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GEOLOGY AND MINERAL RESOURCES OF THE GASCOYNE REGION

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Perth 2000

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Gascoyne
Murchison
Strategy ~ *a new lease on life.*

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Cover photograph:
Salt and gypsum stockpiles at the port loading facility, Cape Cuvier.
Photograph courtesy of Dampier Salt Ltd

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Executive summary

The minerals sector provides significant revenue for the Gascoyne Region and, in 1998, mining in the study area was worth $62.3 million, but this represents only 0.3% of the value of the State's mineral production for that year. In the Gascoyne Region, the two most important commodities currently being produced are salt (75% of the total value) and gypsum (24%). Lake MacLeod, north of Carnarvon, is the largest gypsum deposit in Western Australia. Production of gypsum and salt from the region is important in a State context also, reaching 83.1% and 22.1%, by value, of the State's output for each commodity in 1998. Salt production in the Pilbara–Gascoyne is poised to increase further with plans by the consortium of Dow Chemical Co. and Shell Chemicals to commence construction of a $2 billion petrochemical complex in the Pilbara. Cape Range is one of the most important localities in Western Australia for high-grade metallurgical limestone, and production is set to expand following the commencement of mining in 1998 by Exmouth Mining Pty Ltd.

Other commodities, by comparison, are minor in value, and consist of (in order of importance) limestone and limesand, construction materials, and chalcedony. Other industrial minerals in the Gascoyne Region with potential are barite, graphite, and heavy mineral sands.

The Gascoyne Region has produced a variety of semi-precious gemstones (e.g. agate, tourmaline, and amethyst), and a few microdiamonds (less than 0.5 mm across) have been found from rocks in the Bangemall and Carnarvon Basins. Current exploration for diamonds in the Byro area of the northwest Yilgarn Craton may upgrade the perceived diamond potential of the region.

Gold and silver have been mined from within the Gascoyne Region, but on a small scale. Most gold deposits and prospects are located at the three mining centres of Egerton, Bangemall, and Mangaroon, which were worked intermittently until 1983. Total recorded production is 463.78 kg of gold, with an average recovered grade of 31 g/t gold. Low-grade gold mineralization near Victoria Bore (Apollo prospect) was outlined in 1995–96 by Helix Resources NL.

Rare earth elements (REE) and tantalum are found within the region and have potential to be produced. Twelve deposits of REE mineralization are known in a belt of carbonatites intruding the Bangemall Basin, 20–30 km north of Gifford Creek Homestead. The Geological Survey of Western Australia has found elevated REE in regolith collected over Palaeoproterozoic rocks of the Gascoyne Complex north of Erong Springs Station. These and other lower order anomalies in the area imply that intrusive carbonatites are present.

There are at least 22 widely scattered base metal occurrences in the study area, most of which lie within the Bangemall Basin. Despite mine workings on some, there is no recorded production. Numerous styles of base metal mineralization are known from the area. Of these, the polymetallic Abra deposit within the Jillawarra Sub-basin of the Bangemall Basin is the largest.

In the energy sector, the Gascoyne Region has resources of coal and uranium, and is prospective for petroleum. Preliminary calculations indicate an inferred resource of approximately 130 Mt of steaming coal in the Permian Talisker coal deposit, about 180 km north-northeast of Geraldton. This deposit is logistically remote and development can only be viewed as a long term proposition.

The onshore Southern Carnarvon Basin has had relatively little exploration for hydrocarbons compared to other Australian sedimentary basins. To date, 75 onshore and two offshore wells have been drilled there. No fields or accumulations have been discovered, but poor to fair gas flows were obtained in four wells. There have been very few valid tests of hydrocarbon plays in the region. Favourable source and reservoir rocks exist within the Southern Carnarvon Basin, and untested structural highs have been demonstrated adjacent to major faults (mainly along the eastern edge of the Gascoyne Platform) that may have provided vertical conduits for hydrocarbons generated from deep Permian source rocks in the adjacent Merlinleigh Sub-basin.

Some 16 uranium occurrences, mostly of the calcrete-hosted type, are known in the Gascoyne Region. Resources have been estimated at only three of the deposits, but none is considered economic to mine at present.

An assessment of the mineral resources and prospectivity of any region is only as good as the level of detailed exploration carried out to the present time; however, much of the Gascoyne Region has not been explored beyond the reconnaissance level. Further regional geological mapping and geophysical surveys would undoubtedly enhance the prospectivity of the region.

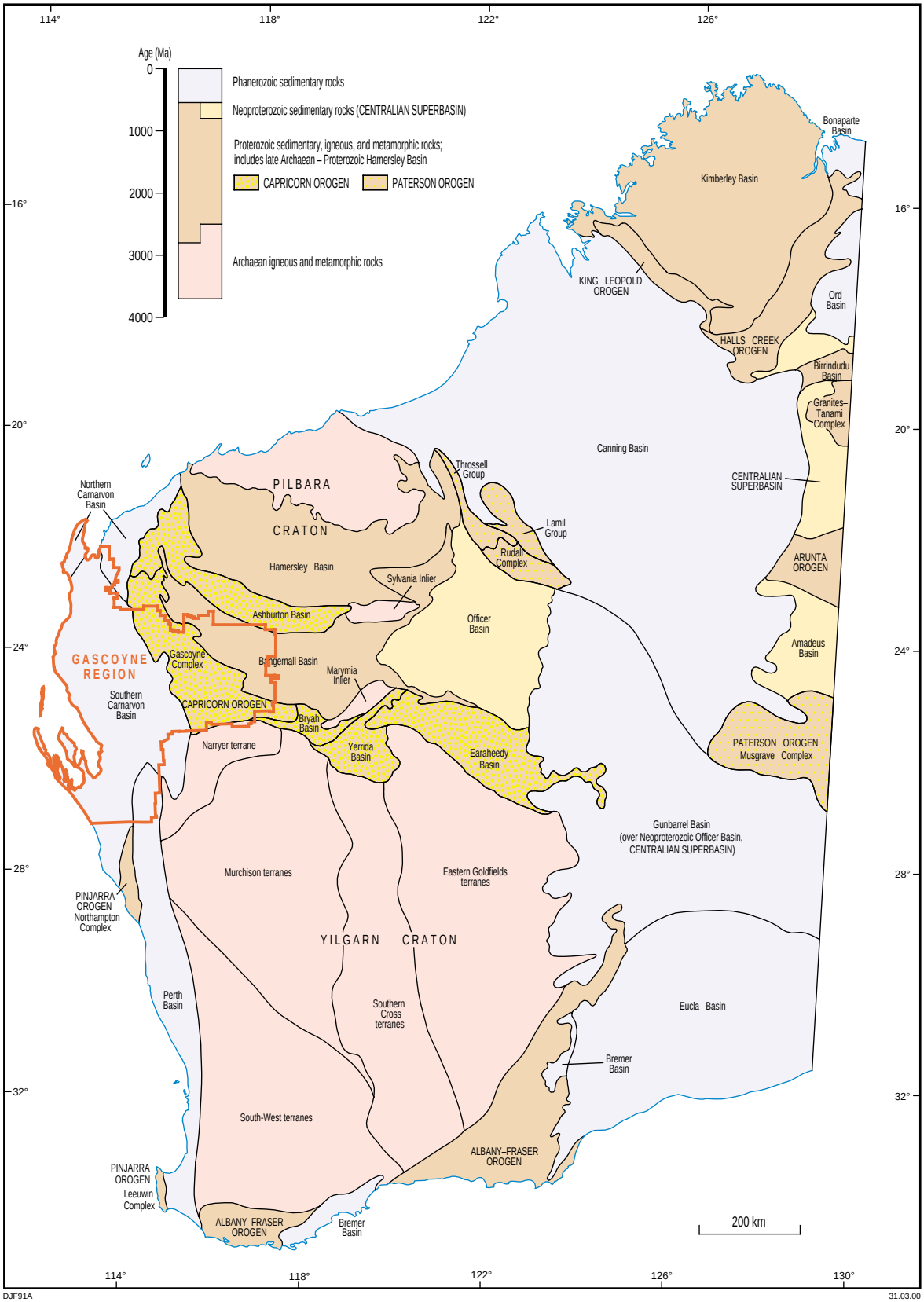

Figure 1. Main geological subdivisions of Western Australia and the Gascoyne Region

Introduction

This study of the geology and mineral resources of the Gascoyne Region was prepared for the Regional Based Alternatives Subcommittee of the Gascoyne–Murchison Strategy (GMS). The GMS is a five-year, $45 million, rural development and adjustment initiative operating in the Gascoyne–Murchison pastoral rangelands. The GMS is charged with the identification and delivery of initiatives that will broaden and strengthen the economic base of this region, leading to sustainable industries and communities within this rangeland. The Gascoyne Region, for the purposes of this work, consists of the local government areas of Carnarvon, Exmouth, Gascoyne, and Shark Bay.

The following is an extract from the GMS Cabinet action plan.

> 'The Department of Minerals and Energy in association with the Department of Resources Development and the Gascoyne and Mid West Development Commissions support a mineral prospectivity analysis in the Gascoyne–Murchison Region to stimulate ongoing exploration activity by industry'.

This study complements similar studies that cover the remainder of the Gascoyne–Murchison rangelands (Hardcastle and Richards, 1996; Flint et al., in prep.).

This assessment of the geology and mineral and petroleum resources of the Gascoyne Region has focused on: compilation of new 1:500 000-scale geological maps (digital data only); compilation and presentation of a new 1:1 000 000-scale interpreted Pre-Cainozoic solid geology map (Plate 1, attached); collation of data on mineral occurrences and deposits; and a brief review of mineral and petroleum potential.

Geological setting

The oldest tectonic unit of the Gascoyne Region is the Archaean Narryer Terrane of the northwest Yilgarn Craton. Flanking the Yilgarn Craton are Palaeoproterozoic rocks of the Capricorn Orogen, which includes parts of the Gascoyne Complex, and the Bryah, Ashburton, and Bresnahan Basins. These rocks, in turn, are overlain by younger sedimentary successions of the Mesoproterozoic Bangemall Basin and the Phanerozoic Carnarvon and Perth Basins (Figs 1 and 2).

Narryer Terrane (Yilgarn Craton)

The Narryer Gneiss Complex forms the northwestern part of the Yilgarn Craton and contains Early to Late Archaean (3.3–2.55 Ga) rocks. Gneisses are common, and are derived mainly from monzogranite and leucocratic tonalite. They contain inclusions of a layered gabbro–anorthosite, narrow layers of metasedimentary rocks, and a variety of basic intrusions. The gneiss-forming events (older than 3.0 Ga) are postdated by a major tectono-thermal event that occurred around 2.55 Ga. Further details are presented by Myers (1990a).

Capricorn Orogen

The Palaeoproterozoic Capricorn Orogen lies between the Pilbara and Yilgarn Cratons and was formed between about 2.0 and 1.6 Ga. It makes up the east-central part of the Gascoyne Region, where it can be subdivided into five principal components:

- the Gascoyne Complex (Myers, 1990b), which is made up of high-grade metamorphic rocks and abundant granitoid intrusions;
- the Ashburton and Bryah Basins (Thorne and Seymour, 1991; Pirajno et al., 1998), consisting of low-grade sedimentary and minor volcanic rocks;
- and the Mount James Formation and the Bresnahan Group, both of which are made up of siliciclastic sedimentary rock (Hunter, 1990a, 1990b).

Bangemall Basin

The Mesoproterozoic Bangemall Basin (1.6–1.0 Ga) consists of a thick sequence of siliciclastic and carbonate sedimentary rocks, which outcrop in the northeastern part of the region (Williams, 1990). The basin is intruded by large volumes of basaltic magma that occurs mainly as sills but also as dykes. It is one of the largest tholeiite provinces of the world. The current stratigraphic nomenclature for rocks of the Bangemall Basin is in a state of flux, but a broad two-fold subdivision has been proposed — with the Bangemall Supergroup consisting of the Collier and Edmund Groups (Martin et al., 1999).

Carnarvon Basin

The north- to south-trending Southern Carnarvon Basin is basically composed of three sub-basins: the Gascoyne Platform to the west and the Merlinleigh and Byro Sub-basins to the east (Fig. 2). The Gascoyne Platform contains up to 5 km of gently folded Ordovician to Devonian strata, unconformably overlain by up to 800 m of Mesozoic and younger rocks. By comparison, the Merlinleigh and Byro Sub-basins to the east are characterized by thick Upper Carboniferous to Permian sections, underlain by Lower Carboniferous – Devonian sections (Fig. 3) and, in the west, unconformably overlain by a veneer of Cretaceous to Tertiary rocks. In the north, Triassic rocks cover the Permian sequence. Northerly and northwesterly trending faults are present, and the Palaeozoic succession is up to 8000 m thick. Seismic data indicate that the breakup of Gondwana during the Early Cretaceous had the greatest impact on the structural evolution of the area. This tectonism produced wrenching that resulted in long-wavelength folds and strike-slip faults, which were rejuvenated in the mid-Miocene. Further details are presented in Hocking (1990); Crostella (1995); Crostella and Iasky (1997); Iasky et al. (1998); Iasky and Mory (1999); and Ghori (1999).

The Cape Range area falls within the Exmouth Sub-basin of the Northern Carnarvon Basin (Fig. 2).

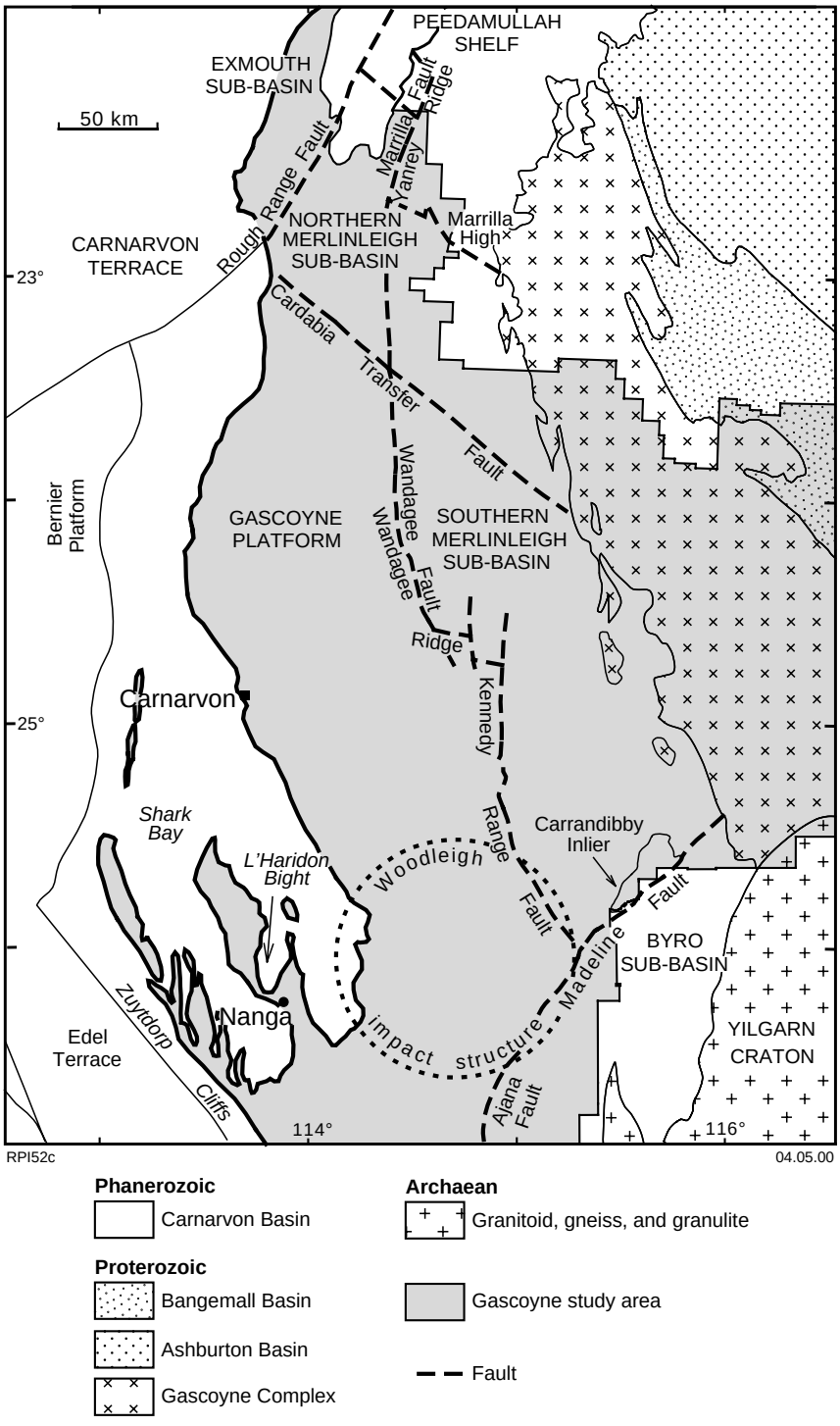

Figure 2. The Woodleigh impact structure and the main geological subdivisions of the Gascoyne Region

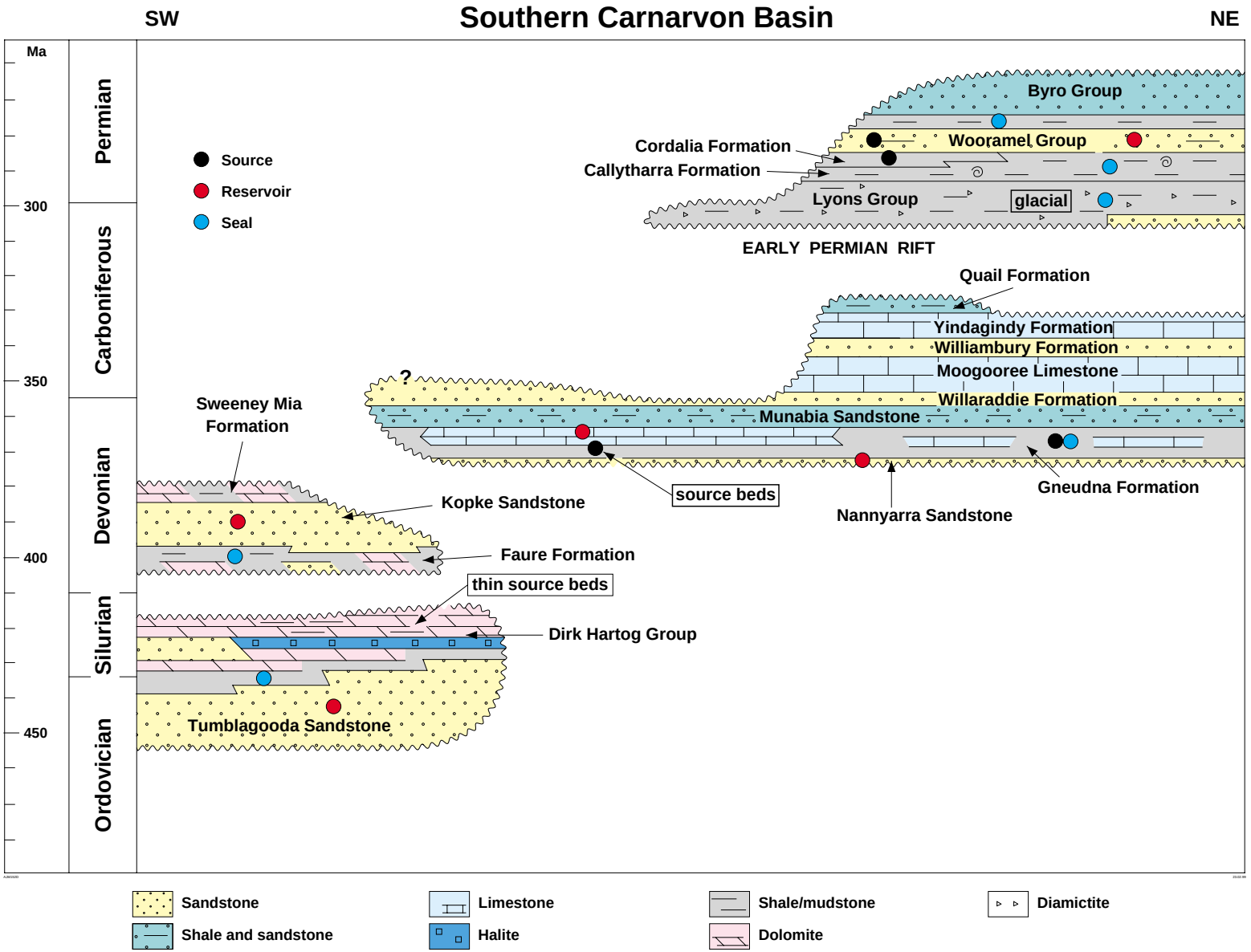

Figure 3. Stratigraphy and petroleum systems of the Southern Carnarvon Basin

Perth Basin

The only part of the Perth Basin present within the Gascoyne Region is the northern end of the Coolcalalaya Sub-basin, which consists of up to 8500 m of ?Ordovician to Permian strata. The Darling Fault, along the eastern margin of the sub-basin, has dominated the depositional history of the sub-basin. The Coolcalalaya Sub-basin has generally been placed within the Perth Basin, although there have been suggestions of links to the Byro Sub-basin of the Southern Carnarvon Basin (Mory et al., 1998).

Cainozoic rocks

Extensive surficial sediments, which range in age from early Tertiary to Holocene, lie along the coast. These consist of a variety of mostly unconsolidated or poorly consolidated marine, coastal, eolian, alluvial, and fluvial sediments.

Woodleigh impact structure

A very large meteorite impact structure, the Woodleigh impact structure, has been found within rocks of the Carnarvon Basin (Iasky et al., 1998). It is a circular feature at least 60 km, and possibly as much as 120 km, in diameter, centred at latitude 26°03'22"S and longitude 114°40'02"E, about 160 km south-southeast of Carnarvon and due east of Hamelin Pool, Shark Bay (Fig. 2 and Plate 1). The structure is evident from Bouguer gravity data, but elements of the structure are also seen in aeromagnetic data. Although the structure is buried beneath 60–500 m of surficial sand and Cretaceous and Jurassic strata, there is some surface expression of the structure in the form of arcuate alluvial deposits along its northern and eastern margins. The impact apparently post-dates the Early Permian, and the Lower Jurassic lacustrine shale of the Woodleigh Formation infills the central part of the structure. This implies an earliest Jurassic age, possibly coinciding with the mass faunal extinctions at the Jurassic–Triassic boundary (Iasky et al., 1998).

Mineral deposits and occurrences

Plate 1 depicts the operating mines, historic mines, and undeveloped deposits (from the Department of Minerals and Energy's MINEDEX* database), as well as all of the known mineral occurrences in the Gascoyne Region. Mineral occurrences, as extracted from the Geological Survey of Western Australia's (GSWA) WAMIN† database, are included as Appendix 1. Note that previous exploration activities by companies have been thoroughly researched and spatially indexed for the Bangemall Basin only (Cooper et al., 1998), hence the list of mineral occurrences included in Appendix 1, plotted on Plate 1, or discussed here is not complete.

* Mines and mineral deposits information database
† Western Australian Mineral Occurrence database

Plate 1 depicts the interpreted pre-Cainozoic geology for the Gascoyne Region. When assessing those mineral occurrences and deposits that formed within Cainozoic units over the Carnarvon Basin (e.g. Lake MacLeod gypsum and salt), further information on the local geology should be sought from the references cited in the text. Appendix 3 lists sources of information covering legislative matters, codes of conduct, and prospecting and exploration guidelines.

Recent mineral production

The minerals sector provides significant revenue to the Gascoyne Region and, in 1998, mining from 14 operating mine sites in the study area was worth $62.3 million. However, this represented only 0.3% of the value of the State's mineral production for 1998. In the Gascoyne Region, the two most important commodities in production are salt (75% of the region's total value) and gypsum (24%) (Table 1). Production of gypsum and salt from the region is also important in a State context, reaching 83.1% and 22.1%, by value, of the State's output for each commodity in 1998. By comparison, other commodities produced in the Gascoyne Region are minor, consisting of (in order of importance) limestone and limesand, construction materials, and chalcedony.

Industrial minerals

Barite

Barite has been mined in the past from east of Austin Well in the Mount Sandiman area, but no production has been reported to the Department of Minerals and Energy (DME). At this locality, barite is found as vein fillings up to 1.5 m wide along the contact between the Harris Sandstone (the basal sandstone of the Late Carboniferous to Early Permian Lyons Group) and Proterozoic granitoids and metamorphic rocks. Barite is also found with minor amounts of galena and traces of sphalerite in and adjacent to a small Precambrian inlier, about 7 km south of Mount Sandiman Homestead.

Barite veins, about 30 m long and 0.6 – 1.2 m wide, are common within gneiss in the Mooloo Downs area, approximately 1.5 km south of Jones Bore, but the available information suggests that the prospect does not have great potential.

Another barite prospect, located approximately 5 km west of Mangaroon Homestead, is considered to be of limited economic potential because of the remoteness of the location, poor quality of the barite, and the probable small size of the deposit.

Barite is found elsewhere in the region at Cardabia Creek, Reid Well, Cork Tree Bore, and on Mount James Station (Abeysinghe and Fetherston, 1997).

Graphite

Near Yalbra (approximately 200 km east of Shark Bay), on Glenburgh Station, graphite deposits form lenses in the

Table 1. Mineral production for 1998 from the Gascoyne Region

Commodity and producer	*LGA*	*Tonnes*	*Value ($A)*	*___ % of State total _ by quantity*	*by value*
Construction materials					
Gravel					
McDonald L. G.	Exmouth	1 600	9 600	0.9	0.9
Gem and semi-precious stone					
Chalcedony					
Butler R. G. & A. W.	Carnarvon	(kg) 8 053	4 027	100	100
Gypsum					
Dampier Salt Pty Ltd	Carnarvon	792 852	15 248 845	73.8	83.1
Limesand and limestone					
Various	Exmouth	103 797	433 705	3.5	3.6
Todtona Pty Ltd	Shark Bay	1 283	160 375	0.04	1.34
Salt					
Dampier Salt Pty Ltd	Carnarvon	1 255 079	33 079 948	14.8	15.7
Shark Bay Salt Joint Venture	Shark Bay	685 268	13 348 093	8.1	6.4

NOTES: Source is Department of Minerals and Energy
Includes Local Government Areas (LGA) of Exmouth, Carnarvon, Gascoyne, and Shark Bay

Archaean graphitic gneiss. The main graphite deposit is 25 m wide and 1 km long. However, it is considered to be uneconomic due to the remoteness of the area and the high mica content in the graphite.

Gypsum

At present, the largest gypsum mine in Western Australia is in Lake MacLeod, 70 km north of Carnarvon in the Gascoyne Region. In 1998, production of gypsum from this deposit was 792 852 t (valued at $15.2 million) and represented approximately 74% of the State's production of 1 074 741 t (valued at $18.3 million). There are other gypsum deposits in the region (Appendix 1), but these have had no reported production in recent times, mostly due to environmental constraints.

Lake MacLeod

The Lake MacLeod gypsum deposit, held by Dampier Salt Ltd, is the largest in Western Australia. The deposit was formed by barring of a former marine embayment, and contains gypsum both on the surface and within sediments of a saline playa. The thickness of the deposit is reported to reach between 12 and 15 m and includes predominantly gypsum and halite. Dunes formed beside the lake and on the lake surface also contain varying amounts of kopi gypsum. The potential resource in the area is considered to be in excess of 1000 Mt (Jones, 1994). Associated deposits east, west, and north of this lake contain another 100 Mt. Note that these are order of magnitude estimates only and that a grade of gypsum has not been estimated.

In June 1997, Dampier Salt Ltd officially opened the gypsum operation at Lake MacLeod, allowing the resumption of gypsum exports after a lapse of about 10 years. The company has delineated a measured resource at Lake MacLeod of 25 Mt of gypsum of uniform particle size and chemical quality. According to Dampier Salt Ltd, gypsum of similar quality extends over 150 km^2 of the exploration area, suggesting a resource of 280 Mt (Flint and Abeysinghe, 1997; Flint et al., 1998). Note that this is only an order of magnitude estimate.

Shark Bay

The gypsum deposits at Shark Bay lie within the recently declared World Heritage Area, and prospects for development are therefore poor at present. Recorded production from the Useless Loop deposit between 1968 and 1987 was 2.4 Mt of gypsum. Important deposits in the Shark Bay region are Brown Inlet, Useless Loop, and Cape Peron.

Brown Inlet

The Brown Inlet deposits are located in two north-trending depressions or birridas. The eastern birrida is about 6 km long and 0.6 km wide. The western birrida is approximately 2 km long and is separated into two smaller arms by north-trending vegetated dunes. A typical profile through these deposits is 0.5–1 m of kopi or gypsite overlying 2–5 m of seed gypsum on the birrida floor, with rock gypsum occasionally found in some places below the watertable. The main impurities are clay and carbonate sand in the kopi, and calcium carbonate in the seed gypsum. No production has been reported. The resources are estimated to be 5 Mt of 93% purity (2–5 m thick) and 0.2 Mt of 87.3% purity (1–3 m thick; Jones, 1994).

Useless Loop

Gypsum at Useless Loop formed in a birrida approximately 4 km long and 2 km wide, which trends in a

northerly direction. The deposit contains rock gypsum (at or below the watertable), seed gypsum (on the birrida floor and in truncated dunes), and kopi gypsum (capping the dunes and birrida floor). Interbedded, underlying, or overlying calcareous sand, travertine, silica sand, clay, and ferruginous material are present as impurities, which resulted in complications when the deposit was mined. Total production during the period from 1968 to 1987 was 2.5 Mt of gypsum, all of which was exported after washing and screening. Most of the deposit has been mined out (Jones, 1994).

Cape Peron

The Cape Peron gypsum deposit is in a birrida, approximately 9 km long and up to 3 km wide, trending in a northerly direction. This birrida is a complex depression containing a marine embayment and several onshore interdunal depressions. The deposit contains rock gypsum (at or below the water level), seed gypsum (on or near the surface and in dunes), and kopi (usually capping any exposed gypsum outcrop). The thickness of the rock gypsum has not been investigated, but the seed gypsum varies from 1 to 5 m on the birrida surface and from 1 to 3 m in dunes, and the kopi varies between 0.3 and 1.5 m. There is no reported production. The deposit is estimated to contain 8.8 Mt of seed gypsum at 96% purity, or 5.5 Mt of seed gypsum at 98% purity. Cape Peron Gypsum Pty Ltd, a subsidiary of Shark Bay Resources Pty Ltd, proposes to mine gypsum from this deposit at a rate of 750 000 tpa, for a period of some 18 years.

Gypsum potential

All the significant gypsum deposits in the Gascoyne Region occur in birridas in the Lake MacLeod and Shark Bay areas. In these deposits, seawater has been partly or totally cut off from the ocean and the salts concentrated by evaporation. In terms of potential, these deposits far outstrip the salt-lake deposits in many of the interior regions of the State.

Heavy mineral sands

Since at least the mid-1960s many companies have explored along the present-day coastline for heavy minerals, but without significant success. Little attempt has been made to explore for heavy minerals within inland raised beach deposits. Recent reconnaissance exploration work (E09/939–941) by Stuart Metals NL for heavy mineral sands in the Shark Bay area is based on their interpretation that the structural setting for the area is similar to that of the Eneabba deposits, south of Dongara. The exploration area falls within and outside the Shark Bay World Heritage Area. An initial reconnaissance air-core drilling program in September 1999 yielded encouraging results, with up to 1.5% heavy minerals in dune sands 10–20 km south-southeast of Hamelin Pool. Heavy minerals consist dominantly of ilmenite, with zircon, leucoxene, and rutile.

Limestone

Cape Range

Cape Range is one of the most important localities in Western Australia for high-grade metallurgical limestone but, until recently, the mining of limestone from the region has been limited by environmental constraints and the remoteness of the locality from major population centres. In May 1998, Exmouth Limestone Pty Ltd started quarrying operations in a deposit estimated to contain 200 Mt of limestone. Adelaide Brighton Cement Ltd owns 51% and Whitecrest Enterprises Pty Ltd owns 49% of the company, which is managed by Swan Cement, a division of Adelaide Brighton. The initial capacity of the operation is 1 Mt tpa of crushed metallurgical limestone. In 1998, Pioneer Concrete (WA) produced about 100 000 t of <40 mm by-product limestone from the quarry for the Learmonth airport project, and another 70 000 t for market development, mainly targeting the steel industries in Australia, Asia, and India.

The main limestone formations in the Cape Range area are the Miocene Mandu, Tulki, and Trealla Limestones. The Mandu Limestone, forming the base of the Cape Range Group, is exposed in the lower parts of the major gorges and is overlain by the Tulki Limestone, which outcrops widely in Cape Range. In the western part of Cape Range, the Trealla Limestone disconformably overlies the Tulki Limestone.

A typical high-quality limestone from the Cape Range area contains 0.8% SiO_2, 54.7% CaO (97.7% $CaCO_3$), and 0.2% MgO (0.4% $MgCO_3$), whereas a typical sample of poor-quality dolomitic limestone from this area assayed 0.8% SiO_2, 34.4% CaO (61.4% $CaCO_3$) and 17.2% MgO (36.0% $MgCO_3$). Phosphorus is commonly below 0.02%. The area has inferred resources estimated at 4000 Mt of high-grade limestone grading 55.3% CaO (98.7% $CaCO_3$), 0.4% MgO (0.8% $MgCO_3$) and 0.6% SiO_2 (Kojan, et al., 1995; Abeysinghe, 1998).

Shark Bay

The Hamelin Coquina in the Shark Bay area forms beach ridges composed of small shells of the bivalve *Fragum erugatum*. The extensive shoreline deposits are up to 6 m thick, 1 km wide, and 40 km long (Townsend, 1996).

There are two coquina mining areas on the eastern shore of L'Haridon Bight, both operated by Todtona Pty Ltd, with a total reported production of 1283 t in 1998. The material mined is used for concrete aggregate and sand, landscaping supplies, road base, and shell-grit for poultry. Apart from poultry shell-grit, which is bagged and shipped to markets outside the region, the coquina is only used locally for landscaping because of the lack of other suitable raw materials. Townsend (1996) estimated approximately 0.7 Mt of coquina in the beach ridges of the eastern margin of L'Haridon Bight. Coquina is also quarried near Bibby Giddy Outcamp, for landscaping at Useless Loop. Ad hoc mining of coquinite continues near the Telegraph Station at the southern end of Hamelin Pool.

A grab sample of loose shell material from a location 1 km northwest of the Hamelin Telegraph Station contained 53.6% CaO (95.7% $CaCO_3$), 0.3% MgO (0.6% $MgCO_3$), and 0.14% total iron oxide. Another sample from a large mass of dune material on the western shoreline of Hamelin Pool, about 1 km southeast of the abandoned Nilemah Homestead, gave 42.8% CaO (76.4% $CaCO_3$), 0.8% MgO (1.7% $MgCO_3$), and 0.12% total iron. Simpson (1948) analysed a typical specimen of shell material containing 55.9% CaO (99.8% $CaCO_3$), 0.1% MgO (0.2% $MgCO_3$), and 0.3% Al_2O_3 + Fe_2O_3.

Unconsolidated Bibra Limestone from the area has also been used for road construction.

Limestone potential

The Trealla and Tulki Limestones (part of the Miocene Cape Range Group) extend over a north–south distance of about 200 km in the coastal regions. However, the marine reserve across Ningaloo Reef on the western and northern sides of the Cape Range peninsula, and the current restriction of any mining operation to a distance of less than 20 km from a deep-water port (for it to be economically viable), leave the area closest to Exmouth Gulf as the most favourable for development of any mining operation. According to Kojan et al. (1995), there are possible port sites on the eastern side of Cape Range as far south as Learmonth, and a 20 km radius from these sites includes significant limestone outcrop both inside and outside possible conservation areas. South of Cape Range, approximately 400 Mt of limestone (order of magnitude estimate only) could be present at Rough Range.

Exploration for limestone, in an area north of Minilya and at the northeast end of Lake MacLeod, has indicated that subhorizontal Trealla Limestone is 9–15 m thick within an open anticlinal structure. The limestone is hard, dense, fresh, cream to white, and fossiliferous. Assays of six surface samples indicate 53.4–55.3% CaO + MgO and 0.2–1.2% SiO_2.

BHP Minerals Ltd investigated the Trealla Limestone in the Cape Cuvier area to assess its viability for a planned steel-making industry. The Trealla Limestone is overlain by calcarenite, the thickness of which was estimated by seismic methods and by two diamond drill holes. The first hole, for which the overburden was interpreted from seismic data to be 75 m thick, was terminated due to drilling difficulties at 70 m — still within the calcarenite overburden. The second hole, which had a seismically interpreted overburden thickness of 30 m, intersected limestone between 34 and 52 m (Abeysinghe, 1998). The overburden was considered too thick for commercial development of the limestone. In addition, the silica content of the limestone is too high for use in the steel industry.

Salt

Salt is an important industrial mineral in the Gascoyne Region and the total reported production in 1998 was 1.9 Mt valued at $46.4 million. The most important deposits are located near the coast at Lake MacLeod and Useless Loop.

Lake MacLeod

At Lake MacLeod, salt is obtained from natural brine from the southern section of the lake. Salt is recovered from shallow wells from depths of between 4 and 6 m, and is circulated by gravity through an evaporating pan system (Carter, 1976). The deposit is owned by Dampier Salt Ltd. Production from this operation in 1998 was 1.26 Mt, valued at $33 million.

Useless Loop

The Useless Loop operation in the Shark Bay region is owned by the Shark Bay Salt Joint Venture. Participants in the joint venture are the Australian Mutual Provident Society, Clough Engineering Group, and Mitsui and Company Ltd. The Useless Loop salt operation is in a shallow tidal inlet of the Freycinet Estuary and is approximately 6 km long. It is enclosed by levees through which seawater is led into a system of evaporation and crystallizer ponds. This operation was Australia's first modern salt field, constructed in 1965 to supply the growing export markets in Asia. Production from this operation in 1998 was 0.69 Mt, valued at $ 13.3 million.

Salt potential

The coastal part of most of the Gascoyne Region has a high potential for salt deposits. However, there is restricted access to some of the areas due to their environmentally sensitive nature, especially in the vicinity of the Shark Bay World Heritage Area.

Precious minerals

Diamond

In the 1970s and early 1980s, following the discovery of the Argyle diamond-bearing lamproite in the East Kimberley, diamond exploration dramatically increased throughout Western Australia, extending across the Yilgarn Craton, the Gascoyne Complex, and the Bangemall Basin. Kimberlite–lamproite and related rocks were found in the Bangemall Basin, northwest Yilgarn Craton, and the Carnarvon Basin. Only a few diamonds have been recovered and the possibility of finding commercial quantities has been regarded as low for many years. However, current exploration for diamonds in the Byro area of the northwest Yilgarn Craton may improve the perceived diamond potential of the region.

A suite of 22 bodies (14 diatremes, 8 sills and dykes) was found along the Wandagee Ridge of the Carnarvon Basin as early as 1978 by CRA Exploration Pty Ltd, with subsequent exploration by Stockdale Prospecting Ltd. The rocks are kimberlite-like, classified petrologically as alkali picrite or picritic monchiquites (Jaques et al., 1980, 1986). The kimberlitic rocks were emplaced during the Jurassic, and intrude Permian strata of the Wooramel and Byro Groups. Four of the diatremes are covered by Cretaceous sedimentary rocks. The diatremes were thoroughly tested and partly drilled, but only four microdiamonds (less than 0.5 mm in diameter) were recovered. The rarity of

diamonds in the Wandagee diatremes suggests that either the alkali picrite was derived from a part of the mantle above the diamond stability field or from a diamond-poor part of the mantle. Alternatively, any diamond may have been largely resorbed during diatreme emplacement (Jaques et al., 1980). As emplacement of the diatremes is interpreted to be related to tensional crustal fracturing during separation of the Australian and Indian plates, more of these intrusives may be present within major fault structures of the Carnarvon Basin.

Within the Bangemall Basin, a small number of diamonds have been recovered from stream samples, narrow kimberlite and lamproite dykes, and from kimberlitic float where no host rock was identified (Cooper et al., 1998) — several are from the study area. In addition, possible kimberlitic pipe structures, each of several hectares in surface area, were investigated in the Ullawarra area (just outside the study area) in the mid-1990s by Astro Mining NL in a joint venture with Diamin Resources NL. Exploration was scaled back in 1998 when Astro Mining NL withdrew from the joint venture.

A kimberlite dyke, 7 km southwest of Mount Palgrave and along the northern boundary of the study area, was reported as diamondiferous, but with 'no economic potential' (Duncan, 1993). One diamond weighing 0.000017 metric carats was recovered from a 135 kg kimberlite sample. The kimberlite dyke (<0.5 m wide), trends at 080° to 085°, and is intruded over a strike length of 2 km into the Devil Creek Formation and possibly the Discovery Chert (Edmund Group). This dyke also contains chrome spinel.

Small diamonds have also been recovered from stream samples taken 17 km southwest of Ullawarra Station, in the area of the Eerstelling lamproites (Rohde, 1993), suggesting that these lamproite bodies are weakly diamondiferous. However, lamproitic outcrop samples have not so far yielded diamonds (Cooper et al., 1998).

The early Proterozoic basins are still considered prospective for diamonds, and exploration within them was given a boost following the discovery by Livingstone Resources NL in 1997–98 of macrodiamonds in the Earaheedy Basin (east-northeast of Wiluna). The largest diamond weighed 1.7 carats.

Along the northwest margin of the Yilgarn Craton, several companies have been exploring for diamonds in kimberlitic pipes. Few results have been released. In the Byro area (just to the south of the Gascoyne Region), Astro Mining NL has found kimberlitic chromite that appears to indicate post-Permian kimberlitic pipes. Any discovery of diamonds in these pipes will lead to a re-examination of the diamond potential of the Southern Carnarvon Basin.

Gems and semi-precious stones

During the last ten years, recorded production of semi-precious stones from the Gascoyne Region has been limited to chalcedony from Mooka Station in the vicinity of Carnarvon. Here, opaline silicification of the Windalia Radiolarite has produced a red, white, yellow, and brown lapidary stone, which has become known as 'mookaite'. In 1998, 8053 kg (valued at $4027) was produced.

Good-quality, red and white banded agate has been found as nodules in sedimentary rocks on Wandagee Station.

Dravite (brown tourmaline) and schorl (black tourmaline) have been mined from 7 km north of Yinnietharra Homestead, where the tourmaline is partly in muscovite-bearing pegmatite and partly in phlogopite schist within augen gneiss. Both varieties have been sold as specimen material only.

Amethyst has been mined at Leake Spring (close to Mount Phillips Station), from quartz segregations in zoned pegmatite near calc-silicate and marble palaeosomes in migmatite (Connolly, 1976; Hickman, 1990).

Precious metals

Gold

Within the Gascoyne Region, gold deposits and prospects are mostly at the three mining centres of Egerton, Bangemall, and Mangaroon. Gold was first discovered in 1896 at the Bangemall Mining Centre near Cobra Station, with the earliest recorded production being from the Carnarvon Gem deposit (Bangemall Mining Centre) in 1897. The Egerton and Bangemall deposits were worked intermittently until 1953; however, the most recent recorded production from the area is from the Star of Mangaroon deposit (Mangaroon Mining Centre), which closed in 1983. Total recorded production from all deposits within the three mining centres is 14 678 t of ore that yielded 463.78 kg of gold, with an average recovered grade of 31 g/t gold (Table 2). Minor silver (3.24 kg) was recovered as a by-product, with an average recovered grade of only 0.5 g/t silver. Production for a short period in 1983 (Cooper et al., 1998) was not recorded, nor are there figures for more recent activities (metal detecting, dry-blowing, and alluvial operations).

The geology at these mining centres and the major exploration programs are summarized in Cooper et al. (1998). Mineralization is mostly of the vein and hydrothermal type, but residual to eluvial placers are also present.

Mineralization at the Egerton and Mangaroon Mining Centres is within Gascoyne Complex rocks — quartz–mica schist, sericite–chlorite schist, schistose amphibolite, calc-silicate schist, and quartzite. In contrast, mineralization at the Bangemall Mining Centre is within sedimentary rocks (Edmund Group) of the Bangemall Basin, and intrusive dolerite.

The Bangemall Mining Centre and the associated McCarthys Patch are situated in a 50 km-long synclinal structure, the Cobra Synclinorium (Muhling and Brakel, 1985). Quartz forms saddle reefs and veins parallel to the axial-plane cleavage that contain free gold, pyrite, sphalerite, and carbonate. Individual veins have limited

Table 2. Historic production of gold and silver from mines in the Gascoyne Region

MINEDEX site code	*Mine*	*Latitude (°S)*	*Longitude (°E)*	*Start date*	*End date*	*Tonnage (t)*	*Contained metal (kg)*	*Mineral*
S06772	Boss	24.20844	116.46442	1899	1899	20	0.768	Gold
S06773	Carnarvon Gem	24.20738	116.46001	1897	1899	179	4.735	Gold
S06774	Eldorado	24.21083	116.45416	1899	1899	42	1.293	Gold
S06775	Gem	24.20752	116.46092	1915	1916	116	2.965	Gold
S06777	Star of Mangaroon	23.86974	115.74591	1961	1983	4 742	185.570	Gold
							3.197	Silver
S13963	Dorothy	24.94250	117.74667	1916	1916	91	4.012	Gold
S13966	Egerton	24.94035	117.74835	1938	1953	2 153	116.805	Gold
							0.044	Silver
S13972	Excelsior	24.95343	117.73576	1911	1911	4	0.502	Gold
S13985	Hibernian	24.93977	117.74802	1912	1924	4 481	51.625	Gold
S13987	Homeward Bound	24.94250	117.74667	1914	1915	225	6.683	Gold
S14034	Pegasus	24.94250	117.74667	1937	1938	358	25.588	Gold
S14057	Wyndham	24.94250	117.74667	1908	1908	98	0.220	Gold
S16042	Edwards Reward	24.75639	117.04834	1933	1971	2 169	63.014	Gold
Total						**14 678**	**463.780**	**Gold**
						6 895	**3.241**	**Silver**

SOURCE: MINEDEX (Department of Minerals and Energy's Mines and mineral deposits information database)

strike length, but some vein stockworks are locally up to 10 m wide. The reefs and veins are in shale and dolerite sills near the top of the Jillawarra Formation. Muhling and Brakel (1985) suggested that the emplacement of these deposits may have been related to deformation and low-grade metamorphism. Modern exploration has been restricted to ground investigations and limited target drilling under the old workings. The excellent exposure and thin overburden in the area of the main workings suggest that no significant vein-related mineralization has been overlooked (Cooper et al., 1998).

At the Egerton Mining Centre, the dominant mineralization is shear-related quartz–pyrite or quartz–pyrite–carbonate veining, with the dominant trend of the veins, cleavage, and shears being northeasterly. This mineralization is best developed along the Hibernian trend, along the sheared contact between gabbro and quartz–muscovite schist. Chlorite, epidote, carbonate, sulfides, and silicification characterize the associated hydrothermal alteration. Zones of mineralization up to 11 m thick are exposed at the Hibernian mine, but similar zones at Gaffney Find and Eastern Ridge, where mafic rock is absent, are commonly less than 2 m thick (Cooper et al., 1998).

Devlin (1985) suggested that exhalative mineralization is also present at the Egerton Mining Centre, associated with both pyritic and chloritic siltstone and pyritic chert containing narrow high-grade sulfide bands. During a period of high heat flow, the sulfides were remobilized from this primary source, forming quartz–chlorite veins within shear zones. The heat flow could have been related to the intrusion of granitoids within the inlier.

Recent exploration in the Gascoyne Complex by Helix Resources NL (E09/644) led to the discovery of gold mineralization along a shear zone in the vicinity of Victoria Bore, 25 km east of Dairy Creek Homestead. Drilling in 1995 and 1996 outlined inferred resources of low-grade mineralization (averaging 1.5–2.2 g/t Au) containing about 90 000 ounces of gold, but there has been little recent work.

Platinum-group elements (PGE)

Platinum and palladium values of up to 15 ppb and 8 ppb respectively have been recorded in regolith samples over Archaean–Proterozoic rocks along the boundary of the Yilgarn Craton and the Gascoyne Complex on GLENBURGH* (Sanders et al., 1998). These samples also show higher values of Cr, Co, and Ni, and appear to be related to dolerite–gabbro dykes or sills; mafic–ultramafic rocks may also be present. A similar style of mineralization is apparently present at the Imagi Well – Byro Cr–PGE prospect, located about 60 km to the south and in the Narryer Terrane, but within the Mid West region. The Imagi Well – Byro prospect is within layered ultramafic rocks, and was explored in the 1970s and early 1980s (Flint et al., in prep.).

Speciality metals

Rare earth elements (REE)

Potentially economic REE and phosphate mineralization is found within Western Australia in intrusive Archaean–Proterozoic carbonatites, the best known example of which is the Mount Weld carbonatite, approximately 35 km south of Laverton. Mount Weld contains large resources of lanthanum, yttrium, niobium, tantalum, and

* 1:250 000 sheet names are capitalized

Table 3. Rare earth deposits north of Gifford Creek Homestead

Deposit name	*Location description (distance from Gifford Creek Homestead)*	*Latitude (°S)*	*Longitude (°E)*	*Resource Mt at rare earth oxides (%)*	
				Indicated	*Inferred*
Kanes Gossan	28 km north	23.8731	116.2541	0.449 at 1.570	
Gossan–Yangibana	29 km north	23.8616	116.2014	0.038 at 1.75	
Tongue	24 km north	23.9041	116.1512	0.077 at 0.67	
Hook South	29 km north	23.8680	116.2426	0.085 at 1.54	
Frasers–Yangibana	21 km north	23.9525	116.3099	0.091 at 2.18	
Yangibana South	24 km north	23.9107	116.2010	0.161 at 0.83	
Yangibana	25 km north	23.8970	116.1869	0.169 at 0.85	
Hook	29 km north	23.8675	116.2246	0.136 at 2.326	
Yangibana North	30 km north	23.8470	116.1852	1.009 at 1.86	0.575 at 1.508
Lions Ear	29 km north	23.8639	116.2128	0.083 at 1.74	0.064 at 2.2
Bald Hill North and South – Yangibana	26 km north	23.9080	116.2956	0.113 at 1.22 (Bald Hill North) 0.355 at 1.652 (Bald Hill South)	

phosphorus, and is potentially capable of supplying 10% of the world's demand for rare earths for more than twenty years. Ashton Rare Earths Pty Ltd recently recommenced a feasibility study of the Mount Weld deposit.

Within the Gascoyne Region, significant deposits of REE mineralization are associated with carbonatites intruding Mesoproterozoic Tringadee Formation (Bangemall Basin), 20–30 km north of Gifford Creek Homestead. Within this 10-km zone, twelve deposits are known and are estimated to contain a total indicated resource of 2.77 Mt at an average of 1.52% rare earth oxides, with an additional inferred resource of 0.64 Mt at 1.854% rare earth oxides (Table 3).

The exploration potential for REE on GLENBURGH has been enhanced by a recent GSWA geochemical survey of the regolith (Sanders et al., 1998). This survey found elevated REE values in Ce, La, and Y within Archaean–Proterozoic rocks along the northwest margin of the Yilgarn Craton in the vicinity of the Bullbadger Shear Zone (but just outside the Gascoyne Region).

Elevated levels of Th, Pb, and P_2O_5 in conjunction with the REE suggest that the REE are in the phosphate minerals xenotime, monazite, or apatite. Within the study area, Sanders et al. (1998) also found elevated REE in regolith samples from 10 km north of Erong Springs Station over Palaeoproterozoic rocks of the Gascoyne Complex (Morrissey Metamorphic Suite). These and other lower order anomalies in the area imply that intrusive carbonatites are present.

Tantalum

Tantalite–columbite mineralization at the Arthur River prospect, near Gascoyne Junction, is within pegmatite of the Gascoyne Complex. The area is held by Rare Resources NL, but Border Gold NL has entered a Heads of Agreement to acquire the tenements. Border Gold believes the area has a high potential to host significant economic resources of both tantalite and columbite and plans to carry out a drilling program to determine an initial resource estimate for the deposit. Jays Exploration Pty Ltd produced 4.4 t of tantalite–columbite concentrate in 1980–81 from Morrissey Hill.

A number of small occurrences of pegmatites bearing tantalum, rare earth minerals, and lithium are known from the Gascoyne Region, and these are summarized in Appendix 1.

Base metals (copper, lead, and zinc)

There are at least 22 widely scattered base metal occurrences in the study area, most of which lie within the Bangemall Basin. All are quite small, however, and, despite mine workings on some, there is no recorded production. None of the occurrences in the study area is large enough or sufficiently promising for a resource estimate to have been prepared.

Base metal potential of the Bangemall Basin

Base metal exploration in the Bangemall Basin since 1965 is summarized by Chuck (1984) and Cooper et al. (1998). Numerous styles of base metal mineralization are known from the area including fault- and fissure-related copper (with a possible dolerite association); fault- and fissure-related lead and minor zinc; carbonate-hosted lead; base metal veins with a dolerite–gabbro host or association; and stratabound mineralization. Stratabound mineralization of the Bangemall Basin is further subdivided into three groups: within the Jillawarra Sub-basin (i.e. Abra style); within dominantly carbonaceous and pyritic shale at various stratigraphic levels; and dolostone-hosted occurrences (Cooper et al., 1998).

The Abra deposit is the largest base metal deposit in the region and has the most potential to become an economic deposit, but lies just east of the Gascoyne Region. This style of deposit may be present at depth within the study area and, if so, could be located using magnetic surveys.

The Abra deposit is a large, blind, polymetallic deposit at the top of the Irregully Formation (Edmund Group) in a succession of intertidal sedimentary rocks at the eastern end of the Jillawarra Sub-basin. The upper boundary of the deposit lies between 250 and 500 m below the surface and extends to a depth of 800 m. An aeromagnetic anomaly at Abra delineates an elliptical body 1.5 km in diameter. From limited diamond drilling, the deposit has been estimated to contain about 200 Mt at 6 g/t Ag, 1.8% Pb, 0.18% Cu, and 6.0% Ba (Boddington, 1990). The deposit is enclosed within an alteration envelope and consists of two styles of mineralization: a layered, stratabound zone and an underlying funnel-shaped stringer or stockwork zone.

Collins and McDonald (1994) and Vogt (1995) considered the Abra deposit to be an exhalative polymetallic sediment-hosted epithermal system, coeval with the accumulation of sediments in a subaerial, subtidal to intertidal environment. There is general agreement amongst various authors that the mineralizing hydrothermal systems in the Jillawarra Sub-basin were associated with the initial intracratonic rifting of the Bangemall Basin and accompanying localized increase in geothermal gradient. This probably also gave rise to felsic magmatism that is represented by the Tangadee Rhyolite, east of the Abra deposit (Cooper et al., 1998).

Base metal potential of the Southern Carnarvon Basin

Phanerozoic sedimentary rocks of the Southern Carnarvon Basin have the potential to host base metal mineralization (Harrison, 1985; Hocking et al., 1987; Iasky and Mory, 1999). Although little base metal mineralization has been recorded from the Gascoyne Platform, there is the possibility of lead–zinc–silver–copper enrichment in carbonates of the Silurian Dirk Hartog Group and Devonian Gneudna Formation, and pyritic shale in the Cretaceous Winning Group. Such mineralization is most likely to be present along the faulted eastern and western margins of the platform. Along the eastern margin, the Kennedy Range Fault System places carbonaceous shale and probable volcanic rock in the Merlinleigh, Byro, and Coolcalalaya Sub-basins in close proximity to likely host rocks. In addition, basement rocks are relatively shallow along this part of the platform, that is, within the Wandagee and Ajana Ridges. To the west, the presence of volcanic rocks is inferred from gravity data and such rocks could have sourced base metals to the platform, for example, those found in the Giralia area further north. Exploration in the centre of the platform by BHP Minerals Ltd (for Irish-style copper–lead mineralization in the Dirk Hartog Group) failed to find significant levels of enrichment (Edgar, 1994), possibly because of the lack of a direct conduit for mineralizing fluids from the basement (Iasky and Mory, 1999).

Several carbonate units have been tested and drilled by International Nickel Australia Ltd and Aquitaine Australia Minerals Pty Ltd in the late 1970s and early 1980s, based on the concept of Mississippi Valley-type lead–zinc mineralization in carbonates. Results were discouraging, although some targets remain untested (Harrison, 1985).

The exploration potential of the eastern margin of the Southern Carnarvon Basin, in the vicinity of GLENBURGH has been enhanced by a recent GSWA geochemical survey of the regolith (Sanders et al., 1998). The survey found elevated levels of zinc (to 151 ppm) in samples of erosional regolith over sedimentary rocks of the Wooramel Group, 8 km southwest of Keogh Hill.

There has been no investigation of the potential for copper–cobalt–uranium–vanadium mineralization associated with sabkha-type redbeds, similar to those in the Sweeney Mia Formation and the Kopke and Tumblagooda Sandstones. The most likely area for such mineralization is along the Wandagee and Ajana Ridges (Iasky and Mory, 1999).

North of the Gascoyne Platform, in the Giralia Anticline, anomalous silver and zinc values have been reported from sulfide and goethite nodules in the Cretaceous Gearle Siltstone of the Winning Group (International Nickel Australia Ltd, 1980). This anomalous silver was the target for Capricorn Resources Australia NL in 1996–97 (Exploration Licence 08/905), but no exploration was conducted. If this mineralization is related to the steeply dipping faults cutting through the anticline or along its eastern margin, there may be similar occurrences associated with the Salt Marsh anticlines in the northern part of the Gascoyne Platform. However, any deposits are likely to be deeply buried (Iasky and Mory, 1999).

Energy minerals

Coal

The following summary on the Talisker coal deposit is from Le Blanc Smith (1990).

The Talisker deposit, of Permian age, is within the Coolcalalaya Sub-basin, approximately 180 km north-northeast of Geraldton. Esso Australia Ltd (Coal & Synthetic Fuels Dept) explored the area in 1980 and 1981, but all tenements for coal have lapsed and the area is currently being explored by Stockdale Prospecting Ltd for diamonds (E09/914). A total of 1621 m of rotary air blast/mud drilling was completed in 16 holes, and a gravity survey was also conducted. Two coal seams occur over an area of almost 100 km^2.

The coals are Permian in age and are in the Keogh Formation, which attains a thickness of 60 m. These coal-bearing strata correlate with the Irwin River Coal Measures and Collie Coal Measures. The thickest aggregate coal seam is 2.3 m thick, and lies in the southern part of the deposit, down to a depth of 96 m. Faulting and open, low-amplitude folding of strata affect the deposit.

Drilling has indicated that the deposit is fault bounded, and a north-northeasterly trending synclinal axis traverses the deposit.

The seam has a single principal zone that is split by a thin parting. No detailed resource estimate is available. Preliminary calculations indicate an inferred resource of approximately 130 Mt. The general quality indicates a steam coal, with a high ash-fusion temperature and moderate to high sulfur. This deposit is logistically remote and development can only be viewed as long term.

Petroleum

The following comments on the petroleum prospectivity of the Southern Carnarvon Basin are from the Department of Minerals and Energy Western Australia (1999). Further specific details from the Petroleum Initiatives activities of the GSWA in recent years are presented in Crostella (1995); Crostella and Iasky (1997); Iasky et al. (1998); Ghori (1999); Haworth and Arden (1999); and Iasky and Mory (1999).

The onshore, primarily Palaeozoic, Southern Carnarvon Basin is one of the less-explored sedimentary basins of Australia. The basin extends west from the Yilgarn Craton to the edge of the Continental Shelf and covers approximately 200 000 square kilometres (Fig. 2). Petroleum exploration commenced in the Southern Carnarvon Basin in the 1930s after W. G. Woolnough first drew attention to the Wooramel River area, and when hydrocarbon shows were encountered in shallow waterbores in the northern part of the region (Table 4). WAPET was the first company with serious exploration programs in the region in the 1950s and 1960s, following its oil discovery at Rough Range. After early work near Rough Range proved non-commercial, most exploration moved north to the offshore Northern Carnarvon Basin. To date, 75 onshore (including 57 stratigraphic tests) and two offshore wells have been drilled in the Southern Carnarvon Basin. No fields or accumulations have been discovered.

The northernmost part of the Southern Carnarvon Basin is characterized by three large Middle Miocene anticlines: Rough Range, Giralia, and Marrilla. Several smaller anticlines of the same age, exposed along the eastern and western shores of Lake MacLeod, in the central part of the basin, are known as the Salt Marsh anticlines.

There have been only a few valid tests for hydrocarbon plays in the region (Petroleum Operations Division and Geological Survey of Western Australia, 1999). Lower Cretaceous sandstone, which has excellent reservoir characteristics, has been the main objective for oil exploration in the northern part of the basin, but distance from effective source rocks, or adequacy of seal are risks. Source rocks are present in the Lower Permian, Upper Devonian, and Silurian successions (Fig. 3). Lower Permian source rocks are regionally immature to marginally mature, and are mostly gas prone. By comparison, Devonian–Silurian source rocks have been shown to have good potential for both oil and gas generation, although Silurian source beds found to date are thin. The Cretaceous succession may still offer some potential for hydrocarbon generation and for an oil discovery. The Devonian succession offers the most challenging, yet untested, objective. Untested structural highs have been demonstrated adjacent to major faults (mainly along the eastern edge of the Gascoyne Platform) that may have provided vertical conduits for migrating hydrocarbons.

Uranium

The main phase of uranium exploration in the region was between 1970 and 1980, with three styles of mineralization found — calcrete-hosted deposits and occurrences, stratabound sandstone-hosted occurrences, and supergene or residual mineralization. Major exploration programs in the Bangemall Basin are summarized by Cooper et al. (1998).

At least 16 uranium occurrences are known in the study area; most are hosted by calcrete. With these, there is a strong spatial relationship to the underlying geology, with most of the occurrences found at, or near, the unconformable contact between the Bangemall Basin and the underlying basement (dominantly the Gascoyne Complex). Primary mineralization in the Gascoyne Complex rocks is the source of uranium for secondary calcrete-hosted deposits.

All calcrete-hosted deposits are small, with resources estimated for only three of the deposits — Jailor Bore, Minindi Creek and Mount James (Table 5). All three have inferred resources only, and none is considered economic to mine at present.

The only occurrence of stratabound sandstone-hosted uranium mineralization known within the study area is at Centipede Range. It is located about 7 km west of Cobra

Table 4. Hydrocarbon shows, onshore Carnarvon Basin

Well	*Quality of show*	*Formation*	*Formation age*
Kennedy Range 1	Fair gas shows	Moogooloo Sandstone	Early Permian
Quail 1	Trace oil	Gneudna Formation	Devonian
Quobba 1	High background C4	Point Maud Formation	Devonian
Wandagee 1	Poor gas show	Tumblagooda Sandstone	Ordovician
Rough Range 1	Good oil show	Birdrong Sandstone	Cretaceous

Table 5. Inferred resources of uranium at deposits within the Gascoyne Region

Deposit	*Tonnage (million tonnes)*	*Grade (kg/t U_3O_8)*	*Contained uranium (tonnes of U_3O_8)*
Jailor Bore	0.7	0.5	350
Minindi Creek	3.5	0.123	430
Mount James	0.61	0.067	41

Homestead, in arkosic sandstone of the Tringadee Formation (Edmund Group). Radiometric surveys show the sandstone is thorium rich, and contains significant uranium. Both surface and deeper mineralization (90 m downhole) were encountered (Sise, 1980). Petrological investigations indicated the presence of the thorium-rich minerals xenotime and thorite, and/or auerlite (Cooper et al., 1998).

Several uranium prospects are known within the Carnarvon Basin, and have been the target of numerous unsuccessful exploration programmes (Harrison, 1985). The main models used for exploration have been of stratabound sandstone-hosted uranium and sandstone-hosted roll-front uranium. Target horizons include the Cretaceous Birdrong Sandstone (for example, as at Manyingee Hill deposit, to the northeast of the study area) and the Permian Moogooloo Sandstone.

Construction materials

The total reported production of construction material from the Gascoyne Region is small, and in 1998 amounted to 1600 t of gravel (valued at $9600). Some of this production is from tenement M8/46 in the Exmouth area, and appears to be limestone byproduct used for construction aggregate. Additional sites with potential for production of construction materials are listed below.

Shark Bay

In the Shark Bay region, red, eolian quartz sand, shelly limesand, thick calcrete, gypsum from birridas, and consolidated Tamala Limestone have been quarried for road construction purposes. Some quarries are still operating. Tamala Limestone has been used for breakwater material near Useless Loop. Blocks of the consolidated Hamelin Coquina, composed of the bivalve *Fragum erugatum*, have been used for building construction (e.g. at Carbla Homestead), but excavation on the edge of the bay has ceased because of environmental restrictions. Unconsolidated coquina is still used for road-building and decorative purposes (Butcher et al., 1984; Townsend, 1996).

Carnarvon region

The bed of the Gascoyne River provides sand and gravel for building purposes in the Carnarvon area. Trealla Limestone, Windalia Radiolarite and calcrete are used locally for road construction. The Trealla Limestone is commonly the only good source of aggregate in coastal areas, although pisolitic calcrete is used locally. Some quarries for construction material are currently located 7 and 9 km northeast of Carnarvon, 25 km east of Carnarvon, and 128 km north of Carnarvon (Denman and van de Graaff, 1982; Hocking et al., 1985).

Gascoyne Junction

Stone Enterprises Pty Ltd holds a Mining Tenement (M9/51) 60 km east of Gascoyne Junction, and produces dimension stone and aggregate. Material mined is dolomitic marble with the trade name Weedara Marble (after the nearby Weedarrah Homestead), which was formerly known as Bidgemia Marble (after Bidgemia Station).

Other areas

The Early Permian Callytharra Formation and Moogooloo Sandstone have been used as paving and building stones. Sand and gravel aggregate occurs in riverbeds such as Yannarie River and Rouse Creek. On the Cape Range peninsula, calcreted eolianite has been used for road building (van de Graaff et al., 1980; Hocking et al., 1985).

Woodleigh impact structure

The following comments on the mineral potential of the Woodleigh impact structure are from Iasky and Mory (1999). Note that mineralization associated with the Woodleigh impact structure has yet to be identified.

Diverse styles of mineralization are documented from impact sites, related to brecciation, structural displacement, phase transitions, melting, hydrothermal activity, and sedimentation, including chemical and biochemical processes. Some 25% of known impact structures worldwide are associated with economic mineralization including hydrocarbons, and about 12% are or have been exploited. The formation of a hydrothermal cell upon impact, and the consequent heating and mobilization of intergranular pore fluids within the deformed aureole, can result in metalliferous mineralization such as nickel–copper in Sudbury (Canada), and lead–zinc in Siljan (Sweden), Serpent Mount, Decaturville, and Crooked Creek (USA). In addition, there may be post-impact hydrothermal remobilization of uranium (e.g. Temovka, Ukraine; Carswell, Canada; and Vredefort, South Africa;

Grieve and Masaitis, 1994). The shock effects of an impact on carbon-bearing sedimentary rocks may result in important diamond deposits. However, this is unlikely in the Woodleigh impact structure as carbonaceous deposits are relatively minor within the Gascoyne Platform. In view of its very large diameter (possibly 120 km), further studies of the Woodleigh impact structure are justified.

Summary

Salt is the most important commodity produced in the Gascoyne Region, and production in the Pilbara–Gascoyne may be poised to increase, with plans by the consortium of Dow Chemical Co and Shell Chemicals to set up a $2 billion petrochemical complex in the Pilbara. The largest gypsum deposit in the State is also in this region — at Lake MacLeod. Dampier Salt Ltd has increased production there fivefold in the years 1997 and 1998.

High-grade metallurgical limestone is mined at Cape Range, and production is set to expand following the start up of mining in 1998 by Exmouth Mining Pty Ltd.

Other industrial minerals with potential are barite, graphite, and heavy mineral sands. Semi-precious gemstones have been produced, and a few micro-diamonds have been discovered in lamproites northeast of Carnarvon.

Gold and silver production has been small-scale in the past but exploration is continuing. A gold resource at the Apollo prospect has been outlined in Gascoyne Complex rocks. Tantalum and REE are found. Tantalum has been mined in the past from Morrissey Hill and an indicated resource of rare earth oxides has been outlined in 12 deposits in a belt of carbonatites intruding rocks of the Bangemall Basin. The Bangemall Basin is also prospective for base metals. About 22 base metal occurrences, some with mine workings, are located in the region, and the polymetallic Abra deposit lies just outside.

The Gascoyne Region has resources of coal and uranium and is prospective for petroleum. The Talisker coal deposit in the southeast corner of the region is deep and logistically remote, but development may possibly be viewed in the long term. In the Southern Carnarvon Basin, 75 onshore and two offshore wells have been drilled for petroleum. No fields or accumulations have been discovered, but poor to fair gas flows were obtained in several wells, and one had a trace of oil. Further exploration is warranted as favourable source and reservoir rocks exist within the basin. Sixteen uranium discoveries resulted from exploration in the 1970s and 1980s. Most of these are calcrete-hosted bodies, which are small and are considered to be uneconomic at present.

The Woodleigh meteorite impact structure has been recently identified within rocks of the Carnarvon Basin and its mineral potential remains to be tested.

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Appendix 1

Mineral occurrences of the Gascoyne Region

Commodity	*Deposit name*	*Location description*	*Latitude (°S)*	*Longitude (°E)*	*Comments*
Amethyst Tourmaline Chalcedony	Gascoyne Amethyst (Soklich)	Just north of O'Connor Well	24.4803	116.4667	No details other than production
Asbestos		5 km east of Coobaroo Bore	23.7751	116.5258	
Barite		5 km west of Mangaroon	23.9046	115.5755	Fine-grained barite lenses in a granitic host. Also contains pods of granitoid within barite
Barite	Cardabia Creek	Barite located 5.6 km north-northeast of Cardabia Pool	23.1722	114.1500	Small barite crystals in the upper part of the Cretaceous Gearle Siltstone. Large spheroidal crystalline barite nodules east of Mount Remarkable
Barite	Mount Sandiman	180 km east-northeast of Carnarvon	24.4778	115.3861	Exploration drilling of this area indicated 320–9400 ppm Ba in drill chips
Barite	Mangaroon	5 km west of Mangaroon Homestead	23.9167	115.5764	Translucent to faint brown, euhedral, white, and fine-grained barite occurs as outcrops, which contain discrete unmineralized granitic pods
Barite	Mooloo Downs	1.5 km south of Jones Bore	25.0819	116.0653	Barite veins in gneiss. The barite is commonly off-white to pale-pink and coarsely crystalline
Barite	Reid Well	3 km southeast of Reid Well	24.5306	116.3236	Discontinuous lenses of low-grade barite
Barite	Cork Tree Bore	1.5 km south-southeast of Cork Tree Bore	24.6625	115.7125	Minor barite occurrence in a quartz-filled shear trending north-northeast in augen gneiss. Fluorite also occurs
Barite	Mount James Station	Near Mount Gascoyne	24.8500	116.9000	A sample of coarsely crystalline, white, but partly iron-stained, barite was collected from this location. The sample was poor quality
Beryl Tantalum REE		Located at Marloo Well in E09/395	24.7561	115.8643	Columbite–tantalite mineralization in pegmatite
Copper	Alston Well	1 km north of Alston Well. Unconfirmed occurrence	24.2112	116.5327	Not located on the ground — location approximate
Copper	Ti Tree Syncline	6 km southeast of Dingo Well	24.6037	116.4246	
Copper	Charlie Creek 2	8 km east of Mount Boggola	23.8019	117.5795	Rough dimensions of quartz–ironstone gossan with malachite

Appendix 1 (continued)

Commodity	*Deposit name*	*Location description*	*Latitude (°S)*	*Longitude (°E)*	*Comments*
Copper		4 km southwest of Mount Genoa. Coordinates at quartz vein	24.4124	116.9413	Detrital malachite in sandstone. Channels cut in dolomite. Minor quartz veins
Copper		700 m north-northeast of Mount Candolle	24.5184	117.1242	Few cm-thick veins in gabbro intruded along Area F lineament
Copper		9.5 km southeast of Mount Augustus Homestead	24.3402	116.9951	General location only
Copper		9 km southwest of Mount Genoa	24.4793	116.9388	Malachite on joint planes
Copper	Star of Mangaroon South	0.4 km south of Star of Mangaroon mine; reading 2 m west of headframe	23.8730	115.7473	No evidence that gold was extracted
Copper	Mount Phillips Homestead	7.5 km south-southwest of Mount Phillips Homestead	24.4622	116.2846	
Copper		24 km southwest of Waldburg Homestead. Approximate location	24.8531	117.1534	Disseminated malachite — similar to Mount Genoa area
Copper	High Range	8 km west-northwest of Maroonah Well. High Range Syncline	23.6470	115.5367	Minor copper staining
Copper Gold	Dalgety Downs East		25.3089	116.2436	Narrow (<1 m) quartz veins with malachite; chrysocolla and azurite within biotite granodiorite and biotite–muscovite adamellite. Locality anomalous in gold and copper
Copper Gold	Dalgety Downs South		25.3644	116.1453	Narrow (<1 m) quartz veins with malachite; chrysocolla and azurite within biotite granodiorite and biotite–muscovite adamellite. Locality anomalous in copper and gold
Copper Lead Molybdenum Zinc	Ti Tree Well	2.5 km east of Ti Tree Well	24.3524	116.0906	Area of surface mineralization with pyrite (up to 15%) and secondary Cu, Pb, and Mo minerals. Porphyry Cu-style alteration zones
Copper Lead Silver	Mount Genoa	Upper Lyons River. 2 km north of Mount Genoa	24.3920	116.9830	Coordinates from company description, but may be further south
Copper Lead Silver Gold	Mangaroon (Pb)	1.6 km northwest of Star of Mangaroon mine. Coordinates 4 m north of decline	23.8577	115.7383	Cleavage strikes 286º, dips 80ºN
Copper Lead Zinc	Coria Springs Ironstone	5 km south of Yandie Bore. High Range Syncline	23.5263	115.4510	Elements scavenged from weakly anomalous bedrock

Appendix 1 (continued)

Commodity	*Deposit name*	*Location description*	*Latitude (°S)*	*Longitude (°E)*	*Comments*
Copper Zinc		1 km east of Mount Candolle	24.5155	117.1312	Minor veining associated with nearby gabbro intrusion
Copper Zinc	Mount Augustus	May be general location for Mount Genoa area	24.2833	116.9000	No Kiangi Creek Formation at this locality. Copper minerals with associated Zn
Copper Zinc	Dunnice Well	4 km west of Dunnice Well. Unconfirmed occurrence	24.2716	116.6399	Not located on ground — approximate location
Copper Zinc		500 m northwest of Mount Candolle. Second vein at 512099E 7287372N	24.5268	117.1185	Minor veinlets
Copper Zinc Lead Gold	Charlie Creek 1	7 km east of Mount Boggola	23.7999	117.5860	Quartz–ironstone gossan with malachite
Diamond		37 km north of Edmund Homestead. Five lamproite bodies located	23.5951	116.0123	Stream sample in area with lamproitic siltstone float. Thin dykes may be present in the area. No source located
Diamond		14 km northwest of (Gregorys) Gap Bore	23.8675	116.7905	20 kg stream samples. One fine diamond — detailed stream follow-up produced negative results
Diamond		35 km north of Edmund Homestead. Five lamproite bodies located	23.6090	116.0001	35 kg stream sample or rock sample (no details). Eerstelling (ETL3) lamproite within 100 m
Gold	Boss	Bangemall Mining Centre near Cobra Homestead	24.2096	116.4649	Bedding strikes 283º, dips 68ºN. Quartz veins intruded along fold axis
Gold		4 km southwest of Pritchard Well	23.8502	115.6569	Area of dryblowing for gold
Gold		220 km northwest of Meekatharra. Egerton Mining Centre	24.9345	117.7769	Coordinates for Claim 373P at northeast end of trend. Further line of old workings
Gold	Carnarvon Gem	Bangemall Mining Centre near Cobra Homestead	24.2084	116.4607	Main reef — single shaft at 7322740N, 445076E not visited
Gold	Bangemall Mining Centre	Near Cobra Homestead. Same coordinates as Carnarvon Gem	24.2084	116.4607	General site with gold production from alluvials and sundry sites
Gold	Eldorado–Bangemall	Bangemall Mining Centre near Cobra Homestead	24.2146	116.4726	
Gold	Mount Egerton	110 km southeast of Mount Augustus. Coordinates for Mount Egerton mine	24.9433	117.7562	Area of workings. Old mines — Hibernian; Egerton; Dorothy; Excelsior; Homeward Bound; Pegasus; Wyndham and others. General site with all production? May or may not include Hibernian production

Appendix 1 (continued)

Commodity	*Deposit name*	*Location description*	*Latitude (°S)*	*Longitude (°E)*	*Comments*
Gold	Bustler Well	Old pits south of Bustler Well	24.7967	116.9580	Plunge of 40º to the northeast
Gold	Diamonds	Exploration Licences E09/132, 135, 136, and 137	23.8774	115.5680	Abandoned mine. Location is approximate
Gold	Gaffney North	1.3 km north-northeast of Gaffneys Find	24.9360	117.6361	
Gold	McCarthys Patch	14 km northwest of Bangemall Mining Centre. Shafts not located	24.1248	116.3662	No shafts observed. Veins >2 m wide. One WAMEX report (A21355) indicates the veins are hosted by granitoid
Gold	Cobra (Sexton)	Bangemall Mining Centre; near Cobra Homestead	24.2018	116.4583	Small pits and larger dryblowing area with narrow quartz veins exposed
Gold	Bangemall Old Battery Dryblowing	Bangemall Mining Centre; near Cobra Homestead	24.2032	116.4608	Probably old treatment site with sluices and boilers. Area reworked recently
Gold	Ada Alice Dryblowing	Bangemall Mining Centre; near Cobra Homestead	24.2123	116.4701	Dryblowing area with push-ups and small pits. Supergene gold with small nuggets
Gold	Eldorado South	Bangemall Mining Centre; near Cobra Homestead	24.2170	116.4750	One shaft only
Gold	Black Hill	Bangemall Mining Centre; near Cobra Homestead	24.2052	116.4642	Shallow pits and dryblowing in ironstones
Gold	Envy	Bangemall Mining Centre; near Cobra Homestead	24.2097	116.4626	No recorded production. Cleavage strikes 85º
Gold	Gaffney Find	12 km west of Mount Egerton Gold Field	24.9491	117.6286	Area of six mineralized shear zones (20–50 m long by 4 m wide). Some alluvial workings to the south
Gold	Western Flats	1 km southwest of Mount Egerton Bore. Coordinates from map and Landsat	24.9534	117.7376	1 shaft and 1 pit
Gold		1.5 km west of Gaffney North	24.9332	117.6211	Gold nuggets, generally >2 g and found by metal detecting, define the occurrence
Gold	Zone B	2 km southeast of Mount Egerton Bore. Coordinates from map and Landsat	24.9507	117.7627	9 pits. Dip of strata is near vertical
Gold		3 km southeast of Gaffney Find	24.9616	117.6509	Surface area of gold nuggets (generally >2 g) outlined by metal detecting
Gold	McCarthys Patch (alluvial)	14 km northwest of Bangemall Mining Centre. Position of plant	24.1290	116.3747	Area of dryblowing and surface workings. Plant still on site — sporadic activity
Gold	Mount Egerton (alluvial)	1 km north of Mount Egerton Bore. General location	24.9399	117.7562	General location for patchy and widespread alluvial workings. No accurate plans

Appendix 1 (continued)

Commodity	*Deposit name*	*Location description*	*Latitude (°S)*	*Longitude (°E)*	*Comments*
Gold		2.5 km north of Mount Egerton Bore. Coordinates from map and Landsat	24.9263	117.7643	3 shallow pits
Gold		Reading beside Pritchard Well	23.8160	115.6812	Area of dryblowing
Gold	Eastern Flats Southeast	3.5 km east of Mount Egerton Bore. Coordinates from map and Landsat	24.9444	117.7857	2 shafts and 6 pits. Two mineralized zones 80 m apart
Gold	Zone C	2 km southeast of Mount Egerton Bore. Coordinates from map and Landsat	24.9499	117.7644	4 pits — no detail
Gold	Zone A	2 km southeast of Mount Egerton Bore. Coordinates from map and Landsat	24.9522	117.7598	2 old pits. Low-angle shearing in pyritic siltstones. Dip of strata is near vertical
Gold	Zone D	2 km southeast of Mount Egerton Bore. Coordinates from map and Landsat	24.9497	117.7678	2 shafts and some small pits
Gold	Zone E	2 km east of Mount Egerton Bore. Coordinates from map and Landsat	24.9454	117.7685	1 pit — low values. Possibly trial pit only
Gold		3 km southeast of Gaffney Find	24.9588	117.6591	Surface area of gold nuggets (generally >2 g) outlined by metal detecting
Gold	Zone F	3 km southeast of Mount Egerton Bore. Coordinates from map and Landsat	24.9460	117.7732	1 shaft. Narrow mineralized and sheared siltstones
Gold	Zone G	3 km east of Mount Egerton Bore. Coordinates from map and Landsat	24.9456	117.7750	Many small pits and shafts — coordinates for most south-westerly. Zone G West — 30 m long by 12 m wide — 11.4 m @ 6 g/t Au. Mineralization dominantly in pyritic siltstone
Gold	Zone H	3 km east of Mount Egerton Bore. Coordinates from map and Landsat	24.9438	117.7802	2 pits in metabasite
Gold	Eastern Flats Northwest	3 km east of Mount Egerton Bore. Coordinates from map and Landsat	24.9427	117.7832	5 pits. Zone of deeply weathered shales
Gold	Zone I	3 km west of Mount Egerton Bore. Coordinates from map and Landsat	24.9525	117.7130	3 pits and 2 shafts. May be sheared metabasite
Gold Copper	Egerton West	Zone of mineralization is 50 m by 0.5 m	24.9400	117.6900	Narrow stratabound mineralization
Gold	Hibernian	1 km north of Mount Egerton Bore. Coordinates from map and Landsat	24.9412	117.7489	Extensive underground workings — plan not included. Main Zone with parallel vein sets

Appendix 1 (continued)

Commodity	*Deposit name*	*Location description*	*Latitude (°S)*	*Longitude (°E)*	*Comments*
Gold Lead Copper Silver	Two Peaks – Mangaroon	3 km southwest of Two Peaks Bore; reading south end of decline	23.8038	115.6996	Veins strike 285º, dip 50º — bulldozing then metal detecting
Gold Silver Gold	Star of Mangaroon	14 km northeast of Mangaroon Homestead. Coordinates of main shaft	23.8692	115.7446	Second shaft 5 m north. Adit 5 m south. Vein 1.5–2 m wide
Graphite	Yalbra		25.5626	116.3917	Podiform occurrences of graphitic schist within shale and siltstone (quartz–tremolite–chlorite–mica–feldspar schist) units. Weathering leaves graphite in a kaolin–gypsum–nontronite–chalcedony–dolomite–magnesite matrix. Subeconomic
Gypsum	Useless Loop	9 km south of Useless Loop township	26.2208	113.4208	Birrida is 4 km long and 2 km wide
Gypsum	Lake MacLeod North	11 km east of Warroora Station	23.4833	113.9333	Information is only available for the largest of these deposits
Gypsum	Lake MacLeod East	33 km southeast of Cape Cuvier and 70 km northwest of Carnarvon	24.2833	113.8000	Deposit No 1 has 0.6 m of gypsum overlain by a thin layer of kopi and soil. Deposit No 2 has 1 m of kopi overlain by soil and underlain by an unknown thickness of crystalline gypsum. Deposit No 3 has 1 m of kopi overlying 2 m of crystalline gypsum
Gypsum	Lake MacLeod	30 km east of Cape Cuvier and 70 km northwest of Carnarvon	24.1667	113.6666	The estimated thickness of the evaporite sequence is 12–15 m and includes predominantly gypsum and halite. Gypsum was reported as granular crystals, and recrystallized and bedded forms. Nearby dunes also contain gypsum and kopi
Gypsum	Cape Peron	Near the northern end of the Peron Peninsula	25.6085	113.4833	Gypsum deposited in a complex depression, which consists of an embayment and several onshore interdunal depressions. Gypsum occurs as rock gypsum and seed (1–5 m thick on birrida surface and 1–3 m in the dunes) and kopi (which varies from 0.3–1.5 m thick)
Gypsum	Bibby Giddy	7 km south of the southern end of Useless Loop	26.3083	113.4417	Bibby Giddy is an irregular-shaped birrida
Gypsum	Lake MacLeod West	12.5 km southeast of Cape Cuvier and 70 km northwest of Carnarvon	24.2500	113.4833	Gypsum occurs near the west shore of Lake MacLeod. It has formed in a large sinkhole about 400 m long, 30 m wide, and 2.4 m deep. It consists of 1 m of consolidated kopi overlying 1.4 m of hard-packed consolidated gypsum
Gypsum	Brown Inlet	6 km northwest of Mount Elliot and 40 km south-southeast of Useless Loop	26.5167	113.5000	Gypsum is located in two northwest-trending birridas

Appendix 1 (continued)

Commodity	*Deposit name*	*Location description*	*Latitude (°S)*	*Longitude (°E)*	*Comments*
Lead		0.6 km northeast of Star of Mangaroon mine; not located	23.8636	115.7478	Not located in field
Lead Copper		5 km west of Mount Genoa	24.4160	116.9339	Not sampled
Lead Copper	Tabletop Well	16 km east-northeast of Gifford Creek Homestead	24.0228	116.3752	Vein. Costean to south — AMG 7342922N, 429787E; 315 m AHD
Lead Copper Gold		0.8 km north of Star of Mangaroon mine; reading at west end of decline	23.8616	115.7440	Quartz vein 0.3 m thick
Lead Copper Silver	Kurabuka Creek	1 km southwest of Deep Well. Coordinates — at adit mouth (232°)	24.0522	116.6849	Also known as Kurabuka and as McCarthy Find. Further veining 60 m south
Lead Copper Zinc		5 km south of Mount Genoa	24.4472	116.9678	Tested by one drillhole — poor results
Lead Vanadium		0.4 km south of Star of Mangaroon mine; reading south end of costean	23.8723	115.7482	No mineralization seen in the field
Lead Zinc	Deep Frederick Well	1.1 km southeast of Deep Frederick Well	24.0796	116.8950	Disseminated and small veinlets in Mn-rich horizons
Lead Zinc	Coria Springs Lead Zinc	5 km south of Yandie Bore. High Range Syncline	23.5331	115.4539	From rock-chip line. Presumed to be minor quartz veining
Manganese		7 km east of Wanna Homestead. Best fit with Landsat	23.9395	116.6256	Sample point and occurrence
Manganese		0.5 km north of Coodardo Well. Best fit with Landsat	23.8156	116.6262	Sample site and occurrence
Manganese		1 km northwest of Pingandy Bore. Best fit with Landsat	23.7906	116.5513	
Platinum Palladium Gold Copper Nickel		Mineralized mafic intrusion 2 km northwest of Star of Mangaroon mine	23.7478	115.6185	Mafic intrusion mineralized at the base. Max Pt 2.2 g/t; Pd 2.1 g/t; Au 0.442 g/t
PGE		Rock-chip sampling from E09/146. No accurate location	23.7719	115.5328	Rock chip sampling with high PGE; no prospect name is provided. Location close to Star of Mangaroon mine

Appendix 1 (continued)

Commodity	*Deposit name*	*Location description*	*Latitude (°S)*	*Longitude (°E)*	*Comments*
REE	Kanes Gossan	28 km north of Gifford Creek Homestead	23.8731	116.2541	Carbonatite intrudes the Tringadee Formation
REE	Gossan–Yangibana	29 km north of Gifford Creek Homestead	23.8616	116.2014	Carbonatite intrudes the Tringadee Formation
REE	Tongue	24 km north of Gifford Creek Homestead	23.9041	116.1512	Carbonatite intrudes the Tringadee Formation
REE	Hook South	29 km north of Gifford Creek Homestead	23.8680	116.2426	Carbonatite intrudes the Tringadee Formation
REE	Frasers–Yangibana	21 km north of Gifford Creek Homestead	23.9525	116.3099	Carbonatite intrudes the Tringadee Formation
REE	Yangibana South	24 km north of Gifford Creek Homestead	23.9107	116.2010	Carbonatite intrudes the Tringadee Formation
REE	Yangibana	25 km north of Gifford Creek Homestead	23.8970	116.1869	Carbonatite intrudes the Tringadee Formation
REE	Hook	29 km north of Gifford Creek Homestead	23.8675	116.2246	Carbonatite intrudes the Tringadee Formation
REE	Yangibana North	30 km north of Gifford Creek Homestead	23.8470	116.1852	Carbonatite intrudes the Tringadee Formation
REE	Lions Ear	29 km north of Gifford Creek Homestead	23.8639	116.2128	Carbonatite intrudes the Tringadee Formation
REE	Bald Hill North and South – Yangibana	26 km north of Gifford Creek Homestead	23.9080	116.2956	Carbonatite intrudes the Tringadee Formation
Silver Copper Zinc		Drillhole collar	24.4132	117.0530	Probably supergene concentration
Silver Copper Zinc		Probably GPS reading	24.4599	117.0438	Drill intersection — centred on fault zone
Silver Copper Zinc		Probably GPS reading	24.4816	117.0621	Drill intersection
Silver Copper Zinc		Probably GPS reading	24.4843	117.0665	Drill intersection
Talc	Mooloo Downs	Approximately 6.5 km east of Mooloo Downs	25.0500	116.0556	Somewhat iron-stained, but is considered to yield good powder
Tantalum		Located at Marloo Well in E09/257	24.6842	115.7996	Columbite–tantalite mineralization in pegmatite

Appendix 1 (continued)

Commodity	*Deposit name*	*Location description*	*Latitude (°S)*	*Longitude (°E)*	*Comments*
Tantalum Beryl REE Bismuth		Located north of Cairn Mining Centre	24.4879	116.0212	Eluvial and alluvial occurrence of columbite, tantalite, and other minerals
Tantalum Niobium		An occurrence of pegmatite bearing Ta, Nb	24.6340	115.7600	Zoned pegmatite bearing tantalite, columbite, uranopyrochlore mineralization
Tantalum REE		Located at Morrissey Hill	24.5343	116.1813	Columbite–tantalite mineralization in pegmatite
Tantalum REE Beryl Niobium		Located at Morrissey Hill	24.5478	116.1872	Columbite–tantalite mineralization in pegmatite
Tantalum REE Mica Niobium		An occurrence of pegmatite bearing Ta, Nb at Wabli Creek	24.8947	116.2673	An occurrence of zoned pegmatite with samarskite, ilmeno-rutile, and columbite mineralization
Tungsten	O'Connor Well	0.8 km north-northwest of O'Connor Well	24.4769	116.4577	
Uranium	Minnie Creek	At 17 Mile Outcamp Bore. Coordinates approximate	24.1048	115.9964	Along Minnie Creek in valleys of tributaries
Uranium		18 km southeast of Mount Phillips Homestead	24.5008	116.4349	Surface mineralization in clay and silt
Uranium		2 km southwest of Howlett Bore	24.4939	116.5243	Ground anomaly 150 cps
Uranium	Kendell Bore Southwest	3.5 km southwest of Kendell Bore	24.4462	116.4475	Dissected valley calcrete; average 100 cps
Uranium	Gifford Creek (U)	7 km north of Gifford Creek Homestead	23.9859	116.2086	Dissected calcrete terrace. Airborne response — 400 cpm; surface — 15 000 cpm
Uranium	Rubberoid Well	8 km east-southeast of Mount James Homestead	24.8848	116.9896	Surface calcrete with secondary U
Uranium		18 km southeast of Mount Phillips Homestead	24.5035	116.4295	Surface mineralization in clay and silt
Uranium		2 km north of Recovery Well	24.7242	117.0499	Small pocket of uraniferous calcrete with gypsum
Uranium	Minindi Creek		24.9194	116.1722	Related to deformation; pre-fracturing
Uranium	Jamieson Well	1 km north of Jamieson Well	24.1299	116.5340	In trunk valley calcrete

Appendix 1 (continued)

Commodity	*Deposit name*	*Location description*	*Latitude (°S)*	*Longitude (°E)*	*Comments*
Uranium	Winmar Creek	3 km northeast of Snowy Well. Approximate coordinates	24.1143	116.0711	Extensive in valleys of tributaries along Winmar Creek
Uranium	Fraser Creek	4 km south of Fraser Well. Approximate coordinates	23.9895	116.2135	Pedimented calcretes 10–15 m above river
Uranium	Centipede Range	10 km west of Cobra Homestead. Drillhole collar	24.1849	116.3798	Hole inclined 55º towards 245º. Depth of intersection is 93 m
Uranium	Kendell Bore	2.5 km northwest of Kendell Bore	24.4088	116.4595	Thin calcrete over granitoid. Airborne radiometric anomaly 40 cpm
Uranium	Spring Creek	13 km northwest of Jamieson Well	24.0686	116.4314	
Uranium		5 km northeast of Kendell Bore	24.3990	116.5217	Ground anomaly 100 cps
Uranium Copper	Two Peaks (U, Cu)	2 km north of Two Peaks Bore. High Range Syncline	23.7670	115.7168	Surface area. No Cu or U minerals noted. Individual shears 2 m wide
Uranium Zinc	Gillie Well		24.6166	116.4500	
Zinc	Reiffel	Pingandy Creek. Drillhole collar coordinates	23.9236	117.5838	Peebeezee horizon with patchy surface ironstone gossans stretches for 41 km. Dimensions of local gossan
Zinc Copper	Hughes	Pingandy Creek. Drillhole collar coordinates	23.9941	117.7103	Peebeezee horizon with patchy surface ironstone gossans stretches for 41 km. Best developed at Hughes
Zinc Copper	Warne Valley	Pingandy Creek. Drillhole collar coordinates	23.9470	117.6261	Peebeezee horizon with patchy surface ironstone gossans stretches for 41 km. Dimensions of local gossan at contact between Jillawarra and Irregully Formations
Zinc Copper	Border	Pingandy Creek. Drillhole collar coordinates	23.8872	117.5076	Peebeezee horizon with patchy surface ironstone gossans stretches for 41 km
Zinc Copper Lead	High Range (Zn)	3 km west of Maroonah Well. High Range Syncline	23.6735	115.5804	Ferruginous quartz veins
Zinc Lead	Hughes Chert	Pingandy Creek. Drillhole collar coordinates	23.9941	117.7103	Restricted mineralization possibly fault controlled

NOTES: PGE Platinum-group elements
REE Rare earth elements
cps counts per second
cpm counts per minute

Appendix 2

Some sources of information on the Gascoyne Region

Further sources of information on legislation, guides to adhering to the legislation, codes of conduct, prospecting, exploring, and available publications include but are not limited to the following:

- Mining Act 1978
- Mining Act 1978: Information Series Pamphlets, Numbers 1–5, 7, 8, 10, and 14–17
- Petroleum Act 1967
- Code of conduct for mineral exploration on Pastoral Leases (pamphlet)
- A code of conduct for the owners of farming properties and persons exploring or mining on private (agricultural) land in the Central Great Southern (pamphlet; September 1999)
- The Series 5 paper: A guide for a better relationship between pastoralists and miners (pamphlet)
- Prospecting in Western Australia (Edition 1, October 1999) — informing people of their initial rights and obligations as they begin prospecting
- DME Fact Sheet 23 — Geology of the North West Cape
- Where will you find your next mineral deposit (GSWA pamphlet)
- Catalogue of geological maps and publications March 1999

Purchases, orders, and enquiries about publications and maps of the Geological Survey of Western Australia should be directed to:

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