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MINERAL OCCURRENCES AND EXPLORATION POTENTIAL OF THE NORTH KIMBERLEY

by I. Ruddock

Geological Survey of Western Australia

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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I. Ruddock

Perth 2003

MINISTER FOR STATE DEVELOPMENT
Hon. Clive Brown MLA

DIRECTOR GENERAL, DEPARTMENT OF INDUSTRY AND RESOURCES
Jim Limerick

DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
Tim Griffin

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100 Plain Street
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Cover photograph:
King George Falls and the King George River looking south over the diamond-bearing district of the North Kimberley kimberlite field.
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by

I. Ruddock

Abstract

Because of its remoteness, difficult access, and limited infrastructure, there was little prospecting or exploration activity in the north Kimberley area until the mid-1960s. Since then, exploration has led to the discovery of several significant deposits of bauxite, base metals, and diamonds, but none of these has yet been developed. The area continues to be a focus for diamond exploration and, recently, widespread interest in gold exploration has been sparked following the recovery of alluvial gold in the northeast.

Geologically, the north Kimberley area includes mainly the eastern parts of the Palaeoproterozoic Kimberley and Speewah Basins and the Mesoproterozoic Bastion Basin. To the east these basins unconformably overlie the Palaeoproterozoic Lamboo Complex, which in turn is overlain (to the east) by sedimentary rocks of the Mesoproterozoic Carr Boyd Basin and the Phanerozoic Southern and Northern Bonaparte Basins. In the southwest of the area, the Kimberley and Speewah Basins are thrust over the Palaeoproterozoic Hooper Complex. Also in the southwest, the Kimberley and Speewah Basins are unconformably overlain by sedimentary rocks of the Neoproterozoic Mount House Group and sedimentary rocks of a small part of the Phanerozoic Canning Basin.

In the late 1950s and early 1960s, the bauxite potential of the northwestern part of the area was highlighted during regional exploration by mining companies and geological mapping by the former Bureau of Mineral Resources (now Geoscience Australia) and the Geological Survey of Western Australia. This led to the discovery of extensive bauxite deposits at Cape Bougainville (and at Mitchell Plateau further west). Base metal potential in the east of the area was highlighted in the mid-1960s during oil exploration drilling in the Southern Bonaparte Basin, and in 1971 this led to the discovery of stratabound sedimentary Mississippi Valley-type deposits of lead–silver–zinc at Sorby Hills. In the late 1960s and early 1970s, exploration targeted stratabound copper mineralization in the mafic Carson Volcanics, the Elgee Siltstone, and the Pentecost Sandstone, within the Kimberley Basin, but no economic mineralization was located. Diamond exploration in the mid-1970s, in the northeastern and central parts of the Kimberley Basin, led to the discovery of alluvial diamonds and a diamondiferous kimberlitic pipe at Pteropus Creek with an additional (barren) pipe at Skerring and several barren kimberlitic dykes. Further exploration from the mid-1980s to early 1990s located diamondiferous intrusions at Aries, Seppelt, Ashmore, and Lower Bulgurri. Exploration for offshore accumulations of diamonds recovered some diamonds between 1988 and 1993, but bulk testing of diamondiferous horizons just below the seabed, using high-cost ship-mounted recovery systems, was abandoned after encountering technical difficulties with sampling equipment.

In more recent developments, there have been assessments of the feasibility of diamond production from known kimberlite pipes in the northeast of the area at Seppelt and Ashmore, also in the southwest at Aries. Exploration to locate large kimberlite intrusions in these areas is currently using an airborne gravity technique and various hyperspectral remote-sensing methods. Also in the northeast of the area, possible vein gold mineralization was recognized during diamond exploration in 2001, and exploration for similar gold mineralization is currently being carried out elsewhere in the Kimberley Basin. Interest in base metals, however, has waned since the mid-1990s with plans to quarantine the Sorby Hills deposits from further development in favour of a major expansion of the Ord River Irrigation Scheme.

KEYWORDS: mineral exploration, mineral occurrences, mineralization, Lamboo Complex, Hooper Complex, Speewah Basin, Kimberley Basin, Hart Dolerite, Bastion Basin, Carr Boyd Basin, Mount House Group, Southern Bonaparte Basin, Northern Bonaparte Basin, Canning Basin, kimberlite intrusions, regolith, impact structure, diamond, bauxite, copper, lead, zinc, silver, gold, iron ore, uranium, heavy minerals, coal, salt, gypsum, phosphate, barite, fluorite.

Introduction

Present study

This study of the north Kimberley area aims to promote and enhance the mineral prospectivity of this remote region by presenting an up-to-date review of its geological setting, mineral exploration history, mineral occurrences, and the controls on mineralization in the area. The study collates information from all available published sources and, in particular, it incorporates information held in databases of the Geological Survey of Western Australia (GSWA) covering mineral exploration activity, mineral occurrences, and mineral resources.

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 former Department of Mineral and Petroleum Resources (MPR), now Department of Industry and Resources (DoIR);
- the database of Western Australia's mines and mineral deposits information (MINEDEX) held at MPR;
- books, journals, industry publications and datasets, Australian Stock Exchange reports and announcements, and company web sites;
- regional geological and airborne geophysical surveys and remote-sensing datasets.

This study of the mineral prospectivity of the north Kimberley has three main parts: this report, a 1:500 000-scale map (Plate 1), and a digital dataset on CD-ROM. The report reviews the regional geology of the area, the history of mining and mineral exploration, the main mineral occurrences, the mineralization controls, and the potential for further mineralization. Plate 1 shows the mineral occurrences, indicating commodity and mineralization style, on a geological map (a simplified interpretation of the bedrock geology and regolith). The key to the mineral occurrences on Plate 1 is provided in Appendix 1. Where mineral occurrences are referred to in the report they are also identified by the WAMIN 'deposit name' and the WAMIN 'deposit number' shown thus: Seppelt 2 (**10522**).

In order to show the continuity of mineral occurrence distribution, in relation to geological units, Plate 1 also includes the mineralization and geology of the northern part of the east Kimberley area that was studied by Hassan (2000). Text figures 12–14, 17, and 19–20 show the distribution of mineral occurrences according to mineralization style and commodity group.

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

The accompanying CD-ROM includes all the data used to compile the report and Plate 1, and it also includes files of geophysical, remote sensing, topographic, and mining tenement position data. The CD-ROM contains the files necessary for viewing the data in the ArcView GIS environment plus 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.

Location, physiography, climate, and access

The north Kimberley area covered in this report includes the six 1:250 000-scale geological map sheets — DRYSDALE and LONDONDERRY*, ASHTON, MOUNT ELIZABETH, LANSDOWNE, MEDUSA BANKS, and CAMBRIDGE GULF (Fig. 1). Main centres of population are Kununurra, the regional capital (population 6000), and Wyndham (population 1000), the regional port on Cambridge Gulf that services the local cattle industry, the Ord River Irrigation Project, and the zinc–lead mining operations in the west Kimberley at Lennard Shelf.

The area is broadly divided into five main physiographic units (Fig. 2) based on the criteria used by Plumb and Gemuts (1976):

- Kimberley Plateau (and escarpments)
- Kimberley Foreland
- Bow River and Lamboo Hills
- Cambridge Gulf Lowlands
- Tidal flats

The Kimberley Plateau is an irregular dissected plateau with distinctive prominent escarpments, in particular the northerly trending Carson Escarpment. The seaward edge of the plateau is marked by the scenically attractive, rugged ria coastline that is typical of a submergent coast. Coral reefs are developed around many of the northerly islands and peninsulas, as far east as Cape Rulhieres. The Kimberley Plateau has been further subdivided into three parts that are closely related to underlying bedrocks of the Kimberley Basin (Gellatly and Sofoulis, 1969). From west to east these are Prince Regent Plateau, Gibb Hills, and Karunjie Plateau. The Prince Regent Plateau is underlain by the King Leopold Sandstone, the Gibb Hills by the Carson Volcanics, and the Karunjie Plateau by the Warton Sandstone, Elgee Siltstone, and Pentecost Sandstone.

The Kimberley Foreland flanks the Kimberley Plateau to the east and south, and it includes areas of elongated, high, almost vertical scarps that face outward from the central plateau area, in particular the King Leopold and Durack Ranges. The Bow River and Lamboo Hills lie to the south of the Kimberley Foreland and include ridges and rounded hills of moderate relief formed by rocks of the Hooper and Lamboo Complexes. The Cambridge Gulf lowlands spread over most of the area to the east of Cambridge Gulf, and include alluvial, erosional, and residual plains with numerous isolated residual hills (such as Onslow Hills and Weaber Range). Tidal flats include

* Capitalized names refer to standard map sheets

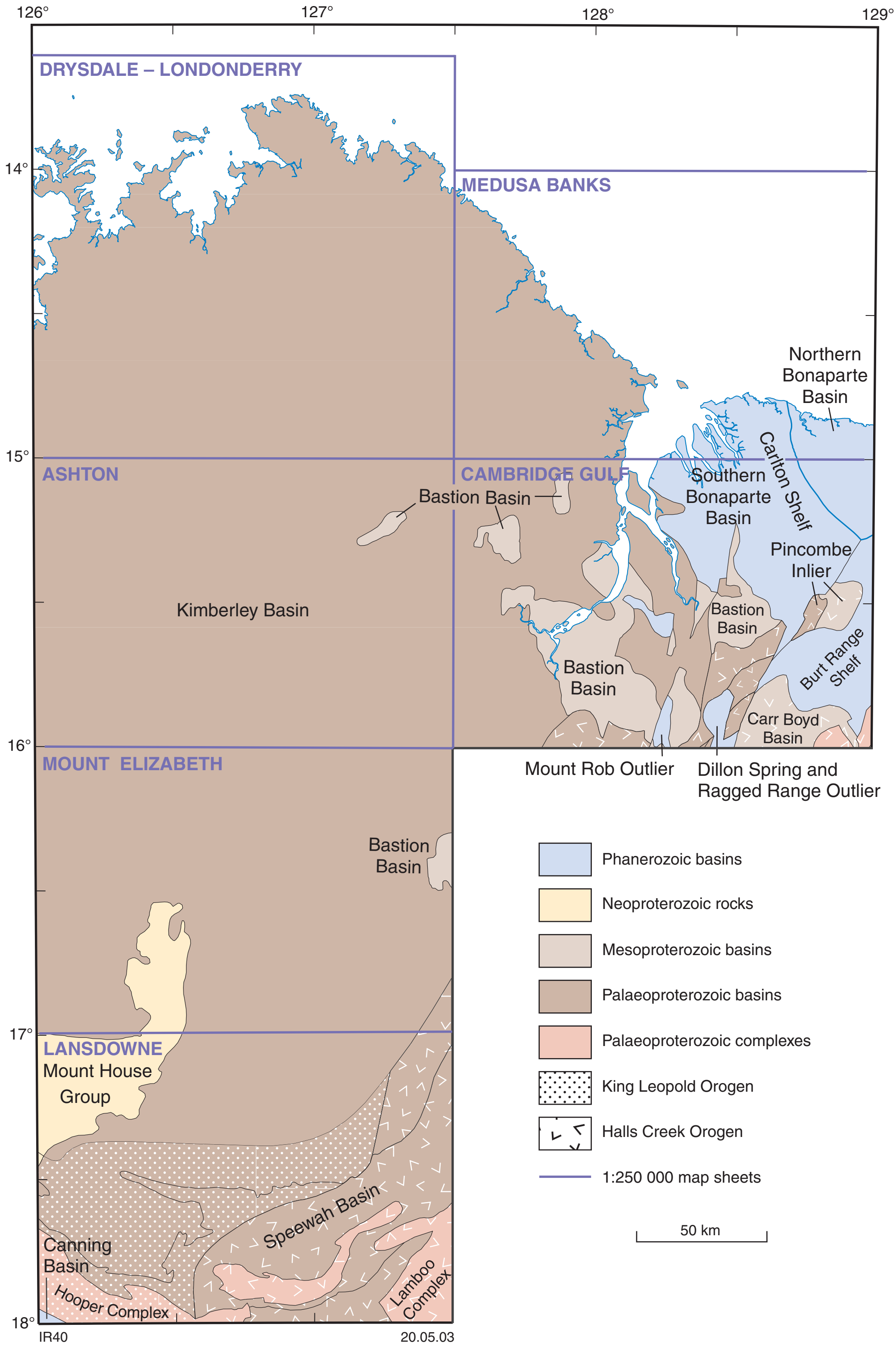

Figure 1. Tectonic units of the north Kimberley, showing boundaries of the six 1: 250 000 geological maps included in the area

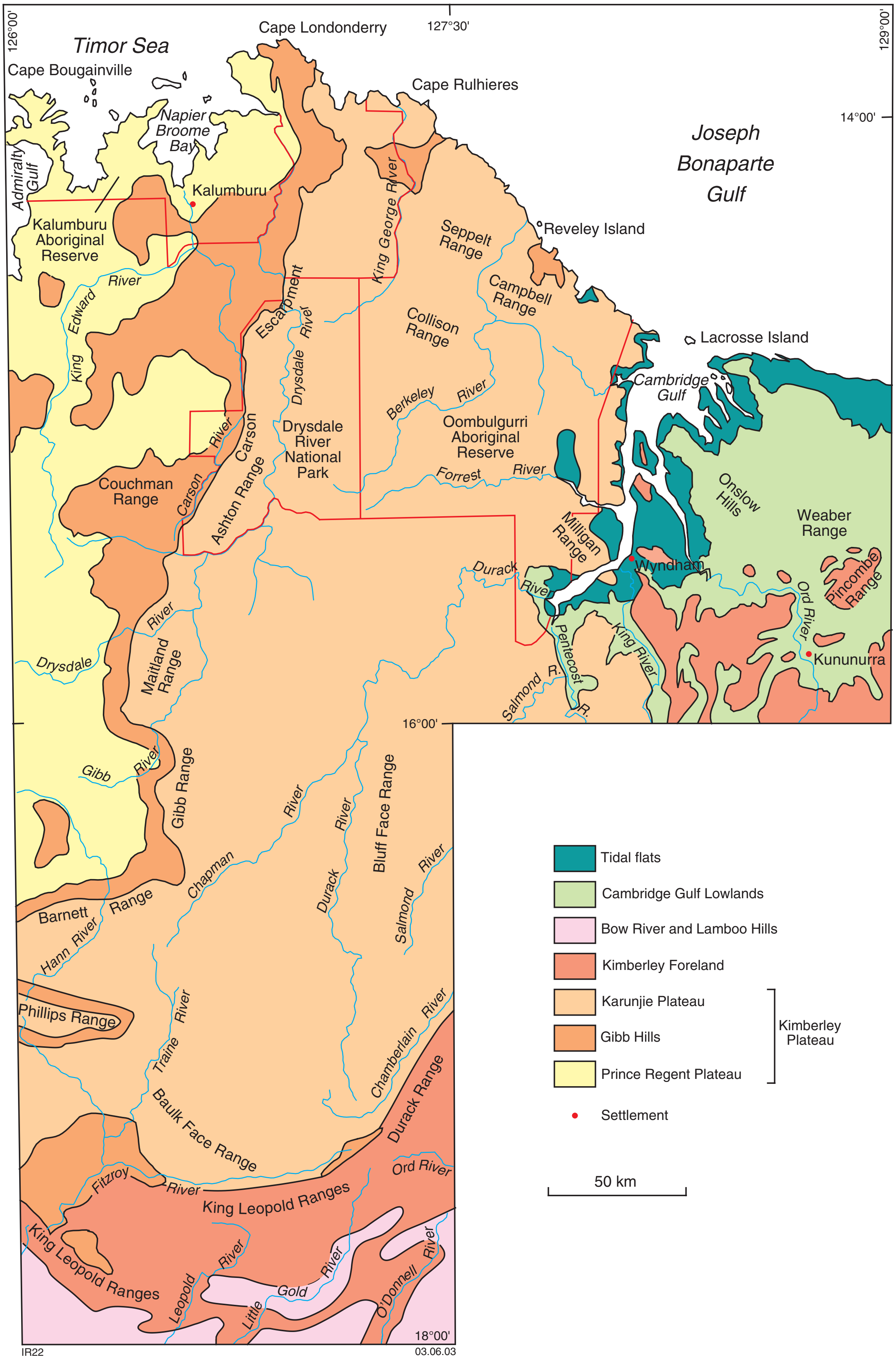

Figure 2. Location map of the north Kimberley, showing physiographic units, towns, settlements, and boundaries of the Drysdale River National Park, and the Kalumburu and Oombulgurri Aboriginal Reserves

extensive areas of mangrove swamps, samphire flats, silt and mud flats, plus areas of coastal dunes, which occur along the southern coast of Joseph Bonaparte Gulf and around Cambridge Gulf; smaller areas of tidal mangrove swamps also fringe the northern ria coastline of the Kimberley Plateau.

Numerous large, northerly flowing rivers, with abundant permanent waterholes in the dry season, characterize the scenic north Kimberley area. These rivers from west to east are as follows: the King Edward and its tributary the Carson, the Drysdale and its tributary the Gibb; the King George; the Berkeley and its tributary the De Lancourt; the Forrest; the Durack and its tributary the Chapman; the Pentecost and its tributaries the Chamberlain and the Salmond; and the Ord. In the southwest, the area is drained by the westerly flowing Fitzroy River and its southerly flowing tributaries the Hann, the Traine, the Leopold, the Little Gold, and the O'Donnell Rivers (Fig. 2 and Plate 1).

The area has a semi-arid monsoonal tropical climate, with an annual rainfall ranging from about 1000 mm in the northwest (Kalumburu) to about 750 mm in the east (Kununurra). Most of the rain falls during the tropical thunderstorms and cyclones of the 'wet' season from November to April. During the wet season the days are hot and humid, with temperatures ranging between daytime maxima of around 36°C to night-time minima of around 27°C. During the 'dry' season from May to October the days are warm and dry with diurnal temperature ranges between 30°C and 19°C.

Vegetation of the area has been described in detail by Beard (1979, 1981) and Petheram and Kok (1983). The plateau areas are covered by high-grass savanna open woodland together with spinifex low-tree savanna; there is denser vegetation cover along numerous watercourses. Isolated small pockets of rainforest also occur, mainly along the near-coastal strip of land around the north Kimberley and west of the Carson Escarpment along the drainages of the King Edward and Drysdale Rivers (McKenzie et al., 1991). Mangroves fringe much of the coastline.

The sealed Great Northern Highway provides the main road access to the area, linking with a network of unsealed graded shire and pastoral roads and tracks that provide reasonable access in the east of the north Kimberley over areas of low relief. Access for motor vehicles in the dissected plateau areas is limited to the graded Gibb River Road and Kalumburu Road, plus pastoral station tracks, and several tracks that have been developed and maintained by mineral exploration companies. However, for many mineral exploration activities much of the region is only accessible by helicopter or light aircraft. Heavy rainfall during the wet season causes flooding in the main drainage systems with consequent frequent disruptions to road traffic; most of the tracks in the plateau area are inaccessible to vehicles between November and April each year.

A daily air service operates between Perth and Kununurra, and there are other smaller airfields at Wyndham and Kalumburu. The main economic activities in the north Kimberley area are tropical farming and horticulture in the Ord River Irrigation Project and cattle ranching elsewhere. The area has also become a major tourist region in the State, based on the outstanding scenery offered by its natural features, and many tour operators use Kununurra as a base for their activities.

Pastoral leases cover some 62% of the area, National Parks and conservation areas occupy about 5%, Aboriginal Reserves occupy about 17%, and Vacant Crown Land makes up about 13% of the region. There are various requirements relating to access for exploration and mining activities and these are referred to in guidelines issued by the former Department of Minerals and Energy* (1996, 1998a,b).

All new mining tenement applications and tenement renewals under the Mining Act 1978 are subject to the legislation and procedures of the Commonwealth Native Title Act 1993, except where it is determined that the applications or renewals are over land where native title has been extinguished. This requirement does not affect applications and renewals for offshore mineral tenure under the Commonwealth Offshore Minerals Act 1994.

Previous work

The earliest non-geological exploration in the north Kimberley was in 1898 by Hann, who named many of the topographical features in the south of the area (Hann, 1901; Donaldson and Elliot, 1998). The first geological reconnaissance in the area was in 1901 by Maitland and Gibson of GSWA (Maitland, 1902), who accompanied the land-survey party of Brockman and Crossland that assessed the area's suitability for pastoral land development (Brockman and Crossland, 1901). Maitland joined the expedition to investigate the mineral potential of the north Kimberley, particularly in the valley of the Carson River where, in 1886, an explorer had suggested there was gold potential (Maitland, 1902). Although Maitland intended to publish a full report on his work it was never completed, presumably due to priorities of his other geoscientific work in the Eastern Goldfields and the Pilbara. However, in some later publications he did make brief reference to the volcanic rocks (Carson Volcanics) he had examined on the Kimberley Plateau, suggesting they were of Tertiary age (Maitland, 1907, 1928). Mafic rock samples collected on the 1901 expedition were initially described by Farquharson (1902). The rocks were further studied and analysed by Edwards (1943), who also produced a geological sketch map based on Maitland's 1901 investigations. Edwards also studied other rock samples that were collected by Fitzgerald (1907), a botanist (and prospector), who accompanied another Kimberley expedition led by Crossland in 1905. Fitzgerald (1907) provided geological field descriptions of the country he traversed, in particular the 'eruptive series' of rocks (Carson Volcanics). He also obtained samples of auriferous quartz reefs that intruded the volcanic rocks, but his account of these reefs appears to

* Renamed Department of Mineral and Petroleum Resources, which, in 2003, became Department of Industry and Resources (DoIR)

have been overlooked by later authors in their descriptions of the geology and mineralization of the Kimberley. Geological observations were also made in 1921 by the surveyor Easton (1922), and a copy of his north Kimberley map appears in the later physiographical study of Jutson (1950).

As part of a more detailed land classification survey of the north Kimberley by the Commonwealth Scientific & Industrial Research Organisation (CSIRO) in 1954, Speck et al. (1960) included a generalized geological map of the area based on their photo-interpretation and observations in addition to information from Traves (1955a,b). Harms (1959) produced a more detailed map of all of the Kimberley area and revised the stratigraphic nomenclature of Traves (1955b); the report of Harms provided a framework for the later regional mapping (referred to below) of the Bureau of Mineral Resources (BMR)* and GSWA. In the east of the area, south of Joseph Bonaparte Gulf, the first stratigraphic study was carried out by Matheson and Teichert (1948) and this was extended in a more detailed study by Traves (1955b).

Systematic 1:250 000-scale geological mapping in the north Kimberley, largely of a reconnaissance nature, was carried out during the mid-1960s in a joint program by BMR and GSWA, with coverage including DRYSDALE and LONDONDERRY, ASHTON, MOUNT ELIZABETH, LANSDOWNE, MEDUSA BANKS, and CAMBRIDGE GULF (Derrick, 1966, 1969; Gellatly and Sofoulis, 1966, 1969; Gellatly and Derrick, 1967; Plumb and Veevers, 1971; Plumb and Perry, 1969, 1971; Roberts and Perry, 1969; Gellatly et al., 1965, 1975). Although BMR intended to publish a bulletin on the Kimberley Basin based on the results of this mapping program, the project was curtailed and only the 1:500 000-scale geological map that was to accompany the bulletin was published (Plumb et al., 1976). Also, some of the information to be included in the bulletin was published separately (Plumb and Gemuts, 1976; Plumb et al., 1981; Plumb et al., 1985).

In the Bonaparte Basin BMR undertook detailed investigations in the early 1960s (Kaulback and Veevers, 1969; Roberts and Veevers, 1973). GSWA carried out a further detailed study of the onshore Bonaparte Basin during the early 1980s (Mory and Beere, 1988) and a later detailed study of the offshore Bonaparte Basin (Mory, 1991). Reviews were also made of the geology of the Kimberley Basin by Griffin and Grey (1990) and the geology of the Bonaparte Basin by Mory (1990). During a remapping program of the East Kimberley carried out by GSWA in the early 1990s, much of LANSDOWNE was also re-interpreted and this has been incorporated in the latest 1:500 000-scale bedrock geology interpretation of the north Kimberley (Tyler, 2000).

Since the early 1960s GSWA has published a number of commodity-specific and commodity-related studies of the State, and these include details of mineral occurrences in the north Kimberley: lead–zinc–silver (Blockley, 1971; Ringrose, 1989; Ferguson, 1999); bauxite (Smurthwaite, 1990); diamonds (Jaques et al., 1986); and copper (Low, 1963; Marston, 1979). As part of the BMR–GSWA joint mapping program of the 1960s, Roberts et al. (1966) reported on some copper occurrences in the north Kimberley, and a geochemical orientation study of stream sediments and rocks on LANSDOWNE was undertaken by Gellatly (1967). There has also been a small number of research papers and articles on the geology and mineralization of the north Kimberley (other than studies by GSWA and AGSO), and references to these are provided in other parts of this report where appropriate. More recently, mineral deposits and exploration in the north Kimberley have also been discussed in a regional appraisal of the prospectivity of the whole Kimberley Region for State planning purposes (Department of Resources Development and Department of Minerals and Energy, 1997).

* The Bureau of Mineral Resources (BMR) later became the Australian Geological Survey Organisation (AGSO), and in 2001 it became Geoscience Australia (GA)

Regional geology

Most of the north Kimberley area includes Palaeoproterozoic rocks of the Speewah and Kimberley Basins that overlie the postulated, but unexposed, Kimberley Craton — stable continental crust that may include Archaean rocks and earlier Palaeoproterozoic rocks (Tyler et al., 1999). On the southeastern and southwestern flanks of these basins there are other Palaeoproterozoic rocks that form parts of the Halls Creek Orogen (Lamboo Complex) and the King Leopold Orogen (Hooper Complex). Mesoproterozoic rocks in the Bastion Basin (and other outliers of this) overlie the Kimberley Basin in the east, and other Mesoproterozoic rocks in the Carr Boyd Basin form part of the Halls Creek Orogen. In the southwest, Neoproterozoic rocks (Mount House Group) overlie the Speewah and Kimberley Basins. Phanerozoic rocks of the Southern and Northern Bonaparte Basins are in the easternmost part of the area, and a very small part of the northeastern Canning Basin lies in the far southwest (Fig. 1). The 1:500 000-scale map showing the regional geology and mineralization (Plate 1) and the digital geological data on the CD-ROM, which accompany this report, are based on the 1:250 000 and 1:500 000-scale geological maps of the north Kimberley that were published by GSWA and BMR between 1966 and 1976, the 1:250 000-scale GSWA geological maps of the Bonaparte Basin (Mory and Beere, 1988) and the 1:500 000-scale GSWA geological map of the east Kimberley (Tyler, 2000). Cainozoic regolith units have been interpreted from the GSWA and BMR 1:250 000-scale geological maps of the area.

Halls Creek and King Leopold Orogens

The Halls Creek and King Leopold Orogens initially developed during the Palaeoproterozoic (Page and Hancock, 1988; Tyler et al., 1999; Blake et al., 2000; Page et al., 2001) between the Kimberley Craton to the northwest and the North Australian Craton to the east and south (Sheppard et al., 1999; Tyler et al., in prep.). The orogens flank the Kimberley Craton (now covered by the Speewah and Kimberley Basins) along its southwestern and southeastern edges (Fig. 1). Further tectonism within the orogens occurred intermittently during the Proterozoic and Phanerozoic (Tyler et al., 1995, in prep.; Blake et al., 2000).

Halls Creek Orogen

The oldest part of the orogen is the Palaeoproterozoic Lamboo Complex (Gemuts, 1971; Griffin and Grey, 1990; Tyler et al., in prep.), with the younger parts of the orogen comprising the folded margins of the Palaeoproterozoic Speewah and Kimberley Basins (the Durack Fold Belt) and the deformed parts of later Proterozoic and Phanerozoic sedimentary basins; the distribution of these units and the limits of orogenic deformation are shown on Figure 1.

Lamboo Complex (Palaeoproterozoic)

The Lamboo Complex consists of plutonic rocks and metamorphosed sedimentary and volcanic rocks that developed within three main tectonic components: the Western, Central, and Eastern Zones, each of which has a distinct stratigraphy and metamorphic and structural history (Tyler et al., 1995; Blake et al., 2000; Tyler et al., in prep.). These three zones have been interpreted as tectonostratigraphic terranes that were moved into their present positions (by subduction and large-scale faulting) by c. 1820 Ma, when they were all intruded by plutons of granite and gabbro (Tyler et al., 1995; Sheppard et al., 1999, 2001; Griffin et al., 2000; Tyler et al., in prep.); only the Western Zone is represented in the north Kimberley area. Earlier models for the development of the Lamboo Complex described it as intracratonic, based on the correlation of rock units across the Halls Creek Fault (Hancock and Rutland, 1984; Page and Hancock, 1988). But more recent work by Tyler et al. (1999) has shown these correlations to be incorrect, suggesting instead that the Lamboo Complex may represent a Palaeoproterozoic plate collision zone, based on the difference in the geophysical nature of the crust on either side of the complex (Shaw et al., 2000) and the presence of terranes (Tyler et al., 1995, 1999).

In the north Kimberley area the Western Zone of the Lamboo Complex lies in the southeastern part of LANSDOWNE, where it is represented by the Whitewater Volcanics, the Marboo Formation, and felsic intrusive rocks of the Paperbark Supersuite.

King Leopold Orogen

The oldest part of the orogen is the Palaeoproterozoic Hooper Complex (Griffin and Grey, 1990), with the younger parts comprising the folded margins of the Palaeoproterozoic Speewah and Kimberley Basins and deformed parts of the Neoproterozoic Mount House Group (Precipice–Yampi Fold Belts); the distribution of these units and the limits of orogenic deformation are shown on Figure 1.

Hooper Complex (Palaeoproterozoic)

The Hooper Complex is a northwestern extension of the Western Zone of the Lamboo Complex, and it consists of felsic plutonic rocks (the Paperbark Supersuite), metamorphosed sedimentary rocks (Marboo Formation), metamorphosed mafic intrusive rocks (Ruins Dolerite), and metamorphosed volcanic rocks (Whitewater Volcanics). In the north Kimberley area the complex is exposed in the southwest and south-central parts of LANSDOWNE.

Palaeoproterozoic basins

Most of the north Kimberley area is occupied by sedimentary and volcanic rocks (1835–1790 Ma) of the Speewah Group (deposited in the Speewah Basin) and the Kimberley Group (deposited in the Kimberley Basin). These rocks initially and unconformably overlay the Lamboo and Hooper Complexes (Dow and Gemuts, 1969; Griffin et al., 1993) and the postulated unexposed Kimberley Craton. The Speewah and Kimberley Groups have been described previously by Dow et al. (1964); Plumb (1968); Dow and Gemuts (1969); Gellatly et al. (1970, 1975); Plumb and Derrick (1975); Plumb and Gemuts (1976); Plumb et al. (1981, 1985); Griffin et al. (1993); and Thorne et al. (1999). Prior to this, the earliest stratigraphic subdivision of Kimberley Basin rocks was made by Guppy et al. (1958) as an ancillary part of a major BMR study of the Fitzroy Basin. Recent SHRIMP U–Pb dating of diagenetic xenotime suggests that the upper part of the Kimberley Group may have been deposited at c. 1704 Ma (McNaughton et al., 1999).

The Speewah Group and overlying Kimberley Group were earlier considered to have been deposited in a single 'Kimberley Basin' (Plumb and Gemuts, 1976), but more recent work by Griffin et al. (1993) showed that the two groups are separated by a significant unconformity or disconformity, and that they had different palaeogeographies representing separate basins with different tectonic settings.

The rocks of the Speewah and Kimberley Groups are unconformably overlain, in the east of the area, by sedimentary rocks of the Bastion Group that formed in the Palaeoproterozoic to Mesoproterozoic Bastion Basin. Extensive sills of the Palaeoproterozoic Hart Dolerite intrude the Speewah Group and lower parts of the Kimberley Group.

Speewah Basin

The sedimentary rocks of the Speewah Group comprise six main units (Griffin et al., 1993; Thorne et al., 1999), and these are descibed below. The units represent part of a transgressive–regessive cycle, with fluvial sands passing into or alternating with shallow-marine facies and then back into fluvial sands (Plumb et al., 1981). Measurements of palaeocurrent directions indicate that sediments were derived from the northeast and east (Gellatly et al., 1970).

O'Donnell Formation

The O'Donnell Formation unconformably overlies the Hooper and Lamboo Complexes and is up to 300 m thick. It consists of a lower member of quartz sandstone and minor siltstone, and an upper member of siltstone and thin-bedded sandstone. Locally, the base of the lower member is marked by a pebbly quartz sandstone or conglomerate unit that is up to 5 m thick.

Tunganary Formation

The Tunganary Formation is about 290 m thick and conformably overlies the O'Donnell Formation. It consists of lower and upper sandstone units separated by a prominent central unit of siltstone.

Valentine Siltstone

The Valentine Siltstone conformably overlies the Tunganary Formation and is about 75 m thick. It consists of laminated siltstone and thinly bedded sandstone, and is characterized by thin interbeds of felsic volcanic tuff and tuffaceous siltstone. A rhyolite tuff at the base of the formation on LISSADELL was dated at 1834 ± 3 Ma by Page and Sun (1994). The Valentine Siltstone is extensively intruded by massive sills of the Hart Dolerite.

Lansdowne Arkose

The Lansdowne Arkose is about 400 m thick and conformably overlies the Valentine Siltstone. It consists mainly of feldspathic sandstones that grade into arkose, with subordinate interbeds of poorly sorted quartz sandstone, micaceous siltstone, and shale. The formation forms low, finely terraced, parallel escarpments and is intruded by the Hart Dolerite.

Luman Siltstone

The Luman Siltstone conformably overlies the Lansdowne Arkose and is about 70 m thick. It forms a recessive unit showing steep scarp slopes lying below cliffs of Bedford Sandstone and King Leopold Sandstone. The formation consists of micaceous siltstone and shale, with thin beds of fine-grained feldspathic sandstone.

Bedford Sandstone

The Bedford Sandstone is from 300 to 600 m thick within the north Kimberley area, and forms impressive cliffs in the King Leopold Ranges. In early publications it has been included either in the overlying King Leopold Sandstone (Dow and Gemuts, 1969; Gellatly et al., 1975) or in the underlying Lansdowne Arkose (Derrick and Playford, 1973), but more recently it has been defined as a separate unit (Griffin et al., 1993). The Bedford Sandstone is conformable with the underlying Luman Siltstone, whereas its contact with the overlying King Leopold Sandstone is disconfomable to unconformable (Griffin et al., 1993; Thorne et al., 1999). It is typically a medium- to coarse-grained sandstone with abundant large-scale trough and channel cross-bedding.

Kimberley Basin

The Kimberley Basin contains volcanic and sedimentary rocks of the Kimberley Group that unconformably and disconformaby overlie the Speewah Group (Griffin et al., 1993; Thorne et al., 1999). The rocks of the group were deposited within a broad, semi-enclosed, shallow-marine basin (Plumb et al., 1981) and palaeocurrent measurements indicate that sediments were derived from the north and northwest (Gellatly et al., 1970). The Kimberley Group consists of five main units (Griffin et al., 1993; Thorne et al., 1999), and these are descibed below.

King Leopold Sandstone

The King Leopold Sandstone is the basal unit of the Kimberley Group, and lies unconformably to disconformably on the Speewah Group (Bedford Sandstone or Lansdowne Arkose). It consists of medium- to coarse-grained sandstone (with minor conglomerate, arkose, and fine-grained sandstone) characterized by medium- to large-scale trough cross-stratification (Gellatly et al., 1975; Thorne et al., 1999). The succession is 700 to 1000 m thick and the rocks form spectacular rugged terrain in the north Kimberley, exhibited by prominent ridges and cliffs of the King Leopold Ranges and Durack Range in the south, and a deeply dissected plateau in the northwestern and central areas (Prince Regent Plateau and Phillips Range).

Carson Volcanics

The Carson Volcanics conformably overlie the King Leopold Sandstone and occupy a north-northeasterly trending belt in the western central part of the north Kimberley area, where they dip gently to the east. To the south and east of this, the Carson Volcanics are steeply upturned along the southern and eastern margins of the Kimberley Basin. Several outliers of the volcanic rocks are in the west and northwest of the area and there are two inliers on the northeast coast. The Carson Volcanics vary in thickness between 200 and 700 m across the north Kimberley area, forming rounded hills and low undulating rocky plains (Gibb Hills).

First mentions of the volcanic rocks were by Maitland (1902, 1907, 1928) and Fitzgerald (1907) who both described their field appearance. Farquharson (1902) provided the initial petrographic descriptions of specimens collected by Maitland and Fitzgerald. Further petrographic studies and whole-rock chemical analyses were carried out by Edwards (1943) on specimens from both collections.

The Carson Volcanics consist predominantly of mafic volcanic rocks, containing numerous flows of pillow lava, and subordinate volcaniclastic rocks interlayered with discontinuous beds of quartz sandstone, feldspathic sandstone, siltstone, and chert (Gellatly et al., 1975; Thorne et al., 1999). A purple sandstone unit, containing radioactive lenses of heavy mineral sands (with abundant monazite, zircon, and anatase) at the top of the Carson Volcanics, was located in the Durack Range by Planet Mining during uranium exploration (Planet Mining Co. Pty Ltd, 1970). A thin unit of stromatolitic chert has also been observed near the top of the Carson Volcanics at a number of localities on DRYSDALE and LONDONDERRY, and ASHTON (Derrick, 1966; Gellatly and Sofoulis, 1966; Grey, K., 2001, written comm.); this unit may correlate with a unit of siltstone, shale, and chert on LANSDOWNE that was mapped as 'Kalumburu Formation' by BHP (in joint venture with Western Nuclear) during exploration for uranium in 1969 (Western Nuclear (Australia) Pty Ltd, 1969). The chert unit may represent rather widespread hydrothermal hot-spring activity within the basin at the close of the volcanic period.

The mafic volcanic rocks have been described as tholeiitic basalts and spilites that are typically amygdaloidal, with amygdales containing quartz, epidote, calcite, chalcedony, zeolite, and chalcopyrite; in places non-amygdaloidal spilite contains disseminated chalcopyrite (Derrick, 1969; Gellatly and Sofoulis, 1969; Gellatly et al., 1975). Andesine basalt rocks have been described by Edwards amongst samples of volcanic rocks collected by Fitzgerald (Fitzgerald, 1907; Edwards, 1943).

Subeconomic, stratabound, disseminated copper mineralization is widespread throughout the Kimberley Basin in some lava flows and interflow sedimentary rocks, and this mineralization was the focus for exploration in the late 1960s and early 1970s (Bruinsma, 1970; Klaric, 1971, 1975; Marston, 1979). Derrick (1968) recorded thin quartz veins containing prehnite and galena on ASHTON.

In the northwest of the area the Carson Volcanics are extensively lateritized to form mesa cappings of laterite, and large areas of low- to medium-grade bauxite have been identified (Gellatly and Sofoulis, 1966; Derrick, 1966; Joklik et al., 1975; Bardossy and Aleva, 1990; Smurthwaite, 1990).

The Carson Volcanics represent the generation of extremely large volumes of mafic magma in the Kimberley Basin, suggesting a phase of intracratonic rifting that may be related to mantle-plume activity below the Kimberley Craton.

Warton Sandstone

The Warton Sandstone conformably overlies the Carson Volcanics and consists of coarse-grained quartz sandstone with minor feldspathic sandstone. The sandstone has medium- to large-scale trough cross-stratification and horizontal planar stratification (Gellatly et al., 1975; Thorne et al., 1999). The unit is 300 to 500 m thick and forms most of the Karunjie Plateau in the centre of the area; the lower part of the Warton Sandstone forms the prominent cliffs of the Carson Escarpment that extends north-northeasterly for about 100 km on DRYSDALE and LONDONDERRY, and ASHTON.

Elgee Siltstone

The Elgee Siltstone conformably overlies the Warton Sandstone and is about 150 to 220 m thick. It consists predominantly of distinctive red-brown siltstone with thin interbedded quartz sandstone. A carbonate–siltstone unit at the base is called the Teronis Member (Plumb, 1968; Gellatly et al., 1975). Bruinsma (1970) subdivided the Teronis Member 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 stromatolitic dolomite (Thorne et al., 1999); Teronis III consisting of red-brown siltstone and minor shale; and Teronis IV consisting of green shale, siltstone, sandstone, calcareous sandstone and siltstone, and stromatolitic dolomite. Subeconomic, stratabound, syngenetic copper mineralization is widespread in the Teronis IV unit. Owen (1970) suggested that the Teronis Member represented a tidal-flat, or open shallow-lagoon environment; Klaric (1975) suggested shallow-water marine to estuarine deposition.

Pentecost Sandstone

The Pentecost Sandstone conformably overlies the Elgee Siltstone, and is about 1000 m thick. It has been subdivided into three sandstone units (Gellatly et al., 1975; Thorne et al., 1999). 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 (containing subeconomic syngenetic copper in places); and the upper unit consists of massive, trough cross-bedded quartz sandstone and pebbly sandstone. The unit forms an undulating plateau (eastern part of the Karunjie Plateau) with numerous benches and low scarps, except for a very prominent scarp formed at the contact with the Elgee Siltstone.

Hart Dolerite

The Hart Dolerite forms an extensive series of massive tholeiitic dolerite sills and associated, but less extensive, granophyre intrusions. It is one of the largest dolerite sill complexes in the world and appears to underlie much of the 160 000 km^2 of the Kimberley Basin (Plumb and Gemuts, 1976). The estimated combined thickness of the sills is 3000 m and the estimated total volume is 250 000 km^3 (Plumb and Gemuts, 1976). Such large volumes of mafic magma suggest continued mantle-plume activity below the Kimberley Craton. The most comprehensive account of the Hart Dolerite is that by Gellatly et al. (1975).

The dolerite sills mainly intrude the Speewah Group and the lower parts of the Kimberley Group, but thin sills also intrude units as high as the Pentecost Sandstone. A Palaeoproterozoic age has been established for the Hart Dolerite using a date of c. 1790 Ma determined by SHRIMP U–Pb geochronology (Thorne et al., 1999). Rock types range in composition from olivine dolerite and gabbro, through tholeiitic dolerite, quartz dolerite, granophyric dolerite and diorite, to granophyre. The thickest sheets of granophyre are on LANSDOWNE, where they mainly intrude rocks of the Speewah Group (Gellatly et al., 1975).

Late-stage hydrothermal alteration has produced epidote veins and local prehnite replacement in the dolerite, and there are veins of calcite and quartz, often with trace amounts of chalcopyrite (Gellatly et al., 1975). To the west of Kununurra there are several areas of hydrothermal veins that cut a dolerite sill and contain significant polymetallic silver, gold, and base metal mineralization (Sofoulis, 1968; Moder and Moder, 1985; Ferguson, 1999).

Mesoproterozoic basins

Bastion Basin

The Bastion Group unconformably overlies the Kimberley Group in the Bastion Basin (Thorne et al., 1999). The group includes three formations in ascending order: the Mendena Formation, consisting of sandstone with minor siltstone and carbonate; the Wyndham Shale, consisting of siltstone with minor sandstone; and the Cockburn Sandstone, consisting of quartz sandstone and micaceous sandstone (Plumb and Veevers, 1971; Plumb and Perry, 1971; Gellatly et al., 1975; Thorne et al., 1999). In the southern part of the north Kimberley only the Mendena Formation is present (Roberts and Perry, 1969; Gellatly et al., 1975). The data that support the probable age of the Bastion Group are discussed in Thorne et al. (1999), who suggested that the Bastion Group may be late Palaeoproterozoic to early Mesoproterozoic in age.

Carr Boyd Basin

The sedimentary rocks of the Carr Boyd Group are exposed in the Carr Boyd and Pincombe Ranges in the east of the area, and unconformably overlie rocks of the Palaeoproterozoic Lamboo Complex and the Revolver Creek Formation, which is a probable stratigraphic equivalent of the Kimberley Group (Thorne and Tyler, 1996; Thorne et al., 1999). An estimated 4400 m of sedimentary rocks were deposited in the Carr Boyd Basin and the rocks are divided into the following six formations (in ascending order): Hensman Sandstone, Golden Gate Siltstone, Lissadell Formation, Glenhill Formation, Stonewall Sandstone, and Pincombe Formation*. These are interpreted to have formed in a sandy, braided delta complex and an adjacent siliciclastic marine shelf (Thorne and Tyler, 1996).

Recent work suggests that the Carr Boyd Group has an age of about 1200 Ma and that it probably correlates with the Fitzmaurice Group of the Fitzmaurice Mobile Zone (northeast of the Halls Creek Orogen) in the Northern Territory (Thorne and Tyler, 1996; Thorne et al., 1999).

Kimberlite intrusions

Kimberlites intrude rocks of the Kimberley Group and are mainly in two separate fields (or 'provinces') in the north Kimberley area: the North Kimberley kimberlite field in the northeast of the area and the Phillips Range kimberlite field in the southwest (Fig. 3). The age of the intrusions in both fields is c. 800 Ma (Pidgeon et al., 1989; Edwards et al., 1992; Towie et al., 1994). There may be another small kimberlite field in a downfaulted graben of Kimberley Group rocks, in the Halls Creek Orogen, in southeast LANSDOWNE (Flinders Diamonds Limited, 2001). Kimberlite intrusions have been discovered (and continue to be discovered) in the north Kimberley through diamond exploration that has been ongoing since the 1970s.

In the North Kimberley kimberlite field, diamond-bearing and barren pipes and dykes (Fig. 4) lie along north-northeasterly trending zones subparallel to dolerite dyke swarms that also intrude the Kimberley Group. Kimberlite was first discovered in a breccia pipe at Pteropus Creek in early 1976 (Atkinson et al., 1984; Smith et al., 1990). The Skerring kimberlite pipe and several kimberlite dykes (Jumpup, KGB2, Wishy Washy, Hadfields, and Geebung Airstrip) were discovered soon afterwards. Since 1990 more kimberlitic pipes and dykes have been found at Seppelt, Lower Bulgurri, Ashmore, De Lancourt, Berkeley, Yandil, and Banksia. The dykes are narrow, measuring 0.1 to 2 m across. The approximate areas of surface exposures of the pipes are: Pteropus — 2 ha, Skerring — 1.75 ha, Seppelt — 1.5 ha, and Ashmore pipe cluster — 1 ha.

In the Phillips Range kimberlite field one large kimberlite intrusion called the Aries pipe was discovered in 1986 (Edwards et al., 1992; Towie et al., 1994). It is

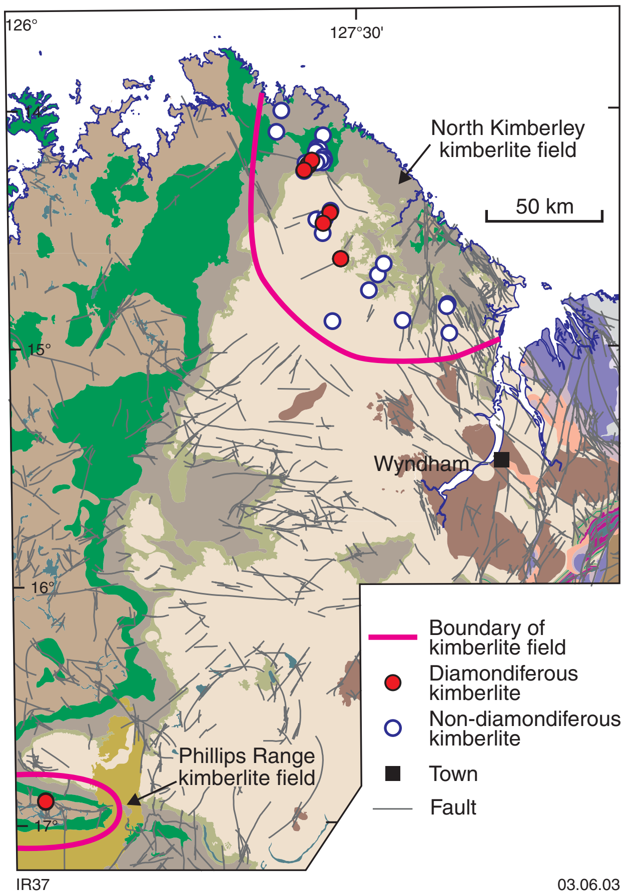

Figure 3. Kimberlite fields in the north Kimberley. See Figure 11 for geological legend

* A fault-bound unit named the 'Bandicoot Range Beds' (Plumb and Veevers, 1971), containing stratabound iron mineralization, is assigned to the Carr Boyd Group but its stratigraphic position within the group is unknown (Plumb and Veevers, 1971; Plumb et al., 1985)

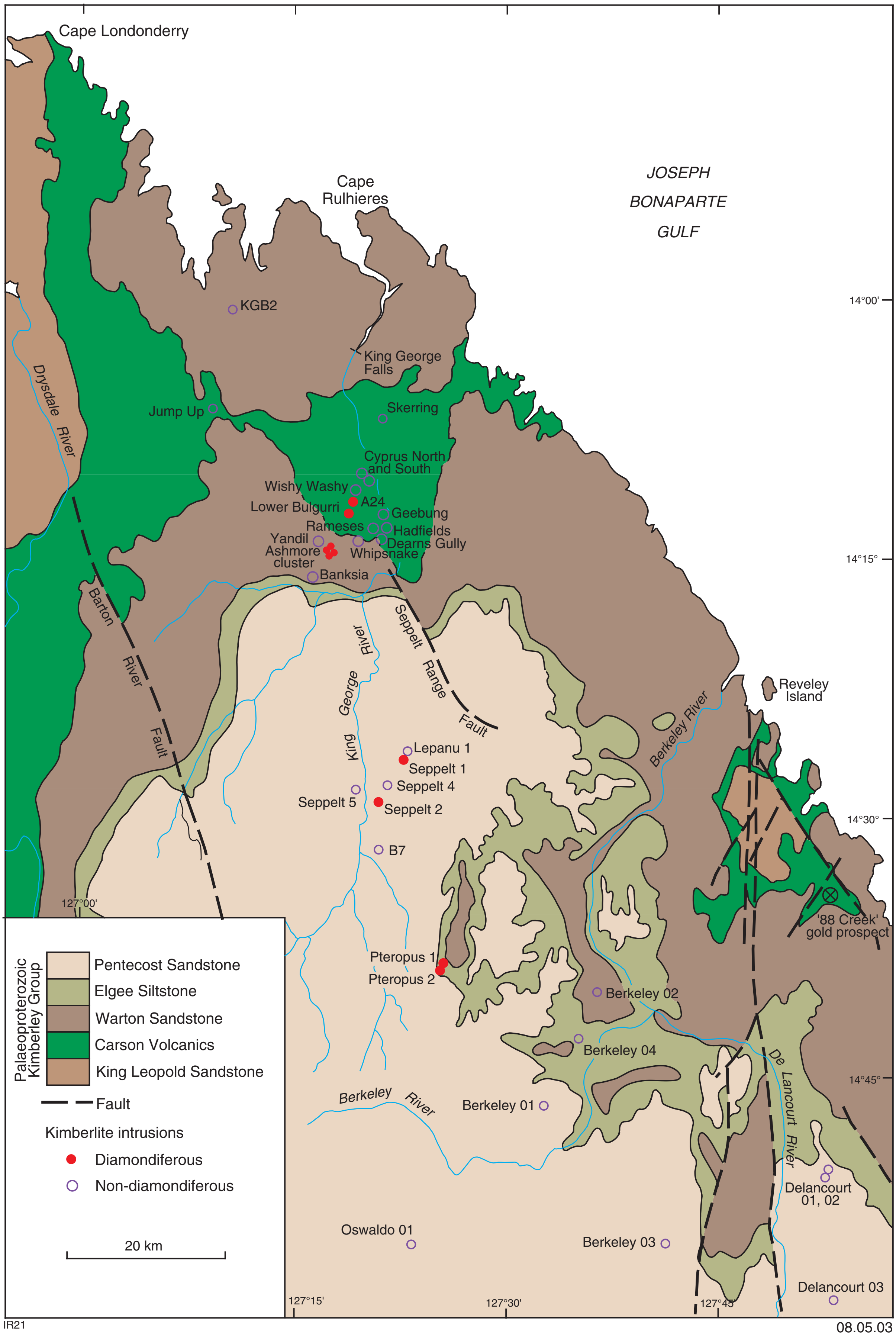

Figure 4. North Kimberley kimberlite field showing diamondiferous and non-diamondiferous kimberlite intrusions. Source: Jaques (2002)

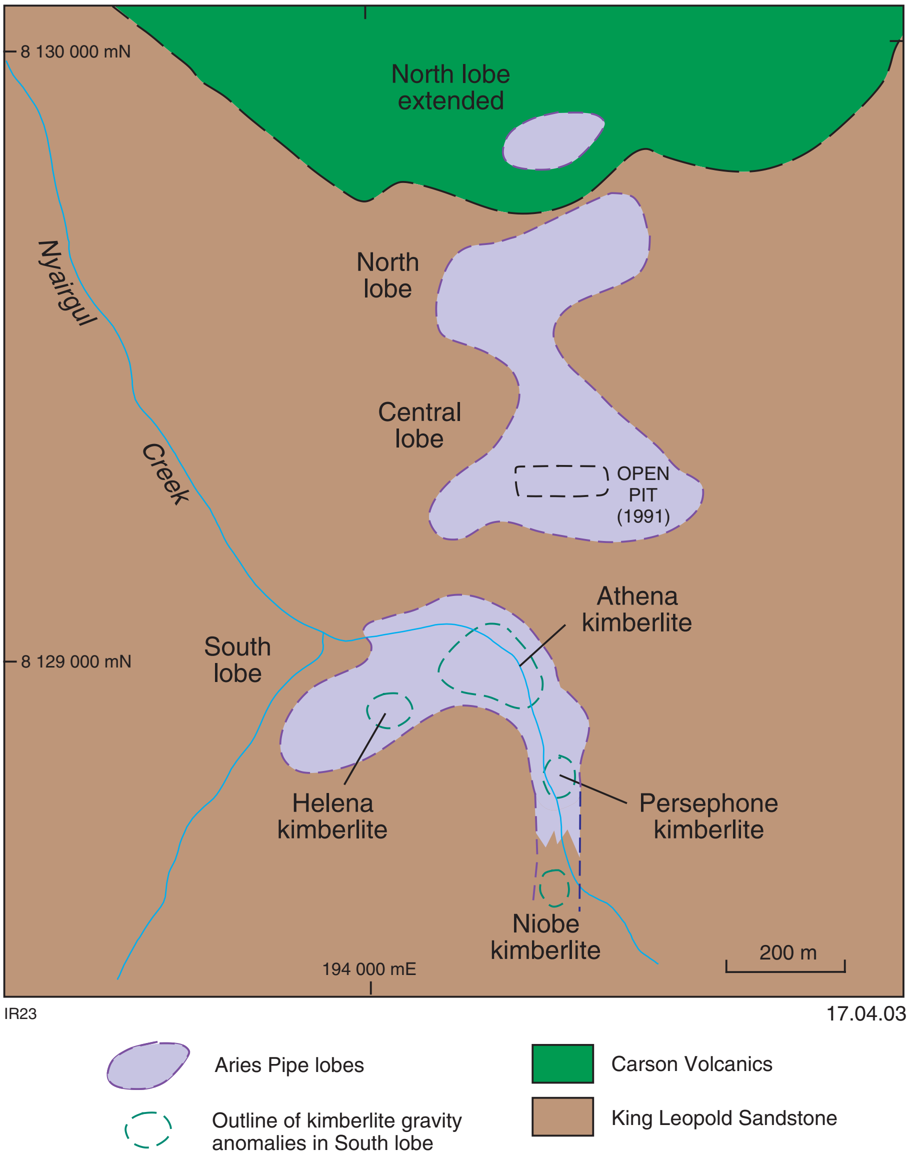

Figure 5. Aries kimberlite pipe in the Phillips Range kimberlite field. Source: Thundelarra Exploration Ltd

Australia's largest kimberlite body (about 18 ha). It is on the northern limb of the Phillips Range Anticline, a major easterly plunging structure (on Mount Elizabeth) in the southern part of the Kimberley Basin. The pipe is concealed beneath a thin veneer of sand, clay, and rubble, and was discovered during exploration drilling. The kimberlite intrudes both the King Leopold Sandstone and the Carson Volcanics, straddling the contact between the two, and its age is c. 820 ± 20 Ma (Edwards et al., 1992). The pipe consists of four lobes that lie within a north–south trend: the South, Central, and North lobes (intruding King Leopold Sandstone) and the North lobe extended (intruding Carson Volcanics). At its southern edge South lobe passes into a series of small dykes and stringers within sandstone, and Edwards et al. (1992) suggested that the present morphology of the pipe is typical of the root zone of an original, much larger, diatreme. Exploration within Aries South lobe since 2000, by Thundelarra Exploration Ltd and joint venture partner BHP–Billiton Ltd, has identified four separate diamondiferous kimberlite bodies called Helena, Athena, Persephone, and Niobe (Fig. 5; Thundelarra Exploration Ltd, announcement to Australian Stock Exchange (ASX), 15 February 2002).

Edwards et al. (1992) recognized three textural varieties of Aries kimberlite, together with autoclastic breccias, below the upper weathered portion of the pipe: uniformly textured medium-grained macrocrystal kimberlite; uniformly textured aphanitic macrocrystal kimberlite; and macrocrystal segregated kimberlite (containing numerous country-rock xenoliths and clasts of kimberlite). The autoclastic breccias are rich in country-rock xenoliths, but there are no polymineralic-mantle or deep-crustal xenoliths.

The other possible small field known as Skeleton Flats in the Mad Gap Yards area, about 65 km northwest of

Halls Creek, was identified during diamond exploration in 1995–96 (Diamin Resources NL, 1996; Flinders Diamonds Limited, 2001). Near two sites where alluvial diamonds were recovered, drilling intersected barren kimberlite bodies that appear to be aligned in a north-northeasterly direction, subparallel to the Greenvale Fault that is 1 to 2 km to the west (this is a similar structural setting to the Argyle AK1 pipe).

Spider impact structure (Mesoproterozoic to Neoproterozoic)

This structure was first noticed on aerial photographs by Harms (1959) during his regional minerals assessment work for BHP: he referred to it as a 'glacial feature' on a map accompanying his report. It is also shown as a distinctive cluster of anastomosing faults near the axis of the Mount Barnett Syncline in southwest MOUNT ELIZABETH (Roberts and Perry, 1969). More recently Shoemaker and Shoemaker (1996) described the feature as an impact structure, about 13 km in diameter, developed in the Pentecost Sandstone. From field observations of topographic features in the Spider structure and the level of unconformity surfaces below the Mount House Group, Shoemaker and Shoemaker (1996) inferred the age of impact to be Mesoproterozoic to Neoproterozoic.

Mount House Group (Neoproterozoic)

In the southwest of the north Kimberley area, the Kimberley Group is unconformably overlain by the Neoproterozoic glacigene rocks of the Mount House Group. The glacigene sequence is about 250 to 550 m thick and consists of four formations (in ascending order): Walsh Tillite, Traine Formation, Throssell Shale, and Estaughs Formation (Derrick and Playford, 1973; Gellatly et al., 1975; Griffin et al., 1993). Stromatolites occur in a dolomite unit at the top of the Walsh Tillite (Gellatly et al., 1975). Below the Walsh Tillite, striations on glaciated pavements of Pentecost Sandstone show that the direction of ice movement was from the north (Perry and Roberts, 1968). Coates and Preiss (1980) assessed the stratigraphy and geochronology of the Mount House Group and suggested that it correlated with the Marinoan glaciation (670 Ma) recognized in South Australia. However, based on palaeomagnetic results, Li (2000) correlated the Walsh Tillite with the older (c. 750 Ma) Sturtian glaciation.

Southern Bonaparte Basin

The Southern Bonaparte Basin covers an area of about 8000 km^2. Onshore it is entirely made up of Palaeozoic sedimentary and volcanic rocks (Mory and Beere, 1988), and includes the following parts of the basin — Carlton Shelf, Burt Range Shelf, Dillon Spring Outlier, Mount Rob Outlier, and Ragged Range Outlier. The three basin outliers lie within the Halls Creek Orogen and on the Kimberley Basin, and are the eroded remnants of a series of grabens (related to strike slip) parallel to the northeasterly trending Halls Creek Fault (Thorne and Tyler, 1996). Within the Southern Bonaparte Basin, north of Kununurra, the Pincombe Inlier is the surface expression of a northeasterly trending palaeohigh of Proterozoic rocks (Carr Boyd Group) that separates the Carlton Shelf and Burt Range Shelf (Fig. 1).

The initiation of the Bonaparte Basin (and adjacent Palaeozoic basins in northern Australia) may have been due to crustal sag that resulted from the removal of a very large amount of mafic magma from the mantle in the Early Cambrian, when huge volumes of continental tholeiitic basalt (Antrim Plateau Volcanics) were erupted at the surface (Veevers, 1967). The resulting interior-sag basin was filled with shallow-marine and marginal-marine siliciclastic rocks during the Middle Cambrian to Ordovician (Carlton Group). Rifting and the development of northwesterly trending faults led to extension of the basin as an interior-fracture basin during the Silurian to Late Carboniferous, with most of the sequence (of the onshore part of the basin) dominated by marine sedimentary rocks of Frasnian to Tournaisian age (Cockatoo, Ningbing, and Langfield Groups) that accumulated on the Carlton and Burt Range Shelves (Mory and Beere, 1988). In the Petrel Sub-basin, thick successions of basinal black shale were deposited continuously from the Frasnian to the Visean (Bonaparte Formation), and in the Early Visean the basinal shale encroached over the two shelves. In the Middle Visean to the Namurian, a deltaic sequence was deposited, which graded offshore into a shelf-carbonate sequence (Weaber Group).

Antrim Plateau Volcanics (Early Cambrian)

The Antrim Plateau Volcanics are unconformable on Proterozoic rocks and consist predominantly of tholeiitic basalt flows, with minor agglomerate, siltstone, sandstone, tuff, and chert. A basal eolian sandstone is developed locally, in the area between Mount Connection and Onslow Hills (Plate 1). The tholeiitic basalt is massive and porphyritic. It is vesicular and amygdaloidal at the tops of flows, with pipe-shaped vesicles at the base of flows. Vesicles are commonly filled with quartz, chert, agate, calcite, prehnite, and pumpellyite. The thickness of the Antrim Plateau Volcanics decreases to the north, from about 500 m in the Mount Rob Outlier to about 100 m on the edge of the Carlton Shelf. Hanley and Wingate (2000) suggested a wider distribution of the Antrim Plateau Volcanics — previously extending westwards over much of the Kimberley Plateau — based on the chemical similarity of the basalts to the 250 km-long Milliwindi dolerite dyke (a probable feeder dyke dated at 513 ± 12 Ma) in the west Kimberley.

Carlton Group (Middle Cambrian to Ordovician)

Sedimentary rocks of the Carlton Group conformably overlie the Antrim Plateau Volcanics. The succession consists predominantly of shallow-marine and subtidal siliciclastic rocks overlain by minor stromatolitic carbonate rocks, and shallow-marine sandstone and shale in the uppermost part. The group outcrops along the southwestern margin of the Carlton Shelf and in outliers to the southwest; these rocks are also in the subsurface along the northern edge of the Pincombe Inlier, but are absent from the Burt Range Shelf.

Unnamed Palaeozoic evaporitic unit (Silurian to Early Devonian)

An evaporitic succession has been interpreted from offshore seismic data. It appears to underlie the Bonaparte Formation of Late Devonian to Early Carboniferous age that is the offshore equivalent to the Cockatoo, Ningbing, and Langfield Groups. Intersections of salt diapirs in petroleum wells (Pelican Island 1) confirm the presence of halite with minor amounts of gypsum and calcite. The age of the unit is inferred to be Silurian to Early Devonian (Mory, 1991).

Cockatoo Group (Frasnian)

The Cockatoo Group rests unconformably on Proterozoic and Carlton Group rocks. The group is predominantly a coarse- to medium-grained siliciclastic succession of alluvial-fan, fluvial, and deltaic deposits derived from active fault scarps. The predominant rocks are quartz sandstone, feldspathic sandstone, arkose, and conglomerate; with minor shale and limestone in the upper part of the group. The main outcrops of the group are on the Carlton and Burt Range Shelves, and also in outliers to the south.

Ningbing Group (Famennian)

The Ningbing Group is made up of carbonate rocks representing a reef complex that developed along the western margin of the Southern Bonaparte Basin on the Carlton and Burt Range Shelves. This reef complex is marked by rapid lateral facies changes and local disconformities and it is similar to, but somewhat younger than, the Frasnian–Famennian reef complexes along the Lennard Shelf of the Canning Basin.

On the Carlton Shelf, the Ningbing Group conformably overlies the Cockatoo Group but is disconformably overlain by the Langfield and Weaber Groups. Over most of the Burt Range Shelf the reef complex disconformably overlies the Cockatoo Group and is conformably overlain by the Langfield Group. However, at the northern end of the shelf, near Sorby Hills, the Ningbing Group disconformably overlies Proterozoic rocks of the Pincombe Inlier and Cambrian Antrim Plateau Volcanics, whereas the group is disconformably overlain by the Weaber Group.

Langfield Group (Tournaisian)

The Langfield Group rocks consist of marine-shelf carbonate and shoreline siliciclastic rocks that were deposited over the Upper Devonian reef complex. These rocks outcrop mainly on the Burt Range Shelf and as small erosional remnants on the Carlton Shelf.

Weaber Group (Visean to Late Carboniferous)

The Weaber Group rocks unconformably overlie the Langfield Group and consist of a thick succession (up to 2000 m) of offshore-marine siltstone and mudstone overlain by shoreface and deltaic sandstone. The group outcrops along the basinward edges of the Carlton and Burt Range Shelves and thickens to the north and northeast.

Northern Bonaparte Basin

The Northern Bonaparte Basin is almost entirely offshore and contains considerable thicknesses of Mesozoic and Cainozoic strata, distinguishing it from the Southern Bonaparte Basin that was much less affected by Mesozoic tectonic events (Hocking et al., 1994). In the north Kimberley area the Northern Bonaparte Basin is represented by the Petrel Sub-basin, which is a broad northwest-opening trough in the southeast of the basin. The southernmost part of the Petrel Sub-basin extends onshore and contains Palaeozoic rocks of the Kulshill Group, in which the sedimentary succession is marked by fan–delta sedimentary rocks in the south, and fluvial and glacigene marine clastic strata towards the north (Mory and Beere, 1988).

Kulshill Group (latest Carboniferous to Early Permian)

Of the Kulshill Group, only the Keep Inlet Formation is represented onshore. This formation unconformably overlies the Weaber Group (Southern Bonaparte Basin) and consists of a thick succession of deltaic sandstone, pebbly sandstone, mudstone, and minor coal.

Canning Basin

Only a very small part of the Canning Basin is within the north Kimberley area, in the southwest corner of LANSDOWNE, where Late Devonian (Frasnian–Famennian) reef-complex carbonate successions are present on the Lennard Shelf (Gellatly et al., 1975; Griffin et al., 1993).

Regolith

Cainozoic

Regolith materials were developed in the Cainozoic as the products of weathering, mass wasting, erosion, and transport. These materials form extensive surficial cover over most of the low-lying eastern part of the area (on CAMBRIDGE GULF and MEDUSA BANKS), but have a scattered distribution in the more rugged northern, central, and western parts. Scattered large mesas of ferruginous and bauxitic laterite form cappings, mainly over the Carson Volcanics, in the northwestern part of the area. The regolith consists of residual and depositional units, as shown on the accompanying CD-ROM. The various units are subdivided further and are described below (map codes are those shown on the CD-ROM, based on Hocking et al., 2001).

Duricrust (*Rf*, *Rx_a*, *Rfp*) — residual

Ferruginous duricrust (*Rf*) and bauxitic duricrust (*Rx_a*) profiles are developed over mafic volcanic rocks of the Palaeoproterozoic Carson Volcanics. Ferruginous duricrust (*Rf*) is developed to a lesser extent on the underlying King Leopold Sandstone and the overlying Warton Sandstone.

Alluvium (*A, Ak*) — depositional

Alluvial deposits occupy the present drainage channels, and they have also formed on the floodplains and deltas of major rivers. The deposits are very extensive to the east of Cambridge Gulf. They consist of unconsolidated or partly consolidated clay, black soils, silt, sand, and gravel. In places older alluvial deposits form eroded terraces along drainage channels and floodplains.

Colluvium (*C*) — depositional

Colluvial deposits include sheetwash deposits, which formed on extensive floodplains to the east of Cambridge Gulf and in broad valleys on the Kimberley Plateau; these deposits also include residual sands formed on the surface of gently dipping to horizontal sandstones of the Kimberley Group on the plateau.

Coastal deposits (*Tc, Tf*) — depositional

Coastal deposits are most extensive from Cambridge Gulf eastwards, and include tidal, intertidal, and supratidal muds and silts (with mangroves). Westwards from the gulf, similar deposits are scattered along the coastal fringe of the north Kimberley Plateau where they have formed in estuaries, lagoons, and small bays.

Exploration and mining

Early history

The north Kimberley is one of the least-explored parts of the State, due largely to its remote location and its poor infrastructure, apart from areas close to Kununurra and Wyndham. During the Kimberley gold rush of 1886 to 1888 the port of Wyndham was established to provide for prospectors and miners who came to exploit the new discoveries in the Halls Creek area to the south. Presumably there was also some prospecting activity in the eastern part of the north Kimberley area at that time, but there are no records of this. However, there are references to early gold prospecting some time during the mid-1880s, in the valley of the Carson River (Maitland, 1907), and in 1924 on Cape Bougainville (Simpson, 1948, p. 424). Also, Fitzgerald (1907) located gold-bearing reefs in the vicinity of Mount Brennan in the western part of LANSDOWNE, although his account of these appears to have been ignored over the last 95 years (see **Gold**). The earliest account of modern exploration within the north Kimberley is the reconnaissance report by Harms (1959) that was compiled during his regional minerals assessment work for BHP between 1953 and 1957. Exploration in the area since then is discussed below, under the headings for the relevant commodities.

Bauxite

The first to discover bauxite in the north Kimberley was Reynolds Pacific Mines Pty Ltd (subsidiary of Reynolds Metal Company of USA) in 1958 at Cape Bougainville (Reynolds Pacific Mines Pty Ltd, 1958). The company sampled and tested bauxite material on the peninsula and decided that it was too low grade to be of interest, so the company relinquished its temporary reserves (TR 1606H and 1702H). In 1965 the United States Metals Refining Co. (a subsidiary of AMAX — American Metal Climax Inc.) located deposits of lateritic bauxite in the Couchman Range (northern part of ASHTON) that subsequently proved to be subeconomic. The company extended its search in 1965 to the west and discovered much larger, higher grade bauxite deposits at Mitchell Plateau*. This discovery was followed by a major evaluation program involving drilling, costeaning, and metallurgical testing from 1965 to 1971 (Joklik et al., 1975; Bardossy and Aleva, 1990; Smurthwaite, 1990). AMAX also carried out extensive drilling and trenching to evaluate bauxite resources at Cape Bougainville between 1969 and 1971. Based on these initial detailed investigations, Joklik et al. (1975) reported in situ resources of bauxite at Cape Bougainville as 980 Mt at 36% Al_2O_3 (total chemical alumina (TCA)) and 1.9% SiO_2 (total silica) and at Mitchell Plateau as 230 Mt at 47% Al_2O_3 (TCA) and 2.6% SiO_2 (total silica). Other smaller deposits were also identified at Mount Connor to the northeast of the Mitchell Plateau.

During 1967 BHP identified several small bauxite deposits in an area to the west of Kalumburu and in an area around Mount Leeming to the south of Kalumburu (BHP Co. Ltd, 1968). BHP carried out limited testing with costeans and pits (sampling only the accessible parts of some of the deposits) so no tonnages were estimated. Beneficiation results from bauxite samples provided encouraging values of between 28% and 49% available Al_2O_3, with quite high reactive silica (12–37%). However, BHP decided not to continue further investigations of the deposits.

In 1971 AMAX entered into a State Agreement — The Alumina Refinery (Mitchell Plateau) Agreement Act, 1971

* Prior to the AMAX discovery, W. J. Perry of BMR (now Geoscience Australia) had independently recognized mesas of laterite developed over Carson Volcanics from airphotos in early 1965, and he recommended that BMR examine the bauxite potential of the Mitchell Plateau area during its 1965 field mapping program (Plumb and Gostin, 1973)

— 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, but the project was curtailed because of a dramatic fall in alumina and aluminium prices in 1972. 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. Pty Limited (MPBC). In 1980 Alumax disposed of its entire interests to MPBC, Alcoa of Australia Limited, Billiton, Sumitomo, and Marubeni. 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). From this work, revised figures for bauxite reserves (after beneficiation) were reported by Bardossy and Aleva (1990) as 457 Mt at 46.6% Al_2O_3 (TCA) and 4.6% SiO_2 (total silica). As well, zones of refractory grade bauxite (with low TiO_2 and Fe_2O_3) within the deposits were assessed. In 1984, CRA (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 (Smurthwaite, 1990). However, once again, project development was postponed because of declining world prices for aluminium and high costs of mining and beneficiation.

The larger bauxite deposits at Cape Bougainville (Fig. 6) were not further drilled by MPBC in the early 1980s; however, the AMAX resource data were reassessed and this confirmed the earlier resource estimate. Also, some further exploration was carried out in the Couchman Range and around Kalumburu but no substantial deposits were found. Since 1969 the deposits at Cape Bougainville have remained under consideration for development in the longer term should the project at Mitchell Plateau proceed.

Another study by MPBC to assess the Mitchell Plateau project was undertaken in 1994 and this confirmed that development was still uneconomic. Current ownership of Mitchell Plateau and Cape Bougainville is Alcoa World Alumina Australia (21.875%), Anglogold Ltd (12.5%), and Comalco Ltd (65.625%) through MPBC.

Base metals

Exploration for base metals in the north Kimberley began in the mid-1950s with regional reconnaissance by major mining companies: the first record of this is by Harms (1959). In the mid-1960s BMR also located several copper prospects and undertook some regional geochemical prospecting for base metals (Roberts et al., 1966; Gellatly, 1967). Pickands Mather & Co. International also undertook a large regional geochemical program in the mid- to late-1960s over Proterozoic rocks of the whole Kimberley region.

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Figure 6. Photograph of bauxite deposits at Cape Bougainville, looking southward, taken from the air in 1981 during a reassessment of the deposits. The Cainozoic bauxitic duricrust profiles, forming mesa cappings, are developed over mafic volcanic rocks of the Palaeoproterozoic Carson Volcanics. Photograph courtesy Rio Tinto

Lead–zinc–silver

Early discoveries of lead mineralization in the Southern Bonaparte Basin were made during petroleum exploration activities between the mid-1950s and the early 1960s (Lee and Rowley, 1990). Surface occurrences of cerussite were noted during mapping in the Spirit Hill area in the Northern Territory, about 17 km southeast of Sorby Hills, and lead–zinc mineralization was intersected in 1960 in the petroleum exploration well Spirit Hill 1 drilled by Oil Development NL and Westralian Oil Ltd. Also in 1960, surface lead mineralization at Sorby Hills was noted by a geologist, E. Rod, during petroleum exploration for the Atlantic Refining Company. These discoveries were followed up by Aquitaine Australia Minerals Pty Ltd, in joint venture with SEREM (Australia) Pty Ltd and BRGM, who undertook an intensive search for Mississippi Valley-type base metal mineralization in the early 1970s. Exploration encompassed regional and detailed mapping, geochemical sampling, geophysical surveys, and drilling. The Sorby Hills mineralized outcrops were rediscovered by Aquitaine in mid-1971, but follow-up exploration drilling showed that these did not relate to significant subsurface mineralization in the immediate vicinity. However, in 1973 bedrock geochemical drilling intersected a zone of significant mineralization beneath 25 m of black soil cover about 2 km east of Sorby Hills, and this zone became known as the Sorby Hills deposits*.

Further exploration between 1974 and 1977 highlighted the main mineralized trends at Sorby Hills using detailed geophysical surveys (IP, EM, and aeromagnetics), and follow-up percussion and diamond drilling delineated numerous pods of lead-rich sulfide mineralization. Mount Isa Mines entered the joint venture in 1977, and during 1978–79 the company carried out closely spaced drilling and some underground exploration. These investigations showed that the ore zones were narrow and complex, and that the highest grade mineralization had poor continuity. Also, the exploration decline encountered large inflows of water and poor ground-conditions in the ore zones that would pose problems for any proposed mining. Further diamond drilling between 1981 and 1984 did not succeed in increasing tonnages or locating higher grades.

BHP entered the joint venture in 1986. In addition to further drilling and evaluation of the Sorby Hills ore zones, exploration drilling was also directed towards base metal targets elsewhere in the joint venture area that had potential for higher grade zinc mineralization (Jorgensen et al., 1990). Results were not encouraging, and after reviewing the feasibility of the project in 1989 BHP concluded that the known resources remained subeconomic. Further geophysical surveys were undertaken by BHP to identify new targets, and North Mining Ltd entered the joint venture briefly in 1994–95. However, ground fieldwork and follow-up drilling were curtailed due to difficulties in obtaining approvals from Aboriginal communities for land access, and BHP withdrew from the project in 1996. Since then, further work by the current owners Triako Resources Ltd has been held up, due to land access problems and State proposals to extend the Ord River Irrigation Area over the Sorby Hills project area.

Exploration for Mississippi Valley-type mineralization has also been undertaken over reef complexes in the Carlton Sub-basin since the 1970s. Companies involved in this work included CRA Exploration Pty Ltd, Seltrust Mining Corporation Pty Ltd, AMAX Exploration, ALCOA of Australia Ltd, Aquitaine Australia Minerals Pty Ltd, St Joe Bonaparte, MIM Exploration Pty Ltd, United States Steel, Placer Exploration Ltd, Conwest Australia NL, and Tenneco Australia Inc. A number of mineralized prospects were discovered, but the companies concluded from their follow-up investigations that mineralization was of limited extent. Further exploration in the area was conducted by BHP, CRA, and Poseidon Exploration Ltd from the mid-1980s to early 1990s. Some promising targets were outlined for drilling, but this work was curtailed due to difficulties in obtaining access from local Aboriginal communities.

In 1967 the Shangri-La polymetalliic silver–gold–lead–copper deposit was discovered in the Hart Dolerite near Kununurra by P. Costeo, a local prospector (Sofoulis, 1968). Conwest Australia NL drilled the deposit in 1968 and identified a small resource. Some bulk sampling was later undertaken, but there has been no recorded production. However, the Shangri-La ‘mine’ contains a large variety of lead, copper, and silver minerals, so it has become a well-known site for mineral specimen collectors. In 1984, H. F. and E. M. Moder discovered similar polymetallic mineralization in several vein occurrences to the west of Shangri-La (Moder and Moder, 1985).

Copper

Minor copper occurrences in the Carson Volcanics were known to prospectors in the early half of the 20th century. Simpson (1948, p. 424) noted that in 1924 a prospecting party had located copper at Cape Bougainville. In his regional minerals assessment, Harms (1959) remarked that copper minerals had been ‘widely reported’ in the Carson Volcanics and he also described previously known copper occurrences in the Hart Dolerite. Harms (1959) was the first to recognize stratabound copper in sedimentary rocks within the Kimberley Basin: in the Palaeoproterozoic Elgee Siltstone and Pentecost Sandstone, and in the Neoproterozoic Traine Formation. In the 1960s further occurrences of copper in the Carson Volcanics, Hart Dolerite, Elgee Siltstone, and Pentecost Sandstone were reported and investigated during the joint mapping program of GSWA and the former BMR (Derrick, 1966, 1969; Gellatly and Sofoulis, 1966, 1969; Roberts et al., 1966; Gellatly and Derrick, 1967; Plumb and Veevers, 1971; Plumb and Perry, 1969, 1971; Roberts and Perry, 1969; Gellatly et al., 1975). This work included a geochemical sampling study on LANSDOWNE that highlighted copper enrichment in the Teronis Member of the Elgee Siltstone (Gellatly, 1967).

* Companies involved in the Sorby Hills joint venture have included Aquitaine Australia Minerals Pty Ltd (1971–1984), SEREM and BRGM (1972–79), Mount Isa Mines (1977–1985), St Joe Bonaparte Pty Ltd (1982–85), Elf Aquitaine Triako Mines Ltd (1984–86), BHP Minerals Ltd (1986–1996), North Mining Ltd (1994–95), and Triako Resources Ltd (1986 onwards, and 100% owners and operators since 1996)

Mineral exploration companies began to take an interest in the stratabound copper potential of the Kimberley Basin, from the mid-1960s to the early 1970s, and these included Pickands Mather, Planet Mining Company, BHP, CRA, Australian Anglo American Ltd, and Tanganyika Holdings Ltd. Two main styles of copper mineralization were investigated: Zambian-style sedimentary copper (clastic-hosted and carbonate-hosted) in the Pentecost Sandstone and the Elgee Siltstone (in particular the Teronis Member); and mafic volcanic-hosted copper in the Carson Volcanics (Bruinsma, 1970; Owen, 1970; Klaric, 1971, 1975). Copper mineralization in the Hart Dolerite was also examined. Although many copper prospects and geochemically anomalous zones were identified and tested between the mid-1960s and early 1970s, companies became discouraged from further evaluation after initial exploration drilling indicated that the prospects, identified during mapping and geochemical surveys, contained only low economic grades and limited tonnages. During the 1980s there was exploration in the Mad Gap Yards area for stratabound (VMS) base metal mineralization in the Whitewater Volcanics. Some prospects were identified but were considered to be too small to warrant further exploration.

Diamond

During the early 1970s, one of the areas in the State initially selected for diamond exploration was the north Kimberley, where sampling programs were undertaken in the drainages of the Drysdale, King George, Berkeley, and Forrest Rivers — a large area of about 20 000 km^2. According to Smith et al. (1990) the rationale for company interest in the north Kimberley area was based on its analogy with the geological setting of diamond-bearing kimberlites in Africa where, according to Clifford (1966), kimberlites are emplaced in cratons that have been stable for at least 1500 million years*. The Kimberley region is also attractive because it has a good drainage network that is amenable to the traditional heavy-mineral sampling techniques for kimberlite indicator minerals (e.g. pyrope garnet, picroilmenite, chromian spinel, and chromian diopside).

Over the last 30 years the search for diamonds throughout the north Kimberley has revealed a large number of diamond indicator minerals and widely scattered diamonds. In order to establish controls on the distribution of diamond indicators (to detect kimberlite intrusions), explorers have used various combinations of remote sensing (Landsat, multispectral scanning, and hyperspectral scanning), aeromagnetic and ground magnetic surveys, gravity surveys, electromagnetic surveys, geochemical investigations of indicator minerals, and palaeo-geomorphological studies. Numerous kimberlite intrusives have been discovered in the Kimberley Basin, although the majority are very small (i.e. thin dykes, some only one metre or less in width). Most of the dykes have a northeasterly trend, parallel to a dolerite dyke suite that intrudes the Kimberley Group, and subparallel to the trend of the Halls Creek Orogen. Several kimberlites have been shown to be diamondiferous but, until recently, none appeared to contain economic grades. A number of alluvial accumulations of diamonds have been tested too, but, as yet, none has proved to be commercially viable. Exploration for offshore diamond accumulations, along the southwestern margin of Joseph Bonaparte Gulf, has recovered some diamonds from gravel layers. However, technical difficulties with bulk-sampling equipment have prevented satisfactory testing of their potential. During the period 2000 to 2002, there have been encouraging results from bulk sampling programs of 'small' kimberlites and there has been renewed interest by major companies in the search for large kimberlite bodies using a new airborne gravity gradiometer system.

Reviews of early sampling programs and discoveries of kimberlites and diamonds in the area are provided in Jaques et al. (1986) and Smith et al. (1990). There are no statutory mineral exploration reports to record much of the early reconnaissance sampling in the north Kimberley, because work was undertaken on 'open ground' (areas not covered by mining tenements) where there was no obligation for diamond explorers to report results to the Department of Mines (now Department of Industry and Resources).

Initial exploration under mineral tenure was undertaken in 1972 by the Kalumburu Joint Venture (comprising Tanganyika Holdings Limited, AO Australia Pty Ltd, Jennings Mining Ltd, Northern Mining Corporation NL, and Sibeka) and this led to the discovery of indicator minerals and diamonds in the drainage systems of the Forrest River and King George River. Following the discovery of commercial-sized diamonds by the JV partners in 1976, Conzinc Rio Tinto Australia Exploration (CRAE) entered the joint venture, which was renamed the Ashton Joint Venture in 1977. In early 1976, further detailed stream and loam sampling by CRAE located the first kimberlite body in the north Kimberley — at Pteropus Creek — and other kimberlite intrusives at Skerring, Jumpup, KGB2, Hadfields, Dearns Gully, and Wishy Washy (in the King George River area). However, all of these appeared to be virtually barren of diamonds; although samples collected by CRAE in 1978–79 showed that the Pteropus pipe breccia contained a very low concentration of small diamonds. At about this time the Ashton Joint Venture was also evaluating more promising diamond prospects in lamproite intrusives of the Ellendale area (in the west Kimberley) and the Smoke Creek – Lake Argyle area (east Kimberley), where the major Argyle lamproite pipe was discovered in 1979. As a consequence, the joint venture curtailed further exploration of the north Kimberley at that time.

During the late 1970s and early 1980s BHP undertook extensive exploration of the Charnley and Forrest River drainages, in a program that started as a joint venture with Swan Resources Ltd. BHP located alluvial diamonds at numerous sites, with some samples containing diamonds up to 0.5 carats (ct). Later, in 1985, Stockdale Prospecting

* There is anecdotal information that the Drysdale River area, east of Kalumburu, was known to be prospective for diamonds many years prior to the 1970s. Edwards (1991) reported that before the Second World War, a man named Watson came to the Kalumburu Mission with a quantity of stones said to be diamonds taken from the Sir Frederick Hills. The 'diamonds' were subsequently sent to a Sydney jeweller who later described one yellow stone as 'of the Drysdale region'

Limited (a subsidiary of De Beers) entered a more extensive joint venture with BHP known as the Forrest River project. Further exploration by BHP–Stockdale led to the discovery of the diamondiferous Seppelt pipe in 1990, Pteropus 2 pipe in 1993, and smaller kimberlites at De Lancourt and Berkeley in 1994. However, the results of bulk testing of the diamond content at Seppelt did not fulfill the parameters required by the joint venture partners and, after a review of the project's potential, it was sold to Striker Resources NL in 1995 (but with De Beers retaining a royalty interest and future diamond marketing rights).

Striker Resources NL (formerly Gem Exploration and Minerals Ltd) held the view that small kimberlite bodies had good potential for gem-quality diamonds, based on examples known in Siberia. From 1992 the company targeted the area of Beta Creek (a tributary of King George River) where previous sampling in the early 1980s, by the Ashton JV partners and BHP–Stockdale, had located high concentrations of diamonds and indicator minerals. In 1993 Striker delineated the Lower Bulgurri diamondiferous fissure, and further exploration of the southwestern extension of this fissure in 1995 and 1996 led to the discovery of the diamondiferous Ashmore pipe cluster (Ashmore 1, 2, 3, and 4). Bulk sampling in pits at Ashmore 1, 2, and 4 in 1999 and 2000 provided encouraging results from sandy 'infill material' representing the weathered upper parts of the pipes, with indications of an average grade of up to 30 ct/100 t in some samples from pipes 2 and 4 and the recovery of three diamonds of over 10 ct (Striker Resources NL, Quarterly Report to ASX, 30 June 2001). Deeper bulk sampling in 2001 to test 'fresh kimberlite' in pipes 2 and 4 showed this material to be of lower grade (less than 10 ct/100 t), suggesting there has been enrichment in the near surface portions of the pipes (Striker Resources NL, 2001).

Further work by Striker in the Seppelt area, along a northeasterly trending diamond-bearing structure, located another diamondiferous pipe, Seppelt 2, about 5 km southwest of Seppelt 1. Recent resource drilling of the north and south lobes at Seppelt 1 (Fig. 7a,b) has shown that there is an inferred resource of 700 000 ct of diamonds, at an average inferred grade of 40 ct/100 t (Striker Resources NL, 2002, announcement to ASX, 8 January 2002). During 2002, a bulk sample (183 t) from a test pit at Seppelt 2 (Fig. 8a,b) has indicated very high grades of 2 ct/t — the best bulk sampling results in Australia since the discovery of the Argyle AK1 pipe (Striker Resources NL, 2002). As at December 2002, most of the North Kimberley kimberlite field was covered by Striker's mining tenements and exploration was being carried out with a number of joint venture partners, including De Beers Australia Exploration Ltd, Rio Tinto, BHP Billiton, Ellendale Resources NL, Dioro Exploration NL, and a few prospecting syndicates.

In the central and southern parts of the north Kimberley (i.e. to the west of the King George and Forrest River project areas) extensive regional exploration programs were undertaken by junior exploration companies during the late 1970s and early 1980s; in particular Gem Exploration and Minerals Ltd and the Magnet Group of companies. By 1983, other larger companies, such as Seltrust, Freeport of Australia Inc, CRA, BHP, and Stockdale, had also begun to explore in these areas.

During the early 1980s the area of the Phillips Range Anticline, on western MOUNT ELIZABETH, emerged as a significant target area based on the large numbers of alluvial diamonds and kimberlite indicator minerals that had been recovered in gravel sampling since the late 1970s in the Police Valley and adjacent drainages. From the mid-1980s to early 1990s exploration in the area now referred to as the Phillips Range kimberlite field was undertaken by junior explorers Moonstone Mines NL, Capricorn Resources Australia NL, Carr Boyd Minerals Ltd, and Triad Minerals NL (Diamin Resources NL since 1994). Detailed drainage sampling led to the discovery of the large Aries kimberlite pipe, concealed below a thin regolith veneer.

The initial discovery of the pipe, on the northern limb of the Phillips Range Anticline, was made in 1986 by Triad Minerals, in joint venture with Freeport (merged into Poseidon Exploration Ltd in 1989, then Normandy Exploration Ltd in 1994). Previous exploration in the area by the Ashton Joint Venture (managed by CRA) had shown that a nearby drainage system contained kimberlitic chromites, but follow-up work was not carried out. Detailed drainage sampling in 1985 by Triad–Freeport narrowed the search to Nyairgul Creek, a tributary of Harris Creek, where high counts of chromian spinel in samples were traced upstream to a distinct natural feature of three basins that mark the site of the pipe (Towie et al., 1994). Loam sampling, pitting, and drilling in 1986 confirmed that the pipe contained diamondiferous kimberlite.

Drilling and sampling in 1987–88 indicated that the Aries pipe was diamond bearing to a depth of 100 m. Further testing of the pipe in the early 1990s produced promising results, with 1819 ct of 95% gem-quality diamonds (with an average price of US$100/ct) recovered from an openpit on Aries Central lobe. However, bulk testing in the openpit in late 1994 indicated disappointing average grades of between 2 and 5 ct per 100 t. Also in 1994, samples from large-diameter drilling of Aries North lobe showed very low-grade results.

Normandy Exploration withdrew its interest in the project in 1996 and Diamin also sold its interests to Ragged Range Mining Pty Ltd, who recommenced exploration in 1997. After a brief joint venture with Astro Mining NL, Ragged Range sold 44% of its interest to Thundelarra Exploration Ltd in 1999; an additional 51% was sold to Thundelarra in 2000. Since then exploration within Aries South lobe, by Thundelarra and its joint venture partner BHP–Billiton, has identified three separate diamondiferous kimberlite bodies called Helena, Athena, and Persephone (Thundelarra Exploration Ltd, announcement to ASX, 15 February 2002): the three kimberlites were located by the new Falcon airborne gravity-survey system. A fourth diamondiferous kimberlite called Niobe (Fig. 5) was identified in late 2002 during exploration by a third joint venture partner, Gravity Capital (Gravity Capital Limited, announcement to ASX, 2 December 2002).

a)

b)

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Figure 7. a) Photograph of bulk sampling pit at Southern lobe of Seppelt 1 in 2002; b) Selection of diamonds recovered from Seppelt 1 bulk sample (diameter of coin is 19 mm). Photographs courtesy Striker Resources NL

a)

b)

IR35 28.03.03

Figure 8. a) Photograph of bulk sampling pit at Seppelt 2 in 2002 (looking north); b) Selection of diamonds recovered from Seppelt 2 bulk sample (diameter of coin is 19 mm). Photographs courtesy Striker Resources NL

In the southern part of the north Kimberley area, to the southwest of Mad Gap Yards, indicator minerals were located in the mid-1980s by CRA and Kimberley Resources Ltd. Further work by the Triad–Freeport joint venture in the late 1980s recovered diamonds from bulk stream samples at three sites and intersected barren kimberlite dykes in drillholes close to these sites. The kimberlite bodies appear to be aligned in a north-northeasterly trending zone, subparallel to the Greenvale Fault some 1 to 2 km to the west, in a similar structural setting to the Argyle AK1 pipe. The Mad Gap Yards area may prove to be a third kimberlite field in the north Kimberley and is currently being reassessed by Flinders Diamonds, who refer to the area as Skeleton Flats (Flinders Diamonds Limited, 2001).

A number of companies have explored for alluvial diamonds in buried palaeochannels of the Ord, Dunham, and Keep Rivers, where diamonds may have been transported and deposited from eroded parts of the AK1 pipe. In the early 1980s Gemex located diamonds in Proto-Ord palaeo-alluvial gravels just west of Kununurra, on the Ivanhoe and Packsaddle Plains. Bulk testing of the gravels in the early 1990s by AuDax Resources NL and Carnegie Minerals NL recovered numerous macrodiamonds, including gem-quality stones up to 1.13 ct in size; the companies have recently relinquished the ground after further testing produced disappointing results.

Diamonds were obtained from alluvial gravels between Nyairgul Creek and Harris Creek downstream from the Aries kimberlite pipe. In 1989 Diamin located deeply buried alluvial gravels in two palaeochannels of Nyairgul Creek and, using a treatment plant, recovered 796 diamonds (180.2 ct).

Exploration for marine and littoral placer diamond deposits, similar to those mined along the coasts of Namibia and South Africa, has been undertaken along the coastline of Joseph Bonaparte Gulf. The earliest offshore coastal sampling programs were undertaken by Capricorn Resources in 1988, in an area near the mouth of the Berkeley River. The company targeted diamond accumulations that it postulated could be derived from large onshore kimberlite deposits (not yet discovered). Protective diving cages were used during sampling by exploration personnel to prevent attack from salt-water crocodiles, tiger sharks, poisonous sea snakes, and jellyfish (Fig. 9). The program was technically successful with diamonds recovered from gravels trapped in jointed bedrock on the seabed. However, further sampling was curtailed due to a breakdown in access negotiations with the local Aboriginal community.

Offshore exploration within Cambridge Gulf was also undertaken by Pacific Arc Exploration NL in 1988. The company sampled bottom sediments at various sites with a drag-line bucket system, although this proved to be rather ineffective for testing possible diamond accumulations due to frequent snagging of the bucket on boulders and rock bars.

In the late 1980s a number of companies considered the potential for diamonds in gravel horizons further offshore on the seabed of Joseph Bonaparte Gulf, which represented submerged former drainage channels of the King Edward, Drysdale, King George, Berkeley, Ord, and Keep River systems. Exploration was limited to State coastal waters on tenements under the WA Mining Act 1978, and investigations further offshore could not begin until Commonwealth offshore minerals legislation was introduced in 1990*; this enabled mineral tenements to be granted for exploration beyond the limit of 3 nautical miles (5.56 km) from the coast. Cambridge Gulf Exploration NL was the first successful tenderer for offshore mining

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Figure 9. Near-shore diamond sampling in the vicinity of Reveley Island, showing geologist Tony Gates and the protective diving cage. Photograph courtesy Pacific Exploration Consultants Pty Ltd

* The Minerals (Submerged Lands) Act was enacted on 1 February 1990, and this was replaced by the Offshore Minerals Act 1994 that was enacted on 1 March 1994

tenements. The offshore exploration methods used by the company included some of those used along the coast of South West Africa: a review of these is provided in Murray (1970).

Cambridge Gulf Exploration was the only company to carry out full-scale offshore exploration, commencing in 1991 with high-resolution shallow seismic surveys to detect gravel horizons. This was followed by ship-mounted drill sampling to test for alluvial diamonds in interpreted gravel horizons in submerged palaeochannels of the Berkeley and Ord Rivers. During drilling in 1993, the company recovered 14 macrodiamonds (totalling 8.8 ct) from submerged palaeochannels of the Berkeley River. A further 23 diamonds (totalling 5.87 ct) were also recovered in 1993 from a palaeochannel of the Ord River (Fig. 10a,b), about 10 km northwest of Lacrosse Island, on a tenement held by joint venture partners Australian Kimberley Diamonds NL and Zephyr Minerals NL.

During 1994, Cambridge Gulf Exploration undertook bulk testing of the gravels in the palaeochannel of the Ord River to evaluate diamond grades. The company used a wide-diameter core-sampling system mounted on a larger ship. However, technical difficulties with the sampling system in adverse seabed conditions caused the program to be abandoned. After this, Cambridge Gulf Exploration and other companies holding offshore tenements relinquished their ground.

Diamond exploration on the southern coastal flats of Joseph Bonaparte Gulf between 1995 and 1998 by Carnegie Minerals NL (in joint venture with Mining Corporation of Australia Ltd) examined the potential for buried alluvial deposits in palaeodrainages of the Proto-Ord and Proto-Keep rivers, also the potential for beach-placer occurrences along palaeoshorelines immediately offshore. These alluvial and beach-placer occurrences could have accumulated from diamond sources such as the Argyle AK1 pipe, Bow River gravels, Smoke Creek, or Limestone Creek gravels. Onshore, the companies also targeted possible kimberlite pipes (concealed by a thin Cainozoic sequence) along the concealed north-northeasterly corridor of the Halls Creek Orogen, but without encouraging results.

Gold

There is very little information on early gold prospecting in the area, except for some mention of prospecting parties by Maitland (1907, 1927) and Simpson (1948, p. 424). The first official record of a significant gold occurrence was by the botanist (and prospector) W. V. Fitzgerald, in a report on his investigations as a member of the State Government's 1905 Crossland expedition to the Kimberley (Fitzgerald, 1907). Fitzgerald located low-grade auriferous quartz reefs within Carson Volcanics that assayed up to 2.5 g/t gold in an area around Mount Brennan in the southwestern part of LANSDOWNE. More significantly, he also sampled similar but richer auriferous reefs, also in Carson Volcanics, at Plover Hill (71 g/t gold) and Manning Creek (12.7 g/t gold) located in the southeastern part of CHARNLEY in the west Kimberley (Hassan, in prep.). It is remarkable that these gold occurrences were never referred to by Maitland in the early 20th century nor mentioned later in GSWA and BMR publications on the Kimberley area in the 1960s and 1970s, even though the authors of these publications refer to Fitzgerald's 1907 report.

Since the mid-1970s detrital gold has been reported in stream-sediment samples collected during diamond exploration programs in the Kimberley Basin. Several such sites, derived from open-file mineral exploration reports, are shown as occurrences of alluvial gold mineralization on Plate 1. Some companies have commented that the primary source of the gold was unknown but, in view of Fitzgerald's sampling, a possible source would appear to be auriferous quartz veins in the Carson Volcanics.

However, in a new development, Striker Resources NL announced that during diamond exploration in late 2001 its joint venture partner, De Beers, had obtained samples containing numerous particles of fine-grained alluvial gold, related to a large area of possible epithermal gold mineralization located southeast of the lower reaches of the Berkeley River (Striker Resources NL, announcement to ASX, 30 January 2002). De Beers initially carried out an airborne survey in 2001 using its proprietary multi-spectral scanner equipment, and this identified a large area (70 km × 20 km) of argillic alteration in Warton Sandstone and Carson Volcanics, located along the northeast coast (between Cape Whiskey and Obstruction Hill). Follow-up fieldwork by Striker Resources, in this area of argillic alteration, has confirmed that there are extensive zones of quartz veining, brecciation, iron enrichment, and silicification, with some veins showing colloform epithermal textures (Striker Resources NL, announcement to ASX, 6 March 2002). Soil and rock-chip sampling identified two areas of gold anomalism at '88 Creek' and Magnesite Creek, located about 12 km apart. Reverse circulation drilling at '88 Creek' in 2002 intersected low-grade gold (highest intersection of 1 m at 1.36 g/t gold) in a flat-lying zone up to 20 m thick showing phyllosilicate alteration in sandstone.

In the early 1970s, auriferous quartz veins were located in a sill of the Hart Dolerite, near the Shangri-La mine to the west of Kununurra in the eastern part of the north Kimberley. In the south of the area (on LANSDOWNE) minor amounts of gold were located in felsic-volcanic rocks of the Whitewater Volcanics during base metal exploration in the mid-1970s.

Iron

Ferruginous sandstones and siltstones in the Bandicoot Range, 10 km west of Kununurra, were first reported by Plumb and Veevers (1971). A preliminary assessment of the iron ore potential of these horizons was made in 1971 by Alliance Minerals Australia NL. Results from mapping and sampling showed that the iron mineralization was of low overall grade (averaging 22.7% Fe). Lateritic iron deposits were identified in 1970 by Planet Mining Co. Pty Ltd during uranium exploration in the Durack Range (northeast LANSDOWNE). The deposits appear to have developed in a palaeodrainage, with grades ranging from 45 to 56% iron.

a)

b)

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Figure 10. Photographs of offshore large-diameter drill sampling operations, northwest of Lacrosse Island: a) ship out at sea; b) large-diameter drill sampling system lies on deck of the ship. Photographs courtesy J. M. Graindorge

Uranium

An intensive search for sandstone-hosted uranium in the late 1960s and early 1970s in the King Leopold and Durack Ranges, targeted radiometric anomalies associated with conglomerate, grit, and sandstone horizons in the O'Donnell Formation, Lansdowne Arkose, King Leopold Sandstone, and Pentecost Sandstone. Companies involved in various exploration programs included AGIP Nucleare Aust. Pty Ltd, BHP, Carpentaria, CRA, Planet Mining, Portoil Ltd, South Pacific Minière Pty Ltd, Uranerz Australia Pty Ltd, and Western Nuclear Australia Pty Ltd.

In 1970 Dr B. Campana (joint venture partner with South Pacific Minière and Portoil) located high-grade secondary uranium mineralization (up to 1.7% U_3O_8) in rock chip samples (Campana, 1970). This mineralization is in basal sandstone of the O'Donnell Formation in an area west of Mad Gap Yards on southeastern LANSDOWNE. Later exploration drilling gave disappointing results indicating that the high uranium values at the surface were caused by near-surface enrichment of very weak uranium mineralization at depth.

Follow-up uranium exploration to examine areas of radiometric anomalies associated with coarse clastic units in Lansdowne Arkose, King Leopold Sandstone, and Pentecost Sandstone, showed that the anomalies were due to concentrations of thorium (Hughes and Harms, 1975; Carter, 1981).

In 1969 Planet Mining investigated radioactive lenses of heavy minerals in a purple sandstone unit near the top of the Carson Volcanics in the Durack Range. The lenses contain concentrations of monazite and zircon with high contents of uranium and thorium that assayed up to 0.136% U and 2.037% Th (Planet Management and Research Pty Ltd, 1969; Planet Mining Company, 1970).

Mineralization

A total of 560 mineral occurrences have been recorded in the WAMIN database for the north Kimberley area, and these are shown on Plate 1 and on Figure 11. On Plate 1, and in the listing in Appendix 1, mineral occurrences are grouped by commodity (colour) and mineralization style (symbol), as explained in Appendix 2. In the following sections the occurrences are grouped by mineralization style and then by commodity groups under various sub-headings. Mineral occurrences referred to below are identified by the WAMIN 'deposit name' and 'deposit number', shown thus: Sorby Hills (**2798**).

Mineralization in kimberlite and lamproite intrusions

Precious mineral — diamond

There are 14 diamond occurrences in the north Kimberley, all of which are kimberlite hosted. The kimberlites and diamondiferous kimberlites have been dated at c. 800 Ma (Pidgeon et al., 1989), and intrude rocks of the Kimberley Group in the Kimberley Basin. They are in two main fields, the North Kimberley kimberlite field and the Phillips Range kimberlite field, and there may be another minor field at Skeleton Flat (Mad Gap Yards), which is possibly diamondiferous, in a downfaulted part of the basin in the Halls Creek Orogen in southeastern LANSDOWNE (Plate 1 and Fig. 12).

North Kimberley kimberlite field

The North Kimberley kimberlite field occupies an area 80 km × 175 km, parallel to the northeast coast between the Drysdale and Forrest Rivers (Figs 3 and 4). Within the field, diamond-bearing pipes and dykes occur along northeasterly trending zones that are parallel or sub-parallel to dolerite dyke swarms and main fault trends. Commercial-size diamonds (>1 mm) have been recovered from the Seppelt and Ashmore pipe cluster and the Bulgurri fissure; the Seppelt deposits contain the most encouraging diamond grades in the area to date.

In the Seppelt area there are two diamondiferous kimberlitic pipes, Seppelt 1 and Seppelt 2, which intrude the Pentecost Sandstone, about 85 km east-southeast of Kalumburu. The pipes are 5 km apart and lie along a northeasterly trending structure about 10 km long. The Seppelt 1 pipe, northeast of Seppelt 2, consists of two lobes of diamondiferous kimberlite with a combined surface area of around 1.5 ha: North lobe (**10516**) and South lobe (**5247**). Following initial resource-definition drilling of the two lobes in 2001, an inferred resource of 1.7 Mt of macrocrystic kimberlite has been estimated (Striker Resources NL, 2002). This inferred resource was also estimated to contain 700 000 ct of diamonds, at an average inferred grade of 40 ct/100 t (Striker Resources NL, announcement to ASX, 8 January 2002). Initial testing of Seppelt 2 (**10522**) in 2000 showed that the pipe contained diamondiferous kimberlite (Striker Resources NL, announcement to ASX, 8 January 2002) and bulk sampling (183 t) of macrocrystic kimberlite in 2002 has produced 6000 diamonds with a total weight of 359.6 ct, indicating an exceptional grade of around 2 ct/t (Striker Resources NL, 2002). The bulk sample pit at Seppelt 2 is shown in Figure 8a.

Another significant northeasterly trending diamond-bearing structure, the Bulgurri fissure, is located about 25 km north-northwest of the Seppelt area. The structure is about 8 km long and intrudes the Carson Volcanics and Warton Sandstone. It contains the diamondiferous Ashmore pipe cluster, the Lower Bulgurri dyke, which was discovered in 1993, and the Banksia dyke (discovered in 2000). The structure may also be traced intermittently to the northeast, and for a further 10 km, to the non-diamondiferous kimberlitic Wishy Washy dyke and Skerring pipe that were discovered in 1976 by the Ashton Joint Venture. The pipe cluster at Ashmore contains four kimberlite pipes with a combined surface area of just over 1 ha: Ashmore 1 (**5241**), Ashmore 2 (**5242**), Ashmore 3 (**5243**), and Ashmore 4 (**5244**). The pipes are believed to be connected at depth. The Ashmore cluster was delineated in 1995 by Striker Resources, and initial bulk testing and evaluation were undertaken in 1999 and 2000. The material sampled from the uppermost 20 m of the pipes consisted of deeply weathered kimberlite, gravel,

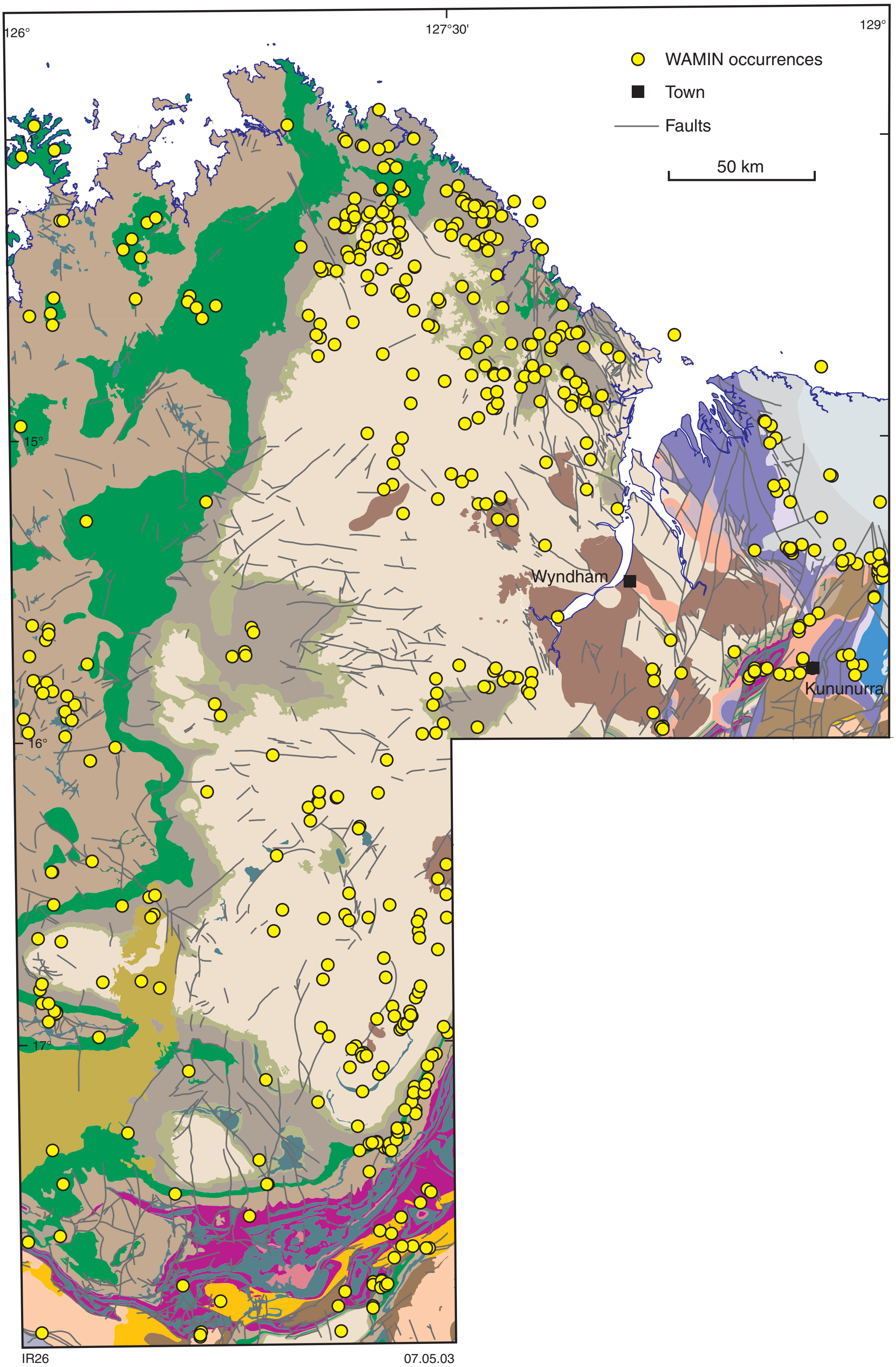
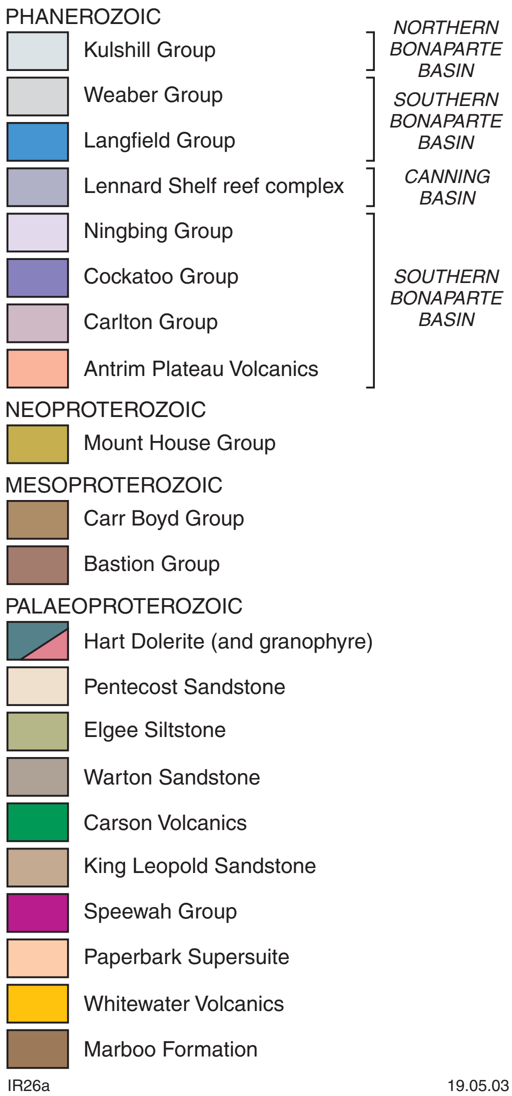


Figure 11. Distribution of 560 WAMIN occurrences in the north Kimberley



sand, and siltstone interpreted as near-surface infill collapse of the pipes. Sampling results were encouraging, particularly in Ashmore 2 where diamond grades up to 27 ct/100 t were obtained, and three diamonds of more than 10 ct each were recovered. However, the grades were quite variable between the pipes (ranging between 3 and 31 ct/100 t). Deeper sampling in 2001 (to about 100 m) tested recognizable kimberlite material in the pipes and gave disappointing grades of less than 10 ct/100 t, generally lower than those in the infill material.

At Lower Bulgurri (**5245**) very narrow diamondiferous dykes are in the northern end of the Bulgurri fissure, almost 4 km northeast of the Ashmore pipe cluster. The dykes were the first kimberlites discovered by Striker in 1993. Subsequent sampling in 1994–95 and in 1998 revealed some gem quality diamonds, but the average grade is low and the area of potential kimberlite is small. Another narrow dyke at Banksia (**10539**), at the southern end of the Bulgurri fissure, was shown to be diamond bearing following sampling by Striker in 2000.

Larger kimberlitic pipes are at Pteropus 1 (**3257**) covering 2 ha, and Pteropus 2 (**10538**) covering 10 ha, located in the headwaters of Pteropus Creek about 18 km south-southeast of Seppelt 2. Pteropus 1 pipe intrudes Warton Sandstone. It was discovered by the Ashton Joint Venture in 1976 — the first kimberlite to be discovered in the North Kimberley field (Jaques et al., 1986; Smith et al., 1990). Pteropus 2 pipe, discovered by the BHP–Stockdale JV in 1993, intrudes Warton Sandstone and Elgee Siltstone; it is located about 800 m southwest of Pteropus 1 on the same northeasterly trending structure. Bulk sampling of both pipes has so far recovered only small non-commercial diamonds.

Phillips Range kimberlite field

The large (18 ha) diamondiferous Aries kimberlite pipe, located 160 km north-northeast of Fitzroy Crossing, is the only pipe so far discovered in the Phillips Range kimberlite field. It lies under a thin cover of transported regolith material and was located in 1986 during exploration drilling to follow up indicator-mineral anomalies. The Aries pipe has three main diamondiferous lobes that lie within a north–south trend: North, Central, and South lobes (**8062–64**). A fourth lobe, North lobe extended, appears to be barren. The pipe intrudes the King Leopold Sandstone and the Carson Volcanics, straddling the contact between the two, and its age is c. 820 ± 20 Ma (Edwards et al., 1992). Results from recent gravity surveys and drilling have shown that Aries South lobe contains four separate diamondiferous kimberlite entities known as Helena, Athena, Persephone, and Niobe (Fig. 5; Thundelarra Exploration Ltd, announcement to ASX, 15 February 2002).

Bulk testing from an openpit at the Aries Central lobe in 1991, by Triad and Poseidon, produced 1819 ct of diamonds, 95% of which were of gem quality (at an average price of US$100/ct). Further testing of the Central lobe in late 1994 indicated disappointing average grades of between 2 and 5 ct/100 t. Also in 1994, samples from large-diameter drilling of Aries North lobe showed very low grade results (less than 1 ct/100 t).

Stratabound volcanic and sedimentary mineralization

Twenty occurrences of volcanic-hosted sulfide mineralization (VMS) are found in the north Kimberley, including base metal (specifically copper) mineralization in mafic volcanic rocks and interbedded sedimentary rocks of the Palaeoproterozoic Carson Volcanics (Plate 1 and Fig. 13).

Base metal — copper

Copper mineralization is widespread in the Carson Volcanics throughout the Kimberley Basin. However, the distribution shown on Figure 13 and on Plate 1 is biased by a concentration of occurrences in the Durack Range (northeastern LANSDOWNE). This concentration represents the large number of copper prospects that were located by Planet Mining and its joint venture partners during systematic exploration in the late 1960s and early 1970s. Secondary mineralization at the surface is malachite, with subordinate chalcocite, and minor bornite. Planet

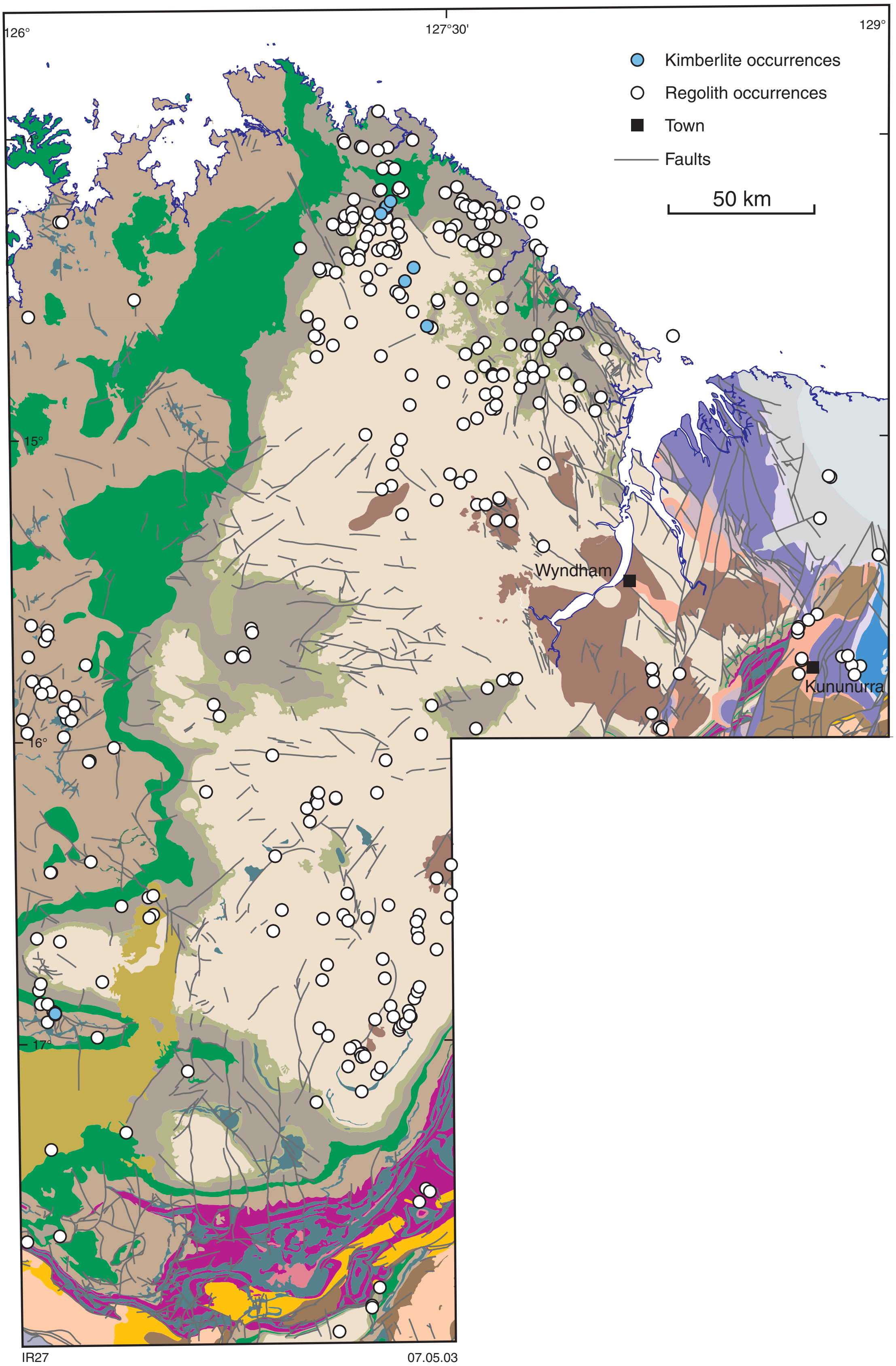


Figure 12. Distribution of diamond occurrences in the north Kimberley showing diamonds in kimberlite intrusions, and alluvial and eluvial diamond occurrences. See Figure 11 for geological legend

recognized four types of copper occurrence in the Durack Range (Marston, 1979). In order of decreasing abundance these are:

(i) copper disseminations and veinlets in the tuffaceous (or vesicular) top of the second basalt flow (from base), or in the overlying shale or chert, or in both;

(ii) copper disseminations along bedding planes or joints in sandstone interbeds between flows;

(iii) copper veinlets and disseminations in fractured, faulted, or epidotized basalt; and

(iv) copper veinlets and disseminations in the lowest amygdaloidal basalt.

The style of mineralization is similar to that of the Keweenaw 'native-copper' district in Northern Michigan, U.S.A. (White, 1968; Nicholson et al., 1992; Schulz et al., 1998; Ojakangas et al., 2001), where copper mineralization is in a number of amygdaloidal basalt flow-tops and conglomerate beds in the Mesoproterozoic Portage Lake Lava Series (c. 1100 Ma).

Orthomagmatic mafic and ultramafic mineralization

There are five occurrences of magmatic sulfide mineralization in the area, and all are copper occurrences in mafic sills of the Palaeoproterozoic Hart Dolerite (Fig. 13).

Base metal — copper

At Karunjie (**5217**) disseminated chalcocite and chalcopyrite in dolerite were noted during regional mapping by BMR (Roberts et al., 1966; Marston, 1979). Other occurrences were located during the course of uranium exploration in the early 1970s at Lansdowne 6, 8, and 9 (**10135**, **4669**, **4676**).

Stratabound sedimentary mineralization

A total of 83 occurrences of stratabound sedimentary mineralization have been recorded in the north Kimberley (Plate 1 and Fig. 14). These include carbonate-hosted occurrences, clastic-hosted occurrences, and sandstone-hosted uranium occurrences.

Carbonate-hosted mineralization

Base metal — lead, zinc (copper, silver)

Significant stratabound lead–zinc–silver mineralization occurs in the Southern Bonaparte Basin at Sorby Hills (**3058–61**, **3063–72**), located about 45 km northeast of Kununurra close to the Northern Territory border. The mineralization is of Mississippi Valley-type (MVT) developed in carbonate rocks of the Carboniferous Burt Range Formation in the Burt Range Sub-basin around the northeastern flank of the Mesoproterozoic Pincombe Inlier. Other smaller occurrences in carbonate rocks have been located elsewhere in the Carlton and Burt Range Sub-basins (Ferguson, 1999).

The Sorby Hills lead–silver–zinc deposits are located a few kilometres to the east and north of Sorby Hills, lying at depths of between 40 and 180 m below the black soil plain (Fig. 15). Mineralization is in 13 separate irregular-shaped bodies distributed along a north-trending zone having a length of about 8 km (Fig. 16). Resources have been estimated as 16.25 Mt of 5.3% Pb, 0.6% Zn, and 56 g/t Ag, using a cut-off grade of 2.5% for lead plus zinc, and a 3.0 m minimum ore thickness (Rowley and Lee, 1986).

The mineralization is mainly developed in a lenticular intraformational breccia in the Burt Range Formation of Tournaisian age. The breccia zone is 15 to 20 m thick, and is at the boundary between the underlying Sorby Dolomite Member and overlying Knox Siltstone Member; the breccia contains clasts of both members. Ore minerals are galena, sphalerite, and chalcopyrite, plus minor amounts of pyrargyrite–proustite, tetrahedrite–tennantite, and bournonite. Gangue minerals are marcasite, pyrite, calcite, and dolomite. Studies of the sulfide mineralogy, textures, geochemistry, paragenesis, and structural and stratigraphic settings of the deposits have been made by Morris (1977), Rowley and Lee (1986), Mory and Beere (1988), Ringrose (1989), Jorgensen et al. (1990), Lee and Rowley (1990), and Ferguson (1999).

Pervasive dolomitization preceded local silicification and sulfide precipitation. Rowley and Lee (1986) proposed a 'mixing' genetic model for mineralization, in which sulfides precipitated from metal-rich basinal brines, after mixing with locally derived reduced-sulfur solutions, at relatively shallow depths.

Other stratabound lead–zinc–silver occurrences are located in reef complexes in the Burt Range Sub-basin to the west and northwest of Sorby Hills at Redbank (**8220–21**, **8223**, **8226**), Carlton Hill (**3010**), and Ningbing (**10604**), where zinc-rich mineralization was intersected by AMAX during drilling in 1979 (Ferguson, 1999). A copper-rich stratabound occurrence was intersected in drilling at Petes Find (**3041**).

Clastic-hosted mineralization

Base metal — copper

Within the Palaeoproterozoic Kimberley Basin low-grade disseminated syngenetic 'Zambian style' copper mineralization (Annels, 1989; Kirkham, 1989; Sweeney et al., 1991) is widespread in the Teronis Member of the Elgee Siltstone and in the basal part of the Middle Pentecost Sandstone (Harms, 1959; Bruinsma, 1970; Owen, 1970; Klaric, 1971, 1975; Marston, 1979). The Teronis Member is the lowermost unit of the Elgee Siltstone, and was the focus of exploration at various mineralized prospects in the late 1960s and early 1970s: around Menuairs Dome (**5211**, **5214–16**), and in the Lyne River area (**5057**, **5059–62**, **5064–65**). The unit consists mainly of grey-green shale and siltstone with some interbeds of sandstone and dolomite (often with stromatolites and ooliths),

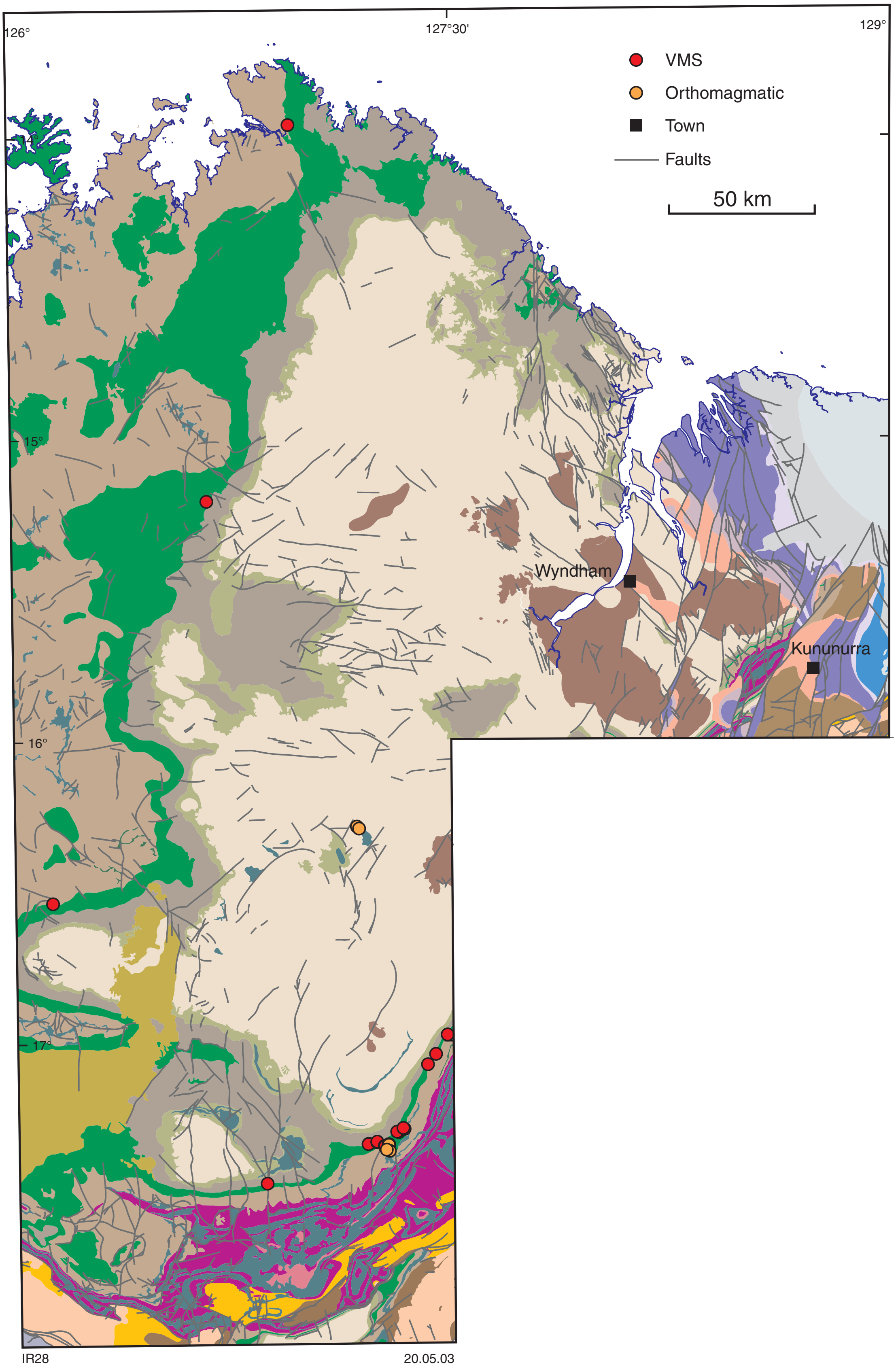


Figure 13. Distribution of stratabound volcanic and sedimentary mineral occurrences, and orthomagmatic and ultramafic mineralization in the north Kimberley. See Figure 11 for geological legend

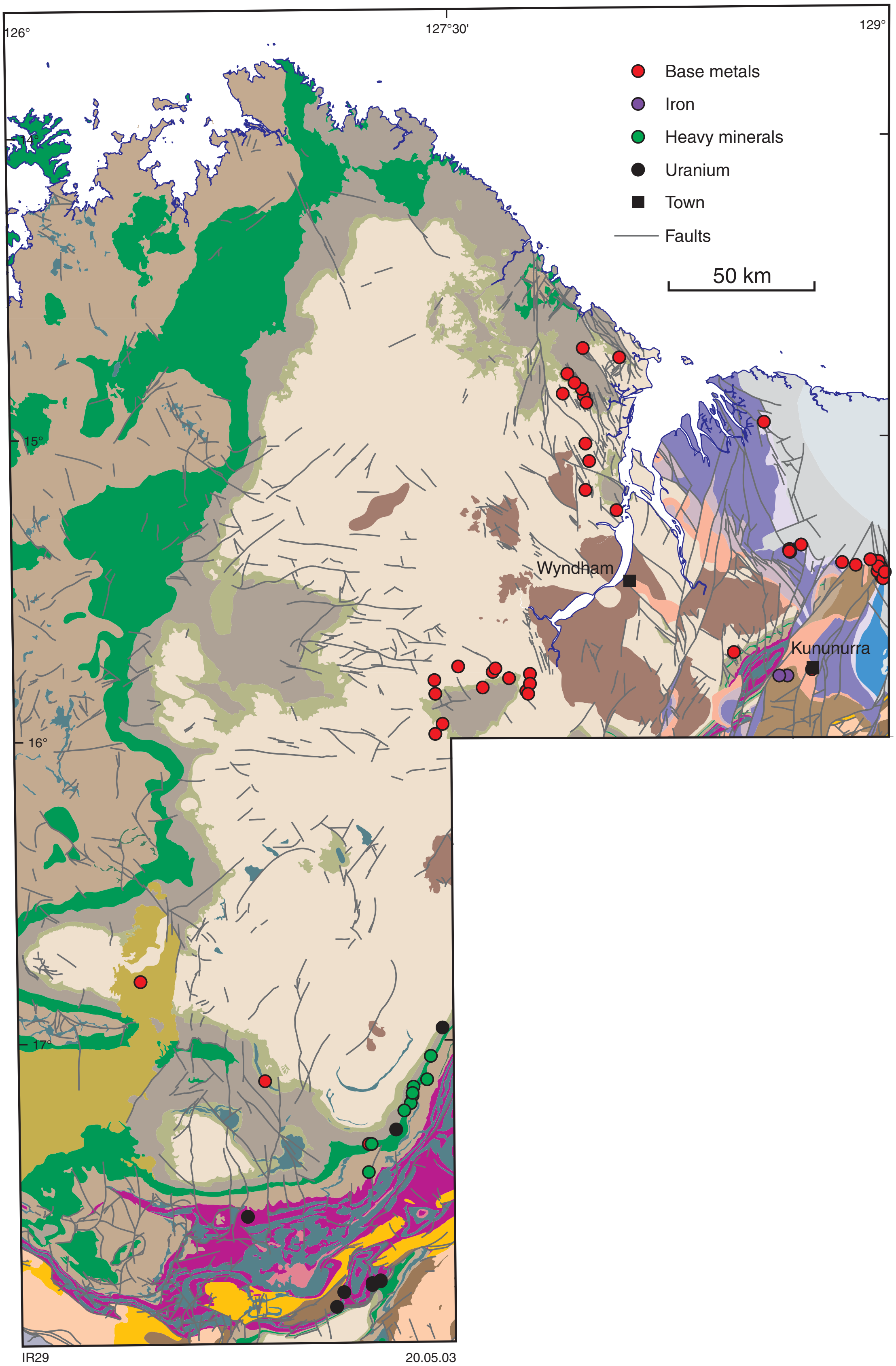


Figure 14. Distribution of stratabound sedimentary mineral occurrences in the north Kimberley. See Figure 11 for geological legend

Figure 15. Photograph of the Sorby Hills discovery gossan, looking towards the south. The lead–zinc deposits that lie below black soil plain are to left of the outcrop. Photograph courtesy P. C. Muhling

suggesting a shallow-water near-shore environment of deposition. Mineralization at the surface is usually disseminated malachite and chalcocite.

Disseminations and aggregates of malachite are also in shale at the base of the Middle Pentecost Sandstone at Menuairs Dome 1 (**4523**) and Menuairs Dome 2 (**4535**). Anglo American reported up to 0.75% Cu in some rock-chip samples around Menuairs Dome, but follow-up drilling encountered only very low Cu values, suggesting that mineralization was due to surface enrichment of very minor syngenetic copper (Orr, 1971).

In the Walsh Tillite, Harms (1959) noted disseminated copper mineralization (chalcocite and native copper) in dolomitic limestone in the headwaters of Police Creek (**10082**).

The source of mineralized fluids for stratabound mineralization in the Elgee Siltstone and Pentecost Sandstone is presumed to be from the underlying copper-bearing Carson Volcanics.

Iron

Low-grade iron mineralization occurs in the Bandicoot Range Beds of the Mesoproterozoic Carr Boyd Group (Plumb and Veevers, 1971), about 10 km west of Kununurra (**2989**, **2991**). Iron mineralization (hematite and limonite) is in ten separate horizons of ferruginous sandstone and siltstone ranging in thickness from 0.7 to 10 m. Mapping and sampling of the mineralized horizons showed that they had a low average grade of 22.7% Fe (Alliance Minerals Australia NL, 1971). According to Plumb and Veevers (1971), the Bandicoot Range Beds may be equivalent to the Golden Gate Siltstone (on LISSADELL), which contains the iron deposits of Pompeys Pillar and Matsu in the east Kimberley area (Hassan, 2000).

Heavy minerals

Heavy minerals with abundant monazite and zircon (plus some anatase) are concentrated in lenses, up to 1.2 m thick, in a purple sandstone unit near the top of the Carson Volcanics. The lenses have been traced over a strike length of about 50 km in the Durack Range, west of Bedford Downs Homestead (**10626–28**, **10750**, **10752–53**, **10770–72**), and may represent heavy mineral accumulations along palaeoshorelines. The lenses are radioactive, due to the high thorium and uranium content of monazite and zircon, and were located and assessed for their uranium potential during 1969–70 (Planet Mining Co. Pty Ltd, 1970). One lens (**10751**) has a particularly high uranium and thorium content and is referred to below, see '**Uranium**'.

Uranium

At Durack Range 2 (**10751**) a lens of heavy minerals was drilled by Planet Mining in 1969 and one sample

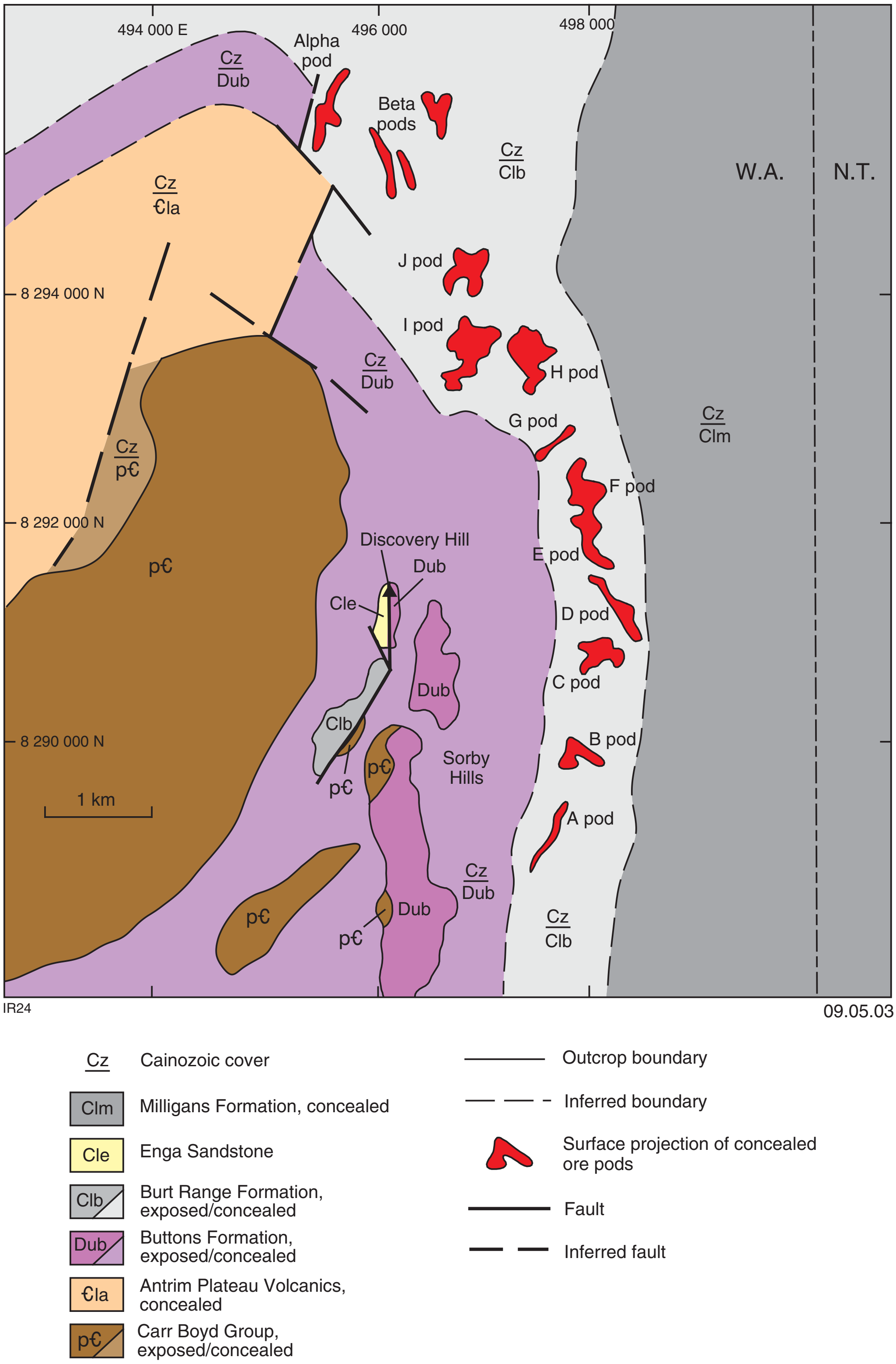


Figure 16. Sorby Hills lead–zinc ore pods and general geology (modified from Ringrose, 1989)

contained 0.136% U and 2.037% Th. The radioactive lenses of heavy minerals in the Carson Volcanics were compared to the uranium deposits at Blind River, Ontario (Planet Mining Co. Pty Ltd, 1970).

In 1970 secondary uranium mineralization was located by South Pacific Minière Pty Ltd in a sandstone unit (informally named 'Brown Sandstone') within the O'Donnell Formation (Speewah Group) in the area of Mad GapYards (**2525–27**, **10559**) and an area west of this (**5328**, **9659**). Rock-chip samples contained between 0.6% and 1.7% U_3O_8, but subsequent drilling showed that these high values were probably surface enrichment of minor vein mineralization at depth.

Speciality metal — tin

Cassiterite was intersected in conglomerates during uranium exploration drilling of King Leopold Sandstone (Kimberley Group) at Lansdowne 1 (**4659**) and Mount Bedford (**4678**).

Industrial mineral — barite

Disseminated barite was intersected in sandstone (stratigraphically above galena mineralization) during drilling of the Tournaisian 'Upper Formation' at central Sorby Hills (**3123**).

Sedimentary mineralization — undivided

Industrial minerals — salt, gypsum, phosphate

Massive halite has been intersected in petroleum exploration well Pelican Island 1 (**3031**). A gypsum–clay horizon was intersected during base metal exploration at Carlton Hill (**3011**). Phosphate nodules containing up to 20% P_2O_5 are in an extensive zone at Waggon Creek (**2986**), Gum Creek (**2985**), and Ningbing Range (**2982**).

Sedimentary basin mineralization

Coal

In the Skull Creek area (**5253**) thin intervals of coal (0.2 to 0.5 m thick) were intersected in one drillhole in carbonaceous mudstones within a sandstone-dominated sequence in the Keep Inlet Formation of the latest Carboniferous (McBain, 1982). More significant coal intersections have been made to the east of this in the Northern Territory in petroleum exploration well Keep River 1, where coal beds are 1.5 to 3 m thick in a shale-dominated sequence of the Keep Inlet Formation (Caye, 1969).

Vein and hydrothermal mineralization — undivided

There are 57 occurrences of vein and hydrothermal mineralization in the north Kimberley (Plate 1 and Fig. 17).

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

Vein and hydrothermal base metal occurrences are located mainly in the east and south of the north Kimberley area (Fig. 17). The best known of these is the Shangri-La polymetallic deposit, also known as Costeos or Shangri-La mine (**1492**), which is a popular site for mineral collectors. Shangri-La is located about 21 km west of Kununurra just north of the Duncan Highway, where it is exposed in a shallow openpit. The deposit was discovered in 1967 by P. Costeo, a local prospector, and it consists of polymetallic quartz veins in a thick sill of Hart Dolerite intruding the Valentine Siltstone of the Speewah Group (Sofoulis, 1968). The veins in the dolerite have a shallow northerly dip and are en echelon within a west-northwesterly trending zone about 300 m in length. Mineralization is predominantly lead with some copper and zinc; there is also a high content of silver and gold in the veins (Sofoulis, 1968; Blockley, 1971; Marston, 1979; Ferguson, 1999). Another vein at Shangri-La South (**10863**) was investigated by Thiess Exploration in 1970 (Thiess Exploration Co. Pty Ltd, 1970).

West of Shangri-La there are similar polymetallic veins, with high-grade values of silver and gold, in Hart Dolerite and Valentine Siltstone in the Silver Hills area (**1494**) and in Hart Dolerite in the Donkey Hills area (**3006**, **3025**). The veins at Silver Hills North and at Donkey Hills were discovered by H. F. and E. M. Moder in 1984 (Moder and Moder, 1985; Ferguson, 1999).

Other vein occurrences, in the east of the area, are located in Devonian reef complexes to the north and northeast of Kununurra in the Ningbing Range, Pretlove Hills, and Sorby Hills areas, where veins are in limestone and sandstone units in the Ningbing and Cockatoo Groups of the Southern Bonaparte Basin. These include Redbank (**3035**), Knob Peak (**3019**), Ningbing Amax gossan (**3028**), and Sorby Deep South (**3091**).

In the south of the area are several base metal veins in the Whitewater Volcanics of the Lamboo and Hooper Complexes. Other, mainly copper, veins are in the Carson Volcanics of the Kimberley Basin in the areas of Teronis Gorge (**9650**, **9652–53**, **9656**, **9658**) and Tunganary Bore (**8760**, **8762**).

Precious metal — gold

There are few vein and hydrothermal gold occurrences known in the north Kimberley. The most significant of these are in the Shangri-La area, described above. However, the auriferous veins in Carson Volcanics near Mount Brennan (**10562**) that were noted by Fitzgerald (1907) could have a more widespread distribution throughout the Kimberley Basin as suggested by recent exploration results. Striker Resources announced that there may be a new district of epithermal gold mineralization in the North Kimberley kimberlite field, within a north-westerly trending structural corridor located to the southeast of the mouth of the Berkeley River (Striker Resources NL, announcement to ASX, 30 January 2002).

This announcement from Striker Resources reported that significant alluvial gold had been located in the

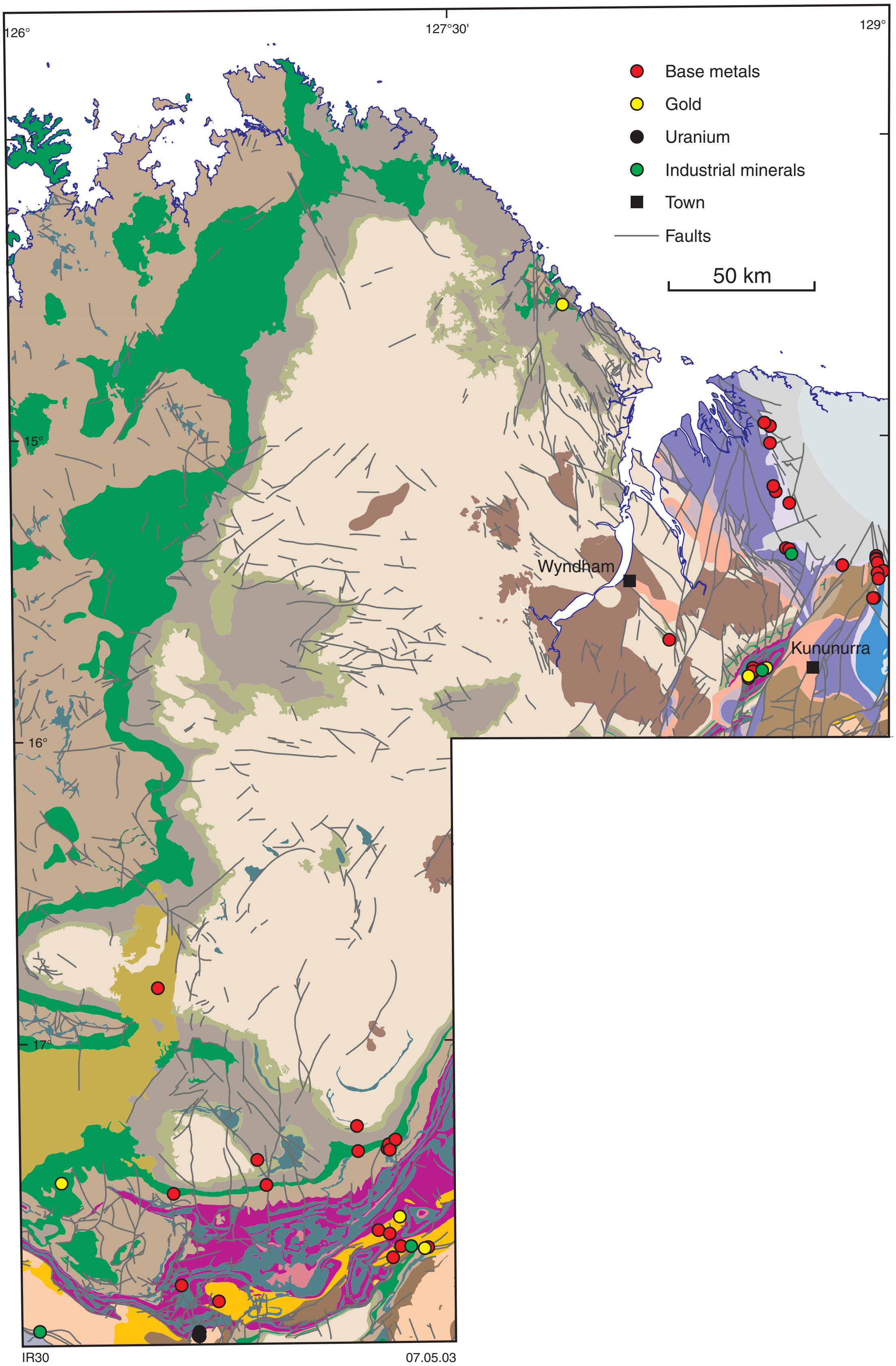


Figure 17. Distribution of vein and hydrothermal mineral occurrences in the north Kimberley. See Figure 11 for geological legend

vicinity of the ‘88 Creek’ alluvial gold occurrence (**10631**) during a diamond-exploration program conducted by its joint venture partner De Beers in late 2001. The area is coincident with an extensive zone (70 × 20 km) of argillic alteration, interpreted from a multispectral scanning survey, in rocks of the Kimberley Group. Further investigations on the ground have confirmed the presence of argillic alteration and have located extensive zones of quartz veining, brecciation, iron enrichment, and silicification, with some veins showing colloform textures (Fig. 18) that may indicate epithermal activity (Striker Resources NL, announcement to ASX, 6 March 2002). Drilling at ‘88 Creek’ in 2002 intersected a 20 m-thick zone of phyllosilicate alteration in flat-lying sandstone that contains low-grade gold mineralization (Striker Resources NL, 2002).

Uranium

Secondary uranium mineralization (meta-autunite and torbernite) was intersected in shears in the Palaeoproterozoic Whitewater Volcanics, during exploration drilling by Metals Minière Exploration Pty Ltd in 1971 at Juno (**5336**) and Jupiter (**5337**) prospects.

Industrial minerals — barite, fluorite

Massive barite in a fault breccia zone at Silver Hills West (**11280**) is in association with minor copper mineralization (Sofoulis, 1968). Barite (presumed to be in veins) was noted in geological mapping during diamond exploration in the Carson Volcanics at Sandy Gorge (**8030–31**). Two minor occurrences of fluorite (in veins less than 10 cm wide) were recorded on LANSDOWNE by Gellatly and Derrick (1967): in Long Hole Granite at Stony Creek (**9688**); and in Whitewater Volcanics at Tumagee Yard (**1377**), where it is associated with copper mineralization.

Regolith — residual and supergene mineralization

The distribution of residual and supergene bauxite mineralization is shown on Plate 1 and Figure 19.

Bauxite

The lateritic bauxite deposits in the Admiralty Gulf region at Cape Bougainville (**8735**, **10128–29**), together with the deposits at Mitchell Plateau to the west (Hassan, in prep.), contain about 1400 Mt of total chemical alumina, and represent almost 50% of the State’s bauxite resources. The deposits form sheet-like masses within mesa remnants of a dissected duricrusted plateau, developed in the early Cainozoic over mafic volcanic and volcaniclastic rocks of the Palaeoproterozoic Carson Volcanics (Figs 6 and 19).

The bauxite profile at Cape Bougainville (some 8 to 9 m thick) is significantly thicker than at Mitchell Plateau (3 m). Bardossy and Aleva (1990) reported that the bauxite texture ranges from massive to tubular, and there is a higher iron oxide content (40% Fe_2O_3) than in bauxites at Mitchell Plateau (7 to 38% Fe_2O_3). Kaolin is low to absent throughout most of the profile (Smurthwaite, 1990, figs 7–9). Although the bauxite resources at Cape Bougainville are larger, they have not been tested to the same extent as those at Mitchell Plateau.

Table 1 summarizes the results of the initial AMAX investigations between 1969 and 1971.

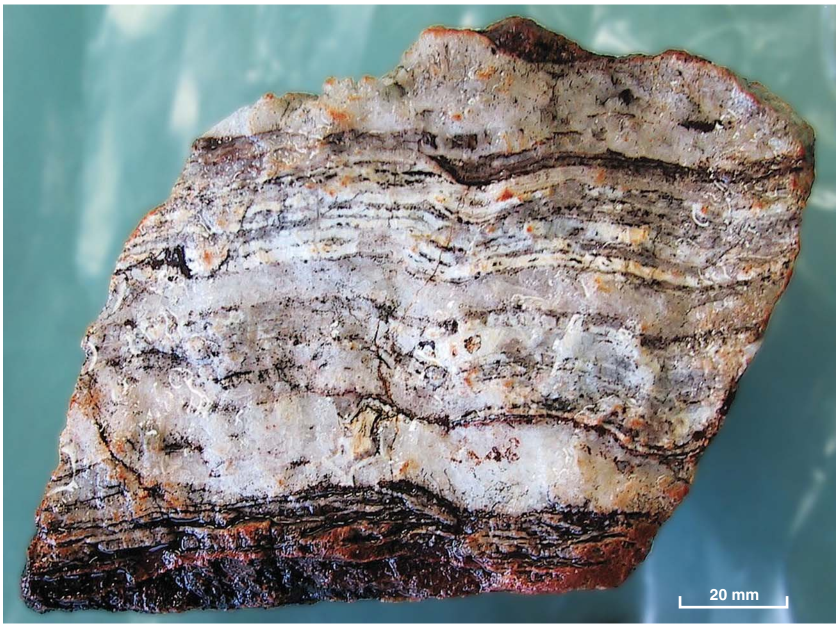


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Figure 18. Photograph of epithermal vein showing colloform textures, from Epithermal Creek about 4 km northwest of ‘88 Creek’ locality. Photograph courtesy Striker Resources NL

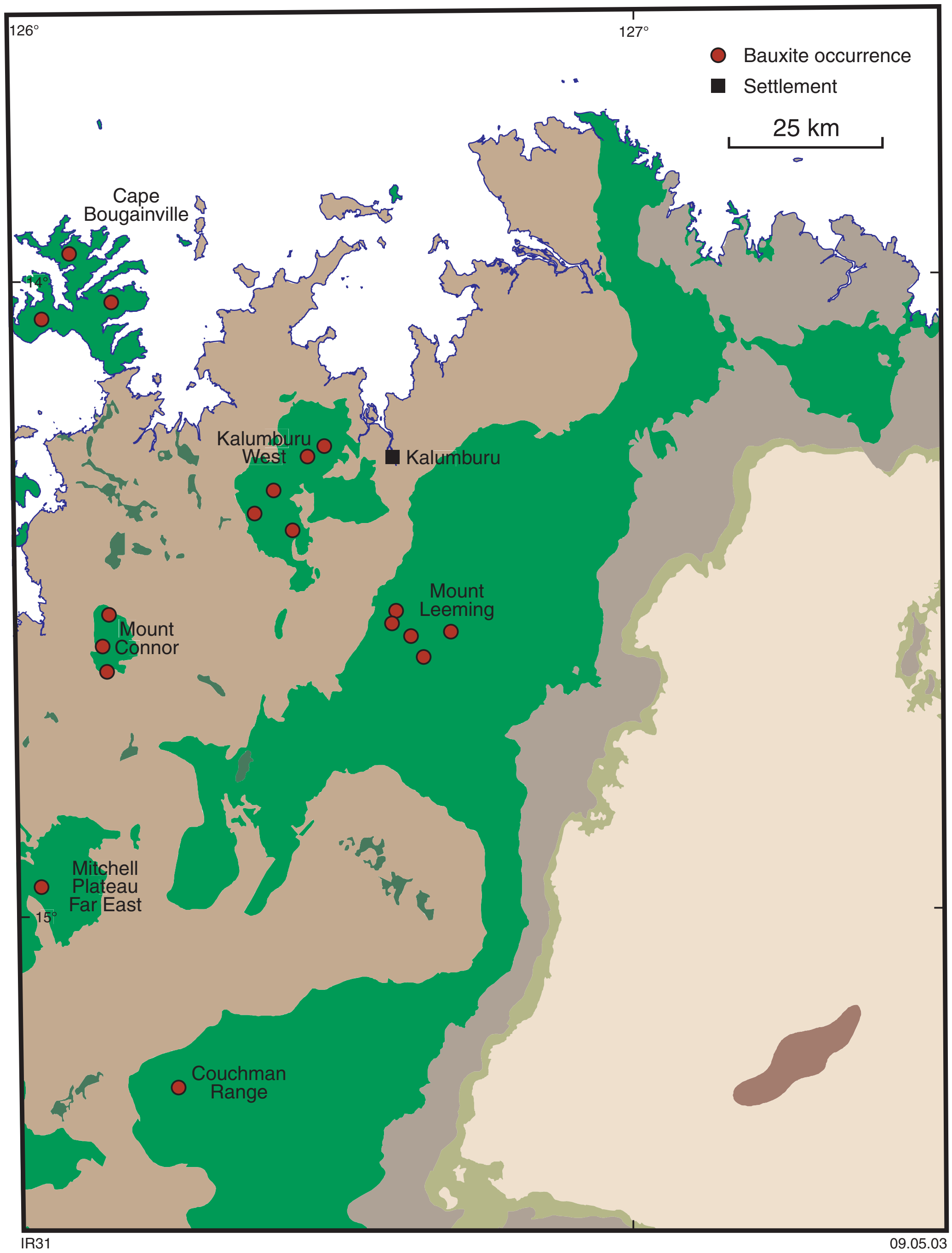

Figure 19. Distribution of bauxite occurrences in the north Kimberley area. See Figure 11 for geological legend

The bauxite at Cape Bougainville is regarded as ferruginous bauxite (Joklik et al., 1975). The profile shows a tubular structure throughout (compared to the pisolitic and massive structures at Mitchell Plateau). The ratio of boehmite (trihydrate alumina: $Al_2O_3.3H_2O$) to gibbsite (monohydrate alumina: $Al_2O_3.H_2O$) is relatively high at 1:2 to 1:3. In the Bayer process of alumina production, a higher gibbsite content is preferred because alumina may be extracted from it at a digestion temperature of 150°C, whereas boehmite requires a higher temperature of 250°C. The low silica content (present in the clay minerals kaolinite and montmorillonite) is favourable in processing, because high silica consumes large amounts of caustic soda and acid in the alumina process.

To the southeast and south of Cape Bougainville, smaller deposits of bauxite (developed over Carson Volcanics) exist at Mount Leeming (**8285**, **10341–44**), West Kalumburu (**8281–84**, **10340**), Mount Connor (**8728–30**), and Couchman Range (**10596**). Mitchell Plateau Far East (**8731**) is an eastern extension of the Mitchell Plateau bauxite deposits (Hassan, in prep.).

Table 1. Comparison of the bauxites from Cape Bougainville and Mitchell Plateau

	Cape Bougainville	*Mitchell Plateau*
TCA indicated reserves	980 Mt	234 Mt
Areal extent of bauxite	44 km^2	40 km^2
Thickness (average)	8.6 m	3.2 m
Thickness (maximum)	12.5 m	10 m
TCA	36%	47%
Available alumina (at 250°C)	29.6%	42.5%
Boehmite:gibbsite ratio	1:2	1:10
Total silica	1.9%	2.6%

SOURCE: from Joklik et al. (1975)
NOTE: TCA: Total chemical alumina

Regolith — alluvial to beach placer mineralization

There are 339 occurrences of alluvial to beach placer mineralization in the north Kimberley area (Plate 1 and Fig. 20), including precious mineral, precious metal, and iron occurrences.

Precious mineral — diamond: onshore and offshore

The majority of the alluvial diamond occurrences are sites where exploration drainage-sampling has recovered macrodiamonds of at least 0.4 mm in diameter. Some of the alluvial sites are prospects where there has been assessment for possible commercial development: at Ivanhoe Crossing and Proto-Ord River (**3158**) just west of Kununurra townsite, at Nyairgul Creek (**8589**), and at Harris Creek (**8591**) north of the Aries pipe.

In a small kimberlite field located to the southwest of Mad Gap Yards, about 65 km northwest of Halls Creek, Diamin located alluvial diamonds at two sites: Sandy Gorge A1 (**8029**) and Skeleton Flat 1 (**9693**). Although past drilling near these sites intersected only barren kimberlite bodies, the area is to be reassessed to locate the sources of these diamonds (Flinders Diamonds Limited, 2001).

Diamonds have been located offshore in jointed sandstone on the seabed in the vicinity of Reveley Island (**4959–60**). Capricorn Resources recovered several diamonds in 1988 that ranged in size from 0.176 ct to 0.35 ct. In 1993 Cambridge Gulf Exploration recovered 14 diamonds of gem quality (totalling 8.8 ct) in gravel within palaeochannels of the Berkeley River at three sites (**10112–14**), and 23 diamonds of gem quality (totalling 5.87 ct) in gravel within palaeochannels of the Ord River at one site (**10122**) to the northwest of Lacrosse Island.

Precious metal — gold

Concentrations of fine-grained detrital gold were located at six sites (**3304**, **3308**, **3979**, **8295**, **8297–98**) in alluvial gravels during drainage sampling, as reported in open-file reports on diamond exploration. In addition, the newly announced occurrence at '88 Creek' (**10631**), southeast of the Berkeley River, represents the largest concentration of detrital gold in the north Kimberley (Fig. 21). This occurrence was located during diamond exploration in 2001 (Striker Resources NL, announcement to ASX, 30 January 2002).

Iron

Lateritic iron deposits recorded as Durack Laterite 1–4 (**4473**, **4482**, **10775–76**) were located during 1969 by Planet Mining in the Durack Range, about 11 km west-northwest of Bedford Downs Homestead. The deposits extend in a north-northeasterly direction for about 13 km, and may represent the eroded remnants of a lateritic iron ore zone that formed along a palaeodrainage underlain by King Leopold Sandstone. The mineralization is limonite–goethite (and minor hematite) with surface samples showing grades of 45% to 56% Fe. A rough resource assessment in 1970 estimated that the deposits contained about 9 Mt of ore material, with a further 1 Mt contained in smaller remnants of lateritic ore in a palaeodrainage zone located 40–50 km to the northeast on LISSADELL (Planet Mining Co. Pty Ltd, 1970).

Regolith — residual to eluvial placer mineralization

Precious mineral — diamond

All 16 of the occurrences in the north Kimberley, as shown on Plate 1, are sites where macrodiamonds (>0.4 mm) have been recovered from loam samples.

Mineralization controls and exploration potential

Most of the mineralization in the north Kimberley, as shown on Plate 1, is predominantly within the Palaeoproterozoic Kimberley Basin and includes diamonds,

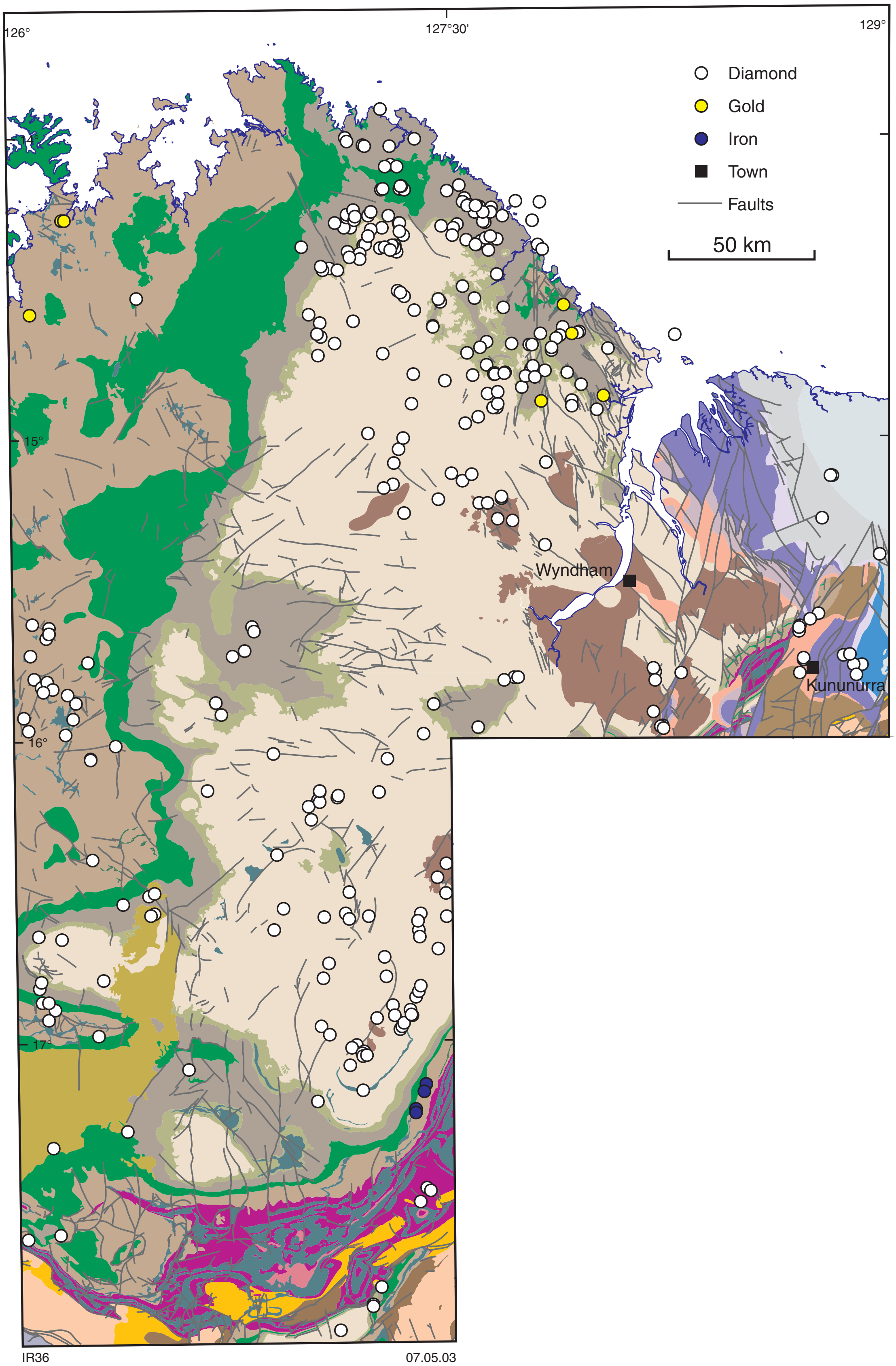

Figure 20. Distribution of mineral occurrences in the north Kimberley classified as regolith — alluvial to beach placer mineralization. See Figure 11 for geological legend

Figure 21. Photograph of alluvial gold grains collected at '88 Creek' locality. The gold grains were reported in the -0.5 mm to +0.3 mm size fraction. Photograph courtesy Striker Resources NL

bauxite, copper, and gold. In the Phanerozoic Southern Bonaparte Basin there is significant lead–silver–zinc mineralization on the Carlton and Burt Range Shelves. In the Halls Creek and King Leopold Orogens there are a few vein and hydrothermal occurrences of base metals and precious metals.

Mineralization in kimberlite and lamproite intrusions

Diamond

Extensive drainage sampling and follow-up detailed exploration since the mid-1970s has so far located two main fields of kimberlite and diamondiferous kimberlite (North Kimberley and Phillips Range kimberlite fields) and a possible new field of kimberlites that may yet yield diamondiferous bodies (the Skeleton Flats area). In each of the three fields, the dominant trend of kimberlite dykes and kimberlite pipe clusters is north-northeasterly, parallel to the trend of the Halls Creek Orogen. There is a high potential for further kimberlites to be found in each field. Bulk testing to assess diamond grades at Aries, Ashmore, and Seppelt has shown that Seppelt contains the most promising grades: 40 ct/100 t for the inferred resource of 1.7 Mt at Seppelt 1 and about 2 ct/t for a 183 t bulk sample at Seppelt 2. Although the average grade at Ashmore is much lower (5 ct/100 t), it is encouraging that some large stones (over 10 ct) have been recovered, suggesting conditions were favourable for the formation of large diamonds in the mantle below the North Kimberley kimberlite field. The area, therefore, remains highly prospective for commercial diamond deposits.

Stratabound volcanic and sedimentary mineralization

Copper

The initial exploration assessment of disseminated copper mineralization in the Carson Volcanics during the late 1960s and early 1970s focused on the Durack Range, and no exploration has tested the potential in the Carson Volcanics elsewhere. Whereas the initial exploration in the Durack Range included outcrop, soil, and stream-sediment sampling, and follow-up drilling of geochemical targets, it did not include electromagnetic (EM) geophysical surveys, and there is scope for these to be used to highlight other target areas that may represent concealed zones containing economic resources of copper mineralization.

Stratabound sedimentary (clastic-hosted) mineralization

Copper

Early exploration for disseminated copper mineralization in the Palaeoproterozoic Elgee Siltstone and Pentecost Sandstone in the east of the area, during the late 1960s and early 1970s, was limited to drilling targets defined by mapping and geochemical surveys. Disappointing drilling results discouraged companies from undertaking further work. However, as discussed above, there is scope for EM geophysical surveys to be applied to highlight other targets representing concealed economic copper mineralization.

Stratabound sedimentary (carbonate-hosted) mineralization

Lead, silver, zinc

The discovery in the early 1970s of significant stratabound carbonate-hosted lead–silver–(zinc) mineralization, of Mississippi Valley-type, at Sorby Hills and at prospects to the west and northwest has enhanced the prospectivity of Devonian reef complexes in the Southern Bonaparte Basin. However, development of the deposits at Sorby Hills has been deterred by the relatively low zinc content of mineralization and the difficult underground mining conditions. Exploration at other prospects in Devonian reef complexes to the west and northwest, in the Ningbing Ranges, indicates that there is potential here for significant zinc-rich mineralization. Further exploration to test this possibility was curtailed during the 1990s because of difficulties in negotiating access with local Aboriginal groups.

Vein and hydrothermal mineralization

Gold

Until Striker's announcement in 2002 about gold at '88 Creek', the Kimberley Basin was regarded as having low prospectivity for gold, although particles of gold have been recovered during stream-sediment sampling for diamonds throughout the area since the early 1970s. The recent announcement by Striker Resources of a possible new district of epithermal gold mineralization in the North Kimberley kimberlite field has significantly changed the gold prospectivity of the Kimberley Basin in that area and possibly elsewhere. Within Striker's Oombulgurri gold project area, zones of hematitic alteration and quartz veins with epithermal textures coincide with intersections of major faults trending northerly, northeasterly, and northwesterly within a northwesterly trending structural corridor that is parallel to the coast. The age of the epithermal gold event is unknown, but Hassan (in prep.) has suggested it may be as young as late Miocene to early Pliocene.

There is moderate potential for gold mineralization in veins in the Whitewater Volcanics of the King Leopold Orogen and in the western zone of the Halls Creek Orogen; also for vein deposits in the vicinity of Shangri-La mine west of Kununurra.

Orthomagmatic mafic mineralization

Nickel, platinum group elements (gold)

The Carson Volcanics of the Kimberley Group represent the eruption of large volumes of mafic material, suggesting a phase of intracratonic rifting that may have been associated with mantle-plume activity in the Palaeoproterozoic. There is therefore potential for the mafic magmas to have contained nickel–copper sulfides with minor PGE and gold, which could be present in picritic mafic rocks close to eruptive centres. To date, only the copper potential of the Carson Volcanics has been explored, and that has been over a relatively small area.

Similarly, there is potential for nickel–copper sulfides and PGE in the Hart Dolerite, which also represents a major phase of mafic magma production in a continued mantle-plume event.

Regolith — residual and supergene mineralization

Bauxite

There is little potential for further discoveries of bauxite. The extensive known deposits and prospects were located and examined in the 1960s.

Regolith — alluvial to beach placer mineralization

Diamond

There is potential for the discovery of alluvial deposits in older terrace gravels along existing drainages and in palaeochannels. Offshore, there is potential for diamond accumulations in trap sites close to the coastline near existing river mouths, and further offshore in gravels occupying submerged palaeochannels of the major rivers.

Conclusions

The north Kimberley area is a remote under-explored part of the State that has potential for a range of commodities in a number of mineralization styles. Exploration since the late 1950s has shown various areas as being prospective for bauxite, diamonds, base metals, and gold.

There are no operating mines, but the large bauxite deposits at Cape Bougainville, outlined in the 1960s, may be considered for development in the longer term if development of the Mitchell Plateau bauxite deposits were to proceed. The Mississippi Valley-type base metal deposits at Sorby Hills (lead rich but zinc poor), delineated in the 1980s, are unlikely to be developed if the Ord River Irrigation Project is expanded (under Stage 2) to cover the Weaber Plains. Although there is potential for zinc-rich mineralization in the Ningbing Range to the north-northwest of Sorby Hills, approvals for exploration and access have been difficult to obtain from Aboriginal communities.

Diamond exploration since the mid-1970s has shown that the north Kimberley is highly prospective, and nearly all of the drainage systems in the area contain indicator minerals and both macrodiamonds and microdiamonds. A number of kimberlite bodies have been discovered, and there is considerable potential for other bodies to be found using new exploration technologies. Although early assessments of known kimberlite bodies indicate that they are either non-diamondiferous or that diamond grades are too low for economic development at present, recent and current exploration in the North Kimberley and Phillips Range kimberlite fields suggests that further evaluation of known diamondiferous bodies is warranted.

Stratabound copper mineralization in the Carson Volcanics and in the Elgee Siltstone, initially examined in the late 1960s and early 1970s, warrants further assessment using modern geophysical methods to detect possible larger economic deposits concealed at depth.

There is also untested potential for nickel–copper sulfides and PGE in the Carson Volcanics and the Hart Dolerite.

The north Kimberley has recently emerged as a possible new province of vein gold mineralization, following encouraging initial exploration results in the northeast of the area.

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Appendix 1

List of mineral occurrences in the north Kimberley

*** KEY TO OPERATING STATUS**

Bold	Operating status
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	Fe	Iron	Salt	Salt
Au	Gold	Fl	Flourite	Sb	Antimony
Bi	Bismuth	Gp	Gypsum	Sn	Tin
Brt	Barite	HM	Heavy mineral sands	Th	Thorium
Bx	Bauxite	Ilm	Ilmenite	U	Uranium
Coal	Coal	Mag	Magnetite	Zn	Zinc
Cu	Copper	Pb	Lead	Zrn	Zircon
Dmd	Diamond	Phos	Phosphate		

KEY TO LOCATIONS
(all locations in Zone 52)

EAST	MGA Easting
NORTH	MGA Northing

NO.*	COMMODITY	EAST	NORTH	NAME
PRECIOUS MINERAL				
	Kimberlite and lamproite intrusions			
3257	Dmd	330850	8381900	Pteropus 1
5241	Dmd	315800	8425650	Ashmore 1
5242	Dmd	315900	8425800	Ashmore 2
5243	Dmd	315850	8425550	Ashmore 3
5244	Dmd	315950	8426000	Ashmore 4
5245	Dmd	317443	8427783	Lower Bulgurri
5247	Dmd	325850	8403400	Seppelt 1 south lobe
8062	Dmd	194350	8129900	Aries North Lobe
8063	Dmd	194300	8129000	Aries South Lobe
8064	Dmd	194300	8129600	Aries Central Lobe
10516	Dmd	325915	8403600	Seppelt 1
10522	Dmd	322700	8398700	Seppelt 2
10538	Dmd	331000	8382200	Pteropus 2
10539	Dmd	314100	8423400	Banksia
	Regolith — alluvial to beach placers			
3144	Dmd	362463	8252758	
3146	Dmd	332690	8242731	
3147	Dmd	363683	8252708	
3148	Dmd	315580	8222503	
3149	Dmd	328883	8232038	
3150	Dmd	358592	8251789	
3151	Dmd	353214	8248912	
3152	Dmd	348942	8234462	
3158	Dmd	466973	8269513	Ivanhoe Crossing – Proto-Ord
3165	Dmd	467343	8271608	
3167	Dmd	467033	8271108	

NO.*	COMMODITY	EAST	NORTH	NAME
PRECIOUS MINERAL				
3168	Dmd	474073	8276328	
3169	Dmd	471013	8274028	
3176	Dmd	489933	8257308	
3178	Dmd	486961	8257534	
3180	Dmd	487777	8253862	
3182	Dmd	467333	8254508	
3184	Dmd	468533	8259158	
3185	Dmd	468433	8259958	
3199	Dmd	313013	8461268	
3200	Dmd	294199	8402714	
3201	Dmd	319219	8408815	
3202	Dmd	317044	8410083	
3203	Dmd	318492	8411374	
3204	Dmd	319968	8419563	
3205	Dmd	313302	8431659	
3206	Dmd	320236	8432066	
3207	Dmd	322096	8431484	
3208	Dmd	325717	8450465	
3209	Dmd	300189	8450610	
3210	Dmd	291023	8382595	
3211	Dmd	314128	8371245	
3212	Dmd	332298	8381640	
3215	Dmd	343312	8396153	
3216	Dmd	352143	8375948	
3217	Dmd	352033	8367202	
3218	Dmd	355018	8364272	
3219	Dmd	381875	8364730	
3220	Dmd	392677	8350901	
3221	Dmd	316719	8440824	
3222	Dmd	319028	8440005	
3223	Dmd	320709	8432931	
3224	Dmd	320177	8419526	
3225	Dmd	321380	8414868	
3226	Dmd	317344	8410236	
3227	Dmd	318532	8410331	
3249	Dmd	332537	8381443	
3284	Dmd	386157	8379449	
3285	Dmd	355940	8413524	
3286	Dmd Au	352927	8409432	
3287	Dmd	344832	8413458	
3288	Dmd Au	348306	8411620	
3290	Dmd	348530	8411816	
3291	Dmd	349983	8412908	
3292	Dmd	351740	8414065	
3294	Dmd	353512	8414590	
3301	Dmd	387011	8360301	
3302	Dmd	361467	8375338	
3303	Dmd	380180	8381471	
3305	Dmd	385433	8379258	
3315	Dmd	353925	8425290	
3316	Dmd	344097	8428627	
3317	Dmd	357833	8422158	
3318	Dmd	349333	8425558	
3319	Dmd	348483	8426058	
3320	Dmd	343323	8427318	
3321	Dmd	351533	8419908	
3322	Dmd	341453	8419138	
3323	Dmd	347853	8423438	
3981	Dmd	346953	8363570	
3982	Dmd	383656	8354397	
3983	Dmd	355132	8364128	
3987	Dmd	339882	8417555	
3988	Dmd	345783	8426318	
3990	Dmd	353567	8423469	
3993	Dmd	345033	8426078	
3996	Dmd	350754	8419980	
3998	Dmd	350833	8423658	
3999	Dmd	348075	8425708	
4019	Dmd	358934	8364465	
4020	Dmd	367640	8374790	
4021	Dmd	383466	8352454	
4022	Dmd	365039	8359281	
4023	Dmd	368473	8365983	
4024	Dmd	366333	8363476	
4025	Dmd	344310	8346045	

NO.*	COMMODITY	EAST	NORTH	NAME
PRECIOUS MINERAL				
4026	Dmd	396633	8373408	
4030	Dmd	378989	8378236	
4033	Dmd	373683	8365408	
4035	Dmd	369383	8367058	
4050	Dmd	347959	8411508	
4051	Dmd	336846	8361532	
4055	Dmd	339366	8415181	
4075	Dmd	223413	8391708	
4091	Dmd	321806	8392610	
4093	Dmd	325246	8363978	
4094	Dmd	349242	8348208	
4134	Dmd	325524	8387243	
4136	Dmd	335180	8390428	
4138	Dmd	334570	8391672	
4140	Dmd	319584	8394683	
4166	Dmd	352493	8356928	
4167	Dmd	355911	8351675	
4168	Dmd	354602	8351641	
4169	Dmd	356400	8353212	
4170	Dmd	356186	8357627	
4177	Dmd	369998	8363024	
4178	Dmd	355057	8363955	
4179	Dmd	355211	8363803	
4181	Dmd	358732	8364184	
4182	Dmd	377740	8377113	
4183	Dmd	376081	8372715	
4184	Dmd	375875	8373866	
4185	Dmd	371726	8379063	
4187	Dmd	368835	8374915	
4188	Dmd	347660	8391901	
4189	Dmd	358344	8388557	
4191	Dmd	355985	8400634	
4192	Dmd	324403	8353169	
4193	Dmd	344850	8371796	
4195	Dmd	349660	8373964	
4229	Dmd	252673	8243013	
4230	Dmd	254700	8238835	
4242	Dmd	228397	8172026	
4243	Dmd	218649	8169096	
4244	Dmd	207579	8185332	
4259	Dmd	188225	8138107	
4260	Dmd	188953	8140229	
4276	Dmd	196233	8155908	
4277	Dmd	187883	8157128	
4282	Dmd	230433	8173008	
4283	Dmd	230245	8165660	
4286	Dmd	229033	8164908	
4296	Dmd	275146	8187346	
4684	Dmd	413963	8254743	
4685	Dmd	423633	8254408	
4686	Dmd	413508	8239944	
4687	Dmd	416893	8235088	
4688	Dmd	416233	8234608	
4689	Dmd	417182	8233908	
4706	Dmd	413313	8255958	
4708	Dmd	414033	8251658	
4872	Dmd	483206	8260708	
4873	Dmd	485483	8261158	
4914	Dmd Au	496553	8298043	
4959	Dmd	370883	8411528	
4960	Dmd	372633	8409958	
4990	Dmd	321851	8312957	
4991	Dmd	334458	8318081	
4992	Dmd	339384	8327604	
4993	Dmd	343243	8324653	
4994	Dmd	346762	8327153	
4995	Dmd	349330	8316517	
4996	Dmd	308477	8342292	
4997	Dmd	317750	8323488	
4998	Dmd	314491	8321930	
4999	Dmd	319805	8336404	
5000	Dmd	318252	8331285	
5001	Dmd	321486	8340605	
5002	Dmd	374046	8331699	
5003	Dmd	352337	8316507	

NO.*	COMMODITY	EAST	NORTH	NAME
PRECIOUS MINERAL				
5004	Dmd	357631	8318324	
5005	Dmd	357499	8318998	
5006	Dmd	361599	8310296	
5007	Dmd	356411	8310820	
5008	Dmd	373699	8301309	
5106	Dmd	290797	8210366	
5107	Dmd	290322	8207352	
5108	Dmd	287691	8200131	
5109	Dmd	286900	8204998	
5111	Dmd	290831	8206773	
5112	Dmd	290962	8210678	
5114	Dmd	297386	8208563	
5115	Dmd	297550	8208962	
5118	Dmd	300361	8165928	
5119	Dmd	309110	8164823	
5120	Dmd	301879	8163835	
5121	Dmd	301712	8173713	
5122	Dmd	327440	8159816	
5123	Dmd	328077	8165906	
5124	Dmd	327083	8163185	
5125	Dmd	327612	8157315	
5127	Dmd	292719	8164429	
5130	Dmd	312533	8210478	
5131	Dmd	334291	8179094	
5134	Dmd	294163	8147361	
5136	Dmd	292323	8141938	
5138	Dmd	314592	8149760	
5139	Dmd	315412	8142578	
5144	Dmd	334433	8153108	
5145	Dmd	326433	8135158	
5146	Dmd	327333	8137438	
5147	Dmd	328043	8139458	
5148	Dmd	291461	8124232	
5149	Dmd	294495	8121252	
5150	Dmd	304462	8117488	
5151	Dmd	302743	8116658	
5153	Dmd	290353	8096908	
5154	Dmd	339587	8184157	
5155	Dmd	338220	8164888	
5156	Dmd	339575	8173247	
5170	Dmd	274310	8159695	
5171	Dmd	317632	8132171	
5172	Dmd	311986	8127504	
5173	Dmd	307313	8115058	
5174	Dmd	306583	8114638	
5175	Dmd	318527	8128473	
5176	Dmd	320603	8123494	
5177	Dmd	321163	8124458	
5178	Dmd	321943	8125683	
5180	Dmd	324329	8130482	
5181	Dmd	302033	8109958	
5182	Dmd	306833	8100908	
5183	Dmd	306833	8113558	
5184	Dmd	308133	8113958	
5246	Dmd	313633	8417858	Beta Creek
8004	Dmd	298850	8012850	Wolooer Creek 1
8010	Dmd	328100	8060150	Watery River 1
8029	Dmd	313700	8028800	Sandy Gorge A1
8044	Dmd	220662	8085729	Glenroy 1
8047	Dmd	243032	8108469	Tableland 1
8073	Dmd	249670	8210858	East Gibb Yard
8120	Dmd	317434	8411365	King George 2
8121	Dmd	313934	8432164	Wishy Washy 1
8122	Dmd	320634	8432965	Wishy Washy 2
8124	Dmd	300635	8449465	King George 3
8136	Dmd	284191	8410709	Beta Creek 1
8137	Dmd	302134	8417799	Beta Creek 2
8308	Dmd	478935	8326865	Grant Creek 1
8309	Dmd	478535	8327000	Grant Creek 2
8311	Dmd	475275	8311365	Carnegie J46
8399	Dmd	320289	8416148	King George River 3
8400	Dmd	258943	8260265	Damper Creek 1
8401	Dmd	266183	8271053	Damper Creek 2
8402	Dmd	263440	8262145	Damper Creek 3
8403	Dmd	266830	8269370	Damper Creek 4

NO.*	COMMODITY	EAST	NORTH	NAME
PRECIOUS MINERAL				
8421	Dmd	324909	8128602	Salmond 1
8423	Dmd	291888	8402001	King George River 5
8424	Dmd	299918	8417783	King George River 2
8425	Dmd	291253	8403311	King George River 4
8489	Dmd	306901	8411117	Barton North
8490	Dmd	307431	8411620	Barton North
8491	Dmd	297331	8401924	King George
8492	Dmd	341925	8433258	Forrest River 1
8493	Dmd	335500	8418450	Forrest River 2
8494	Dmd	334872	8418532	Forrest River 3
8495	Dmd	286899	8385623	Collison 1
8496	Dmd	296480	8375132	Collison 2
8497	Dmd	291183	8377404	Collison 3
8498	Dmd	289760	8378417	Collison 4
8499	Dmd	290389	8370834	Collison 5
8500	Dmd	303132	8383303	Collison 6
8501	Dmd	306610	8448076	King George North 1
8502	Dmd	307095	8447591	King George North 2
8504	Dmd	305676	8408032	Beta Creek 3
8506	Dmd	300708	8421551	Beta Creek 4
8507	Dmd	300778	8422457	Beta Creek 5
8508	Dmd	303217	8424175	Beta Creek 6
8509	Dmd	308605	8421992	Beta Creek 7
8510	Dmd	303519	8420552	Beta Creek 8
8511	Dmd	303798	8421783	Beta Creek 9
8512	Dmd	309578	8417137	Beta Creek 10
8513	Dmd	305702	8408056	Beta Creek 11
8514	Dmd	305702	8406291	Beta Creek 12
8516	Dmd	301223	8408868	Beta Creek 13
8517	Dmd	301919	8406856	Beta Creek 14
8530	Dmd	316491	8447739	King George North 4
8531	Dmd	314726	8440020	King George North 5
8533	Dmd	312946	8410064	King George South 1
8540	Dmd	196013	8047599	Adcock River 1
8541	Dmd	193114	8079320	Mount Brennan 1
8543	Dmd	277502	8167512	Rosewood Creek 1
8544	Dmd	189077	8133040	Nyairgul Creek North
8545	Dmd	209912	8120762	MacNamara Creek 1
8550	Dmd	211500	8141100	Barnett 1
8552	Dmd	296500	8419350	Beta Creek 15
8553	Dmd	309475	8423613	Beta Creek 16
8555	Dmd	308657	8414820	King George River 14
8556	Dmd	314643	8410662	King George South 2
8561	Dmd	320517	8394014	Pteropus Creek 1
8570	Dmd	316184	8422091	Beta Creek 17
8571	Dmd	316710	8409594	King George South 3
8589	Dmd	193770	8130310	Nyairgul Creek South
8591	Dmd	191472	8133034	Harris Creek 1
8709	Dmd	185419	8271880	Dawrra Creek 1
8710	Dmd	191690	8270377	Woodhouse NW 1
8713	Dmd	190495	8266461	Dawrra Creek 2
8714	Dmd	184574	8260298	Woodhouse River 2
8715	Dmd	182438	8237364	Drysdale River Tributary
8716	Dmd	186070	8251705	Drysdale River 1
8717	Dmd	188795	8248467	Drysdale River 3
8718	Dmd	190868	8250729	Drysdale River 2
8719	Dmd	193061	8247816	
8720	Dmd	201303	8242847	Drysdale River 5
8723	Dmd	200257	8237114	Woodhouse SW
8724	Dmd	198218	8245845	Drysdale River 4
8771	Dmd	310728	8022297	Skeleton Flat 2
8772	Dmd	330425	8065250	Watery Creek 3
8773	Dmd	331854	8064073	Watery Creek 4
9627	Dmd	184200	8045600	Diamond Gorge
9660	Dmd	184200	8232500	Woodhouse 1
9662	Dmd	197500	8231200	Woodhouse 3
9663	Dmd	274000	8224300	Woodhouse 4
9664	Dmd	216000	8227100	Woodhouse 5
9665	Dmd	207000	8222300	Woodhouse 6
9666	Dmd	206900	8222000	Woodhouse 7
9667	Dmd	189600	8247000	Woodhouse 8
9670	Dmd	205760	8257620	Woodhouse 9

NO.*	COMMODITY	EAST	NORTH	NAME
PRECIOUS MINERAL				
9671	Dmd	191845	8268645	Woodhouse 10
9672	Dmd	189185	8270200	Woodhouse 11
9689	Dmd	324700	8128800	Salmond
9692	Dmd	191600	8126500	Barnett
9693	Dmd	310680	8021439	Skeleton Flat 1
10112	Dmd	368911	8420454	Berkeley Offshore 1
10113	Dmd	362635	8427500	Berkeley Offshore 2
10114	Dmd	371596	8427247	Berkeley Offshore 3
10122	Dmd	421211	8378682	Cambridge Gulf 1
10821	Dmd	194613	8138716	Police Valley 1
10822	Dmd	187987	8137719	Hann River 2
10823	Dmd	188675	8137552	Hann River 4
10824	Dmd	188522	8138111	Hann River 3
10825	Dmd	194634	8138865	Police Valley 2
10835	Dmd	467240	8271220	Ord River 1
10836	Dmd	467450	8269880	Ord River 4
10837	Dmd	467000	8270300	Ord River 3
10838	Dmd	466890	8270625	Ord River 2
11667	Dmd	312400	8437500	King George Falls southwest
Regolith — residual to eluvial placers				
5133	Dmd	316883	8169308	
5179	Dmd	323133	8125908	
5185	Dmd	312693	8107208	
5186	Dmd	314133	8109658	
8119	Dmd	316334	8410465	King George River 1
8144	Dmd	308581	8400171	
8147	Dmd	314058	8402791	
8148	Dmd	310135	8395317	
8404	Dmd	264035	8260840	Damper Creek 5
8503	Dmd	303979	8428487	King George North 3
8515	Dmd	300546	8418067	Beta Creek 14
8551	Dmd	312832	8446500	King George 4
8654	Dmd	192908	8181243	Barnette River 1
8656	Dmd	192707	8181516	Barnette River 2
8721	Dmd	198464	8237837	Woodhouse SW
8722	Dmd	197498	8240118	Woodhouse SW
PRECIOUS METAL				
Vein and hydrothermal — undivided				
2976	Au Ag Cu Pb	449083	8253358	Silver Hills North
2979	Au Ag Cu Zn Sb	455383	8256158	
8317	Au	320875	8054855	Middle Branch Bore 1
10562	Au	196887	8066977	Mount Brennan
Regolith — alluvial to beach placers				
3304	Au	383333	8378908	
3308	Au	394944	8356024	
3979	Au	372066	8353941	
8295	Au	195835	8420264	Vansittart 1
8297	Au	196935	8420265	Vansittart 2
8298	Au	184546	8385264	Mount Connor Au 2
10631	Au	380300	8389400	88 Creek
SPECIALITY METAL				
Stratabound sedimentary — clastic-hosted				
4678	Sn Bi	309466	8071628	Mount Bedford
10626	HM Th	326020	8102855	Durack Ranges 7
10627	HM	325430	8099590	Durack Ranges 5
10628	HM	324810	8097000	Durack Ranges 4
10750	HM U	322520	8094190	Durack Ranges 3
10752	HM U	325510	8100630	Durack Ranges 6
10770	HM Zrn	310400	8082000	Durack Ranges 1
10771	HM	332250	8114195	Durack Ranges 9
10772	HM Th	330760	8105620	Durack Ranges 8
Regolith — alluvial to beach placers				
4336	Ilm Mag	378533	8274908	Pentecost Estuary

NO.*	COMMODITY	EAST	NORTH	NAME
BASE METAL				
Orthomagmatic mafic and ultramafic — undivided				
4669	Cu	317333	8079435	Lansdowne 8
4676	Cu	316280	8080007	Lansdowne 9
5217	Cu	305849	8197927	Karunjie
8726	Cu	305350	8197350	Karunjie Homestead
10135	Cu	316752	8081805	Lansdowne 6
Vein and hydrothermal — undivided				
1377	Cu Fl	331324	8043673	Tumagee Yard
1492	Pb Au Ag Cu Zn Brt	453960	8255760	Shangri La
1494	Cu Pb Au Ag Sb	448794	8252483	Silver Hills
2724	Cu	254638	8023809	Goads Yard East
2977	Pb Cu Ag	450733	8254858	
3000	Zn	456633	8345258	
3006	Pb Ag Au Cu	450633	8256308	Donkey Hills North
3019	Zn Pb	454545	8346574	Knob Peak Gossan
3020	Zn Pb	456533	8338718	Discovery Gossan
3021	Zn Brt	458763	8321158	
3022	Zn Pb	457993	8323441	
3025	Pb Cu Au Ag	450683	8255108	Donkey Hills South
3028	Zn Pb	463833	8317058	Ningbing (Amax)
3029	Zn Pb	483155	8293950	Weaber Plains (Amax)
3035	Cu Zn	462533	8300518	Redbank Cu
3039	Zn Pb	463734	8299808	Redbank Zn
3071	Pb Zn Ag	496234	8291008	Discovery Hill
3077	Pb Zn Ag	496683	8289158	
3091	Zn Pb	494683	8282278	Sorby Deep South
3105	Zn Pb Ag	494883	8282138	
3106	Pb Zn Ag	495843	8297368	
3107	Pb Zn Ag	495793	8296568	
3108	Pb Ag Zn	495892	8296378	
3109	Pb Ag Zn Brt	496063	8295008	
3134	Pb Ag Zn	498383	8292068	
5072	Cu	419929	8266584	Maggys Creek
5338	Cu	247532	8012658	Jupiter Cu 1
5339	Cu	247233	8011458	Jupiter Cu 2
8318	Cu	313285	8049915	Middle Branch Bore 2
8319	Pb	317385	8048795	Middle Branch Bore 3
8760	Cu	318635	8040050	Tunganary Cu 1
8762	Cu	321435	8044175	Tunganary Cu 2
9650	Cu	316255	8079997	Ternis South 3
9652	Cu	316887	8081614	Teronis South 6
9653	Cu	319313	8083231	Teronis SE 1
9656	Cu	305637	8079223	Teronis SW 1
9658	Cu	317380	8079399	Teronis SE 2
9684	Cu Pb	240800	8029800	Coolan Creek Yard
9686	Cu	238000	8063200	Colass Yard
9687	Cu	268700	8075700	Little Fitzroy River
10085	Cu	305195	8088045	Elgee Cliffs
10382	Cu	232200	8138750	Traine River Cu
10813	Cu	304714	8194593	Nettlepus Pool
10863	Pb Cu Ag Au	454020	8255440	Shangri La South
Stratabound volcanic and sedimentary — volcanic-hosted sulfide				
2431	Cu	333840	8114554	Carson Volcanics 2
4664	Cu	312296	8082344	Lansdowne 3
4665	Cu	319632	8085976	Lansdowne 4
4666	Cu	321779	8087371	Lansdowne 5
4668	Cu	316562	8081438	Lansdowne 7
4677	Cu	315126	8080590	Lansdowne 10
8725	Cu	193200	8169500	Barnett River Gorge
8727	Cu	279300	8455300	Londonderry
8733	Pb	249476	8317156	Couchman Range 1
9631	Cu	309118	8081544	Teronis Airstrip 1
9647	Cu	309258	8081647	Teronis Airstrip 2
9648	Cu	314919	8080876	Teronis South 1
9649	Cu	315130	8080454	Teronis South 2
9651	Cu	316712	8081333	Teronis South 5
9654	Cu	320087	8085868	Teronis NE 1
9655	Cu	322231	8087169	Teronis NE 2
9657	Cu	312211	8082176	Wire Yard 1

BASE METAL

Stratabound volcanic and sedimentary — sedimentary-hosted sulfide

NO.*	COMMODITY	EAST	NORTH	NAME
2432	Cu	338215	8122428	Carson Volcanics 3

Stratabound volcanic and sedimentary — undivided

NO.*	COMMODITY	EAST	NORTH	NAME
2430	Cu	272279	8066808	Carson Volcanics 1
2448	Cu	330769	8110533	Carson Volcanics 14

Stratabound sedimentary — carbonate-hosted

NO.*	COMMODITY	EAST	NORTH	NAME
2914	Cu	271365	8105027	Wood Yard South
3001	Zn Pb	454252	8346958	
3010	Pb Zn	467983	8301758	Carlton Hill
3033	Pb Brt Ag	488233	8294538	Point Springs
3058	Pb Zn Ag	497683	8290108	Sorby Pod A
3059	Pb Zn Ag	497933	8289958	Sorby Pod B
3060	Pb Zn Ag	497953	8290708	Sorby Pod C
3061	Pb Zn Ag	498133	8291658	Sorby Pod D
3063	Pb Zn Ag	497933	8292158	Sorby Pods E and F
3064	Pb Zn Ag	497883	8292808	Sorby Pod G
3065	Pb Zn Ag	497473	8293508	Sorby Pod H
3066	Pb Zn Ag	496883	8293518	Sorby Pod I
3067	Pb Zn Ag	496983	8294208	Sorby Pod J
3068	Pb Zn Ag	496333	8295158	Sorby Beta Trend East
3069	Pb Zn Ag	496133	8295158	Sorby Beta Trend West
3070	Zn Ag Pb	495683	8295808	Sorby Alpha Trend
3072	Pb Ag Zn	496483	8295778	Sorby Beta Trend Northeast
3081	Pb Zn Ag	496283	8292218	
3092	Pb Ag Zn	498273	8289408	
3104	Zn Pb	496342	8293808	
3122	Zn Pb Ag	493454	8296558	Northwest Sorby
8220	Zn Pb	472150	8256074	Redbank 2
8221	Zn Pb	464244	8299283	Redbank 3
8223	Zn Pb	464111	8300184	Redbank 4
8226	Zn	463725	8300330	Redbank 5
10604	Zn Pb	483050	8295550	Ningbing
10848	Zn	457210	8336830	Ningbing Zn 1
10849	Pb	454505	8345300	Ningbing Pb 2
10850	Cu	454360	8345770	Ningbing Cu 1
10851	Cu	454030	8346380	Ningbing Cu 2
10852	Cu	453590	8346785	Ningbing Cu 3
10853	Pb	452235	8344900	Ningbing Pb 1

Stratabound sedimentary — clastic-hosted

NO.*	COMMODITY	EAST	NORTH	NAME
3041	Cu Pb Brt Zn	463573	8299668	Petes Find
3123	Ag Brt Pb	498683	8291858	
4523	Cu	367332	8247958	Menuairs Dome 1
4535	Cu	355033	8255258	Menuairs Dome 2
4557	Cu	400327	8314545	The Paps
4662	Cu	309516	8081849	Lansdowne 2
5057	Cu	388233	8356708	Lyne River
5059	Cu	387733	8358758	
5060	Cu	389233	8353808	
5061	Cu	382133	8364508	Lyne River North
5062	Cu	385033	8361158	
5064	Cu	401132	8370478	Helby River
5065	Cu	388133	8373878	Helby River West
5066	Cu	443475	8262442	Spring Creek
5068	Cu	389033	8321683	Terrace Hill North
5069	Cu	390333	8332708	Mount Fraser West
5070	Cu	388933	8338958	Mendena Creek
5071	Cu	380832	8357358	Mount McMillan South
5206	Cu	333844	8232344	New York
5207	Cu	333696	8252191	Pentecost Range
5208	Cu	368683	8254608	Pentecost Range North
5209	Cu	368713	8250758	Pentecost Range South 1
5210	Cu	367993	8246958	Pentecost Range South 2
5211	Cu	360895	8252909	Mount Edith East
5212	Cu	355833	8256308	Mount Edith North
5213	Cu	342333	8257258	Durack River Cu
5214	Cu	334002	8247152	Bindoola Creek
5215	Cu	336533	8236058	Menuairs Dome Southwest
5216	Cu	351303	8249508	Menuairs Dome Northeast
10082	Cu	225750	8141400	Police Creek Cu

Stratabound sedimentary — undivided

NO.*	COMMODITY	EAST	NORTH	NAME
10812	Cu	354902	8252360	Cambridge Gulf 2

IRON

Stratabound sedimentary — clastic-hosted

NO.*	COMMODITY	EAST	NORTH	NAME
2989	Fe	463190	8253750	Bandicoot Range 1
2991	Fe	460063	8253958	Bandicoot Range 2

Regolith — alluvial to beach placers

NO.*	COMMODITY	EAST	NORTH	NAME
4473	Fe	326350	8094050	Durack Laterite 2
4482	Fe	326350	8092650	Durack Laterite 1
10775	Fe	329450	8100450	Durack Laterite 3
10776	Fe	329950	8103350	Durack Laterite 4

ALUMINA

Regolith — residual and supergene

NO.*	COMMODITY	EAST	NORTH	NAME
8281	Bx	218829	8409830	West Kalumburu D
8282	Bx	222134	8413781	West Kalumburu C
8283	Bx	227805	8419740	West Kalumburu B
8284	Bx	230910	8421249	West Kalumburu A
8285	Bx	247984	8384652	Mt Leeming D
8728	Bx	192352	8386445	Mount Connor Bauxite
8729	Bx	193203	8391976	Mount Connor North
8730	Bx	192874	8382144	Mount Connor South
8731	Bx	181400	8344730	Mitchell Plateau Far East
8735	Bx	186335	8454998	Cape Bougainville North
10128	Bx	193828	8446415	Cape Bougainville East
10129	Bx	181701	8443590	Cape Bougainville West
10340	Bx	225094	8406826	West Kalumburu E
10341	Bx	243377	8392784	Mt Leeming A
10342	Bx	242500	8390714	Mt Leeming B
10343	Bx	245848	8388535	Mt Leeming C
10344	Bx	252820	8389068	Mt Leeming E
10596	Bx	205500	8310000	Couchman Range

ENERGY

Vein and hydrothermal — undivided

NO.*	COMMODITY	EAST	NORTH	NAME
5336	U	247332	8010658	Juno
5337	U	247432	8012358	Jupiter (U)

Stratabound sedimentary — clastic-hosted

NO.*	COMMODITY	EAST	NORTH	NAME
2525	U	310766	8030994	Mad Gap 2
2526	U	310828	8030110	Mad Gap 3
2527	U	313954	8031405	Mad Gap 4
4659	U Sn	265372	8055139	Lansdowne 1
5328	U	297933	8022158	Diana
9659	U	300475	8027427	Mad Gap 5
10559	U	314017	8031941	Mad Gap 1
10751	U Th HM	319626	8087271	Durack Ranges 2
10753	HM U	336675	8124595	Durack Ranges 10

Sedimentary — basin

NO.*	COMMODITY	EAST	NORTH	NAME
3018	Coal	461313	8323438	
3124	Coal	485634	8296458	
5253	Coal	496933	8317258	Skull Creek

NO.*	COMMODITY	EAST	NORTH	NAME
INDUSTRIAL MINERAL				
	Vein and hydrothermal — undivided			
3040	Brt	464483	8298258	
8030	Brt	315350	8029750	Sandy Gorge 2
8031	Brt	316100	8030250	Sandy Gorge 3
8759	Brt	325135	8044175	Tunganary Barite
9688	Fl	189000	8012400	Stony Creek Fluorite
10855	Brt	354520	8344900	Ningbing Barite
11280	Brt	448480	8253270	Silver Hills West
	Sedimentary — undivided			
2982	Phos	458534	8340508	
2985	Phos	482073	8301708	
2986	Phos	450633	8299458	
3011	Gp	472832	8299358	
3031	Salt	475302	8366762	Pelican Island No 1

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 west Kimberley (Hassan, in prep.).

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	white
Precious metal	Ag, Au, PGE	yellow
Steel-industry metal	Co, Cr, Mn, Mo, Ni, V, W	orange
Speciality metal	Li, REE, Sn, Ta, Nb, Ti, Zr, Be	light green
Base metal	Cu, Pb, Zn, Sb	red
Iron	Fe	blue
Aluminium	Al (bauxite)	brown
Energy	Coal, U	black
Industrial mineral	Asbestos, barite, kaolin, talc, fluorite	dark green
Construction material	Clay, dimension stone, limestone	light blue

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.

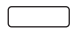
Mineralization style

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 intrusions	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

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 hardcopy 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:

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

- 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 analysed 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 north Kimberley area, was compiled between 1998 and 2002, 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 hardcopy 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) and available 1:250 000-scale maps from Geoscience Australia (formerly Bureau of Mineral Resources). The interpreted bedrock geology is shown on Plate 1, and full details of the interpreted bedrock geology and regolith are on the CD-ROM. The CD-ROM also includes a large number of 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 obtained from Geoscience Australia (GA), mostly at a line spacing of 400 m (except for the DRYSDALE–LONDONDERRY map sheet, collected at 800 m line-spacing) and gridded to a cell size of 200 m for the colour image. More-detailed data, gridded to a cell size of 100 m, may be obtained from GA.

Measurements of the background radiation using an airborne crystal usually took place concurrently with the GA 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 GA, 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 2 km.

Landsat

Landsat TM imagery has been acquired for all the 1:250 000-scale map sheets in the north Kimberley study. The raw data are available commercially through the Remote Sensing Services section of the Department of Land Administration (DOLA). 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.

* TENGRAPH is available on the DoIR website

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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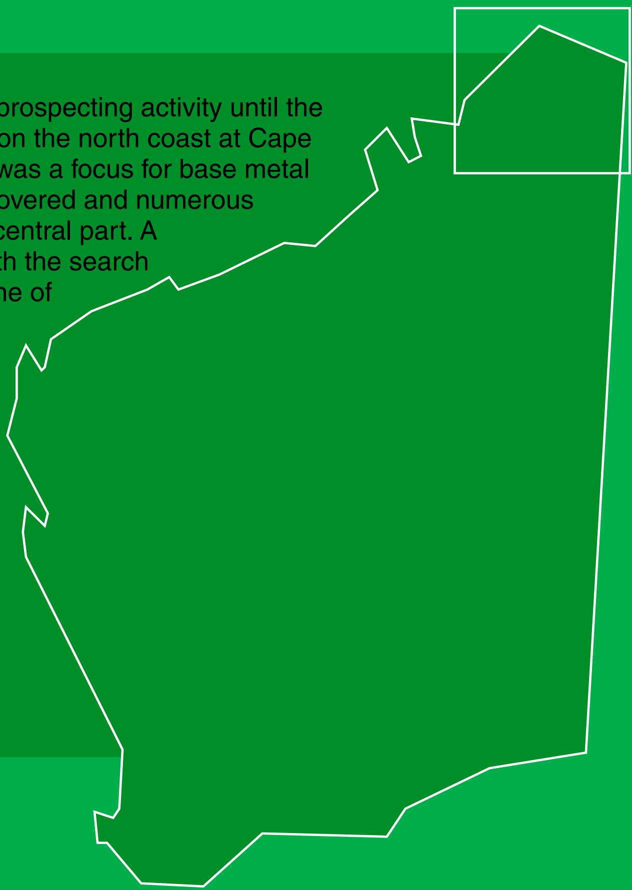
TOWNSEND, D. B., PRESTON, W. A., and COOPER, R. W., 1996, Mineral resources and locations, Western Australia: digital dataset from MINEDEX: Western Australia Geological Survey, Record 1996/13, 19p.

The remote north Kimberley area experienced very little prospecting activity until the 1960s when large resources of bauxite were discovered on the north coast at Cape Bougainville. In the late 1960s and early 1970s the area was a focus for base metal exploration — the Sorby Hills lead–zinc deposit was discovered and numerous low-grade copper prospects were identified in the south-central part. A new era of exploration commenced in the early 1970s with the search for diamonds, and the north Kimberley continues to be one of the most prospective regions in Australia. At Seppelt, in the northeast, there are two kimberlite intrusions where bulk testing in 2002 has produced encouraging grades of diamonds. Also in the northeast a new area of epithermal gold mineralization was identified in 2001, and this has stimulated interest in the Proterozoic Kimberley Basin as a new gold province.

This report summarizes the geology, mineralization, and exploration potential of the north Kimberley and is an explanatory note to a major new dataset of mineral exploration activities and mineral occurrences for the region. The report includes a 1:500 000-scale map and the dataset is provided on an accompanying CD-ROM.



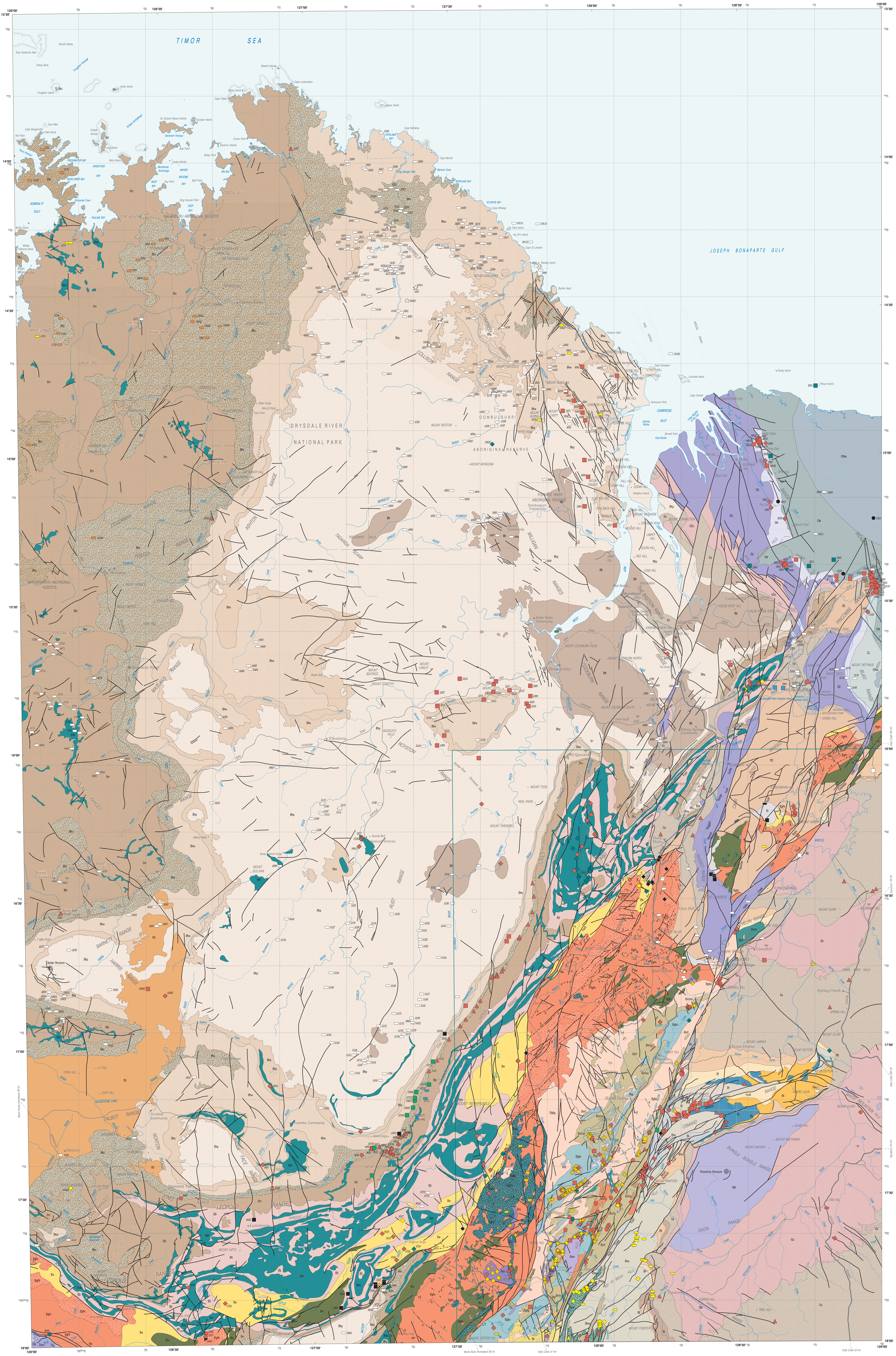
RUDDOCK

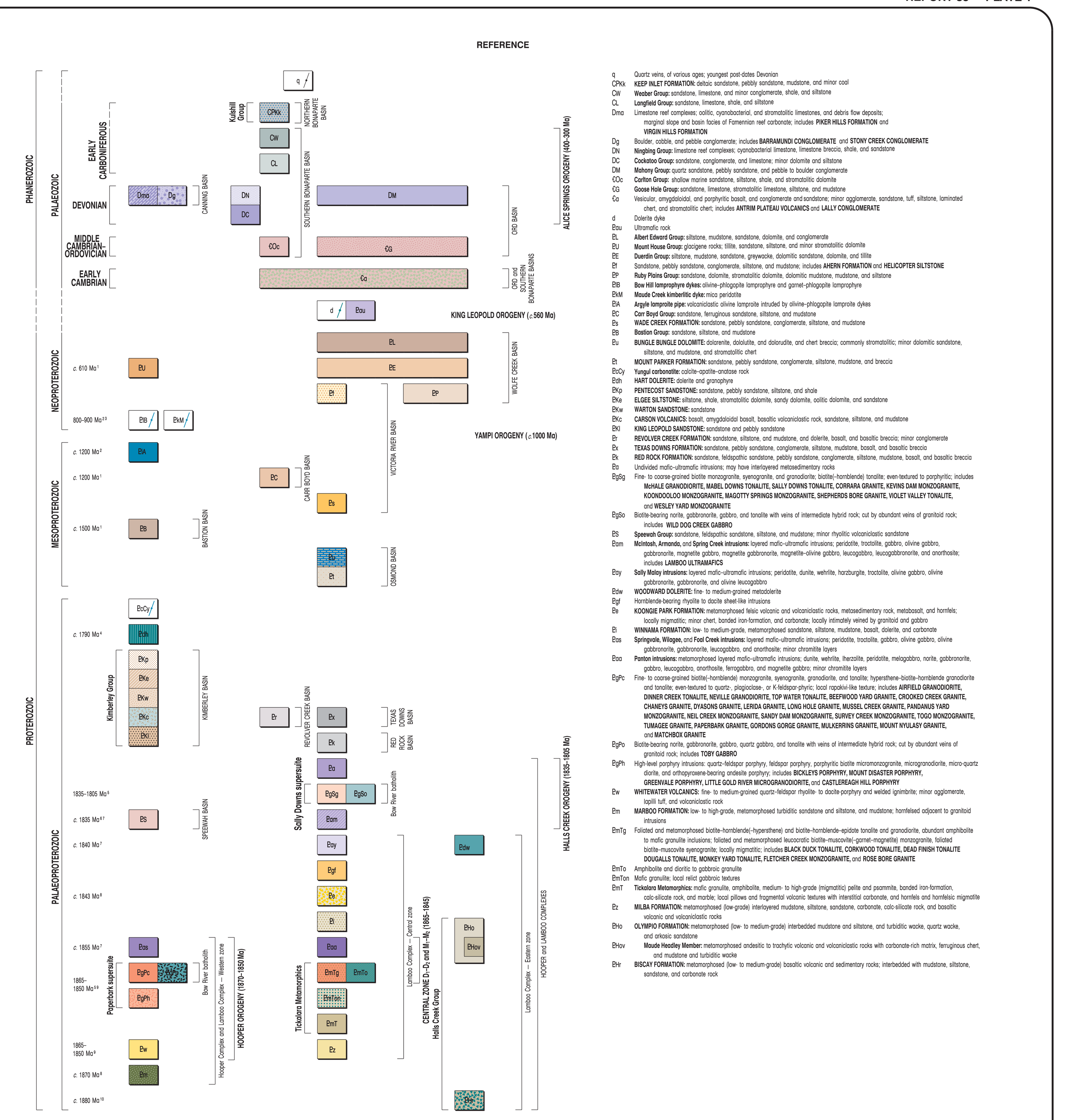
Mineral occurrences and exploration potential of the north Kimberley

REPORT 85

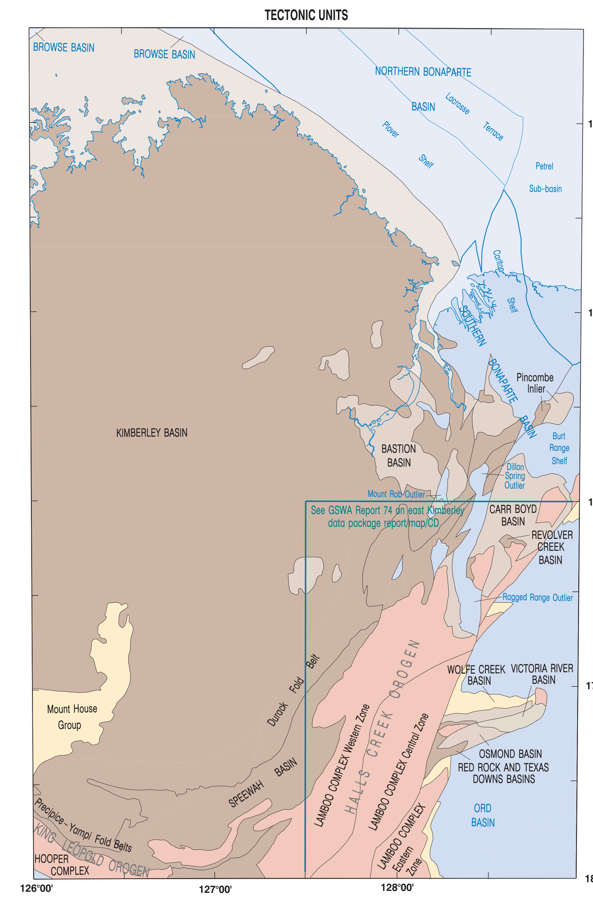
Further details of geological publications and maps produced by the Geological Survey of Western Australia can be obtained by contacting:

Information Centre
Department of Industry and Resources
100 Plain Street
East Perth WA 6004
Phone: (08) 9222 3459   Fax: (08) 9222 3444
www.doir.wa.gov.au





TECTONIC UNITS



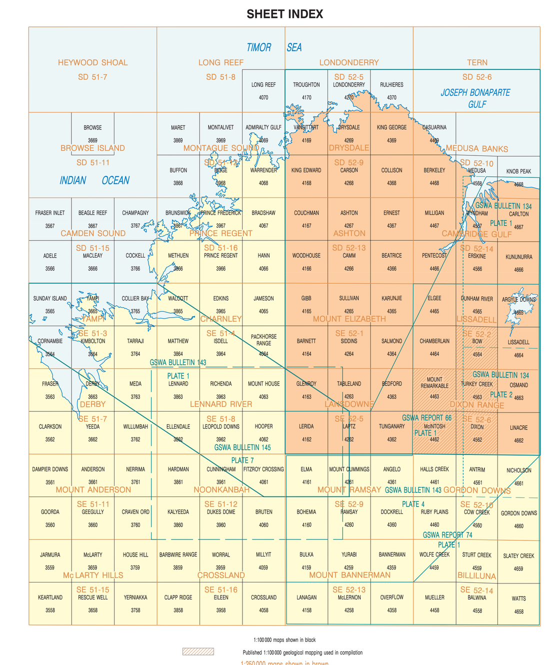
SCALE 1:2 500 000

0 50 100 150 200 Kilometres

REFERENCE

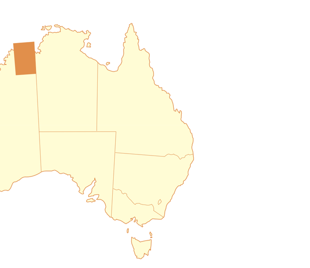
- Phanerozoic basins
- Neoproterozoic basins
- Mesoproterozoic – Neoproterozoic basins
- Mesoproterozoic basins
- Palaeoproterozoic basins
- Palaeoproterozoic complexes

SHEET INDEX



Non-series maps used in compilation shown in green

See current GSWA map catalogue for full range of published products



SYMBOLS

Geological boundary	
Fault	
Meteorite impact structure	
Highway, with national route marker	1
Formed road	
Major track	
Airfield	
Landing ground	
Townsite	
population 1000–10000	KUNUNURRA
less than 1000	Wyndham
Homestead	Doongan
Locality	Clean Skin Pocket
Aboriginal community	Neildu Community
Microwave repeater station	
National park boundary	
Reserve boundary	
Watercourse	

Mineral occurrence data compiled by I. Ruddock, E. P. W. Peiris, R. W. Cooper, and L. Y. Hassan 1998–2002

Geology compiled by I. M. Tyler 1999–2001 and R. Flint 1999–2000 using published GSWA maps (see sheet index), and PLUMB, K. A., DOW, D. B., and DEN HERTOG, J. G. A., 1976, Geology of the Kimberley region, Western Australia, north Kimberley (1:500 000 scale map): Australia Bureau of Mineral Resources

Geochronology by:

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(3) A. L. Jaques et al., 1986, GSWA Bulletin 132.
(4) R. W. Page, 1995, written communication.
(5) R. W. Page, et al., 2001, Journal of the Geological Society of London, v. 158, p. 535–545.
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(7) R. W. Page, and D. M. Hoatson, 2000, AGSO Bulletin 246, p. 163–172.
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(10) D. H. Blake, 1999, Geology of the Halls Creek 1:100 000 Sheet area (4461) Western Australia: AGSO.

Interpreted geochronology by:

(1) I. M. TYLER et al., 1998, AGSO Journal of Geology and Geophysics, v. 17, p. 223–244.

Edited by G. Hall and K. Greenberg

Cartography by A. Francois and S. Hamill

Mineralization information on this map is from non-confidential data held in the WAMIN database, GSWA at November 2002

Topography from the Department of Land Administration 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:
RUDDOCK, I., TYLER, I. M., and FLINT, R., 2002, Mineralization and geology of the north Kimberley (1:500 000), *in* Mineral occurrences and exploration potential of the north Kimberley *by* I. RUDDOCK: Western Australia Geological Survey, Report 85, Plate 1

MINERAL OCCURRENCES

The detailed list of mineral occurrences is in Appendix 1 of Report 85

MINERALIZATION STYLES	MINERAL AND ROCK COMMODITIES GROUP
Kimberlite, lamproite, and carbonatite mineralization	Precious mineral
Felsic intrusive, greisen, and skarn mineralization	Precious metal
Orthomagmatic mafic and ultramafic mineralization	Steel industry metal
Vein and hydrothermal mineralization	Speciality metal
Stratabound volcanic and sedimentary mineralization	Base metal
Sedimentary mineralization	Iron
Basin hosted	Aluminium
Mineralization in the regolith	Energy
Undivided	Industrial mineral
	Construction material

Mineral occurrences and numbers are from the GSWA WAMIN database and include operating and abandoned mines, deposits, prospects, and occurrences.

KEY TO OPERATING STATUS

Bold and italic numbers (i.e. 1492)	Abandoned mine
Plain numbers (i.e. 4473)	Mineral deposit
Italic numbers (i.e. 4336)	Mineral occurrence or prospect

Number for sites in east Kimberley area shown on Plate 1 and 1A of Report 74

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 Metres 0 5 10 15 20 25 30 35 40 45 50 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 52

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 85 PLATE 1

MINERALIZATION AND GEOLOGY OF THE NORTH KIMBERLEY