REPORT 64

GOVERNMENT OF WESTERN AUSTRALIA

MINERAL OCCURRENCES AND EXPLORATION POTENTIAL OF THE BANGEMALL BASIN

by R. W. Cooper, R. L. Langford, and F. Pirajno

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY

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Cover photograph:
Northernmost of three abandoned shafts located about 150 m north of Rinaldi copper mine (deposit no. 70).

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Mineral occurrences and exploration potential of the Bangemall Basin

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Abstract

The intracontinental Mesoproterozoic Bangemall Basin (c. 1640–1000 Ma) was formed between the Archaean Pilbara and Yilgarn Cratons.

Mineral occurrences in the Bangemall Basin have been classified as diamondiferous kimberlite and lamproite, vein and hydrothermal, stratabound, sedimentary, and residual and supergene. The origin of these mineral occurrences can be related to episodes of igneous activity and basin dynamics.

The Bangemall Basin has seen limited production of gold, base metals, and gems since the first mineral discoveries were made in 1896. A minor gold resource at Hibernian, in the Egerton Mining Centre, and a minor copper resource at Ilgarari Mine have been outlined for possible future development. The Abra deposit, discovered in 1981 in the Jillawarra Sub-basin, is a very large (>200 Mt) epigenetic and stratabound polymetallic deposit, but is of a grade and depth that currently makes it uneconomic. Deposits and occurrences of low-grade manganese, uranium, talc, and asbestos are also present in the area.

This Report, Plate, and GIS dataset describe the geology and 150 mineral occurrences from within the main Bangemall Group outcrop area. The geology and a further 140 mineral occurrences, which fall outside the Bangemall Group outcrop, are included on Plate 1 but not described in the text. These occurrences, viewed in the broader geological and structural context, point to a significant potential for mineral discoveries. In particular, the controls of mineralization indicate that the greatest potential is for mineral discoveries of Mesoproterozoic iron-oxide (polymetallic) deposits that have formed in extensional tectonic environments.

KEYWORDS: Mineral exploration, mining, mineral deposits, mineral occurrences, Bangemall Basin, Jillawarra Sub-basin, Abra, Mesoproterozoic, base metals, gold, iron oxide, barite, manganese, uranium.

Introduction

Present study

This study aims to enhance and promote the mineral prospectivity of the Mesoproterozoic Bangemall Basin in the Mid-West Region of Western Australia (Fig. 1). The expected outcome is increased mineral industry interest in, and awareness of, the prospectivity of the basin.

The summary of the geology of the Bangemall Basin included in this study provides the lithological, stratigraphic, and tectonic context for assessing the controls on mineralization and the individual mineral occurrences. Details of the mineralization are based on mineral data extracted from published and unpublished sources, and selectively enhanced through field verification. Open-file data extracted from the Western Australian Mineral Exploration Index (WAMEX) form a large part of the study, and also contribute to the description of mineral exploration and development trends.

Although the bulk of the area is underlain by the Bangemall Basin, a seamless mapping approach has been adopted, using standard 1:250 000, 1:100 000, and 1:50 000 sheet boundaries. As a consequence, the area also includes older geological units marginal to the basin, and excludes small parts of the basin, particularly in the east (Plate 1). The description of mineral occurrences in the Report is restricted to those that fall within the Bangemall Basin, including the older basement inliers. However, for the sake of completeness, mineral occurrences both inside and outside the Bangemall Basin

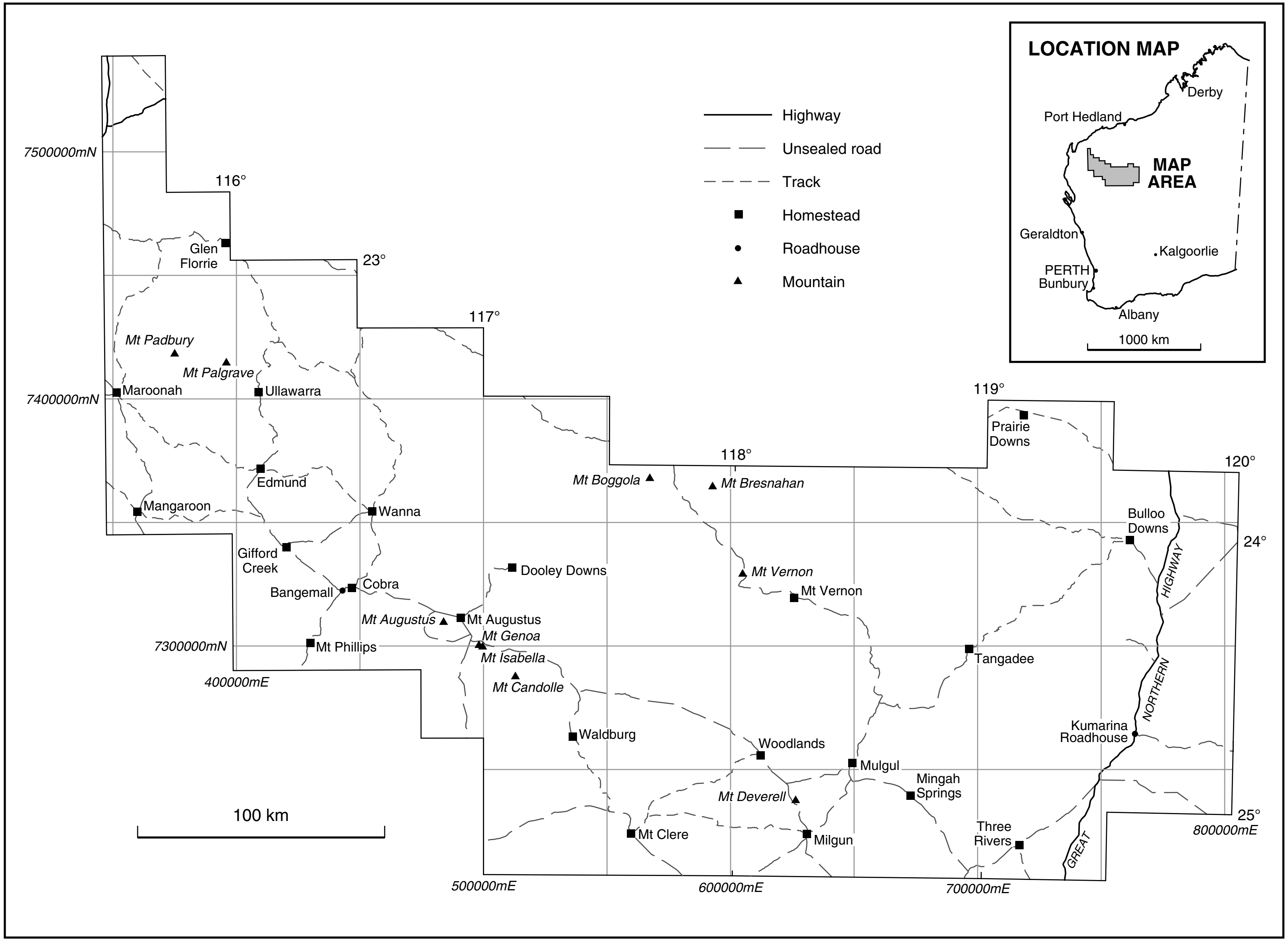

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Figure 1. Principal locality names, major roads, and tracks

have been detailed on Plate 1 and the accompanying CD-ROM.

Appendix 1 defines the terms used in the Geological Survey of Western Australia (GSWA) mineral occurrence database (WAMIN) and Appendix 2 gives a description of the digital datasets. The CD–ROM includes all the data used to compile the map and Report, and also includes files of geophysical, remote-sensing, and topographic data. The CD–ROM contains the files necessary for viewing the data in the ArcView GIS environment and a self-loading version of the ArcExplorer software package modified to suit this particular dataset. Metadata statements on the geological, geophysical, and topographic datasets are also provided.

Location, physiography, and access

The western part of the Bangemall Basin covered by this study is a westerly to northwesterly trending arcuate belt that is up to 500 km long and 160 km wide. The belt lies between longitudes 115°30'E and 120°00'E, and latitudes 22°15'S and 25°15'S (Plate 1). Most of the Bangemall Basin lies more than 500 m above sea level, and is physiographically dominated by a series of strongly dissected ranges separated by wide slopes and plains along major drainage lines. The highest point in the area is Mount Augustus (1106 m Australian Height Datum). The basin is flanked to the north by the Ashburton River and its southern tributaries, and to the south by the Gascoyne River and its northern tributaries, most notably the Lyons River; all rivers flow west towards the Indian Ocean.

The area is bounded to the west by the North West Coastal Highway and to the east by the Great Northern Highway. These highways are sealed all-weather roads, and are linked by graded shire roads and station tracks that skirt the main ranges on the periphery of the Bangemall Basin (Fig. 1). Access within station areas is by tracks connecting bores and along fence lines, but is severely limited in the central upland ranges. Roads and tracks, other than the sealed highways, are often impassable during and after heavy rains, and may be closed for weeks at a time.

Most of the area is held as Pastoral Leases, with small areas of National Park, reserve, and vacant Crown Land. Standard guidelines have been developed to cover mineral exploration and mining activities in the different types of conservation reserves, proposed conservation reserves, National Parks, and other environmentally sensitive areas. These guidelines have been published by the Department of Minerals and Energy (DME, 1995). DME (1994) deals specifically with prospecting, exploration, and mining on Pastoral Leases.

All new tenements and exploration-licence renewals are subject to the legislation and procedures of the Commonwealth Native Title Act 1993, except where it is determined that the applications are over land where native title has been extinguished.

Previous work

The rocks of the Bangemall Basin were first described by Woodward (1890); this work was later refined by Maitland (1909). Daniels (1975) first used the term Bangemall Basin to describe the depositional basin of the Bangemall Group. Subsequent detailed studies of the area include Muhling and Brakel (1985), Chuck (1984), and Vogt (1995).

Systematic 1:250 000 geological mapping by GSWA commenced in 1965 on EDMUND* and WYLOO, and was completed in 1991 for the nine 1:250 000 sheets and Explanatory Notes covering the study area. These are: COLLIER (Brakel et al., 1982), EDMUND (Daniels, 1969), MOUNT EGERTON (Muhling et al., 1978), MOUNT PHILLIPS (Williams et al., 1983), NEWMAN (Tyler et al., 1989), PEAK HILL (MacLeod, 1970; Gee, 1987), ROBINSON RANGE (Elias and Williams, 1980), TUREE CREEK (Daniels, 1968; Thorne et al., 1991), and WYLOO (Daniels, 1970; Seymour et al., 1988). Sheet locations are shown on Plate 1.

Regional 1:100 000 geological mapping has been completed for some adjoining areas of the Bryah Basin to the south (Swager and Myers, in prep.), and mapping commenced in 1997 on EDMUND as part of the Bangemall Basin Project, and in the Southern Gascoyne region. Regolith mapping and sampling of most of the 1:250 000 sheets covering the Bangemall Basin has been completed. These are: MOUNT PHILLIPS (Sanders et al., 1997), ROBINSON RANGE (Bradley and Faulkner, 1997), MOUNT EGERTON (Morris et al., 1998), PEAK HILL (Subramanya et al., 1995), TUREE CREEK (Coker et al., 1998), and EDMUND (Pye et al., 1998).

Mineralization and mapping studies that have covered aspects of the Bangemall Basin include Davy (1980), Chuck (1984), Muhling and Brakel (1985), and Vogt (1995). There are several studies covering the whole of Western Australia that include details of the mineralization of the Bangemall Basin, notably that of Simpson (1948, 1951, 1952). The commodity-specific studies cover lead–zinc–silver (Blockley, 1971; Ferguson, in prep.), copper (Marston, 1979), gold (Maitland, 1919), and uranium (Butt et al., 1977; Carter, 1981).

Regional geology

Geological setting

The Mesoproterozoic Bangemall Basin, located between the Yilgarn and Pilbara Cratons, overlies the tectonic units of the Palaeoproterozoic Capricorn Orogen (such as the Gascoyne Complex; Plate 1). It is contentious whether or not the Bangemall Basin is part of the Capricorn Orogen. Its younger age (1.64–1.0 Ga; Williams, 1990) suggests that it may be an intracratonic basin developed during extensional movements on an already cratonized Capricorn orogenic zone that was formed during

* Capitalized names refer to standard map sheets. Where sheet names are duplicated at different scales, the name refers to the 1:250 000 map unless specified.

continental collision between the Pilbara and Yilgarn Cratons (Tyler and Thorne, 1990). The basin unconformably overlies the Ashburton and Bresnahan Basins on its northern boundary, the Gascoyne Complex to the west and southwest, and the Bryah, Padbury, and Earaheedy Basins to the south and southeast. To the east, units of the Greater Officer Basin unconformably overlie the Bangemall Basin.

The initial structure was probably a broad basin in which a succession of stromatolitic dolomite, chert, sandstone, and mudstone was deposited in lagoonal to shallow-marine environments (Edmund Subgroup; Muhling et al., 1985). This was followed by deposition, in deeper waters, of clastic sediments including black shale, mudstone, and siltstone. The upper part of the Bangemall succession (Collier Subgroup) contains shale and siltstone, intercalated with carbonate, glauconitic sandstone, turbiditic rocks, conglomerate, and chert. Sedimentation was probably controlled by pre-existing basement structures, some of which were reactivated during the infilling of the basin. Numerous dolerite sills of tholeiitic composition intruded the Edmund and Collier Subgroups. These sills are most abundant in the western facies domain, to the northwest and southeast, and their distribution suggests a three-armed rift zone (Muhling and Brakel, 1985). The dolerite sills indicate the presence of a major tholeiite province suggesting that magmatism took place during a second extensional episode, which could have resulted from major subcrustal underplating of mantle asthenosphere (Vogt, 1995).

The age of the Bangemall Basin is poorly constrained. Two U–Pb sensitive high-resolution ion-microprobe (SHRIMP) ages of 1638 ± 14 Ma for the Tangadee Rhyolite (Tringadee Formation) and 1797 ± 8 Ma for granodiorite in the Coobarra Dome have been determined (Nelson, 1995). Based on these ages it is inferred that the western part of the basin began to develop at approximately 1.64 Ga. The U–Pb zircon age of 1.64 Ga for felsic volcanic rocks (see below) in the lower part of the basin's succession provides a time constraint for initial rifting. According to Collins and McDonald (1994) and Vogt (1995), the rifting took place in the central part of the basin and along the northern margin of the Gascoyne Complex (Tyler et al., 1998).

Geology and structure

The name Bangemall Basin was first used by Daniels (1975) to refer to the depositional basin of the Bangemall Group, a thick sequence of mainly clastic sedimentary rocks. The extent of the Bangemall Basin, and the stratigraphic nomenclature of the Bangemall Group, was revised by Williams (1990). This revision was based on the remapping of BALFOUR DOWNS (Williams, 1989), ROBERTSON (Williams and Tyler, 1991), and NEWMAN (Tyler et al., 1989).

The principal facies domains of the Bangemall Basin are shown in Figure 2. Muhling and Brakel (1985) originally subdivided the basin into three facies domains. These are a northern facies zone (Pingandy Shelf), comprising the Top Camp Formation and Mucalana Subgroup; a western facies domain containing the Edmund Subgroup (Edmund Fold Belt); and an eastern facies domain comprising the Collier, Manganese, Kahrban, and Diebil Subgroups. Williams (1990) subsequently modified this subdivision into two distinct domains of different ages: an approximately 1.6 to less than 1.2 Ga western domain including the Edmund Subgroup (and the Scorpion Subgroup in the east), and the approximately 1.2–1.0 Ga eastern domain, which includes the Mucalana, Collier, Manganese, and Kahrban Subgroups, and Cornelia Sandstone (compare figures 4-13 and 4-14, Williams, 1990).

The western facies is dominated by complex interfingering of shale, sandstone, carbonate, and conglomerate units. The eastern facies contains continuous units of sandstone and shale. Rocks of the western facies constitute the Edmund Fold Belt and have undergone the most deformation, including crustal shortening and fault reactivation, giving a distinctive, basin-parallel, steep-plunging, open to tight fold pattern (Muhling and Brakel, 1985). The Bullen Platform and Pingandy Shelf are relatively undeformed areas.

The major structural elements of the Bangemall Basin are shown in Figure 3. Three major lineaments or fault systems are present. Two northeasterly trending structures are the Flint Hill and Tangadee Lineaments. These appear to be truncated by an arcuate, approximately easterly trending fault, which delimits the southern margin of the Pingandy Shelf. These structural features and associated deformation are probably controlled by the pre-existing underlying basement structures. Southeasterly and east-northeasterly trending block faulting (horst and graben structures) have been postulated to characterize the basement structure, the erosion of which produced the clastic units of the Tringadee Formation. An economically important horst-and-graben structural element is the easterly trending Jillawarra Sub-basin, about 65 km long, situated in the central part of the basin between the Tangadee and Flint Hill Lineaments (Fig. 3). Vogt (1995) first described the Jillawarra Sub-basin in detail.

Vogt and Stumpfl (1987) suggested that the Jillawarra Sub-basin represents an initial zone of rifting in the development of the Bangemall Basin. The Abra sediment-hosted lead–copper–silver–barite deposit discovered in 1981 (Vogt and Stumpfl, 1987) is located in the Jillawarra Sub-basin, which is discussed below under **Mineralization**.

Basement inliers

There are five inliers of older basement rocks within the Bangemall Group; the Egerton Inlier, the Woodlands Dome, the Coobarra Dome, and two unnamed granitic inliers (Fig. 3; Plate 1). These inliers are crystalline rocks of the Capricorn Orogen and are assigned to the Gascoyne Complex (Muhling and Brakel, 1985). The granitic inliers, which include the Woodlands and

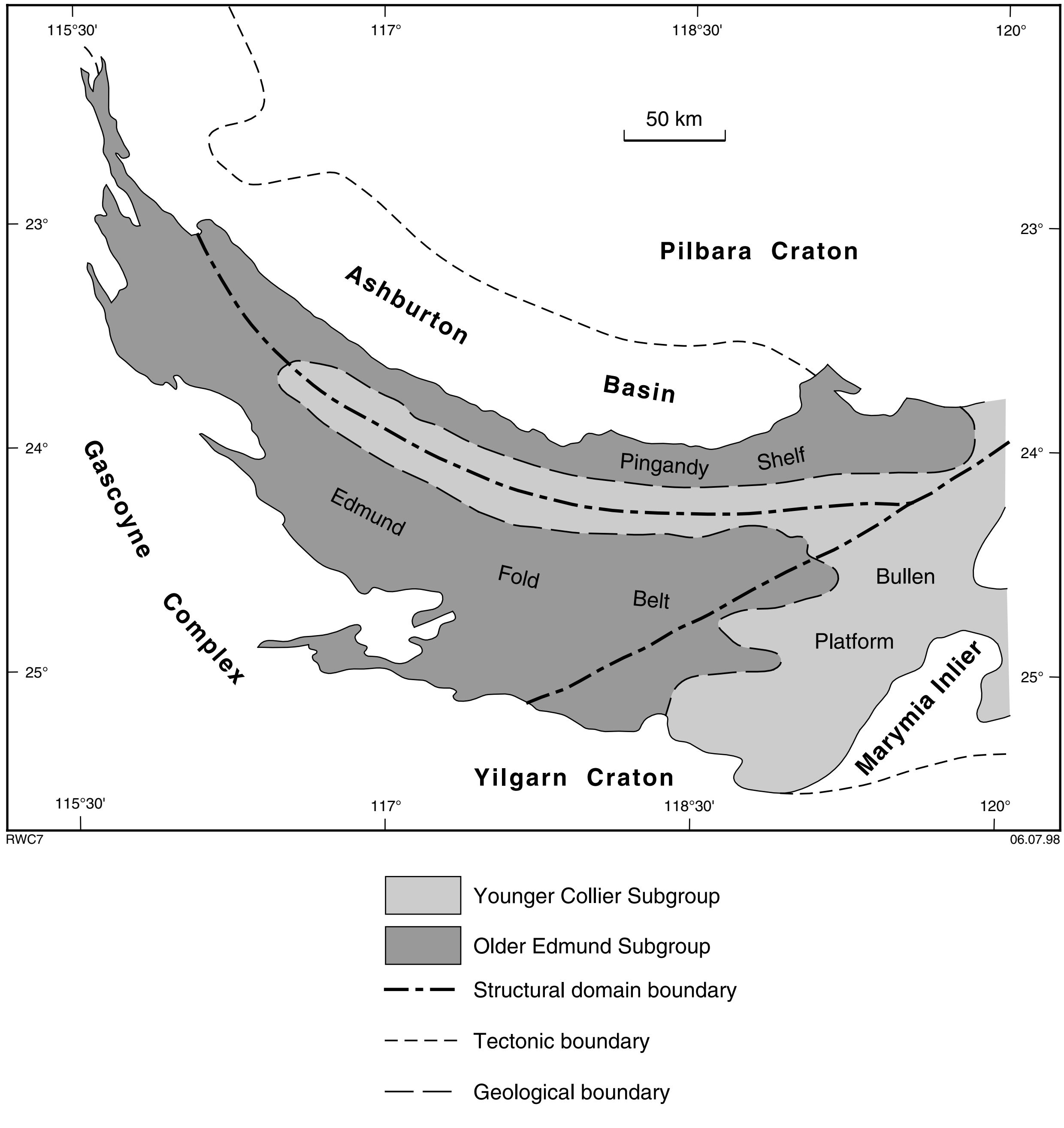

Figure 2. Structural and facies domains of the Bangemall Basin (after Williams, 1990)

Coobarra Domes, are aligned along the Tangadee Lineament. A drillhole on the southwestern margin of the Coobarra Dome located at the Cadabra Prospect intersected a granodiorite that gave a SHRIMP U–Pb zircon age of 1797 ± 8 Ma (Nelson, 1995). These inliers are briefly discussed below.

Egerton Inlier

The name Egerton Inlier (*Els*) was established by Muhling and Brakel (1985) to describe the basement metasedimentary rocks at the core of the easterly trending Hibernian Anticline. The inlier contains quartz–muscovite–biotite schist, with interbedded wacke, sandstone, and shale. Other rock types include calc-silicate schist, schistose amphibolite, and quartzite. Chemical sedimentary rocks, including sulfide-bearing chert, banded iron-formation, and pyritic siltstone are locally present around the Egerton Mining Centre. The metasedimentary rocks are intruded by an east-northeasterly trending gabbro body, which locally hosts gold mineralization along its sheared contact with the country rocks (see below).

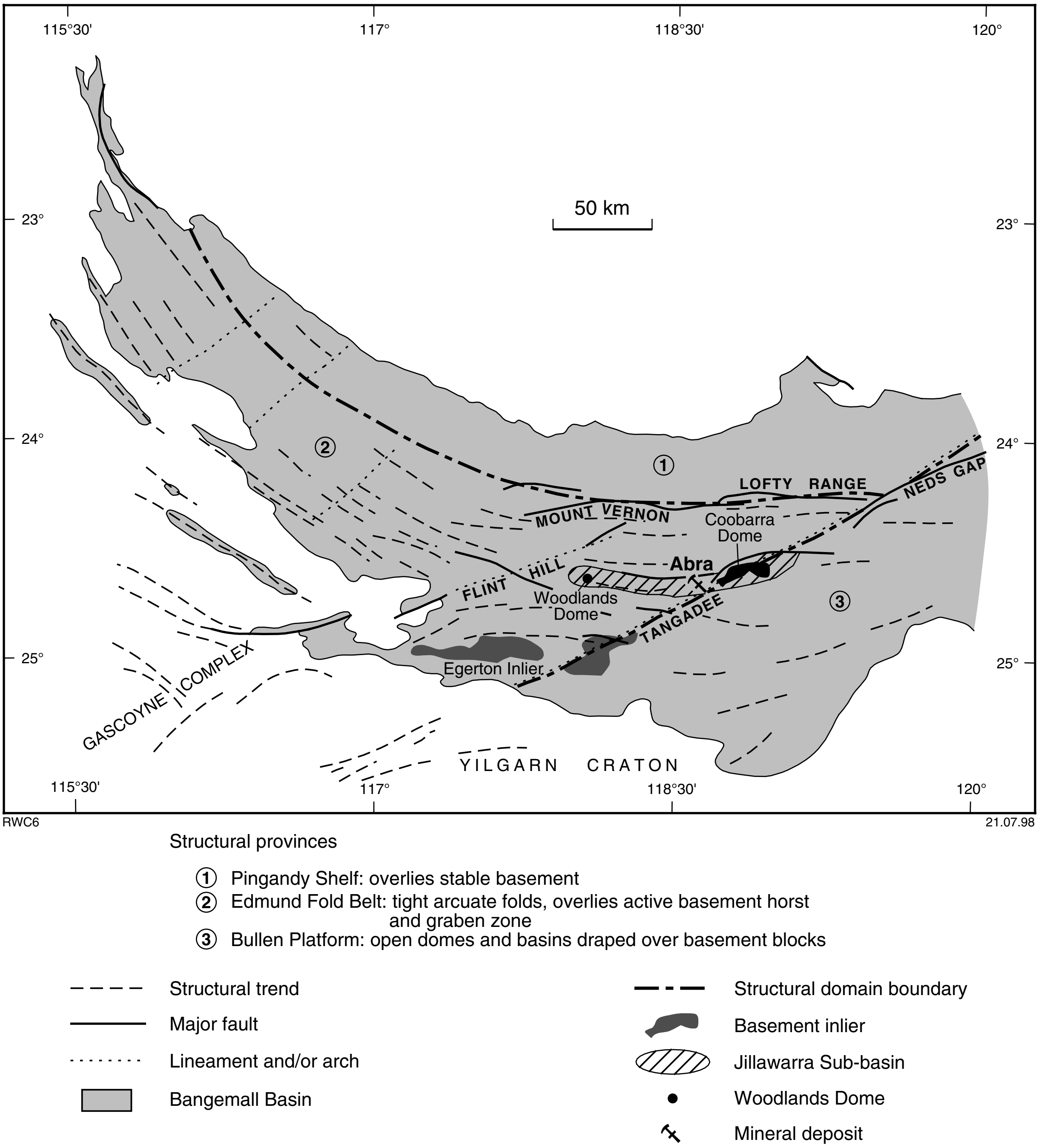

Figure 3. Major structures, lineaments, and structural domains in the western and central Bangemall Basin (modified from Chuck, 1984)

Woodlands Dome

The Woodlands Dome (Australian Map Grid (AMG) 610400 mE 7272150 mN) is located 26 km north of Woodlands Homestead (Vogt, 1995). The dome is exposed in a narrow creek as a small outcrop measuring 200 m long by 5 m wide, which is too small to show on Plate 1. The inlier consists of deeply weathered schist intruded by pegmatite veins. The dome is overlain by immature quartz–muscovite sandstone (now part of the Tringadee Formation).

Coobarra Dome

The Coobarra Dome (*Pg*) is elongate, and inferred to extend for about 25 km in an east-northeasterly direction. The dome predominantly consists of granitoid rocks that are deeply weathered (Vogt, 1995). Quartz–tourmaline veins, pegmatite, and sporadic fluorite veins are present (Vogt, 1995; no locations are given for the fluorite veins). In the non-exposed western part of the dome, aeromagnetic surveys have shown marked anomalies, trending east-northeasterly, that are interpreted as

Table 1. Stratigraphy of the Bangemall Basin in the study area (Plate 1)

Formation *Member*	*Code*	*Thickness (m)*	*Lithologies*
Collier Subgroup	*ⱣMC*		
Ilgarari Formation	*ⱣMCz*	>650	Siltstone, mudstone, and fine-grained sandstone; includes units previously mapped as Kurabuka Formation
Calyie Sandstone	*ⱣMCy*	300 – 1 220	Quartz sandstone, siltstone, mudstone, conglomerate, and dolostone; includes units previously mapped as Mount Vernon Sandstone and Stag Arrow Formation
Backdoor Formation	*ⱣMCb*	~3 700	Mudstone and siltstone; minor chert, dolostone, and sandstone; includes units previously mapped as Fords Creek Shale
Wonyulgunna Sandstone	*ⱣMCw*	~800	Quartz sandstone and minor cobble-conglomerate, siltstone, mudstone, and chert; includes units previously mapped as the Jeeaila Sandstone Member of Fords Creek Shale
Edmund Subgroup	*ⱣME*		
Coodardoo Formation	*ⱣMEc*	370	Sandstone; minor siltstone and mudstone
Ullawarra Formation	*ⱣMEl*	1 500 – 2 500	Mudstone and siltstone, minor fine-grained sandstone, dolostone, and chert; intruded by kimberlitic dykes
Devil Creek Formation	*ⱣMEv*	30 – 800	Dolostone and mudstone; minor siltstone, fine-grained sandstone, conglomerate, and chert; intruded by kimberlitic dykes
Discovery Chert	*ⱣMEd*	50 – 80	Massive and laminated chert, mudstone, and siltstone
Jillawarra Formation	*ⱣMEj*	60 – 1 020	Mudstone, siltstone, chert, dolostone, and sandstone; intruded by kimberlitic and lamproitic dykes; includes the Glen Ross Shale Member and units previously mapped as the Prospect Shale
Kiangi Creek Formation	*ⱣMEk*	700 – 2 000	Quartz sandstone, siltstone, and mudstone; minor dolostone, chert, and conglomerate; includes West Creek Formation of the Jillawarra area
Cheyne Springs Formation	*ⱣMEp*	200 – 700	Dololutite, dolarenite, and dolorudite; minor mudstone, siltstone, and sandstone
Irregully Formation	*ⱣMEi*	1 500	Stromatolitic and non-stromatolitic dolostone, mudstone, siltstone, and sandstone; minor chert and conglomerate; includes upper Gap Well Formation
Gooragoora Sandstone Member	*ⱣMEid*	10 – 250	Medium- to coarse-grained sandstone; minor conglomerate, mudstone, and siltstone; pyritic
Tringadee Formation	*ⱣMEe*	1 100	Coarse-grained sandstone, conglomerate, arkose, and minor siltstone; includes Coobarra Formation and the basal Gap Well Formation; Coobarra Formation includes plugs and flows of Tangadee Rhyolite
Tangadee Rhyolite	*ⱣMEet*		Rhyolite plugs and flows

basement features. In 1977, percussion drilling of one of the anomalies intersected dolerite or gabbro (I. Ruddock, 1998, pers. comm.).

Unnamed granitic inliers

A granitic body (*Ᵽg*) located 16 km south of Waldburg Homestead (Muhling et al., 1978) extends for approximately 8 km in an east-northeasterly direction. This granite inlier was described by Muhling et al. (1978) as even-grained or porphyritic adamellite and granite, with biotite, muscovite, and tourmaline.

Another granitic inlier is located 10 km to the west of Mount Deverell, and its extent (about 20 km) is inferred on the basis of aeromagnetic data (Swager and Myers, in prep.). These authors interpreted this granite as uplifted Archaean or Palaeoproterozoic basement. They interpreted the granite as Archaean (Narryer Terrane) in age, but in this study the inlier is provisionally assigned to the Gascoyne Complex.

Stratigraphy

The Bangemall Basin stratigraphy defined in this study is modified after Williams (1990). In this Report, discussion of the stratigraphy is confined to the area of Plate 1 and summarized in Table 1. Published geochronological data, together with the conclusions drawn from GSWA regional mapping in the 1980s (Williams, 1990), reinforce the growing evidence for a two-fold subdivision of the Bangemall Group. These are the older (1.6–1.2 Ga) Edmund Subgroup in the west, and the younger (1.2–1.0 Ga) Collier Subgroup in the east (Fig. 2). Previously, the stratigraphy of the entire Bangemall Basin included the Mucalana, Kahrban, Diebil, and Manganese Subgroups. The Mucalana Subgroup is now incorporated in the Collier Subgroup, whereas the Kahrban, Diebil, and

Manganese Subgroups are in the eastern part of the Bangemall Basin and are not discussed in this Report.

Edmund Subgroup

The basal units of the Edmund Subgroup (*ᵽME*) rest unconformably on the Gascoyne Complex, Ashburton Basin, and Bresnahan Basin (which now includes the Mount Augustus Sandstone, formerly assigned to the Bangemall Group). The Edmund Subgroup comprises nine formations with a maximum thickness of approximately 10 000 m (see Table 1 for individual thicknesses). The formations of the Edmund Subgroup are briefly discussed below from oldest to youngest.

The Tringadee Formation (*ᵽMEe*) outcrops around the Coobarra Dome and sporadically along the southern margin of the Bangemall Basin, where it is unconformable on rocks of the Gascoyne Complex (Plate 1). In this Report, the former Coobarra and basal Gap Well Formations, which unconformably overlie sheared granitoid rocks of the Coobarra Dome (Boddington, 1987; Vogt and Stumpfl, 1987; Vogt, 1995), are included in the Tringadee Formation on the basis of the recent isotopic age obtained for the Tangadee Rhyolite. The Tringadee Formation is characterized by a succession of clastic rocks, including a basal coarse-grained sandstone and conglomerate (Table 1). The formation also includes plugs and flows of the Tangadee Rhyolite (*ᵽMEet*), which is discussed more fully below in the section on **Igneous rocks**. SHRIMP U–Pb zircon dating (Nelson, 1995) of the Tangadee Rhyolite suggests a maximum age for emplacement of 1638 ± 14 Ma. The Tringadee Formation is overlain to the east by the Backdoor Formation (*ᵽMCb*) of the Collier Subgroup. In the west it is conformably overlain by the Irregully Formation (*ᵽMEi*).

The largely dolomitic Irregully Formation (*ᵽMEi*) outcrops along the western and northern margins of the basin and, where the Tringadee Formation is absent, is unconformable on the older basement (Plate 1). An important feature of the Irregully Formation is the presence of stromatolitic dolostone, in which a new stromatolite form was discovered (*Colonella*; Grey, 1985). Outcrops along the northern margin of the Bangemall Basin include the arenaceous Gooragoora Sandstone Member (*ᵽMEid*; Chuck, 1984), now assigned to the Irregully Formation (Plate 1). The relationship of the Irregully Formation with the overlying Kiangi Creek and Jillawarra Formations (*ᵽMEk* and *ᵽMEj*) is complex, but in a vertical profile it appears that they laterally interfinger (Williams, 1990).

Rocks of the Irregully and Kiangi Creek Formations extend into the Jillawarra Sub-basin, although Vogt (1995) proposed that the rocks of the Jillawarra Sub-basin be renamed the Gap Well and West Creek Formations. This proposal is not accepted in this work and the Jillawarra Sub-basin rocks are included in the Tringadee, Irregully, and Kiangi Creek Formations (Table 1).

The Irregully Formation is overlain by the widespread Cheyne Springs Formation (*ᵽMEp*), which contains dolomitic rocks, mudstone, siltstone, and sandstone.

The predominantly clastic Kiangi Creek Formation is well developed in the southern, western, and central parts of the Edmund Fold Belt, but only poorly developed along the northern margins.

The Jillawarra Formation is a widespread succession, thickest in the southern part of the basin, that interfingers with the adjacent Kiangi Creek Formation (Williams, 1990). The formation includes clastic and calcareous rocks, the Glen Ross Shale Member, and units previously mapped as the Prospect Shale.

The Discovery Chert (*ᵽMEd*) is a widespread and persistent key marker horizon in the western part of the Bangemall Group with a total outcrop area of about 3800 km^2 (Plate 1). This rock is a massive, laminated, or fissile chert, with subordinate shale. Porous bands, representing weathered pyrite layers, and possible gypsum moulds and pseudomorphs are present at some localities. The Discovery Chert is considered to be a chemical precipitate (Muhling and Brakel, 1985), perhaps of evaporitic origin.

Conformably overlying the Discovery Chert is the Devil Creek Formation (*ᵽMEv*). This unit contains dolostone–lutite rocks, but is not developed everywhere. Shale and siltstone of the overlying Ullawarra Formation (*ᵽMEl*) may rest directly on the Discovery Chert.

The Devil Creek Formation is conformably overlain by the Ullawarra Formation (*ᵽMEl*), a thick shale–siltstone succession. The true thickness (1500–2500 m; Table 1) of the Ullawarra Formation is difficult to estimate because of the intrusion of numerous dolerite sills.

The Coodardoo Formation (*ᵽMEc*) conformably overlies the Ullawarra Formation and consists of sandstone, with minor siltstone and mudstone.

Collier Subgroup

The Collier Subgroup (*ᵽMc*) is younger than the Edmund Subgroup (Table 1), with which it has an apparently conformable relationship in the west and unconformable relationships in the northern and eastern parts of the basin. The Collier Subgroup incorporates the former Mucalana Subgroup. In the south, rocks of the subgroup are unconformable on, or faulted against, the Marymia Inlier, the Earaheedy Group, and the Troy Creek Beds. In the north, they are unconformable on the Sylvania Inlier. In the east, the rocks of the Greater Officer Basin unconformably overlie the Collier Subgroup. The estimated total maximum thickness of the subgroup is 6400 m (see Table 1 for individual thicknesses).

The Wonyulgunna Sandstone (*ᵽMCw*), which includes minor cobble conglomerate, outcrops in the southern part of the Bangemall Basin, and lies unconformably on the Marymia Inlier and Earaheedy Group. The sandstone is conformably overlain by the Backdoor Formation.

The Backdoor Formation (*ᵽMCb*), predominantly containing clastic and calcareous rocks, is unconformable on the Tringadee Formation and conformable on the

Wonyulgunna Sandstone. The western extent of the Backdoor Formation appears to coincide with the northeasterly trending Tangadee Lineament (Muhling and Brakel, 1985). The formation has been correlated with the Fords Creek Shale (Table 1). The Backdoor Formation wedges out against the Sylvania Inlier in the north, where it is overlapped conformably by Calyie Sandstone.

The Calyie Sandstone (*ⱣMCy*) is correlated with, and incorporates, the Mount Vernon Sandstone and Stag Arrow Formation. The unit contains sandstone, conglomerate, and dolostone.

The Ilgarari Formation (*ⱣMCz*) rests conformably on the Calyie Sandstone. The formation includes units previously mapped as the Kurabuka Formation and predominantly consists of siltstone and mudstone.

Igneous rocks

The suites of igneous rocks in the Bangemall Basin are characteristic of those found in continental rift-zone settings. Typically, this magmatism includes a pre–synrifting episode of alkaline affinity and a late to postrifting episode of voluminous tholeiitic (subalkaline) activity. In the Bangemall Basin, the former includes the 1.64 Ga, high-K Tangadee Rhyolite and the carbonatitic members of the 1.68 Ga Gifford Creek complex (Pearson et al., 1996). Also present in the Bangemall Basin are kimberlitic and lamproitic dykes; their age is not known, but they may be part of this alkaline igneous suite. Pearson (1996) has studied the alkaline rocks of the Gifford Creek complex. Information on kimberlitic rocks is derived from WAMEX company reports. Outcrops of the kimberlitic rocks are too small to be represented on Plate 1. Early rift-related alkaline rocks are volumetrically minor, but it is considered possible that this early igneous episode may have been more widespread than currently realised, owing to the difficulty of recognizing these rocks in the field. Collins and McDonald (1994) have suggested that the polymetallic Abra mineralization may be linked with this alkaline magmatism.

The second igneous episode is represented by a voluminous suite of fissure-fed dolerite intrusions of tholeiitic composition. Muhling and Brakel (1985), and Vogt (1995) describe the mafic and felsic volcanic rocks of the Bangemall Basin.

Alkaline igneous rocks

Pearson et al. (1996) recently identified a suite of high-level alkaline intrusions (Gifford Creek complex) on the northeastern margin of the Gascoyne Complex, close to and astride the contact with rocks of the Bangemall Group. The Yangibana Carbonatites of the Gifford Creek complex are 20 km north of Gifford Creek Homestead and are shown on Plate 1 as carbonatite rare-earth element (REE) deposits. REE resources were outlined in 1988 for the larger bodies, which have all been intruded into Gascoyne Complex basement rocks (Pooley, 1988). Pearson et al. (1996) recognized two phases of intrusion in the Gifford Creek complex: ultrabasic intrusions, which were emplaced at 1679 ± 6 Ma, prior to the deposition of the Bangemall Group, and intrusions of carbonatitic affinity, which were emplaced during a later period of extension of the basin. Pearson (1996) details the geology, petrology, and geochemistry of these rocks. For the purpose of the present work, it is important to note that some of the Gifford Creek complex alkaline rocks intrude the basal sedimentary layers of the Bangemall Group (Bald Hill intrusion). These rocks consist of weathered limonitic material, forming narrow sills and dykes. Mineral phases include limonite, silica, rutile, and secondary phosphate minerals, typically associated with weathered carbonatites (Pearson et al., 1996).

The Tangadee Rhyolite (*ⱣMEet*; Plate 1) was emplaced in the Tringadee Formation, overlying the Coobarra Dome. No associated volcaniclastic rocks have been noted, except for a small outcrop of lapilli tuff reported by Vogt (1995). In addition, three pipe-like bodies consisting of black silica- and chlorite-rich rock are intrusive into the Coobarra granitic basement and were interpreted by Vogt (1995) as possible volcanic vents. The rhyolite consists of euhedral quartz and feldspar phenocrysts in a cryptocrystalline groundmass of quartz and microcline, with accessory biotite, chlorite, zircon, and opaque minerals (Muhling and Brakel, 1985). The rocks contain disseminated pyrite and flow banding. The age of the Tangadee Rhyolite has been discussed above. The chemistry of the Tangadee Rhyolite is poorly known. Four analyses provided by Vogt (1995) reveal a composition characterized by high K_2O (up to 10.45 wt%) and low Na_2O (up to 0.55 wt%). The lapilli tuff has a high Ba content (2950–3356 ppm).

Minor outcrops of possible alkaline felsic lava and tuff have been reported in a number of areas, such as the Mount Palgrave, Cobra, Kurabuka, Peedawarra, Isabella, Candolle, and Mount Vernon Synclines (Muhling and Brakel, 1985). Of these, however, only two have been confirmed in the Tangadee area, namely: high-K_2O rocks, about 12 km northwest of Tangadee Homestead, and some carbonate-rich rocks containing high Ce, Cu, La, Ni, Pb, Rb, and Sc. Muhling and Brakel (1995) interpreted the latter as a metamorphosed dolomitic rock, but, based on their chemistry and spatial association with K-rich rocks, it is possible that this rock is a carbonatite.

None of these occurrences have been rigorously studied, and the available information is scanty at best. Current regional mapping by GSWA may resolve this.

Kimberlite and lamproite

Exploration by Ashton Mining in 1988–93 outlined a number of north-northeasterly trending lamproitic dykes, known as the Eerstelling Lamproites (Rohde, 1993). These dykes outcrop about 17 km southwest of Ullawarra Homestead, and intrude siltstone and quartzite of the Jillawarra Formation. There are four mapped dykes less than 5 m wide and 10–300 m long, with others inferred by the presence of 'lampro-siltstone' and 'lampro-tuff' float (Rohde, 1993). Microdiamonds have been recovered from streams draining these bodies, but they are considered to be of no economic potential.

A thin kimberlitic dyke exposed 7 km to the southwest of Mount Padbury intrudes the Devil Creek Formation and possibly the underlying Discovery Chert (Duncan, 1993).

Thin dykes and stringers of probable kimberlitic affinity, locally associated with shear zones, intrude dolerite dykes in the Ullawarra Formation. These younger dykes have been exposed in trenches located 2 km southwest of Ullawarra Homestead.

Mafic rocks

The dolerite sills (*Ed*) in the entire Bangemall Basin cover about 143 000 km^2, therefore forming one of the larger continental tholeiite provinces of the world (Muhling and Brakel, 1985). Apart from a little information provided by Muhling and Brakel (1985), virtually no work has been carried out to ascertain the nature, composition, and significance of these sills in terms of magmatic and tectonic evolution of the basin. The sills commonly exceed 100 m in thickness with a maximum length of 60 km; they are generally concordant, but locally cross-cut bedding, in zones that vary from less than one metre to hundreds of metres in length. The regional distribution of the sills is shown on Plate 1 and is further described in Muhling and Brakel (1985, figure 89).

The region west of the Tangadee Lineament (the Edmund Fold Belt) is the area of the largest concentration of sills, which also correlates broadly with the area of more intense deformation. Dolerite contains plagioclase, clino- and orthopyroxenes, and magnetite, locally with interstitial granophyric intergrowths (quartz and feldspar), and pyrite (rarely up to 5% by volume). Olivine is rare. Alteration minerals, where present, include biotite, sericite, hornblende, clinozoisite, and chlorite. Limited chemical data (Muhling and Brakel, 1985) indicate that the Bangemall dolerite has a uniform composition, which compares well with continental tholeiites, being characterized by high K_2O and incompatible elements (Pb, Rb, Th, and U). Of particular interest is the high Ba content (180–1000 ppm) compared to other continental tholeiitic rocks (e.g., Karroo region; Muhling and Brakel, 1985, table 28).

Dolerite dykes (*d*) of similar composition to the sills are of two generations; older dykes, that are feeders to the sills, and younger dykes, which transect the sills and folds in the sedimentary rocks and post-date the main period of deformation (Plate 1).

Regolith

A large proportion of the land surface of the study area is mantled by regolith. This surficial cover comprises both indurated relict deposits, and a variety of younger clastic and chemical deposits. Plate 1, which is principally designed to illustrate the distribution of mineral occurrences in a solid-geology context, does not show the full complexity of this regolith. The rock types described in detail below are not shown on Plate 1 but are included in the digital dataset that accompanies this Report. The relict units and the depositional units are grouped into two larger units, distinguished on Plate 1 by overprints. Complementing these units are the mapped areas of exposed rock that have no overprint.

Individual regolith units have been delineated on the basis of field observations undertaken for the earlier phase of 1:250 000-scale mapping, coupled with a new Landsat Thematic Mapper (TM) image interpretation. The classification of these materials uses a modification of the Commonwealth Scientific and Industrial Research Organisation scheme (Smith et al., 1992), in which the three broad groups are differentiated, termed here Relict–Exposed–Depositional (RED). The regolith in the digital files has been broadly separated into Cainozoic and Quaternary deposits.

Cainozoic undivided deposits

In some areas of the map, the distinction between a range of deposits of presumed Cainozoic age is either too complex, or is unclear, and these deposits are categorized as undivided (*Czx*). They include colluvium, reworked alluvium, eolian sand, clay, and limestone.

Cainozoic duricrust and chemical deposits

The oldest regolith units in the relict regime, consisting of duricrust and related chemical deposits, typically outcrop on low hills and breakaways. These are divided into ferricrete and ferruginous duricrust (*Czrf*), carbonate rock and related material (*Czak*), and silcrete and siliceous caprock (*Czrz*). The carbonate rocks include calcrete, calcareous sandstone, and vuggy opaline silica, and are typically along major drainage lines. All other Cainozoic units are formed by the transport and deposition of material derived from the weathering and erosion of duricrust and exposed rock.

Cainozoic mass-wasting deposits

Weakly cemented and compacted proximal slope deposits have been mapped as colluvium (*Czc*). They typically form extensive aprons surrounding upstanding areas of exposed rock, and may form a thin veneer over duricrust.

Cainozoic fluvial, lacustrine, and eolian sediments

Weakly cemented and compacted alluvium of presumed Cainozoic age (*Cza*) grades upslope into the proximal slope deposits (colluvium; *Czc*). Downslope the alluvium may grade into lacustrine deposits (*Czl*). These are typically composed of clay, silt, and sand, and may be saline in part. Eolian sand (*Czss*) forms in sheets and dunes on extensive plains, particularly in the east of the area.

Quaternary mass-wasting deposits

Younger colluvium (*Qc*), of presumed Quaternary age, is composed of unconsolidated quartz and rock fragments in soil. Unconsolidated mass-wasting deposits at the base of larger slopes (*Qcf*) typically consist of ferruginous rubble and debris.

Quaternary fluvial, lacustrine, and eolian sediments

Unconsolidated alluvium (*Qa*) of Quaternary age lies along intermittently active fluvial channels and on floodplains. The alluvium is composed of silt, sand, and gravel, and grades laterally into sheetwash, including younger sheetwash containing sand and clay (*Qw*), and colluvial deposits. The deposits are commonly considered to be Quaternary in age because the alluvium outcrops in fluvial systems that are currently active and cut into older regolith.

The flood plains may also contain small playa lakes (*Ql*) as part of the active system, and in the larger valleys there may be deposits of mixed lacustrine and eolian origin (*Qls*) adjacent to the larger areas of eolian sand in sheets and dunes (*Qs*).

Evolution of the Bangemall Basin

From the data presented in this Report, a tentative model for the evolution of the Bangemall Basin is proposed and briefly discussed below. Intracontinental rifting began between 1.67 and 1.64 Ga, during which alkaline igneous activity took place. The products of this alkaline activity are volumetrically minor, but at least two phases are recognized: an early pre-rift ultrabasic phase, and a late syn-rift phase in which high-K rocks, including rhyolite and perhaps carbonatites, were emplaced.

Sedimentation began as clastic accumulation sourced from rising horst basement structures. The underlying structure of the Bangemall rift basin was such that subsequent sedimentation was controlled by three main structural domains, which in turn influenced the sedimentary facies. One of these domains was characterized by complex horst and graben basement structures, in which the sedimentary packages are discontinuous and interfinger — this was later deformed to form the Edmund Fold Belt. In the north, a shelf facies (Pingandy Shelf) is characterized by carbonate and clastic sedimentation. At a later stage, the predominantly clastic Collier Subgroup was deposited on a platform domain in the east (Bullen Platform; Fig. 2).

Although there is no absolute age constraint, the continental tholeiitic magmatism of the Bangemall Basin is characterized by abundant dolerite sills and dykes that intruded along fractures that are dominantly subparallel to the margins of the basin.

Exploration and mining history

Since the 1960s there have been a number of commodity-driven cycles of exploration in the Bangemall Basin, chiefly for base metals, gold, uranium, diamonds, and manganese. Other commodities that have attracted exploration interest include other gemstones (e.g. variscite), talc, and asbestos. Various exploration methodologies have complemented geological mapping and remote sensing in the Bangemall Basin, including surface stream and soil sampling, and magnetic and electromagnetic (EM) surveying, all with varying degrees of success.

Stream- and soil-sampling surveys were effective in locating near-surface mineralization in the Bangemall Basin, but these surveys have not led to any major discoveries. Since the discovery, in 1981, of the concealed Abra deposit, which was initially an aeromagnetic target, the exploration emphasis has been to test geophysical targets. However, identifying and exploring aeromagnetic targets has also met with little success. GEOTEM–DEEP surveying, the most recent airborne EM technique, was undertaken by Aberfoyle and BHP in 1997. This survey may have deeper penetration than other EM methods, and has generated targets for drill-testing that may lead to further discoveries.

Both copper and gold mines have been systematically explored in recent years, but none are being currently mined. In-ground resources have been outlined for both the Ilgarari Mining Centre and the Hibernian Mine at the Egerton Mining Centre of 2.55 Mt at 3.3% Cu and 0.17 Mt at 5.5 g/t Au respectively. Lead, copper, and zinc were mined in the late 1940s from the Joy Helen deposit, 34 km northeast of Maroonah Homestead, but no production was recorded.

The only recent, significant discovery (in 1981) of base metals was the stratabound Abra lead–copper–silver–barite deposit (298)[*] in the Jillawarra Sub-basin, an early easterly trending graben on MOUNT EGERTON and COLLIER (Boddington, 1987, 1990; Vogt, 1995).

The following account of the exploration history and mineral development activity is a summary of data held on open-file in the WAMEX database, and is intended to highlight the positive results of exploration since the first mineral discoveries in the area in 1896.

Base metals

Chuck (1984) summarizes base-metal exploration in the Bangemall Basin in the period 1965–1982. Major exploration programs are summarized in Table 2. There

* The number in parentheses following a named occurrence is the unique WAMIN database Deposit Number used on Plate 1.

Table 2. Summary of major base-metal exploration programs in the Bangemall Basin since 1965

Company	*I-numbers*	*Period*	*Areas*	*Activities*	*Results*
Anaconda Australia Inc.	I37	1965–68	Irregully Creek	Regional stream sampling	Three anomalous areas of pyritic black shale
Westfield Minerals	I3227	1961–67	Edmund, Mount Egerton	Stream-sediment sampling, mapping, and drilling	Widespread areas of anomalous pyritic black shale
Carpentaria Exploration Co. Pty Ltd and Carr Boyd Minerals	I1046 I1048 I1050 I1053	1969–71	Edmund, Parry Ranges, Ilgarari	Stream-sediment, soil, rock-chip sampling, and costeaning	Weakly anomalous base-metal values; no further action
Falconbridge	I1051	1970	Irregully Creek	Stream-sediment, rock-chip sampling	Weakly anomalous Zn in black shale of the Jillawarra Formation
BHP	I1108	1971–73	Mount Palgrave	Stream sampling, prospecting for malachite float	Anomalous Cu in shale of the Jillawarra Formation
Union Oil Development Corporation	I1052	1973	Edmund	Orientation stream-sediment sampling over nine mineralized/structural areas	No further work
Amoco Minerals, Geopeko, Renison Goldfields, and North Mining	I4641	1974–98	Jillawarra Sub-basin	Major exploration program	Abra deposit and satellites discovered and drill-tested
Kennecott Exploration (Australia) Ltd	I932	1977	Brumby Creek Anticline	Stream-sediment survey	Anomalous Zn and Cu in gossans over black shale
Pacminex Pty Ltd	I1110	1977–79	Resolution Synclinorium (Mount Egerton)	Mapping, stream-sediment and rock-chip sampling, and aeromagnetic and radiometric survey	Three targets tested by drilling; no mineralization outlined. Acid volcanic and basaltic tuff located
International Nickel Australia Ltd	I933 I934 I1111	1978–79	Glen Ross Anticline, Barlee Range, Mount Isabella – Genoa Bore	Stream-sediment and rock-chip sampling and mapping	Weak base-metal mineralization located in Barlee Range and Mount Isabella – Genoa Bore
Noranda Australia Ltd	I935	1978–79	Coobarra Inlier	Photogeology, surface geochemistry, and magnetics	No mineralization located
Alcoa of Australia Ltd	I1469 I1470 I2482	1980–82	Irregully Creek, Mount Genoa, Ilgarari, Needle Hill	Soil and rock-chip sampling, and drilling	Results disappointing, area downgraded
CRA Ltd	I2725	1980–82	Mansfield (Maroonah)	Drill-testing of coincident geochemical and geophysical anomalies	No significant results
CRA Ltd	I2569	1981–82	Mount Boggola	Stream-sediment sampling, aeromagnetics, INPUT, radiometrics, SIROTEM	Pyrite–malachite mineralization in shear zones; anomalies not drill-tested
BP Minerals Australia Pty Ltd	I2612	1984–85	Lofty Ranges, Keep-It-Dark	SIROTEM, and drill-testing of both SIROTEM and geochemical and/or mineralization anomalies	New fault- and vein-hosted Pb–Cu–barite mineralization located at Koode Magi Well
BHP	I4401 I4402	1984–86	Koorabooka and Carnaby Well	Mapping, rock-chip sampling, gravity, ground magnetics, SIROTEM, RAB- and diamond-drilling	No significant mineralization; pyritic black shale intersected

Table 2. (continued)

Company	*I-numbers*	*Period*	*Areas*	*Activities*	*Results*
Cyprus Gold Australia	I4644	1987–90	Manganese Range	Stream-sediment, soil, and rock-chip sampling. Amoco drillholes were analysed for Au. Ground magnetics, chargeability and resistivity surveys, and drilling	Cu–Ag zone — no mineralization; Pb–Hg zone — drilling too shallow
West Australian Metals NL	I6909	1989–92	Ilgarari Mine	Detailed drilling and resource definition	Resources outlined and ore treatment scenarios discussed
Newcrest Mining Ltd and Pasminco	I7605 I8395 I9082	1989–96	Mount Boggola	Landsat and aerial photography, processing of early CRA data, ground reconnaissance, sampling and mapping, ground magnetics, RC-drilling	41 km-long Peebeezee gossan in black shales — minor base metals, low gold
Newcrest Mining Ltd	I7180	1990–91	Koorabooka, Gifford Creek	Surface exploration of BMR magnetic and radiometric anomalies	No mineralization located
Newcrest Mining Ltd	I7181	1990–91	Mount Vernon	Surface exploration of BMR magnetic and radiometric anomalies	No mineralization located
Newcrest Mining Ltd	I7316	1991–92	Kenneth and Godfrey Ranges	Surface exploration of BMR magnetic, radiometric, and Landsat anomalies	No mineralization located
Newcrest Mining Ltd	I6172	1991–92	Northeast of Abra	Rock-chip and stream-sediment sampling	Fault zones gave weak Au; stream sediments gave weak base-metal anomalies
WMC	I8031	1991–93	Deadman Hill	TEM, lag geochemistry, percussion drilling	Zn and Ag anomalism — no significant results
WMC	I7995	1992–94	Munjang (Waldburg)	Surface geochemical sampling, drill-testing of magnetic anomalies	No significant results
CRA Ltd	I8271	1992–94	Joy Helen	Surface sampling	No anomalies away from the old workings
Pasminco	I7615	1992–94	Prairie Downs Fault	Surface sampling and geological reconnaissance	No significant results
WMC	I8926	1993–94	CANDOLLE	Aeromagnetics, IP and TEM, drilling	One anomaly with supergene-enriched copper in a dolerite with significant vein quartz
WMC	I9030	1993–96	Wannery (WYLOO and EDMUND)	Photogeology, IP, aeromagnetic, ground magnetic and electromagnetic surveys, lag sampling and RC-drilling	No significant copper mineralization identified

NOTES: INPUT: Electromagnetic method
SIROTEM: Transient electromagnetic method developed by CSIRO
RC-drilling: Reverse circulation drilling
TEM: Transient electromagnetics
IP: Induced polarization
RAB: rotary air-blast

are many small copper occurrences in the area, but only the Ilgarari and Kumarina mining centres, and associated satellite-deposits, have recorded copper production (Marston, 1979). These deposits, located on COLLIER, were discovered in 1913 and intermittently produced ore until 1974 (Marston, 1979).

Exploration in the Jillawarra Sub-basin principally involved Amoco Minerals, Geopeko, Renison Goldfields, and North Mining. Amoco's initial work was centred on Airport – Maryta Hill (311), where anomalous lead, iron, and manganese values in calcareous sedimentary rocks were thought to be indicative of stratabound lead–zinc–silver deposits. In 1975, the area was extended and base-metal prospects were identified at Quartzite Well (49), Manganese Range (304, 305, 312, 315), Copper Chert (309), and Jeds (310). Aeromagnetic surveys, in 1976, delineated a 6 km-diameter anomaly called TP (308), and satellite anomalies called TC (306), 46–40 Prospect (303), Woodlands (307), and Gnamma (313). In 1977, a further airborne survey located the Abra 'bullseye' magnetic anomaly (298) and a lesser anomaly called Cadabra. Geopeko commenced drilling in 1981, during which they intersected the Abra mineralization. Diamond drilling was successful in outlining extensive low-grade copper–barite mineralization at TC, Gnamma, and Woodlands.

In the late 1980s, Cyprus Gold Australia tested the Manganese Range area for supergene copper–gold mineralization. Anomalous copper–gold and anomalous lead–mercury zones, from a combination of stream-sediment, rock-chip, and soil sampling, were outlined and tested by drilling, but near-surface mineralization was not located.

In the 1960s, Anaconda Australia identified a number of areas anomalous in base metals, including one area in pyritic black shale of the Jillawarra Formation centred on the Irregully Creek. Falconbridge subsequently located anomalous (maximum 0.42% Zn) Jillawarra black shale in the Irregully Creek area.

Westfield Minerals located anomalous zones at the Jillawarra Formation – Discovery Chert contact in the Mount Palgrave, Cobra, Kurabuka, and Isabella (Mount Genoa) Synclines. Similar mineralization was found in the Glen Ross Shale at Mount Vernon where the host rock is pyritic black shale. BHP targeted sedimentary-hosted copper in the Kiangi Creek and Devil Creek Formations as well as dolerite-hosted copper. Target areas around Mount Palgrave provided the best areas of surface mineralization, with shale in the Jillawarra Formation giving a highest value of 0.5% Cu.

Carpentaria Exploration and Carr Boyd Minerals, working in the western Bangemall Basin (EDMUND), targeted stratiform lead–zinc–copper in the Irregully Formation and located three types of anomalies; lead in dolostone, scattered copper related to dolerite, and zinc in dolostone. Follow-up rock sampling gave maximum values of 0.27% Zn in dolostone. A similar program in the Parry Ranges (WYLOO) located weak lead mineralization (0.2% Pb) near the Warrada Creek copper occurrence (88).

Working in the Brumby Creek Anticline on COLLIER, Kennecott Exploration (Australia) identified anomalous zinc and copper in sedimentary rocks and minor gossans located in the Jillawarra and Devil Creek Formations.

International Nickel Australia (INCO) located weak copper mineralization in the Jillawarra and Kiangi Creek Formations at Mount Isabella – Genoa Bore on MOUNT EGERTON.

In the period 1984–85, BP Minerals Australia identified new fault- and vein-hosted lead–copper–barite mineralization (3196, 3197, and 3198) west and southwest of the Koode Magi deposit (78).

Newcrest and Pasminco, mapping in the area of the Hughes Chert occurrence (3007), identified a lead-bearing siliceous alteration zone and coincident magnetic anomaly in the Irregully Formation at an estimated depth of 700 m.

At Mount Boggola, CRA located pyrite–malachite mineralization in shear zones in the Jillawarra Formation, mainly over the Ashburton and Irregully Formations. Subsequent exploration from 1989–96 in the Mount Boggola area, first by Newcrest Mining and later by joint venture partner Pasminco, targeted a 41 km-long gossanous ironstone and malachite horizon called the Peebeezee horizon. This horizon is in black pyritic shale of the Jillawarra Formation, lies just above the contact with the underlying Irregully Formation, and is zinc-rich at depth. Early prospecting by Newcrest located linear copper gossans close to Mount Boggola (2982, 2983, and 2986). Several mineral occurrences (3006, 3008, 3009, and 3010) were identified where the gossan was best developed.

West Australian Metals NL carried out a detailed investigation of the Ilgarari Mine area on COLLIER between 1989 and 1992. Resources were outlined, and treatment of the oxide ore by acid leach and electrowinning was considered. A West Australian Metals NL – GME Resources NL feasibility study concluded that the acid leach plus electrowinning extraction process was technically sound, but returns were marginal based on current resources.

In 1993–94, Western Mining Corporation (WMC) targeted the southern margin of the Bangemall Basin and adjacent Gascoyne Complex for gold and base metals on CANDOLLE south of Waldburg. Supergene-enriched copper values were identified in a dolerite with significant vein quartz.

Gold

Gold was first discovered in 1896 at the Bangemall Mining Centre (99) near Cobra Station, and was mined intermittently until 1916 (Williams et al., 1983). A similar deposit was mined at McCarthys Patch located 13 km to the northwest of Cobra Station. The Egerton Mining Centre, hosted by older Gascoyne Complex rocks of the Egerton Inlier, lies about 50 km to the southwest of Woodlands Station. Mining was carried out from 1910 to 1953 (Woodward, 1911; Muhling et al., 1978), and for a short period in 1983. The bulk of the gold was extracted from auriferous quartz veins, with smaller amounts subsequently being taken from alluvial deposits and the mullock dumps. Major exploration programs are summarized in Table 3.

The Bangemall Mining Centre was thoroughly mapped and rock-chip sampled at surface, but has only had limited shallow drill-testing. Quartz-vein intersections are typically low-grade and narrow, giving no encouragement for deeper drill-testing. Ivanhoe Mining's evaluation of the Bangemall Mining Centre in the 1980s highlighted the main potential to be alluvial gold in the immediate area of the workings known as Prospectors Gully. At present the mining centre is being worked with metal detectors and by dryblowing, producing small quantities of gold nuggets.

Exploration of the Egerton Inlier by Amoco Minerals in the 1970s identified auriferous pyritic siltstone, together with weakly mineralized metasedimentary rocks and alteration zones. In the early 1980s, WMC identified thin (<300 mm) chloritic siltstone with narrow (20 mm) bands of auriferous pyrite and pyrrhotite at the old Hibernian workings. Gold grades were restricted to these bands, with the highest drill-intersection being 0.14 m at 21 g/t. Since 1993, Egerton Gold NL has located mineralization with widths and grades in the order of 2 m at 5 g/t and 11 m at 4–20 g/t Au for Gaffney Find and Hibernian respectively. A preliminary inferred and indicated resource of 170 000 t at 5.5 g/t Au has been announced for Hibernian.

On COLLIER, Fire Hills Gold NL carried out limited sampling for gold around the old base-metal mines centred on Koode Magi to the north of Ilgarari. A few rock-chip samples gave assays ranging from 1–7 g/t gold.

Uranium

The main phase of uranium exploration in the region was from 1970 to 1980, with most of the targets located at the unconformable contact between the Bangemall Basin and the underlying basement, composed dominantly of the Gascoyne Complex. These basement rocks host the most significant uranium occurrences, but there are three locations where uranium has been discovered in the Bangemall Basin; Horse Well, Telfer South, and Centipede Range. Major exploration programs are summarized in Table 4.

Uranerz Australia was active in the area between 1972 and 1980, with activity centred on the Horse Well area on MAROONAH. Two areas of significant secondary mineralization (245, 246) were identified in Cainoizoic channel sediments overlying carbonaceous shale of the Irregully Formation.

Afmeco outlined anomalous areas around the Telfer Granite both in the basement and in the overlying rocks of the Bangemall Group on EDMUND, west of Mount Padbury. One of the areas, Telfer South (3201), was located in Tertiary calcareous sediments overlying siltstone of the Irregully Formation.

The first investigation for sandstone-hosted mineralization was in sandstone and conglomerate of the Tringadee Formation west of Cobra Station, in which Occidental Minerals Corporation located Centipede Range in the period 1978–80. Grab samples assayed 3500 ppm U_3O_8, 1150 ppm Pb, and 2.23% Th. Uranium was associated with thorium in the mineral xenotime. Drilling confirmed an anomalous interval of 1.5 m at 473 ppm U_3O_8 from 93–94.5 m in drillhole CR1.

Diamond

In the early 1980s, following the discovery of the Argyle diamond-bearing lamproite in the Kimberley, diamond exploration dramatically increased throughout Western Australia, including the Bangemall Basin.

A number of diamonds were recovered from stream samples, and narrow kimberlite and lamproite dykes were discovered; one kimberlite dyke yielded a small diamond from a bulk sample. Possible kimberlitic pipe structures of several hectares in surface area have recently been outlined as targets for exploration by Astro Mining in joint venture with Diamin Resources in the Ullawarra area.

Manganese

Two areas of the Bangemall Basin have significant manganese occurrences, namely the Jillawarra Sub-basin on MOUNT EGERTON and the Yanneri Pool area on COLLIER.

The Jillawarra Sub-basin contains units with strong silicification and manganese replacement: lateritic processes at surface have enriched these deposits. The silica and manganese enrichment is a distal phase of the hydrothermal fluids associated with base-metal mineralization (Vogt, 1995). De la Hunty (1963) describes the Woodlands Station deposit (314), and Vogt (1995) describes other mineral occurrences. The Mulgul Station deposit (315) on MOUNT EGERTON is described by Muhling et al. (1978).

The only recent exploration for manganese was in the late 1970s by BHP at Yanneri Pool, south and east of Ilgarari Outcamp on COLLIER. They identified manganese enrichment in both near-surface shale of the Calyie Sandstone and the overlying ferricrete (pisolitic) deposits, and produced global estimates of tonnage potential for the area.

Mineralization

Plate 1 and Figure 4 show all mineral occurrences in the Bangemall Group and adjacent areas. On Plate 1, these occurrences have been grouped by commodity (symbol colour) and mineralization style (symbol shape). In the following description, the principal mineral occurrences of the Bangemall Basin are grouped first by mineral-

Table 3. Summary of major gold exploration programs in the Bangemall Basin since 1974

Company	*I-numbers*	*Period*	*Areas*	*Activities*	*Results*
Newmont Mining Ltd	I928	1974–75	Bangemall Mining Centre, McCarthys Patch, Gem Hill	RC drilling, mapping, and rock-chip sampling	Quartz vein highest value of 1 ppm Au
Tern Associates	I6548	1982	Bangemall Mining Centre	Rock-chip sampling	No significant results
Ivanhoe Mining	I2635	1980–85	Bangemall Mining Centre, Prospectors Gully	Mapping, mullock and rock-chip sampling	High Au and Ag values; no further work; alluvial potential at Prospectors Gully
BHP	I3161	1983–85	Cobra area	Mapping, stream-sediment sampling, and limited drilling	No anomalous results outside old workings
Indian Ocean Gold NL	I4793	1986–90	Bangemall Mining Centre	Remapping and rock-chip sampling	No significant results
Capricorn Resources Australia NL	I7150	1990–93	Bangemall Mining Centre	Limited geological reconnaissance and rock-chip sampling	No extensions to mineralization
Sons Of Gwalia NL	I7002	1991	McCarthys Patch	Drilling	Best value of 2 m at 1.87 g/t Au from quartz iron-stone veining
Amoco Minerals	I930	1977–79	Egerton Inlier	Mapping, stream-sediment sampling, shallow RAB drilling, and aeromagnetic surveying	RAB drilling failed to intersect encouraging base-metal mineralization
WMC	I2044	1980–81	Hibernian	Photogeology, geophysical and geochemical surveying, and diamond drilling	Narrow (2 cm) bands of auriferous pyrite and pyrrhotite in chloritic siltstone; best intersection 0.14 m at 21 g/t Au
Onshore Resources Ltd	I6570	1987–91	Eastern Ridge – Egerton	Mapping and costeaning	Significant surface mineralization; planned drilling not undertaken
Northern Gold NL	I5432	1988–91	Parry Ranges	Stream-sediment and rock-chip sampling, mapping	Anomalies in Gascoyne rocks
Fire Hills Gold NL	I6057	1988–91	Koode Magi	Rock-chip sampling	Few samples over 1–7 g/t Au

Table 4. Summary of major uranium exploration programs in the Bangemall Basin since 1972

Company	*I-numbers*	*Period*	*Areas*	*Activities*	*Results*
Endeavour Oil Co. NL	I656	1972	Capricorn — general	Field visits	Descriptions of U and base-metal deposits
Uranerz Australia Pty Ltd	I415 B	1972–76	Horse Well	Ground radiometrics, mapping, trenching, and drilling	Two areas of significant secondary mineralization in Cainozoic channel sediments
Uranerz Australia Pty Ltd	I415 A	1972–76	Telfer River	Ground radiometrics, mapping, trenching, and drilling	Minor mineralization in Yilgatherra Sandstone Member
Canadian Superior Mining (Australia) Pty Ltd	I423	1972–74	EDMUND	Detailed evaluation of black (pyritic) graphitic shale	Low potential
Canadian Superior Mining (Australia) Pty Ltd	I413	1972–74	Telfer South, EDMUND	Detailed evaluation of calcrete-hosted U	Outlined Telfer South area
Afmeco Pty Ltd	I808	1975	Telfer South, EDMUND	Airborne radiometrics, detailed mapping, surface sampling, and costeaning	Outlined Telfer South deposit in calcrete
Canadian Australian Petroleum NL	I448	1976	Centipede Range	Airborne radiometrics, ground radiometrics, and drilling	No significant uranium in arkosic sandstone
Occidental Minerals Corporation	I1104	1978–80	Centipede Range	Rock-chip and gossan sampling, mapping, airborne and ground magnetics and/or radiometrics, drilling	Xenotime mineralization outlined in drillhole — no economic potential

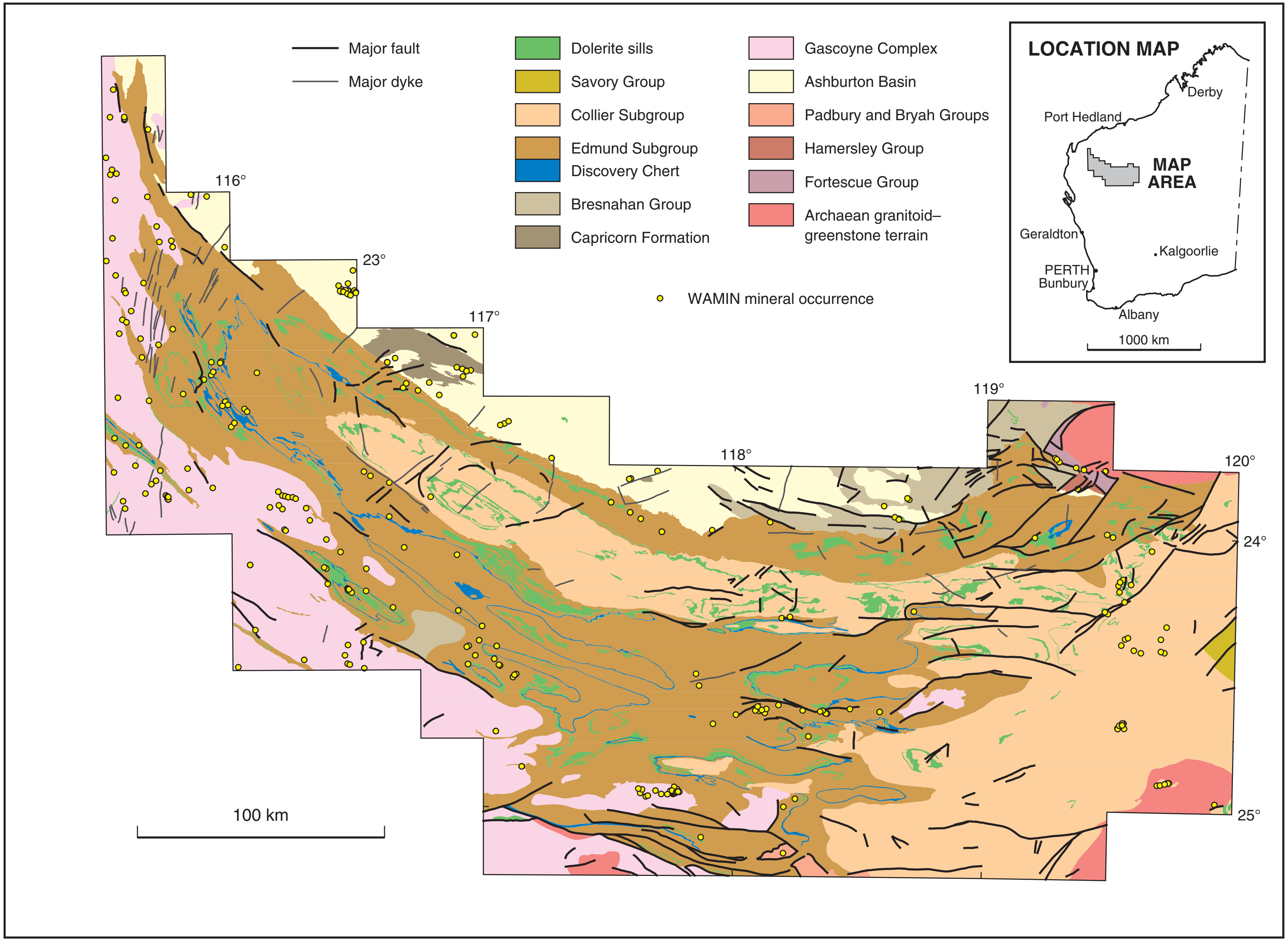

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Figure 4. Distribution of mineral occurrences in the Bangemall Basin

ization style and then by commodity group. Associated commodities are given in parentheses. All maps in this section include occurrences outside the Bangemall Basin, but these are not described here. Details of mineral occurrence definitions are presented in Appendix 1.

Kimberlite and lamproite mineralization

Precious mineral — diamond

Diamonds have been recovered from kimberlitic rocks (3003) and from stream-sediment samples (231, 2905–6) where no host rock was identified (Fig. 5). Non-diamondiferous lamproite and kimberlite, described above, are not included as mineral occurrences. Likewise, indicator minerals such as ilmenite, garnet, and chrome spinel have not been included as mineral occurrences.

A kimberlite dyke (3003) located 7 km southwest of Mount Palgrave 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) is intruded over a strike length of 2 km into the Devil Creek Formation and possibly the Discovery Chert, and trends at 080° to 085°. This dyke also contains chrome spinel.

Diamonds recovered from stream samples taken 17 km southwest of Ullawarra Station (2905 and 2906), in the area of the Eerstelling Lamproites (Rohde, 1993), suggest that these bodies must be weakly diamondiferous. However, lamproitic outcrop samples yielded no diamonds.

Vein and hydrothermal mineralization

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

Most base-metal occurrences are described in Blockley (1971), Marston (1979), Chuck (1984), Muhling and Brakel (1985), Ferguson (in prep.), and in various exploration reports. All base-metal occurrences are shown in Figure 6. The mineralization under this category can be subdivided into: fault- and fissure-related copper (with a possible dolerite association), fault- and fissure-related lead and minor zinc, carbonate-hosted lead, and base-metal veins with dolerite–gabbro host or association.

Fault- and fissure-related copper

Fault- and fissure-related copper mineralization accounts for the largest group of occurrences in the Bangemall Basin (52, 55, 59, 63, 67, 70, 72, 74, 75, 77–80, 83, 369, 1502, 2825–27, 2834, 3226–27). The main mineralized area is on COLLIER, where the Ilgarari and Kumarina deposits, and satellites, are associated with northeasterly trending faults that parallel the major Tangadee Lineament. Muhling and Brakel (1985) also note that the main deposits trend to the north-northwest in line with prospects in older successions, such as the Wyloo Group (Ashburton Basin) and Fortescue Group, suggesting that these faults may have tapped a basement source of base metals. Marston (1979) notes that the mineralization commonly occurs at faulted shale–dolerite contacts. All mineralization in this area has undergone supergene enrichment. A brief description of Ilgarari Main taken from Marston (1979) follows, as this is the best example of this group. Production for these deposits from 1913 to 1970 is given in Table 5.

Table 5. Copper production for Ilgarari, Kumarina, and associated satellite deposits, 1913 to 1970

Mining centre or mine	*Ore (t)*	*Copper ore grade (% Cu)*
Ilgarari Group	789.68	27
Kumarina Group	579.3	23.4
Butcher Bird	8.46	22.63
Koode Magi	1.75	12.73
Towers Find	0.82	40.39

At Ilgarari Main (52; Fig. 7), an indicated resource of 117 000 t of ore at 3.2% Cu was defined in 1990. When compared with the historical production figures (Table 5), this lower grade highlights the poor nature of the remaining deeper ore. The host rocks are laminated siltstone, sandstone, and shale of the Ilgarari Formation. Pyritic and carbonaceous intervals, 1.5–8.0 m thick, contain elevated base-metal values typical of stratabound mineralization. Weakly pyritic dolerite dykes and sills intrude the sedimentary rocks with only narrow zones of contact metamorphism.

The mineralization was worked over 650 m in 'east-northeasterly striking and steeply southerly dipping en echelon faults and shears, which are commonly developed at or near dolerite-shale contacts' (Marston, 1979). The deposit consists of a series of composite shears with narrow limonitic veins, typically 1–100 mm thick, but rarely up to 1 m thick, occurring over a zone of about 10 m width. There are narrow quartz veins, and the host rocks are kaolinized and variably silicified. Ore minerals include malachite, azurite, chrysocolla, cuprite, chalcocite, and native copper between the surface and 38 m depth, with chalcocite and sparse chalcopyrite 38–130 m in depth.

Other fault- and fissure-related copper deposits, prospects, and occurrences are remarkably similar in mineralization style and ore minerals to that at Ilgarari. The only variations are the width and development of the fault zone, and the degree of supergene enrichment.

Fault- and fissure-related lead and minor zinc

Fault- and fissure-related lead and minor zinc mineralization is an unusual style in the Bangemall Basin, occurring only at Keep-It-Dark, Cork Tree, and Hughes Chert.

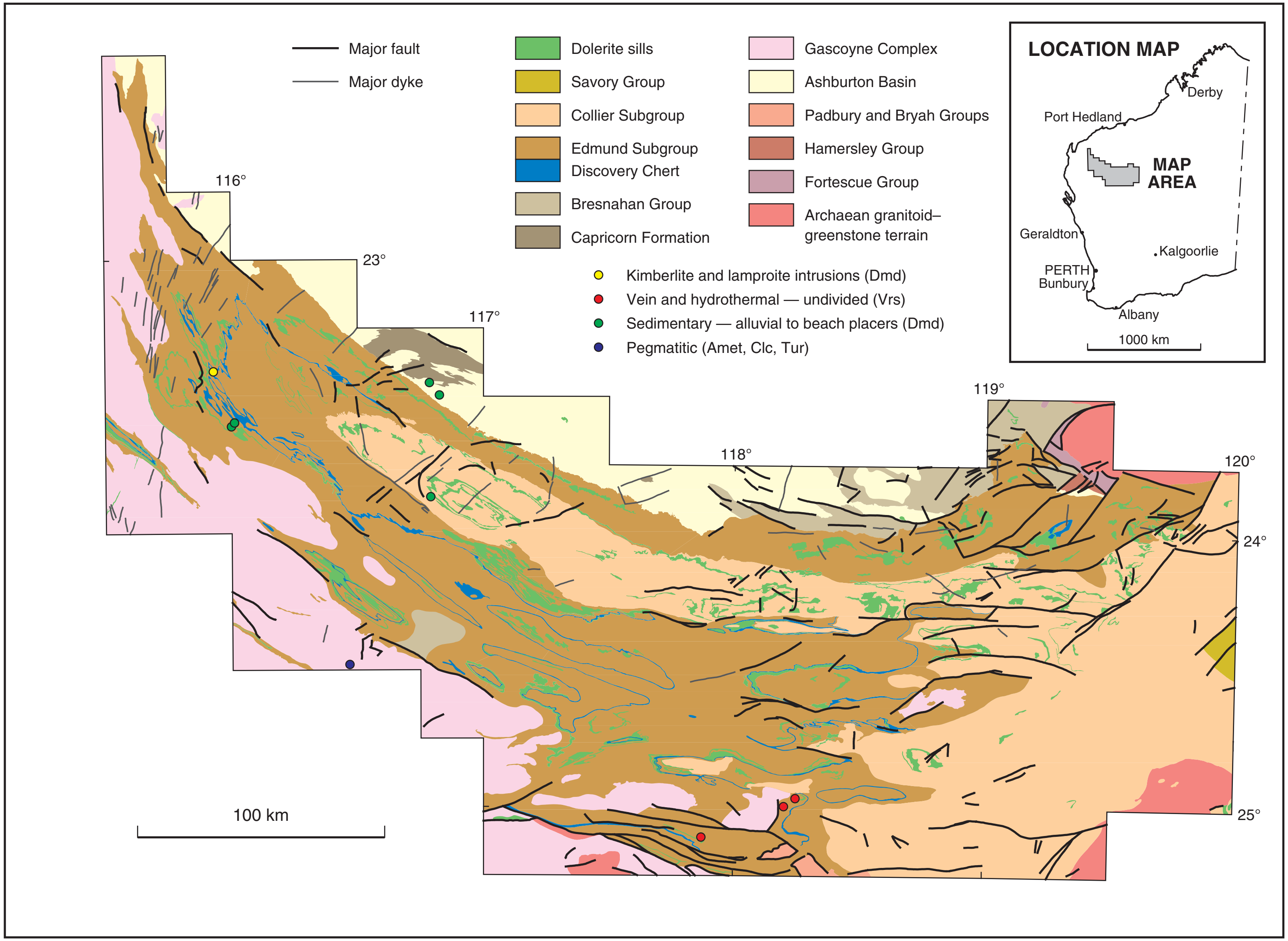

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Figure 5. Distribution of precious minerals in the Bangemall Basin — diamond (Dmd), gems (Amet — amthyst; Clc — chalcedony; Tur — tourmaline), and variscite (Vrs) by mineralization style

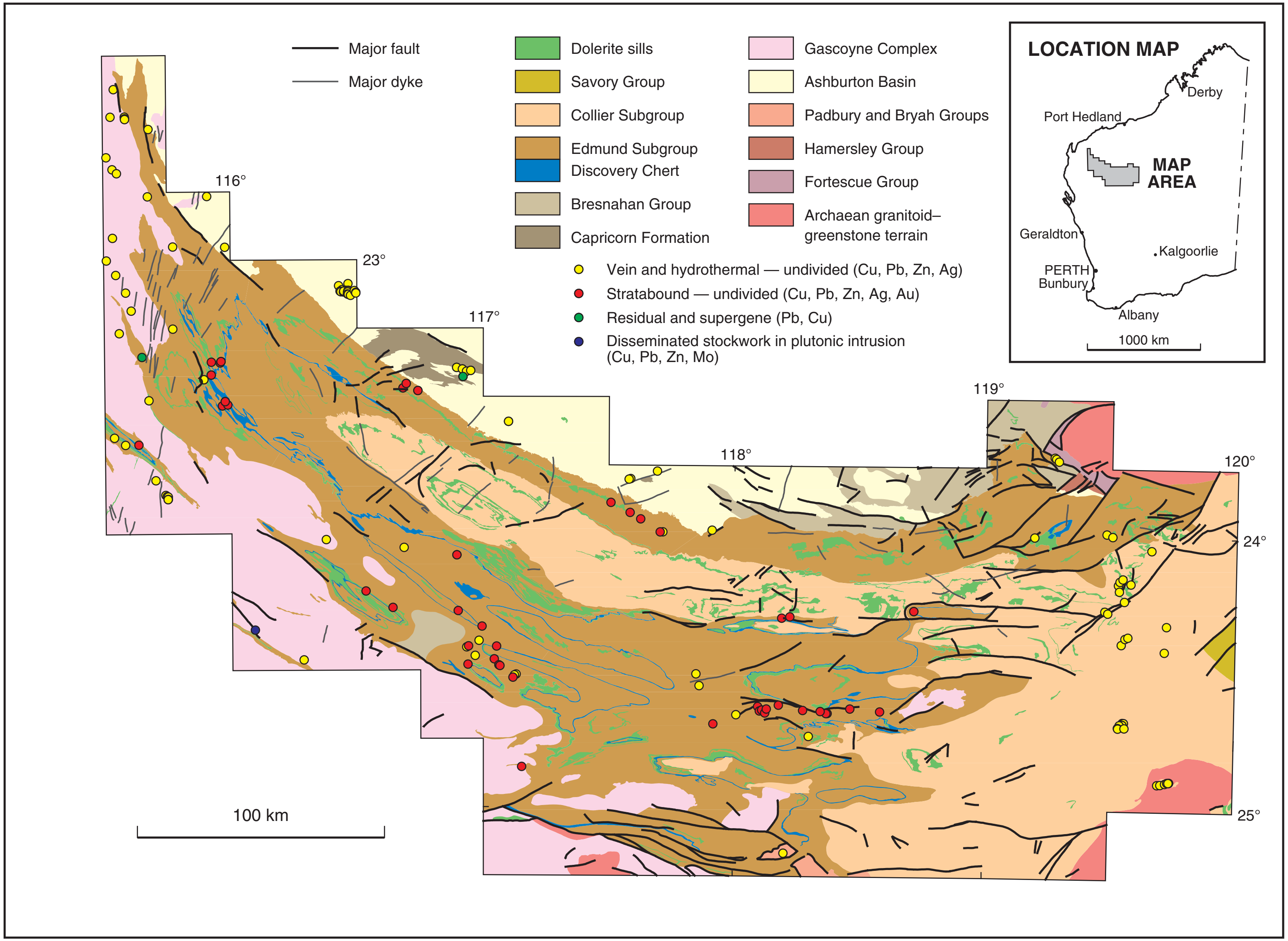

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Figure 6. Distribution of base metals in the Bangemall Basin — copper, lead, and zinc by mineralization style

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Figure 7. West mine shaft at Ilgarari Main copper mine (52), looking southwest

The abandoned Keep-It-Dark mine (296), together with minor surface galena (3196–98), is to the north of the Ilgarari copper mine, and is associated with the same fault system. The mineralization is hosted by a 150–300 mm quartz breccia within a shear zone trending 020° and dipping 75° west. Ore minerals are galena and cerussite, with manganese oxides. The sedimentary host rocks, formerly assigned to the Fords Creek Shale, are now included in the Backdoor Formation. A thin, irregular dolerite dyke forms the footwall to the deposit. In 1949, 4.3 tons (4.23 t) of lead and 59.95 fine ounces (1.86 kg) of silver were produced. Grades from the dump were 24.3% Pb, 0.34% Zn, and 21.77 g/t Ag. Similar fault-hosted lead mineralization is present along the Prairie Downs Fault (364, 2842–43) in older rocks of the Fortescue Group.

The Cork Tree occurrence (2876) is located 20 km north-northwest of Woodlands Homestead. This occurrence has only been sampled at the surface, but is related to the southwesterly extension of the Woodlands Fault, which is a major boundary fault associated with the Abra-style group of deposits. The Cork Tree occurrence is distinguished from the other Abra-style deposits only because it exhibits no stratabound characteristics. The mineralization is in a quartz-vein network, with veins of 0.5–1.0 m width, and the host rock consists of sandstone of the Gap Well Formation. The sulfides include small aggregates of galena, chalcopyrite, and pyrite, with secondary malachite and goethite.

Hughes Chert (3007) is located 21 km south of Mount Boggola on TUREE CREEK. The mineralization lies below the Peebeezee horizon in chert of the Irregully Formation. The chert is pyritic (up to 20%) throughout, with both disseminated and vein mineralization. Coarse-grained galena and sphalerite occur in veins, and possibly also in nodules. This base-metal mineralization lies at different stratigraphic levels, in close proximity to a northeasterly trending fault pair. A drillhole (PBZ11) intersection, between 98 and 102 m, gave 0.44% Pb and 0.44% Zn (Saxon, 1994; Parfrey and Roberts, 1995).

Carbonate-hosted lead

In most cases, carbonate-hosted lead mineralization is associated with fault zones, although the ore is not actually located within faults.

The most significant deposit, mined in 1949, is the Joy Helen Mine (87), located on EDMUND about 10 km north of Mount Padbury. No production figures have been recorded for the deposit. The mineralization forms irregular, flat-dipping segregations in silicified stromatolitic dolostone breccia of the Irregully Formation. Ore minerals are cerussite, galena, sphalerite, malachite, azurite, cuprite, and chrysocolla. A number of surface samples gave assays ranging up to 35% Pb, 5% Cu, and 340 g/t Ag. The workings only extend for a distance of 46 m, and costeaning, drilling, and soil geochemistry did not reveal extensions along strike.

Two hypotheses have been proposed for the origin of this mineralization. In one, Blockley (1971) suggested a Mississippi Valley-type (MVT) affiliation; in the other, Chuck (1984) proposed that remobilization from a pre-existing fault-hosted mineralization and the silicification of the host dolostone breccia took place during the Tertiary. However, Ferguson (in prep.) reports that lead-isotope determinations indicate a Mesoproterozoic age for this mineralization.

Two occurrences loosely associated with the Flint Hill Lineament (Fig. 3) are Teano River (319) and Postcutters (320). The mineralization at these localities is in vein systems, hosted by dolostone, in the Irregully Formation (Delaney, 1978). They are located about 17 km east-southeast of Staten Hill on MOUNT EGERTON. Both lie in zones of intense silicification, with Teano River trending northeasterly, parallel to the lineament, and Postcutters trending southeasterly. The zones of mineralization are 20 m wide by 2000 m long at Teano River, and 5 m wide by 1000 m long at Postcutters. Mineralization is disseminated and hosted in quartz veins and pods ranging from a few millimetres to 2 m wide. The ore mineral at Teano River is galena, with minor amounts of chalcopyrite, pyrite, and malachite; ore grades of up to 40% Pb and 16.3 g/t Ag have been recorded. At Postcutters, the style of mineralization is the same, but only galena and pyrite were noted, giving grades of up to 1.92% Pb and 28 g/t Ag.

In the Mount Genoa area, (1358) on MOUNT EGERTON, a vein 50 m long by 1 m thick cuts both sandstone and dolostone of the Kiangi Creek Formation, with some stockwork development in the dolostone. The mineralization is described as pegmatite-hosted, comprising 'clots of chalcopyrite and galena in a quartz, tourmaline, mica gangue' (Delaney, 1979). Later descriptions by Senini (1982) do not include any references to pegmatite. Senini (1982) also records that one drillhole encountered a small number of galena stringers in pyritic, brecciated and fractured dolostone at 76–78 m, grading 0.44% Pb.

Base-metal veins with dolerite–gabbro host or association

Minor occurrences of veins containing base-metals, and with a dolerite–gabbro host or association, may have a structural control, but are not hosted in fault breccia. The structural control is suggested by their proximity to major lineaments.

The Latham Prospect (867), located 8 km east of East Paddock Hill on EDMUND, is described as a narrow vein intruded close to the eastern margin of a dolerite sill (Blockley, 1971). The vein is 60 m long, with a maximum width of 0.5 m, and is the locus for several small-scale workings. The adjacent dolerite sill intrudes dolostone of the Irregully Formation, close to the basal unconformity with the underlying Gascoyne Complex. Mineralization at the Latham Prospect includes chrysocolla, galena, and malachite, and grades of 3.53% Pb, 0.02% Zn, and 13.06 g/t Ag have been recorded.

Just north of Mount Candolle, on MOUNT EGERTON, two gabbro-hosted occurrences (1373, 1376) lie close to a prominent west-northwesterly trending lineament. Thin (centimetre-scale) mineralized quartz veins at these localities contain malachite, cuprite, and minor amounts of chalcopyrite.

Precious metal — gold (copper)

The Bangemall and Egerton mining centres are the only areas where significant vein and hydrothermal gold mineralization has been identified (Fig. 8).

The Bangemall Mining Centre and associated McCarthys Patch are situated in a 50 km-long synclinal structure (Cobra Synclinorium; Muhling and Brakel, 1985). Quartz veins form saddle reefs and veins parallel to axial cleavage, and contain free gold, pyrite, sphalerite, and carbonate. Individual veins have limited strike length, but some vein stockworks are locally up to 10 m wide. Near-surface exposures commonly contain malachite. The reefs and veins are in shale and dolerite sills near the top of the Jillawarra Formation. Muhling and Brakel (1985) suggest 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 such as the Envy Shaft at the Bangemall Mining Centre (Fig. 9). The excellent exposure and thin overburden in the area of the main workings suggest that no significant vein-related mineralization has been overlooked.

At the Egerton Mining Centre, the dominant mineralization type 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 the mafic rock is absent, are commonly only less than 2 m thick.

Devlin (1985) suggested that the other style of mineralization present is exhalative in nature, and is associated with both pyritic–chloritic siltstone and pyritic chert containing narrow high-grade sulfide bands. The sulfides were then remobilized from this primary source, during a period of high heat flow, forming quartz–chlorite veins within shear zones. The heat flow could have been related to the intrusion of granites that are present in the inlier.

Precious mineral — variscite

Two deposits of variscite (a green, hydrated aluminium phosphate) are located near Mount Deverell, in the

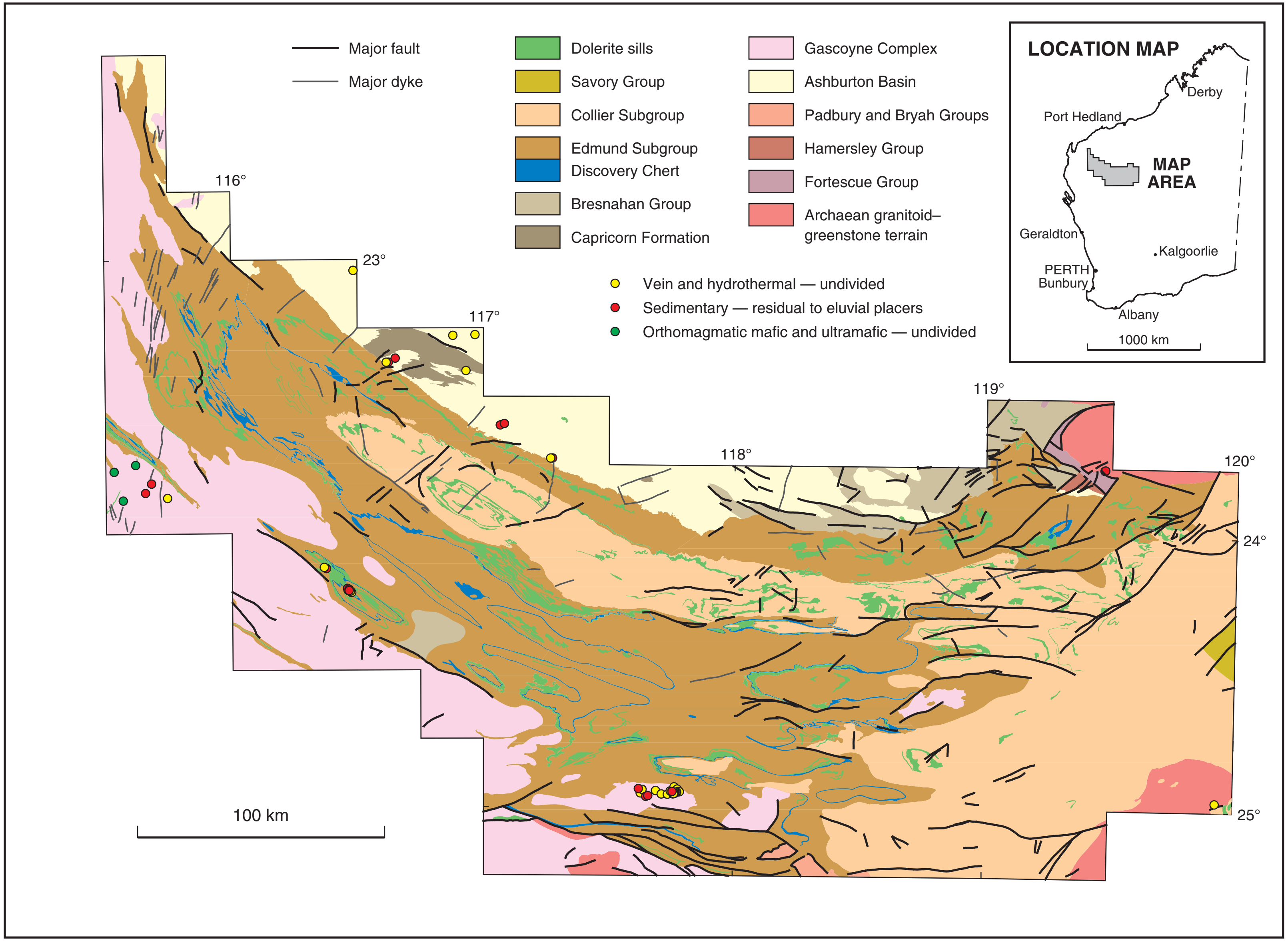

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Figure 8. Distribution of precious metals in the Bangemall Basin — gold by mineralization style

southeastern corner of MOUNT EGERTON. Mount Deverell (2946) is being sporadically mined for gemstones, whereas a second deposit in the area (2948) is currently undeveloped.

Bridge and Pryce (1974) describe the variscite deposits in some detail. The variscite is in narrow veins (<100 mm) in silicified shale and mudstone of the Jillawarra Formation. The main mineralization is associated with a concentration of secondary phosphate. There is also evidence of minor concentrations of stratabound phosphate in one horizon within the Jillawarra Formation, which may be the source of the vein mineralization. Recorded production for 1994–95 at Mount Deverell was 29.345 t of variscite.

A further occurrence of variscite is located 1.5 km southwest of Sawback Bore (in the Sawback Range; Plate 1) on ROBINSON RANGE. The variscite occurs as irregular patches in brecciated chert of the Kiangi Creek Formation. Thin cross-cutting veins (10 mm) are located in nearby dolerite (location unknown; Elias and Williams, 1980).

Stratabound mineralization

Undivided

Base-metal — copper, lead, zinc (silver, gold, barite, manganese)

In the Bangemall Basin, an attempt has been made to separate the primary mineralization into the vein and hydrothermal, and stratabound styles (Fig. 6). Stratabound mineralization in the Bangemall Basin, locally, may also have vein-style characteristics (e.g. stockworks). However, these veins are either part of feeder systems for the stratabound mineralization, or they may have formed during remobilization of the primary ore. For these reasons, the vein-style deposits that appear to be genetically and spatially associated with the stratabound deposits are included in this category.

Three groups of stratabound mineralization can be recognized in the Bangemall Basin: the Abra and associated deposits and occurrences in the Jillawarra Sub-basin, mineralization related to dominantly carbonaceous and pyritic shale at various stratigraphic levels, and dolostone-hosted occurrences.

Abra and other occurrences in the Jillawarra Sub-basin

The Abra and associated deposits and occurrences (49, 298–313) are located on MOUNT EGERTON and COLLIER to the northwest, north, and northeast of Woodlands Homestead. Boddington (1987, 1990), Collins and McDonald (1994), and Vogt (1995) have described the Abra mineralization and alteration, and their work is summarized below. The deposits are hosted by the Irregully Formation (Gap Well Formation of Vogt, 1995).

The Abra deposit (298) is a large, blind, polymetallic deposit at the top of the Irregully Formation in a sequence of intertidal sedimentary rocks and overlying evaporitic sedimentary rocks at the eastern end of the Jillawarra Sub-basin. The upper boundary of the deposit lies between 250 and 500 m below surface and extends to 800 m depth. An aeromagnetic anomaly at Abra is 1.5 km in diameter, defining an elliptical body.

From limited diamond drilling, the deposit is 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, below this, a funnel-shaped stringer or stockwork zone.

The stratabound zone includes an upper Red zone and lower Black zone, which contain approximately 50 Mt of ore. The Red zone is dominated by jaspilite, hematite, barite, carbonate, and magnetite mineralization. The Red zone has relatively low base-metal values. The Black zone consists of hematite, magnetite, carbonate and barite laminations, and it contains higher base-metal values. The main sulfides are pyrite, galena, and chalcopyrite, with minor tetrahedrite and sphalerite; minor scheelite occurs throughout.

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Figure 9. Envy Shaft in black shale bedrock at Bangemall Mining Centre, looking northeast

The underlying Stringer zone, which is probably a feeder system, is estimated to contain about 150 Mt of base metals, which include 0.13 g/t Au. The Stringer zone consists of a stockwork of mineralized carbonate–quartz veins cutting through chloritized siltstone and shale with intercalations of fine-grained sandstone. Boddington (1990) noted that the upper part of the zone showed higher barium–lead–silver values overlying a lower part characterized by high copper–gold values.

Collins and McDonald (1994) established that the alteration surrounding the Abra deposit is characterized by a pervasive chlorite–siderite envelope, which is expressed by enrichment in silica and Fe and depletion in Al, Ca, Pb, and Rb, in relation to the unaltered rocks.

Vogt (1995) suggests that minerals such as carbonates, iron oxides, calcium sulfate, and pyrite in the stratabound zone, and carbonate plus clastic minerals in the Stringer zone, were present as syngenetic material and probably remobilized by later hydrothermal fluids. The later hydrothermal minerals comprise all sulfides present, as well as iron oxides, quartz, barite, chlorite, albite, and hyalophane. Vogt (1995) notes that the mode of emplacement of these minerals differs. In the Stringer zone, sulfide veining, silicification, and chloritization prevail, whereas the Black and Red zones are characterized by some albitization and replacement of sedimentary carbonate by quartz, replacement of early sulfate (gypsum or anhydrite) by barite, quartz, and carbonate, and replacement of pyrite by other sulfides. Vogt (1995) contends that a possible source of lead, barite, and iron is the subaerial talus-slope breccia and fluvial arkose unit at the base of the Bangemall succession, estimated to be 2000 m thick.

Collins and McDonald (1994) and Vogt (1995) considered that the Abra deposit is an exhalative polymetallic sediment-hosted epithermal system, coeval with the accumulation of sediments in a subaerial, subtidal to intertidal environment.

In the central and western parts of the Jillawarra Sub-basin there are several large, but low-grade, zones of stratabound base-metal mineralization where copper is commonly predominant. These zones are associated with silicification and chloritization together with enrichment in iron, manganese, and barium. Some of these occurrences are at the same stratigraphic horizon as the Abra body, whereas others are in lithologies assigned to the lowermost part of the Gap Well Formation. Each of the occurrences show as aeromagnetic anomalies.

In the central part of the area, Copper Chert (309) is a low-grade copper occurrence in arenites and siltstones at the same horizon as the Abra deposit. At Manganese Range (304, 305, 312, 315), low-grade copper and lead mineralization occurs in iron-rich siltstones in the lowermost part of the Gap Well Formation: the occurrences are capped by manganese-rich lateritic material.

At Quartzite Well (49), lead–zinc–silver mineralization is present in silicified pyritic siltstone and shale, and brecciated carbonaceous shale in the Quartzite Well fault zone, which is gossanous for 1400 m. Stratabound mineralization is also present. Here, the Jillawarra Formation host rock has been overthrust by sandstone of the lowermost Gap Well Formation. Drilling over a strike length of 900 m failed to outline a resource. The best intersection was 115–149 m depth (drillhole JLWA75-7), which gave 34 m at 1.99% Pb, 1.07% Zn, and 27.9 ppm Ag. The main ore mineral is sphalerite, but pyrite comprises up to 60% of whole rock in some cases. This is the only prospect in the sub-basin that contains significant zinc. Davy (1980) suggests transport of metals by connate water or palaeoriver (spring) water for zinc, and mechanical erosion of older copper-bearing strata for copper. Vogt (1995), however, suggests a hydrothermal source, and tentatively relates this deposit to the Abra deposit based on its high barite content.

In the western part of the sub-basin, drilling of aeromagnetic targets has revealed substantial thicknesses (30–50 m) of low-grade copper–barium–iron in siltstones and arenties of the lowermost Gap Well Formation at TC (306), Woodlands (307), and Gnamma (313). These prospects lie on the western side of a large circular aeromagnetic anomoly called TP (308), which is 6 km in diameter. One drillhole that tested this prospect was terminated at 1200 m. The only significant intersection was 4 m of 3.6% Pb, associated with barite veins, at 594–598 m. In the last 100 m of this hole, dolomitic carbonate rocks contain abundant veins of magnetite, siderite, and barite. Although the source of the iron-rich vein material is uncertain, it is tempting to suggest a carbonatitic affinity for this mineralization, perhaps similar to that at Bayan Obo (Oreskes and Hitzman, 1993).

To the northwest of the TP Prospect there is a zone of stratabound lead–copper–barium–iron at 46–40 Prospect (303), which lies close to the northeasterly trending Woodlands Fault. The small 'Abra-style' mineralized body consists of a 'black zone' and a 'stringer zone'. One drillhole at this prospect intersected 1 m of 5.5 g/t Au in a copper-rich section.

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 also gave rise to felsic magmatism that is represented by the Tangadee Rhyolite, east of the Abra deposit (Boddington, 1987, 1990; Vogt and Stumpfl, 1987; Collins and McDonald, 1994; Vogt, 1995).

Dominantly shale-hosted syngenetic mineralization

Occurrences of dominantly shale-hosted mineralization are widespread throughout the Bangemall Basin. This group consists of all remaining deposit numbers in the stratabound category. They are described in Chuck (1984), and further described in Blockley (1971), Marston (1979), Davy (1980), and Muhling and Brakel (1985). Marston (1979) describes the deposits as 'stratiform' in nature. Limited outcrops of felsic volcanic rock, including pyritic rhyolite and tuff, suggest a volcanic origin for the metals, but this correlation remains tenuous.

The exposed mineralized horizons vary from malachite-bearing gossans to well-developed ironstone gossans, all with elevated base-metal values. Drill intersections below the gossans in fresh bedrock revealed the presence of pyritic and carbonaceous shale, siltstone, or chert with minor sphalerite–galena–chalcopyrite. Copper values in the surface gossans are up to 10–12%. The pyrite mineralization has a bedding-parallel, banded appearance (?syngenetic), but has been locally remobilized in discordant veins and fractures. The main stratigraphic horizon for this mineralization is at the top of the Jillawarra Formation and in the overlying Discovery Chert. Other mineralized horizons are in the Irregully, Kiangi Creek, and Cheyne Springs Formations.

Davy (1980) suggests a strongly reducing depositional environment, with the fixing and concentration of metals on carbonaceous material.

A number of occurrences are located on EDMUND, to the west and south of Mount Palgrave, in the Prospect Shale at the top of the Jillawarra Formation. Prospect 2 (236) typifies this cluster of occurrences, and is one of the drillholes studied by Davy (1980). Surface malachite and azurite are widespread in veins and fracture coatings, and are also present in the oxidized zone. A rock-chip channel sample, 5 m long, gave an average of 1.2% Cu. Drilling by Westfield Minerals intersected this horizon at depth, with the best results of 2.4% Zn from 78–81 m depth. Pyrite is present throughout the black carbonaceous siltstone as disseminations and massive layers up to 20 mm thick. Covellite and sphalerite were restricted to a zone of 28 m width. The matrix contains both sulfides, with most of the sphalerite in late-stage siliceous veins. Two similar occurrences are located 8 km south of Mount Vernon on MOUNT EGERTON (48 and 317).

Another significant concentration of shale-hosted syngenetic mineralization is within a 20 km radius of Mount Genoa on the western margin of MOUNT EGERTON. This area has been well explored, with projects also named Mount Isabella, Mount Augustus, and Isabella. This area is well described in Chuck (1984). The host rocks are black pyritic carbonaceous mudstone and shale in the Jillawarra, Kiangi Creek, and Cheyne Springs Formations. A deposit typical of the area (325) contains abundant laminated pyrite and pyrrhotite in shale host rocks, and includes zones of elevated base-metals, with minor chalcopyrite and sphalerite. Drillhole ISBD1 intersected 6 m of mineralization at 1.73 g/t Ag, with weakly anomalous copper and zinc. Surface outcrops show supergene enrichment of copper and zinc to low levels.

The Peebeezee horizon is a near-continuous malachite–ironstone gossan that extends for 41 km. This horizon is the surface expression of pyritic carbonaceous shale at the base of the Jillawarra Formation (Saxon, 1994; Parfrey and Roberts, 1995). The Peebeezee gossan is best developed at the Hughes prospect (3006), where drillhole PBZ11 gave an average of 0.5% Zn and 730 ppm Cu in fresh bedrock from 37–42 m depth.

Dolostone-hosted mineralization

Deep Frederick Well (352), located 25 km north of Mount Augustus Homestead, is the only occurrence hosted by dolostone that has some stratabound characteristics. BHP (Page, 1985) describes the mineralization as disseminations and veinlets in manganese-rich silty dolostone of the Cheyne Springs Formation containing possible cyanobacterial mat structures. The mineralization includes galena, sphalerite, and malachite, and the highest rock chip analyses were 1.74% Pb, 1.03% Zn, 13 g/t Ag, and 1700 ppm Cu.

Industrial mineral — asbestos, talc

Industrial mineral occurrences in the Bangemall Basin include Sheela Bore Talc and two minor asbestos occurrences (Fig. 10). The two asbestos-only occurrences are located 10 km southwest of Ullawarra Homestead (229) and 8 km northeast of Cardibar Peak (3194) on EDMUND, and are not discussed further here.

Daniels (1969) first described the Sheela Bore Talc (247) and associated chrysotile asbestos occurrences. Concept Geological Consultants (1992) give further details, together with recent mapping and drilling results. Sheela Bore is located 27 km east of Maroonah Homestead, and the main mineralized area is 900 by 200 m. The talc and chrysotile asbestos are hosted in stromatolitic dolostone. The talc is cream to creamy white, and occurs as float and subcrop, with a maximum thickness of 16 m (Daniels, 1969). Chrysotile asbestos and finely to coarsely crystalline wollastonite and/or diopside are also present. The host rock also contains chalcedonic quartz and cryptocrystalline calcite layers, and Concept Geological Consultants (1992) suggest that this quartz could have replaced anhydrite layers, formed in a sabkha environment.

Concept Geological Consultants (1992) proposed that the formation of the talc was by 'authigenic crystallization during de-dolomitization of primary dolomitic micritic sediments'. The addition of chrysotile and wollastonite is thought to be from contact metamorphism of the already existing talc deposit, with the likely heat source being the nearby dolerite sills. The occurrences have no economic potential due to the non-white colour, presence of chrysotile, and commonly narrow nature (<1 m) of the talc-rich units.

Stratabound sandstone-hosted mineralization

Energy mineral — uranium

The Centipede Range occurrence is the only example of stratabound sandstone-hosted uranium mineralization (Fig. 11). The host rock is an arkosic sandstone of the Tringadee Formation, which in radiometric surveys shows as a thorium emitter, but with significant uranium enhancement (Swingler, 1979). Both surface and deeper mineralization (90 m downhole) was encountered (Sise, 1980). Petrological investigations have indicated the presence of the thorium-rich minerals xenotime and thorite, and/or auerlite.

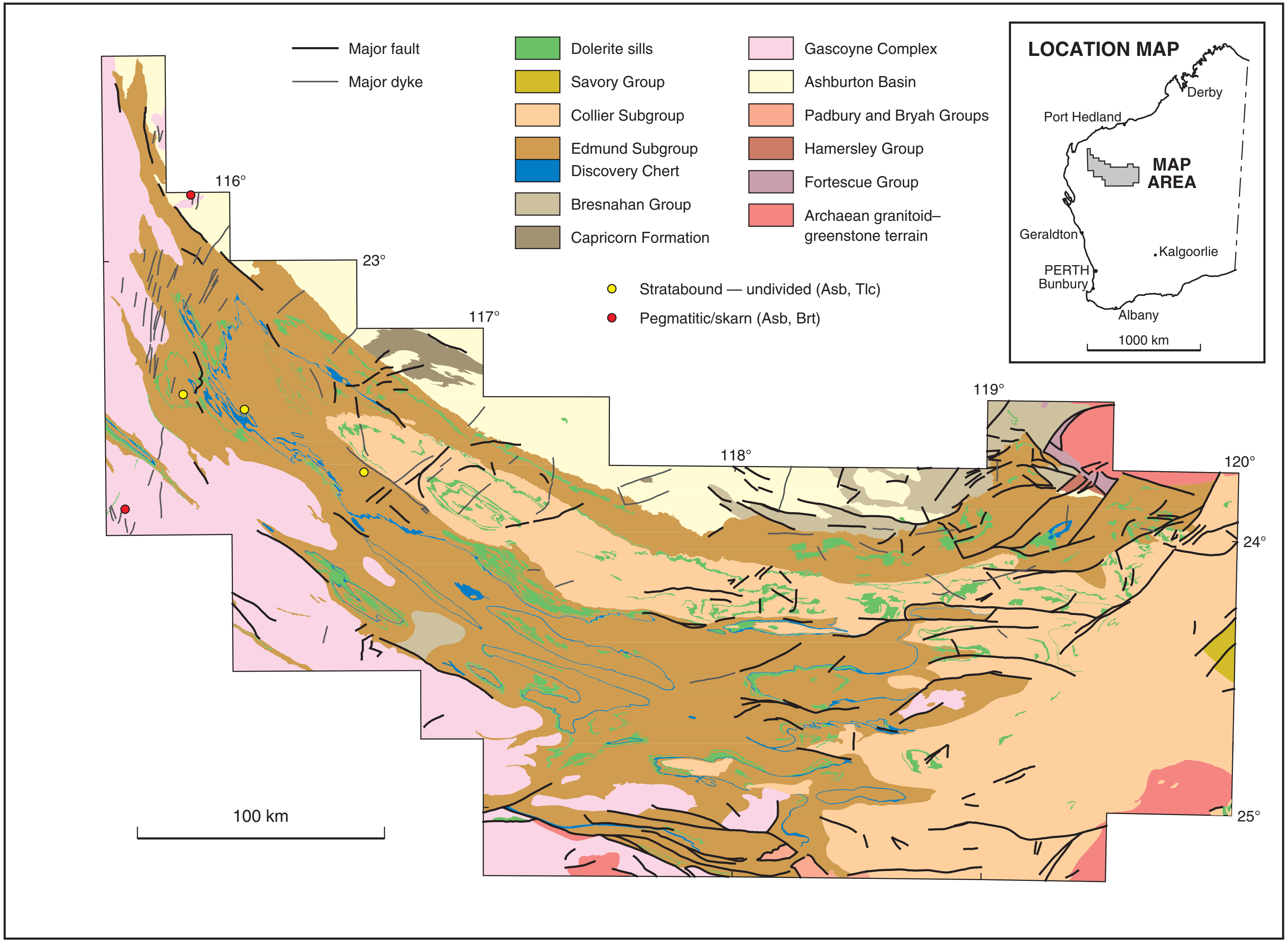

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Figure 10. Distribution of industrial minerals in the Bangemall Basin — asbestos (Asb) and talc (Tlc) by mineralization style

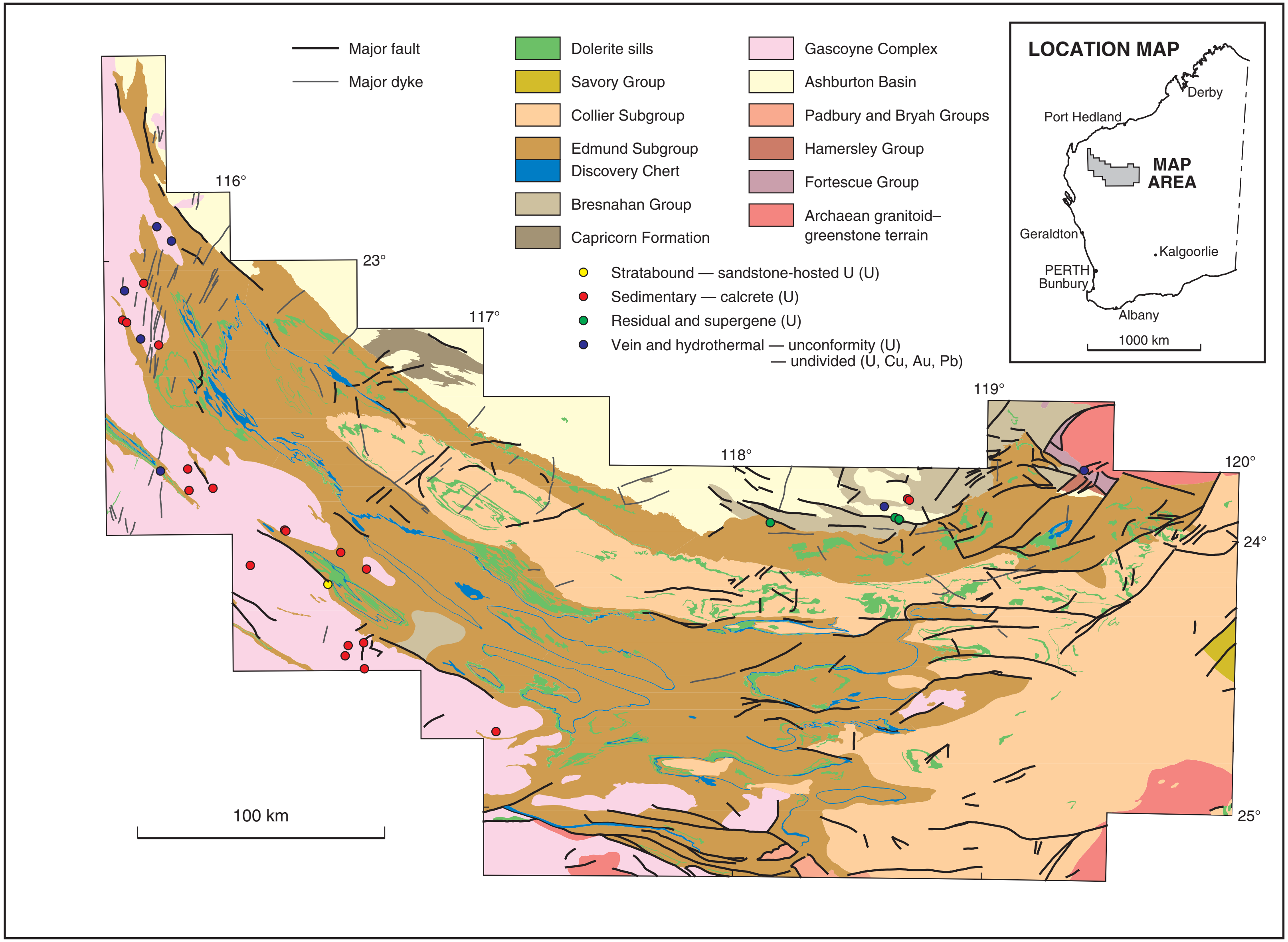

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Figure 11. Distribution of energy minerals in the Bangemall Basin — uranium by mineralization style

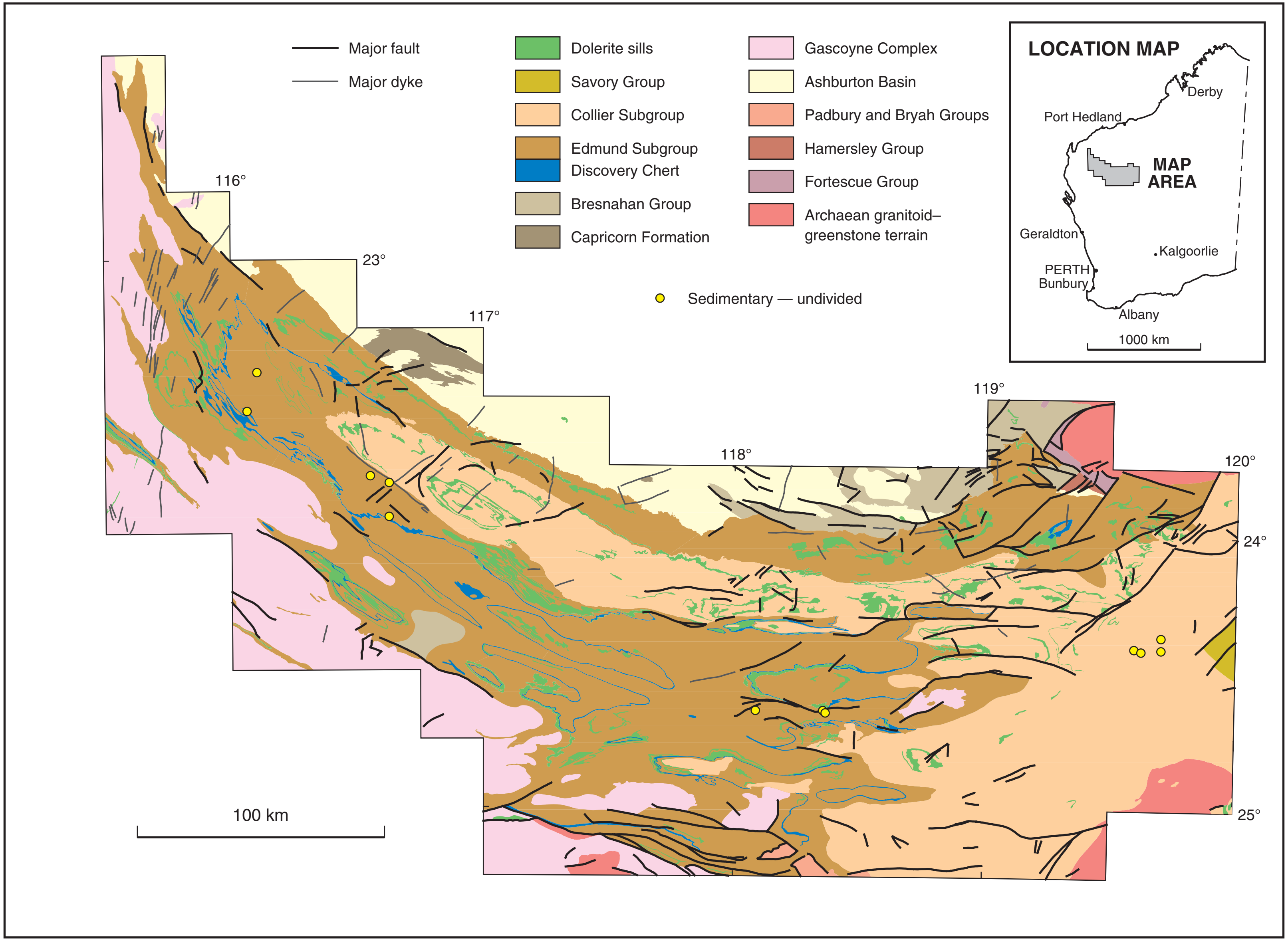

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Figure 12. Distribution of steel-industry metals in the Bangemall Basin — manganese by mineralization style

Sedimentary mineralization

Undivided

Steel-industry metal — manganese (iron)

All manganese occurrences in the Bangemall Basin are classified as 'sedimentary — undivided' (Fig. 12). In all cases, surface lateritic processes have enriched concentrations of manganese from sedimentary source rocks.

On EDMUND, a number of manganese occurrences are present in the Ullawarra Formation and, to a lesser extent, in the underlying Devil Creek Formation. Daniels (1969) notes that manganese staining is common, but no significance has been attached to any of the EDMUND occurrences.

All manganese occurrences in the Jillawarra Sub-basin are in the Irregully Formation in the Manganese Ranges, located 17 km north to northeast of Woodlands Station. The Woodlands Station (314) and Mulgul Station (315) deposits are small, highly ferruginous bodies in the order of 1–3 m thick, comprising pyrolusite encrustations with radiating fibrous structures in shale. Remnant sedimentary textures are common, whereas other textures appear fragmental and lateritic in origin. Vogt (1995) suggests that these manganese occurrences are derived from a type of alteration that is distal to the main alteration envelope at the Abra deposit. He also proposed that this alteration is related to fluids rich in manganese, silica, and iron.

At Yanneri Pool (294, 2831–33), near Ilgarari Outcamp, Madan (1978) describes two horizons enriched in iron and manganese in the Collier Subgroup. The first is a manganiferous rubbly, pisolitic, and nodular horizon (top to bottom), commonly 0.1–0.3 m thick. A hardpan and pallid zone separate the horizon from shale of the Calyie Sandstone. At least two shale horizons of 1 m thickness are surficially enriched, and the source for this enrichment is manganese bands up to 20 mm thick in white and brown, banded shale (Fig. 13).

Alluvial to beach placers

Precious mineral — diamond

For the purposes of this Report, diamonds recorded from stream-sediment sampling programs have been included as mineral occurrences, but should not be confused with economic alluvial deposits. Microdiamonds have been located in the Ullawarra area on EDMUND near known lamproitic bodies. The only other sample, for which no source rocks could be found, is in the Godfrey Range (231), 19 km northeast of Wanna Hill (Fig. 5).

Residual to eluvial placers

Precious metal — gold

Past and current dryblowing operations exist around the Bangemall and Egerton Mining Centres (Fig. 14). These deposits have been referred to as alluvial deposits, but the proximity of the placer mineralization to the vein-hosted primary mineralization places them all in the residual to eluvial category (Fig. 8). The placers are derived from erosion of both the primary mineralization and the surface-enriched, duricrust caps. Gold is distributed as free nuggets, combined with iron-rich fragments or nodules on eluvial slopes, or concentrated in local drainage channels. Three areas at Egerton (3165, 3167–8) have surface nuggets, pointing to untested areas of possibly significant primary mineralization.

Calcrete

Energy mineral — uranium

Widespread uranium anomalism characterizes a belt trending along the contact of the Bangemall Basin with the older Gascoyne Complex rocks from WYLOO through to MOUNT PHILLIPS. Primary mineralization in the Gascoyne Complex rocks is the source of uranium for secondary calcrete-hosted deposits. These have developed both over the Gascoyne Complex and, to a lesser extent, over the lower part of the Bangemall Group in close proximity to the unconformity with the Gascoyne Complex (Fig. 11).

In the Bangemall Basin, uranium has been found in Tertiary calcareous or carbonaceous channel sediment or calcrete that overlie dolostone of the Irregully Formation. Being susceptible to dissolution, the dolostone was amenable to channel and calcrete development.

One group of occurrences is west and northwest of Mount Padbury, encircling the Telfer granite (244–246, 3200–3201, 3210) on EDMUND, in close proximity to the unconformity.

Telfer South (3201) is the most significant of a group of anomalies along the eastern margin of the Telfer granite. The mineralization is in siltstone between basal sandstone and conglomerate and the overlying massive dolostone. The base of the Irregully Formation feldspathic sandstone (the Yilgatherra Member; not shown on Plate 1) shows anomalous radioactivity due to the thorium content of the detrital heavy minerals. The mineralization in Tertiary groundwater channels is carnotite, as fracture coatings and cavity fillings in siltstone of the Irregully Formation, and in fractures and joints close to the weathered surface of the siltstone. The distribution of carnotite in the siltstone is more intense where the density of fracturing is greatest. The mineralization occupies an area 400 by 100 m in a topographic depression around the Telfer granite that preferentially collects uranium-bearing rainwater percolations from the granite.

Two uranium occurrences (245–6) occupy the same stratigraphic position above siltstone of the Irregully Formation. In this case, two types of mineralization were noted (Butt et al., 1977): 0–6 m in calcareous sediments (Type I), and 18–25 m associated with carbonaceous sediments (Type II). On the basis of microfauna fossils, the carbonaceous sediments were dated as late Upper Jurassic to lower Tertiary (Butt et al., 1977). These channel sediments extend over the Gascoyne Complex basement. The genesis of Type I mineralization is the

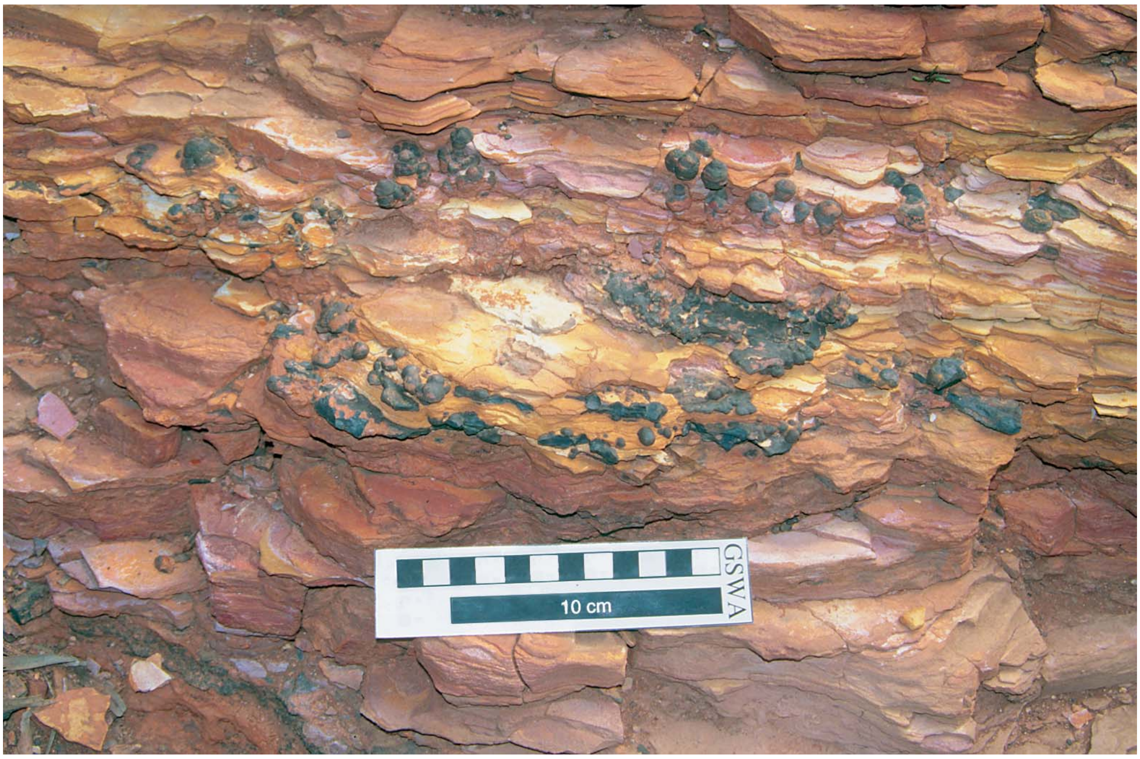

Figure 13. Manganese concretions interbedded with shallow-dipping shale near Yanneri Pool

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Figure 14. View north showing Bangemall Old Battery Dryblowing (1094)

same as for Telfer South (groundwater channels), whereas Type II mineralization develops in a reducing environment with pyrite. There are no uraniferous minerals, and the uranium is probably fixed to organic compounds.

Primary mineralization has formed around the Telfer granite at Mundong Well (244) and Laura (3200) in the Gascoyne Complex.

Residual and supergene mineralization

Base-metal — lead

Residual and supergene galena mineralization is located at Middle Bore (331), 15 km north of East Paddock Hill on EDMUND (Fig. 6). The mineralization is in a ferruginous silcrete overlying dolostone of the Irregully Formation containing no base-metal sulfides. The best drilling result for the anomaly was 9 m at 0.584% Pb. The primary mineralization is likely to be similar to that at Joy Helen.

Energy mineral — uranium

A surficial uranium occurrence (2980) is located 27 km southeast of Mount Bresnahan, on the northern margin of the Bangemall Basin (Fig. 11). Ferricrete over both dolostone and shale of the Irregully Formation contains up to 1700 ppm U and elevated base-metals.

Mineralization controls and exploration potential

In terms of mineral deposition, the data presented in this Report suggest that mineralization in the Bangemall Basin is intimately related to igneous and tectonic activity. The distribution of mineral deposits and occurrences in the Bangemall Basin is shown in Figure 4.

The early alkaline igneous event may have provided the heat source and the hydrothermal fluids that were responsible for the Abra-style polymetallic mineralization, as well as precious mineral mineralization associated with rocks of kimberlitic affinity. Hydrothermal alteration associated with the Abra-style deposits is typically silica- and iron-rich with minor sodium and is of regional extent. This, together with the epithermal nature of the main Abra deposit, suggests a regional setting within which Olympic Dam-style deposits (such as Roxby Downs, Cloncurry, Ernest Henry, Kiruna; Oreskes and Hitzman, 1993) are found. These diverse deposits all share common features such as an association with intracratonic rifting and alkaline magmatism, and iron-rich lithologies (Oreskes and Hitzman, 1993).

Basin-margin parallel structures, as well as the northeasterly trending Tangadee Lineament and associated parallel faults, channelled later hydrothermal fluids, resulting in a variety of mineralization styles that are presented in this Report under the category of fault- and fissure-related copper, gold, lead, and zinc (Figs 4 and 6). Many of the mafic intrusions are spatially associated with mineralization, particularly along their sheared contacts with the country rocks. The contact between dolerite and country rocks provides an easy pathway for fluids due to competency contrasts and enhanced permeabilities. It is also worth noting that gold appears to be confined to the southern margin of the basin, along the structurally controlled contact with the Gascoyne Complex (Fig. 8). The emplacement of dolerite dykes and sills in the sedimentary succession of the Bangemall Basin was probably related to a major subcrustal thermal anomaly. Vogt (1995) invoked a mantle plume to explain this rift-related tholeiitic magmatism. The thermal anomaly associated with the dolerite intrusions, together with heat dissipation during cooling of the mafic melts, may well have driven hydrothermal convection cells within the sedimentary pile. It is possible that the resulting hydrothermal activity was responsible for much of the fault- and fissure-related metalliferous mineralization.

Shale-hosted base-metal mineralization may be of syngenetic origin. This is suggested by the mode of occurrence of sulfides (mainly pyrite) as bedding-parallel lenses and laminae. Not enough data are available for the dolomite-hosted base-metal occurrences to provide constraints on their origin; however, carbonate-hosted mineralization is located in stable, relatively undisturbed platform carbonates on the Pingandy Shelf, and along the stable margins of the Edmund Fold Belt. This indicates an environment similar to that of Mississippi Valley-type deposits (Leach and Sangster, 1993). The manganese deposits in the Collier Subgroup may also be of syngenetic origin, but not enough data are available to confirm this either.

Calcrete-uranium channel deposits formed above dolostone beds of the Irregully Formation, close to the unconformity with the underlying Gascoyne Complex, which may be the source of the uranium. The deposits are controlled by a rock type susceptible to channelling and calcrete formation, and also by the close proximity to a uranium source.

All mineral occurrences in the Bangemall Basin have some surface expression except for the Abra and related deposits (aeromagnetic targets). Supergene enrichment and gossan development are common, with metal values far exceeding those of the primary mineralization.

The first phases of mining at all major gold and base-metal localities have been in the supergene material. Residual and eluvial gold placers are mined in areas where primary grades are too low or intersections too narrow to be economic. Manganese deposits at Yanneri Pool have been enriched to subeconomic levels by supergene processes, with pisolitic caps also rich in manganese.

Surficial enrichment has made surface-stream and rock-chip sampling effective tools for exploration, but surficial mineralization tends to be of relatively limited extent. Although residual and supergene mineral occurrences are unlikely to be of economic interest, they are often pointers to mineralization that has other controls, and that may be of greater significance.

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Appendix 1

Mineral occurrence definitions

The GSWA WAMIN database 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, commodities, mineralization classification, order of magnitude of resource tonnage and estimated grade, ore and gangue mineralogy, details of host rocks, and both published and unpublished references.

The WAMIN database uses a number of authority tables to constrain the essential elements of a mineral occurrence, including the operating status, the commodity group, and the style of mineralization. In addition, there are parameters that dictate whether the presence of a mineral or analyzed element is sufficiently high to rank occurrence status; this Report only deals with mineral occurrences. Other attributes were extracted from reports provided by mineral exploration companies or from authoritative references.

Those elements of the database that were used to create the mineral occurrences symbols and tabular information displayed in Plate 1 are:

- operating status and occurrence name (occurrence number style),
- position and spatial accuracy (symbol position),
- commodity group (symbol colour),
- mineralization style (symbol shape),
- determination limits, and;
- source and reliability of the data.

The elements of the database used for symbology in Plate 1 are operating status, commodity group, and mineralization style. These parameters have been defined for the Mineral Prospectivity Enhancement studies that have been completed for southwest Western Australia, the north Eastern Goldfields, and the Bangemall Basin. The definitions presented here will be used in all future prospectivity studies.

Operating status

The database includes mineralization sites ranging from small, but mineralogically significant, mineral occurrences up to operating mines. The classification takes into account all deposits and mines with established resources in the DME mine and mineral deposits information database (MINEDEX; Townsend et al., 1996). All occurrences in the WAMIN database are assigned a unique, system-generated number. The style of this number (bold, italicized, and so on) is used as the coding to indicate operating status both on the face of the map and in the accompanying table. The system used in Plate 1 is:

- Mineral occurrence — any economic mineral exceeding an agreed concentration and size found in bedrock or regolith (italic serif numbers, e.g. *2906*).
- Prospect — any working or exploration activity that has found subeconomic mineral occurrences, and from which there is no recorded production (italic serif numbers, e.g. *84*).
- Mineral deposit — economic minerals for which there is an established resource figure (serif numbers, e.g. 314).
- 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. ***263***).
- 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. **1457**).

The name of an occurrence, and any synonyms that may have been used, are derived from the published literature and from company reporting. As some occurrences will not have been named in the past, these appear without names in the WAMIN database. That is, no attempt has been made to provide names where none are currently recognized. Names that appear in the MINEDEX database have been used where possible, although there may be differences created because MINEDEX reports on production and resources, whereas WAMIN notes individual occurrences.

Commodity group

The WAMIN database includes a broad grouping based on potential or typical end-use of the principal commodities comprising a mineral occurrence. The commodity group as given in Table 1.1 determines the colours of the mineral occurrence symbols in Plate 1.

The commodity groupings are based on those published by the Mining Journal (1997), modified as

Table 1.1. WAMIN authority table for commodity groups

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

shown in Table 1.2 to suit the range of minerals and end-uses for Western Australian mineral output.

Mineralization style

There are a number of detailed schemes for dividing mineral occurrences into groups representing the style of mineralization, the most widely used probably being that of Cox and Singer (1986). 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.

GSWA has adopted the principles of ore deposit classification from Evans (1987). 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 below 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 1.3).

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.

Mineral occurrence determination limits

The lower cut off for a mineral occurrence is more reliably based on WAMEX exploration company information. Minimum intersections in drillholes or trenches for a number of commodities are given in Table 1.4.

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

References

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Table 1.2. Modifications made to the Mining Journal Ltd (1997) commodity classification

Commodity group (Mining Journal Ltd, 1997)	*Commodities*	*Changes made for WAMIN commodity group*
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
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 minerals	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 1.3. WAMIN authority table for mineralization styles and groups

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

NOTE: (a) The white symbol colour used in this table does not indicate the commodity group in Table 1.1

Table 1.4. Minimum intersections for mineral occurrences in drill-holes or trenches

Element	*Intersection length (m)*	*Grade*
Hard rock and lateritic deposits		
Gold	>5	>1 ppm
Silver	>10	>1 ppm
Platinum	>0.5	>1 ppm
Lead	>5	>0.5%
Zinc	>5	>2%
Copper	>5	>0.5%
Nickel	>5	>0.5%
Cobalt	>5	>0.1%
Chromium	>0.2	>5% Cr_2O_3
Tin	>5	>0.02%
Iron	>5	>40% Fe
Manganese	>5	>25%
Uranium	>5	>1000 ppm U
Diamonds	na	any diamonds
Tantalum	>5	>200 ppm
Tungsten	>5	>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: na: not applicable

Appendix 2

Description of digital datasets

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.

Solid geology and regolith

The solid geology and regolith incorporates an interpretation of the study area, based on a recent compilation of GSWA mapping and Landsat TM interpretation at 1:100 000 scale. The full details of the solid geology and regolith are held on the CD-ROM. The regolith on Plate 1 is a simplified version of the digital dataset on the CD-ROM, and uses two overprints to distinguish relict and depositional regimes. The CD-ROM also includes a large number of solid geology and regolith units that are smaller than 250 000 m^2 in area that were omitted from Plate 1 for simplicity.

Mineral occurrences (WAMIN)

The mineral occurrence dataset as used in this Report and on Plate 1 is described in Appendix 1. The dataset on the CD-ROM includes textual and numeric information on:

- location of the occurrences (AMG 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.

WAMEX

All relevant open-file company mineral exploration reports held in the DME WAMEX database and library 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 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 JORC (1996) 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 number as a cross-reference for this information. WAMIN may contain pre-resource global estimates that do not conform to the JORC (1996) code, and are not included in MINEDEX.

TENGRAPH

The TENGRAPH database (DME'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. 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.

SPINDEX

A GIS based spatial activity index (SPINDEX) to historical open-file mineral exploration in the study area has been assembled (Ferguson, 1995). The index contains spatial and textual information defining the location of exploration activity in the area. SPINDEX, for the Bangemall area, was compiled between 1996 and 1997, and contains information on types of mineral exploration activity such as statistics relating to:

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

Positional data were taken from hard-copy maps of various scales, from company reports, located from coordinate and/or geographical information, transferred onto 1:50 000 scale maps, and then digitized. Table 2.1 lists the activity types.

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

Table 2.1. Exploration activity types

Activity	*Description*
ACH	Airborne geochemistry
AEM	Airborne electromagnetic surveys
AGRA	Airborne gravity surveys
AMAG	Airborne magnetic surveys
ARAD	Airborne radiometric surveys
DIAM	Diamond drilling
EM	Electromagnetic surveys (includes TEM, SIROTEM)
GEOL	Geological mapping
GEOP	Other geophysical surveys (includes IP, resistivity)
GRAV	Gravity surveys
HYDR	Groundwater surveys
LSAT	Landsat TM data
MAG	Magnetic surveys
NGRD	Non-gridded geochemical surveys (includes chip, channel, dump, and gossan)
RAB	RAB drilling (includes other shallow geochemical drilling, such as auger)
RAD	Radiometric surveys (includes downhole logging)
RC	RC drilling
REGO	Regolith surveys (includes laterite, pisolite, and ironstone)
RES	Resistivity
ROT	Rotary drilling (predominantly percussion drilling)
SEIS	Seismic surveys
SOIL	Soil surveys
SSED	Stream–sediment surveys

Geophysics

The aeromagnetic data covering the area are presented in the form of a colour, total magnetic intensity (TMI) image. The data used to create the image were flown by the Australian Geological Survey Organisation (AGSO), mostly at a line spacing of 1500 m, and gridded to a cell size of 800 m. More-detailed surveys have been undertaken in recent years, but these data are part of a commercial, multi-client survey, and can only be obtained from World Geoscience Corporation.

Measurements of the background radiation using an airborne crystal usually took place concurrently with the AGSO 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 AGSO, at a nominal station spacing of 11 km, is presented in the digital dataset as an image showing the Bouguer anomaly, gridded to a cell size of 5 km.

Landsat

Landsat TM imagery has been acquired for all the 1:250 000 map sheets covered by the western part of the Bangemall Basin (Plate 1). The raw data are available commercially through the Remote Sensing Services section of the Department of Land Administration. 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 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.

Roads and culture

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

Place names for the area are given in a separate file, and include major hills, stations, and communities. More comprehensive topographical and cultural data, including drainage, can be obtained from the Australian Land Information Group (AUSLIG). GSWA is currently completing an initiative that will see the area covered by a fully revised dataset of topography, drainage, and cultural features based on high-resolution satellite imagery.

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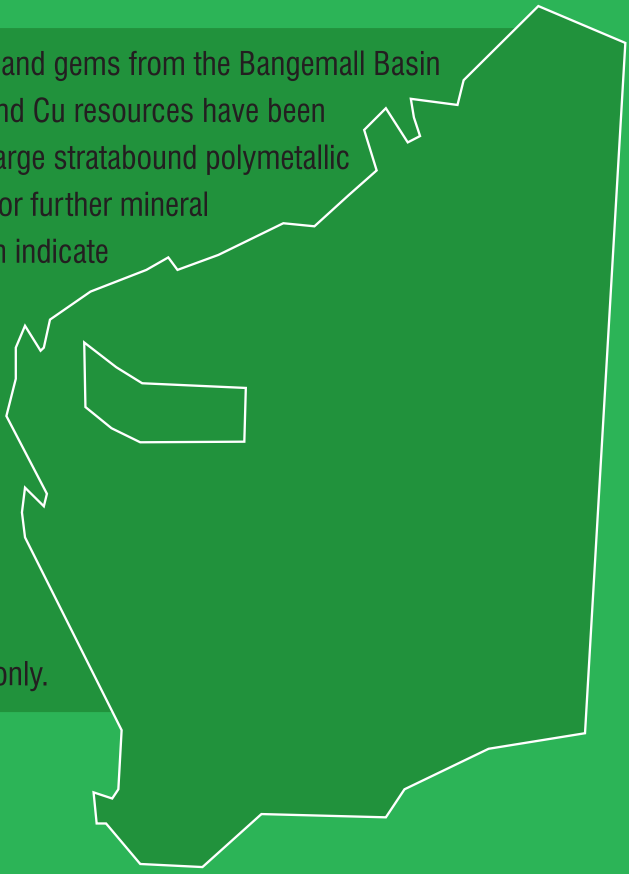
There has been limited production of Au, base metals, and gems from the Bangemall Basin since the first mineral discoveries in 1896. Minor Au and Cu resources have been outlined. The currently uneconomic Abra deposit is a large stratabound polymetallic deposit of 200 Mt. The basin has significant potential for further mineral discoveries. In particular, the controls on mineralization indicate that the greatest potential is for Abra-style Pb–Cu–Ag–barite mineralization. Deposits and occurrences of low-grade Mn, U, talc, and asbestos are also present. This Report, which includes a 1:500 000-scale map, is an explanatory note to a major new digital dataset, and describes the geology and 150 mineral occurrences within the main Bangemall Group outcrop area. The geology and a further 140 mineral occurrences outside the basin are included in the dataset and map only.



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

Information Centre
Department of Minerals and Energy
100 Plain Street
East Perth WA 6004

Phone: (08) 9222 3459   Fax: (08) 9222 3444

Mineral occurrence data compiled by R. W. Cooper, R. L. Langford, and M. Keep 1998

Geology compiled by L. Bagas, A. M. Thorne, I. M. Tyler, and I. Copp 1997, and using GSWA maps (see sheet index)

Edited by F. Apidopoulos and G. Loan

Cartography by S. Collopy, N. Kashani, J. Kirk, and B. Williams

Mineralization information on this map is largely derived from non-confidential data held in the WAMIN database, GSWA at February 1998

Topography from the Department of Land Administration Sheets SF 50-10, -14, -15, -16; SG 50-2, -3, -4, -7, -8

Published by the Geological Survey of Western Australia. Copies available from the Information Centre, Department of Minerlas and Energy, 100 Plain Street, East Perth, WA, 6004. Phone (08) 9222 3459, Fax (08) 9222 3444

Data presented on this map are available in digital form

Printed by the Sands Print Group, Western Australia

The recommended reference for this map is:
COOPER, R. W., BAGAS, L., THORNE, A. M., TYLER, I. M., COPP, I. M., and LANGFORD, R. L., 1998 Mineralization and geology of the Bangemall Basin (1:500 000 scale), *in* Mineral occurences and exploration potential of the Bangemall Basin *by* R. W. COOPER, R. L. LANGFORD, and F. PIRAJNO: Western Australia Geological Survey, Report 64, Plate 1.

DEPARTMENT OF MINERALS AND ENERGY
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GOVERNMENT OF WESTERN AUSTRALIA
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MINISTER FOR MINES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
DAVID BLIGHT, DIRECTOR

SCALE 1:500 000

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 50

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

REPORT 64 PLATE 1

MINERALIZATION AND GEOLOGY OF THE BANGEMALL BASIN