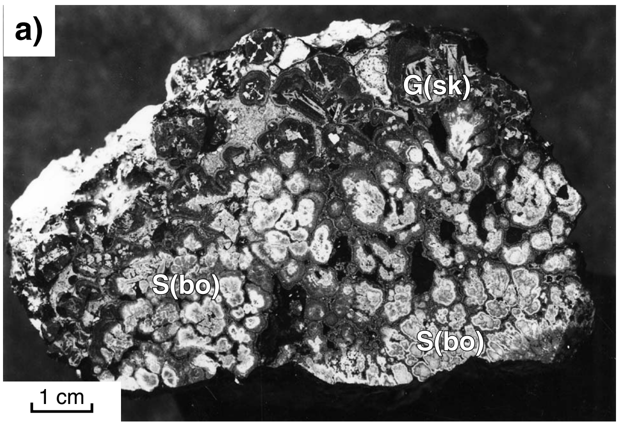
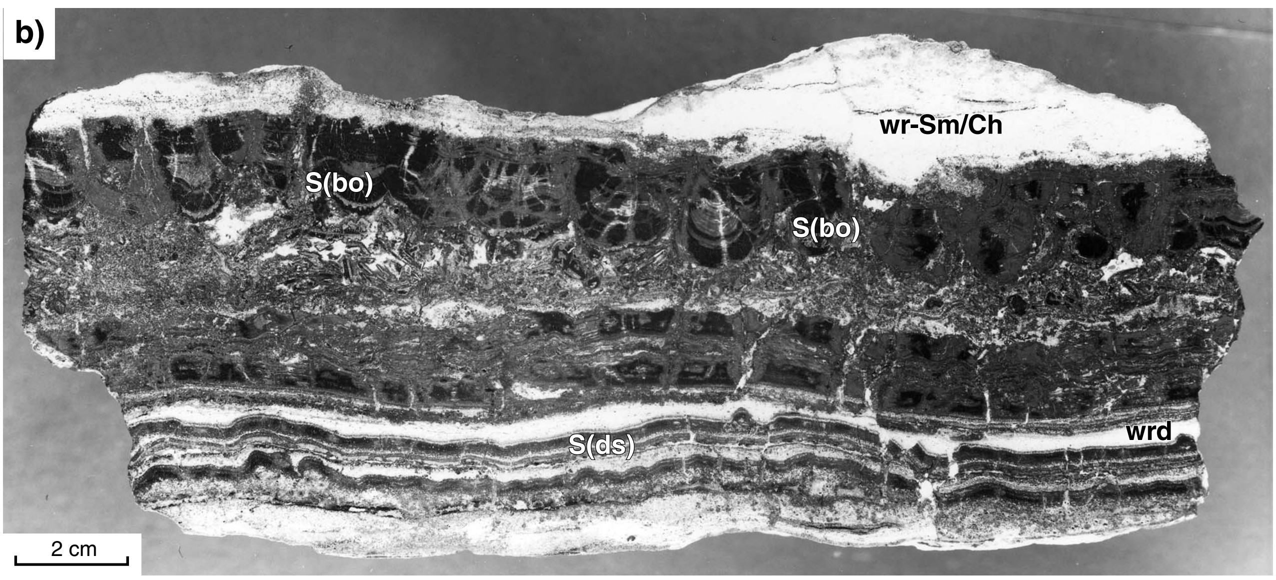


Figure 25. Specimens of Narlarla ore showing ore textures: a) botryoidal-skeletal sphalerite–galena ore; b) bedded sphalerite–galena ore (after Ringrose, 1989). Abbreviations as for Figure 22, and: S(bo) — sphalerite botryoids, S(ds) — disseminated sphalerite, G(sk) — skeletal galena, wr — wall rock, wrd — wall rock detritus, Sm/Ch — smithsonite/chlorite



The reef-margin Windjana Limestone hosts lead–zinc mineralization at Chedda Cliffs 1 (***8303***) in the northern Napier Range, where there is a small gossan (20 × 30 m) with high Pb–Zn–Cu–Ag(–Cd–Co–Hg) values. This was tested by six percussion drillholes that intersected mineralization over a strike length of 100 m with the best intersection being 10 m at 8.6% Pb, 1.2% Zn, and 37.5 ppm Ag from 0 to 10 m in drillhole RDH5 (Mimets Exploration Proprietary Limited, 1976).

At Mount Pierre (***8809***), there is disseminated and fracture-filling chalcocite, malachite, and azurite mineralization in a thin crinoidal shell-bed of the Piker Hills Formation. This was tested by Clackline Refractories: 35 RAB holes were drilled, only two of which intersected grades exceeding 1% Cu over 1 m. The best intersection was 3 m at 3.55% Cu and 12.1 g/t Ag between 2 and 5 m in MP24 (Bourn, 1985).

There are isolated occurrences in the Frasnian–Famennian Virgin Hills Formation (marginal-slope facies). At Bobs Bore (***8778***), there is a zone of fore-reef carbonate 800 m long and up to 200 m wide that contains abundant ironstone veins, blebs, and small massive pods. The surface ironstones assayed up to 1.2% Pb and 0.74% Zn but diamond drillhole LSVD1 drilled beneath the zone intersected only minor pyrite veining (Fitton, 1985).

Mineralization hosted by the Carboniferous Fairfield Group

The only recorded occurrence in the Fairfield Group is an ironstone assaying 6500 ppm Zn and 630 ppm Pb at Twelve Mile Bore 2 (***9685***) reported by Hancock (1983).

Industrial mineral — barite

At Longs Well Barite (***10598***), there is a bladed barite outcrop, interpreted as exhalative mineralization within a stromatolitic mound in the Gogo Formation (De Kever, 1998; Playford and Wallace, 2001).

Industrial mineral — high-grade limestone

Two samples of Pillara Limestone from Oscar Plateau East (***11362–63***) were assayed. They are high grade, with up to 98.4% $CaCO_3$ (Abeysinghe, 1998).

Stratabound sedimentary — clastic-hosted mineralization

The distribution of mineral occurrences classified as ‘Stratabound sedimentary — clastic-hosted’ is shown on Figure 26. Deposits and occurrences of iron, energy mineral (uranium), base metal (copper), precious metal (gold), speciality metal (tin, rutile), and industrial mineral (corundum, kyanite, glauconite) have been included in this classification.

Iron

Hematitic iron ore is hosted by the Palaeoproterozoic Yampi Formation on a number of islands in Yampi Sound, but the largest deposits are on Koolan Island and Cockatoo Island. Total iron ore production from Koolan Island and Cockatoo Island between 1951 and 2000 was 94.6 Mt. The ore is high grade (66–69% Fe) with very low impurities (BHP staff, 1975; Portman Limited, 2002; Aztec Resources Limited, 2004). Portman is planning to mine the Cockatoo Island deposit below sea level (Portman Limited, 2002), and Aztec is evaluating the remaining Koolan Island deposits (Aztec Resources Limited, 2004).

The Main orebody (***8481***) on Koolan Island is about 2 km long, 30 m thick, and dips at between 45 and 65° along the overturned southern limb of a syncline (Fig. 27a,b). The Acacia (***8485***) and Mullet (***8520***) orebodies are in the same stratigraphic horizon on the southern and northern limbs, respectively, of the adjacent anticline (Fig. 27a,b) and the Barramundi (***8522***) and Eastern ore bodies (***8526***), shown in Figure 27a, are on the same anticline further east (Reid, 1965). Canavan and Edwards (1938) summarized the characteristics of the ore as follows. Most of the ore consists of hard, fine-grained, bluish-grey hematite. There is a gradation along strike from almost pure quartzite into hematite quartzite and then into hard, almost pure hematite. The hematite quartzites show wave and current ripple-marks and current bedding that suggest deposition on a seashore. The hematite in the hematite quartzites shows fine twinning parallel to an octahedral parting and contains remnants of magnetite, suggesting that the hematite has replaced magnetite. The hematite quartzites also grade into hematite conglomerates. On Cockatoo Island (***9768***), a bed of soft hematite schist underlies massive hematite.

Energy mineral — uranium

A total resource of 4640 t uranium metal at an average grade of 1200 ppm U was outlined by Afmeco Proprietary Limited (1983) within a series of lenses in Lower Carboniferous sandstones equivalent to the Fairfield Group at Oobagooma Uranium (***8736–39***, ***8748–49***). The mineralization consists of uraninite and pitchblende associated with pyrite and organic matter in strongly reduced sandstones. The sandstones were deposited on a delta or tidal plain (Afmeco Proprietary Limited, 1983; Botten, 1984).

At Myroodah Uranium (***8706***), radiometric anomalies are associated with a thin ferruginous sandstone at the contact between the Triassic Erskine Sandstone and Blina Shale along the Myroodah Syncline. Counts of up to 700 cps (equivalent to 354 ppm U_3O_8) were obtained in drillhole M12A. The ferruginous sandstone may represent the upper limb of a roll-front deposit (Bolton, 1979)

Base metal — copper

Mineralization in the Hooper Complex

In the Little Tarraji River area, at the northwestern end of the Hooper Complex, there are a significant number of stratabound copper occurrences within the Palaeoproterozoic Marboo Formation. Woodall (1957) noted that the copper mineralization is in areas of less altered and less metamorphosed slate, siltstone, and sandstone, and that it is mostly hosted by slate.

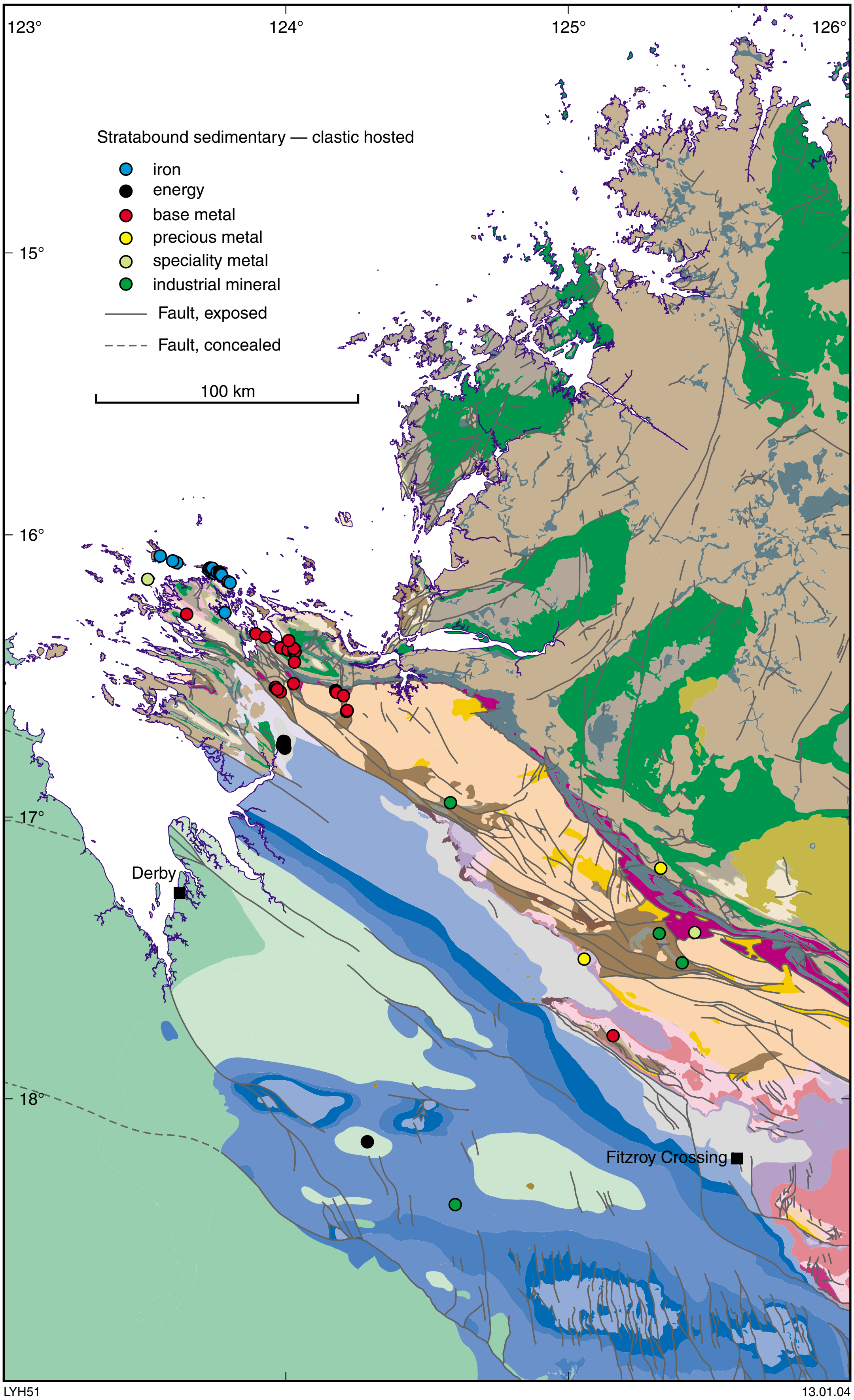


Figure 26. Simplified geological map showing distribution of stratabound sedimentary — clastic-hosted mineralization in the west Kimberley. See Figure 7 for geological legend

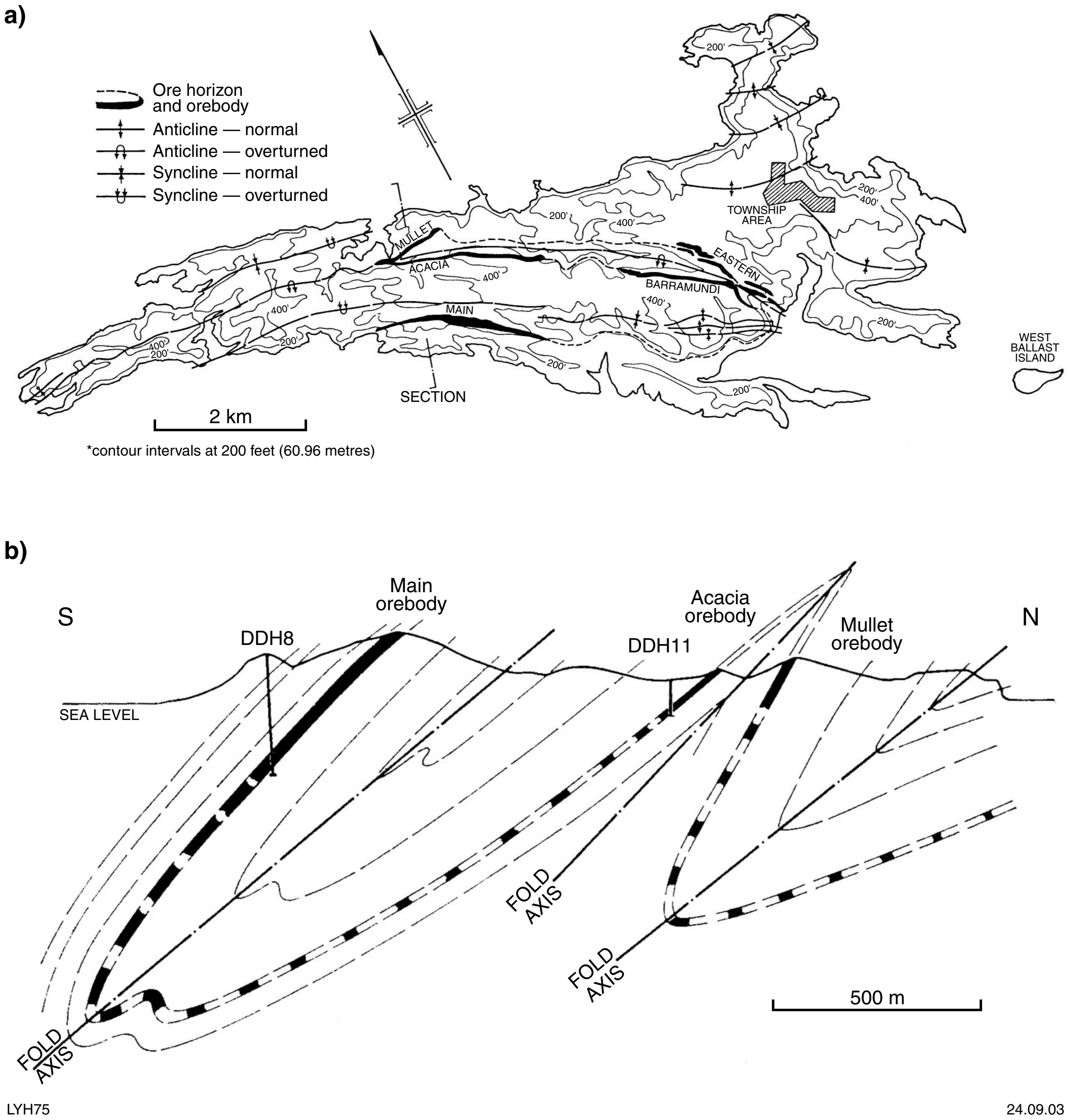


Figure 27. a) Koolan Island orebodies and their relation to structure; b) cross section through orebodies on Koolan Island (after Reid, 1965)

The Mangrove prospect (***2922***), discovered by Western Mining Corporation, consists of dark carbonaceous slate veined with iron oxide and malachite. The slate outcrop can be traced for 90 m and is up to 4.6 m wide (Woodall, 1957). At Wilsons Reward (***352***), the copper-bearing lode is essentially stratabound and consists mainly of phyllite partially replaced by quartz containing pyrite and chalcopyrite (Reid, 1959). There has been no recorded production from Wilsons Reward although there is a shaft and several shallow workings. A selected surface sample assayed 37.6% Cu (Maitland, 1919b). The best intersection from four diamond drillholes was 3.8 m at 1.4% Cu from 119 m in drillhole WS2 (Reid, 1959). At Townshend River B1 (***2923***) pods of copper mineralization, in silvery fine-grained mica schist, can be traced for about 140 m around a fold hinge (Reid, 1958). At Rough Triangle 1 (***7667***) copper mineralization is in bleached contorted phyllite over a strike length of 210 m. The mineralization has an average width of 1.8 m, but may be up to 4.6 m wide in places. Silicified parts of the lode contain less copper mineralization than the non-silicified phyllite (Reid, 1958).

The workings in the Grants Find area are also essentially stratabound but the mineralization is in conformable quartz veins within a black-slate horizon and hence it has been classified as 'vein and hydrothermal' (see **Vein and hydrothermal mineralization**, below).

Mineralization in the Kimberley Basin

Low-grade copper mineralization extends over a strike length of 36 km in the McLarty Range area (***3340–47***, ***3349***). The mineralization lies within siltstone and banded ferruginous chert of the Jap Bay Member of the Palaeoproterozoic Warton Sandstone (Gellatly, 1972a). Within the siltstone, the primary mineralization occurs as disseminations and in ferruginous nodules, which Gellatly (1972a) interpreted as primary pyrite–chalcopyrite segregations. Supergene redistribution of mineralization has also taken place (Gellatly, 1972a).

At Mundurral River (***10088***), there is a copper occurrence in the middle section of the Pentecost Sandstone, on the southern limb of a syncline that dips steeply to the north (Marston, 1979).

Precious metal — gold

The Devonian Mount Behn Conglomerate, which was originally interpreted as a palaeoplacer, was explored for gold and diamonds by Moonstone Mines NL between 1989 and 1992 (Muggeridge, 1992). A panned sample from a trench in the Mount Behn Conglomerate at Mount Behn 2 (***9199***) showed fine flour gold. Plant tailings from a bulk sample from the trench gave a calculated head grade of 1.13 g/t gold when passed through a flotation processing plant but only 0.5 g/t by AAS (Atomic Absorption Spectrometry). However, other samples from Mount Behn 2 were of low grade. Moonstone Mines suggested that the processing plant was possibly contaminated (Muggeridge, 1992).

At Mount Bell (***8816***), a vertical diamond drillhole (DD88MB2) intersected 1.03 m at 0.69 ppm Au between 126 and 127 m, and 0.9 m at 0.64 ppm Au between 432.1 and 433.0 m, in hematitic sandstone within the King Leopold Sandstone. No evidence of fracturing was found (Hamdorf, 1989), but it is not clear whether the mineralization is syngenetic or whether it has been introduced along thrust faults in the region.

Speciality metal — tin, rutile

At Richenda River Tin 1 (***8390***), cassiterite is associated with a heavy mineral concentration in the matrix of an indurated conglomerate of the O'Donnell Formation in the Palaeoproterozoic Speewah Group. Sample LRMV18 assayed 7800 ppm Sn (Varkey et al., 1978).

At Gibbings Island 2 (***10100***), a mica schist within the Palaeoproterozoic Pentecost Sandstone consists of phlogopite, hydromuscovite, and kyanite with abundant prismatic rutile along foliation planes (Farrand, 1965).

Industrial mineral — corundum

Gellatly, Sofoulis et al. (1974) reported emery as veins and lenses up to 0.6 m wide, at the contact between phyllite (Marboo Formation) and dolerite (Ruins Dolerite) at Richenda River Corundum (***8801***). The emery is a dark, dense, finely crystalline rock composed of variable proportions of corundum and diaspore and has excellent sharp qualities for use as an abrasive (Simpson, 1951). George Wye mined 50–100 t of emery from the deposit (Forman, 1943). Simpson (1951) stated that hundreds of tons could be collected from the surface. Emery was also reported from Mount Rose (***10086***) by Forman (1943). Corundum-bearing rock is found adjacent to the Ruins Dolerite at the Hawkstone kyanite deposit (see **Industrial mineral — kyanite**, below).

Industrial mineral — kyanite

The Hawkstone kyanite deposit (***7722***) has been described in detail by Derrick and Morgan (1966). It consists of poorly outcropping lenses of kyanite rock, kyanite schist, vein kyanite, and minor corundum-bearing rock. The kyanite deposits are surrounded by greenschist-facies phyllites of the Marboo Formation. Corundum-bearing rock has developed adjacent to the Ruins Dolerite (previously described by Derrick and Morgan (1966) as the Woodward Dolerite). Derrick and Morgan (1966) recognized two types of kyanite rock: massive, dense rock consisting almost entirely of subhedral kyanite with accessory rutile and iron oxides, and interstitial micaceous minerals; and massive kyanite–tourmaline rock consisting of euhedral crystals of kyanite and tourmaline with inclusions of prismatic crystals of dumortierite and accessory rutile, corundum, and iron oxide in a micaceous matrix containing paragonite and possibly pyrophyllite. The tourmaline is the magnesium variety dravite. The kyanite schist consists of bladed crystals of kyanite in a matrix of sub-parallel ?sericite flakes with accessory rutile (Derrick and Morgan, 1966). The massive kyanite rock is cut by kyanite veins in which blades of blue kyanite between 0.5 and 10 cm long are developed at right angles to the wall of the vein; this kyanite is undeformed and free from inclusions (Derrick and Morgan, 1966). Derrick and Morgan (1966) estimated a possible tonnage of 18 000 t of kyanite rock or 11 000 t of kyanite per vertical foot (0.3 m). Samples assayed between 53.8 and 60.4% Al_2O_3 (Gellatly, Sofoulis, et al., 1974).

Industrial mineral — glauconite

At Mount Abbott Glauconite 2 (***10158***), thin laminae of green glauconite are interbedded with fine-grained grey and brown sandstone of the Hicks Range Sandstone Member of the Permian Hardman Formation (Hardman, 1884; Simpson, 1951).

Stratabound sedimentary mineralization — undivided

Iron, base metal, and industrial mineral (phosphate) occurrences classified as 'Stratabound sedimentary — undivided' are shown on Figure 28.

Iron

Oolitic iron formation — consisting of limonitic oolites, limonitic casts of macrofossils (gastropods and pelecypods), quartz, and feldspar — is intercalated with calcareous, sandy sedimentary rocks of the Permian Lightjack Formation at Jimberlura (***10045***), Grant Range (***10052***), Shore Range 1 (***10053***), and Shore Range 2 (***10054***), as reported by Guppy et al. (1952) and Edwards (1953). Sample W.69 from Jimberlura assayed 50.63% Fe_2O_3, 19.1% SiO_2, 12.81% Al_2O_3, 0.3% MgO, 0.16% CaO,

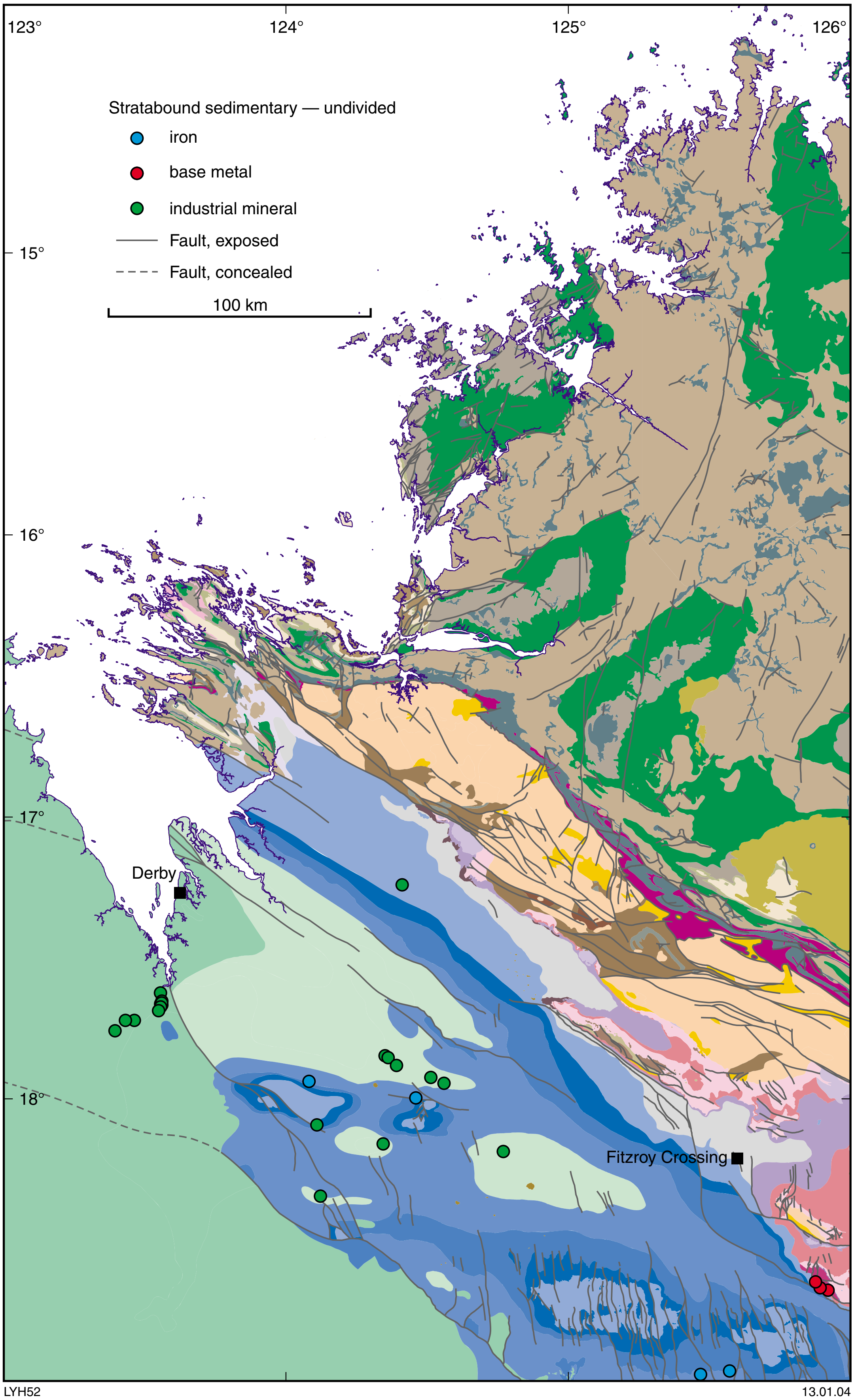


Figure 28. Simplified geological map showing distribution of stratabound sedimentary — undivided mineralization in the west Kimberley. See Figure 7 for geological legend

11.73% H_2O^+, 1.97% H_2O^-, 0.15% TiO_2, 0.41% P_2O_5, and 0.5% MnO (Edwards, 1953). The oolitic iron formation is similar to oxidized oolitic iron ore of Jurassic age mined from the Kettering–Corby district of eastern England, but it has higher silica and alumina content (Edwards, 1953). Below the zone of oxidation the iron will probably be in the form of chamosite, or a similar mineral, and there may be a significant proportion of carbonate (Edwards, 1953).

Industrial mineral — phosphate

A phosphate-nodule bed, within the Jurassic Jarlemai Siltstone, was exposed in a trench at Langey Crossing 1 (***7816***) and was also intersected in many drillholes in the Langey Crossing area (Russel, 1966a,b). The best intersection was from Langey Crossing 4 (***7839***) where about 2.1 m (poor recovery) at 11.6% P_2O_5 was intersected from 33.2 m in drillhole L79 (Russel, 1966b). Metallurgical testing indicated that an acceptable concentrate could be obtained from the Langey Crossing phosphate bed using flotation and that no deleterious elements were present. However, the deposit was considered to be of low priority for development because of its small size, low grade, and remoteness (Mines Exploration Proprietary Limited, 1976). Significant intersections of phosphate in the Jarlemai Siltstone have been reported from petroleum wells drilled to the west of the study area including 15 m at 4.3% P_2O_5 in Thangoo no. 1 (Freas and Zimmerman, 1965).

Rock-chip samples of shale with numerous small phosphatic brachiopods from the Blina Shale at Erskine Hill (***7795***) assayed up to 17.7% P_2O_5 (Russel, 1966c). A hole drilled to the north contained less than 1% P_2O_5 and costeaning revealed only two thin *Lingula* beds less than 5 cm thick (Russel, 1966d). Russel (1966d) also reported that low-grade phosphate mineralization was intersected in the Blina Shale at Erskine Hill – Paradise 1 (***7796***) and Erskine Hill – Paradise 2 (***7797***). At Dry Corner (***10102***), there is a thin (up to 30 cm) phosphatic bone-bed near the base of the Blina Shale (Brunnschweiler, 1954; Freas and Zimmerman, 1965). Samples assayed up to 18% P_2O_5 over the bone bed but a 3 m channel-sample assayed less than 1% P_2O_5 (Freas and Zimmerman, 1965).

Cuttings from WAPET's petroleum well Hawkstone Peak 1 (***2965***) contained 3 m at 4.6% P_2O_5 from 488 to 491 m, and 3 m at 1.1% P_2O_5 from 408.5 to 411.6 m within the Devonian to Carboniferous Fairfield Group (Freas and Zimmerman, 1965).

At Liveringa Ridge Phosphate (***2960***) spheroidal concretions and nodules of phosphate lie in a bed up to 15 cm thick at the base of the Poole Sandstone (Freas and Zimmerman, 1965). Phosphate concretions and nodules have also been reported from the base of the Noonkanbah Formation and at the base of the Lightjack Formation (Guppy et al., 1958; Freas and Zimmerman, 1965).

Sedimentary — basin

Mineral occurrences classified as 'Sedimentary — basin' are shown on Figure 29. They are all energy (coal) occurrences.

Energy — coal

Coal has been intersected over a wide area of the Canning Basin (Fig. 29). Many of the occurrences are in the Lightjack Formation, in the lower part of the Permian Liveringa Group, but coal has also been intersected in the Condren Sandstone, and the Kirby Range Member, Hicks Range Sandstone Member, and Cherrabun Member of the Hardman Formation of the Liveringa Group. Coal has also been reported from the Early Permian Poole Sandstone, the Carboniferous Anderson Formation, and the Late Jurassic to Early Cretaceous Jarlemai Siltstone.

Australian Inland Exploration Company calculated an inferred resource at Liveringa Ridge (***9953***) of 35 Mt of sub-bituminous coal over a strike length of 8 km, down dip to 300 m, using a seam thickness of 3.3 m, and based on eight drillholes (Lee et al., 1980). The coal has a high ash content (24–35%), a calorific value of 7500 k cal/kg, moisture of between 6.5 and 12.5%, and volatile matter in the range between 31 and 33%, which is attractive for steaming coal (Lee et al., 1980). The coal has a crucible swelling number of 2, indicating that it is approaching a coking coal, with a crucible swelling number of 5 (Gair, 1972).

At Audreys Bore (***9831***), drilling by Premier Mining in 1965 intersected a sub-bituminous coal seam varying from 0.8 to 2.23 m thick over a strike length of 6.6 km within the Lightjack Formation. An additional thin seam of coal was intersected about 9 m below the main seam in two drillholes (Baarda, 1966). The coal was weathered to clay above the watertable. The estimated inferred resource is 46 Mt for the main seam to 152 m vertical depth or 4360 m downdip, assuming a strike length of 13.3 km (Baarda, 1966).

Drilling by Broken Hill Proprietary in 1977 intersected two coal seams in the Lightjack Formation over a strike length of 23 km on the northern limb of the McLarty Syncline at Mount Fenton (***9919***). Seam A is from 0.43 to 2.38 m thick; it appears to be of good quality but has no coking properties. Seam B is between 0.91 and 8.19 m thick and of poor quality (Broken Hill Proprietary Company Limited Australia, 1978).

At Myroodah Coal (***9798***), drilling by Theiss Brothers in 1966 intersected coal measures consisting of interbedded thin seams of coal, black shale, and white clay in the Liveringa Group over a strike length of 2000 m and downdip for about 900 m. The coal measures are bounded to the north and south by normal faults and to the east by a strike-slip fault (Pickering, 1968). The thickest seam intersected was 70 cm thick, and contained 20.0% moisture, 20.8% volatile matter, 27.6% fixed carbon, and 31.6% ash. The indicated resource estimated for the Myroodah area is 110 000 m^3 based on 50% coal in the coal measures (Pickering, 1968).

A rotary hole drilled by Esso Exploration and Production at Fitzroy Trough 9 (***10037***) intersected 60% coal from 117 to 118 m and 70% coal from 137 to 138 m in the Condren Sandstone (Galloway and Howell, 1975; Crowe and Towner, 1981). Examples of coal occurrences in the Hardman Formation include Fitzroy Trough 13 (***10108***) in the Kirby Range Member (Galloway and

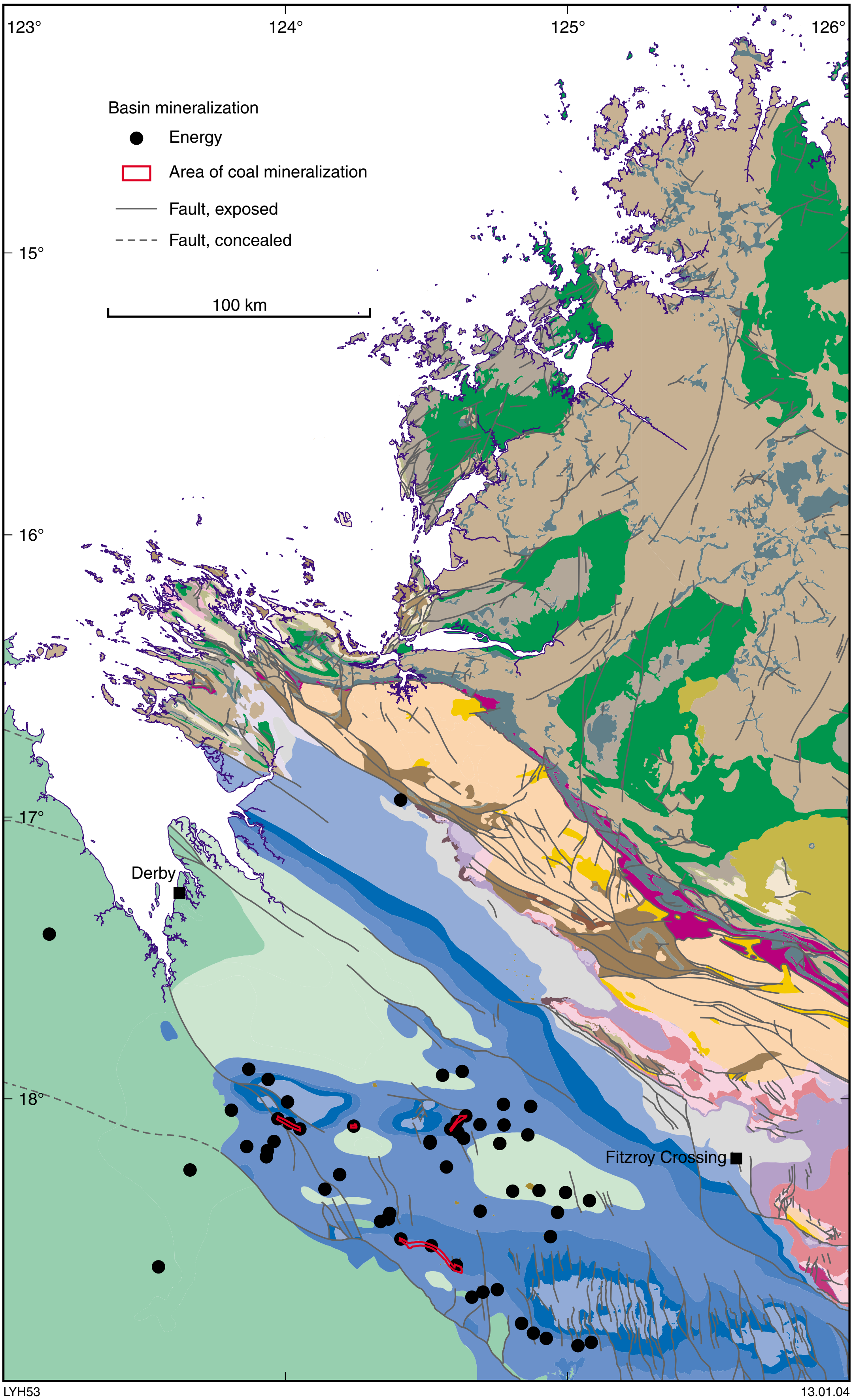


Figure 29. Simplified geological map showing distribution of basin mineralization in the west Kimberley. See Figure 7 for geological legend

Howell, 1975); Fitzroy Trough 1 (***10004***) and Watsons Bore (***9818***) in the Hicks Range Sandstone Member (Galloway and Howell, 1975; Pickering, 1968; respectively); and Fitzroy Trough 14 (***10109***) in the Cherrabun Member (Galloway and Howell, 1975). In petroleum well Frome Rocks 2 (***10107***), thin beds of low-grade coal were intersected in the Early Permian Poole Sandstone at 548.8 m (West Australian Petroleum Pty Limited, 1962).

Coal was intersected over a 3 m interval from 3368.9 m in the Carboniferous Anderson Formation in oil well Grant Range 1 (***10125***) drilled by WAPET in 1954–55 (Roberts, 1956). Coal and plant remains were also intersected in Late Carboniferous siltstone between 1892.7 and 1902.7 m in petroleum well Fraser River 1 (***10124***) drilled by WAPET in 1955 (Hunt, 1956).

Black shiny lignite was also associated with sandstone and siltstone between 146.3 and 149.4 m in petroleum well Fraser River 1 (Hunt, 1956). The host formation was interpreted by Campbell (1956) as Broome Sandstone, but as Jarlemai Siltstone by Gorter et al. (1979). Coal was reported to have been found by P. F. King in 1921 in the Jarlemai Siltstone near Babrongan Tower (DoIR historical tenement register; *Murchison Times*, 1921).

Sedimentary mineralization — undivided

Industrial mineral — salt

A salt diapir was intersected in WAPET petroleum well Frome Rocks 1 (***9130***) from 687.8 to 1220.4 m (West Australian Petroleum Pty Limited, 1962). On the basis of the intersection in Frome Rocks 1 well and seismic data, Offshore Diamond Mines NL (1991) estimated the diapir to be 3 km in diameter at a depth of 2000 m and 4 km in diameter at a depth of 4000 m, up to 6 km deep, and to have an inferred salt resource of 55 Gt. Thick salt beds are also present in the Carribuddy Group (Lehmann, 1984). The Carribuddy Group is probably the source of the salt in the diapir (West Australian Petroleum Pty Limited, 1962; Brown et al., 1984).

Vein and hydrothermal mineralization

Mineral occurrences classified as 'Vein and hydrothermal' are shown on Figure 30. These include occurrences of precious metal (gold), base metal (copper, lead, zinc, silver, gold), steel industry metal (tungsten, tin), iron, precious mineral (quartz crystal), and industrial mineral (fluorite, barite).

Precious metal — gold

Gold has been worked from several quartz reefs in the Whitewater Volcanics in the Mount Broome area. These include Turners (***7713***), where a quartz reef extends for 150 m and a small quantity of specimen stone is said to have been produced by Captain Turner (Finucane, 1938b); and Pattersons (***7715***), where two shallow pits were sunk by W. Patterson in 1936 on a quartz reef containing tourmaline, fluorite, and chalcopyrite. In the Richenda River area, there are a number of auriferous quartz reefs in the Marboo Formation. An example is Richenda River 1 (***7699***), where there are two shafts (7.6 and 3.4 m deep) and several test pits over a strike length of 73 m, along a quartz reef that varies from 15 cm to 90 cm in width. A parcel of ore from the Mount Broome – Richenda River area was shipped to Marble Bar for treatment and assayed 3 oz 3 dwt 14 gr per ton, equivalent to 98 g/t gold, but the high amounts of arsenic in the ore meant gold recovery was very low (Barnes and Associates, 1987). De Havelland (1986) reported that the total recorded gold production from Mount Broome Creek was only 454 g, and from Richenda River 78 g. Gold is also associated with copper mineralization at Mondooma (see **Base metal — copper, lead, zinc (silver, gold)**, below).

Fitzgerald (1905, 1907) noted the presence of probable auriferous quartz veins over a wide area in the Carson Volcanics. A sample from a westerly trending 1.5 m-wide quartz reef outcropping in the Isdell River north of Plover Hill (***10273***) assayed 71.0 g/t gold. Other samples included quartz from a reef in Manning Creek (***10275***) that assayed 12.3 g/t gold, and pyritic quartz from Mount Synnot (***10298***) that assayed 2 g/t gold (Fitzgerald, 1907). The quartz reef at Mount Synnot is along a major north-trending fault. Fitzgerald (1907) noted that the reef extends for at least 5.8 km north of Mount Synnot. Fitzgerald (1905, 1907) also reported auriferous quartz reefs with specular hematite and limonite at Mount Brennan, to the east of the study area (Ruddock, 2003).

Prospector Charlie James reported (*Sunday Times*, 1909a,b,c) a series of ferruginous quartz veins from rugged country north of Mount Heytesbury and south of Yampi Sound (Mount Heytesbury, ***11364***). The exact location is unknown, but it could lie on a north-trending fault cutting rocks of the Kimberley Group in that area.

Epithermal quartz veins and fault breccias with associated hematitic and argillic alteration in Carson Volcanics and Warton Sandstone have recently been discovered in the north Kimberley, to the east of the study area, by Striker Resources NL (2002a,b,c). Alluvial gold and soil anomalies up to 16.7 g/t have been reported in the '88 Creek' area (Striker Resources, 2002b,d; Ruddock, 2003). The best intersection at the time of writing this report was 1 m at 1140 ppb in sandstone with phyllo-silicate alteration and abundant micro-veinlets (Striker Resources NL, 2002e).

Base metal — copper, lead, zinc (silver, gold)

About half of the vein and hydrothermal base metal occurrences in the west Kimberley are in the Marboo Formation of the Hooper Complex (Fig. 30). Most of these are copper workings in the Little Tarraji River area. Soufoulis (1967b) estimated that copper production from the west Kimberley area, prior to 1914, was probably less than 350 t. At Grants Find (***351***), there are three main quartz veins and the richest ore forms small veins or bunches of malachite and cuprite (Woodward, 1907). A

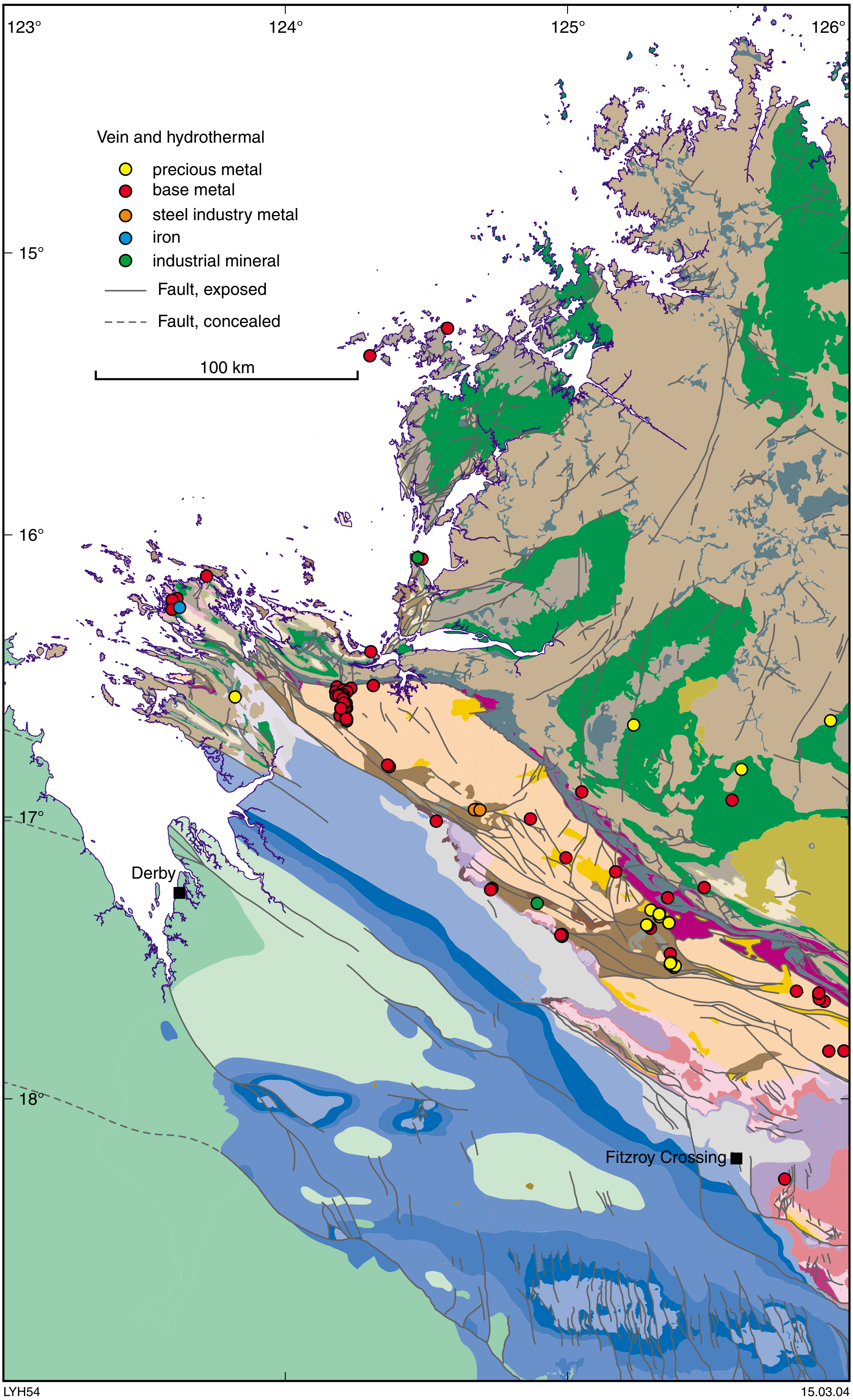


Figure 30. Simplified geological map showing distribution of vein and hydrothermal mineralization in the west Kimberley. See Figure 7 for geological legend

selective sample of ore from Grants Find assayed 34.63% Cu, 0.72% Pb, 7.4 g/t Ag, and 1.2 g/t Au (Maitland, 1919a). Disseminated chalcopyrite is also in quartz-impregnated slate (Woodall, 1957), and quartz-impregnated breccia zones within a shear zone (Reid, 1959). The main shaft was 11 m deep with a drive 50 m long at this depth (Harms, 1959). There is no recorded production from the Grants Find mine. On the basis of five diamond drillholes at Grants Find, Western Mining Corporation calculated an inferred resource of 400 000 t at 1.5–2% Cu to a depth of 120 m (Reid, 1959).

In the Monarch area, copper was mined from north-northwesterly trending, subvertical pinch and swell quartz veins and veinlets (Marston, 1979). Official recorded copper production for the year 1915 from the Monarch Group is 0.94 t Cu from 4.22 t ore from ML 227H Monarch South (***7692***) and 1.82 t Cu from 9.97 t ore from ML 228H Monarch Extended (***7691***). Pre-1914 production from these leases and the main Monarch workings (***10540***) is not recorded. Gossan from Monarch 2 (***7942***) at the northern end of the Monarch line of workings assayed up to 43% Cu, 2–5% Bi, and 0.2% Pb (Carr Boyd Minerals Limited, 1971). At Mondooma (***7672***), also known as Robinson River, there is a shaft 3 m deep and several trenches (Pickands Mather and Company International, 1967a) that lie along a major northwesterly trending fault zone separating the Marboo Formation from granite (Barnes, 1990). At the surface, mineralization consists of malachite, cuprite, azurite, limonite, hematite, galena, and gold (Barnes, 1990). The best mineralization is in a stockwork of quartz veins 20 m wide over a strike length of 100 m, and minor disseminated copper mineralization extends over 1.0 km (Woodall, 1957; Pickands Mather and Company International, 1967a; Barnes, 1990). A 10-m channel sample across the central part of the orebody assayed 8.56 g/t Au (Barnes, 1990).

Fitzgerald (1907) noted the occurrence of many vugs with traces of azurite and malachite in siliceous slate of the Marboo Formation at Mount Herbert (***10286***).

A few base metal occurrences are also hosted by the Whitewater Volcanics, Lennard Granite, Lerida Granite, Louisa Monzogranite, and the Ruins Dolerite within the Hooper Complex. The most significant of these is the Lead Prospect (***8324***), where subparallel quartz–galena–limonite veins, from 15 to 40 cm thick and up to 250 m long, are found in sheared Ruins Dolerite (McConnell, 1973). The prospect was drilled by Western Mining Corporation; their best intersection was 4 m at 5.3% Pb and 42.8 g/t Ag from 42 to 46 m in drillhole RP29 (McConnell, 1973). Anomalous antimony is associated with the mineralization — a selective rock-chip sample assayed 47.9% Pb and 1820 ppm Sb (Warland, 1977).

In the Kimberley Basin, base metal vein occurrences are hosted by the Hart Dolerite, Carson Volcanics, Wotjulum Porphyry, Warton Sandstone, and Yampi Formation. A total of 94.35 t at 24.55% Cu was produced from ML 221H on a mineralized fault zone in the Wotjulum Porphyry at the Yampi Sound copper mine (***339***) between 1914 and 1915 (Sofoulis, 1967b). Simpson (1948, p. 265) described a copper lode on ML 153H Norah (***10143***), consisting of coarsely crystallized chalcocite cut by veinlets of brochantite, malachite, and atacamite. It is probable that the Norah lease is identical to the Yampi Sound copper mine lease — although the tenement map shows it further west — as Simpson (1948, p. 412) gave a very similar mineralogical description for the Yampi Sound copper mine assemblage. An unusual mineral assemblage has also developed at Collier Bay (***10072***), where chalcocite in a copper lode has reacted with seabird guano deposits to form the hydrous phosphate of copper, dihydrite or pseudomalachite (Simpson, 1930, 1951). The host rock for the copper mineralization is probably the Yampi Formation, which has been mapped along the coast of Collier Bay on YAMPI.

Minor base metal vein occurrences have been reported from Phanerozoic sedimentary rocks of the Lennard Shelf. These may be related to the MVT mineralization but are hosted predominantly by clastic sedimentary rocks. Windjana Gorge 1 (***8386***) comprises narrow veins and lenses of malachite, tenorite, and cuprite in limestone, sandstone, and conglomerate of the Napier Formation, and malachite infilling pore spaces in sandstone (Wilson, 1973).

Steel industry metal — tungsten (tin)

King Sound 1 (***337***), also known as Taylors Wolfram Reward (ML 146H), is an opencut on part of a vein system that is 400 m long and 21 m wide. The opencut exposes two quartz veins up to 38 cm wide separated by 60 to 75 cm of phyllite (Finucane, 1938a). Harms (1959) noted that the veins were subparallel to the enclosing slate, schist, and amphibolite (Marboo Formation), and were nearly vertical on a strike of about 285°. The veins contain fine-grained cassiterite, coarsely crystalline wolframite, and scorodite that has formed from the oxidation of arsenopyrite (Campbell, 1909a; Blatchford, 1914; Finucane, 1938a). Blockley (1980) reported that tungsten production from the King Sound mine (ML 146H) between 1911 and 1913 was 27.4 t ore and concentrates (2.03 t WO_3). There is no recorded tin production, but part of the 0.43 t tin concentrate recorded as production from the Patterson Range between 1951 and 1955 may have come from King Sound (Blockley, 1980). A 3-m shaft was sunk by J. Stewart on a quartz reef showing patchy arsenopyrite and scheelite at King Sound 6 (***7650***), to the east of the main King Sound workings, but although some scheelite specimens were obtained, the vein was not economic to work (Harms, 1959).

Speciality metal — tin

See **Steel industry metal — tungsten (tin)**, above.

Iron

Harms (1959) noted that quartz–hematite veins of considerable size were present on YAMPI. The largest of these is Wotjulum (***10044***), where the quartz–hematite vein is in the form of a dyke-like body about 30 m wide and 90 m long. Harms (1959) did not consider the vein to be of economic interest because the overall grade was less than 40% Fe.

Precious mineral — quartz crystal

At the Mondooma copper mine (***7672***), specimens of well-terminated clear quartz crystals, up to 2.5 cm across, are found in vuggy fissures within the vein (Pickands Mather and Company International, 1967a). See **Base metal — copper, lead, zinc (silver, gold)**, above.

Industrial mineral — fluorite, barite

At Mount Amy (***10078***), there are veins of fluorite with intergrown crystals of barite (Simpson 1948, 1951) within either Marboo Formation or Lennard Granite of the Hooper Complex. At Doubtful Bay Barite (***10079***), there are veins of barite within a fault zone that cuts Warton Sandstone, Elgee Siltstone, and Carson Volcanics. Some of the barite is of fair quality but most is ironstained (Harms, 1959).

Regolith — residual and supergene mineralization

Mineral occurrences classified as 'Regolith — residual and supergene' in the west Kimberley include aluminium (bauxite), precious metal (gold), and industrial mineral (phosphate, ochre). Their distribution is shown on Figure 31.

Aluminium — bauxite

The bauxite deposits at Mitchell Plateau in the west Kimberley and at Cape Bougainville in the north Kimberley area (Ruddock, 2003) have been described in detail by Joklik et al. (1975), Parker and Sadleir (1984), and Bardossy and Aleva (1990). The bauxite and laterite (ferricrete) developed over Palaeoproterozoic Carson Volcanics on a Cainozoic peneplain that was subsequently elevated and dissected. The resource tested by drilling at Mitchell Plateau comprises South Plateau (***10547–48***), Central Plateau (***10549***), and North Plateau (***10550***) localities (Parker and Sadleir, 1984). These are all within the northernmost area of bauxite and laterite mapped by Joklik et al. (1975) and are shown on Figure 32. Patchy bauxite has also developed at Lone Dingo (***10554***), Jacks Folly (***10551***), Parkers Point (***10552***), and Debatable Point (***10553***) prospects (Parker and Sadleir, 1984).

The average thickness of the bauxite (3.2 m) at Mitchell Plateau is much less than that (8.6 m) at Cape Bougainville, resulting in lower tonnages — 230 Mt on Mitchell Plateau compared with 980 Mt on Cape Bougainville. However, the grade of the bauxite at Mitchell Plateau is much higher at 47% total alumina compared with 36% total alumina at Cape Bougainville (Joklik et al., 1975). There is a lower iron oxide content (between 7 and 38% Fe_2O_3) in bauxites from the Mitchell Plateau than in bauxite from Cape Bougainville, with 40% Fe_2O_3 (Bardossy and Aleva, 1990). The grade of the Mitchell Plateau bauxite is locally high enough to meet the specifications for refractory grade ore.

Gibbsite is the most abundant ore mineral in the Mitchell Plateau bauxite and its concentration tends to increase with depth. Boehmite is generally concentrated near the surface. The ratio of gibbsite to boehmite in the Mitchell Plateau ore averages 1:10 but is locally as high as 1:4 (Joklik et al., 1975). A typical bauxite profile from the Mitchell Plateau has a gibbsitic zone consisting of gibbsitic pisolites in a gibbsitic matrix at the base (Fig. 33). This is followed by a pisolitic zone containing pisolites from 1 to 3.5 mm across with alternating concentric layers of gibbsite and ferruginous material in a matrix of gibbsite or ferruginous gibbsite, which in turn is overlain by a ferruginous zone (Joklik et al., 1975). The bauxite at Cape Bougainville differs in being more ferruginous, containing more boehmite, and having a tubular structure (Joklik et al., 1975).

Low-grade bauxite mineralization is also present further south. At Sharp Hill (***8734***), the best intersection from 47 holes was 1.5 m at 21.2% average Al_2O_3, including 0.6 m at 26.5% average Al_2O_3, in drillhole 10166 near the edge of a breakaway (Mason, 1980).

Precious metal — gold

A rock-chip sample (Q54118) of ironstone and ironstone float from Richenda (***9505***) assayed 2.1 ppm Au.

Industrial mineral — phosphate

On White Island (***10166***), rock phosphate consists mainly of variscite (hydrated aluminium phosphate) that underlies guano deposits and overlies dolerite (Simpson, 1911, 1952). Minor deposits of seabird guano have been reported by Allen (1971) from West Montalivet Island (***10105***) and East Montalivet Island (***10104***).

Industrial mineral — ochre

Hardman (1884) reported that deposits of good-quality red and yellow ochres up to 3 m thick could be traced for several miles along the banks of Forrest Creek at Forrest Branch (***10056***).

Regolith — alluvial to beach placer mineralization

The distribution of mineral occurrences classified as 'Regolith —alluvial to beach placer' is shown on Figure 34. The occurrences include precious mineral (diamond), precious metal (gold), speciality metal (heavy minerals, tin, tantalum), and industrial mineral (garnet, glauconite).

Precious mineral — diamond

The alluvial diamond occurrences are shown on Figures 34 and 35. Most of the alluvial diamond and microdiamond occurrences are in the Canning Basin and in close proximity to known diamond-bearing lamproites.

Significant concentrations of diamonds in the Ellendale field have been found in the Terrace 5 palaeochannel (Fig. 35), named after Pit 5 (***10184***), where 14

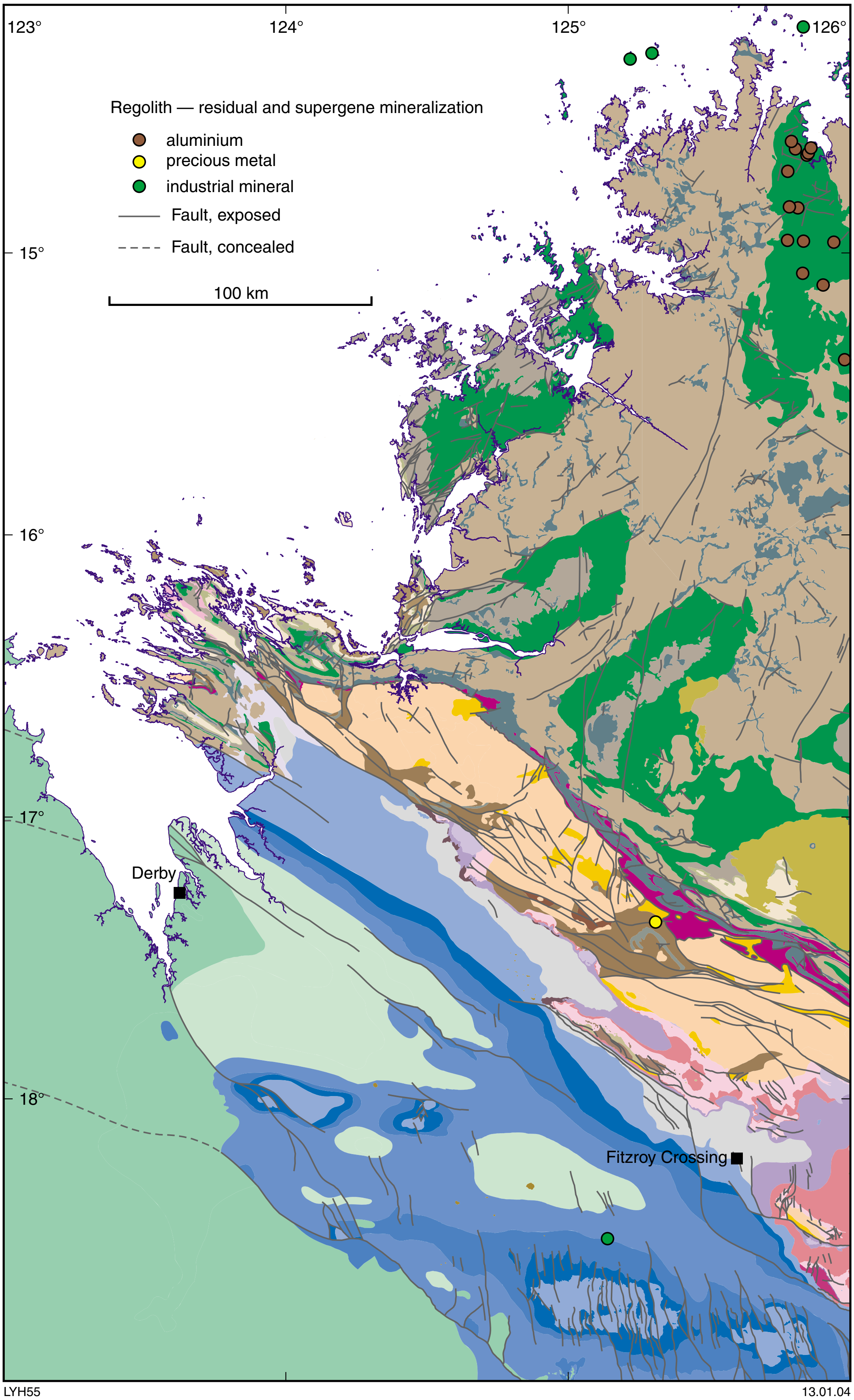


Figure 31. Simplified geological map showing distribution of regolith — residual and supergene mineralization in the west Kimberley. See Figure 7 for geological legend

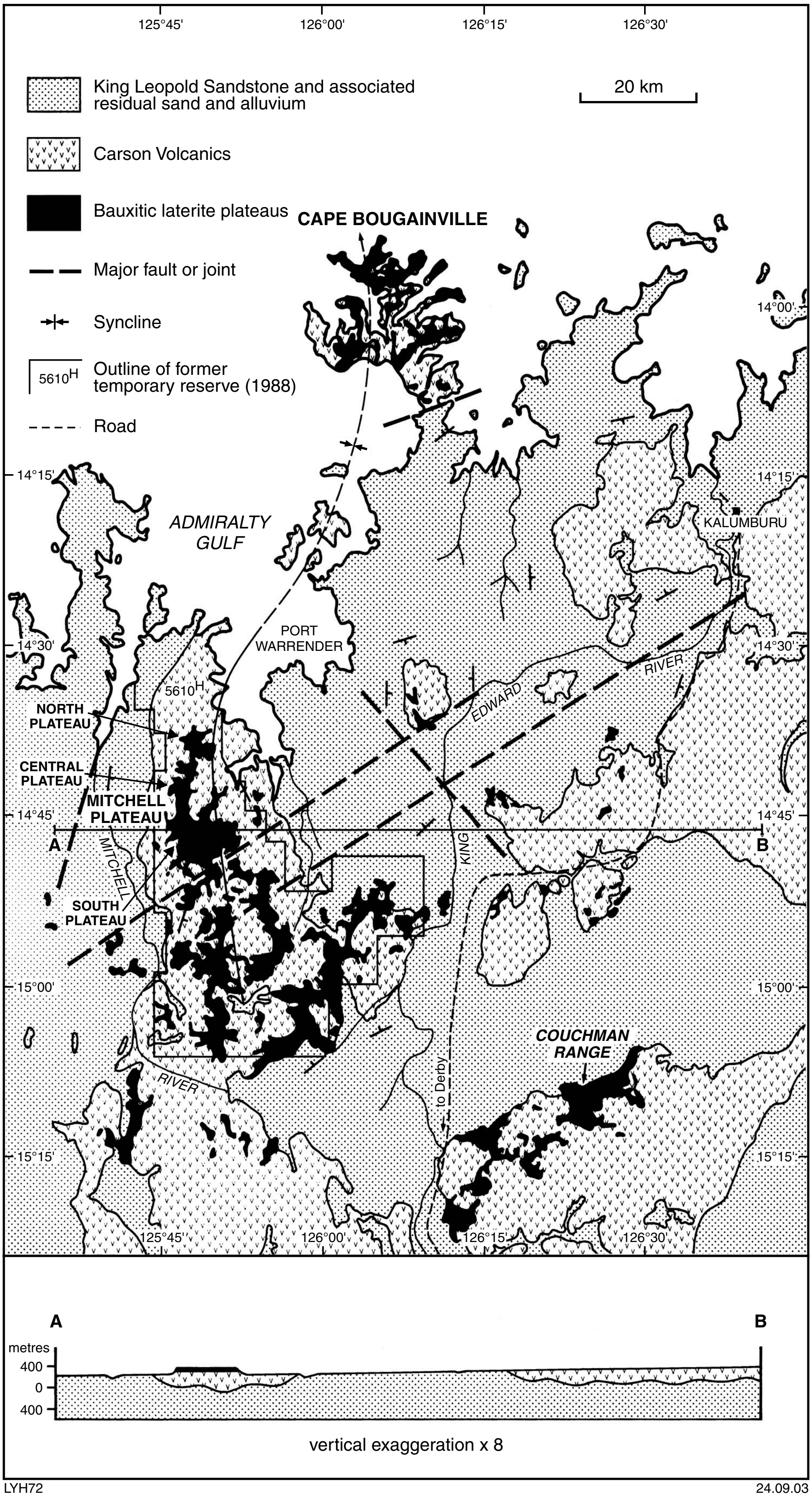


Figure 32. Geological map and cross section showing the distribution of bauxite and laterite (ferricrete) over Carson Volcanics in the Kimberley (after Joklik et al., 1975)

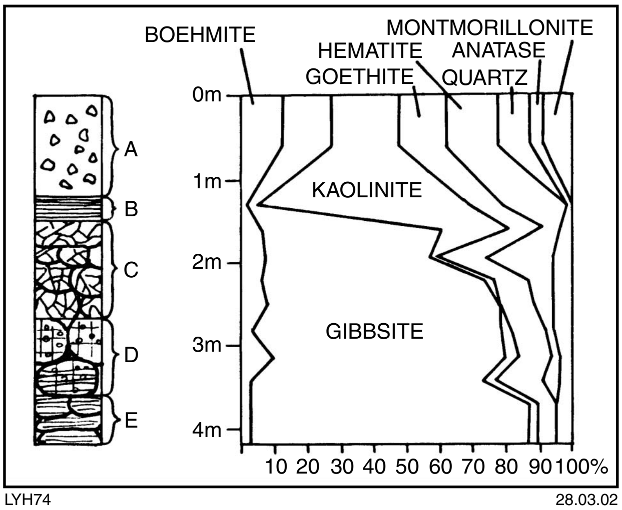


Figure 33. Typical profile and modal analysis of bauxite on the Mitchell Plateau (after Joklik et al., 1975). Profile is as follows: A — overburden and soil; B — overburden and bedded ferruginous clay; C — ferruginous pillows with root pattern; D — pisolitic zone; E — gibbsitic zone

diamonds totalling 6.3 ct including a 2.3 ct gem were discovered in a 247 t sample (Kimberley Diamond Company NL, 1996). Economic concentrations of diamonds in Pit 61 (***8704***) were obtained from a 220 t sample that contained 44 diamonds weighing 21.31 ct, equivalent to 10 ct/100 t (Kimberley Diamond Company NL, 2000).

Diamonds have also been reported from the J-Channel palaeochannel (Fig. 35), which is in close proximity to the Ellendale 4 pipe. Ninety three diamonds weighing 16.07 ct were recovered from a 435 t sample from J-Channel 1 (***8805***) at the southern end of the palaeochannnel (Kimberley Diamond Company NL, 2002f).

However, there are some occurrences, e.g. Camerons Bore 1 (***8826***) reported by Muggeridge (1994), in the Eastern Lennard Shelf field that are on creeks that do not drain from known lamproites. The northeastern part of the area also has some alluvial diamond and microdiamond occurrences for which the source is not yet known. These include Mount Fyfe 1 (***8765***) where one 0.058 ct diamond and two microdiamonds were recovered from a 40 kg stream-gravel sample (PR383) from a tributary of the Drysdale River (Fielding and Thomas, 1984a). Alluvial diamond occurrences in the Kimberley Basin further south are possibly sourced from the Aries pipe or related kimberlites in the north Kimberley, e.g. Manning Creek Diamond (***4220***), where eight diamonds totalling 0.22 ct were recovered from a 372 m^3 sample (Beckett, 1986).

Precious metal — gold

At Mount Broome 1 (***7780***), alluvial gold has been worked from Mount Broome Creek and surrounding gullies since at least 1898 (Donaldson and Elliot, 1998; Hann, 1901). Recorded production was only 454 g although production may have been much greater (de Havelland, 1986). In the Richenda River area a number of alluvial occurrences, including Colemans Find (***7782***), were reported by de Havelland (1986).

At Oobagooma Gold (***10170***), 280 g of alluvial gold is reputed to have been won from a gully on Oobagooma Station (*Sunday Times*, 1914). *Sunday Times* (1909a,b,c) has also reported auriferous gravels associated with ferruginous quartz veins from north of Mount Heytesbury (***11364***).

Speciality metal — heavy minerals

Broadly spaced auger–baler holes drilled by Geodrillers Proprietary Limited for Metals Investments Proprietary Limited in King Sound, e.g. King Sound HM 1 (***8326***), intersected significant heavy mineral concentrations. An inferred resource of more than 100 Mt heavy minerals assaying nearly 35% TiO_2 was calculated for the King Sound deposit (Brown, 1971). However, the high heavy mineral content was not duplicated in a subsequent drilling program by BHP, who found that most holes contained less than 1% heavy minerals (Moore, 1987). Concentrations of heavy minerals have also been reported by Wyatt (1970) from the May River Mouth (***4898***), Robinson River Mouth (***4901***), and Secure Bay (***4894***).

Speciality metal — tin (tantalum)

Thirteen test pits were sunk on an alluvial tin deposit at Dyasons Creek Alluvial (***7712***) close to Dyasons Creek Pegmatite (***7711***). A composite sample taken from the pits assayed 0.071 kg/m^3 cassiterite (Finucane, 1939a). At Silent Valley 2 (***10077***), the alluvial tin workings are in the headwaters of a north-flowing gully that cuts through granite containing cassiterite veins and greisen (Harms, 1959). Tin and tantalum minerals are common accessories in all creeks draining granite in the Richenda River area. A small tin plant operated at Richenda River Tin 2 (***8802***), between 1984 and 1985, but there is no record of production (Barnes and Associates, 1987).

Industrial mineral — garnet

At Hawkstone Creek (***7928***), an alluvial and eluvial garnet deposit has been derived from garnet–mica schist and staurolite–garnet schist of the Marboo Formation. The alluvial deposit is about 2 m thick with the heaviest concentration of garnet in the lower metre. An inferred resource of 0.5 Mt of between 5 and 10% garnet has been calculated (Russell Mining, 1992). This resource does not conform to the reporting requirements of the JORC Code.

Industrial mineral — glauconite

Hardman (1884) and Simpson (1951) reported that green glauconitic grit is interbedded with soft brown sandstone in a billabong of the Fitzroy River at Mount Abbott Glauconite 1 (***10157***).

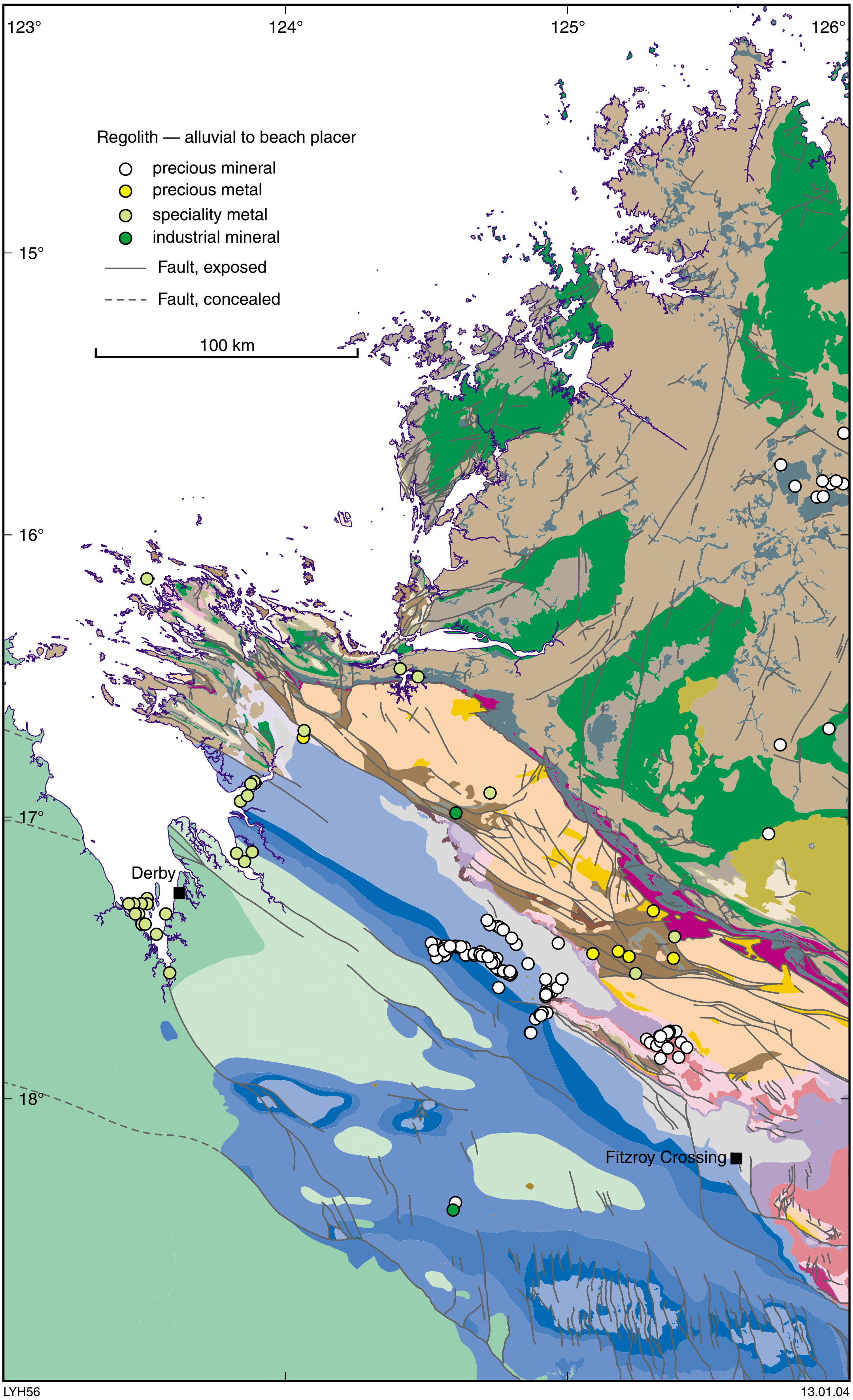


Figure 34. Simplified geological map showing distribution of regolith — alluvial to beach placer mineralization in the west Kimberley. See Figure 7 for geological legend

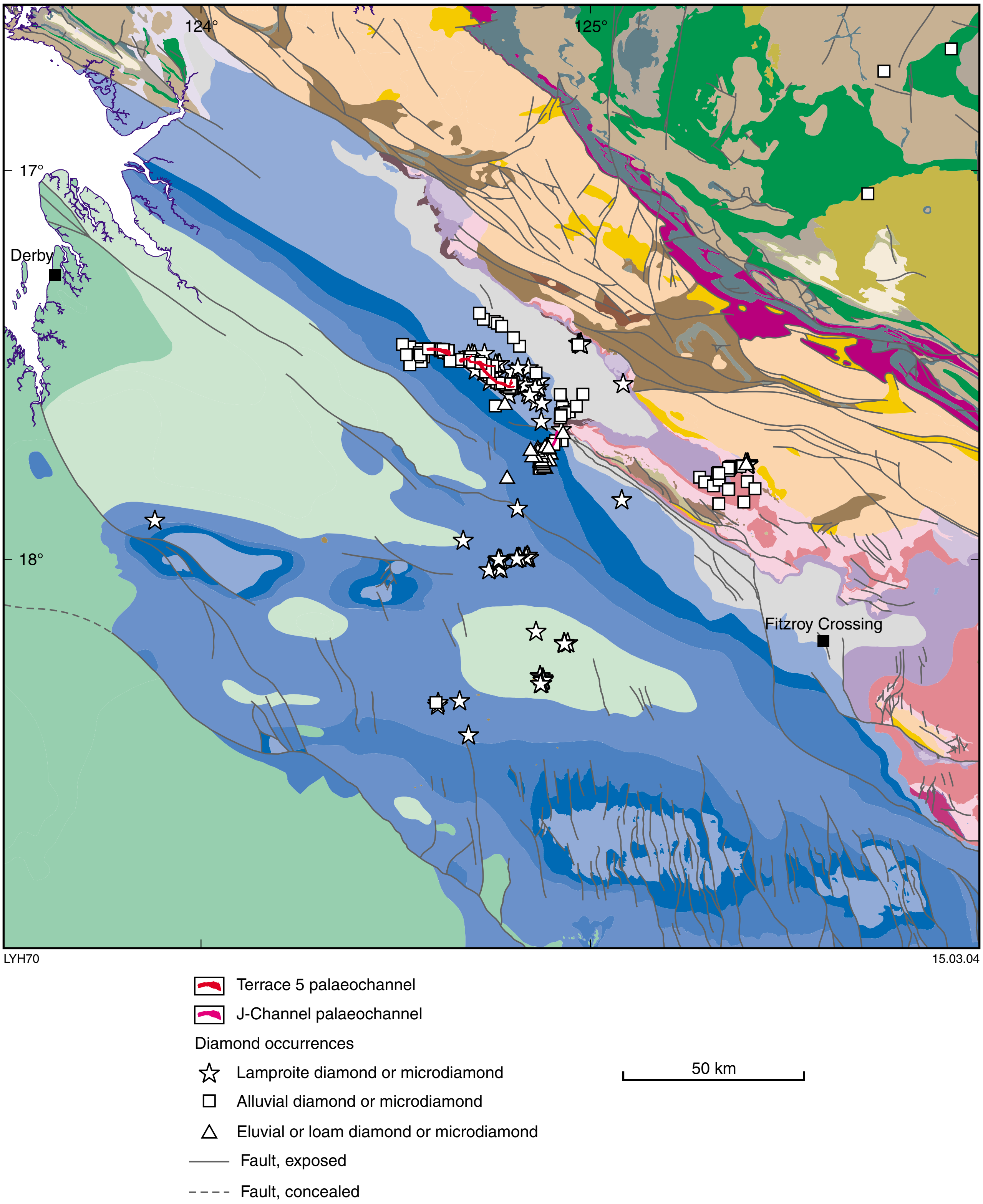


Figure 35. Distribution of lamproite, and alluvial and eluvial diamond occurrences relative to major faults. See figure 7 for geological legend

Regolith — residual to eluvial placer mineralization

Mineral occurrences classified as 'Regolith — residual to eluvial placer' are shown on Figure 36, and include precious mineral (diamond) and precious metal (gold).

Precious mineral — diamond

The eluvial diamond occurrences shown on Figures 35 and 36 are diamonds and microdiamonds reported from loam samples and can mostly be attributed to lamproites in the Ellendale, India Bore, and Big Spring areas. The exceptions are the four occurrences in the Mount Fyfe area, e.g. Mount Fyfe 3 (***8767***), which probably have the same origin as the alluvial occurrence at Mount Fyfe 1 described above (see **Regolith — alluvial to beach placer mineralization**).

Precious metal — gold

Gold nuggets have been obtained from a small area of quartz scree at Central Robinson River (***8810***) near a major northwesterly trending lineament (Barnes, 1990). Gold nuggets are also reputed to have been found near Camden Harbour (***10725***) by a convict called Wildman in 1856 (Battye, 1915).

Undivided mineralization

The distribution of 'Undivided mineralization' is shown on Figure 37. Apart from a minor gold occurrence of uncertain type, all the occurrences are of construction materials.

Construction materials — dimension stone

Granite and 'black granite' (dolerite) within the Hooper Complex have been worked or tested as a source of dimension stone. Sample blocks totalling 336 t were quarried from the Lennard Granite at the Kimberley Ice (***9677***) quarry in 1995, with a 75% recovery of quality stone (Elkington, 1998). 'Black granite' is found in the Wombarella Creek area at a number of sites including Nardma Black Granite 1 (***9153***), reported by Martinick and Associates Pty Limited (1988). It is not certain whether the Wombarella Quartz Gabbro or dolerite dykes are the source of the 'black granite'. Hart Dolerite with potential for dimension stone has been recorded from Mount Hart Dimension Stone (***9634***). A polished slab of the Hart Dolerite showed that the dolerite is deep green, weakly altered, and coarsely ophitic (Temby, 1992).

The Canning Basin is a source of limestone and sandstone suitable for dimension stone. Windjana Limestone suitable as a source of 'pink marble' has been reported by Martinick and Associates Pty Limited (1988) from Barlil (***9178***). At Janganbarr (***9280***), coloured sandstone of the Broome Sandstone is suitable for use as dimension stone (Martinick and Associates Pty Limited, 1988).

Construction materials — road metal, aggregate, gravel, sand

Limestone of the Napier Formation has been quarried for road metal by Readymix at Oscar Range 1 (***8067***). Silicified sandstone of the Melligo Sandstone has been quarried as aggregate by Pioneer and Kimberley Quarry Proprietary Limited at Nillibubbaca 1 (***10237***). Gravel and sand have been quarried from many of the rivers in the area, e.g. Langey Crossing Gravel (***10238***).

Mineral controls and exploration potential

Mineralization in kimberlite and lamproite

Precious mineral — diamond

From mineral-inclusion studies and carbon-isotope values, Hall and Smith (1984) concluded that the lamproitic diamonds at Ellendale have similar properties to kimberlitic diamonds and that they probably formed in the same way (i.e. they are xenocrysts in the lamproite). These authors estimated a temperature of formation for the Ellendale diamonds between 1053 and 1117°C assuming a pressure of 50 kb. These studies suggest that the diamonds were formed in the upper mantle at a depth in excess of 125 km and that the lamproites acted only as the transporting medium (Smith, 1984).

Most of the lamproites in the west Kimberley lie close to northwest-trending faults that were active in the Palaeoproterozoic and were reactivated in the Palaeozoic and Mesozoic (Smith, 1984). The main group of lamproites in the Ellendale lamproite field is clustered about the inferred extension of the northwesterly trending fault along the base of the Oscar Range. The remaining lamproites in the Ellendale lamproite field are at the edge of the Napier Range, along the same trend as the Big Spring lamproites 60 km to the southeast. The Calwynyardah lamproite field and northern lamproites of the Noonkanbah lamproite field are adjacent to the Pinnacle fault system (Smith, 1984). The Liveringa Diamond occurrence is also close to a northwesterly trending fault. The southern lamproites of the Noonkanbah lamproite field are not near any known fault, but are on the same trend as the fault near the Liveringa Diamond occurrence and it is possible that there is a subsurface continuation of this fault. Figure 8 and Plate 1 show the location of these fault systems.

Smith (1984) suggested that the lamproite vulcanicity could be associated with the northward drift of the Australian continent over a hot-spot, on the basis of the north–south alignment of the three main lamproite fields (Noonkanbah–Calwynyardah–Ellendale) and the overall increase in age of the lamproites to the north.

Thirty-one new lamproites were discovered in the Ellendale area between 1997 and December 2001 using airborne magnetic and EM techniques (Kimberley

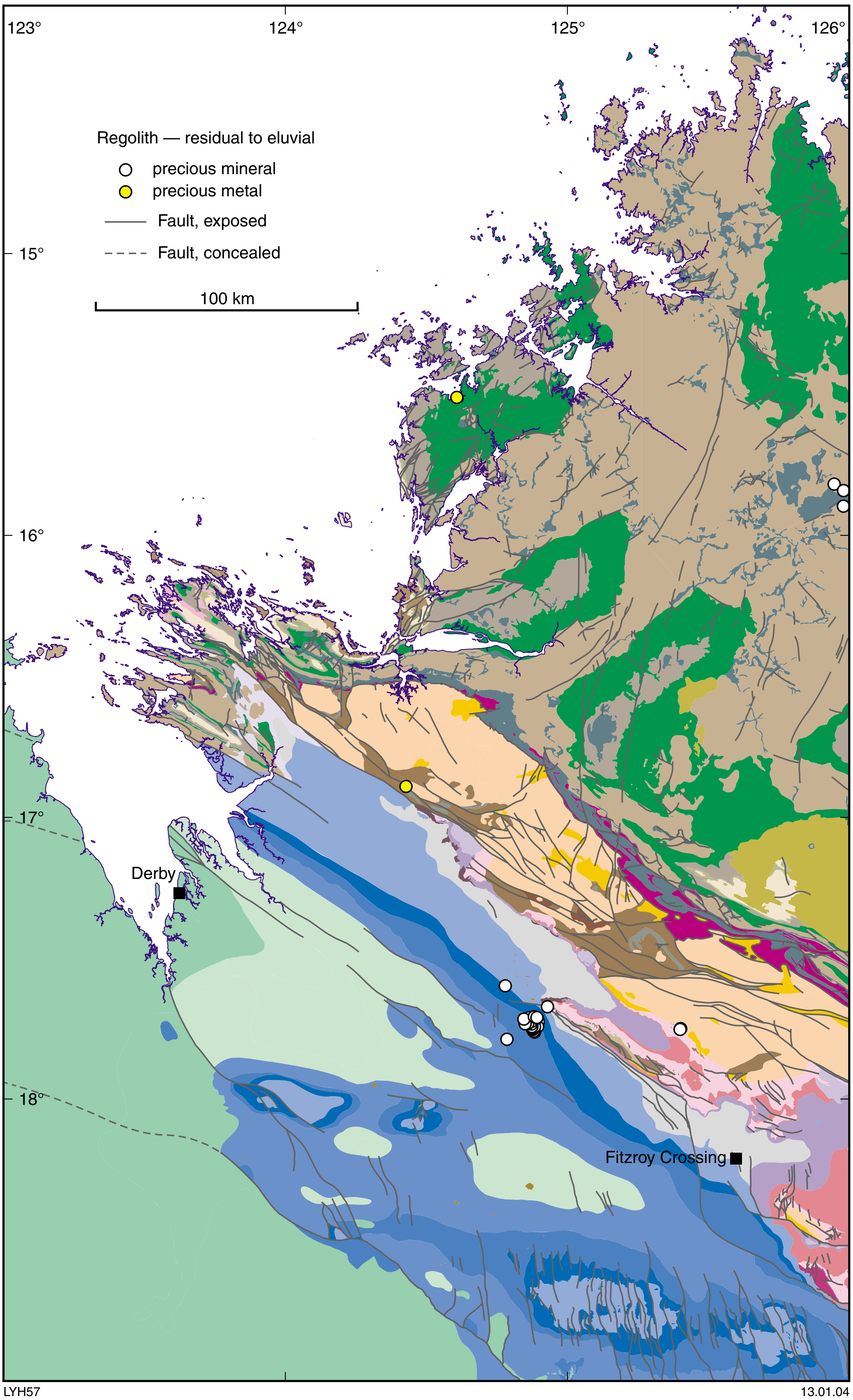


Figure 36. Simplified geological map showing distribution of regolith — residual to eluvial mineralization in the west Kimberley. See Figure 7 for geological legend

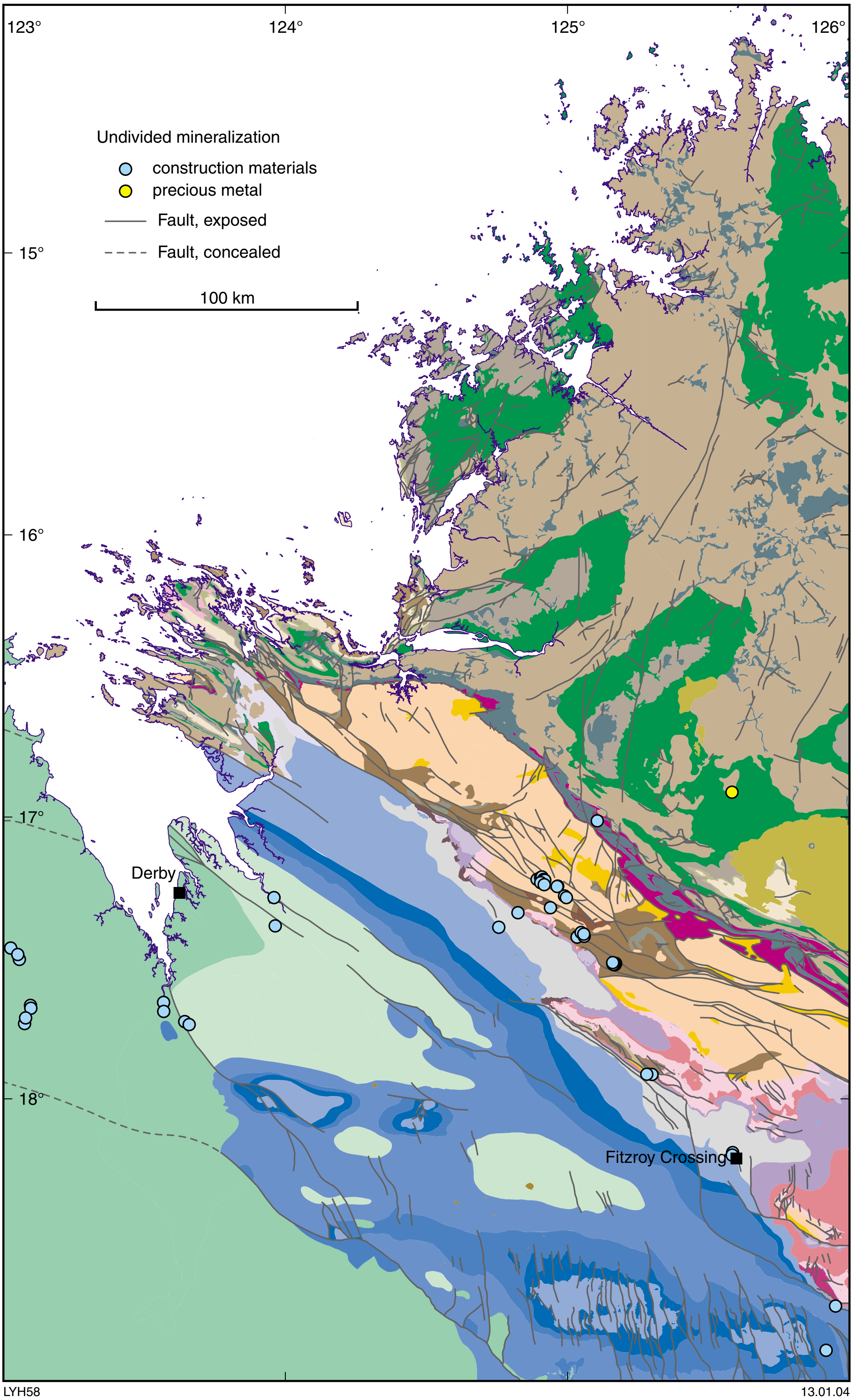


Figure 37. Simplified geological map showing distribution of undivided mineralization in the west Kimberley. See Figure 7 for geological legend

Resources NL, 1998; Kimberley Diamond Company NL, 1999, 2000, 2001a,c), and sampling of termite mounds (Mason, 2000; Weir, 2002), demonstrating that the area is highly prospective for diamonds. Areas worthy of further exploration include: the southern edge of the Napier Range between the northern Ellendale intrusions and Big Spring; the northwest and southeast extensions of Ellendale; and the possible subsurface extension of the fault near Liveringa Diamond (***9125***). New airborne gravity surveys, such as Gravity Capital's 'Falcon' gradiometer survey, may assist in finding lamproite pipes without a magnetic signature. De Beers Hyperspectral HyMap MK1 scanner was successful in delineating the Brockman kimberlite dyke in the Pilbara (De Beers Australia Exploration, 2002) and could also have application in the west Kimberley.

Exploration targets are the alluvial diamond occurrences with no obvious source, such as Camerons Bore 1 in the Canning Basin and Mount Fyfe in the Kimberley Basin. Diamond-bearing kimberlites of c. 820 Ma similar to the Aries pipe and the Ashmore, Seppelt, and Pteropus kimberlites in the north Kimberley (Ruddock, 2003) may be present in the Kimberley Basin in the west Kimberley area. During exploration follow-up, caution is needed when interpreting microdiamond occurrences from loam samples, because microdiamonds may have been reworked many times and form part of the general background distribution of diamond in the Kimberley region (Wirtz, 1997).

Industrial mineral — bentonite, feldspar

Crater-lake sediments associated with some of the lamproite vents in the Calwynyardah field have been shown to be prospective for bentonite and potassium feldspar by Kimberley Resources NL (Jones, 1997; Abeysinghe, 2002).

Orthomagmatic mafic and ultramafic mineralization

Steel-industry metal — nickel (copper, cobalt)

The early Cambrian Milliwindi dolerite dyke has been interpreted by Hanley and Wingate (2000) as a feeder dyke for the Antrim Plateau Volcanics. If this interpretation is correct, the Milliwindi dyke has potential for Voiseys Bay-style Ni–Cu–Co mineralization. At Voiseys Bay, in Labrador, Canada, mineralization is hosted within a feeder dyke and, at the entry point of the dyke into the overlying mafic intrusion, there is evidence of contamination of the magma by sulfide-rich gneiss, which may have been the cause of sulfide immiscibility (Naldrett et al., 1996; Naldrett, 1997). The Carson Volcanics and Marboo Formation are possible sources of sulfur for the Milliwindi dyke, but at this stage no evidence has been found to suggest that the magma has been contaminated. The Hart Dolerite also has potential for Ni–Cu–Co mineralization, with the inferred feeder zones for the Hart Dolerite to the east of the study area in the north Kimberley (Gunn and Meixner, 1998). The presence of Cu–Ni mineralization in the Ruins Dolerite at Limestone Spring indicates that this dolerite is also prospective.

Greisen mineralization

Speciality metal — tin

Silent Valley is the only known greisen occurrence in the area. The potential for economic deposits of this style of mineralization is not considered to be very high.

Pegmatitic mineralization

Speciality metal — tin

Cassiterite-bearing pegmatites have been reported from Dysons Creek (Finucane 1939a; Harms, 1959) and possibly from Kalganu Island (Blockley, 1980) but no economic occurrences have been reported to date. The granites in the area are all I-type granites, which suggests that the potential for tin pegmatites is low.

Industrial mineral — mica, beryl

Harms (1959) considered that there was potential for further small-scale production of high-quality muscovite from both Gussys and Stewarts as these deposits have not been worked out. Harms (1959) also noted that some of the beryl from Stewarts was semi-transparent and that some of the better crystals might contain gem-quality material.

Stratabound volcanic and sedimentary mineralization

Base metal — copper, lead, zinc (silver)

Chianti 1 appears to be an example of proximal volcanogenic mineralization within the Marboo Formation. Given the association of minor tuff beds with the Turtle Creek 1 prospect, it is probable that this deposit is also a distal volcanogenic exhalative deposit. These occurrences are 160 km apart, suggesting that the Marboo Formation is prospective for volcanogenic deposits over a wide area wherever felsic volcanic rocks or tuffs are present.

The Carson Volcanics of the Kimberley Basin contain copper mineralization of possible volcanogenic origin in chert, interflow sedimentary rocks, and tuff in the east Kimberley (Planet Management and Research Proprietary Limited, 1971; Hassan, 2000). Fitzgerald (1905, 1907) noted that there was tuff and agglomerate (in the Carson Volcanics) near the junction of the Sprigg and Isdell Rivers (on CHARNLEY) but there has been no detailed mapping of the Carson Volcanics in the west Kimberley. However, it is likely that chert, interflow sedimentary rocks, and tuff are as widespread in the west Kimberley as in the east Kimberley and these rock types are considered prospective for volcanogenic and remobilized volcanogenic copper sulfide mineralization.

The Carson Volcanics may also be prospective for Michigan-style native copper mineralization (native copper in vesicular basalt flow-tops and interflow sedimentary rocks of the Portage Lake Lava Series in the Keweenaw area of Michigan), as described by White (1968) and Nicholson et al. (1992), given the reported occurrence of slugs of native copper in the Brecknock Harbour area (*Sunday Times*, 1908a). The Portage Lake Lava Series is interpreted to have been erupted into an intercontinental rift zone caused by a mantle plume (Nicholson et al., 1992). Ruddock (2003) suggested that the Carson Volcanics were also in an intracratonic rift that may be related to mantle-plume activity below the Kimberley Craton. Rb–Sr dates of 1045–1060 Ma on amygdale-filling microcline, calcite, epidote, and chlorite associated with the Michigan copper mineralization indicates that the mineralization postdated rifting and the 1094–1096 Ma Portage Lake Lava Series (Nicholson et al., 1992). There are insufficient data available on the copper mineralization in the Carson Volcanics to determine the relative ages of the volcanics and the mineralization.

Precious metal — gold

Turtle Creek 2 is a possible example of distal volcanogenic gold mineralization within the Marboo Formation. The small gold workings at Richenda River 7 were interpreted by Pickands Mather and Company International (1967a) to be associated with small pockets of metavolcanic rocks. The area has been mapped as Marboo Formation on LENNARD RIVER, suggesting that felsic volcanic rocks within the Marboo Formation are prospective for gold mineralization as well as base metal mineralization. Alternatively, the mineralization may be related to the Whitewater Volcanics.

Stratabound sedimentary — carbonate-hosted mineralization

Base metal — lead, zinc, copper (silver, gold)

The stratabound lead–zinc deposits and occurrences on the Lennard Shelf are MVT deposits. Leach and Sangster (1993) summarized the characteristics of this variable family of stratabound epigenetic lead–zinc deposits. The Lennard Shelf deposits show strong stratigraphic and structural control.

Most occurrences in the southeastern part of the Lennard Shelf (Pillara Range and Emanuel Range area) are hosted by Pillara Cycle association 1 platform facies (Copp, 2000) or pre-reef facies Cadjebut Formation. Further north, in the Fossil Downs area, mineralization is hosted by platform facies stromatoporoid limestone and marginal-slope facies of Pillara Cycle association 3 (Copp, 2000) and, to a lesser extent, marginal-slope Sadler Formation. Still further north, in the Oscar and Napier Range areas, the occurrences are hosted by massive reef-slope and fore-reef limestone of the Nullara Cycle Napier Formation or, locally, the Windjana Limestone (Fig. 19).

The Cadjebut, Goongewa, Kutarta, and Kapok ore-bodies are situated close to the Cadjebut Fault, a synsedimentary (Late Devonian) normal fault, which, in turn, is a splay of the Pinnacle Fault. The Pinnacle Fault was probably the main basin-tapping fluid conduit for the mineralizing brines (Tompkins et al., 1997). Oil and gas generation in the basin, triggered by a fall in sea level, may have been a contributing factor to the generation of over-pressured fluid that deposited the breccia ore (Tompkins et al., 1997). Dolomitized Pillara Limestone hosts mineralization at both Goongewa and Kutarta. At Cadjebut, rhythmically banded ore is hosted by evaporites of the Cadjebut Formation. Tompkins et al. (1994b, 1997) interpreted the evaporites as the source of sulfur. A later phase of mineralization is represented by sulfides in vugs and cavities within the Cadjebut Formation. The second phase of mineralization is interpreted by Tompkins et al. (1994a, 1997) to be related to a period of reefal-platform emergence and minor uplift of the Lennard Shelf coinciding with the waning stages of the Alice Springs Orogeny.

Most of the mineralization at Pillara is controlled by the north-northeast trending, east-dipping Western Fault and F10 Fault and the west-dipping Eastern Fault. There is also strong stratigraphic control, with mineralization developed preferentially in a fenestral Amphipora limestone unit of the Pillara Limestone (Murphy et al., 1986). Unlike most MVT deposits, which are hosted by dolostone (Leach and Sangster, 1993), the limestones at Pillara show no evidence of dolomitization (Murphy et al., 1990). Fluid-inclusion studies on sphalerite from Pillara gave homogenization temperatures of 55 to 110°C and salinities of 17 to 27 wt% NaCl (Moyle, 1980), similar to other MVT deposits (Leach and Sangster, 1993). These figures are consistent with derivation of highly saline brines from considerable depth, probably from dewatering of sediments in the adjacent Fitzroy Trough (Murphy et al., 1986; Ringrose, 1989).

A number of gossans are close to the northwesterly trending fault along the base of the Oscar Range suggesting that this fault has acted as a channelway for mineralizing solutions.

No regional-scale faults are known in the vicinity of Napier Range, but there are minor faults associated with the Nullara and Wagon Pass deposits. Extensive dolomitization and localized chloritic alteration at these deposits is indicative of substantial fluid-flow through these rocks (Ringrose, 1989).

Typically, MVT deposits are small — rarely exceeding 10 Mt and mostly in the range between 0.1 and 2 Mt (Leach and Sangster, 1993). However, in the Pine Point area of Canada there are more than 80 deposits, and in the Upper Mississippi Valley district there are nearly 400 deposits (Leach and Sangster, 1993). To date, eleven deposits have been defined on the Lennard Shelf, ranging in size from 0.5 Mt to 14.27 Mt, although most of these are made up of a series of ore lenses. Total ore resources and reserves for the Lennard Shelf Project at the end of June 2001 were 23.63 Mt grading 7.7% Zn and 3.7% Pb, and 16.29 Mt grading 7.5% Zn and 2.9% Pb, respectively (Western Metals Limited, 2002). The Pillara mill has a nominal capacity of 2.4 Mt per annum, which made the Lennard Shelf operations the sixth biggest zinc–lead mining complex in the world (Hamilton, 2000). The large number of Pb–Zn occurrences in the area suggests that there is considerable potential for further discoveries of economic MVT deposits. To date, the only successful exploration technique has been close-spaced grid drilling, because the ore bodies are small and poddy with rapid vertical and lateral facies changes.

Industrial mineral — high-grade limestone

Two samples of high-grade Pillara Limestone have come from Oscar Plateau East. Large areas of limestone of similar appearance suggest that there could be a large resource of high-grade limestone on the Lennard Shelf (Abeysinghe, 1998).

Stratabound sedimentary — clastic-hosted mineralization

Iron

The hematite ores of Yampi Sound are restricted to a particular stratigraphic horizon within the Yampi Formation that can be traced over a syncline and anticline on Koolan Island (Fig. 27b). This, together with ripple and current marks within the hematite quartzites, suggests that the ores are sedimentary in origin and were deposited along a shoreline (Canavan and Edwards, 1938). The palaeocurrent direction for the hematite quartzites on Koolan Island and Cockatoo Island is from the south, compared with a palaeocurrent direction from the north-northwest for the Kimberley Group on the mainland of Yampi Sound and most other places in the Kimberley Basin (Gellatly, 1972b). As discussed above, petrographic evidence indicates that hematite replaced magnetite (Canavan and Edwards, 1938). The ore still consists of hematite at depths greater than 500 m below sea level indicating that the alteration of magnetite to hematite is not a present-day weathering effect (Reid, 1965). Reid (1965) also suggested that the iron in the sedimentary rocks was derived from pre-existing iron formation, although no iron formation has yet been discovered in the area. Gellatly (1972b) suggested a two-stage process in which iron from jaspilite was first eroded and deposited in the Warton Sandstone. This was followed by erosion of the iron from the Warton Sandstone and concentration over a long period of time, when quartz and less dense heavy minerals, such as tourmaline, were progressively removed.

Portman (Portman Limited, 2002) is planning to mine below sea level on Cockatoo Island by constructing an offshore engineered embankment, and Aztec (Aztec Resources Limited, 2004) is investigating the feasibility of restarting mining on Koolan Island. There is a small amount of iron ore on Irvine Island and the Ballast Islands.

Energy — uranium

Afmeco Proprietary Limited (1983) concluded that the uranium mineralization at Oobagooma was controlled by a combination of sedimentological, structural, and redox factors. The Fairfield Group equivalent was deposited in a tectonically controlled embayment and the mineralized sandstones were deposited on a delta or tidal plain (Afmeco Proprietary Limited, 1983). The mineralization is associated with strongly reduced sandstones rich in organic matter with or without pyrite. Roll-front mineralization on a small scale is associated with recent oxidation processes (Afmeco Proprietary Limited, 1983).

Stratigraphic and redox controls are also important at Myroodah Uranium, where Bolton (1979) interpreted the thin, ferruginous sandstone hosting the uranium (at the contact between the Triassic Erskine Sandstone and Blina Shale) to represent the upper limb of a roll-front deposit. Bolton (1979) stated that more drilling is required to test the mineralization, as most of the early drillholes did not reach their target.

The Yampi Formation, Erskine Sandstone, and Blina Shale should also be considered prospective for uranium elsewhere, where favourable stratigraphic conditions are present. Anomalous levels of uranium have also been reported from the Triassic Millyit Sandstone, the Jurassic Wallal Sandstone, and the Late Devonian to Carboniferous Lillybooroora Conglomerate, suggesting that these units may also be prospective.

Base metal — copper, lead, zinc

Mineralization in the Hooper Complex

Carbonaceous slate and phyllite of the Marboo Formation host many base metal occurrences and are clearly prospective. In the Little Tarraji River area, there is a gradation from sediment-hosted stratabound mineralization, such as that at Mangrove, through phyllite partially replaced by quartz (as at Wilsons Find), to conformable quartz veins at Grants Find. It is thus difficult to establish whether the mineralization is syngenetic (i.e. of SEDEX type) or whether the mineralization has selectively replaced the carbonaceous horizon at a later stage. Given the presence of volcanogenic mineralization at Chianti, it is also possible that a distal volcanic centre was the source of the mineralizing solutions.

Mineralization in the Kimberley Basin

Low-grade copper mineralization within siltstone and banded ferruginous-chert of the Jap Bay Member of the Warton Sandstone in the McLarty Range area extends over a strike length of 36 km. The mineralization was interpreted by Gellatly (1972a) as essentially primary with some supergene redistribution. However, Gellatly, quoted in Marston (1979), later concluded that the mineralization was formed by replacement of pyrite in the siltstone by copper-bearing solutions derived from the Carson Volcanics, with the style of the mineralization being similar to that at White Point in Michigan, USA (Brown, 1971). Gellatly (1972a) considered that the Jap Bay Member in the McLarty Range area had good potential for a medium tonnage, low- to medium-grade copper deposit.

There is also potential for copper mineralization in the middle section of the Pentecost Sandstone and in the

Teronis Member of the Elgee Siltstone, as in the east Kimberley (Hassan, 2000) and north Kimberley (Ruddock, 2003), where stratabound copper occurrences have been recorded in these stratigraphic horizons.

Precious metal — gold

The Devonian Mount Behn Conglomerate may be prospective for conglomerate-hosted gold mineralization. However, Muggeridge (1992) suggested that the plant that treated the sample from Mount Behn 2 may have been contaminated. The presence of alluvial gold at Mount Behn 1 (Muggeridge, 1992) does suggest that at least there is some gold in the area.

The presence of anomalous gold in hematitic sandstone of the King Leopold Sandstone at Mount Bell (Hamdorf, 1989) is interesting in view of the recent discovery of epithermal gold mineralization associated with hematitic alteration in the north Kimberley by Striker Resources (Striker Resources NL, 2002a,b,c). Although Hamdorf (1989) found no evidence of fracturing in the core from the hole drilled, complex faulting has been mapped on LENNARD RIVER in that area.

Speciality metal — tin, rutile

Cassiterite has been reported from heavy mineral concentrations in the matrix of an indurated conglomerate of the O'Donnell Formation in the Richenda River area (Varkey et al., 1978), but no evidence of economic concentrations has been found.

Rutile-rich mica schist of the Pentecost Sandstone, such as that on Gibbings Island (Farrand, 1965), is a possible source of rutile.

Industrial mineral — corundum

The corundum at Richenda River Corundum, Mount Rose, and the Hawkstone deposit is close to the contact between phyllite and the Ruins Dolerite, suggesting that the dolerite has played a part in the genesis of the deposit (Gellatly, Sofoulis et al., 1974; Derrick and Morgan, 1966) though Gellatly, Sofoulis et al. (1974) did not consider the corundum to be the product of simple contact metamorphism. According to Simpson (1951) there are hundreds of tons of emery on the surface at Richenda River Corundum. There is potential for further occurrences of emery at the contact between the Ruins Dolerite and phyllites of the Marboo Formation.

Industrial mineral — kyanite

Derrick and Morgan (1966) suggested that the massive kyanite rock and kyanite–sericite schist at the Hawkstone kyanite deposit formed under greenschist-facies regional metamorphism. The veins of blue kyanite are interpreted by Derrick and Morgan (1966) as the product of metasomatism after deformation. The presence of dravite and dumortierite suggests that the kyanite may have crystallized from low-temperature hydrothermal fluids rich in boron (Derrick and Morgan, 1966). The deposit was not considered economic at the time of examination by Derrick and Morgan (1966).

Industrial mineral — glauconite

Glauconite has been reported from Mount Abbott (Hardman, 1894; Simpson, 1951) but there is no evidence of an economic occurrence.

Stratabound sedimentary mineralization — undivided

Iron

Oolitic iron formation is intercalated with calcareous, sandy sedimentary rocks of the Lightjack Formation in the Fitzroy Trough (Guppy et al., 1952; Edwards, 1953) but there is no evidence to date that economic thicknesses of iron formation are present.

Industrial mineral — phosphate

The phosphate occurrences in the Fitzroy Trough are stratigraphically controlled and formed during periods of slow clastic deposition (Yeates et al., 1984). Freas and Zimmerman (1965) concluded that most of the occurrences in the Canning Basin appear to have formed in restricted basins and that unlike most of the world's major phosphate deposits, they were not the product of ocean upwelling. They suggested that the phosphate and iron in the Jarlemai Siltstone may have been derived from the landmass and deposited in a restricted marine environment under reducing conditions. The deposits discovered to date are too thin to be of economic significance for the foreseeable future.

Sedimentary basin

Energy — coal

Galloway and Howell (1975) concluded that the coal seams in the Lightjack Member, Condren Sandstone, and Hardman Formation of the Permian Liveringa Group were generated by the Permian equivalent of present-day mangroves. All of these formations are prospective for coal. Other formations where coal has been found, and which may be prospective, include the Early Permian Poole Sandstone, the Carboniferous Anderson Formation, and the Late Jurassic to Early Cretaceous Jarlemai Siltstone. The coal resources found to date are of low grade. However, the Liveringa Ridge coal has a crucible swelling number approaching that of coking coal and it is possible that coking coal will be found where there has been a greater depth of burial (Gair, 1972). BHP Billiton has recently signed an agreement with Customers Limited to re-examine the Liveringa Ridge deposit and to explore for higher grade coal deposits. Customers Limited (2002) considered that the Fitzroy Sub-basin and other sub-basins of the Canning Basin had better potential than any other region for exportable coal deposits: with proximity to the southeast Asian and Indian markets, favourable geology, and the presence of known coal seams.

Sedimentary mineralization — undivided

Industrial mineral — salt

The salt diapir intersected in WAPET petroleum well Frome Rocks 1 may have been mobilized from evaporites of the Carribuddy Group (West Australian Petroleum Pty Limited, 1962; Brown et al., 1984). A very large resource has been inferred by Offshore Diamond Mines NL (1991), but it may be too deep to be economically mined. There is potential for other salt diapirs to be discovered within the Canning Basin, where the Carribuddy Group is present at depth.

Vein and hydrothermal mineralization

Precious metal — gold

The Kimberley Basin in the west Kimberley area has the potential to host epithermal gold mineralization similar to that reported by Striker Resources in the north Kimberley (Striker Resources NL, 2002a,b,c,d,e; Ruddock, 2003; Hassan, 2003a,b). Alluvial gold and anomalous gold in soils have been found in a 12 km-long, northwest-trending structural corridor parallel to the coast at Striker's Oombulgurri gold project (Striker Resources NL, 2002d,e; Garlick, 2003). The mineralization tends to be at the intersection of major north-trending, northwest-trending, and northeast-trending faults (Striker Resources NL, 2002d,e; Garlick, 2003). Argillic alteration (pyrophyllite, paragonite, and dickite) and hematitic alteration are associated with the mineralization, with significant centres of pyrophyllite alteration being proximal to the major gold anomalies (Garlick, 2003). The presence of quartz veins with epithermal textures (Striker Resources NL, 2002b), together with argillic and hematitic alteration, suggests that the mineralization is epithermal.

The age of the mineralization is uncertain. The major northwest-trending structures — such as the rift between the Browse and Bonaparte Basins known as NW1 (Fig. 6) — have been interpreted by O'Brien et al. (1999) as being initiated in the Palaeoproterozoic (c. 1800 Ma) but have been reactivated many times (Hassan, 2003b). The northeast-trending faults have been interpreted by Gunn and Meixner (1998) as extensional faults related to Devonian–Carboniferous rifting, but O'Brien et al. (1999) interpreted similar faults intersecting the Browse–Bonaparte rift zone as Mesozoic extensional faults.

As discussed above (see **Intrusions associated with late Phanerozoic or Mesozoic rifting**), there is a prominent magnetic high in the northeastern part of the Kimberley Basin that is on the same trend as a series of offshore magnetic anomalies along NW1 (Fig. 6). Napier Minerals' model for the epithermal mineralization in the Oombulgurri area is that the large magnetic anomaly represents a Phanerozoic granitoid that has focused gold-bearing fluids along near-vertical conduits where northerly, northwesterly, and possibly northeasterly, faults intersect (Garlick, 2003). However, as noted by Garlick (2003), and suggested by the modelling of Gunn and Meixner (1998), the anomaly could alternatively represent a magnetic granitoid in the Archaean basement beneath the Kimberley and Speewah Basins and be unrelated to mineralization.

Galena from epithermal fluorite and base metal veins from the Speewah Basin at Speewah in the east Kimberley has given model lead ages between 15 and 131 Ma, and direct Sm–Nd dating of the veins gave an age of 120 Ma (Alvin, 1993) indicating other occurrences of relatively recent epithermal mineralization in the Kimberley area. Rogers (1998) suggested that the carbonatite and associated igneous rocks at Speewah may have been the source of the fluids. A similar source is possible for the epithermal gold mineralization in the Kimberley Basin (Hassan, 2003a,b). Alternatively, the gold could be related to rifting associated with continental breakup (Hassan, 2003b).

The discovery of gold mineralization by Fitzgerald (1905, 1907) in the Carson Volcanics indicates that there is good potential for gold discoveries elsewhere in the Kimberley Basin, but it is not known whether the quartz reefs discovered by Fitzgerald are epithermal or mesothermal. The abundance of hematite at Mount Brennan and the association of auriferous quartz with a major northerly trending fault at Mount Synnot suggests that the mineralization described by Fitzgerald (1905,1907) has some similarities with the mineralization at Oombulgurri.

The ferruginous quartz veins reported from north of Mount Heytesbury (*Sunday Times*, 1909a,b,c) could lie on a northerly trending fault cutting rocks of the Kimberley Group, indicating another area worthy of follow-up exploration.

The gold in the Whitewater Volcanics in the Mount Broome area may be remobilized volcanogenic gold but could also be from an external source, introduced along fault zones. This area has been relatively well explored without success.

Base metal — copper, lead, zinc

As already discussed (see **Stratabound sedimentary — clastic-hosted mineralization**), the Marboo Formation is clearly prospective for copper mineralization. Most of the copper prospects and workings in the Marboo Formation were probably derived by mobilization of syngenetic copper, as there are known stratabound deposits and volcanogenic occurrences in this formation. Structural controls may also have been important as indicated by the Mondooma prospect, which lies on a major northwest-trending fault zone separating Marboo Formation from granite (Barnes, 1990).

Too little is known about the base metal occurrences in the Kimberley Basin to establish their mineralogical controls. The presence of vein occurrences in the Hart Dolerite, Carson Volcanics, Wotjulum Porphyry, Warton Sandstone, and Yampi Formation suggests that these units are prospective for base metals.

Minor base metal vein occurrences hosted by predominantly clastic sedimentary rocks of the Lennard Shelf (Napier Formation, Piker Hills Formation, Windjana Limestone, and Virgin Hills Formation) may be related to MVT mineralization.

Steel industry metal — tungsten (tin)

The King Sound tungsten and tin mineralization is within quartz veins that parallel the host metasedimentary rocks of the Marboo Formation. The Lennard Granite and Mondooma Granite outcrop about 3 km from this mineralization, but there is no evidence that these granites played any role in the mineralization. The area has been poorly explored and there may be potential for the discovery of further deposits of cassiterite, wolframite, and scheelite in the Marboo Formation.

Speciality metal — tin

See King Sound in the section above.

Precious mineral — quartz crystal

Specimen quartz has been recorded from Mondooma (Pickands Mather and Company International, 1967a), and there is potential for other occurrences in veins in the Marboo Formation and elsewhere.

Regolith — residual and supergene mineralization

Aluminium — bauxite

Joklik et al. (1975) considered that the bauxite on the Mitchell Plateau and at Cape Bougainville was formed by in situ bauxitization of the Carson Volcanics, citing evidence of preserved textures such as pillow lavas and pyroclastic breccias, and the preservation of heavy minerals typical of the Carson Volcanics within the bauxite. According to Joklik et al. (1975), the factors that influenced the formation of the bauxite included physiography, climate, and surface vegetation combined with groundwater interaction with the Carson Volcanics. Bauxite formation was preceded by the weathering of basalt and leaching of alkalis, resulting in the formation of surficial clay. Iron moved upward from the basalt by capillary action to form a ferruginous crust. In the Cape Bougainville area, the flow of groundwater was interpreted by Joklik et al. (1975) to have been relatively rapid, causing watertable fluctuations resulting in thick, ferruginous, and tubular bauxite. In the Mitchell Plateau area, they interpreted the movement of groundwater to have been slow, with humic acid from dense vegetation causing a decrease in pH of the groundwater resulting in dissolution of the iron and aluminium in the tubular bauxite. The iron was re-precipitated at the surface as ironstone and the aluminium precipitated as gibbsite in the bauxite zone (Joklik et al., 1975). These authors relate the thickness and grade of the bauxite to the intensity of jointing. All areas mapped as laterite (duricrust) should be considered as having potential for bauxite, especially where there is evidence of strong jointing.

Regolith — alluvial to beach placer mineralization

Precious mineral — diamond

Alluvial diamond occurrences are important pathfinders to primary diamond occurrences. However, the Terrace 5 palaeochannel (Fig. 35) contains significant concentrations of gem-quality diamonds (Kimberley Diamond Company NL, 2000) and may be economic to mine as an alluvial deposit. The Terrace 5 palaeochannel has been traced over a distance of 27 km (Kimberley Diamond Company NL, 2002f). The source of the diamonds in the Terrace 5 palaeochannel has not yet been established but four dyke-like lamproite intrusions have been found in the catchment of the palaeochannel and one of these, Kimberley 23, has significant diamond grades of 1 ct/100 t (Kimberley Diamond Company NL, 2002g). J-channel is another diamond-bearing palaeochannel; the diamonds have possibly been derived from the Ellendale 4 pipe, which is nearby. There is potential for the discovery of other diamond-bearing palaeochannels.

Speciality metal — heavy minerals

Although the work of Geodrillers Proprietary Limited for Metals Investments Proprietary Limited suggested that King Sound had high potential for heavy minerals (Brown, 1971), later work by BHP downgraded this potential (Moore, 1987).

Undivided mineralization

Construction materials — dimension stone

Potential for granite and 'black granite' (dolerite) suitable for use as dimension stone from within the Hooper Complex and for limestone and coloured sandstone from within the Canning Basin has been demonstrated, but, as with all construction materials, the distance from ports and lack of infrastructure will reduce the economic viability of such deposits.

Construction materials — road metal, aggregate, gravel, sand

There is an adequate supply of hard rock suitable for road-making material along most of the roads in the west Kimberley. The large rivers have a plentiful supply of sand and gravel.

Conclusions

The west Kimberley region hosts a wide range of mineral commodities in a variety of mineralization styles. The MVT Lennard Shelf project was Western Australia's largest producer of zinc and lead. Mining of diamonds from lamproites at Ellendale commenced in 2002 — Australia's second diamond mine. High-grade iron ore has been mined from Cockatoo and Koolan Island in Yampi Sound since 1951. Small quantities of copper, tungsten, tin, and gold have also been produced. High-grade bauxite is present on the Mitchell Plateau and there is a significant uranium resource at Oobagooma. There are extensive deposits of coal in the Canning Basin that are currently being reviewed. Occurrences of nickel, fluorite, barite, beryl, mica, corundum, kyanite, rutile, garnet, glauconite, phosphate, bentonite, ochre, salt, limestone, and dimension stone have also been reported.

The west Kimberley has potential for further discoveries of all of the above commodities. In particular, there is high potential for further discoveries of MVT deposits as these small, poddy deposits commonly cluster within a district. Many lamproites have been discovered over the last few years and it is likely that continued exploration will result in the discovery of many more, some of which may be diamond bearing. The recent discovery of an epithermal gold province in the north Kimberley by Striker Resources and De Beers, together with the reported occurrence of gold in the Carson Volcanics (Fitzgerald, 1907), suggests that the Kimberley Basin in the west Kimberley also has potential for gold mineralization.

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Appendix 1

List of mineral occurrences in the west Kimberley

* KEY TO OPERATING STATUS

Bold numbers	Operating mine
Bold and italic numbers	Abandoned mine
Plain numbers	Mineral deposit
Italic numbers	Mineral occurrence or prospect

KEY TO COMMODITY CODES

(Minor commodities shown in brackets)

Ag	Silver	Fl	Fluorite	Phos	Phosphate
As	Arsenic	Grt	Garnet	Qtz	Quartz (crystal)
Au	Gold	Glt	Glauconite	Rt	Rutile
Bent	Bentonite	Gran	Granite	Salt	Salt
Bi	Bismuth	Gvl	Gravel	Sapp	Sapphire
Brl	Beryl	HM	Heavy mineral sands	Sb	Antimony
Brt	Barite	Ilm	Ilmenite	Sd	Sand
Bx	Bauxite	Ky	Kyanite	Sdst	Sandstone
Coal	Coal	Lst	Limestone	Sn	Tin
Cor	Corundum	Mag	Magnetite	Ta	Tantalum
Cu	Copper	Mica	Mica	Ti	Titanium
Dlt	Dolerite	Ni	Nickel	U	Uranium
Dmd	Diamond	Och	Ochre	W	Tungsten
Emer	Emerald	Pb	Lead	Zn	Zinc
Fe	Iron	PGE	Platinum Group Elements	Zrn	Zircon
Fel	Feldspar				

KEY TO LOCATIONS

EAST	MGA Easting
NORTH	MGA Northing
Z	Zone

PRECIOUS MINERAL

☆ Kimberlite and lamproite

No*	COMMODITY	EAST	NORTH	Z	NAME
8391	Dmd	754354	8035707	51	Big Spring 1
8393	Dmd	754845	8035665	51	Big Spring 3
8394	Dmd	754928	8035461	51	Big Spring 4
8395	Dmd	754817	8035137	51	Big Spring 5
8410	Dmd	704180	8045700	51	Ellendale 4
8411	Dmd	696880	8057450	51	Ellendale 9
8417	Dmd	697300	8053740	51	Ellendale 7
8418	Dmd	695177	8057979	51	Ellendale 11
8419	Dmd	698709	8048168	51	Ellendale 6
8420	Dmd	698480	8059654	51	Ellendale 8
8422	Dmd	695166	8056309	51	Ellendale 10
8426	Dmd	692851	8057733	51	Ellendale 12
8427	Dmd	692600	8058700	51	Ellendale 13
8428	Dmd	689989	8055826	51	Ellendale 14
8429	Dmd	689640	8059860	51	Ellendale 15
8430	Dmd	709468	8070256	51	Ellendale 17
8431	Dmd	687180	8064600	51	Ellendale 18
8432	Dmd	690880	8066180	51	Ellendale 19
8433	Dmd	686140	8061500	51	Ellendale 22
8434	Dmd	684740	8059600	51	Ellendale 23
8435	Dmd	683240	8062560	51	Ellendale 24
8436	Dmd	683380	8067660	51	Ellendale 25
8437	Dmd	692503	8063433	51	Ellendale 27
8438	Dmd	698910	8053346	51	Ellendale 33
8439	Dmd	698244	8057831	51	Ellendale 34
8440	Dmd	680880	8062900	51	Ellendale 37
8442	Dmd	721193	8058624	51	Ellendale 39
8470	Dmd	695272	8063361	51	Ellendale 40
8472	Dmd	679080	8067460	51	Ellendale 41
8476	Dmd	680080	8067460	51	Ellendale 42
8477	Dmd	680680	8067360	51	Ellendale 43
8634	Dmd	675735	7968857	51	Mount Noreen

PRECIOUS MINERAL

Kimberlite and lamproite

No*	COMMODITY	EAST	NORTH	Z	NAME
8637	Dmd	669735	7967657	51	Mount Abbott 1
8640	Dmd	669935	7968357	51	Mount Abbott 2
8646	Dmd	705285	7985107	51	No. 33 Bore 1
8647	Dmd	704335	7985157	51	No. 33 Bore 2
8648	Dmd	704385	7984857	51	No. 33 Bore 3
8650	Dmd	686435	8006457	51	Metters Bore no. 1
8651	Dmd	684035	8006057	51	Metters Bore no. 3
8652	Dmd	687335	8006357	51	Metters Bore no. 6
8658	Dmd	694535	8009257	51	Laymans Bore East 1
8659	Dmd	694635	8009357	51	Laymans Bore East 2
8660	Dmd	694935	8009457	51	Laymans Bore East 3
8661	Dmd	694535	8010107	51	Laymans Bore East 4
8662	Dmd	693935	8009507	51	Laymans Bore East 5
8663	Dmd	694235	8009507	51	Laymans Bore East 6
8667	Dmd	692235	8009557	51	Laymans Bore West A1
8668	Dmd	692535	8009457	51	Laymans Bore West A2
8669	Dmd	691735	8009457	51	Laymans Bore West B1
8670	Dmd	691635	8009157	51	Laymans Bore West B2
8678	Dmd	687005	8008997	51	Calwynyardah 1
8689	Dmd	687305	8008797	51	Calwynyardah 2
8690	Dmd	686705	8008497	51	Calwynyardah 3
8692	Dmd	686505	8008797	51	Calwynyardah 4
8693	Dmd	686705	8009097	51	Calwynyardah 5
8694	Dmd	696675	7988427	51	20 Bore no. 2
8695	Dmd	692035	8023457	51	Billys Bore West
8696	Dmd	677135	8014507	51	Merrilees Bore
8705	Dmd	678074	7959077	51	Mount Ibis
8792	Dmd	705563	8052179	51	Mount Percy Airstrip
8795	Dmd	709167	8070201	51	Western Pipe A
8796	Dmd	709340	8070210	51	Western Pipe B
8797	Dmd	709786	8070410	51	Northern Pipe 2
8798	Dmd	709841	8069919	51	Ellendale 17B
8799	Dmd	697935	8037517	51	India Bore 1
8854	Dmd	697731	7975775	51	Walgidee Hills 1
8855	Dmd	697685	7975683	51	Walgidee Hills 2
8856	Dmd	698445	7975172	51	Walgidee Hills 3
8857	Dmd	698586	7974736	51	Walgidee Hills 4
8858	Dmd	698409	7974429	51	Walgidee Hills 5
8862	Dmd	698094	7973584	51	Walgidee Hills 6
8863	Dmd	697713	7973537	51	Walgidee Hills 7
9125	Dmd	593235	8020807	51	Liveringa Diamond
9126	Dmd	720435	8025557	51	Camarotoechia Creek
10182	Dmd	687480	8064660	51	Kimberley 18
10183	Dmd	686440	8064600	51	Kimberley 13
10459	Dmd	694220	8058300	51	Kimberley 21
10468	Dmd	694440	8058540	51	Kimberley 23
10482	Dmd	691720	8058940	51	Kimberley 24
11385	Dmd	698140	8057160	51	Kimberley 19
11386	Dmd	695700	8055720	51	Kimberley 26
15606	Dmd	705040	8045430	51	Ellendale 4 satellite pipe

Regolith — alluvial to beach placers

No*	COMMODITY	EAST	NORTH	Z	NAME
4220	Dmd	812138	8152564	51	Manning Creek Diamond
7884	Dmd	686175	8076467	51	Lennard River 1
7886	Dmd	686991	8076016	51	Lennard River 2
7891	Dmd	688174	8075144	51	Lennard River 3
7925	Dmd	683191	8077105	51	Lennard River 4
7926	Dmd	682130	8078898	51	Lennard River 5
8409	Dmd	686200	8052500	51	Ellendale (alluvial)
8643	Dmd	669335	7968257	51	Mount Abbott 3
8701	Dmd	679340	8066100	51	Pit 31
8702	Dmd	681140	8064860	51	Pit 57
8703	Dmd	685635	8063857	51	Pit 55
8704	Dmd	689640	8057960	51	Pit 61
8761	Dmd	819546	8268513	51	Mount Bomford
8763	Dmd	808891	8243569	51	Mount Hann 1
8764	Dmd	800593	8247927	51	Mount Hann 2
8765	Dmd	814238	8248621	51	Mount Fyfe 1
8766	Dmd	811067	8249900	51	Mount Fyfe 2
8768	Dmd	818885	8248679	51	Mount Fyfe 4
8769	Dmd	811268	8243768	51	Mount Fyfe 5
8774	Dmd	816281	8249781	51	Mount Fyfe 7
8777	Dmd	795296	8256447	51	Moran River
8779	Dmd	704569	8051871	51	Mount Percy 1
8780	Dmd	704367	8050196	51	Mount Percy 2
8782	Dmd	703871	8048876	51	Mount Percy 3
8783	Dmd	706366	8050604	51	Mount Percy 4
8784	Dmd	704240	8050109	51	Mount Percy 5
8785	Dmd	704040	8049996	51	Mount Percy 6

PRECIOUS MINERAL

Regolith — alluvial to beach placers

No*	COMMODITY	EAST	NORTH	Z	NAME
8786	Dmd	705104	8050380	51	Mount Percy 7
8787	Dmd	708327	8052196	51	Mount Percy 8
8788	Dmd	710133	8055567	51	Mount Percy 9
8789	Dmd	703996	8055567	51	Mount Percy 10
8790	Dmd	704108	8049736	51	Mount Percy 11
8791	Dmd	704084	8049521	51	Mount Percy 12
8793	Dmd	692992	8069355	51	Munjaweela
8794	Dmd	697394	8061708	51	Ellendale 9 drainage
8805	Dmd	699980	8040040	51	J-Channel 1
8806	Dmd	701695	8041640	51	Mount Wynne Creek 3
8807	Dmd	698025	8034720	51	Mount Wynne Creek 4
8808	Dmd	698182	8034562	51	Mount Wynne Creek 5
8812	Dmd	691374	8071805	51	Munjaweela 2
8826	Dmd;Sapp	741685	8031557	51	Camerons Bore 1
8827	Dmd	743085	8030207	51	Camerons Bore 2
8828	Dmd	745435	8029057	51	Camerons Bore 3
8829	Dmd	749635	8028257	51	Camerons Bore 4
8830	Dmd	753685	8024407	51	Camerons Bore 5
8831	Dmd	754685	8030157	51	Camerons Bore 6
8832	Dmd	750647	8034607	51	Camerons Bore 7
8833	Dmd	746935	8032807	51	Camerons Bore 8
8834	Dmd	746585	8032607	51	Camerons Bore 9
8835	Dmd	747135	8032257	51	Camerons Bore 10
8836	Dmd	746985	8030707	51	Camerons Bore 11
8837	Dmd	746835	8023957	51	Camerons Bore 12
8838	Dmd	756735	8028157	51	Camerons Bore 13
8839	Dmd;Au	749575	8027969	51	Camerons Bore 14
8840	Dmd	750542	8034500	51	Camerons Bore 15
8841	Dmd	752714	8034539	51	Camerons Bore 16
8843	Dmd	750285	8034457	51	Camerons Bore 17
8844	Dmd	750135	8034257	51	Camerons Bore 18
8845	Dmd	749942	8034165	51	Camerons Bore 19
8846	Dmd	749887	8034040	51	Camerons Bore 20
8847	Dmd	749768	8033841	51	Camerons Bore 21
8848	Dmd	749744	8033809	51	Camerons Bore 22
8849	Dmd	749585	8033603	51	Camerons Bore 23
8850	Dmd	749521	8033497	51	Camerons Bore 24
8851	Dmd	749625	8033405	51	Camerons Bore 25
8852	Dmd	749585	8034127	51	Camerons Bore 26
8853	Dmd	746905	8032638	51	Camerons Bore 27
9111	Dmd	666710	8066578	51	Century 1
9112	Dmd	673541	8067484	51	Century 2
9114	Dmd	671332	8068273	51	Century 3
9205	Dmd	788727	8111654	51	Mount House
9206	Dmd	708889	8069714	51	Napier (alluvials)
9675	Dmd	793585	8146457	51	Mesmate Creek
10177	Dmd	684640	8061260	51	Pit 63
10178	Dmd	686640	8059160	51	Pit 66
10179	Dmd	679640	8065160	51	Pit 52
10180	Dmd	681880	8065160	51	Pit 53
10181	Dmd	683640	8064160	51	Pit 54
10184	Dmd	671040	8068760	51	Pit 5
10185	Dmd	663040	8069460	51	Pit 2
10186	Dmd	661040	8070160	51	Pit 1
10187	Dmd	666140	8068860	51	Pit 3
10188	Dmd	666140	8065260	51	Pit 4
10189	Dmd	665140	8066560	51	Pit 6
10190	Dmd	662980	8064400	51	Pit 7
10191	Dmd	662140	8067260	51	Pit 9
10192	Dmd	671840	8068360	51	Pit 20
10193	Dmd	669940	8068860	51	Pit 21
10195	Dmd	665640	8067860	51	Pit 22
10196	Dmd	665940	8067160	51	Pit 23
10197	Dmd	672340	8068600	51	Pit 24
10198	Dmd	672340	8067860	51	Pit 25
10199	Dmd	673540	8068360	51	Pit 27
10200	Dmd	673940	8065360	51	Pit 28
10201	Dmd	678080	8065860	51	Pit 29
10202	Dmd	671680	8068660	51	Pit 30
10203	Dmd	672140	8068660	51	Pit 32
10204	Dmd	677140	8065160	51	Pit 33
10205	Dmd	677140	8065760	51	Pit 34
10207	Dmd	668140	8068860	51	Pit 35
10208	Dmd	679640	8066560	51	Pit 50
10209	Dmd	679380	8065560	51	Pit 51
10210	Dmd	680140	8064960	51	Pit 60
10211	Dmd	687640	8058860	51	Pit 64
10212	Dmd	688640	8058600	51	Pit 65
10213	Dmd	685640	8060160	51	Pit 67

PRECIOUS MINERAL

Regolith — alluvial to beach placers

No*	COMMODITY	EAST	NORTH	Z	NAME
10214	Dmd	684640	8062260	51	Pit 68
10215	Dmd	683640	8062160	51	Pit 69
10216	Dmd	682380	8064660	51	Pit 70
10217	Dmd	691040	8057860	51	Pit 71
10218	Dmd	690640	8057360	51	Pit 72
10219	Dmd	690140	8057700	51	Pit 73
10220	Dmd	689140	8058400	51	Pit 74
10221	Dmd	688140	8058960	51	Pit 75
10222	Dmd	690440	8058860	51	Pit 76
10223	Dmd	690640	8058760	51	Pit 77
10227	Dmd	704340	8042360	51	J-Channel 2
10228	Dmd	702580	8042400	51	J-Channel 3
10229	Dmd	702080	8041400	51	J-Channel 4

Regolith – residual to eluvial placers

No*	COMMODITY	EAST	NORTH	Z	NAME
8392	Dmd	754539	8035702	51	Big Spring 2
8396	Dmd	754641	8035591	51	Big Spring 6
8397	Dmd	754446	8035350	51	Big Spring 7
8408	Dmd	704635	8044857	51	Ellendale (eluvial 1)
8767	Dmd	815565	8248789	51	Mount Fyfe 3
8770	Dmd	819857	8240089	51	Mount Fyfe 6
8775	Dmd	821234	8246165	51	Mount Fyfe 8
8776	Dmd	820642	8246165	51	Mount Fyfe 9
8803	Dmd	688835	8053257	51	Ellendale (eluvial 2)
8804	Dmd	689246	8032208	51	Ellendale (eluvial 3)
9690	Dmd	701160	8039032	51	India Bore 2
9691	Dmd	700225	8037457	51	India Bore 3
9741	Dmd	700845	8037107	51	India Bore 4
9743	Dmd	699645	8034957	51	India Bore 5
9745	Dmd	699325	8035307	51	India Bore 6
9746	Dmd	698885	8035957	51	India Bore 7
9747	Dmd	699040	8036097	51	India Bore 8
9748	Dmd	698935	8036557	51	India Bore 9
9751	Dmd	699685	8037137	51	India Bore 10
9752	Dmd	698675	8037142	51	India Bore 11
9753	Dmd	698550	8038187	51	India Bore 12
9754	Dmd	698640	8039197	51	India Bore 13
9755	Dmd	697675	8040607	51	India Bore 14
9756	Dmd	697630	8039672	51	India Bore 15
9759	Dmd	697115	8038367	51	India Bore 16
9760	Dmd	696105	8038282	51	India Bore 17
9761	Dmd	695675	8040092	51	India Bore 18
9764	Dmd	699680	8041032	51	India Bore 19
9765	Dmd	700655	8040472	51	India Bore 20
9766	Dmd	700655	8040657	51	India Bore 21

PRECIOUS METAL

Vein and hydrothermal — undivided

No*	COMMODITY	EAST	NORTH	Z	NAME
7699	Au	751010	8060850	51	Richenda River 1
7700	Au	751530	8060870	51	Richenda River 1A
7701	Au	752440	8059730	51	Richenda River 2
7702	Au	752120	8060360	51	Richenda River 3
7704	Au	752860	8060350	51	Richenda River 4
7705	Au	751280	8061840	51	Richenda River 5
7706	Au	751070	8061330	51	Richenda River 6
7713	Au;As	747250	8079700	51	Turners
7714	Au	747180	8079780	51	Turners North
7715	Au	744010	8082320	51	Pattersons
7781	Au	750690	8077250	51	Mount Broome 2
8800	Au	742333	8076509	51	Lead Prospect North
9529	Au	747218	8080939	51	Mount Broome 3
9531	Au;Cu;Pb	747083	8080692	51	Mount Broome 4
10273	Au	778880	8137160	51	Plover Hill
10275	Au	812842	8155780	51	Manning Creek Gold
10298	Au	738305	8155079	51	Mount Synnot
11364	Au	587600	8167200	51	Mount Heytesbury

Stratabound volcanic and sedimentary — volcanic-hosted sulfide

No*	COMMODITY	EAST	NORTH	Z	NAME
7707	Au	753110	8070017	51	Richenda River 7

Stratabound volcanic and sedimentary — sedimentary-hosted sulfide

No*	COMMODITY	EAST	NORTH	Z	NAME
8322	Au;Pb;As;Ag;Cu	746266	8073004	51	Turtle Creek 2

Stratabound sedimentary — clastic-hosted

No*	COMMODITY	EAST	NORTH	Z	NAME
8816	Au	747585	8098757	51	Mount Bell
9199	Au	718335	8063407	51	Mount Behn 2

PRECIOUS METAL

Regolith — alluvial to beach placers

No*	COMMODITY	EAST	NORTH	Z	NAME
7780	Au	744770	8081970	51	Mount Broome 1
7782	Au	752190	8063210	51	Colemans Find
8823	Au	731450	8066275	51	Fairfield (Au1)
8824	Au	735438	8064133	51	Fairfield (Au2)
9198	Au	721885	8065407	51	Mount Behn 1
10170	Au	613300	8151100	51	Oobagooma Gold

Regolith — residual and supergene

No*	COMMODITY	EAST	NORTH	Z	NAME
9505	Au	745400	8077700	51	Richenda

Regolith — residual to eluvial placers

No*	COMMODITY	EAST	NORTH	Z	NAME
8810	Au	652033	8131847	51	Central Robinson River
10725	Au	672400	8284400	51	Camden Harbour Gold

Undivided

No*	COMMODITY	EAST	NORTH	Z	NAME
9767	Au;W	775109	8128238	51	Isdell River

STEEL INDUSTRY METAL

Vein and hydrothermal — undivided

No*	COMMODITY	EAST	NORTH	Z	NAME
337	W;Sn	678400	8122500	51	King Sound 1
7646	W;Sn	678400	8122450	51	King Sound 2
7647	W;As	678570	8122410	51	King Sound 3
7648	W;As	678690	8122330	51	King Sound 4
7649	W	678530	8122410	51	King Sound 5
7650	W;As	678900	8122300	51	King Sound 6

SPECIALITY METAL

Greisen

No*	COMMODITY	EAST	NORTH	Z	NAME
10076	Sn	683480	8128280	51	Silent Valley 1

Pegmatitic

No*	COMMODITY	EAST	NORTH	Z	NAME
7711	Sn	740710	8056660	51	Dyasons Creek Pegmatite
10101	Sn	517460	8186960	51	Kalganu Island

Stratabound sedimentary — clastic-hosted

No*	COMMODITY	EAST	NORTH	Z	NAME
8390	Sn	760135	8073357	51	Richenda River Tin 1
10100	Rt	554560	8213460	51	Gibbings Island 2

Regolith — alluvial to beach placers

No*	COMMODITY	EAST	NORTH	Z	NAME
4334	Ilm;Mag;Rt	595007	8133354	51	Robinson Delta
4894	HM;Ilm;Zrn	650137	8177854	51	Secure Bay (HM1)
4896	HM;Ilm;Zrn	656837	8174654	51	Secure Bay (HM2)
4898	HM;Ti	590886	8102554	51	May River Mouth
4901	HM;Ti	589437	8126254	51	Robinson River Mouth 1
4903	HM;Ti	613637	8153854	51	Oobagooma Creek
4904	HM;Ti	592136	8128404	51	Robinson River Mouth 2
4906	HM;Ti	587937	8105804	51	Stokes Bay – May River Mouth
4907	HM;Ti	594586	8133954	51	Stokes Bay – Robinson River Mouth
7642	HM	593820	8106370	51	Meda River
7712	Sn	737890	8057440	51	Dyasons Creek Alluvial
7944	HM;Ilm;Zrn	562480	8059010	51	Fitzroy River Mouth
7945	HM;Ilm;Zrn;Rt	593360	8133020	51	Robinson River Mouth 3
8326	HM	554135	8088157	51	King Sound HM 1
8327	HM	554135	8086157	51	King Sound HM 2
8328	HM	551935	8086157	51	King Sound HM 3
8329	HM	549135	8086157	51	King Sound HM 4
8330	HM	547135	8086157	51	King Sound HM 5
8331	HM	550935	8082157	51	King Sound HM 6
8332	HM	549635	8082157	51	King Sound HM 7
8333	HM	561135	8082157	51	King Sound HM 8
8334	HM	552135	8078157	51	King Sound HM 9
8335	HM	553385	8078157	51	King Sound HM 10
8336	HM	557635	8074157	51	King Sound HM 11
8802	Sn;Ta	752747	8071690	51	Richenda River Tin 2
10077	Sn	683700	8128860	51	Silent Valley 2
10099	HM;Ilm;Rt	554400	8213540	51	Gibbings Island 1

BASE METAL

Orthomagmatic mafic and ultramafic — undivided

No*	COMMODITY	EAST	NORTH	Z	NAME
340	Ni;Cu;Au	655500	8126400	51	Limestone Spring
10069	Cu;Ag	654340	8280560	51	Camden Sound

BASE METAL

Vein and hydrothermal — undivided

No*	COMMODITY	EAST	NORTH	Z	NAME
339	Cu;Au;Ag;Ag	565737	8205957	51	Yampi Sound copper mine
351	Cu;Pb;Ag;Au	628950	8168210	51	Grants Find
2929	Cu	625896	8167554	51	Rough Triangle South
2945	Cu	639940	8171430	51	Secure Bay (Cu)
7658	Cu	628790	8168070	51	Grants Find 2
7659	Cu	629170	8168370	51	Grants Find 3
7660	Cu	628660	8167054	51	Grants no. 2 South 1
7661	Cu	628636	8166970	51	Grants no. 2 South 2
7662	Cu	628560	8166820	51	Grants no. 2 South 3
7663	Cu	626290	8170730	51	Amphibolite 1
7664	Cu	626250	8170791	51	Amphibolite 2
7665	Cu	626210	8170840	51	Amphibolite 3
7666	Cu	626160	8170910	51	Amphibolite 4
7669	Cu	625680	8169130	51	Rough Triangle 3
7672	Cu;Qtz;Au	645380	8139980	51	Mondooma 1
7673	Cu	645760	8139550	51	Mondooma 2
7674	Cu	645150	8140150	51	Mondooma 3
7675	Cu	627280	8159740	51	Tarragee
7676	Cu	628020	8166620	51	Mount Nellie
7677	Cu	629640	8164510	51	Little Tarraji 1
7680	Cu	629510	8163700	51	Little Tarraji 2
7681	Cu	629820	8162715	51	Little Tarraji 3
7682	Cu	629080	8161960	51	Copper King Extended
7683	Cu	629176	8162390	51	Little Tarraji 5
7684	Cu	629320	8163280	51	Little Tarraji 6
7685	Cu	629090	8164630	51	Little Tarraji 7
7686	Cu	628780	8165100	51	Little Tarraji 8
7687	Cu	628820	8167280	51	Tarrigee North
7691	Cu	629760	8158340	51	Monarch Extended
7692	Cu	629620	8158020	51	Monarch South
7716	Pb;Ag	806813	8047813	51	Pandanus Creek
7717	Pb	810160	8026060	51	Old Leopold Downs
7934	Cu;Pb	764230	8090970	51	Precipice Range 1
7941	Cu	750350	8087100	51	Precipice Range 8
7942	Cu;Bi;Pb	629540	8158800	51	Monarch 2
7943	Cu	629780	8157640	51	Monarch 3
7950	Cu	684164	8091454	51	Barker Gorge 5
7952	Cu	683608	8090954	51	Barker Gorge 7
8323	Cu;Pb;Ag;As;Au	743707	8075267	51	Top Springs
8324	Pb;Ag;Sb	742738	8076205	51	Lead Prospect
8325	Cu;Ag;Au;Zn;Pb	751067	8065094	51	Colemans Creek
8376	Cu	792835	7976057	51	Pinbilly
8385	Cu	663348	8118050	51	Limestone Spring 2
8386	Cu;Pb;Ag	709939	8072942	51	Windjana Gorge 1
8387	Cu	709986	8072783	51	Windjana Gorge 2
8388	Cu	710343	8072410	51	Windjana Gorge 3
8389	Cu	710431	8073100	51	Windjana Gorge 4
8813	Pb;Cu;Ag	808845	8045665	51	King Leopold 1
8814	Cu	798374	8049794	51	King Leopold 2
10062	Cu	718400	8129000	51	Mount Hart (Cu)
10064	Cu;Ag;Au	658100	8220900	51	Doubtful Bay (Cu)
10067	Cu;Ag	669100	8311400	51	Augustus Island
10072	Cu	639100	8184700	51	Collier Bay
10075	Cu	577000	8214700	51	Nares Point
10081	Pb;Brt;Fl	712180	8103220	51	Macs Jumpup
10083	Pb	806960	8046540	51	Bigelleas Yard
10084	Cu	806780	8048880	51	Ord Gap
10087	Pb	815900	8026000	51	Old Leopold Downs 2
10106	Cu	639420	8300780	51	Bonaparte Archipelago
10143	Cu;Ag;Cu	563920	8205300	51	Norah
10155	Cu	563905	8201671	51	Nellie
10156	Pb;Ag;Cu	698900	8118600	51	Barker River
10286	Cu;Au	730861	8097502	51	Mount Herbert
10525	Cu	628520	8169780	51	Kate
10526	Cu	631480	8170380	51	Manfredin
10527	Cu	629460	8168600	51	Grants no. 1 North
10528	Cu	629940	8169100	51	No. 1 North Berylton
10529	Cu	628720	8167780	51	Grants no. 1 South 1
10530	Cu	628460	8167920	51	Grants no. 1 South 2; Dingo
10531	Cu	628200	8167100	51	Elsie
10532	Cu	627380	8167000	51	Mumberdin
10533	Cu	626900	8167860	51	Ironclad
10534	Cu	626820	8167500	51	Ironclad extended
10535	Cu	628400	8166240	51	Tarigee East
10536	Cu	628720	8164620	51	King Solomon
10537	Cu	627600	8162520	51	Junee Reward
10540	Cu	629580	8158440	51	Monarch
11812	Pb	775131	8125111	51	Plover Hill South

BASE METAL

Stratabound volcanic and sedimentary — volcanic-hosted sulfide

No*	COMMODITY	EAST	NORTH	Z	NAME
8380	Zn;Cu;Pb;Ag	611935	8167157	51	Chianti 1

Stratabound volcanic and sedimentary — sedimentary-hosted sulfide

No*	COMMODITY	EAST	NORTH	Z	NAME
8321	Zn;Pb;Cu;Ag;Au	745663	8072893	51	Turtle Creek 1
8381	Cu;Pb	611735	8166557	51	Chianti 2
9197	Pb;Zn	746133	8073255	51	Turtle Creek North

Stratabound volcanic and sedimentary — undivided

No*	COMMODITY	EAST	NORTH	Z	NAME
7935	Cu	763420	8090410	51	Precipice Range 2
7936	Cu;Pb	759600	8094800	51	Precipice Range 3
7937	Cu	758020	8093620	51	Precipice Range 4
7938	Cu	753800	8099200	51	Precipice Range 5
7939	Cu	766880	8103940	51	Precipice Range 6
7940	Cu	771470	8104320	51	Precipice Range 7
10065	Cu;Ag	673300	8293700	51	Brecknock Harbour
10089	Cu	731000	8307500	51	Saint George Basin
10090	Cu	620668	8176641	51	High Range West
10092	Cu	692520	8266360	51	Glenelg River
10502	Cu	671750	8284900	51	Camden Harbour Copper
10520	Cu	711450	8274650	51	Mount Lyell
10521	Cu	668900	8277400	51	Brecknock Harbour South

Stratabound sedimentary — carbonate-hosted

No*	COMMODITY	EAST	NORTH	Z	NAME
343	Pb;Zn;Ag;Cu	683660	8090760	51	Narlarla no. 2
2915	Cu;Pb;Zn;Ag	684000	8091100	51	Narlarla no. 1
5441	Zn;Pb	817055	7987853	51	Findlay Hill 1
5445	Zn;Pb	815635	7940237	51	Emanuel Range 1
5448	Brt;Pb;Zn	815540	7940380	51	Longs Well 3
5449	Pb	815075	7939917	51	Emanuel Range 3
5450	Zn	814475	7939347	51	Emanuel Range 4
5451	Zn	814250	7939050	51	Emanuel Range 5
5452	Pb;Zn	810215	7938417	51	Emanuel Range 6
5454	Zn	808855	7938897	51	Emanuel Range 7
5457	Zn	811235	7935437	51	Paddys Valley
5463	Zn	809220	7956997	51	Little Mount Pierre 1
5464	Zn;Cu	811085	7953337	51	Little Mount Pierre 2
5465	Zn	810275	7953267	51	Little Mount Pierre 3
7723	Pb;Zn;Ag	792520	7967400	51	Pillara Spring 1
7724	Zn;Pb;Ag	792880	7967640	51	Pillara Spring 2
7725	Zn;Ag;Pb	792450	7971770	51	Pillara Range 1
7726	Pb;Ag;Zn	792410	7971600	51	Pillara Range 2
7727	Pb;Zn;Ag	792560	7971500	51	Pillara Range 3
7728	Pb;Zn;Ag	792460	7971500	51	Pillara Range 4
7729	Pb;Ag;Zn	792690	7971450	51	Pillara Range 5
7731	Pb;Ag;Zn	792680	7971370	51	Pillara Range 6
7747	Pb;Zn	792990	7971790	51	Pillara 1
7750	Zn;Pb	793080	7972190	51	Pillara 2
7751	Zn;Pb	792940	7972440	51	Pillara 3
7752	Zn;Pb	792950	7972570	51	Pillara 4
7753	Zn;Pb	792890	7972690	51	Pillara 5
7755	Zn;Pb	793210	7971960	51	Pillara 6
7757	Zn;Pb	793280	7972360	51	Pillara 7
7769	Zn;Pb	801555	7937798	51	Goongewa
7798	Zn;Pb	812960	7928100	51	Cadjebut 1
7799	Zn;Pb	814210	7927630	51	Cadjebut 2
7800	Zn;Pb	814710	7927300	51	Cadjebut 3
7801	Zn;Pb;Ag	814924	7926770	51	Kapok West
7802	Pb	815460	7926550	51	Bloodwood Pb-rich
7946	Pb;Zn	683530	8091190	51	Barker Gorge 1
7947	Zn;Pb;Ag	682528	8091192	51	Barker Gorge 2
7948	Zn;Pb;Ag	682450	8091382	51	Barker Gorge 3
7949	Pb;Zn	683568	8090723	51	Barker Gorge 4
7951	Cu;Pb;Zn;Ag	682616	8091319	51	Barker Gorge 6
7953	Zn;Pb	794625	8000107	51	Northern Lineament
7954	Zn;Pb	789275	7992052	51	Bacchus Gossan
7955	Zn;Pb	790055	7991167	51	Triodia Gossan
7956	Zn;Pb	790030	7991317	51	Triodia Gossan North
7957	Zn;Pb	790250	7991127	51	Triodia Gossan East
7958	Zn;Pb	788685	7991847	51	Fossil Downs 12
7959	Zn;Pb	789795	7991502	51	Fossil Downs 2
7960	Zn;Pb	789095	7991917	51	Fossil Downs 3
7961	Zn;Pb	789160	7991502	51	Fossil Downs 4
7962	Zn;Pb	789520	7991202	51	Fossil Downs 5
7963	Zn	789775	7991122	51	Fossil Downs 6
7964	Zn;Pb	789900	7991362	51	Fossil Downs 7

BASE METAL

Stratabound sedimentary — carbonate-hosted

No*	COMMODITY	EAST	NORTH	Z	NAME
7965	Zn;Pb	791956	7993182	51	Royal Gossan
7966	Zn;Pb	792805	7992167	51	Fossil Downs 8
7967	Zn;Pb	792910	7992257	51	Fossil Downs 9
7968	Zn;Pb	792660	7992142	51	Fossil Downs 10
7969	Zn;Pb	792265	7992042	51	Fossil Downs 11
8048	Zn	795070	7939265	51	Virgin Creek
8049	Zn;Pb;Cu	687800	8086816	51	Wombarella Gap 1
8050	Cu	688592	8087056	51	Wombarella Gap 2
8051	Cu	693679	8081969	51	Yammera Gap
8052	Cu	692744	8083006	51	Napier Downs
8053	Cu;Pb;Zn;Ag	671481	8106799	51	Area E 1
8054	Cu;Pb;Zn	671388	8106773	51	Area E 2
8055	Pb;Zn;Cu	671312	8106444	51	Area E 3
8056	Cu;Pb;Zn	671363	8106376	51	Area E 4
8057	Zn;Pb;Cu;Ag	673700	8100309	51	Wagon Pass
8058	Zn;Pb	815275	7927127	51	Surprise Gossan
8059	Zn;Pb	810535	7931747	51	Steves Gossan
8060	Zn;Pb	808207	7935998	51	Emanuel Creek Gossan
8061	Pb	810515	7933127	51	Emanuel Range 8
8065	Zn;Pb	739358	8019930	51	Buromin 1
8066	Zn	739735	8019610	51	Buromin 2
8069	Pb	748887	8012543	51	Twelve Mile Creek
8070	Zn;Pb	795969	7968170	51	Pillara Spring 3
8071	Pb;Zn	795274	7968393	51	Pillara Spring 4
8072	Zn;Pb	793654	7968081	51	Pillara Spring 5
8074	Zn	793598	7968587	51	Pillara Spring 6
8075	Zn;Pb	789120	7968860	51	Snake Bore 1
8076	Zn;Pb	789130	7968960	51	Snake Bore 2
8077	Zn	789112	7967664	51	Snake Bore 3
8078	Zn;Pb	789199	7968334	51	Snake Bore 4
8079	Zn;Pb	813206	7954846	51	East Pillara 1
8080	Zn;Pb	812844	7955100	51	East Pillara 2
8081	Pb;Zn	812256	7955479	51	East Pillara 3
8082	Zn;Pb	814897	7954773	51	East Pillara 4
8083	Pb;Zn	813423	7955053	51	East Pillara 5
8084	Pb	811059	7954792	51	East Pillara 6
8085	Cu;Pb	813228	7954505	51	East Pillara 7
8086	Pb;Zn	811968	7927743	51	Pinnacles 1
8088	Zn;Pb	812070	7927558	51	Pinnacles 2
8089	Pb;Zn	812366	7927503	51	Pinnacles 3
8090	Zn;Pb	812561	7927679	51	Pinnacles 4
8091	Zn;Pb	813098	7927586	51	Pinnacles 5
8092	Pb;Zn	813672	7927318	51	Pinnacles 6
8093	Zn;Pb	814320	7927188	51	Pinnacles 7
8094	Zn	813089	7928688	51	Pinnacles 8
8095	Zn	809865	7935369	51	Gap Yard 1
8096	Zn	809912	7934970	51	Gap Yard 2
8097	Zn	802489	7941195	51	Prices Hill 1
8098	Zn	802777	7941677	51	Prices Hill 2
8099	Zn;Pb	802776	7943112	51	Prices Hill 3
8100	Zn	804101	7941056	51	Prices Hill 4
8101	Pb;Zn	804157	7940676	51	Prices Hill 5
8102	Zn	804379	7941750	51	Prices Hill 6
8156	Zn	808375	7938537	51	Emanuel Creek 1
8161	Pb;Zn;Ag	781506	7994837	51	Brooking Springs 1
8162	Zn;Pb	780086	7995793	51	Brooking Springs 2
8163	Zn;Pb	779886	7995948	51	Brooking Springs 3
8164	Zn;Pb	780200	7995708	51	Brooking Springs 4
8165	Zn;Pb	780429	7995499	51	Brooking Springs 5
8166	Zn;Pb	782208	7995497	51	Brooking Springs 6
8167	Zn;Pb;Ag	790745	7966177	51	Simons Fault 1
8176	Zn;Pb	790570	7965547	51	Simons Fault 2
8224	Pb;Zn	796875	7994622	51	Margaret River 7
8225	Pb;Zn	796750	7993682	51	Margaret River 8
8287	Zn;Pb	758210	8004737	51	Discovery Gossan
8288	Zn;Pb;Ag	758265	8004412	51	Screaming Gossan
8289	Zn;Pb	763580	8001392	51	Black Gossan
8290	Zn;Pb	762895	8001407	51	Taranaki Gossan
8291	Zn;Pb	757655	8005252	51	Shy Gossan
8296	Zn;Pb	766137	8003959	51	Small Gossan
8300	Zn;Pb	759097	8007083	51	Replacement Gossan
8305	Zn;Pb;Ag	790677	7966895	51	Simons Gossan
8306	Zn;Pb;Ag	791763	7971351	51	South Blendevale
8307	Pb;Zn;Ag	791596	7971213	51	West Limestone Billy Hills
8312	Zn;Pb;Ag	808075	7930570	51	Kutarta
8313	Pb;Zn;Ag	812050	7925992	51	Palijippa
8315	Zn;Pb	790507	7991116	51	Fossil Downs
8351	Pb;Zn	790997	7970443	51	Limestone Billy Hills
8353	Pb;Zn	791044	7970562	51	Limestone Billy Hills 2
8354	Pb;Zn	791116	7970411	51	Limestone Billy Hills 3
8356	Zn;Pb	791260	7970441	51	Limestone Billy Hills 4
8357	Zn;Pb	790965	7970022	51	Limestone Billy Hills 5
8364	Pb;Zn	790886	7970062	51	Limestone Billy Hills 6
8367	Pb;Zn	790790	7970149	51	Limestone Billy Hills 7
8368	Pb;Zn	795600	7967250	51	Pillara Spring 7
8369	Pb	794016	7968202	51	Pillara Spring 8
8370	Zn;Pb	793348	7967890	51	Pillara Spring 9
8371	Pb	791654	7969121	51	Limestone Billy Hills 8
8372	Pb	789617	7968671	51	Limestone Billy Hills 9
8373	Pb	792858	7971317	51	Limestone Billy Hills 10
8374	Pb	792316	7971052	51	Limestone Billy Hills 11
8375	Pb	792210	7970920	51	Limestone Billy Hills 12
8377	Pb	792357	7961801	51	Outcamp Hill 1
8378	Pb	792573	7961801	51	Outcamp Hill 2
8379	Pb	792747	7961815	51	Outcamp Hill 3
8383	Zn;Pb;Cu;Ag	672414	8098767	51	Chedda Cliffs 1
8384	Pb;Zn	673224	8100378	51	Chedda Cliffs 2
8407	Zn	743751	8016022	51	Twelve Mile Bore
8698	Zn;Pb	808997	7953931	51	Home Range 1
8699	Pb;Zn	808950	7953551	51	Home Range 2
8700	Zn;Pb	808543	7952801	51	Home Range 3
8740	Zn;Pb	713505	8038980	51	Ninety Two Mile Creek 1
8741	Zn;Pb	712463	8040450	51	Ninety Two Mile Creek 2
8742	Cu	716136	8045518	51	Elimberrie
8743	Zn;Pb	708311	8048260	51	Morowyn Cliff 1
8744	Pb	711618	8048648	51	Morowyn Cliff 2
8745	Zn	719015	8044297	51	Trend Gossan
8750	Pb;Ag	794328	7972442	51	Galena Hill
8751	Pb	789697	8003471	51	Copley Valley
8752	Pb	792726	7971146	51	The Keyhole
8753	Zn;Pb	793948	7968044	51	Pillara Spring 10
8754	Zn;Pb	794337	7967942	51	Pillara Spring 11
8755	Pb	794115	7967915	51	Pillara Spring 12
8756	Pb	788956	7965438	51	DIXY
8757	Zn;Pb	790047	7964585	51	Snake Bore 5
8758	Zn;Pb	790553	7964344	51	Snake Bore 6
8778	Pb;Zn;Cu	803585	7952332	51	Bobs Bore
8809	Cu;Ag	802972	7979945	51	Mount Pierre
8825	Pb	571173	7941836	51	Mowla Bluff
8867	Zn;Pb	674725	8094795	51	Chedda Cliffs 3
8868	Pb;Zn	675147	8095691	51	Chedda Cliffs 4
9128	Zn;Pb	713298	8039381	51	Stumpy Bore 1
9129	Zn;Pb	713691	8038621	51	Stumpy Bore 2
9132	Zn	739785	8018957	51	Boab 1
9133	Zn;Pb	740385	8018597	51	Boab 2
9134	Pb;Zn	808690	7951160	51	Home Range South 1
9135	Pb	808255	7951252	51	Home Range South 2
9136	Zn;Pb;Cu	804445	7952157	51	Virgin Hills
9137	Zn;Pb	814788	7939799	51	Longs Well 1
9678	Zn;Pb	814835	7940157	51	Longs Well 2
9683	Zn;Pb	758259	8004698	51	Brooking Springs 7
9685	Zn;Pb	745900	8012950	51	Twelve Mile Bore 2
10561	Zn;Pb	810300	7932900	51	Gindi
10563	Pb;Zn;Ag	793618	7969260	51	Spring Gossan
10564	Zn	793962	7972738	51	Goshawk Fault
10565	Zn;Pb	792323	7970993	51	Eagle Fault
10566	Zn;Pb;Ag	794067	7969793	51	Camp Prospect
10567	Zn;Pb;Ag	807502	7929966	51	Kutarta SW
10568	Zn	801415	7937599	51	Goongewa South
10569	Zn;Pb	802155	7941447	51	Cappas Gossan
10570	Zn;Pb;Ag	800065	7939223	51	Goongewa NW
10571	Zn;Pb;Ag	808976	7929600	51	Area 7
10572	Zn;Pb	806715	7932357	51	Area 8
10573	Zn;Pb;Ag	792955	7971530	51	Pillara South
10574	Zn;Pb;Ag	793825	7973308	51	Pillara North 1
10575	Zn;Pb;Ag	793842	7973281	51	Pillara North 2

Stratabound sedimentary — clastic-hosted

No*	COMMODITY	EAST	NORTH	Z	NAME
352	Cu;Ag	629740	8161480	51	Wilsons Reward 1
2922	Cu	609537	8172354	51	Mangrove
2923	Cu	603390	8170071	51	Townshend River B1
7651	Cu	602660	8170830	51	Townshend River A1
7652	Cu	604550	8169180	51	Townshend River C
7653	Cu	629540	8161360	51	Wilsons Reward 2
7654	Cu	629760	8161700	51	Wilsons Reward 3
7655	Cu	602850	8170940	51	Townshend River A2
7656	Cu	603260	8170170	51	Townshend River B2
7657	Cu	603250	8170140	51	Townshend River B3

BASE METAL

Stratabound sedimentary — clastic-hosted

No*	COMMODITY	EAST	NORTH	Z	NAME
7667	Cu	625430	8169600	51	Rough Triangle 1
7668	Cu	625620	8169130	51	Rough Triangle 2
7670	Cu	625706	8168960	51	Rough Triangle 4
7671	Cu	625895	8168770	51	Rough Triangle 5
7688	Cu	628380	8167500	51	Robinson
8337	Pb;Zn	728870	8033201	51	Oscar Range 3
8340	Cu	595451	8192000	51	McLarty Range 1
8341	Cu	599028	8190639	51	McLarty Range 2
8342	Cu	604816	8186447	51	McLarty Range 3
8343	Cu	607512	8185545	51	McLarty Range 4
8344	Cu	609789	8184493	51	McLarty Range 5
8345	Cu	610294	8184901	51	McLarty Range 6
8346	Cu	609664	8186114	51	McLarty Range 7
8347	Cu	607833	8189242	51	McLarty Range 8
8349	Cu	610009	8180796	51	McLarty Range 9
10088	Cu	569285	8199764	51	Mundurral River

Stratabound sedimentary — undivided

No*	COMMODITY	EAST	NORTH	Z	NAME
8157	Zn;Ag	808035	7932147	51	Emanuel Creek 2
8158	Zn;Pb	805135	7933157	51	Emanuel Creek 3
8159	Zn;Pb	803405	7935497	51	Emanuel Creek 4

IRON

Vein and hydrothermal — undivided

No*	COMMODITY	EAST	NORTH	Z	NAME
10044	Fe	566760	8202380	51	Wotjulum

Stratabound sedimentary — clastic-hosted

No*	COMMODITY	EAST	NORTH	Z	NAME
8481	Fe	578912	8216320	51	Koolan Island – Main 1
8482	Fe	577744	8217134	51	Koolan Island – Main 2
8484	Fe	579904	8215693	51	Koolan Island – Main 3
8485	Fe	579423	8217197	51	Acacia 1
8518	Fe	579967	8216831	51	Acacia 2
8519	Fe	578086	8217855	51	Acacia 3
8520	Fe	578713	8217771	51	Mullet 1
8521	Fe	579089	8217782	51	Mullet 2
8522	Fe	581429	8215839	51	Barramundi 1
8523	Fe	580823	8216226	51	Barramundi 2
8524	Fe	581951	8215474	51	Barramundi 3
8525	Fe	582546	8214858	51	Barramundi 4
8526	Fe	581710	8216174	51	Eastern 1
8527	Fe	582034	8215913	51	Eastern 2
8528	Fe	581930	8215892	51	Eastern 3
8529	Fe	582191	8215401	51	Eastern 4
8532	Fe	582536	8215119	51	Eastern 5
9768	Fe	564900	8220300	51	Cockatoo Island Central
9769	Fe	565600	8219940	51	Cockatoo Island East
9770	Fe	564040	8220720	51	Cockatoo Island West
9771	Fe	559320	8222640	51	Irvine Island
9772	Fe	585060	8212480	51	West Ballast Island
9773	Fe	585760	8212020	51	East Ballast Island
9779	Fe	583780	8200300	51	Talbot Bay

Stratabound sedimentary — undivided

No*	COMMODITY	EAST	NORTH	Z	NAME
10045	Fe	654540	8009520	51	Jimberlura
10052	Fe	614520	8016280	51	Grant Range
10053	Fe	770800	7901000	51	Shore Range 1
10054	Fe	759900	7899800	51	Shore Range 2

ALUMINA

Regolith — residual and supergene

No*	COMMODITY	EAST	NORTH	Z	NAME
8734	Bx	821135	8297457	51	Sharp Hill
10547	Bx	802760	8357340	51	South Plateau 1
10548	Bx	799500	8357760	51	South Plateau 2
10549	Bx	799060	8371700	51	Central Plateau
10550	Bx	802140	8380480	51	North Plateau
10551	Bx	806500	8377960	51	Jacks Folly
10552	Bx	807080	8378800	51	Parkers Point
10553	Bx	808100	8380820	51	Debatable Point
10554	Bx	800640	8383420	51	Lone Dingo
10555	Bx	812000	8326900	51	Southern Mitchell Plateau 1
11272	Bx	804300	8331600	51	Southern Mitchell Plateau 2
11273	Bx	816300	8343700	51	Southern Mitchell Plateau 3
11274	Bx	804800	8344200	51	Southern Mitchell Plateau 4
11275	Bx	798700	8344600	51	Southern Mitchell Plateau 5

ENERGY

Stratabound sedimentary — clastic-hosted

No*	COMMODITY	EAST	NORTH	Z	NAME
8706	U	636284	7992422	51	Myroodah Uranium
8736	U	606168	8147069	51	Oobagooma Uranium 1
8737	U	606001	8148403	51	Oobagooma Uranium 2
8738	U	605174	8148258	51	Oobagooma Uranium 3
8739	U	605882	8149153	51	Oobagooma Uranium 4
8748	U	605609	8149700	51	Oobagooma Uranium 5
8749	U	606016	8149634	51	Oobagooma Uranium 6

Sedimentary — basin

No*	COMMODITY	EAST	NORTH	Z	NAME
9798	Coal	631420	7998560	51	Myroodah Coal
9818	Coal	620400	7973940	51	Watsons Bore
9827	Coal	599380	8017040	51	Lower Liveringa 1
9830	Coal	592120	8021140	51	Lower Liveringa 2
9831	Coal	670240	8000120	51	Audreys Bore 1
9838	Coal	667780	7997120	51	Audreys Bore 2
9862	Coal	673480	8002280	51	Audreys Bore 3
9863	Coal	660020	7991680	51	Duchess Ridge 1
9864	Coal	659980	7992320	51	Duchess Ridge 2
9871	Coal	643960	7962320	51	Freney 1
9873	Coal	644180	7962020	51	Freney 2
9877	Coal	641240	7961080	51	Freney 3
9887	Coal	669380	7943660	51	Mount Fenton 3
9917	Coal	648700	7954180	51	Mount Fenton 2
9919	Coal	660080	7951480	51	Mount Fenton 1
9942	Coal	670500	7995900	51	Paradise 1
9943	Coal	672550	7993500	51	Paradise 2
9944	Coal	704740	7954600	51	‘P’ Hill
9945	Coal	644640	7964220	51	Moffats
9953	Coal	607200	7999860	51	Liveringa Ridge 1
9956	Coal	611140	7997580	51	Liveringa Ridge 2
9959	Coal	602940	8001680	51	Liveringa Ridge 3
9961	Coal	598540	7986700	51	Windbag
9964	Coal	601480	7992700	51	Victory 1
9965	Coal	598940	7989160	51	Victory 2
9967	Coal	591180	7990800	51	Geegully
9969	Coal	585520	8005060	51	Pandamus
9979	Coal	649940	8126420	51	Alexander Creek
9989	Coal	672300	8019700	51	Blina 1
9996	Coal	664900	8018300	51	Blina 2
10004	Coal	690760	7972600	51	Fitzroy Trough 1
10008	Coal	700620	7972700	51	Fitzroy Trough 2
10011	Coal	719520	7968560	51	Fitzroy Trough 3
10016	Coal	707500	7964040	51	Fitzroy Trough 4
10026	Coal	679300	7933060	51	Fitzroy Trough 5
10031	Coal	666040	7982320	51	Fitzroy Trough 6
10032	Coal	696680	7994640	51	Fitzroy Trough 7
10034	Coal	687820	7998560	51	Fitzroy Trough 8
10037	Coal	684640	7933940	51	Fitzroy Trough 9
10039	Coal	702720	7914640	51	Fitzroy Trough 10
10040	Coal	693620	7920640	51	Fitzroy Trough 11
10041	Coal	698020	7916740	51	Fitzroy Trough 12
10107	Coal	569875	7981718	51	Frome Rocks no. 2
10108	Coal	678520	7964800	51	Fitzroy Trough 13
10109	Coal	686120	7991320	51	Fitzroy Trough 14
10110	Coal	678740	7998860	51	Fitzroy Trough 15
10111	Coal	687660	8006660	51	Fitzroy Trough 16
10115	Coal	697880	8005740	51	Fitzroy Trough 17
10116	Coal	710600	7971800	51	Fitzroy Trough 18
10117	Coal	675140	7931100	51	Fitzroy Trough 19
10118	Coal	714540	7911680	51	Fitzroy Trough 20
10119	Coal	719520	7912880	51	Fitzroy Trough 21
10120	Coal	626013	7979584	51	Myroodah no. 1
10124	Coal	517216	8074371	51	Fraser River no. 1
10125	Coal	606641	8008200	51	Grant Range no. 1
10673	Coal	558000	7943700	51	Babrongan Tower

INDUSTRIAL MINERAL

Kimberlite and lamproite

No*	COMMODITY	EAST	NORTH	Z	NAME
10224	Bent;Fel	686860	8008760	51	Calwynyardah Bentonite
10225	Bent;Fel	694460	8009700	51	Laymans Bore East Bentonite

Pegmatitic

No*	COMMODITY	EAST	NORTH	Z	NAME
353	Mica;Brl	651250	8130930	51	Stewarts
2921	Brl;Mica	689850	8102270	51	Gussys
8811	Brl;Mica	651509	8130932	51	Stewarts East
10080	Mica	724500	8078060	51	Mount Joseph

INDUSTRIAL MINERAL

Vein and hydrothermal — undivided

No*	COMMODITY	EAST	NORTH	Z	NAME
10078	Brt;Fl	701160	8085480	51	Mount Amy
10079	Brt	657900	8221500	51	Doubtful Bay Barite

Stratabound sedimentary — carbonate-hosted

No*	COMMODITY	EAST	NORTH	Z	NAME
10598	Brt	815520	7940320	51	Longs Well Barite
11362	Lst	749707	8024622	51	Oscar Plateau East 1
11363	Lst	747579	8024003	51	Oscar Plateau East 2

Stratabound sedimentary — clastic-hosted

No*	COMMODITY	EAST	NORTH	Z	NAME
2920	Cor;Ky	668517	8125272	51	Hawkstone
8801	Cor	746720	8073100	51	Richenda River Corundum
10086	Cor	755180	8061500	51	Mount Rose
10158	Glt	669000	7967500	51	Mount Abbott Glauconite 2

Stratabound sedimentary — undivided

No*	COMMODITY	EAST	NORTH	Z	NAME
2960	Phos	617337	7999153	51	Liveringa Ridge Phosphate
2961	Phos	642138	7991553	51	Myroodah Syncline
2962	Phos	687138	7988153	51	No. 20 Bore
2963	Phos	665138	8015153	51	Egans Bore
2964	Phos	643137	8026153	51	Erskine Range
2965	Phos	650037	8093154	51	Hawkstone Peak no. 1
7795	Phos	644250	8025360	51	Erskine Hill
7796	Phos	647400	8022280	51	Erskine Hill – Paradise 1
7797	Phos	660240	8017470	51	Erskine Hill – Paradise 2
7816	Phos	559360	8046490	51	Langey Crossing 1
7819	Phos	558845	8051238	51	Langey Crossing 2
7837	Phos	558950	8046930	51	Langey Crossing 3
7839	Phos	541727	8036403	51	Langey Crossing 4
7841	Phos	549005	8040482	51	Langey Crossing 5
7842	Phos	545671	8040440	51	Langey Crossing 6
7850	Phos	559410	8048000	51	Langey Crossing 7
7853	Phos	559310	8047250	51	Langey Crossing 8
7857	Phos	558915	8045753	51	Langey Crossing 9
7863	Phos	558143	8044246	51	Langey Crossing 10
10102	Phos	618500	7971220	51	Dry Corner

Sedimentary — undivided

No*	COMMODITY	EAST	NORTH	Z	NAME
9130	Salt	568342	7988086	51	Frome Rocks no. 1

Regolith — alluvial to beach placers

No*	COMMODITY	EAST	NORTH	Z	NAME
7928	Grt	670810	8121112	51	Hawkstone Creek
10157	Glt	668400	7965300	51	Mount Abbott Glauconite 1

Regolith — residual and supergene

No*	COMMODITY	EAST	NORTH	Z	NAME
10056	Och	725800	7953600	51	Forrest Branch
10104	Phos	747720	8418680	51	East Montalivet Island
10105	Phos	739340	8416480	51	West Montalivet Island
10166	Phos	805760	8428300	51	White Island

CONSTRUCTION MATERIALS

Undivided

No*	COMMODITY	EAST	NORTH	Z	NAME
8067	Lst	743552	8017832	51	Oscar Range 1
8068	Lst	741570	8017988	51	Oscar Range 2
8817	Dlt	729328	8061465	51	Fairfield 1
8818	Dlt	730407	8061594	51	Fairfield 2
8819	Dlt	730194	8061124	51	Fairfield 3
8820	Dlt	729991	8061081	51	Fairfield 4
8821	Dlt	729478	8061198	51	Fairfield 5
8822	Dlt	729243	8061947	51	Fairfield 6
9131	Dlt	724105	8117642	51	Mount Hart (dimension stone)
9146	Gran	702750	8094003	51	Nardma Grey Pearl Granite
9153	Dlt	701144	8094904	51	Nardma Black Granite 1
9154	Dlt	702442	8095565	51	Nardma Black Granite 2
9155	Dlt	703026	8095806	51	Nardma Black Granite 3
9157	Dlt	703591	8094861	51	Nardma Black Granite 4
9158	Dlt	704091	8094500	51	Nardma Black Granite 5
9159	Dlt	702510	8093607	51	Wombarella
9160	Dlt	708935	8092158	51	Wombarella 2
9161	Dlt	706045	8083762	51	Wombarella Creek South
9162	Dlt	703841	8092805	51	Wombarella Creek East
9178	Lst	693822	8081881	51	Barlil
9180	Sdst	502685	8068957	51	Janganbarr
9183	Dlt	711453	8088260	51	Wumburrul

CONSTRUCTION MATERIALS

Undivided

No*	COMMODITY	EAST	NORTH	Z	NAME
9190	Dlt	712118	8087636	51	Kimberley Black Granite
9200	Dlt	715986	8072029	51	Carpenters Gap 1
9201	Dlt	716325	8072431	51	Carpenters Gap 2
9202	Dlt	717531	8073838	51	Carpenters Gap 3
9203	Dlt	718674	8072314	51	Carpenters Gap 4
9204	Dlt	718494	8073214	51	Carpenters Gap 5
9677	Gran	708705	8092057	51	Kimberley Ice
10176	Sd	686560	8076200	51	Lennard River – De Biasi
10230	Sdst	505975	8064515	51	Mount Jowlaenga
10231	Sdst	505380	8066420	51	Fraser River
10232	Sd	601960	8088460	51	May River
10233	Gvl	602300	8077420	51	May River South
10235	Sdst	510120	8046440	51	Nillibubbaca 3
10236	Sdst	510300	8045360	51	Nillibubbaca 2
10237	Sdst	507920	8039340	51	Nillibubbaca 1
10238	Sd;Gvl	560160	8047520	51	Langey Crossing Gravel
10239	Sd	560260	8043960	51	Langey Crossing South
10240	Sd;Gvl	568140	8040000	51	Fitzroy River
10241	Gvl	569820	8038800	51	Willare Bridge
10242	Sd	773440	7986760	51	Fitzroy Crossing 1
10243	Sd	773240	7985800	51	Fitzroy Crossing 2
10244	Sdst	508300	8041500	51	Nillibubbaca 4
10250	Gvl	811074	7925954	51	Cadjebut (gravel)
10257	Sd	807226	7908617	51	Christmas Creek (sand)

Appendix 2

WAMIN and EXACT databases

WAMIN database (mineral occurrences)

The WAMIN (Western Australian mineral occurrence) database of the Geological Survey of Western Australia (GSWA) contains geoscience attribute information on mineral occurrences in Western Australia. The database includes textual and numeric information on the location of the occurrences, location accuracy, mineral commodities, mineralization-style classification, order of magnitude of resource tonnage and estimated grade, ore and gangue mineralogy, details of host rocks, and both published and unpublished references. Each of the occurrences in WAMIN is identified by a unique 'deposit number'.

The WAMIN database uses a number of authority tables to constrain the essential elements of a mineral occurrence, such as the operating status, the commodity group, and the style of mineralization. These and other attributes were extracted either from open-file mineral exploration reports in WAMEX (Western Australian mineral exploration database) or from the published literature.

Those elements of the database that were used to create the symbols for mineral occurrences and tabular information displayed in Plate 1 and Appendix 1 of this report are:
- occurrence number and name (deposit number and name)
- operating status (font style of deposit number)
- position and spatial accuracy (symbol position)
- commodity group (symbol colour)
- mineralization style (symbol shape).

The elements of the database used for symbology in Plate 1 and Appendix 1 are operating status, commodity group, and mineralization style. These parameters have previously been defined for the GSWA mineralization mapping projects that have been completed for prospectivity enhancement studies of southwest Western Australia (Hassan, 1998), the north Eastern Goldfields (Ferguson, 1998), the Bangemall Basin (Cooper et al., 1998), the west Pilbara (Ruddock, 1999), the east Kimberley (Hassan, 2000), the east Pilbara (Ferguson and Ruddock, 2001), and the north Kimberley (Ruddock, 2003).

Operating status

The database includes mineralization sites (referred to as deposits) ranging from small, but mineralogically significant, mineral occurrences up to operating mines. The classification includes all MINEDEX sites with established resources: MINEDEX is the Department of Industry and Resources (DoIR) mines and mineral deposits information database (Townsend et al., 1996, 2000; Cooper et al., 2003). All occurrences in the WAMIN database are assigned a unique, system-generated number (deposit number). The font style of this number (**bold**, *italicized*, and plain) is used as the coding to indicate operating status both on the face of the map and in Appendix 1 of this Report. The system used is:
- Mineral occurrence — any outcropping mineralization or gossan or any drill intersection of an economic mineral exceeding an agreed concentration and size found in bedrock or regolith (italic serif numbers, e.g. *1212*).
- Prospect — any mineralized zone that has not been sufficiently sampled at the surface, or in the subsurface, to enable a resource to be identified. A prospect may also be old workings (italic serif numbers, e.g. *1138*).
- Mineral deposit — economic mineralization for which there is an established resource figure (serif numbers, e.g. 1137).
- Abandoned mine — workings that are no longer operating, or are not on a care-and-maintenance basis, and for which there is recorded production, or where field evidence suggests that the workings were for more than prospecting purposes (bold–italic sans serif numbers, e.g. ***2321***).
- Operating mine — workings that are operating, including on a care-and-maintenance basis, or that are in development leading to production (bold sans serif numbers, e.g. **1106**).

The names of the occurrences, and any synonyms that may have been used, are mainly derived from the published literature and from open-file reports (in WAMEX); others are assigned according to the nearest geographical feature. Names that appear in the MINEDEX database have been used where possible, although there may be differences created because MINEDEX uses site names based on overall production and resources, where WAMIN may show names of several individual occurrences at one MINEDEX site.

Table 2.1. WAMIN authority table for commodity groups

WAMIN commodity group	*Typical commodities*	*Symbol colour*
Precious mineral	Diamond, semi-precious gemstones	
Precious metal	Ag, Au, PGE	
Steel-industry metal	Co, Cr, Mn, Mo, Ni, V, W	
Speciality metal	Be, Li, Nb, REE, Sn, Ta, Ti, Zr	
Base metal	Cu, Pb, Sb, Zn	
Iron	Fe	
Aluminium	Al (bauxite)	
Energy	Coal, U	
Industrial mineral	Asbestos, barite, fluorite, kaolin, talc	
Construction material	Clay, dimension stone, limestone	

Commodity group

The WAMIN database includes a broad grouping that is based on the potential end-use or typical end-use of the principal commodities comprising a mineral occurrence. The commodity group, as listed in Table 2.1, determines the particular colour for the mineral occurrence symbols in Plate 1 and Appendix 1.

The commodity groupings are based on those published by the Mining Journal (1998) with modifications, as shown in Table 2.2, to suit the range of minerals and end-uses for the mineral output of Western Australia.

Mineralization style

There are a number of detailed schemes for classifying mineral occurrences into groups representing different styles of mineralization, with the scheme of Cox and Singer (1986) probably being the most widely used. The application of this scheme in Western Australia would necessitate modifications to an already complex scheme, along the lines of those adopted by the Geological Survey of British Columbia (Lefebure and Ray, 1995; Lefebure and Hoy, 1996). Representing the style of mineralization on the face of a map cannot be simply and effectively achieved if the scheme adopted is too complex.

Table 2.2. Modifications made to the Mining Journal Ltd (1998) commodity classification

Commodity group (Mining Journal Ltd, 1998)	*Commodities*	*Changes made for WAMIN commodity group (see Table 2.1)*
Precious metals and minerals	Au, Ag, PGE, diamonds, other gemstones	Diamond and other gemstones in precious minerals group; Au, Ag, and PGE in precious metals group
Steel-industry metals	Iron ore, steel, ferro-alloys, Ni, Co, Mn, Cr, Mo, W, Nb, V	Fe in iron group
Speciality metals	Ti, Mg, Be, REE, Zr, Hf, Li, Ta, Rh, Bi, In, Cd, Sb, Hg	Sn added from major metals; Sb into the base metals group
Major metals	Cu, Al, Zn, Pb, Sn	Cu, Pb, and Zn into the base metals group; Al (bauxite) into aluminium group; Sn in speciality metals
Energy	Coal, U	No change
Industrial minerals	Asbestos, sillimanite minerals, phosphate rock, salt, gypsum, soda ash, potash, boron, sulfur, graphite, barite, fluorspar, vermiculite, perlite, magnesite/ magnesia, industrial diamonds, kaolin	No change

Table 2.3. WAMIN authority table for mineralization styles and groups

Mineralization style	*Typical commodities*	*Group symbol*[(a)]
Carbonatite and alkaline igneous intrusions	Nb, Zr, REE, P	☆
Kimberlite and lamproite	Diamond	
Disseminated and stockwork in plutonic intrusions	Cu, Mo, Au	
Greisen	Sn	⬡
Pegmatitic	Sn, Ta, Nb, Li	
Skarn	W, Mo, Cu, Pb, Zn, Sn	
Orthomagmatic mafic and ultramafic — komatiitic or dunitic	Ni, Cu, Co, PGE	
Orthomagmatic mafic and ultramafic — layered-mafic intrusions	Ni, Cu, Co, V, Ti, PGE, Cr	✚
Orthomagmatic mafic and ultramafic — undivided	Ni, Cu, Co, V, Ti, PGE, Cr	
Vein and hydrothermal — undivided	Au, Ag, Cu, Pb, Zn, Ni, U, Sn, F	◇
Stratabound volcanic and sedimentary — volcanic-hosted sulfide	Cu, Zn, Pb, Ag, Au, Ba	
Stratabound volcanic and sedimentary — sedimentary-hosted sulfide	Pb, Zn, Cu, Ag	△
Stratabound volcanic and sedimentary — volcanic oxide	Fe, P, Cu	
Stratabound volcanic and sedimentary — undivided	Pb, Zn, Cu, Ag, Au, Fe, Ba	
Stratabound sedimentary — carbonate-hosted	Pb, Zn, Ag, Cd	
Stratabound sedimentary — clastic-hosted	Pb, Zn, Cu, Au, Ag, Ba, Cd, U	
Stratabound sedimentary — undivided	Pb, Ba, Cu, Au	
Sedimentary — banded iron-formation (supergene enriched)	Fe	□
Sedimentary — banded iron-formation (taconite)	Fe	
Sedimentary — undivided	Mn	
Sedimentary — basin	Coal, bitumen	○
Regolith — alluvial to beach placers	Au, Fe pisolites, Ti, Zr, REE, diamond, Sn	
Regolith — calcrete	U, V	▭
Regolith — residual and supergene	Al, Au, Ni, Co, Mn, V, Fe crustals, Fe scree	
Regolith — residual to eluvial placers	Au, Sn, Ti, Zr, REE, diamond	
Undivided	Construction materials, various	▽

NOTE: (a) The white symbol colour used in this table does not indicate the commodity group in Table 2.1

The Geological Survey of Western Australia has adopted the principles of ore deposit classification from Evans (1987) with some modifications based on Edwards and Atkinson (1986). This scheme works on the premise that ‘If a classification is to be of any value it must be capable of including all known ore deposits so that it will provide a framework and a terminology for discussion and so be of use to the mining geologist, the prospector and the exploration geologist’. The system above is based on an environmental–rock association classification, with elements of genesis and morphology where they serve to make the system simpler and easier to apply and understand (Table 2.3).

To fully symbolize all the mineralization style groups would result in a system that is too complex. As the full details of the classification are preserved in the underlying WAMIN database, the chosen symbology has been reduced to nine shapes (Table 2.3).

Mineral occurrence determination limits

Any surface expression of mineralization (gossan or identified economic mineral) is an occurrence. Subsurface or placer mineralization is included as an occurrence where it meets the criteria given in Table 2.4.

Professional judgement is used if shorter intercepts or surface occurrences at higher grade (or vice versa) are involved. Any diamonds or gemstones would be mineral occurrences, including diamondiferous kimberlite or lamproite.

EXACT database (exploration activities)

The EXACT* database is a GIS-based spatial index, for exploration activities in WAMEX, which has been developed by the GSWA to improve access to information in open-file mineral exploration reports (Ferguson, 1995). A major limitation to data retrieval in WAMEX, in its current form, is the difficulty in selecting reports that cover a specific area and, further, in precisely locating various individual exploration activities described within a selected report.

* The EXACT database is a GIS-based spatial index of **EX**ploration **ACT**ivities. This term supersedes the acronym SPINDEX (Spatial Index) used in Cooper et al. (1998), Ferguson (1998), and Hassan (1998).

Table 2.4. Suggested minimum intersections for mineral occurrences in drillholes or trenches

Element	*Intersection length (m)*	*Grade*
Hard rock and lateritic deposits		
Gold	>1	>0.5 ppm
Silver	>1	>35 ppm
Platinum	>1	>0.7 ppm
Lead	>1	>1%
Zinc	>1	>0.5%
Copper	>1	>0.25%
Nickel	>1	>0.2%
Cobalt	>1	>0.02%
Chromium	>1	>5% Cr_2O_3
Vanadium	>5	>0.1%
Tin	>5	>0.02%
Iron	>5	>40% Fe
Manganese	>5	>25%
Uranium	>2	>300 ppm U
Diamonds	na	any diamonds
Tantalum	>5	>200 ppm
Tungsten	>1	>1000 ppm (0.1%)
Placer deposits		
Gold	na	>300 mg/m^3 in bulk sample
Diamonds	na	any diamonds
Heavy minerals	>5	>2% ilmenite

NOTE: Modified from Rogers and Hart (1995)
na: not applicable

Table 2.5 Types of exploration activity detailed in the EXACT database

Activity type	*Description*
Geological	
GEOL	Geological mapping
AMS	Airborne multispectral scanning
LSAT	Landsat TM data
Geophysical	
AEM	Airborne electromagnetic surveys
AGRA	Airborne gravity surveys
AMAG	Airborne magnetic surveys
ARAD	Airborne radiometric surveys
MAG	Magnetic surveys
EM	Electromagnetic surveys (includes TEM, SIROTEM)
GEOP	Other geophysical surveys (includes IP, resistivity)
GRAV	Gravity surveys
RAD	Radiometric surveys (includes downhole logging)
SEIS	Seismic surveys
Geochemical	
SOIL	Soil surveys
SSED	Stream-sediment surveys
REGO	Regolith surveys (includes laterite, pisolite, ironstone, and lag)
NGRD	Non-gridded geochemical surveys (includes chip, channel, dump, and gossan)
ACH	Airborne geochemistry
GCDR	Geochemistry drilling (includes auger and RAB drilling for deep sampling)
Mineralogical	
HM	Heavy mineral surveys (ilmenite, zircon, monazite, garnet, gold, tin, tantalum)
DSAM	Diamond sampling surveys (stream sediment, loam)
Drilling	
DIAM	Diamond drilling
ROT	Rotary drilling (predominantly percussion drilling)
RAB	RAB drilling (includes other shallow geochemical drilling such as auger)
RC	RC drilling
Mineral resources	
MRE	Mineral resource estimate
Hydrogeological	
HYDR	Groundwater surveys

In the current WAMEX database, when spatial parameters are used to make data searches, the results of searches are constrained to very large areas. The smallest search polygon that can be effectively used to locate reports in WAMEX is the area of a 1:50 000-scale sheet. Even though a query may be entered as a single point (either MGA or latitude/longitude coordinates), the resulting search will produce all reports for the 1:50 000-scale sheet in which that single point is located. Hence, for example, it is not possible to restrict report selection to small areas of prospective ground of particular interest to the user. As a consequence these WAMEX searches are time consuming, and they have become more time consuming as the number of open-file reports has increased with continuing releases of data.

The EXACT spatial index overcomes this problem and allows easy access to data on specific areas of previous exploration activity. It also provides a spatial representation of the intensity of past exploration, thereby highlighting prospective areas that may have been lightly or inadequately tested by various earlier exploration methods.

The spatial index consists of an attribute database, developed in Microsoft Access, which is linked to ArcView for spatial representation. In the CD-ROM, the dataset includes tabulated textual and numeric information that has been retrieved from open-file mineral exploration reports and attached to individual exploration activities. The areas of exploration activity are digitized (as polygons, lines, or points) using the computer-assisted drafting (CAD) system Microstation, converted into Arc/Info, and then transferred into ArcView to enable an interactive display of EXACT. The positional data are digitized from hard-copy maps and plans in mineral exploration reports, using various published sources (geological maps, topographic maps, Landsat images, and TENGRAPH — DoIR's electronic tenement-graphics system) for georeference purposes. The types of exploration activity detailed are essentially those used in WAMEX, with some rationalization, and these are listed in Table 2.5. In the table, the 27 activities are grouped as follows:

- Geological activities (and remote sensing activities)
- Geophysical activities
- Geochemical activities
- Mineralogical activities
- Drilling activities
- Mineral resources
- Hydrogeological activities.

The above groups relate to those specified in the statutory guidelines for mineral exploration reports (Department of Minerals and Energy, 1995).

For each separate exploration activity the following statistics have been compiled:

- description of activity including prospect name and brief summary of results where appropriate
- sample types and numbers
- elements analyzed and whether the element is anomalous or not
- metres of drilling and number of holes
- scales of presentation of data in reports.

The activity data are also linked in the dataset to the following related information taken from WAMEX:

- A-numbers (WAMEX accession numbers for individual reports)
- I-numbers (WAMEX item numbers for single or groups of reports on microfiche or CD)
- company or companies that submitted reports
- period of exploration (years)
- mineral commodities sought
- summaries (annotations) of exploration projects included in individual item numbers.

In ArcView the exploration activities are included as spatial **themes**, which are displayed as polygons, lines, or points on the interactive on-screen map known as the **view**. The **table of contents** (i.e. map legend) provided alongside the **view** allows access to the **themes**, so that any **theme** or combination of **themes** may be displayed. Details (taken from attribute tables) of any **theme** can be accessed on screen, and **queries** can be carried out either as spatial queries through a **view** or as textual queries direct from the attribute tables. Further details (with examples) of displays, queries, charts, and view layouts are provided by Ferguson (1995).

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Appendix 3

Description of digital datasets on CD-ROM

There are three principal components of this study, which are this report, Plate 1, and a CD-ROM containing digital datasets for use with database or GIS software. The CD-ROM includes all the data used to compile the map and report, and also includes files of exploration and mining activity, geophysical, remote sensing, and topographic data. The CD-ROM also includes the files necessary for viewing the data in the ArcView GIS environment, and a self-loading version of the ArcExplorer software package modified to suit this particular dataset.

Mineral occurrences (WAMIN)

The mineral occurrence dataset (from WAMIN, the Western Australian mineral occurrence database) as used in this report and on Plate 1 is described in Appendix 2. The dataset on the CD-ROM includes textual and numeric information on:

- location of the occurrences (MGA coordinates, latitude and longitude, geological province, location method, and accuracy)
- commodities and commodity group
- mineralization classification and morphology
- order of magnitude of resource tonnage and estimated grade
- mineralogy of ore and gangue
- details of host rocks
- both published and unpublished references.

EXACT

The EXACT dataset (from EXACT, Geological Survey of Western Australia's spatial index of exploration activities) as used in this report is described in Appendix 2. The dataset on CD-ROM contains spatial and textual information (derived from WAMEX open-file reports) defining the locations and descriptions of exploration activities in the area. EXACT for the west Kimberley area was compiled between 2000 and 2003, and contains information on types of mineral exploration activity such as statistics relating to:

- report numbers
- sample types and numbers
- elements assayed
- metres of drilling and number of holes
- scales of presentation of the data.

Positional data were taken from hard-copy maps of various scales, from company reports (in the WAMEX database), located from coordinate and/or geographical information (from topographic maps, Landsat images, or TENGRAPH), and then digitized. Table 2.5 (in Appendix 2) lists the exploration activity types.

The activity data are linked to more general data concerning the individual open-file reports (commonly defined in WAMEX by accession A-numbers) and individual exploration projects (commonly defined in WAMEX by open-file item I-numbers). This information includes the company or companies involved in the project, the commodities explored for, the timing of the project, names of localities in the project, and a summary (annotation) of the project, including exploration concept, activities, and a synopsis of results.

WAMEX

All relevant open-file company mineral exploration reports for the area, indexed in the WAMEX* database held by the former Department of Minerals and Energy, now Department of Industry and Resources (DoIR), were referred to for this study. Information extracted from these reports was used to analyse the historical trends in exploration activity and target commodities.

MINEDEX

The MINEDEX* database (Townsend et al., 1996, 2000; Cooper et al., 2003) has current information on all mines, process plants, and deposits, excluding petroleum and gas, for Western Australia. Mineral resources included in MINEDEX must conform to the Joint Ore Reserves Committee (JORC) (1999) code to be included in the database. The database contains information relevant to WAMIN under the following general headings:

- commodity group and minerals
- corporate ownership and percentage holding
- site type and stage of development
- location data (a centroid) including map, shire, mining district, and centre
- current mineral resource estimates
- mineralization type
- tectonic unit
- tenement details.

MINEDEX contains all the relevant resource information and WAMIN uses the unique MINEDEX site

* WAMEX and MINEDEX are available on the DoIR website.

number as a cross-reference for this information. WAMIN may contain pre-resource global estimates that do not conform to the JORC (1999) code, and are not included in MINEDEX.

TENGRAPH

The TENGRAPH* database (DoIR's electronic tenement-graphics system) shows the position of mining tenements relative to other land information. TENGRAPH provides information on the type and status of the tenement and the name(s) and address(es) of the tenement holders (Department of Minerals and Energy, 1994). It should be borne in mind that the tenement situation is constantly changing and that current tenement plans should be consulted before making any landuse-based decisions or applying for tenements.

Interpreted bedrock geology and regolith

The interpreted bedrock geology and regolith incorporates an interpretation of the study area, at 1:500 000 scale, based on a recent compilation by the Geological Survey of Western Australia (GSWA). The full details of the interpreted bedrock geology and regolith are on the CD-ROM. The regolith on Plate 1 is a simplified version of the digital dataset on the CD-ROM, and uses two overprints to distinguish relict and depositional regimes. The CD-ROM also includes a large number of solid geology and regolith units that are smaller than 250 000 m^2 in area that were omitted from Plate 1 for simplicity.

Geophysics

The aeromagnetic data covering the area are presented in the form of a total magnetic intensity (TMI) colour image. The data used to create the image were flown in 1995 for the National Geoscience Mapping Accord (between Geoscience Australia and GSWA), mostly at a line spacing of 400 m, and gridded to a cell size of 800 m for the colour image. More-detailed data, gridded to a cell size of 100 m, may be obtained from Geoscience Australia.

Measurements of the background radiation using an airborne crystal usually took place concurrently with the Geoscience Australia aeromagnetic surveys over the area. The colour image on the CD-ROM shows the comparative K–Th–U ratios as red–green–blue (RGB). The data are relatively disparate in nature as variations in the crystal size and flying height were not tightly constrained over the area.

A regional gravity survey by Geoscience Australia, at a nominal station spacing of 11 km, is presented in the digital dataset as an image showing the Bouguer anomaly, gridded to a cell size of 5 km.

Landsat

Landsat TM imagery has been acquired for all the 1:250 000-scale map sheets in the west Kimberley study. The raw data are available commercially through the Remote Sensing Services section of the Department of Land Information (DLI). Images are included in the digital package that preserve the original 25 m pixel size, but these cannot be reverse-engineered back to any bands or band ratios of the original 6-band dataset.

Both image datasets comprise a patchwork of 1:250 000-scale map tiles. The simplest of the two uses a decorrelation stretch of the first principal component of bands 1, 2, 3, 4, 5, and 7, written out as an 8-bit dataset that can be viewed as a monochrome image. The second, more complex, image can be viewed in colour, and was created using a decorrelation stretch of bands 4, 5, and 7.

Cultural features

Selected roads and tracks are given as a single dataset, and range from sealed highways through shire roads to major station tracks. The digital data in this file were captured by digitizing from Landsat imagery.

Place names for the area, in a separate file, are given for major hills, stations, and communities. More-comprehensive topographical and cultural data, including drainage, can be obtained from the National Mapping Division of Geoscience Australia (formerly Australian Land Information Group).

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* TENGRAPH is available on the DoIR website

The west Kimberley area in the north of Western Australia is an important producer of zinc, lead, iron ore, and diamonds and is prospective for gold, bauxite, coal, copper, tungsten, tin, beryl, mica, corundum, uranium, and clays. However, much of this rugged and remote region of the state remains relatively underexplored. This report reviews the geology of the area and the history of mining and exploration, and gives examples of mineral occurrences for each style of mineralization, the controls on mineralization, and the potential for new discoveries. More than 800 mineral occurrences for the region are incorporated in the digital dataset on the CD-ROM. A 1:500 000-scale map of the west Kimberley also accompanies the CD.

This Report is published in digital format (PDF) and is available online at: www.doir.wa.gov.au/gswa. This copy is provided for reference only. Laser-printed copies can be ordered from the Information Centre for the cost of printing and binding.

Further details of geological publications and maps produced by the Geological Survey of Western Australia can be obtained by contacting:

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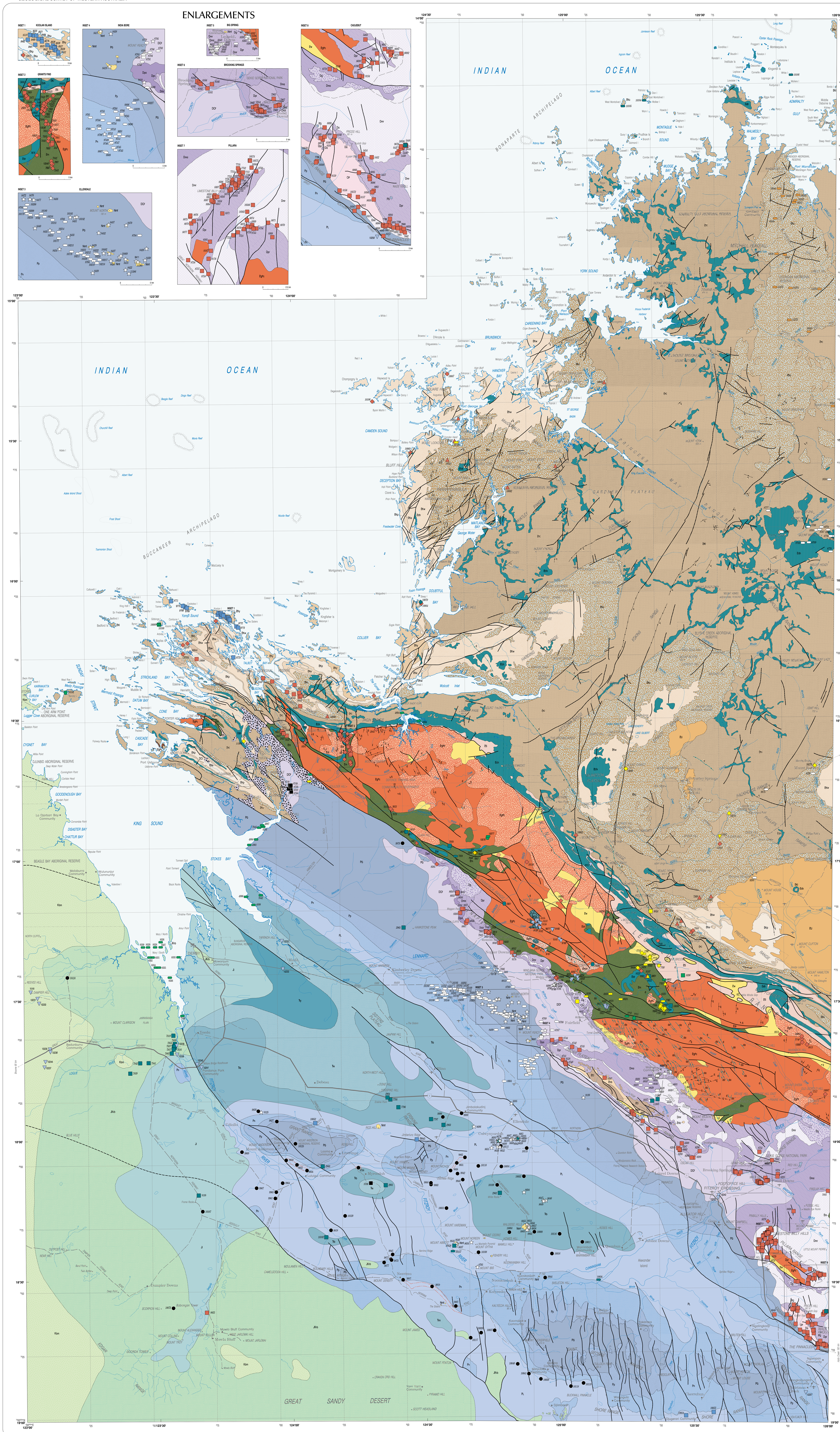
www.doir.wa.gov.au/gswa

HASSAN

Mineral occurrences and exploration potential of the west Kimberley

REPORT 88

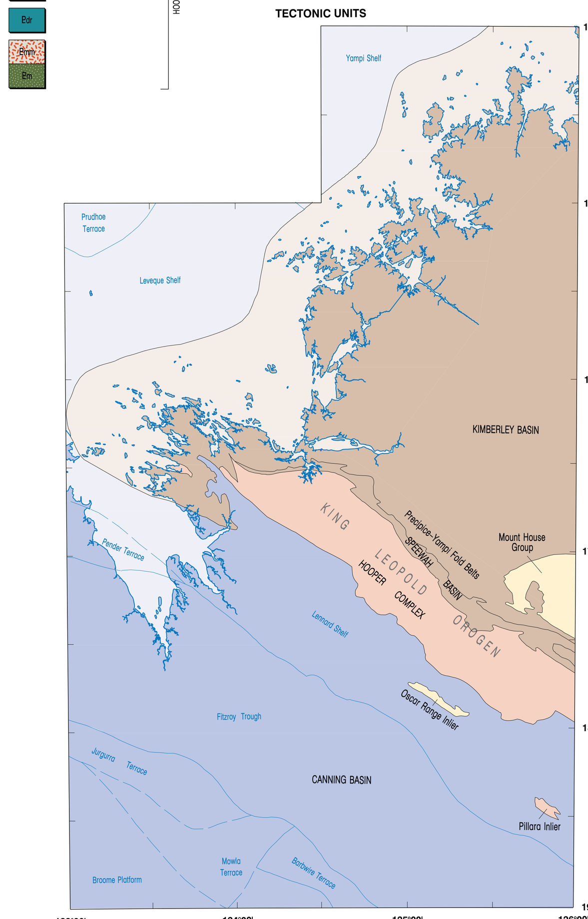
ENLARGEMENTS



REFERENCE

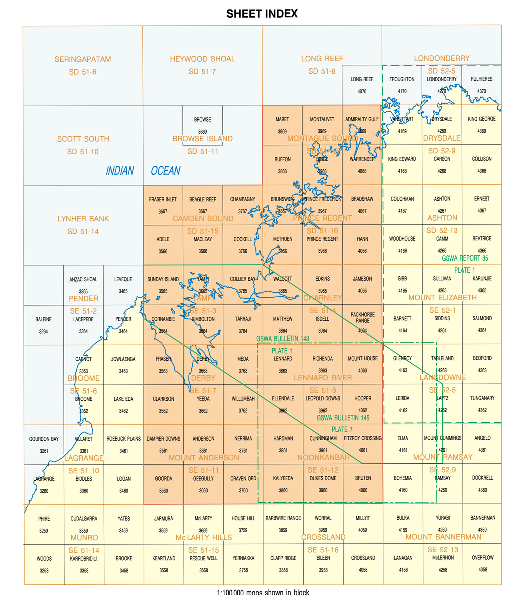
SYMBOLS

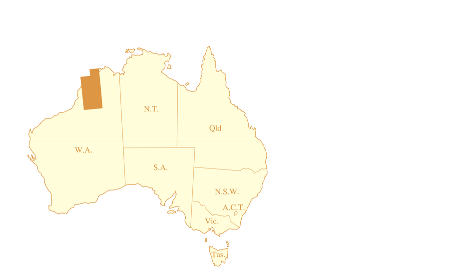
TECTONIC UNITS



SCALE 1:2 500 000

SHEET INDEX





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Interpreted Geochronology by:

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Edited by G. Hall and B. Williams

Cartography by A. Francois

Mineralization information on this map is from non-confidential data held in the WAMIN database, GSWA at October 2003

Topography from the Department of Land Information with modifications from geological field survey

Published by the Geological Survey of Western Australia. Digital and hard copies of this map are available from the Information Centre, Department of Industry and Resources, 100 Plain Street, East Perth, WA, 6004. Phone (08) 9222 3459, Fax (08) 9222 3444 Web www.doir.wa.gov.au Email geological.survey@doir.wa.gov.au

Plotted by the Geological Survey of Western Australia

The recommended reference for this map is:
HASSAN, L. Y., GRIFFIN, T. J., TYLER, I. M., HOCKING, R. M., and FLINT, R., 2003, Mineralization and geology of the west Kimberley (1:500 000), *in* Mineral occurrences and exploration potential of the west Kimberley *by* L. Y. HASSAN: Western Australia Geological Survey, Report 88, Plate 1

MINERAL OCCURRENCES

The detailed list of mineral occurrences is in Appendix 1 of Report 88

MINERALIZATION STYLES	MINERAL AND ROCK COMMODITY GROUPS
Lamproite	Precious mineral (Dmd, Sapp)
Pegmatite	Precious metal (Au, Ag)
Orthomagmatic mafic and ultramafic	Steel industry metal (W, Ni)
Vein and hydrothermal	Speciality metal (HM, Ilm, Mag, Rt, Sn, Ta, Ti, Zr)
Stratabound volcanic and sedimentary	Base metal (Cu, Pb, Zn)
Stratabound sedimentary	Iron (Fe)
Basin hosted	Aluminium (Bx)
Regolith hosted	Energy (Coal, U)
Undivided	Industrial mineral (Mica, Brl, Cor, Ky, Bent, Fel, Fl, Glt, Lst, Och, Phos, Salt)
	Construction material (Dlt, Gran, Gvl, Lst, Sd, Sdst)

Mineral occurrences and numbers are from the GSWA WAMIN database

OPERATING STATUS AND SITE IDENTIFICATION NUMBER

Operating mine	e.g. 9161
Abandoned mine	e.g. *8797*
Mineral deposit	e.g. 9183
Mineral occurrence or prospect	e.g. 8388

Department of Industry and Resources
CLIVE BROWN, M.L.A.
MINISTER FOR STATE DEVELOPMENT
JIM LIMERICK
DIRECTOR GENERAL

Geological Survey of Western Australia
TIM GRIFFIN
DIRECTOR

SCALE 1:500 000

5000 0 5 10 15 20 25 30 35 40 45 50
Metres Kilometres

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

Grid lines indicate 25 000 metre interval of the Map Grid Australia Zone 51

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

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

REPORT 88 PLATE 1

MINERALIZATION AND GEOLOGY OF THE WEST KIMBERLEY