EXPLANATORY NOTES

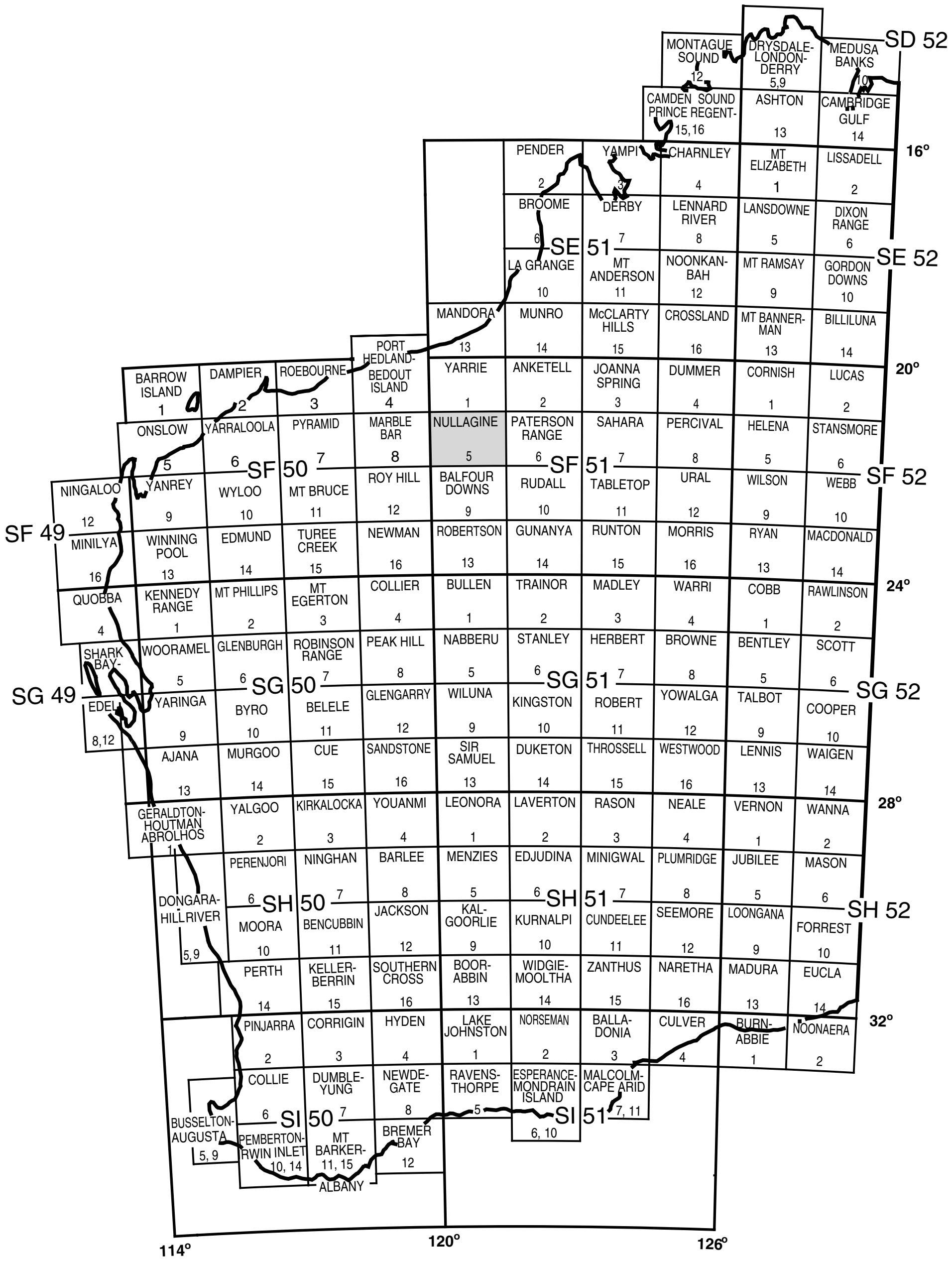
Department of
Industry and Resources

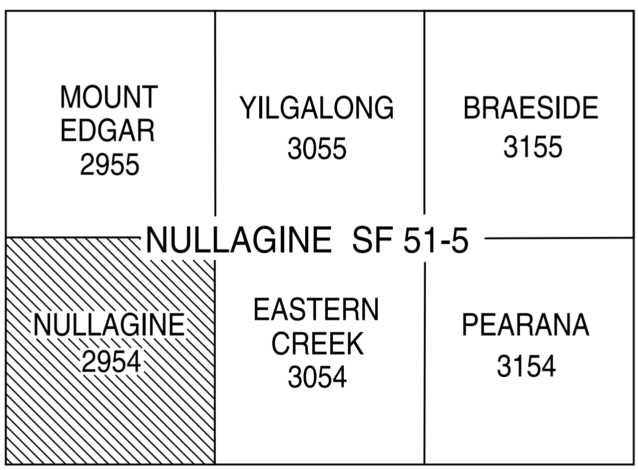
GEOLOGY OF THE NULLAGINE 1:100 000 SHEET

by L. Bagas

1:100 000 GEOLOGICAL SERIES

Geological Survey of Western Australia





LB233 18.05.05

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGY OF THE NULLAGINE 1:100 000 SHEET

by
L. Bagas

Perth 2005

MINISTER FOR STATE DEVELOPMENT
Hon. Alan Carpenter MLA

DIRECTOR GENERAL, DEPARTMENT OF INDUSTRY AND RESOURCES
Jim Limerick

DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
Tim Griffin

REFERENCE
The recommended reference for this publication is:
BAGAS, L., 2005, Geology of the Nullagine 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 33p.

National Library of Australia Card Number and ISBN 1 74168 006 9

ISSN 1321–229X

Grid references in this publication refer to the Geocentric Datum of Australia 1994 (GDA94). Locations mentioned in the text are referenced using Map Grid Australia (MGA) coordinates, Zone 51. All locations are quoted to at least the nearest 100 m.

Copy editor: I. R. Nowak
Cartography: S. Dowsett
Desktop publishing: K. S. Noonan

Published 2005 by Geological Survey of Western Australia
This Explanatory Note is published in digital format (PDF), as part of a digital dataset on CD, and is available online at www.doir.wa.gov.au/gswa/onlinepublications. Laser-printed copies can be ordered from the Information Centre for the cost of printing and binding.

Further details of geological publications and maps produced by the Geological Survey of Western Australia are available from:
Information Centre
Department of Industry and Resources
100 Plain Street
EAST PERTH, WESTERN AUSTRALIA 6004
Telephone: +61 8 9222 3459 Facsimile: +61 8 9222 3444
www.doir.wa.gov.au/gswa/onlinepublications

Cover photograph:
Chevron folded, thinly bedded, ferruginized siltstone in the Paddy Market Formation of the Gorge Creek Group (at MGA 201600E 7609700N)

Contents

Figures

Table

Geology of the Nullagine 1:100 000 sheet

by

L. Bagas

Abstract

The NULLAGINE 1:100 000 sheet covers parts of three of the five major tectonic units within the older, granite–greenstones of the Pilbara Craton. The 3515–2830 Ma East Pilbara Granite–Greenstone Terrane (EPGGT) is unconformably overlain by the 2930–2905 Ma Mosquito Creek Basin (MCB), and this is in faulted contact with the 3200–2840 Ma Kurrana Terrane (KT). The greenstone succession of the EPGGT is referred to as the Pilbara Supergroup, which comprises the 3490–3315 Ma Warrawoona Group, the <3308 Ma Budjan Creek Formation, the undated Copper Gorge Formation, the 3235–2950 Ma Gorge Creek Group, the 2950–2905 Ma De Grey Group, and various lithological units not stratigraphically assigned. NULLAGINE also includes 2775–2717 Ma volcanic and sedimentary formations of the Fortescue Group. This basal unit of the Hamersley Basin unconformably overlies the granite–greenstones. NULLAGINE contains a linear suite of c. 1800 Ma hornblende-bearing quartz syenite to quartz monzodiorite intrusions, probably related to collision between the Pilbara Craton and a continent to the northeast along the Paterson Orogen.

The Pilbara Supergroup outcrops in the Kelly, McPhee, and Yilgalong greenstone belts. ON NULLAGINE the lower part of the Warrawoona Group is not exposed, and the oldest outcropping formation is the c. 3433 Ma Panorama Formation. This is overlain by the Strelley Pool Chert, Euro Basalt (c. 3346 Ma), Wyman Formation (3325–3315 Ma), and Charteris Basalt. Coarse volcaniclastic and clastic sedimentary rocks of the Budjan Creek Formation and volcanic rocks of the Copper Gorge Formation unconformably overlie the Warrawoona Group. Clastic sedimentary rocks of the Gorge Creek Group unconformably overlie the Budjan Creek Formation. The greenstones of the EPGGT are unconformably overlain or in faulted contact with rocks of the Mosquito Creek Basin.

The first deformation event recognized on NULLAGINE, D_{EP2}, resulted in tilting and large-scale open to tight folding of the Warrawoona Group, the development of a penetrative foliation and lineation in the group, and layer-parallel normal and reverse faults within the greenstone belts. D_{EP2} structures formed at between 3315 and 3308 Ma, synchronous with magmatic emplacement of the rocks of the Corunna Downs Granitoid Complex. D_{EP3} deformation involved tilting of the Budjan Creek and Gorge Creek Groups away from the Corunna Downs Granitoid Complex, and thus took place after c. 3308 Ma, but before deposition of the Fortescue Group. The Mosquito Creek Basin and Kurrana Terrane were folded (F_{MB1-2}) and foliated (S_{MB1}) between c. 2926 and 2905 Ma, and folded and faulted (D_{MB3}) at c. 2905 Ma. The first event to affect the Fortescue Group, $D_{FG1,}$ involved syndepositional faulting and dolerite dyke intrusion between c. 2775 and 2756 Ma. A <2719 Ma D_{FG2} event involved folding of the lower formations of the Fortescue Group. The <2719 Ma D_{FG3} deformation included late, east-side-down normal faults.

The greenstone belts on Nullagine contain numerous mineral occurrences of gold and base metals. Base metal mineralization (dominantly Cu) in the Kelly greenstone belt is hydrothermal in origin and probably related to igneous activity associated with the <3308 Ma Budjan Creek Formation and contemporaneous magmatism within the Corunna Downs Granitoid Complex. The Mosquito Creek Formation hosts numerous gold prospects and mines in shear zones parallel to, but offset from, the major D_{MB3} shear zones.

KEYWORDS: Archaean, Warrawoona Group, Gorge Creek Group, De Grey Group, Fortescue Group, lithostratigraphy, geochronology, structure, metamorphism, mineralization

Introduction

The NULLAGINE* (SF 5152954) 1:100 000 sheet covers the southwestern part of the NULLAGINE 1:250 000 sheet (SF 51-5), between latitudes 21°30' and 22°00'S and longitudes 120°00' and 120°30'E (Fig. 1), and lies within the East Pilbara Mineral Field. The area lies in the northeastern part of the Pilbara Craton (Fig. 1), and covers parts of the East Pilbara Granite–Greenstone Terrane (EPGGT; Hickman, 2001), Mosquito Creek Basin (MCB), Kurrana Terrane (KT), and Hamersley Basin.

Access, climate, and vegetation

The town of Nullagine is situated on the banks on the Nullagine River. A graded road links Nullagine with Newman to the south and Marble Bar to the north. Access within NULLAGINE is by intermittently maintained pastoral tracks and mining exploration tracks. These extend from the Newman – Marble Bar Road to the abandoned Copper Hills mining area on SPLIT ROCK to the west and into the area around McPhee Creek to the north (Fig. 2). Numerous tracks also extend from Skull Springs Road, which traverses eastwards from Nullagine. Much of the area is accessible by 4WD vehicle both on and off tracks, with only the rugged terrain in the north and west inaccessible.

The region around NULLAGINE has an arid climate with a mean annual rainfall of approximately 300 mm and an average annual evaporation of about 3600 mm. The region is dry during the late winter to early summer months. Rainfall is erratic, with little precipitation falling during the winter months, but the area is subject to floods during cyclonic and thunderstorm activity between November and March. Average summer temperatures range from daily minima of about 25°C to maxima in the forties (°C), whereas daily winter temperatures typically vary between minima of around 12.5°C and maxima of about 25°C (Pink, 1992). The prevailing winds blow from the east and southeast. Several species of spinifex grass (*Triodia*) are present in the area, with the largest species growing along the banks of drainage lines. Elsewhere, the size and species of spinifex depend on the availability of near-surface water and when the area was last burned. Sandy areas and some valleys contain *Grevillea*, wattles (*Acacia*), soft shrubs (*Crotalaria*), eucalypts, and tea tree (*Melaleuca*). Creeks and rivers contain large eucalypts and grasses, and areas of rock outcrop include small shrubs, grasses, mulga, stunted eucalypts, and fig trees. Mixed outcrop and colluvium contain spinifex, small shrubs, grasses, and *Acacia* spp. (Beard, 1975).

Physiography

Bedrock geology largely influences the physiography of NULLAGINE. Units within the greenstone belts and metasedimentary rocks form strike-controlled ridges and valleys, whereas granitic rocks have a more subdued topography. These geological regions correspond to the erosional 'Range' and 'Low hills' topographic divisions shown on Figure 2, and the Range division represents the most rugged topographic areas.

The dissected plateau and rugged hills with dendritic drainage physiographic units represent a relict erosional land surface in the southwestern part of NULLAGINE. These units have developed over the Fortescue Group. Major creeks and rivers that eventually drain into the northeasterly trending Nullagine River form valleys containing mixed alluvial and colluvial deposits, but these watercourses are generally dry except during, and soon after, the wet summer months.

The highest point elevation is 536 m above mean sea level (AMSL) in the southeastern part of the sheet area (MGA 240251E 7565826N), and the lowest elevation of around 300 m AMSL is on the Nullagine River in the northeastern corner of the sheet area (e.g. MGA 238760E 7618852N).

Previous and current investigations

Alluvial gold was discovered near Nullagine in 1886 and gave impetus for further exploration for gold and other precious metals in the region, which continues to this day. Noldart and Wyatt (1962) give details of the early history of exploration, mining, and geological studies as part of a bulletin on the geology of the Marble Bar and Nullagine areas.

The Geological Survey of Western Australia (GSWA) mapped the NULLAGINE 1:250 000 sheet area in 1973 (Thom et al., 1973; Hickman, 1978). At this time, the Archaean layered succession was subdivided into the lower, dominantly volcanic Warrawoona Group, and the overlying, dominantly sedimentary Gorge Creek Group (Lipple, 1975). The Warrawoona Group was divided into nine formations, assigned to the dominantly basaltic lower Talga Talga and upper Salgash Subgroups, and six formations to the Gorge Creek Group. This subdivision was similar to that of Ingram (1977), who also recognized the cyclic nature of the volcanic formations in the Warrawoona Group.

Hickman (1983) grouped the oldest volcano-sedimentary rocks across the North Pilbara Craton into the 'Archaean Pilbara Supergroup'. Hickman (1990) again modified this stratigraphic nomenclature to include the Mosquito Creek Formation, the Lalla Rookh Sandstone, and the Mallina Formation in the De Grey Group as the youngest component of the Pilbara Supergroup. Davy (1988) and Bagas et al. (2003) presented the results of detailed geochemical studies of the Corunna Downs Granitoid Complex.

Since the 1980s, various research groups have proposed that the structural history of the area involves either horizontal compressional tectonics or various diapiric models for the emplacement of Archaean granitic

* Capitalized names refer to standard map sheets. Where 1:100 000 and 1:250 000 sheets have the same name, the 1:100 000 sheet is implied unless otherwise indicated.

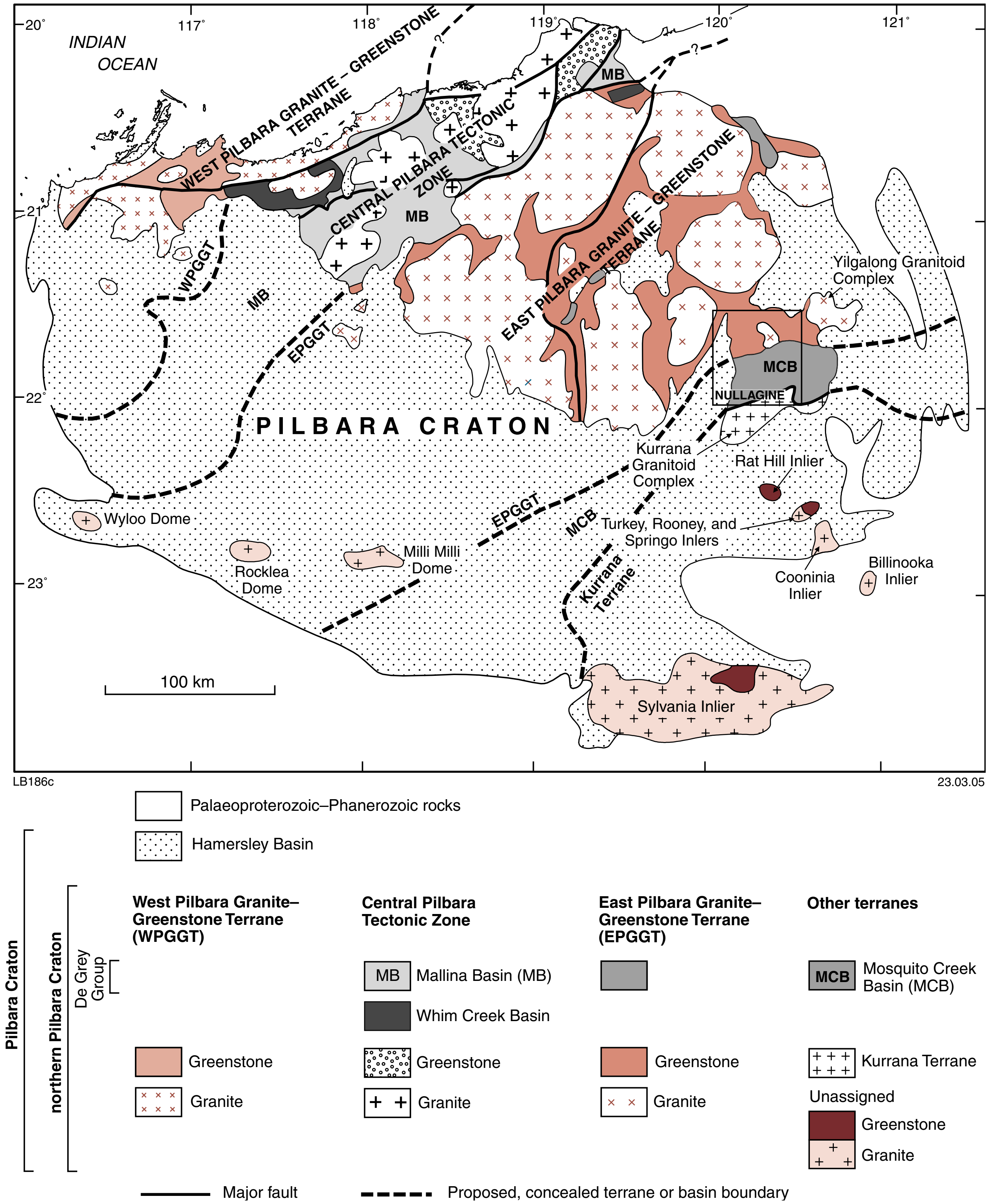


Figure 1. Regional geological setting of NULLAGINE

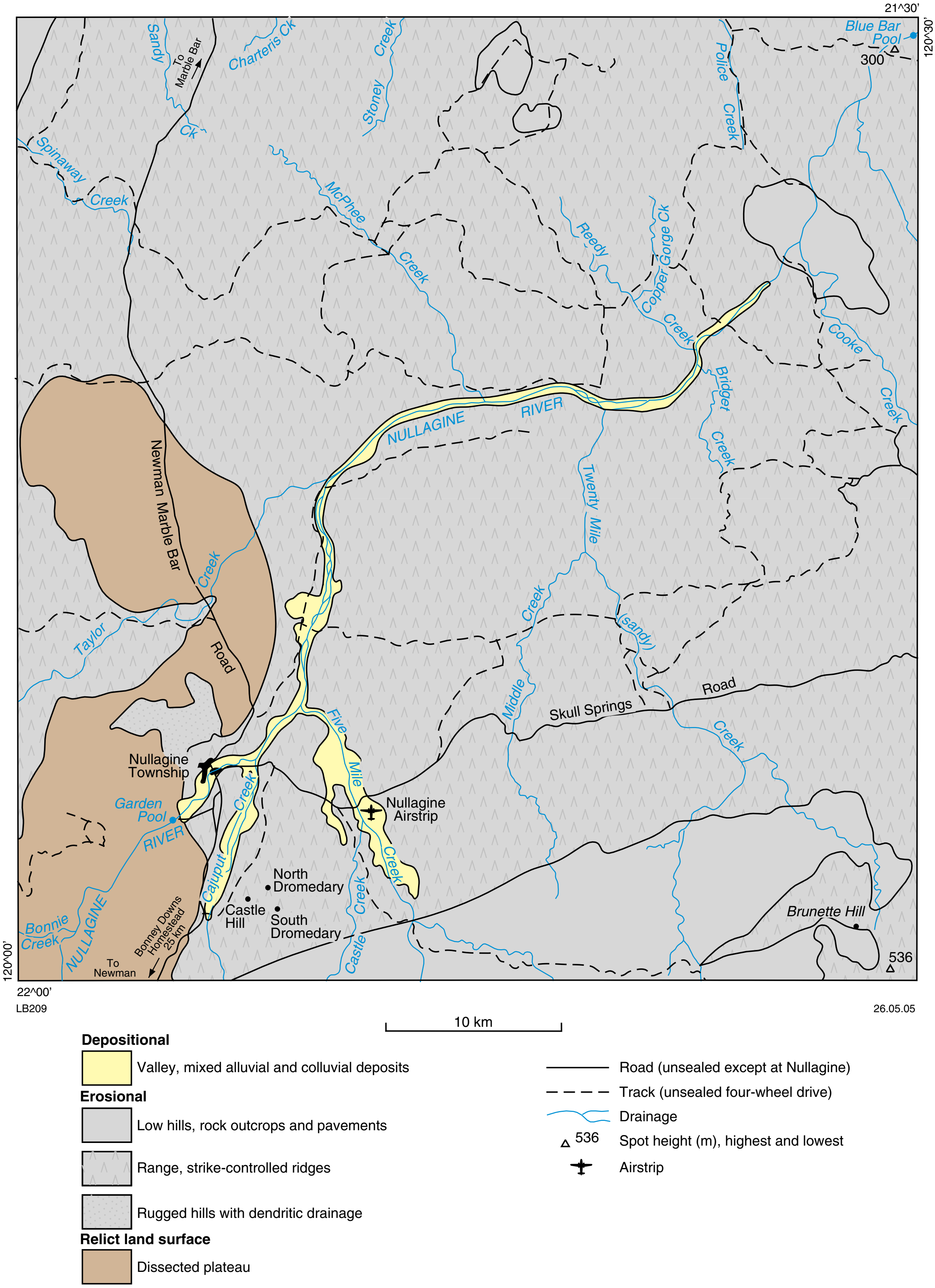


Figure 2. Physiography and access on NULLAGINE

complexes. Summaries of previous work are included in Van Kranendonk et al. (2002) and Blewett (2002).

Under the National Geoscience Mapping Accord (NGMA, later renamed the National Geoscience Agreement, NGA) between GSWA and Geoscience Australia, total aeromagnetic and radiometric surveys of the North Pilbara (Mackey, 1997a,b,c) were completed between 1995 and 1996. The data were acquired on flight lines spaced 400 m apart with a sampling interval of approximately 70 m. Total aeromagnetic and radiometric images for NULLAGINE are available at the Department of Industry and Resources.

Bagas et al. (2004a) redefined the Kelly Subgroup to include the Strelley Pool Chert, Euro Basalt, Wyman Formation, and Charteris Formation, due to the recognized hiatus between the Panorama Formation and overlying Strelley Pool Chert (Van Kranendonk et al., 2004).

These Notes, and the accompanying NULLAGINE geological map, are based on regional mapping by O. Beukenhorst and K. Hos from Utrecht University in The Netherlands (Beukenhorst and Hos, 1999), and L. Bagas of GSWA during 1999–2002, using 1:25 000-scale colour aerial photographs together with interpretation of regional magnetic and radiometric data.

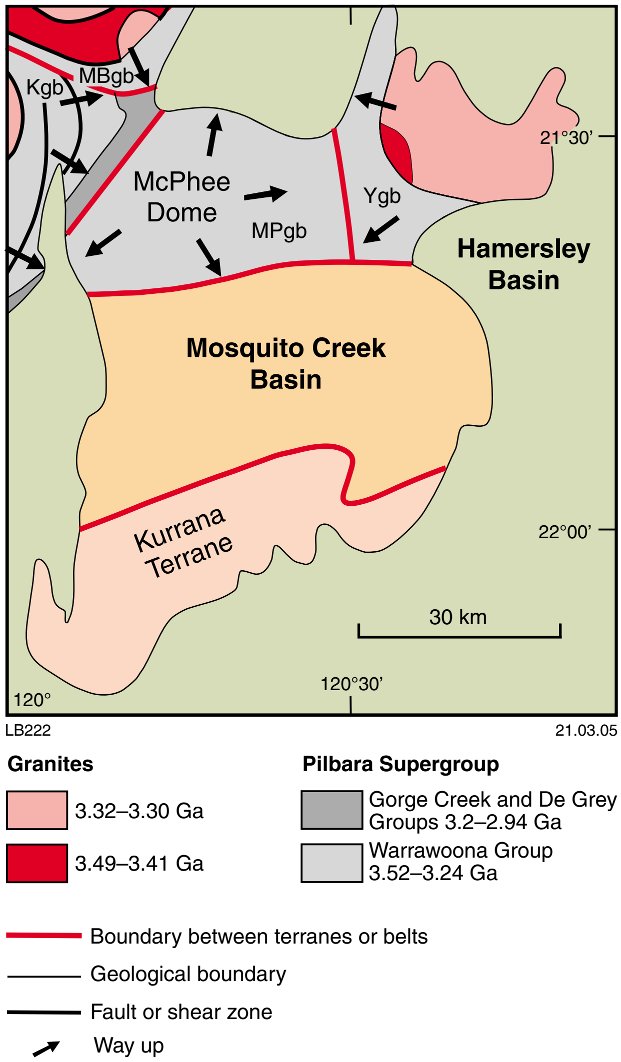


Figure 3. Simplified geological map of the area around NULLAGINE, showing the main tectonic units, generalized stratigraphy, location of greenstone belts, and terrane boundaries. Abbreviations: Kgb, Kelly greenstone belt; MBgb, Marble Bar greenstone belt; MPgb, McPhee greenstone belt; Ygb, Yilgalong greenstone belt

Regional geological setting

The Pilbara Craton has an exposed area of about 183 000km^2. The craton comprises Palaeo- to Mesoarchaean (3655–2830 Ma) granite–greenstone successions of the northern Pilbara Craton, and the unconformably overlying Neoarchaean to Palaeoproterozoic (2770–2400 Ma) volcanic and sedimentary formations of the Hamersley Basin (Hickman, 1983; Blake, 1993). Van Kranendonk et al. (2002) and Thorne and Trendall (2001) summarized the stratigraphy of the northern Pilbara Craton and Hamersley Basin, respectively. Hickman (1983) grouped the older granite–greenstone belts of the northern Pilbara Craton into the Pilbara Supergroup, and Van Kranendonk et al. (2002) subdivided the northern Pilbara Craton into the West Pilbara Granite–Greenstone Terrane (WPGGT), Mallina Basin, EPGGT, Mosquito Creek Basin, and the Kurrana Terrane (Fig. 1). Many of the successions are separated by regional unconformities or disconformities, and generally dip and young away from granitic complexes that range in age from 3650 to 2850 Ma (Smithies and Champion, 1998; Nelson et al., 1999). The 2775–2400 Ma Hamersley Basin unconformably overlies these successions in the south or forms outliers in the northern Pilbara Craton (Trendall, 1990a; Blake, 2001).

NULLAGINE straddles the southeastern part of the EPGGT, Mosquito Creek Basin, and northern part of the Kurrana Terrane (Figs 1 and 3). In this region the arcuate Kelly, domical McPhee, and Yilgalong greenstone belts shown in Figure 3 comprise dominantly greenschist-facies volcanic rocks of the Warrawoona Group (Fig. 4). The Warrawoona Group is intruded by granitic rocks of the 3317–3313 Ma Corunna Downs Granitoid Complex, c. 3313 Ma Gobbos Granodiorite, Cooke Creek Monzogranite, and the c. 1803 Ma Bridget Suite of intrusive rocks, with local contact metamorphism to hornblende-hornfels facies.

The Warrawoona Group in the northwestern part of NULLAGINE is unconformably overlain by the <3308 Ma Budjan Creek Formation, which in turn is unconformably overlain by the dominantly clastic sedimentary rocks of the c. 3235–2950 Ma Gorge Creek Group (Fig. 5). In the central part of NULLAGINE, the Warrawoona Group is unconformably overlain or faulted against the c. 2930 Ma De Grey Group and unassigned mafic, felsic and ultramafic rocks (Fig. 5).

The late Archaean Fortescue Group (c. 2775–2629 Ma) is the oldest component of the Mount Bruce Supergroup in the Hamersley Basin (Trendall, 1990a). The group occupies the northern and southwestern parts of NULLAGINE (Fig. 1).

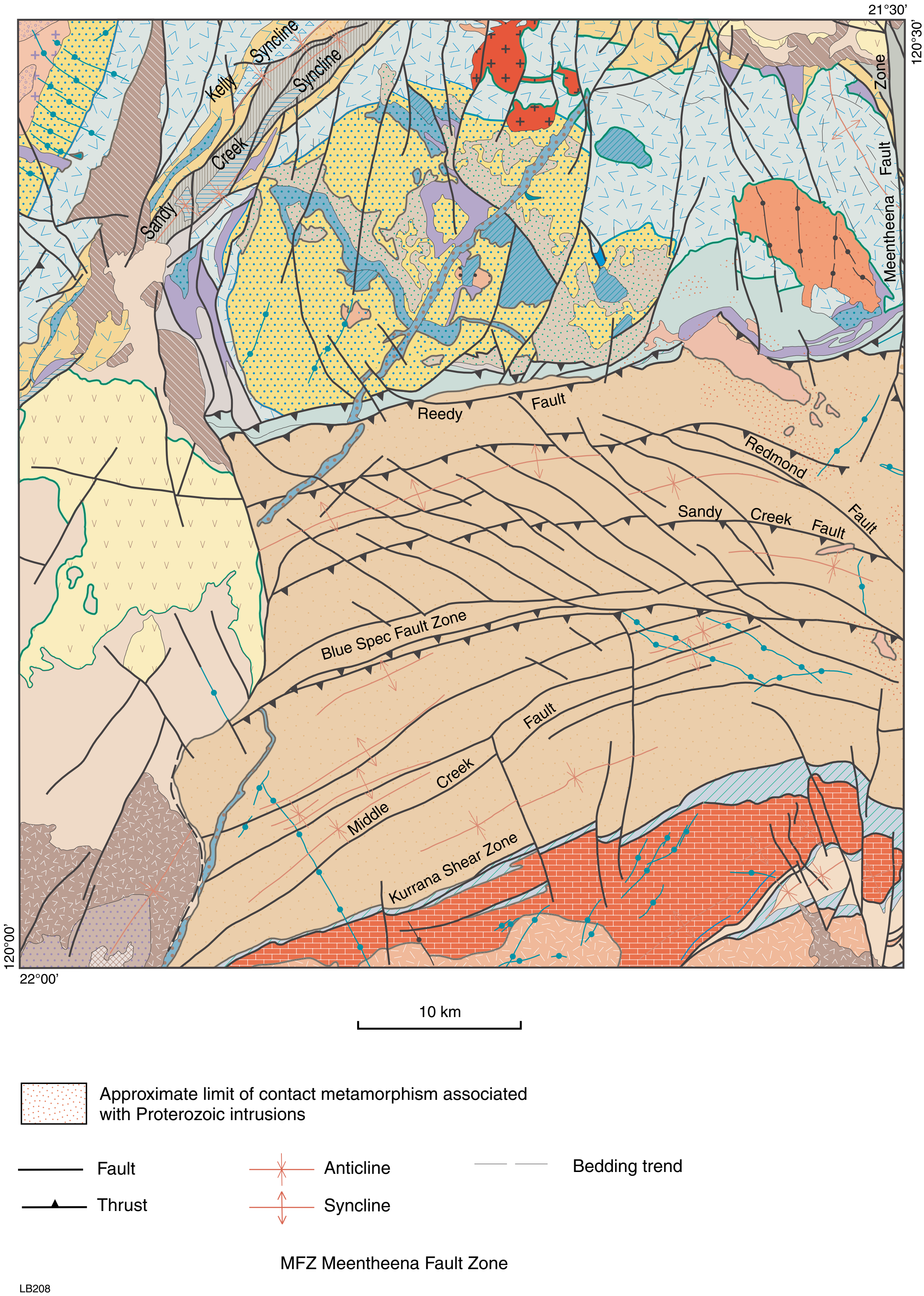
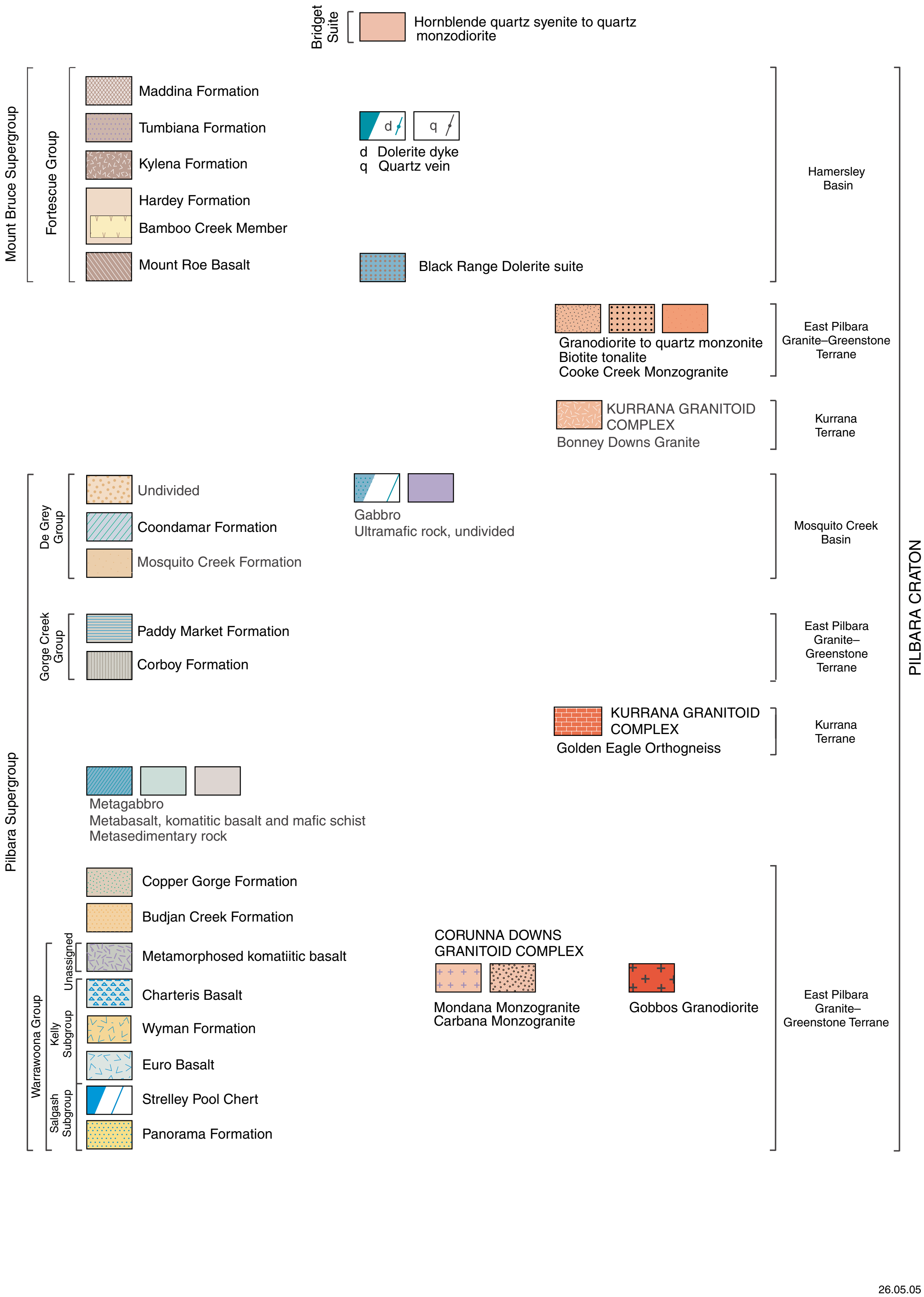


Figure 4. Simplified interpreted bedrock geological map of NULLAGINE



Bridget Suite
Hornblende quartz syenite to quartz monzodiorite
Mount Bruce Supergroup
Fortescue Group
Maddina Formation
Tumbiana Formation
Kylena Formation
Hardey Formation
Bamboo Creek Member
Mount Roe Basalt
d
q
d Dolerite dyke
q Quartz vein
Black Range Dolerite suite
Hamersley Basin
Granodiorite to quartz monzonite
Biotite tonalite
Cooke Creek Monzogranite
East Pilbara Granite–Greenstone Terrane
KURRANA GRANITOID COMPLEX
Bonney Downs Granite
Kurrana Terrane
Pilbara Supergroup
De Grey Group
Undivided
Coondamar Formation
Mosquito Creek Formation
Gabbro
Ultramafic rock, undivided
Mosquito Creek Basin
Gorge Creek Group
Paddy Market Formation
Corboy Formation
East Pilbara Granite–Greenstone Terrane
KURRANA GRANITOID COMPLEX
Golden Eagle Orthogneiss
Kurrana Terrane
PILBARA CRATON
Metagabbro
Metabasalt, komatitic basalt and mafic schist
Metasedimentary rock
Copper Gorge Formation
Budjan Creek Formation
Warrawoona Group
Unassigned
Metamorphosed komatiitic basalt
Kelly Subgroup
Charteris Basalt
Wyman Formation
Euro Basalt
Salgash Subgroup
Strelley Pool Chert
Panorama Formation
CORUNNA DOWNS GRANITOID COMPLEX
Mondana Monzogranite
Carbana Monzogranite
Gobbos Granodiorite
East Pilbara Granite–Greenstone Terrane
26.05.05

Archaean Pilbara Craton

All Archaean rocks on NULLAGINE are part of the Pilbara Craton, and have been deformed and metamorphosed. In these Explanatory Notes, protolith rock terminology is used where possible and rocks have been placed within a lithostratigraphic context. However, in some areas, deformation and metamorphism have so obscured primary features that identification of the protolith is uncertain and rocks are identified solely by their metamorphic lithology.

Archaean supracrustal rocks on NULLAGINE are subdivided into the EPGGT, Kurrana Terrane, Mosquito Creek Basin, and the Hamersley Basin. The EPGGT is subdivided into the Warrawoona Group, Corunna Downs Granitoid Complex, Gobbos Granodiorite, Budjan Creek Formation, Copper Gorge Formation, and Gorge Creek Group. On NULLAGINE, the Mosquito Creek Basin consists only of the De Grey Group, and the Hamersley Basin consists only of the Fortescue Group (Fig. 5).

East Pilbara Granite–Greenstone Terrane

Warrawoona Group

The Warrawoona Group on SPLIT ROCK is, from base to top, subdivided into the Talga Talga Subgroup, Towers Formation, Salgash Subgroup, and Kelly Subgroup (Bagas et al., 2004a). On NULLAGINE, the base of the group is either concealed by younger units or intruded by granitic rocks, and the top is either obscured by faulting or unconformably overlain by rocks of the Budjan Creek Formation, Gorge Creek Group, De Grey Group, or Fortescue Group. The Black Range Dolerite Suite and unassigned granite, dolerite, gabbro, and ultramafic rocks also intrude the group.

The Salgash Subgroup (Hickman, 1983) on NULLAGINE includes the Panorama Formation, and the Strelley Pool Chert. However, the Strelley Pool Chert has recently been re-assigned to the base of the newly defined Kelly Group, because recent mapping outside NULLAGINE indicates that it lies above a disconformity or a regional unconformity on older rocks (Van Kranendonk et al., 2004).

As mapped on NULLAGINE, the Kelly Subgroup includes the Euro Basalt, Wyman Formation, and Charteris Basalt. The age range of the subgroup is defined by c. 3350 Ma ages from the Euro Basalt, and 3325–3315 Ma ages for the Wyman Formation (Bagas et al., 2004a). A maximum age for the subgroup is defined by the youngest age of the unconformably underlying Panorama Formation (Warrawoona Group) at c. 3426 Ma. No age data are available on the stratigraphically youngest Charteris Basalt, which is spatially restricted to the structurally complex area of southern MOUNT EDGAR and northern NULLAGINE. The formation has geochemistry similar to that of the Euro Basalt (Glikson and Hickman, 1981).

The Kelly Subgroup records the onset of sedimentary deposition and a cycle of volcanism after a hiatus that is recorded in the sequence over 220 km across the EPGGT (Van Kranendonk et al., 2002). The hiatus marks the period after the c. 3426 Ma deposition of the Panorama

Supergroup	Group	Subgroup	Formation
Mount Bruce	Fortescue		Maddina Formation (c. 2717 Ma) Tumbiana Formation (c. 2719 Ma) Kylena Formation (c. 2741 Ma) Hardey Formation (c. 2764–2756 Ma) Bamboo Creek Member (c. 2756 Ma) Mount Roe Basalt (c. 2775–2763 Ma) Black Range Dolerite suite (c. 2772 Ma)
Pilbara	De Grey		Mosquito Creek Formation (c.2926 Ma) Coondamar Formation
	Gorge Creek (c. 3235–2950 Ma)		Paddy Market Formation Corboy Formation
			Budjan Creek Formation (<3308 Ma)
	Warrawoona	Kelly	Charteris Basalt Wyman Formation (c. 3325–3315 Ma) Euro Basalt (c. 3350–3325 Ma)
		Salgash	Strelley Pool Chert Panorama Formation (c. 3433–3427 Ma)

LB226 09.03.05

Unconformity

Figure 5. Archaean stratigraphy exposed on NULLAGINE

Formation, and before deposition of the 3350–3315 Ma Kelly Subgroup (Bagas et al. 2004a).

Mount Ada Basalt (AWm) and Duffer Formation (AWd; subsurface only)

Dominantly basaltic rocks of the Mount Ada Basalt and the felsic volcanic rocks of the Duffer Formation are interpreted to be present at depth in the McPhee Dome on NULLAGINE. These rocks are included in the Talga Talga Subgroup (Fig. 5; Van Kranendonk et al., 2002).

Panorama Formation (AWp, AWpfa, AWpft, AWpftd, AWpcc, AWpcch)

On NULLAGINE, the Panorama Formation (Lipple, 1975) consists of 3433–3426 Ma felsic volcaniclastic rocks, with subordinate felsic lavas and chert (*AWp*). The formation outcrops in the centre of the McPhee greenstone belt, and in the northwestern part of NULLAGINE where it is intruded by granitic rocks at the northeastern margin of the Corunna Downs Granitoid Complex. Four samples of dacitic agglomerate and rhyolite, collected from the Kelly greenstone belt at Sandy Creek in the southwestern corner of MOUNT EDGAR, are between 3433 and 3426 Ma (Nelson, 2000, 2001, 2002). Dacite from the formation in the McPhee Dome (UWA sample MP1; approximately from MGA 207600E 7606500N) has a sensitive high-resolution ion microprobe (SHRIMP) U–Pb zircon age of 3430 ± 3 Ma (Barley et al., 1998). These ages are within error of the dates for samples of the Panorama Formation from SPLIT ROCK (Bagas et al., 2004a).

The Panorama Formation is composed of felsic agglomerate interbedded with minor tuff (airfall pyroclastic rocks) and andesitic basalt (*AWpfa*), and felsic tuff interbedded with minor felsic agglomerate, quartz, biotite, hornblende partly replaced by epidote and chlorite, and minor microperthitic K-feldspar, secondary sericite and carbonate, and accessory titanite and apatite. The proportion of interbedded agglomerate increases in the southern part of the McPhee greenstone belt. The agglomerate in the southern part of the McPhee greenstone belt contains subangular fragments of dacite and rhyolite reaching 0.2 m in size. Elsewhere in the belt the agglomerate is finer grained and composed of subrounded fragments of dacite and rhyolite. Similarly, the proportion of agglomerate increases along strike in the Kelly greenstone belt on the northwestern part of NULLAGINE. This facies change is probably controlled by proximity to volcanic centres. The agglomerate also contains phenocrysts of sericitized plagioclase and subhedral quartz in a matrix dominated by quartz with minor amounts of sericite and rare, twinned feldspar. Dolerite sills are interlayered with the felsic tuff and felsic agglomerate (*AWpftd*) in the central part of the McPhee greenstone belt.

Layered grey-blue and white chert and minor massive cream chert (*AWpcc*) form thin units near the top of felsic agglomerate (included in *AWpfa*) in the northern part the McPhee greenstone belt (MGA 222385E 7606236N). The layering is commonly brecciated with abundant quartz veins, and laminae have Fe-oxide staining, probably after sulfide minerals.

Veins and dykes of hydrothermal black chert (*AWpcch*) crosscut the tuffaceous unit (*AWpft*) at the top of the Panorama Formation in the northeastern part of the Kelly greenstone belt. The hydrothermal chert veins appear to be feeders for the overlying Strelley Pool Chert, because they do not extend above this unit.

Strelley Pool Chert (AWs)

The Strelley Pool Chert (Lowe, 1983; Van Kranendonk and Morant, 1998) is a unit of white, grey, and blue-black layered and massive chert (*AWs*), locally including wavy and stromatolitic laminated chert (Fig. 6) and minor felsic ash, that is up to 30 m thick. The chert commonly has pseudomorphs after evaporites and wavy to conical stromatolites. Changes in elevation of the base of the formation provide evidence of relict topography and erosion in the underlying Panorama Formation. Corresponding thickness changes in the Kelly and McPhee greenstone belts accompany the local absence of the formation (e.g. in the southwestern part of the McPhee greenstone belt).

Euro Basalt (AWeb, AWebc, AWebd, AWebk, AWebx, AWed, AWecc, AWecch, AWeccp)

The Euro Basalt (Hickman, 1977) is the dominant stratigraphic unit in the Kelly greenstone belt, forms about half of the McPhee greenstone belt, and is c. 3350 to 3325 Ma (Bagas et al., 2004a). The formation conformably overlies the Strelley Pool Chert (e.g. MGA 102000E 7604000N), is conformably overlain by the 3325–3315 Ma Wyman Formation (e.g. MGA 224000E 7617200N), and is unconformably overlain by unassigned mafic, felsic and ultramafic rocks (e.g. MGA 230000E 7607200N). The Euro Basalt is about 5 km thick in the northern part of the McPhee greenstone belt, where a complete section is preserved. This thickness is similar to the one measured for the formation on SPLIT ROCK, 60 km to the west (Bagas et al., 2004a).

LB 210 27.09.04

Figure 6. Laminated Strelley Pool Chert (*AWs*) from the northern part of the McPhee greenstone belt (MGA 213350E 7616000N)

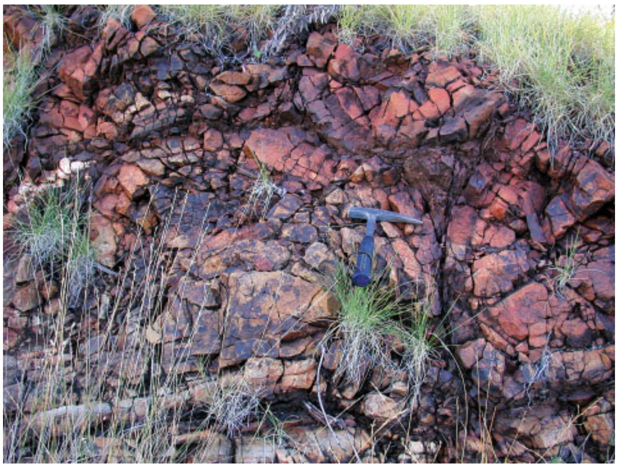


Figure 7. Pillowed Euro Basalt (*AWeb*) from the northwestern part of the McPhee greenstone belt (MGA 202200E 7609100N)

The base of the Euro Basalt on NULLAGINE characteristically contains a 500 m-thick unit of pillowed, ocellar, and locally vesicular komatiitic basalt interbedded with minor basalt (*AWebk*; MGA 206000E 7612300N). The overlying succession consists generally of pillowed basalt (Fig. 7) interlayered with minor komatiitic basalt (*AWeb*), rare basaltic tuff (*AWebx*), basalt interlayered with medium-grained dolerite and gabbro (*AWebd*), and subvolcanic sills of dolerite and local gabbro (*AWed*). In addition to the basaltic rocks, there are units of white, grey, and blue-black layered chert or massive blue-grey chert (*AWecc*), hydrothermal black chert veins (*AWecch*) that typically lack lamination, and chert interbedded with silicified pelite and ashfall tuff (*AWeccp*). In the eastern part of the McPhee greenstone belt (e.g. MGA 229000E 7608700N), other mafic rocks of the formation include intensely carbonate-altered metabasalt and local chlorite–carbonate schist (*AWebc*).

Pillowed basalt (*AWeb*) is fine grained and variably amygdaloidal, with amygdales containing quartz, chalcedony, or carbonate. Pillows have vesicular rims, chilled margins, concentric cooling cracks, intra-pillow hyaloclastite breccia, pillow tails, and pillow breccia. The basalt consists of a recrystallized assemblage of amphibole–plagioclase (variably altered to sericite)–quartz with minor chlorite, epidote, and carbonate. Komatiitic basalt (*AWebk*) has a spinifex texture with skeletal pyroxene blades up to 40 mm long, and patchy ocelli textures (Fig. 8). Komatiitic basalt consists of scattered plagioclase laths, which are up to 1.5 mm long and variably altered to clinozoisite with minor albite, and augite phenocrysts that are about 1 mm long in a fine-grained groundmass of tremolite–actinolite, chlorite, epidote, serpentine, microcrystalline titanite, carbonate (calcite and dolomite), and relict olivine. The relict olivine crystals are less than 1 mm in diameter, are altered, and contain inclusions of magnetite. Dolerite and gabbro that are interlayered with basalt (*AWebd*) are medium to coarse grained, and consist of plagioclase replaced by a combination of sericite, chlorite, quartz, green pleochroic amphibole (probably actinolite), relict pyroxene altered to a combination of chlorite–epidote–carbonate, and accessory titano-magnetite. The mineral assemblages in these rocks are interpreted to be consistent with greenschist facies metamorphism.

The upper part of the Euro Basalt in the northern part of the Kelly greenstone belt contains thin-bedded and locally massive white, grey, and blue-black layered chert (*AWecc*) composed of very fine grained quartz, minor sericite and accessory rutile, chert interbedded with silicified pelite and ashfall tuff (*AWeccp*), and basaltic tuff (*AWebx*). The ashfall tuff within interbedded chert and pelite (*AWeccp*) is composed of fine rock fragments of fine-grained quartz and sericite cemented in a recrystallized quartz matrix. The pelite of this unit is silicified carbonaceous quartz-rich shale, and consists of angular to subangular fine-grained quartz in a very fine grained matrix composed of clay, sericite, quartz, subhedral pyrite, and carbonaceous material. Basaltic tuff (*AWebx*) consists of subangular lithic clasts in a very fine grained matrix composed of interlocking feldspar, relict pyroxene, ?devitrified glass, and secondary chlorite, calcite, quartz, titanite, and pyrite. The top of the formation is marked by a locally massive white, grey, and blue-black layered chert (*AWecc*) in the northern part of the McPhee greenstone belt (e.g. MGA 224000E 7617200N).

Wyman Formation (AWwf, AWwfa, AWwft, AWwftc, AWwb, AWwcc, AWwssz)

The Wyman Formation (Lipple, 1975; Hickman and Lipple, 1978) conformably overlies the Euro Basalt (e.g. MGA 199150E 7512300N) and is interpreted to be conformably overlain by Charteris Basalt (e.g. MGA 021000E 7516000N). The formation is up to 1 km thick, and on NULLAGINE is dominated by felsic volcanic rocks with subordinate clastic sedimentary rocks and basalt. The Wyman Formation has a conventional zircon age of 3325 ± 4 Ma (Thorpe et al., 1992b), and SHRIMP

Figure 8. Komatiitic Euro Basalt containing ocelli (*AWebk*) from the northwestern part of the McPhee greenstone belt (MGA 205250E 7612030N)

U–Pb zircon ages of 3323 ± 3 Ma (Nelson, 2001), 3319 ± 6 Ma (Nelson, 2002), and 3315 ± 3 Ma (Nelson, 2002). The older three ages overlap the 3324 ± 4 Ma U–Pb zircon SHRIMP age obtained from intrusive felsic rocks previously called the Kelly Porphyry on SPLIT ROCK (McNaughton et al., 1993). This confirms that there is a synchronous relationship between volcanism and subvolcanic intrusions in the Kelly greenstone belt. Buick et al. (2002) also reported a 3315 ± 3 Ma age for porphyry in the Warrawoona Syncline north of the Corunna Downs Granitoid Complex on MARBLE BAR, but were uncertain whether the rock is intrusive or extrusive. The Wyman Formation is intruded by the c. 3315 Ma Boobina Porphyry on SPLIT ROCK (Bagas et al., 2004a).

Rhyolitic lava (*AWwf*) has columnar joints in places that are up to 0.2 m across and up to 20 m long (Fig. 9). The lava is massive and commonly porphyritic with quartz and plagioclase phenocrysts up to 1 mm long in a fine quartzofeldspathic groundmass. The plagioclase in the lava is altered to sericite, albite, and quartz, and the groundmass contains the alteration assemblage sericite–quartz–albite–epidote–chlorite–leucoxene. Lamellar leucoxene-rich pseudomorphs of probable biotite are up to 0.5 mm long. Felsic tuff includes cross-bedded tuff, very fine grained porcellanite, and fine-grained cherty tuff, which contain shards of clear crystalline quartz and devitrified felsic glass. Felsic agglomerate (*AWwfa*) contains fine-grained angular porphyritic rhyolite and rhyodacitic fragments up to 0.5 m in diameter in a recrystallized fine-grained matrix containing the alteration assemblage actinolite–chlorite–epidote–quartz. Sandstone within the interbedded siltstone, sandstone, and minor conglomerate unit (*AWwssz*) contains clasts of quartz, and plagioclase, in a fine-grained recrystallized matrix of quartz, mica, chlorite, plagioclase, and opaque minerals. The alteration mineral assemblages in these rocks are indicative of greenschist-facies regional metamorphism. Minor components of the Wyman Formation are felsic tuff interbedded with porphyritic rhyolite and rare rhyodacite (*AWwft*), felsic tuff interbedded with silicified siltstone, chert, carbonaceous pelite, and basalt (*AWwftc*), massive pillowed basalt (*AWwb*), and thin bands of metamorphosed finely layered chert and felsic tuff and schist (*AWwcc*).

LB 213 27.09.04

Figure 9. Columnar jointed, rhyolitic lava (*AWwf*) of the Wyman Formation from the northern part of the McPhee greenstone belt (MGA 222200E 7619200N)

Charteris Basalt (Awcbd, Awcbk)

The Charteris Basalt (Hickman, 1983) outcrops in Charteris Creek on the eastern margin of the Kelly greenstone belt, in the northern part of NULLAGINE. The formation conformably overlies the Wyman Formation and is unconformably overlain by the Budjan Creek Formation, Gorge Creek Group, and Fortescue Group. During the late 1970s, Glikson and Hickman (1981) completed petrographic and geochemical studies of volcanic successions in the Pilbara Craton, including 27 samples from the Charteris Basalt on MOUNT EDGAR. The samples were analysed for major and trace element geochemistry, and the basalt has geochemistry similar to that of the Euro Basalt (Glikson and Hickman, 1981). The Charteris Basalt is about 1 km thick, and consists of pillowed komatiitic basalt and minor tholeiitic basalt (*AWcbk*), and basalt interlayered with dolerite and minor komatiitic basalt (*AWcbd*). The komatiitic basalt commonly contains chlorite pseudomorphs after pyroxene.

Unassigned Warrawoona Group

Structurally isolated and metamorphosed mafic and felsic volcanic rocks and sedimentary rocks, which cannot be placed in the stratigraphy with certainty, are located in the Yilgalong greenstone belt east of the Meentheena Fault Zone along the northeastern margin of NULLAGINE.

Volcanic rocks (AW(bk), AW(bkl))

Pyroxene-spinifex textured komatiitic basalt (*AW(bk)*) is commonly foliated and carbonate altered (*AW(bkl)*) with pillows in places; ocelli are common. Amygdales contain quartz, chalcedony, carbonate, chlorite, epidote, and albite. Pillows have chilled margins, vesicular rims, concentric cooling cracks, intra-pillow hyaloclastite breccia, pillow tails, and pillow breccia.

Chert and felsic volcanic rocks (AW(cc), AW(ft))

Grey chert and silicified rock of uncertain origin (*AW(cc)*) are distributed throughout the greenstone belt along the northeastern margin of NULLAGINE and in the west of EASTERN CREEK (Farrell, in prep.). The chert contains zones of breccia and is commonly crosscut by quartz veins. Metamorphosed fine- to medium-grained, thin-bedded, felsic ash and local grey and white chert representing silicified ash (*AW(ft)*) consists of sericite, quartz, and minor amounts of chlorite.

Corunna Downs Granitoid Complex

The Corunna Downs Granitoid Complex is an ovoid-shaped body that tapers to the southwest on SPLIT ROCK, and extends onto the northwestern part of NULLAGINE. Bagas et al. (2003, 2004a) subdivided the Corunna Downs

Granitoid Complex into the Nandingarra Granodiorite, Carbana Monzogranite, Triberton Granodiorite, Mondana Monzogranite, and Boobina Porphyry. Only the Boobina Porphyry, Mondana Monzogranite, and Carbana Monzogranite outcrop on NULLAGINE.

The Corunna Downs Granitoid Complex is unusual within the EPGGT because it lacks significant volumes of 'classical' TTG (Jahn et al., 1981; Hickman, 1983; Davy, 1988). The complex is dominated by monzogranitic compositions, but also includes rare tonalite, trondhjemite, granodiorite, and syenite (Davy, 1988; Bagas et al., 2003). Granitic rocks show typical calc-alkaline trends with Na_2O decreasing and K_2O increasing as silica contents rise (Davy, 1988; Bagas et al., 2003). Most of the granitic rocks fall into the high-K calc-alkaline field of Le Maître (1989). Tonalitic to granodioritic rocks that fall into the medium-K field constitute about 20% of the outcrop area, and are exposed along the western margin of the complex on SPLIT ROCK (Bagas et al., 2003).

Boobina Porphyry (AgObo)

A dyke of the Boobina Porphyry (*AgObo*; Lipple, 1975) intrudes the Euro Basalt near the western boundary of NULLAGINE (MGA 189700E 7601200N). The dyke is a hornblende-bearing quartz–feldspar porphyry (*AgObo*) containing albitized plagioclase phenocrysts that are up to 2 mm long. The groundmass consists of fine-grained quartz, sericite, minor disseminated chlorite and leucoxene, and accessory zircon, iron oxide, apatite, tourmaline, carbonate, and rutile.

Geochronology on the Boobina Porphyry includes a conventional U–Pb zircon age of 3307 ± 19 Ma (Pidgeon, 1984) and a more accurate U–Pb zircon SHRIMP date of 3315 ± 4 Ma (Barley and Pickard, 1999). This latter age is within error of the age for the Carbana Monzogranite (Bagas et al., 2004a). The Boobina Porphyry intrudes the Wyman Formation (Bagas et al., 2004a), providing a minimum age for that formation.

Mondana Monzogranite (AgOmo)

The c. 3300 Ma Mondana Monzogranite (*AgOmo*; Bagas et al., 2003) intrudes the c. 3315 Ma Boobina Porphyry on SPLIT ROCK (Bagas et al., 2004a), and outcrops as a series of narrow bodies along the northeastern margin of the Corunna Downs Granitoid Complex on NULLAGINE.

The Mondana Monzogranite is a very fine to medium-grained leucogranite containing sparse microcline phenocrysts that are up to 4 mm long with inclusions of quartz and plagioclase, plagioclase altered to albite–sericite–epidote, and quartz. The groundmass is quartz-rich and contains plagioclase, microcline, and biotite altered to chlorite–epidote.

Carbana Monzogranite (AgOcamh)

The Carbana Monzogranite (*AgOcamh*; Bagas et al., 2003) is a fine- to medium-grained, equigranular to slightly porphyritic hornblende monzogranite. It has a U–Pb zircon SHRIMP age of 3317 ± 2 Ma (Barley and Pickard, 1999), and on SPLIT ROCK is intruded by hornblende-bearing monzogranite (*AgOmh*) with a U–Pb zircon SHRIMP age of 3307 ± 4 Ma (GSWA 142978*; Nelson, 2000). The Carbana Monzogranite consists of quartz, plagioclase altered to albite–sericite–epidote–quartz, disseminated hornblende, biotite altered to chlorite and epidote, and accessory epidote, titanite, and apatite.

Gobbos Granodiorite (*Aggo*, *Aggop*)

The Gobbos Granodiorite (Barley, 1982) was named after the Gobbos copper–molybdenum prospect on the northern side of the McPhee greenstone belt (MGA 220765E 7615481N). It includes stocks of biotite granodiorite and monzogranite (*Aggo*), and quartz–feldspar porphyry of dacitic composition (*Aggop*). The granodiorite and monzogranite are hornblende bearing, medium grained, seriate to porphyritic units with coarser grained plagioclase, quartz, and biotite in a matrix of plagioclase, quartz, and K-feldspar (commonly microcline). The porphyry contains phenocrysts of quartz and albitized plagioclase in a matrix of fine-grained quartz, plagioclase, microcline, sericite, minor disseminated chlorite and leucoxene, and accessory zircon, iron oxide, apatite, tourmaline, carbonate, and titanite.

Barley and Pickard (1999) obtained a U–Pb SHRIMP date of 3314 ± 4 Ma from a biotite granodiorite intruding the Warrawoona Group on the northern side of the McPhee greenstone belt (approximately at MGA 219700E 7614200N; Barley and Pickard, 1999). This age is within error of the ages for the Boobina Porphyry and Carbana Monzogranite in the Corunna Downs Granitoid Complex (Bagas et al., 2004a).

Budjan Creek Formation (*Arft*, *Arsef*, *Arb*)

The Budjan Creek Formation (Noldart and Wyatt, 1962; Lipple, 1975) in the northern part of Nullagine (around MGA 206000E 7619000N) is correlated with the stratigraphically highest component of the formation found on SPLIT ROCK to the southwest (Bagas et al., 2004a). On SPLIT ROCK, the basal part of the formation, which is missing on NULLAGINE, consists of conglomerate interbedded with wacke and sandstone (Bagas et al., 2004a).

The Budjan Creek Formation on NULLAGINE is a succession of felsic volcaniclastic sandstone, shale, local chert, minor dacitic tuff (*Arsef*), dacitic tuff with quartz and feldspar phenocrysts (*Arft*), and minor pillowed basalt (*Arb*). The formation unconformably overlies the Warrawoona Group and is, in turn, overlain by the Gorge Creek Group with a low-angle unconformity. The felsic volcaniclastic unit (*Arsef*) is bedded at a metre-scale, and is highly silicified, containing subangular and subrounded pebble-sized clasts of porphyritic dacite, and massive rhyodacite in a rhyodacitic matrix.

* GSWA sample number

The unit is interbedded with thin and recessive pillowed basalt (*Arb*), and overlain by dacitic tuff (*Arft*).

A sample of crystal-lithic tuff from SPLIT ROCK (GSWA 168908) contained a main population of 16 zircons dated at 3308 ± 5 Ma, which was interpreted as the depositional age of the rock (Nelson, 2001). The sample also contained four concordant and younger zircons dated at 3228 ± 6 Ma, which Nelson (2001) suggested records an ancient radiogenic-Pb loss. However, there is a possibility that this younger age is a more accurate estimate for the age of the formation and may indicate that the formation belongs to the c. 3235 Ma Sulphur Springs Group.

Copper Gorge Formation (*Aeb*)

The Copper Gorge Formation (*Aeb*; new name) is located in the northern part of NULLAGINE between the Warrawoona Group to the north and Mosquito Creek Formation to the south. The Copper Gorge Formation consists of basalt and minor komatiitic basalt that are generally pillowed. The type location is the southern part of the McPhee greenstone belt (between MGA 219850E 7600000N and 222600E 7601800N).

Rocks now assigned to the Copper Gorge Formation were previously assigned to the Warrawoona Group, Mosquito Creek Basin, and Mount Roe Basalt of the Fortescue Group (Hickman, 1978, 1983). The formation unconformably overlies the c. 3490–3315 Ma Warrawoona Group (e.g. at MGA 219600E 7601000N), and is overlain by an unassigned conglomerate (*Asc*) that may be a component of the basal part of the Mosquito Creek Basin (e.g. at MGA 215500E 7599900N). The conglomerate is in faulted contact with unassigned mafic and ultramafic rocks interlayered with chert and rare felsic tuff located structurally beneath the c. 2926 Ma Mosquito Creek Formation (e.g. MGA 218500E 7499200N; see Bagas et al., 2004b). These relationships indicate that the Copper Gorge Formation is between 3315 and 2926 Ma.

Unassigned units

Units that are unassigned or are in faulted contact with the underlying Copper Gorge Formation and overlying Mosquito Creek Formation include fine- to medium-grained foliated, metamorphosed, quartz-phyric gabbro (*Aogq*); basalt and komatiitic basalt (*Ab*, *Abk*); amphibolite and chlorite–actinolite schist (*Aba*); layered chert (*Acc*); poorly sorted and matrix-supported pebble conglomerate interlayered in places with cobble conglomerate, sandstone, and siltstone (*Asc*), and ultramafic rock (*Ascu*); interbedded wacke, siltstone, and shale (*Asw*); and thinly bedded felsic tuff (*Aft*).

Mafic and ultramafic rocks (Aogq, Ab, Aba, Abk)

Basalt (*Ab*) outcrops southeast of Cooke Creek Monzogranite (*Agco*), and north of the Mosquito Creek Formation (*ADqs*) in the northeastern part of NULLAGINE. The basalt is fine grained, weakly amygdaloidal, generally pillowed, locally interlayered with komatiitic basalt (*Abk*) and, where sheared, consists of amphibolite and chlorite–actinolite schist (*Aba*). Amphibolite and chlorite–actinolite schist (*Aba*) outcrops are present along the northern margin of the Mosquito Creek Basin, and fine- to medium-grained, quartz-phyric metagabbro (*Aogq*) is present in northeastern NULLAGINE. This metagabbro consists of medium-grained plagioclase replaced by carbonate–albite–clinozoisite–chlorite, relict green amphibole phenocrysts replaced by chlorite, clinopyroxene altered to tremolite–actinolite, and a fine-grained matrix composed of sericite, epidote, quartz, interstitial chlorite, disseminated fine iron oxide, and secondary carbonate.

Metasedimentary and felsic volcanic rocks (Acc, Asc, Ascu, Asw, Aft)

Chert (*Acc*) is commonly ferruginous, and is colour banded with red, green, black or white layers that are between 3 and 15 mm thick. Chert units are usually less than 4 m thick and outcrop as well-exposed lenses that are commonly interlayered with amphibolite and chlorite–actinolite schist (*Aba*), but talus slopes cover the contacts with surrounding rocks. The origin of the chert is uncertain, but these units are probably silicified tuffaceous units, mudstones, or chemical precipitates.

Felsic tuff (*Aft*) is locally cross-bedded and silicified, commonly has lithic fragments of dacite and rhyolite, and consists of plagioclase, quartz, biotite, hornblende, epidote, and chlorite, with minor K-feldspar, secondary sericite, and carbonate, and accessory titanite and apatite.

Conglomerate (*Asc*) that overlies basalt of the Copper Gorge Formation (*Aeb*; e.g. at MGA 220000E 7600200N) dips toward the south. The conglomerate contains angular to subrounded quartz, chert, and basalt clasts in a mafic matrix, and in the Lionel area (e.g. 3 km east of Hales Grave Well) is interleaved with ultramafic rock that is either silicified and serpentinized peridotite or chlorite–actinolite(–tremolite) schist (*Ascu*). The conglomerate in the Lionel mining area may be a local basal unit of the Mosquito Creek Formation.

Fine- to medium-grained wacke in interbedded wacke, siltstone, and shale units (*Asw*) located north of the Lionel mining area (around MGA 199000E 7607000N) contain well-preserved graded bedding. The bedding is less than 2 m thick with a common massive base that grades to a thin, silty, and slaty top. The wacke succession unconformably overlies gabbro (*Aog*) and serpentinized metadunite (*Aupd*), and is unconformably overlain by lithic wacke of the Hardey Formation (*AFhsw*). The lithic wacke of the Hardey Formation also unconformably overlies the Mount Roe Basalt that contains a succession of shale, lithic wacke and minor tuff (*AFrsh*) located less than 2 km northwest of the unassigned wacke succession (*Asw*). Therefore, this unassigned unit may be a component of the Mount Roe Basalt.

Gorge Creek Group

The Gorge Creek Group (Noldart and Wyatt, 1962; Ryan and Kriewaldt, 1964; Hickman and Lipple, 1978; Hickman, 1983) unconformably overlies the c. 3325–3315 Ma Wyman, Charteris and <3308 Ma Budjan Creek

Formations on NULLAGINE. The group disconformably overlies the c. 3240 Ma Sulphur Springs Group on NORTH SHAW and TAMBOURAH (Van Kranendonk and Morant, 1998), is unconformably overlain by the c. 2950 Ma De Grey Group (Van Kranendonk et al., 2002), and is unconformably overlain by the c. 2775 Mount Roe Basalt on NULLAGINE. The age of the group is therefore between c. 3235 and 2950 Ma. On NULLAGINE, the Gorge Creek Group is subdivided into the Corboy and Paddy Market Formations.

Corboy Formation (AGcstq, AGccc)

The Corboy Formation (Lipple, 1975; Hickman and Lipple, 1978) forms the base of the Gorge Creek Group, where it unconformably overlies the Wyman Formation (MGA 200500E 7612100N), Charteris Basalt (MGA 202300E 7615000N), and Budjan Creek Formation (MGA 208300E 7619600N). The Mount Roe Basalt and Hardey Formation unconformably overlie the Corboy Formation in the northwestern part of NULLAGINE (e.g. MGA 196800E 7606600N). The contact between the Budjan Creek Formation and the Gorge Creek Group is a low-angle unconformity (Bagas et al., 2004a). A similar succession is present in the lower part of the undivided Gorge Creek Group in the southern part of SPLIT ROCK, except that a thicker basal conglomerate is present on SPLIT ROCK (Bagas et al., 2004a).

The Corboy Formation consists of sandstone with a lensoidal basal polymictic conglomerate (*AGcstq*), and is interbedded with banded and ferruginous chert, black carbonaceous shale, and siltstone (*AGccc*). The conglomerate is matrix supported and contains clasts of metasandstone, coloured and banded chert, and white vein quartz. The sandstone is cross-laminated with graded bedding.

Paddy Market Formation (AGpcic)

The Paddy Market Formation (Hickman and Lipple, 1978) conformably overlies the Corboy Formation in the core of the faulted Sandy Creek Syncline in the northwestern part of NULLAGINE (Fig. 4). The formation consists of thinly bedded iron-formation interbedded with ferruginous chert (*AGpcic*). The iron-formation consists of white and black laminae of ferruginous shale, and variably ferruginized or silicified chert.

Structures of the East Pilbara Granite–Greenstone Terrane

The structural history of the EPGGT is long and complex, spanning some 700 million years, and has been controversial for the past 25 years. The debate has centred on the relative importance of vertical tectonics (diapirism) and horizontal tectonics (cf. Bickle et al., 1980, 1985; Hickman, 1983, 1984, 2004; Boulter et al., 1987; Collins, 1989, 1993; Zegers et al., 1996, 2001; Collins et al., 1998, 1999; van Haaften and White, 1998, 2001; Collins and Van Kranendonk, 1999; Kloppenburg et al., 2001; Blewett, 2002; Blewett et al., 2004; Van Kranendonk et al., 2002, 2004; Hickman and Van Kranendonk, 2004). Hickman (1975, 1983, 1984) interpreted the dome-and-basin pattern of the EPGGT as resulting from gravity-driven, solid-state diapirism of granitic rocks through overlying greenstones. Subsequently, other workers (Collins et al., 1998; Collins and Van Kranendonk, 1999; Van Kranendonk et al., 2002; Hickman and Van Kranendonk, 2004) modified this diapiric model to include magmatic diapirism associated with partial convective overturn of the upper and middle crust. Other authors have suggested tectonic models involving Alpine-style tectonics (e.g. Bickle et al., 1985), interference folding (Noldart and Wyatt, 1962; Blewett, 2002; Blewett et al., 2004), or metamorphic core complexes (Zegers et al., 1996; Kloppenburg et al., 2001; Kloppenburg, 2003). Hickman and Van Kranendonk (2004) reviewed the key features of these alternative tectonic models, and concluded that only diapiric deformation provides a satisfactory explanation for the detailed structural geology of the EPGGT. Hickman (1983) and Van Kranendonk (1998, 2000) recognized five regional sets of structures dominated by vertical movements between greenstones and granitic complexes, including those that affect the Fortescue Group.

In the southern part of the EPGGT, greenstones of the Pilbara Supergroup and formations of the overlying Fortescue Group dip and face away from the McPhee Dome and domical Corunna Downs Granitoid Complex towards the axes of two main synclines. These include the Kelly Syncline between the Corunna Downs Granitoid Complex and McPhee Dome, and a syncline between the McPhee Dome on NULLAGINE and the Mount Edgar Granitoid Complex on MOUNT EDGAR (Williams and Bagas, in prep.). Successively younger groups or formations unconformably overlie the Warrawoona Group at both the southeastern flank of the Corunna Downs Granitoid Complex, and the northern flank of McPhee Dome. Furthermore, the dips of these formations become increasingly shallow away from the domes. This has been used to suggest that there was at least episodic uplift of the domes during deposition of the successions (e.g. Hickman, 1984; Van Kranendonk et al., 2002).

A summary of the structural history of the EPGGT on NULLAGINE before the deposition of the Fortescue Group is given below, and partly follows the scheme set out by Bagas et al. (2004b). Table 1 summarizes the history of the area, and distinguishes the deformation events in the EPGGT (as D_{EP}) from those in the Mosquito Creek Basin and Kurrana Terrane (as D_{MB}).

D_{EP1} deformation

Structures associated with D_{EP1} events (c. 3490–3410 Ma) in other parts of the EPGGT have not been identified on NULLAGINE. Bagas et al. (2004a) presented a detailed discussion of the D_{EP1} event on SPLIT ROCK (there referred to as D_1).

D_{EP2} structures

Deformation associated with the c. 3315 Ma D_{EP2} event is interpreted to be responsible for the main structural features of the greenstones in the EPGGT, and correlates with the D_2 event described by Bagas et al. (2004a) on

Table 1. Summary of the major geological events on NULLAGINE

Age range (Ma)	*Geological events*
c. 3490–3315	Deposition of the Warrawoona Group and D_{EP1} deformation
c. 3315–3000	Emplacement of the Corunna Down Granitoid Complex and Gobbos Granodiorite
c. 3315	Major doming (D_{EP2}), accompanied by folding and faulting of the Warrawoona Group
<3308	Deposition of the Budjan Creek Formation
c. 3235–2950	Deposition of the Gorge Creek Group
c. 3235–2926	Continued doming (D_{EP3}) of the granitic complexes, and greenschist-facies shear reactivation of greenstones. Crustal extension: initial formation of the Mosquito Creek Basin
c. 3178–2926	Early foliation in the Coondamar Formation and Golden Eagle Orthogneiss. Metamorphic peak between D_{MB1} and D_{MB2}
c. 2926–2905	Deposition of the Mosquito Creek Formation. Major foliation (S_{MB2}) formed in the Mosquito Creek Basin and Kurrana Terrane. Rare isoclinal and reclined F_{MB3} folds suggest west-over-east thrusting (probably during late to post-D_{MB2})
c. 2905	Major ENE–WSW folds and associated faulting (D_{MB4}), penetrative slaty cleavage (S_{MB4}), crenulation lineation (L_{MB4}), weak NNW-plunging mineral lineation (L_{MB4}). Faults associated with this event host Au and base metal mineralization in Mosquito Creek Basin
c. 2905–2765	Development of upright, northerly striking F_{MB5} folds associated with E–W shortening in the Mosquito Creek Basin
c. 2772	Deposition of the Mount Roe Basalt and intrusion of the Black Range Dolerite Suite
c. 2770–2756	Faulting (D_{FG1}) of the Mount Roe Basalt and Hardey Formation before deposition of the Kylena and Tumbiana Formations
<2717	Deposition of the Maddina Formation. Early folding and faulting (D_{FG2}) of the Fortescue Group, possibly contemporaneous with continued doming of the granitic complexes in the EPGGT
<2717	Southeasterly striking dextral and southwesterly striking sinistral D_{MB6} faults in the Mosquito Creek Basin and Kurrana Terrane associated with NNW–SSE shortening. Late (D_{FG3}), southeast-striking faults
?Proterozoic	Brittle faulting and quartz veining associated with east-southeasterly striking dolerite dyke emplacement (*d*)
c. 1800	Emplacement of the north-northwesterly trending Bridget Suite of granitic rocks

SPLIT ROCK. The event took place after deposition of the Wyman Formation (c. 3325–3315 Ma), and was synchronous with the emplacement of granites in the Corunna Downs Granitoid Complex, and with intrusion of the c. 3314 Ma Gobbos Granodiorite (Barley and Pickard, 1999).

D_{EP2} deformation on NULLAGINE is represented by open to tight folds in the Warrawoona Group (e.g. MGA 198700E 761400N) and associated faults (e.g. at MGA 200500E 7617000N). Erosion following D_{EP2} led to development of the unconformities beneath the Copper Gorge and Budjan Creek Formations. The main D_{EP2} structure is the large-scale F_{EP2} Kelly Syncline between the Corunna Downs Granitoid Complex to the west, Mount Edgar Granitoid Complex to the north, and McPhee Dome to the east. The axis of the syncline is a broad zone of high shear strain and splayed faults. Foliation and lineation in greenstones on the northern part of the McPhee greenstone belt on MOUNT EDGAR gradually diminish in intensity away from the Mount Edgar Granitoid Complex towards NULLAGINE (Williams and Bagas, in prep.).

Most of the granites dated from the Corunna Downs Granitoid Complex (c. 3317–3307 Ma) fall within the estimated age range for the D_{EP2} deformation. This suggests that deformation associated with D_{EP2} is contemporaneous with granite magmatism. The curvilinear nature of the fault system in the Kelly greenstone belt on NULLAGINE is broadly parallel with the edge of the domical Corunna Downs Granitoid Complex. This suggests that the domical structure, faulting, and the formation of the syncline are all related. These relationships are similar to those described for the Mount Edgar Granitoid Complex and structures in flanking greenstones (e.g. Collins, 1989; Williams and Collins, 1990; Collins et al., 1998).

D_{EP3} deformation

The c. 3235–2950 Ma Gorge Creek Group occupies the Sandy Creek Syncline at the boundary between the Corunna Downs Granitoid Complex and McPhee Dome. The syncline formed after c. 2950 Ma and before deposition of the Fortescue Group, which truncates it, and is interpreted as a D_{EP3} structure. F_{EP3} folding is conclusive evidence of deformation between the domes after c. 3235 Ma and before deposition of the Fortescue Group, which truncates the Sandy Creek Syncline. Furthermore, the Gorge Creek Group overlies the post-D_{EP2} Budjan Creek Formation with a low-angle unconformity indicating that steepening occurred during the deposition of both these units. The D_{EP3} deformation event is absent in the c. 2926 Ma Mosquito Creek Formation, indicating that the EPGGT was cratonized largely before the Mosquito Creek Basin formed. These relationships suggest that D_{EP3}

is loosely constrained on Nullagine between c. 3235 and 2926 Ma, and is probably equivalent to the D_4 event of Hickman (2004).

Other structures that formed after deposition of the Gorge Creek Group, but before deposition of the Fortescue Group, include faults between the Gorge Creek and Warrawoona Groups in the Kelly greenstone belt, and faults between the Gorge Creek Group and McPhee greenstone belt on the western margin of the McPhee Dome.

Metamorphism in the East Pilbara Granite–Greenstone Terrane

Rocks of the EPGGT have a low grade of metamorphism, which varies from sub-greenschist facies in the Fortescue Group, through widespread greenschist facies in the Pilbara Supergroup, to amphibolite or hornblende-hornfels facies along contacts with granitic complexes. In the Warrawoona Group, tholeiitic basalt typically contains secondary actinolite–plagioclase (albite)–chlorite–quartz, and high-Mg basaltic rocks commonly contain spinifex-textured tremolite (pseudomorphs after pyroxene)–chlorite–quartz, which are assemblages characteristic of the greenschist facies. However, within 1 km of the granite contacts, basaltic rocks commonly contain hornblende–titanite–plagioclase–quartz, retrogressed in places to actinolite–epidote–albite–sericite, and pelitic rocks locally contain biotite–garnet–muscovite. These assemblages are characteristic of the hornblende-hornfels facies of contact metamorphism with retrogression to the albite–epidote-hornfels facies of metamorphism.

Kurrana Terrane

The Kurrana Terrane is exposed in southern Nullagine. The terrane locally includes the c. 3199 to 3178 Ma Golden Eagle Orthogneiss (*AgKge*), and the 'post-tectonic' c. 2838 Ma Bonney Downs Granite (*AgKbd*, *AgKbdn*), both of which are components of the Kurrana Granitoid Complex (renamed from Kurrana Batholith of Hickman, 1983). The Bonney Downs Granite is described with the Cooke Creek Monzogranite under **Post-tectonic granitic rocks**.

Golden Eagle Orthogneiss (AgKge)

The Golden Eagle Orthogneiss (*AgKge*) is a strongly deformed, lithologically layered orthogneiss consisting of foliated protoliths of biotite-bearing monzogranite, granodiorite, and tonalite interlayered with lenses of amphibolite, ultramafic schist, and quartz–mica schist. The orthogneiss is well exposed, and forms low rocky hills with sparse vegetation. The orthogneiss is variably foliated, and ranges from poorly foliated and porphyritic units to quartz–feldspar–muscovite schists. Petrographically, it consists of a recrystallized mosaic of K-feldspar (commonly microcline in the monzogranitic orthogneiss), sericitized or saussuritized plagioclase (commonly oligoclase in granodioritic orthogneiss) and quartz, and variable amounts of white mica and biotite altered to chlorite or epidote. Other minerals include minor titanite, allanite and epidote, and accessory apatite, zircon, and opaque minerals. The tonalitic orthogneiss consists of aligned plagioclase (andesine–oligoclase), quartz, K-feldspar, and biotite with accessory allanite, apatite, chlorite, epidote, magnetite, stilpnomelane in plagioclase or altered biotite, white mica, and zircon. The mineral assemblage of the orthogneiss suggests that it has been metamorphosed at amphibolite facies with retrogression to greenschist facies or lower.

Mosquito Creek Basin

Hickman (1984) interpreted the Mosquito Creek Basin, containing the De Grey Group on Nullagine, to have formed through subsidence during the later stages of diapirism in the east Pilbara, but Eriksson et al. (1994) interpreted it as a forearc basin situated to the north of a subduction complex. Tyler et al. (1992) interpreted the tectonic southern margin of the basin, the Kurrana Shear Zone, as a suture between two distinct terranes that amalgamated between 3000 and 2760 Ma. Krapez and Eisenlohr (1998) suggested that the basin is equivalent in age to the c. 3240 Ma Gorge Creek Group, but Witt et al. (1998) interpreted it to be contemporaneous with the <3000 Ma De Grey Group.

Recent geochronology (Bagas et al., 2004b) indicated that the dominant component of the basin, the Mosquito Creek Formation, was deposited at c. 2926 Ma. The underlying Coondamar Formation, exposed along the faulted margins of the basin, has not been reliably dated. However, the composition of the Coondamar Formation, which includes metamorphosed mafic and ultramafic volcanic rocks, may reflect its relationship to basin formation, interpreted to have been through crustal extension that was probably accompanied by mafic volcanism.

De Grey Group

The Coondamar Formation, rocks of which were originally included in the Mosquito Creek Formation (Hickman, 1978, 1983), is now separated from the Mosquito Creek Formation, and is tentatively included in the De Grey Group until dates are available for the formation.

Coondamar Formation (ADncc, ADnlb, ADnlbn, ADnsl, ADnss, ADnb, ADnbk, ADnog, ADnst)

The Coondamar Formation consists of mafic, ultramafic, and chloritic rocks, and interlayered metasedimentary rocks. The formation is located at the base of the Mosquito Creek Basin in the southern central, and northeastern parts of Nullagine, and is probably a correlative of unassigned rocks (*Ab*, *Aba*, *Abk*, *Acc*, *Asc*, *Aft*, *Aus*) to the north of the Mosquito Creek Formation on Nullagine. The formation is at least 1 km thick.

In the southern part of Nullagine, north of the Kurrana Granitoid Complex, the preserved top of the Coondamar Formation consists of poorly exposed, pale green (chloritic), strongly cleaved metasandstone. The metasandstone is interleaved with chloritic siltstone, chlorite–actinolite schist, phyllite, and rare amphibolite (*ADnss*). In some areas, the proportion of metasandstone (*ADnsl*) is low, with layered chert (*ADncc*) commonly located below the metasandstone. The chert units are about 1 m thick and contain millimetre-thick ferruginized laminae. The chert overlies, and is interlayered in places with, a poorly exposed succession of schist that includes chlorite–actinolite schist, quartz–muscovite schist, amphibolitic schist, and minor biotite schist and andalusite–muscovite schist (*ADnlb*). The unit is in faulted contact with the Golden Eagle Orthogneiss, where it is tectonically interleaved with orthogneiss (*ADlbn*).

In the northeastern part of NULLAGINE, the Coondamar Formation outcrops east of the Meentheena Fault Zone, where it consists of interlayered metabasalt (*ADnb*), metakomatiite basalt (*ADnbk*), fine- to medium-grained, quartz-phyric and lensoidal metagabbro (*ADnog*), and thin layers of metasandstone and minor siltstone (*ADnst*).

Mosquito Creek Formation (ADqs, ADqsc)

The Mosquito Creek Formation (Maitland, 1905; Noldart and Wyatt, 1962; Hickman, 1978) outcrops in an easterly trending rectangular region approximately 60 km long and 30 km wide on NULLAGINE and EASTERN CREEK (Farrell, in prep.). Hickman (1984) interpreted the region as a refolded and faulted synclinorium.

The Mosquito Creek Formation outcrops on NULLAGINE between the EPGGT (chiefly the Copper Gorge Formation and overlying unassigned units) in the north and the Kurrana Terrane to the south. The formation unconformably overlies, or is faulted against, the unassigned mafic, ultramafic, chert, and felsic volcanic rocks that lie structurally above the Copper Gorge Formation in the north. The formation is faulted against the Coondamar Formation in the south, and is unconformably overlain by the Fortescue Group in the southwest. The formation is intruded and contact metamorphosed by a series of north-westerly trending c. 1800 Ma quartz syenite to quartz monzodiorite bodies of the Bridget Suite, the north-northeasterly trending c. 2772 Ma Black Range Dolerite Suite, and various unassigned dolerite dykes. Owing to the lack of continuous suitable marker horizons, and because the top of the Mosquito Creek Formation is not exposed, its total thickness cannot be accurately determined. Hickman (1983) proposed that it is about 5 km thick.

The Mosquito Creek Formation hosts a significant number of gold deposits that are located in shear zones (D_{MB3}; discussed below) known as the Blue Spec Fault Zone, the Middle Creek Fault, and a smaller proportion of deposits on the Sandy Creek Fault. Outcrops of the Mosquito Creek Formation typically form lightly timbered rubble-strewn low strike-ridges, with the freshest exposures found in incised creeks. Rocks of the formation are well cleaved and tightly folded, and consist of interbedded conglomerate and coarse-grained sandstone (*ADqsc*), with interbedded sandstone, siltstone, and shale (*ADqs*) displaying graded bedding.

Conglomerate (*ADqsc*) is present at or near the base of the Mosquito Creek Formation along the northern edge of the preserved Mosquito Creek Basin. The unit is up to 100 m thick, lenticular, and is unconformable on, or in faulted contact with, unassigned mafic, ultramafic and felsic rocks that are structurally above the Copper Gorge Formation. The conglomerate contains poorly sorted, matrix-supported and rounded clasts that are up to about 200 mm across and include vein quartz, chert, basalt, and rare felsic volcanic rocks in a poorly sorted sandstone matrix. The clasts in these beds probably originate from the EPGGT, as suggested by Bagas et al. (2004b). Conglomerate beds in the South and North Dromedary areas of southwestern NULLAGINE are lenticular. They are interbedded with, and overlie, wacke, siltstone, and shale successions. These beds do not appear to be close to the base of the Mosquito Creek Formation as suggested by Noldart and Wyatt (1962), and possibly represent deposition associated with syndepositional movement along the Middle Creek Fault.

The conglomerate fines upwards into a succession comprising interbedded wacke, siltstone, and shale (*ADqs*), which forms the bulk of the Mosquito Creek Formation. The wacke is fine to coarse grained, and contains a variety of angular and unsorted or poorly sorted quartz and feldspar grains, angular to subrounded fragments of quartz, chert, sandstone, shale, and rare felsic igneous rocks and quartz–sericite schist in a fine-grained pelitic matrix. The matrix consists of clay minerals, sericite, and carbonate with clastic grains of quartz, detrital white mica, feldspar, rutile, and pyrite. The sandstone beds are commonly graded and form either thin interbeds with siltstone and shale or massive graded beds up to 2 m thick. Siltstone and shale are laminated or thinly bedded, and well cleaved. They constitute a significant, although poorly exposed, part of the formation. In places, these rocks contain fine cross-bedding and sole marks (Fig. 10), and elsewhere graded beds have irregular bases with flame-structures associated with hydroplastic disruption of the

LB 214 27.09.04

Figure 10. Finely cross-bedded, sole marked, and fine-grained sandstone interbedded with siltstone, and shale (*ADqs*) of the Mosquito Creek Formation (MGA 203775E 7571020N)

LB 215 27.09.04

Figure 11. **Graded and cross-bedded wacke (*ADqs*) with a flame-structure at its irregular base. The flame structure is associated with a hydroplastic disruption of the underlying dark-coloured shale (MGA 203775E 7571020N)**

LB 216 27.09.04

Figure 12. **Reclined fold (F_{MB3}) in foliated (S_{MB2}) chlorite–actinolite schist (*ADolbn*) of the Coondamar Formation (photograph taken facing northward at MGA 234400E 7575250N)**

underlying shale (Fig. 11). The wacke is recrystallized to micaceous hornfels, close to intrusive rocks of the Bridget Suite, with cordierite and andalusite porphyroblasts in a granoblastic matrix containing quartz, biotite, muscovite, and feldspar.

Structures of the Kurrana Terrane and Mosquito Creek Basin

At least six phases of deformation ($D_{MB1–6}$) are recognized in the rocks of the c. 3200 Ma Golden Eagle Orthogneiss of the Kurrana Terrane, and the Mosquito Creek Basin (Table 1). No tectonic structures related to the formation of the basin were identified on NULLAGINE.

D_{MB1}

The earliest phase of deformation is defined by a composite fabric ($D_{MB1–2}$) in both the Golden Eagle Orthogneiss, at the northern edge of the Kurrana Terrane, and the Coondamar Formation, in the southern part of the Mosquito Creek Basin. The Golden Eagle Orthogneiss contains thin monzogranitic leucosome layers (S_{MB1}) that are deformed into rootless, tight to isoclinal folds (F_{MB2}; Farrell, in prep.). A similar composite fabric, which is tentatively correlated with $S_{MB1–2}$ by Farrell (in prep.), is also present in the Coondamar Formation. This fabric is preserved in the hinge zone of F_{MB3} folds as an anastomosing disjunctive schistosity or cleavage (Farrell, in prep.). The timing of $D_{MB1–2}$ is not clear, but it is younger than the c. 3178 Ma Golden Eagle Orthogneiss and older than the c. 2905 Ma D_{MB4} event (see below).

D_{MB2} (between c. 2926 and 2905 Ma)

A strong foliation (S_{MB2}) is present in the Coondamar Formation (Fig. 12), in the c. 2926 Ma Mosquito Creek Formation in the Mosquito Creek Basin, and in the c. 3199–3178 Ma Golden Eagle Orthogneiss (Fig. 13) in the Kurrana Terrane. The foliation is a layer-parallel schistosity or cleavage (S_{MB2}) in rocks of the Mosquito Creek Basin, and interlayered paragneiss, gneissic pegmatite and orthogneiss, and is defined by the alignment of biotite in the Golden Eagle Orthogneiss. The Coondamar Formation and Golden Eagle Orthogneiss have a layer-parallel penetrative schistosity (S_{MB2}; Figs 12 and 13), which trends east to northeast with a steeply plunging bedding–cleavage intersection lineation (L_{MB2}) plunging north. A weak down-dip mineral lineation (L_{MB2}) is present in places, which commonly plunges about 50° northeast (e.g. at MGA 212350E 7567800N). Both the intensity of the D_{MB2} deformation and grade of regional metamorphism

LB 217 27.09.04

Figure 13. **Reclined, tightly folded (F_{MB3}) and strongly foliated (S_{MB2}) orthogneiss interlayered with mafic schist, and ultramafic schist of the Golden Eagle Orthogneiss (*AgKge*; MGA 238400E 7575450N)**

decrease northward towards the Middle Creek Fault. These features and the observation that S_{MB2} is parallel to compositional layering suggest that D_{MB2} may represent an extensional deformation event involving normal shearing at the contact between the Kurrana Granitoid Complex and Mosquito Creek Basin between c. 2926 and 2905 Ma. Either D_{MB2} metamorphism is related to the intrusion of granites in the Kurrana Terrane, or the metamorphism is early and has been largely obliterated during pervasive deformation during D_{MB4} and later events.

D_{MB3}

Rare isoclinal and reclined F_{MB3} folds are preserved in the Coondamar Formation (Fig. 12) and the Golden Eagle Orthogneiss (Fig. 13). These folds are refolded by regional F_{MB4} folds (Fig. 14) that deform the Kurrana Shear Zone in the southeastern part of NULLAGINE and modify the S_{MB2} foliation. Where observed, the axes of the F_{MB3} folds plunge shallowly northwards, and the folds commonly verge to the east. These orientations suggest west-over-east thrusting, but further studies are needed to determine the original orientations of these structures.

D_{MB4} (c. 2905 Ma)

Structures assigned to the c. 2905 Ma D_{MB4} event, which affect the Mosquito Creek Basin and Kurrana Terrane, include regionally significant, east-northeasterly trending, shallowly and commonly double-plunging, open to isoclinal folds, and chevron-like or angular folds (Fig. 15), penetrative slaty cleavage (S_{MB4}), and mineralized faults that are generally parallel to the axial trace of F_{MB4} folds. The folds are associated with vertical to steeply dipping axial planar fabrics defined by a spaced cleavage (S_{MB4}) in sandstone of the Mosquito Creek Formation, a weak and shallow plunging crenulation (Fig. 14), and mineral lineation (L_{MB4}) parallel to the fold axes. The general orientation of these structures indicates a north-northwesterly – south-southeasterly compressional regime.

LB 220 17.03.05

Figure 14. Foliated (S_{MB2}) and crenulated (D_{MB4}) fine-grained ferruginous schist of the Coondamar Formation (*ADoss*; MGA 235850E 7568950N)

LB 218 27.09.04

Figure 15. Folded (F_{MB4}) banded pyritic siltstone interbedded with fine-grained poorly sorted sandstone (*ADqs*) of the Mosquito Creek Formation (MGA 203100E 7570100N)

A single Pb–Pb model age of 2905 ± 9 Ma (Thorpe et al., 1992a) records a lode gold mineralizing event at the Mosquito Creek mine area on eastern NULLAGINE, which is hosted by D_{MB4} structures in the Mosquito Creek Formation. This gives an approximate age for D_{MB4} and constrains the minimum age of the host formation. This event appears to be synchronous with 2905 ± 9 Ma base metal mineralization in the Coondamar Formation (Huston et al., 2002), which suggests that there was a widespread mineralizing event associated with D_{MB4} at c. 2905 Ma in the Mosquito Creek Basin. This event was also broadly synchronous with the emplacement of 2897 ± 6 Ma monzogranite and granodiorite in the Cooninia Inlier (GSWA, 2004), about 100 km to the south.

Given the general similarities in the fabrics associated with the D_{MB2} and D_{MB4} events, deformation during $D_{MB2–4}$ may not represent discrete short-term events affecting all parts of the Mosquito Creek Basin and Kurrana Terrane, but may be related to a single orogenic event that took place sometime between c. 2926 Ma (minimum age of the Mosquito Creek Formation) and 2905 Ma (postulated age of mineralization hosted by D_{MB4} structures in the Mosquito Creek Basin).

D_{MB5} (between 2905 and 2765 Ma)

The fifth deformation event (D_{MB5}) resulted in the development of upright, northerly trending open macroscale F_{MB5} folds (e.g. at MGA 230300E 7593900N), rare spaced and steeply to vertically dipping crenulation cleavage (S_{MB5}), and small-scale kinks and crenulations (L_{MB5}). Dextral movement along the east-northeasterly trending Sandy Creek, Blue Spec, and Middle Creek Faults is also attributed to this event, and the orientation of the folds and faults indicates approximately east–west shortening. The deformation event did not affect the c. 2765 Ma Hardey Formation, indicating that it took place between 2905 and 2765 Ma.

D_{MB6} (<2717 Ma)

Southeasterly striking dextral and southwesterly striking sinistral D_{MB6} faults in the Mosquito Creek Basin and Kurrana Terrane that are 10 to 30 km long define the D_{MB6} event. These faults crosscut F_{MB4} and F_{MB5} folds (e.g. around MGA 230300E 7593900N and 211900E 7692000N), and the overall orientation of these faults is consistent with north-northwesterly – south-southeasterly shortening.

Unassigned mafic and ultramafic rocks

Ultramafic rocks (Auc, Aup, Aupd, Aus, Aux)

A variety of ultramafic rocks in the Kelly and McPhee greenstone belts cannot be correlated with either a particular intrusive suite or formation and are thus left unassigned on NULLAGINE. Ultramafic rocks include talc–carbonate and talc–chlorite–carbonate schist (*Auc*), serpentinized metaperidotite and serpentine–chlorite schist (*Aup*), serpentinized metadunite (*Aupd*), serpentine–chlorite schist (*Aus*), and metapyroxenite (*Aux*).

Pyroxenite (*Aux*), interlayered with minor diorite, gabbro, dolerite, and minor dunite, intruded the Panorama Formation, Strelley Pool Chert, and Euro Basalt in northwestern NULLAGINE. These weakly deformed and recrystallized cross-cutting dykes consist of clinopyroxene rimmed by brown hornblende and altered to carbonate, serpentine after orthopyroxene and possibly olivine, and aggregates of quartz, chlorite, carbonate, actinolite, and talc probably after olivine. The pyroxenite in the Warrawoona Group in the northwestern part of the McPhee greenstone belt (MGA 162000E 7608000N) is compositionally similar to the pyroxenite in the northern part of the Kelly greenstone belt. However, it is parallel to bedding in the Wyman Formation, suggesting that it might have originally been a flow.

Banded, dark green and brownish green serpentinite located to the south of the Cooke Creek Monzogranite is interlayered or enveloped with chlorite–actinolite(–tremolite) schist (*Aus*). These rocks are generally very highly strained, showing good schistosity defined by serpentine, chlorite, tremolite, and talc. The unit is locally carbonate-altered or veined and covered with magnesite, and may be derived from dunite, peridotite, pyroxenite, or komatiitic basalt. However, the unit has been so deformed that protolith recognition is difficult. The serpentinite contains randomly orientated serpentine fibres with secondary iron oxide and epidote, and silicified serpentinite is common in topographically elevated areas. The chlorite–actinolite(–tremolite) schist is characteristically light greenish-grey, and fine to medium grained containing fine- to coarse-grained amphibole (actinolite–tremolite) and chlorite that are parallel to the foliation in the rock. It also contains minor amounts of fine scattered flakes of talc, and accessory iron oxide minerals. The foliation probably developed by recrystallization during shearing, and this recessive unit occupies low-lying areas.

Serpentinized metadunite (*Aupd*) outcrops in the Lionel Mining Centre and contains local variations in grain size, thin compositional zones of peridotite and pyroxenite, with gabbro dykes locally present in the northern part of the unit. The metadunite is identified by pale yellow-tan weathering surfaces, bright green fresh surfaces, and cumulate textures of anhedral cumulate olivine up to 2.5 mm in diameter. The rocks are generally weakly foliated, or foliated in anastomosing domains. In thin section, the olivine phenocrysts are completely replaced by fine-grained serpentine and rimmed by a fine-grained assemblage of carbonate–magnetite–chlorite.

Serpentinized metaperidotite (*Aup*) outcrops along the western edge of an ultramafic complex in the central part of the McPhee greenstone belt, where it intrudes the Panorama Formation and appears to be unconformably overlain by basalt (*Aeb*; e.g. MGA 213400E 7606100N). The peridotite contains serpentinized olivine, oikocrysts of clinopyroxene, minor intercumulus orthopyroxene, rare brown hornblende rimmed by green amphibole, interstitial serpentine with minor amphibole, and secondary chlorite.

Homogeneous units of distinctive pale brown-weathering talc–carbonate rock (*Auc*) outcrop in the Panorama Formation in the northwestern part of NULLAGINE (around MGA 193000E 7618000N). These rocks vary from massive, medium-grained weakly foliated rocks to schists and consist of talc–carbonate–iron oxide(–serpentine–chlorite).

Mafic rocks (Ao, Aog)

Intrusive mafic rocks, which cannot be placed in the recognized stratigraphic nomenclature with certainty, outcrop in several places across NULLAGINE. These rocks include fine- to medium-grained metadolerite and local metagabbro (*Ao*) in the Kelly greenstone belt on the western edge of Nullagine (e.g. MGA 186000E 7608000N), and fine- to medium-grained quartz-phyric metagabbro (*Aog*) in the northern, central, and eastern parts of the McPhee greenstone belt.

Altered, fine- to medium-grained metadolerite and local metagabbro (*Ao*) contain abundant prismatic clinopyroxene, as well as serpentine or chlorite as pseudomorphs of orthopyroxene, plagioclase altered to clinozoisite and sericite, and rare iron oxides. Gabbro dykes (*Aog*) consist of albitized plagioclase, anhedral clinopyroxene altered to various combinations of chlorite–epidote–carbonate, quartz phenocrysts, and accessory titanomagnetite. These rocks intrude the Warrawoona Group and are in turn intruded by the Black Range Dolerite Suite (*AFdb*).

Post-tectonic granitic rocks

Bonney Downs Granite (AgKbd, AgKbdn)

The Bonney Downs Granite (*AgKbd*, *AgKbdn*) intrudes the Golden Eagle Orthogneiss (*AgKge*) in the southern part of NULLAGINE. A sample from the biotite monzogranite (*AgKbd*) from Bonney Downs Granite on NULLAGINE has a U–Pb zircon SHRIMP age of 2838 ± 6 Ma (GSWA 178014; GSWA, 2004). Two widely spaced samples of the granite from NOREENA DOWNS have older Sm–Nd dates of 3283 and 3260 Ma (Tyler et al., 1992), suggesting that the source is either c. 3270 Ma or had mixed components with an average age of c. 3270 Ma. The Bonney Downs Granite is included in the Split Rock Supersuite that is characterized by post-tectonic tin–tantalum–lithium–beryl-bearing c. 2890–2830 Ma granitic rocks in the North Pilbara Craton (Van Kranendonk et al., 2004), which are characterized by pronounced radiometric signatures.

The Bonney Downs Granite on NULLAGINE is a weakly foliated, fine- to medium-grained, sparsely porphyritic biotite monzogranite (*AgKbd*), which locally has abundant xenoliths of granitic gneiss (*AgKbdn*). The biotite monzogranite contains quartz with rare undulose extinction, anhedral to subhedral plagioclase (andesine–oligoclase), inequigranular microcline up to 8 mm long, biotite partially altered to chlorite, and accessory opaque oxide, chlorite, apatite, epidote, muscovite, clinozoisite, titanite, leucoxene, fluorite, and zircon. The presence of chlorite, epidote, sericite, titanite, and fluorite are indicative of hydrothermal alteration.

Cooke Creek Monzogranite (Agco)

The Cooke Creek Monzogranite (*Agco*) has not been successfully dated, but is characterized by a pronounced radiometric signature typical of the ‘tin granites’ forming the c. 2850 Ma Split Rock Suite of Van Kranendonk et al. (2004). The monzogranite intrudes both the Warrawoona Group and ultramafic rocks at the base of the Mosquito Creek Basin, suggesting it is probably younger than the c. 2926 Ma Mosquito Creek Formation (Nelson, D. R., 2004, written comm.). A sample of the monzogranite was collected, but zircons extracted from it were deemed unsuitable for dating (Nelson, D. R., 2003, written comm.). Quartz veins locally containing fluorite, barite, and wolframite crosscut the southern part of the monzogranite. De Laeter et al. (1977) obtained a model biotite age of 2700 Ma from the monzogranite, and a whole-rock isochron of 2568 ± 37 Ma. Their geochemical data from the monzogranite show it to be chemically similar to other intrusions of the Split Rock Suite, and the present interpretation is that the intrusive age is c. 2850 Ma.

The monzogranite is medium to coarse grained, seriate, and consists of anhedral quartz crystals up to 5 mm across, microcline, plagioclase slightly altered to sericite, muscovite and biotite altered to chlorite, with accessory magnetite, apatite, zircon, fluorite, titanite, epidote, metamict allanite, rare opaque oxide, and xenolithic amphibole.

Unassigned granitic intrusive rocks (*Agg*, *Agl*, *Agt*)

Fine-grained granodiorite to quartz monzonite (*Agg*) is located approximately 1 km north of the Quartz Circle prospect, where it intrudes and contains roof pendants of the Panorama Formation. The age of the intrusive rock is uncertain, but the low proportion of quartz suggests that it may be part of the c. 1800 Ma Bridget Suite. The granodiorite to quartz monzonite consists of about 20% or less quartz, partly sericitized plagioclase (?andesine) containing secondary carbonate, minor microcline, biotite, and lath-like chlorite pseudomorphs after biotite and hornblende, and traces of zircon, apatite, pyrite, and magnetite altered to leucoxene.

Leucogranite dykes (*Agl*) intrude the Euro Basalt in the northeasten part of the McPhee greenstone belt, northwest of the Cooke Creek Monzogranite (e.g. at MGA 229800E 7613300N) and may be related to this monzogranite. The dykes are fine grained and consist of rare phenocrysts of microcline and sericitized plagioclase up to 5 mm long, in an inequigranular, fine-grained matrix of quartz, plagioclase, microcline, minor biotite altered to chlorite, granular epidote, and rare zircon and titanite.

Tonalite (*Agt*) at the Reedies Creek prospect area (e.g. MGA 216770E 7604580N) intrudes the Panorama Formation (*AWpfa*). Gabbro (*Aogq*) and ultramafic rock (*Aus*) intrude the tonalite. The tonalite is fine to medium grained and consists of subhedral to euhedral plagioclase altered to albite, sericite and carbonate, inequigranular quartz, and biotite altered to chlorite and leucoxene with accessory apatite and zircon.

Hamersley Basin

Fortescue Group

Mafic and felsic volcanic and sedimentary rocks of the Neoarchaean Fortescue Group in the Hamersley Basin (Trendall, 1990a,b) are located in the western, northeastern, southwestern, and southeastern parts of NULLAGINE (Fig. 4). The group overlies the EPGGT, Kurrana Terrane, and Mosquito Creek Basin with angular unconformities, and comprises weakly metamorphosed volcanic and sedimentary rocks. On NULLAGINE the group includes the c. 2772 Ma Black Range Dolerite Suite (*AFdb*), 2775–2763 Ma Mount Roe Basalt (*AFr*), 2768–2752 Ma Hardey Formation (*AFh*), c. 2741 Ma Kylena Formation (*AFk*), 2727–2715 Ma Tumbiana Formation (*AFt*), and 2718–2713 Ma Maddina Formation (*AFm*; Arndt et al., 1991; Blake, 2001; Kojan and Hickman, 1998; Nelson, 1998, 2001; Trendall, et al., 1998; Wingate, 1999; Blake et al., 2004). Regional airborne radiometric images across the southern part of the North Pilbara Craton indicate that andesite and dacite are widespread in the upper parts of the Kylena and Maddina Formations (Kojan and Hickman, 1998). Well-bedded sedimentary and volcaniclastic rocks of the Tumbiana Formation separate the Kylena and Maddina Formations (Fig. 5).

Blake (1993) and Nelson et al. (1999) described most of the volcanic rocks of the Fortescue Group as flood basalts, whereas Thorne and Trendall (2001) described the Mount Roe Basalt, and the Kylena and the Maddina Formations as subaerial to shallow-marine mafic lavas. Arndt et al. (2001) conversely ascribed the Fortescue Group volcanism to melting of the lithosphere above three successive mantle plumes.

Blake (1993) and Thorne and Trendall (2001) suggested that the felsic volcanic rocks of the Hardey Formation in the northern part of the Pilbara Craton were related to major north-northeasterly trending faults.

Black Range Dolerite Suite (AFdb)

The Black Range Dolerite Suite (*AFdb;* Lewis et al., 1975) is characterized by north to northeasterly trending, medium- to coarse-grained dolerite to gabbro dykes, which on NULLAGINE form prominent ridges in the Mosquito Creek Formation and the McPhee greenstone belt. The dykes range up to 600 m in width and typically have chilled margins. Local melting and hybridization of adjacent country rocks have produced contact metamorphic aureoles that are about 3 m wide. The dykes and contact aureoles form prominent outcrops within more subdued country rock. The dolerite suite has a U–Pb zircon and baddeleyite SHRIMP age of 2772 ± 2 Ma (Wingate, 1997, 1999), and is thought to be a feeder dyke system for the Mount Roe Basalt (Williams, 1999; Wingate, 1999).

The Black Range Dolerite Suite consists of albitized plagioclase, green amphibole replaced by green actinolite and chlorite, anhedral pyroxene with orthopyroxene cores altered to various combinations of chlorite–epidote–carbonate and rims of clinopyroxene, graphic-textured quartz and plagioclase, and accessory titanomagnetite and disseminated granophyre patches containing acicular apatite.

Mount Roe Basalt (AFr, AFrsh, AFrscp)

The Mount Roe Basalt (*AFr*) (Kriewaldt, 1964) unconformably overlies the Warrawoona and Gorge Creek Groups in the northwestern and northeastern parts of NULLAGINE, where it ranges up to about 500 m in thickness. The formation has a U–Pb zircon SHRIMP age of 2775 ± 10 Ma obtained from felsic volcanic rocks on ROEBOURNE and WYLOO (Arndt et al., 1991).

Massive, porphyritic, vesicular, and amygdaloidal basalt (*AFr*) is the common rock type in the Mount Roe Basalt. The basalt is altered to chlorite and epidote in places, and amygdales contain agate, clear quartz, or calcite and vary up to 50 mm in diameter. The base of the formation locally consists of polymictic, poorly sorted, and matrix-supported cobble to boulder conglomerate that grades upward to sandstone, siltstone and shale (*AFrscp*; MGA 234750E 7617700N). The conglomeratic units contain angular to subrounded clasts of black and white chert, vein quartz, and rare clasts of porphyry and mafic volcanic rocks. The onlapping and lensoidal nature of this unit (such as near MGA 236000E 7617750N) indicates that it occupies palaeovalleys eroded in the underlying basement rocks.

Hardey Formation (AFh, AFhs, AFhsg, AFhe, AFhsw, AFhsh, AFhscp)

The Hardey Formation (*AFh*), defined by Thorne et al. (1991), either disconformably or unconformably overlies the Mount Roe Basalt on NULLAGINE. This is evident from the onlap of shale (*AFhsh*) in the Hardey Formation over the Mount Roe Basalt in the northeastern part of NULLAGINE (e.g. near MGA 234750E 7618800N). Uranium–lead zircon dates from the Bamboo Creek Member (*AFhb*) of the Hardey Formation lie in the range from 2768 ± 16 to 2756 ± 8 Ma (Pidgeon, 1984; Arndt et al., 1991). A felsic tuff horizon interbedded with terrigenous fluvial deposits in the upper part of the Hardey Formation in the western part of NULLAGINE has a slightly younger SHRIMP U–Pb zircon date of 2752 ± 5 Ma (Blake et al., 2004).

Thorne and Trendall (2001) have reported five main sedimentary facies for the formation, which are alluvial fan and coarse-grained braided alluvial, sandy braided fluvial, lacustrine, deltaic, and shoreline. The formation on NULLAGINE largely consists of alluvial fan and coarse-grained braided alluvial deposits (*AFh*, *AFhg*, *AFhe*, *AFhscp*).

The thickness of the Hardey Formation in the western part of NULLAGINE ranges from about 1000 m (around MGA 192000E 7572000N) to less than 100 m in its southernmost exposure (e.g. around MGA 200500E 7568600N). The formation consists of sandstone, conglomerate, and minor interbeds of mudstone, shale, siltstone, and felsic tuff (*AFh*). Local successions consist of pebble to cobble conglomerate interbedded with medium- to coarse-grained sandstone (*AFhscp*); lithic wacke interbedded with poorly sorted sandstone, shale and siltstone (*AFhsw*); shale interbedded with lithic wacke, and minor felsic tuff (*AFhs*); locally restricted pebble to cobble conglomerate interbedded with medium- to coarse-grained sandstone in the northeastern part of NULLAGINE (*AFhsg*); and sandstone interbedded with conglomerate, shale, felsic tuff, and ooidal and pisolitic shale (*AFhs*). The basal units of the formation are interlayered with or overlain by a porphyritic rhyodacite with quartz phenocrysts known as the Bamboo Creek Member (*AFhb*; Thorne and Trendall, 2001). The Beaton Creek Member (*AFhe*; originally referred to as the Beatons Creek Conglomerate by Noldart and Wyatt, 1962) is located to the west of Nullagine. The member forms a fault-bound synclinal structure that plunges to the southwest. The conglomerate is very coarse grained, lenticular, rests conformably on the Mosquito Creek Formation, and contains rounded to subangular pebbles and cobbles of granitic and wacke lithic fragments. The lower 30 m of the member consists of units of upward fining and matrix-supported conglomerate that are up to 4 m thick. In places, the matrix in these units contains small crystals and rounded nodules of pyrite, and placer gold deposits (Hickman, 1983).

Sandstone interbedded with minor amounts of pebble to cobble conglomerate, shale and siltstone (*AFh*, *AFhsg*) is the most common rock type in the Hardey Formation. The sandstone is feldspathic, fine to coarse grained, well sorted, or pebbly, and displays local cross-bedding. The conglomerate is polymictic, matrix supported, upward fining, and contains clasts of quartz, chert, and rare mafic volcanic and granitic rocks.

On NULLAGINE, the Bamboo Creek Member (*AFhb*) was previously referred to as the Spinaway Porphyry (Lipple, 1975; Hickman, 1983; Blake et al., 2004), but recent geochronology and more detailed mapping now indicate that the Spinaway Porphyry is a southern continuation of the Bamboo Creek Member. The Bamboo Creek Member is locally present near the base of the Hardey Formation, and consists of massive quartz–feldspar porphyry of rhyodacitic composition and is characterized by subhorizontal joints that probably follow bedding within the unit (Blake, 1984, 1993). Thorne and Trendall (2001) interpret the porphyry to include lava interlayered with pyroclastic deposits and synvolcanic, porphyritic sills and dykes. Peperite found locally at the contact between the porphyry and sedimentary rocks, and the disjointed nature of the porphyry in the northeastern part of NULLAGINE (e.g. near MGA 238000E 7619000N) suggests emplacement of the porphyry as a high-level sill into wet sediments.

Kylena Formation (AFk, AFkbi)

The Kylena Formation (Kriewaldt and Ryan, 1967; Kojan and Hickman, 1998) is about 500 m thick on NULLAGINE, and rests conformably on the Hardey Formation. The oldest age for the formation is constrained by the youngest U–Pb zircon date from the underlying Hardey Formation, which is 2756 ± 8 Ma (Arndt et al., 1991). Mafic tuff from the base of the formation has a SHRIMP U–Pb zircon age of 2741 ± 3 Ma, which has been interpreted as the age of an accidental felsic volcanic component in the tuff (Blake et al., 2004). The youngest U–Pb age constraint for the Kylena Formation is 2715 ± 6 Ma, which is the youngest zircon population in tuffaceous sandstone in the overlying Tumbiana Formation (Arndt et al., 1991).

The Kylena Formation consists of massive vesicular and amygdaloidal basalt, and includes some pillow lava and local columnar jointing, and minor basaltic agglomerate (*AFk*), and massive and amygdaloidal basaltic andesite interbedded with minor basalt, andesite, and rare basaltic fragmental rock (*AFkbi*). High radiometric signatures on the NGA radiometric images characterize the basaltic andesite. Individual basalt flows are less than 10 m thick, and are amygdaloidal at their tops, with amygdales filled with agate, clear quartz, or calcite. The basalt commonly contains clinopyroxene partially altered to plagioclase, orthopyroxene altered to chlorite, and secondary interstitial actinolite, epidote, sericite, and chlorite.

Tumbiana Formation (AFtt, AFtc)

The Tumbiana Formation (Lipple 1975; Hickman and Lipple, 1978; Thorne and Trendall, 2001) conformably overlies the Kylena Formation, is about 500 m thick, and consists of the lower Mingah Member (*AFtt*), and the upper Meentheena Member (*AFtc*).

Mingah Member (AFtt)

The Mingah Member (Lipple, 1975; Thorne and Trendall, 2001) consists of thin- to medium-bedded mafic tuff interbedded with tuffaceous sandstone and siltstone (*AFtt*), and thin carbonate beds that are less than 1 m thick. The tuffaceous beds included pisolitic tuff, accretionary lapilli tuff (Fig. 16), crystal tuff, lithic tuff, and vitric tuff. Although some thin carbonate beds outcrop in the Mingah Member, the first thick (>1 m) carbonate unit is considered to be the basal unit of the conformably overlying Meentheena Member.

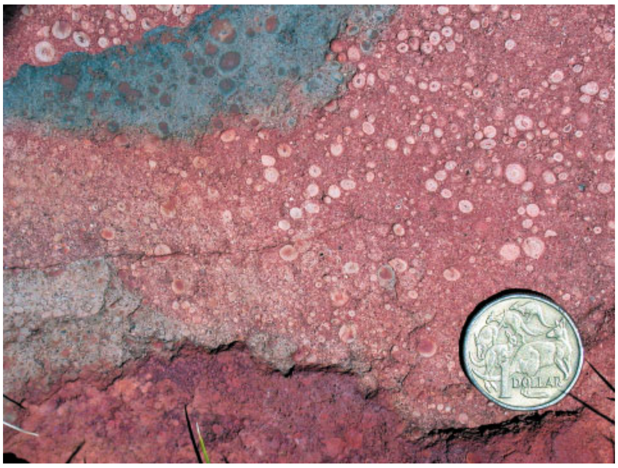
Meentheena Member (AFtc)

The Meentheena Member (Lipple, 1975; Thorne and Trendall, 2001) transitionally overlies the Mingah Member, and consists of banded dark-grey siliceous, stromatolitic dolomite and limestone beds, minor tuffaceous shale and siltstone, and rare thinly bedded tuff (*AFtc*). The limestone beds contain scattered oncolites and stromatolites in bioherms and biostromes, and are oolitic in places.

Maddina Formation (AFm)

The Maddina Formation (Kojan and Hickman, 1998) is located in the southwestern part of NULLAGINE, and is characterized by elevated radiometric signatures on the NGA images. A U–Pb zircon date of 2717 ± 2 Ma (Nelson, 1998, p. 133–135) was obtained from a massive, plagioclase-phyric dacite unit in the lower part of the formation on PINDERI HILLS.

Regionally, the Maddina Formation consists mainly of subaerial basalt flows, pillow lavas, fine- to coarse-grained mafic volcaniclastic rocks, and subordinate dacite, rhyolite, stromatolitic carbonate, and quartz sandstone (Thorne and Trendall, 2001). On NULLAGINE, the formation consists of massive, vesicular, and amygdaloidal basalt and andesite, with silicified flow tops. The stratigraphic top of the formation is not exposed on NULLAGINE, but Thorne



LB 219 27.09.04

Figure 16. Lapilli tuff from the basal part of the Mingah Member (*AFtt*) of the Tumbiana Formation (MGA 197430E 7567285N)

and Trendall (2001) recorded thicknesses of up to 1100 m in other areas.

Structures of the Fortescue Group

Three deformation events (described below) have affected the Fortescue Group: one event of faulting formed during deposition of the Mount Roe Basalt and lower part of the Hardey Formation (D_{FG1}), a second set of more gentle folds (D_{FG2}), and a third event of faults (D_{FG3}) offsetting earlier structures (Table 1). These three events have also been recognized on SPLIT ROCK (Bagas et al., 2004a).

D_{FG1} faulting during the early deposition of the Fortescue Group: c. 2775–2756 Ma

The eastern edge of the Fortescue Group in the western part of NULLAGINE is a major northerly trending, brittle growth fault (D_{FG1}) with west-side-down displacement (e.g. at MGA 197900E 7616500N). It forms a bounding fault to a small sub-basin of the Mount Roe Basalt and the lower part of the Hardey Formation. The fault does not affect the upper levels of the Hardey Formation, suggesting that fault movement ceased before deposition of the Kylena, Tumbiana, and Maddina Formations on NULLAGINE. Therefore, the fault is interpreted to be a growth fault synchronous with the deposition of the Mount Roe Basalt and lower part of the Hardey Formation. This is supported by the presence of polymictic conglomerate and turbidites (*AFrscp*, *AFrsh*, *AFhscp*, *AFhsw*, *AFhe*, *AFhsg*) at various levels in both formations, in addition to the transgressive nature of the Hardey Formation over the Mount Roe Basalt in both the southwestern and northeastern parts of NULLAGINE. The disconformity or unconformity between the Mount Roe Basalt and Hardey Formation is probably due to a period of tilting and faulting before deposition of the Hardey Formation. Similar structures have been recognized on SPLIT ROCK (Bagas et al., 2004a).

D_{FG2} folding of the Fortescue Group: <2717 Ma

The Fortescue Group is gently folded (D_{FG2}) with shallow south-southwesterly plunging axes in the southwestern part of NULLAGINE, and shallow northwesterly plunging axes on northeastern NULLAGINE. Some of these folds have curvilinear traces formed by refolding during D_{FG3}, and are cut by faults trending east, northeast, and southeast (D_{FG3}; such as at MGA 192000E 7580000N in the southwest). These faults also host post-Fortescue age dolerite dykes (*d*; e.g. MGA 200450E 7582000N). The F_{FG2} folds are open and on western NULLAGINE are indicative of east-southeasterly to west-northwesterly directed shortening, whereas in northeastern NULLAGINE they are indicative of southwesterly–northeasterly shortening. This change in orientation of the structures is suggestive of either a period of outward and probably upward growth of the McPhee Dome, or refolding during a later deformation event. The folds are younger than the Maddina Formation, which is c. 2717 Ma (Nelson, 1998; Blake et al., 2004).

D_{FG3} faulting: <2717 Ma

Structures attributed to D_{FG3} include north-northeasterly trending sinistral faults, southeasterly trending dextral faults, and eastward trending thrusts, and flexures of F_{FG2} folds in the Fortescue Group (e.g. near MGA 192000E 7580500N). These structures are younger than the Maddina Formation, which is dated at c. 2717 Ma (Nelson, 1998; Blake et al., 2004). The general orientation of these structures indicates a north-northwesterly to south-southeasterly compressional regime.

The southeast- to south-trending set of D_{MB6} dextral faults in the southern part of the Mosquito Creek Basin and Kurrana Granitoid Complex (including the c. 2838 Ma Bonney Downs Granite) are probably included in this deformation event.

Unassigned rocks of uncertain Precambrian age

Dolerite (d), quartz (q)

Dolerite dykes display a broad range of orientations across NULLAGINE. Most of the dykes are deeply weathered and poorly exposed, and in outcrop are massive and have a basaltic or gabbroic composition.

The north-northeasterly striking suite of fine- to coarse-grained dolerite dykes (*d*) are up to 100 m wide and commonly show evidence of deuteric alteration. The strike of the dykes and their en echelon emplacement pattern are similar to those of the c. 2772 Ma Black Range dolerite dyke, but observations on NORTH SHAW suggest that at least some of the parallel dykes may be younger than the Kylena Formation (Van Kranendonk, 2000) and thus the dykes are designated as unassigned on this map. By analogy with the dolerite dykes on SPLIT ROCK, the northeasterly trending dolerite dykes probably relate to the Mundine Well Suite (Hickman and Lipple, 1978), which Tyler (1991) stated extends across the Pilbara Craton, and was younger than the Bangemall Group. A date of 755 ± 3 Ma was obtained for two dykes of the swarm from the Bangemall Basin (Wingate and Giddings, 2000).

The southeast-trending swarm of dolerite dykes in the northwestern part of NULLAGINE crosscut the Corunna Downs Granitoid Complex and Warrawoona Group, and terminate just below the Mount Roe Basalt. Therefore, they are probably feeder dykes for the Mount Roe Basalt. Dykes with similar trends are found in the Mosquito Creek Formation.

Dolerite dykes on NULLAGINE are generally composed of green to black weathering rocks with a fine ophitic texture of plagioclase laths and interstitial augite. Some of the dykes contain a hydrous mafic mineral assemblage of actinolite and epidote intergrown with plagioclase. In these dykes, pyroxene relicts have been completely altered to fine-grained green chlorite, sericite, and feldspar, probably because of intense deuteric alteration. These dykes occupy fractures that are filled along strike by quartz (*q*), and quartz veins commonly fill dyke-parallel fractures adjacent to dykes. Quartz veins (*q*) also occupy faults, shear zones, tension gashes, and joints in the Warrawoona Group, granitic rocks, and the Mosquito Creek Formation.

Palaeoproterozoic Bridget Suite (*ⱣgBgh*)

Budd et al. (2002) named the Palaeoproterozoic Bridget Suite after the 'Bridget Adamellite' (Hickman, 1978), located northeast of Bridget Creek in the eastern part of Nullagine. Collins et al. (1988) named the Proterozoic Parnell Quartz Monzonite at Granite Hills Well, which was later sampled for dating by Nelson (2002). Rock and Barley (1988) classified the suite as calc-alkaline lamprophyres using texture and chemistry (e.g. high F, Ba, and K).

The Bridget Suite forms an approximately 250 km-long and up to 50 km-wide zone that trends southeast from the Yarrie iron mine on Muccan (Hickman, 1983; Williams, 1999) and across the eastern part of Nullagine to within 17 km of Balfour Downs Homestead on the Balfour Downs 1:250 000 sheet (Williams, 1989). It is subparallel to, and about 100 km west of, the Paterson Orogen (cf. Bagas, 2004).

The Bridget Suite on Nullagine comprises hornblende-bearing, porphyritic to seriate, quartz syenite to quartz monzodiorite (*ⱣgBgh*) that intrudes the Mosquito Creek Basin and Warrawoona Group. The intrusions of the suite have well-developed contact aureoles. A sample of hornblende–biotite quartz monzodiorite from near Granite Hill Well (GSWA 169030, MGA 240380E 7583600N) has a SHRIMP U–Pb zircon age of 1803 ± 19 Ma (Nelson, 2002). On Nullagine, the Bridget Suite consists of fine- to medium-grained, subhedral to euhedral laths of plagioclase, K-feldspar, abundant prisms and poikilitic grains of green hornblende, less than 10% interstitial quartz, irregular patches of sericite, minor biotite altered to chlorite, opaque oxide, titanite, apatite, and accessory zircon, carbonate, stilpnomelane, and fluorite. The K-feldspar forms euhedral crystals that commonly enclose plagioclase, and are aligned parallel to hornblende crystals, which are commonly altered to chlorite and carbonate.

Collins et al. (1988) suggested that the Bridget Suite might have shoshonitic affinities with a lower crustal source produced by high-pressure (1000 MPa) fractionation of near-anhydrous basaltic magma. They further suggested that the rising basaltic magma was trapped at the base of a 30–35 km-thick continental crust. The magma fractionated and solidified as underplated material, which provided a source for the suite. This suggestion, together with the suite's age, is consistent with deformation events recognized in the northwest Paterson Orogen and assigned to the Yapungku Orogeny. This orogeny was accompanied by the intrusion of granites in the northwest Paterson Orogen that spanned the period between c. 1800 and 1765 Ma (Bagas, 2004), when temperatures peaked around 800°C and pressures reached 1200 MPa (Smithies and Bagas, 1997). The orogeny represents a period of crustal thickening of about 35 km, which is indicative of a major continent–continent collision. Therefore, the Bridget Suite may represent a far-field effect of the major continent–continent collision at the eastern edge of the EPGGT during the Yapungku Orogeny.

Cainozoic deposits

Cainozoic deposits on Nullagine are common on granite and sparsely distributed in areas of greenstones and metasedimentary rocks. Older deposits include consolidated alluvial, colluvial, and residual material. Later, unconsolidated Quaternary material includes alluvial, colluvial, eluvial, and eolian deposits.

Gently undulating duricrust surfaces include silcrete deposits that consist of siliceous caprock with angular quartz and chert clasts (*Czrz*), and ferruginous duricrust that includes massive, pisolitic, and nodular laterite with some transported material (*Czrf*). These units expose local underlying dissected bedrock. The ferricrete grades downward into leached and kaolinized deeply weathered rock. The duricrust represents remnants of Cainozoic or older weathering profiles in which the original rock structures or textures are poorly preserved. Ferricrete deposits are several metres thick, include massive, pisolitic and nodular ironstone, and locally consolidated ferruginous alluvium. These rocks form particularly on ferruginous shale and banded iron-formation of the Gorge Creek Group in the northwestern part of Nullagine. Silcrete (*Czrz*) is probably early Cainozoic or older in age, and may represent an early Cainozoic continent-wide weathering event (Idnurm and Senior, 1978). Silcrete consists of angular quartz grains and clasts set in siliceous cement. Residual calcrete (*Czrk*) consists of dissected, massive, nodular, and cavernous carbonate that overlies, and is derived from, altered carbonate-rich ultramafic rocks, and covers large areas bordering rivers or creeks over granitic rocks. The calcrete forms as sheets, encrustations, and joint-fills, and is either massive or nodular. The unit is variably silicified, and developed in situ. Relict eluvium and colluvium, which includes sand, gravel and silt (*Czrg*), overlies and is derived from granitic rock of the Corunna Downs Granitoid Complex in the northwestern corner of Nullagine.

Consolidated and dissected, poorly stratified, alluvial gravel, sand, and silt derived from granitic rock (*Czag*) is present along the banks of creeks on the Corunna Downs Granitoid Complex in northwestern Nullagine. Dissected pisolitic, ferruginous (limonitic, goethitic, and hematitic) channel deposits (*Czaf*) are between 10 and 30 m thick on southwestern Nullagine. These deposits contain local traces of fossil wood. The unit forms elevated and peneplained terraces and mesas and has been correlated by Hickman and Lipple (1978) with the Poondano Formation and the Robe Pisolite (de la Hunty, 1965; MacLeod, 1966). The peneplained surface could be correlated with the Hamersley Surface in the Hamersley Ranges (Campana et al., 1964). Colluvium (*Czc*) is composed of clay, silt, sand, and pebbly sand and gravel with clay or silica cement, and is most widely deposited on flat granitic complexes and on low slopes or flat plains. Dissected, consolidated colluvium (*Czc*) is derived from adjacent rock outcrops and derived from erosion of topographically high points throughout NULLAGINE.

Quaternary deposits

Quaternary deposits on NULLAGINE consist of residual, alluvial, and colluvial deposits, together with sheetwash and lacustrine deposits, and minor eolian deposits. Fine- to medium-grained eolian sand (*Qs*) forms undulating sheets in the southwestern part of NULLAGINE. The variable grain size and coarser grained components of these sands suggest that they constitute a mixture of eolian and eluvial sand. Recent colluvium consisting of sand, silts, and gravel (*Qc*), in the form of outwash fans, scree and talus, is common in hilly areas and on the Corunna Downs Granitoid Complex. Sheetwash deposits of clay, silt, sand, and pebbles (*Qw*) are developed in distal outwash fans that lack defined drainages.

The creek and river system on NULLAGINE has a wide range of alluvial deposits. The surface of the water channels is incised below the top of adjacent floodplains and overbank deposits (*Qao*), which consist of alluvial gravel, sand, silt, clay, and silty sand. The fluvial unit (*Qaa*) consists of unconsolidated silt, and sand. Alluvial fans commonly feed these units, and minor drainage channels commonly have a clay surface, although some have a scattered quartz-pebble or rock-fragment veneer.

Economic geology

Early mineral exploration in the NULLAGINE area began in the late 1880s following the discovery of gold by Mr N. W. Cook at Nullagine in 1886 (Maitland, 1905). The mineral deposits and occurrences on NULLAGINE are described below with WAMIN reference numbers in brackets; these are listed and described in Ferguson and Ruddock (2001). The types of mineralization described below follow the outline set out by Ferguson and Ruddock (2001), and are arranged in the same order as shown on the NULLAGINE map.

Porphyry, pegmatite, greisen and skarn mineralization

Speciality metals — tin, tantalum, tungsten

Blockley (1980) recognized that the 2850–2830 Ma ‘tin granites’ commonly contain cassiterite- and wolframite-bearing pegmatites. The Cooke Greek Granite is probably an example of a tin granite, and has produced about 17.6 t of scheelite and wolframite from 0.1 to 0.2 m-thick pegmatite veins (Hickman, 1983). Two deposits (4976 and 6401, around MGA 235500E 7605520N) have been mined from pegmatite veins in the granite.

Veins containing wolframite, and accessory scheelite and fluorite, were mined during the early 1950s for a production of 25 t of concentrates containing about 360 kg of WO_3 (Baxter, 1978). There are also over 20 scheelite occurrences (4977, 5711, 6294–97, 6392, 6395–98, 6401–02, 6480, 6410–14, 6417–18) along the western margin of the Cooke Creek Monzogranite (Baxter, 1978) that were worked during the 1950s for a production of about 17.6 t of WO_3 (Ferguson and Ruddock, 2001).

Base metals — copper, molybdenum, tungsten

The Gobbos Granodiorite (*Aggo*) and surrounding mafic rocks (*AWeb*) of the Euro Basalt host Cu–Mo–W(–F) deposits and occurrences. These include prospects at Gobbos (4962–63, 5923, around MGA 220765E 7615481N), and Lightning Ridge Southwest (5932, MGA 215755E 7618540N).

The Gobbos prospect area (4962–63, 5923) is a zone of multiple-phase quartz veining containing chalcopyrite, molybdenite, and pyrite in the Euro Basalt. The quartz veining is probably related to the intrusion of the Gobbos Granodiorite. At the northeastern corner of the granodiorite, there is a small, strongly silicified, sericitized, quartz–plagioclase porphyry intrusion that is the focus of a 1 km^2 zone of multiple-phase fracturing and quartz–carbonate veining with up to 2% chalcopyrite, and 1% molybdenite with scheelite, pyrite, and rare galena. The host rocks in the veined area are silicified and show propylitic and sericitic alteration typical of porphyry-style mineralization (Barley, 1982). Mineralization is also present in a breccia along the northeastern intrusive contact of the granodiorite with the Euro Basalt, where breccia fragments contain up to 3% chalcopyrite, molybdenite, and pyrite (Ferguson and Ruddock, 2001).

The Lightning Ridge Southwest prospect (5932) is situated near the contact between sericitized, silicified or chloritized rocks of the Gobbos Granodiorite and Euro Basalt. The mineralization consists of disseminated and veins of pyrite, chalcopyrite, and molybdenite in quartz veins. Conwest Exploration Co. Ltd completed 17 percussion drillholes in the area during 1967, and intersected up to 1.1% Cu over 30 m, and about 0.1% Mo over 12 m (Marston, 1979).

Orthomagmatic mafic and ultramafic mineralization

Steel industry metal — nickel (copper, cobalt)

The Cookes Creek nickel occurrences (6246–50) are located in ultramafic intrusive rocks between the Cooke Creek Monzogranite and Mosquito Creek Basin. At the Anomaly Hill prospect (6246–48), disseminated pentlandite with minor amounts of chalcopyrite is hosted by serpentinized dunite in the basal parts of an intrusive sill (Ferguson and Ruddock, 2001). The estimated resource at the prospect is about 0.5 Mt grading almost 1% Ni. Minor nickel sulfide occurrences are also observed to the east of Anomaly Hill (6249–50) in a mineralized zone that extends over 1200 m along the ultramafic sill (Ferguson and Ruddock, 2001).

Industrial mineral — asbestos (chrysotile)

Several asbestos (chrysotile) deposits have been mined at Lionel Mining Centre in the western part of NULLAGINE (5950, 5980–81, 6627–29, 6631–33; Hickman, 1983). The workings have a recorded production of about 4000 t (Hickman, 1983). They are located in layered metadunite and metaperidotite (*Aupd*) that appears to intrude the Euro Basalt (*AWeb*) and unassigned metasedimentary rocks (*Ascu*) within a tectonically complex zone between the Kelly and McPhee greenstone belts. The ultramafic rocks contain widespread chrysotile in veinlets averaging between 10 and 100 mm wide.

Vein and hydrothermal mineralization

Precious metal — gold (and antimony)

Gold occurrences in the McPhee greenstone belt are located in quartz veins in gabbro (*Aog*) at the McPhees prospect (WAMIN reference 4766 at MGA 209980E 7605270N, and 5919 at MGA 210440E 7605335N), and in the Panorama Formation (*AWpft*, *AWpfa*) at the Gold Show Hill (6654, MGA 210415E 7603060N), Prospector (12440, MGA 212250E 7605350N), and Referendum (12478, MGA 211450E 7606200N) prospects.

Folded, cleaved, and locally crenulated pelite and psammite of the Mosquito Creek Formation host significant lode Au and Au–Sb deposits. Most of the deposits lie within the subparallel and arcuate Middle Creek (predominantly Au with the local presence of Sb) or the Blue Spec Fault Zones (Au–Sb), which are orientated approximately in an east–west direction. The Middle Creek Fault Zone is broadly coincident with the 'Middle Creek' line of deposits although they crosscut in places (Ferguson and Ruddock, 2001), and the Blue Spec Fault Zone is broadly coincident with the 'Blue Spec line' of deposits (Maitland, 1908). Placer deposits situated west of the Blue Spec Fault Zone, north of Nullagine, and in the Hardey Formation represent another style of mineralization (mentioned under **Regolith hosted mineralization**).

Middle Creek Fault Zone

The Middle Creek Fault Zone hosts many deposits, including Golden Eagle (4550, 6640–46, 5654), North Dromedary (7840), Valentine (4566), Castlemaine (4562), Shearers–Otway (5655–56), Cowboy (6423), All Nations (4268), Barton–Hopetoun (4253, 4255–57,4263, 4266), Federation (4270, 4273, 5674–76), Little Wonder (4274–5, 5672, 5746–47, 5749, 5751–56), Latest Surprise (7555–56), Ard Patrick (Au–W, 4372, 7557), Galtee More (4366, 4371, 5766–71), Off Chance (5968), and Lands End (5967). This group of deposits has produced about 0.7 t of gold from over 32 000 t of ore averaging about 23 g/t Au (Ferguson and Ruddock, 2001).

The Golden Eagle (formerly Alexandra) deposit is located about 9 km south of Nullagine (around MGA 202680E 7568070N), in the northern upright limb of a reclined anticline that plunges gently to the east (Blewett et al., 2002). The deposit is estimated to contain around 10 t Au, and is in quartz veins containing veined and disseminated pyrite, and lesser disseminated rutile, disseminated magnetite, chalcopyrite, gold, sphalerite, galena, and feldspar (Ferguson and Ruddock, 2001; Blewett et al., 2002). Higher ore grades are generally in psammitic intervals containing quartz veins with increased concentrations of pyrite (Blewett et al., 2002). Fractures, cleavage, and faults intersecting the anticline control the gold mineralization, and the historical workings followed narrow ferruginized (pyritic) quartz veins with grades reaching 145 g/t Au (Ferguson and Ruddock, 2001).

The Shearers (5655, MGA 211770E 7573500N) and Otways (5656, MGA 212140E 7573450N) deposits are located about 11 km northeast of the Golden Eagle deposit, and 12 km east-southeast of Nullagine. The mineralization at the Shearers deposit is in a stockwork zone of quartz veins, which are up to 1 m wide and hosted by dextral faults trending about 020° that crosscut the Middle Creek Fault (Ferguson and Ruddock, 2001). The mineralization at the Otways deposit is patchy and follows subvertical quartz veins that are parallel to, and north of, the Middle Creek Fault.

The Barton–Hopetoun deposits (located between MGA 219065E 7577600N and 219685E 7578630N) are the biggest producers along the Middle Creek Fault Zone. The deposits are at or near the intersection of two major faults in the Middle Creek Fault Zone, and have a complex structural history involving folding and refolding, with several generations of shearing (Blewett et al., 2002). About 7000 t of ore with an average grade of 36.5 g/t was mined between 1898 and 1926 for a recorded production of over 240 kg of gold. Anastomosing quartz veins that trend north-northeast and dip steeply southeast at about 60° near the surface and shallow off at depth host the mineralization (Hickman, 1983). The ore plunges northeast at about 40°, coinciding with the intersection of quartz veins with cleavage in the country rocks (Hickman, 1983).

The Latest Surprise (4373; MGA 235485E 7581051N), Ard Patrick (4372; MGA 235625E 7580900N), Galtee More or Galteemore (4366; MGA 236450E 7580830N), Off Chance (5968; MGA 241230E 7579560N), and Lands End 1 (7641; MGA 240640E 7578900N) Au(–Sb) deposits form part of the Mosquito Creek Mining Centre situated about 40 km east of Nullagine. Over 230 kg of gold was produced in this area by 1913 from some 7000 t of ore (Hickman, 1983). The mineralization is in easterly trending, quartz veins up to 1 m in width (Hickman, 1983). The veins are vertical or dip steeply to the north, and contain gold, minor pyrite, and local concentrations of scheelite and stibnite (Hickman, 1983).

Blue Spec Fault Zone and Nullagine Mining Centre

Some of the deposits hosted by the Blue Spec Fault Zone are Blue Spec (4345, MGA 218265E 7584440N), Golden Spec (4348, MGA 217085E 7584230N), Branchis (4354, 6206–08, around MGA 225000E 7585700N), Billjim (4355, MGA 231145E 7586490N), and Parnell (4380–85, around MGA 241610E 7583970N). Of these, the Blue Spec deposit has been the most productive with almost 2 t of gold and concentrates containing 1500 t of antimony produced from over 110 000 t of ore with an average grade of over 18 g/t Au (Hickman, 1983; Ferguson and Ruddock, 2001).

The mineralization in the Blue Spec Fault Zone is similar in style to the deposits in the Middle Creek Fault Zone, except the former contains a significant concentration of stibnite. The lodes dip vertically or steeply to the south, and appear to be located in flexures in the fault zone, which are themselves sheared. This suggests that shearing was synchronous with the mineralization (Hickman, 1983). The Blue Spec Au–Sb deposit is the best known in the area, and is located in an east-trending, 15 to 20 m-wide shear zone. The mineralization is concentrated along the margins of the shear zone in lodes that are either vertical or dip steeply to the south. The mineralization is in quartz veins containing stibnite, aurostibnite, gold, pyrite, pyrrhotite and carbonate, with minor scheelite, arsenopyrite, marcasite, sphalerite, chalcopyrite, magnetite, calaverite, rickardite, and gudmundite (Hickman, 1983). Also present are cervantite in the oxidized zone, and traces of mercury (Hickman, 1983).

The Billjim mine is also situated in the Blue Spec Fault Zone, and is located about 15 km east-northeast of Blue Spec. The mine has a recorded production of around 100 kg of gold from about 5000 t of ore. Quartz veins carry gold and stibnite mineralization (Hickman, 1983).

Steel industry metal — nickel

The Otways nickel prospect (5924, MGA 197900 7602300), representing shear-zone-hosted nickel mineralization, is hosted by serpentinized ultramafic sills in unassigned metasedimentary rocks (*Ascu*) west of the McPhee greenstone belt host, which is located in the Lionel Mining Centre (Ferguson and Ruddock, 2001). The nickel mineralization is located in shear zones, and is probably the result of hydrothermal activity interacting with ultramafic rocks (Ferguson and Ruddock, 2001).

Base metals — copper, lead, zinc (silver, molybdenite, tungsten)

The McPhee greenstone belt includes various fracture- and fault-hosted quartz veins containing sulfides. These veins are commonly associated with sericite–chlorite–quartz alteration zones, such as around the Quartz Circle (4640, 6234, 13247, around MGA 209535E 76010110N) and the Copper Gorge (4615, MGA 225655E 7608140N) mineral occurrences. Quartz-veined shear zones in the Golden Eagle Orthogneiss also contain Cu–Pb–Zn mineral occurrences at Coondoon (5832, MGA 237815E 7572500N) and Coondamar Creek (4851, MGA 239335E 7569860N).

Alcoa discovered mineralization in dacitic pyroclastic rocks and felsic agglomerate (*AWpft*) of the Panorama Formation at Quartz Circle in the 1970s. They found massive and vein-type Cu–Zn(–Ag–Au) mineralization at Quartz Circle during a drilling program, which in one hole intersected over 7 m assaying 22.5% Zn, and over 14 m of massive sphalerite assaying 28.5% Zn, 0.33% Cu, 0.5 % Pb, 0.15% Cd, 68 g/t Ag, and 0.5 g/t Au (Ferguson and Ruddock, 2001). Cerussite- and gypsum-lined veins containing traces of pyrite and galena host the sphalerite (Ferguson and Ruddock, 2001).

Ferruginized ultramafic and gabbroic rocks (*Aupd*) to the southwest of McPhee greenstone belt host the Lionel and Hendersons copper deposits (4765, 5021, 5949, 6632, 6637; around MGA 201335E 7601835N). Over 370 t of ore averaging about 15.5% Cu was produced in the area during the 1950s and 60s. The mineralization consists of quartz–limonite–azurite–malachite veins and calcite–chalcopyrite–pyrite veins that are less than 1 m thick (Marston, 1979).

The Euro Basalt hosts gossans containing Cu(–Zn–Ag–Au–Mo) at the Bridget Northeast (4983, 6223–25, 6229) and Wallabirdie Ridge (5283, 5284) prospects. Anglo American investigated the area in the early 1970s and found pyritic mafic volcanic rocks assaying less than 2000 ppm Cu. They also found gossanous quartz veins containing malachite and chrysocolla in silicified zones (Marston, 1979). Maximum grades of 32% Cu, 19% Zn, 300 g/t Ag, 1.3 g/t Au, and 0.4% Mo from hand samples were recorded during their exploration (Ferguson and Ruddock, 2001).

Industrial minerals — barite, fluorite

Barite associated with fluorite in quartz veins is concentrated in the southern part of the Cooke Creek Monzogranite (e.g. 4776 at MGA 236165E 7604360N, where these veins are associated with scheelite and wolframite, and at MGA 238175E 7603765N), and quickly diminishes in the country rock away from the granite boundary. The barite veins trend north, are up to 0.15 m thick, and are commonly silicified in silica-filled fractures. The silica-filled fractures suggest that the barite maybe be related to hydraulic fracturing linked to late igneous activity associated with the emplacement of the Cooke Creek Monzogranite. There are also minor workings on barite veins in chert and sandstone of the Corboy Formation (*AGcstq*) at Lionel North in the northwestern part of NULLAGINE (5982, MGA 200635E 7610760N).

Stratabound volcanic and sedimentary mineralization

Precious mineral and base metal

Gossan containing a small high grade Au–Cu–Zn–Pb deposit at Middle Creek (4628, MGA 219400E 7578580N) is located in a deformed zone near the intersection of two faults in the Mosquito Creek Formation. The gossan is interpreted as stratiform massive sulfide mineralization in exhalative chert containing grades of 21.5% Cu, 3.3% Pb, 7.25% Zn, 7% Sb, 35.5 g/t Au, and 380 g/t Ag from hand samples (Ferguson and Ruddock, 2001).

The Otways copper prospects are located in the northern part of the McPhee greenstone belt (4767, 4768, 7336, 7338, around MGA 216900E 7612650N). There are four shafts within a fractured zone that is about 800 m long and less than 100 m wide. The mineralization consists of disseminated chalcopyrite and malachite veining in carbonated and chloritized amygdaloidal basalt (*Aeb*). The source of the mineralization is probably the volcanic host rocks. The area was worked during the 1960s for a production of about 5.4 t of ore with a grade of 13.5% Cu (Marston, 1979). In 1966, Conwest Exploration Co. Ltd drilled 22 percusson drillholes with the best intersection being about 1.4% Cu over 6 m in the mafic volcanic and underlying felsic volcanic rocks of the Panorama Formation (Marston, 1979). The Otways northwest prospect (4982, MGA 214300E 7614195N) is located about 3 km northwest of the Otways Cu occurrences in quartz-phyric gabbro (*Aogq*) and in 1965 produced over 4 t of ore assaying 12.4% Cu (Marston, 1979).

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

The Copper Gorge Cu–Zn–Ag mineralization (4615) is in a transitional zone between felsic volcanic rocks (*AWpft*) of the Panorama Formation and overlying Euro Basalt (*AWebk*, *AWeb*). Chert beds assigned to the Strelley Pool Chert (*AWs*) separate the two formations. The mineralization is classified by Ferguson and Ruddock (2001) as stratabound volcanic style. However, the mineralization is in quartz veins containing pyrite, chalcopyrite, sphalerite, and minor galena, and is associated with sericite, carbonate, and silica alteration of the country rocks (Ferguson and Ruddock, 2001). Thus, the mineralization may be better classified as vein and hydrothermal type. Cominco Ltd inferred a resource of 0.5 Mt at 0.5% Cu, and Australian Ores and Minerals Ltd intersected 4.5 m at 2.25% Zn, 0.16% Cu, and 8 g/t Ag in a drilling program in the prospect area (Ferguson and Ruddock, 2001).

Stratabound sedimentary and/ or sedimentary banded iron-formation mineralization

Precious metal — gold

The Nullagine Mining Centre is located around the westernmost exposure of the Blue Spec Fault Zone, and includes the Grants Hill (4465, MGA 200025E 7577785N), Freak of Nature (4467, MGA 200340E 7578025N), and the Barneys Hill group of workings (4471–72, 4474, 4483, and 4485, around MGA 200130E 7578375N). A significant proportion of the gold in the area has been mined from placer deposits in the Beaton Creek Member (*AFhe*) of the c. 2764–2756 Ma Hardey Formation, although about half of the production has also been obtained from the Mosquito Creek Formation (*ADqs*; Hickman, 1983). The placer mineralization probably formed in stream channels draining from mineralized areas in the Blue Spec Fault Zone to the east (described under **Vein and hydrothermal mineralization**).

Regolith hosted mineralization

Precious mineral — diamond

Diamonds were discovered during 1895 in faulted conglomerate beds (*AFhe*, *AFhsw*) in the Hardey Formation, in ferricrete (*Czrf*), and in local alluvial concentrations along creeks located about 1 km north, and also 4 km northeast, of Nullagine (Groom, 1896). By 1973, over 70 diamonds had been recovered, of which three were considered marketable (Hickman, 1983). The diamonds are thought to be placer deposits hosted by the Beaton Creek Member (*AFhe*) of the Hardey Formation (Sofoulis, 1958; Noldart and Wyatt, 1962) or from Cainozoic sediments (Carter, 1974). Possible kimberlite intrusions have been identified in a northwest-trending fault in the Beaton Creek Member to the northwest of Nullagine, which could also be a possible source for the diamonds (Blake and Chalmers, 1994).

Precious metal — gold

Placer and supergene gold mineralization is located near vein and hydrothermal mineralization in the Mosquito Creek Formation. Regolith hosted mineralization is located near Nullagine (4494, 4496, 4497, 4499), South Dromedary (5274), Middle Creek (2), and near Sandy Creek Fault (5277) on the eastern side of Nullagine (Ferguson and Ruddock, 2001).

Speciality metal — tin

Cassiterite was recorded in concentrates obtained from the gold-bearing Beaton Creek Member of the Hardey Formation (Blockley, 1980).

References

ARNDT, N. T., BRUZAK, G., and REISCHMANN, T., 2001, The oldest continental and oceanic plateaus: Geochemistry of basalts and komatiites of the Pilbara Craton, Australia, *in* Mantle plumes: their identification through time *edited by* R. E. ERNST and K. L. BUCHAN: Geological Society of America, Boulder, Colorado, Special Paper 352, p. 359–387.

ARNDT, N. T., NELSON, D. R., COMPSTON, W., TRENDALL, A. F., and THORNE, A. M., 1991, The age of the Fortescue Group, Hamersley Basin, Western Australia, from ion microprobe zircon U–Pb results: Australian Journal of Earth Sciences, v. 38, p. 261–281.

BAGAS, L., 2004, Proterozoic evolution and tectonic setting of the northwest Paterson Orogen, Western Australia: Precambrian Research, v. 128, p. 475–496.

BAGAS, L., BEUKENHORST, O., and HOS, K., 2004b, Nullagine, W.A. Sheet 2954: Western Australia Geological Survey, 1:100 000 Geological Series.

BAGAS, L., SMITHIES, R. H., and CHAMPION, D. C., 2003, Geochemistry of the Corunna Downs Granitoid Complex, East Pilbara Granite–Greenstone Terrane: Western Australia Geological Survey, Annual Review 2002–03, p. 61–69.

BAGAS, L., VAN KRANENDONK, M. J., and PAWLEY, M., 2004a, Geology of the Split Rock 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 44p.

BAGAS, L., FARRELL, T. R., and NELSON, D. R., 2004b, The age and provenance of the Mosquito Creek Formation: Western Australia Geological Survey, Annual Review 2003–04, p. 62–70.

BARLEY, M. E., 1982, Porphyry-style mineralization associated with early Archaean calc-alkaline igneous activity, eastern Pilbara, Western Australia: Economic Geology, v. 77, p. 1230–1236.

BARLEY, M. E., LOADER, S. E., McNAUGHTON, N. J., 1998, 3430 to 3417 Ma calc-alkaline volcanism in the McPhee Dome and Kelly Belt, and growth of the eastern Pilbara Craton: Precambrian Research, v. 88, p. 3–23.

BARLEY, M. E., and PICKARD, A. L., 1999, An extensive, crustally-derived, 3325 to 3310 Ma silicic volcanoplutonic suite in the eastern Pilbara Craton: evidence from the Kelly Belt, McPhee Dome and Corunna Downs Batholith: Precambrian Research, v. 96, p. 41–62.

BAXTER, J. L., 1978, Molybdenum, tungsten, vanadium and chromium in Western Australia: Western Australia Geological Survey, Mineral Resources Bulletin 11, 140p.

BEARD, J. S., 1975, The vegetation of the Pilbara area: Vegetation Survey of Western Australia 1:1 000 000 Vegetation Series, Explanatory Notes to Sheet 5: Perth, University of Western Australia Press, 120p.

BEUKENHORST, O., and HOS, K., 1999, Geology of the Mosquito Creek Block: Utrecht University, The Netherlands, BSc honours thesis (unpublished).

BICKLE, M. J., BETTENAY, L. F., BOULTER, C. A., GROVES, D. I., and MORANT, P., 1980, Horizontal tectonic intercalation of an Archaean gneiss belt and greenstones, Pilbara Block, Western Australia: Geology, v. 8, p. 525–529.

BICKLE, M. J., MORANT, P., BETTENAY, L. F., BOULTER, C. A., BLAKE, T. S., and GROVES, D. I., 1985, Archaean tectonics of the Shaw Batholith, Pilbara Block, Western Australia — structural and metamorphic tests of the batholith concept, *in* Evolution of Archean supracrustal sequences *edited by* L. D. AYERS, P. C. THURSTON, K. D. CARD and W. WEBER: Geological Association of Canada, Special Paper 28, p. 325–341.

BLAKE, T. S., 1984, The lower Fortescue Group of the northern Pilbara Craton — stratigraphy and palaeogeography, *in* Archaean and Proterozoic basins of the Pilbara — evolution and mineralization potential *edited by* J. R. MUHLING, D. I. GROVES and T. S. BLAKE: University of Western Australia, Geology Department and University Extension, Publication, no. 9, p. 123–143.

BLAKE, T. S., 1993, Late Archaean crustal extension, sedimentary basin formation, flood basalt volcanism and continental rifting. The Nullagine and Mount Jope Supersequences, Western Australia: Precambrian Research, v. 60, p. 185–241.

BLAKE, T. S., 2001, Cyclic continental mafic tuff and flood basalt volcanism in the Late Archaean Nullagine and Mount Jope Supersequences in the eastern Pilbara, Western Australia: Precambrian Research, v. 107, p. 139–177.

BLAKE, T. S., BUICK, R., BROWN, S. J. A., and BARLEY, M. E., 2004, Geochronology of a Late Archaean flood basalt province in the Pilbara Craton, Australia: constraints on basin evolution, volcanic and sedimentary accumulation, and continental drift rates: Precambrian Research , v. 133(3–4), p. 143–173.

BLAKE, T. S., and CHALMERS, D. I., 1994, A diamondiferous alkaline igneous province in the eastern Pilbara, Western Australia, *in* Notes to accompany conference presentation: Alkane Exploration NL, Australian Diamond Conference, 1994, Perth, 14p.

BLEWETT, R. S., 2002, Archaean tectonic processes: a case for horizontal shortening in the North Pilbara Granite–Greenstone Terrane, Western Australia: Precambrian Research, v. 113, p. 87–120.

BLEWETT, R. S., HUSTON, D. L., MERNAGH, T. P., and KAMPRAD, J., 2002, The diverse structure of Archaean lode gold deposits of the southwest Mosquito Creek belt, east Pilbara Craton, Western Australia: Economic Geology, v. 97, p. 787–800.

BLEWETT, R. S., SHEVCHENKO, S., and BELL, B., 2004, The North Pole Dome: a non-diapiric dome in the Archaean Pilbara Craton, Western Australia: Precambrian Research, v. 133, p. 105–120.

BLOCKLEY, J. G., 1980, Tin deposits of Western Australia with special reference to the associated granites: Western Australia Geological Survey, Mineral Resources Bulletin 12, 184p.

BOULTER, C. A., BICKLE, M. J., GIBSON, B., and WRIGHT, R. K., 1987, Horizontal tectonics pre-dating upper Gorge Creek Group sedimentation, Pilbara Block, Western Australia: Precambrian Research, v. 36, p. 241–258.

BUDD, A. R., WYBORN, L. A. I., and BASTRAKOVA, I. V., 2002, The metallogenic potential of Australian Proterozoic granites: Geoscience Australia, Record 2001/12, 152p.

BUICK, R., BRAUHART, C. W., MORANT, P., THORNETT, J. R., MANIW, J. G., ARCHIBALD, N. J., DOEPEL, M. G., FLETCHER, I. R., PICKARD, A. L., SMITH, J. B., BARLEY, M. E., McNAUGHTON, N. J., and GROVES, D. I., 2002, Geochronology and stratigraphic relationships of the Sulphur Springs Group and Strelley Granite: a temporally distinct igneous province in the Archaean Pilbara Craton, Australia: Precambrian Research, v. 114, p. 87–120.

CAMPANA, B., HUGHES, F. E., BURNS, W. G., WHITCHER, I. G., and MUCENIEKAS, E., 1964, Discovery of the Hamersley iron deposits (Duck Creek – Mt Pyrton – Mt Turner area): Australasian Institute of Mining and Metallurgy, Proceedings, no. 210, p. 1–30.

CARTER, J. D., 1974, Diamond exploration in Western Australia: Western Australia Geological Survey, Annual Report 1973, p. 73–79.

COLLINS, W. J., 1989, Polydiapirism of the Archaean Mount Edgar batholith, Pilbara Block, Western Australia: Precambrian Research, v. 43, p. 41–62.

COLLINS, W. J., 1993, Melting of Archaean sialic crust under high a_{H_2O} conditions: genesis of 3300 Ma Na-rich granitoids in the Mount Edgar Batholith, Pilbara Block, Western Australia: Precambrian Research, v. 60, p. 151–174.

COLLINS, W. J., GRAY, C. M., and GOODE, A. D. T., 1988, The Parnell Quartz Monzonite: a Proterozoic zoned pluton in the Archaean Pilbara Block, Western Australia: Australian Journal of Earth Sciences, v. 35, p. 535–547.

COLLINS, W. J., and VAN KRANENDONK, M. J., 1999, Model for the development of kyanite during partial convective overturn of Archaean granite–greenstone terranes: the Pilbara Craton, Australia: Journal of Metamorphic Geology, v. 17, no. 2, p. 145–156.

COLLINS, W. J., VAN KRANENDONK, M. J., and TEYSSIER, C., 1998, Partial convective overturn of Archaean crust in the east Pilbara Craton, Western Australia — driving mechanisms and tectonic implications: Journal of Structural Geology, v. 20, p. 1405–1424.

DAVY, R., 1988, Geochemical patterns in granitoids of the Corunna Downs Batholith, Western Australia: Western Australia Geological Survey, Report 23, p. 51–84.

de la HUNTY, L. E., 1965, Mount Bruce, Western Australia: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 28p.

de LAETER, J. R., HICKMAN, A. H., TRENDALL, A. F., and LEWIS, J. D., 1977, Geochronological data concerning the eastern extent of the Pilbara Block: Western Australia Geological Survey, Annual Report 1976, p. 100–106.

ERIKSSON, K. A., KRAPEZ, B., and FRALICK, P. W., 1994, Sedimentology of Archean greenstone belts: signatures of tectonic evolution: Earth-Science Reviews, v. 37, p. 1–88.

FARRELL, T. R., in prep., Geology of the Eastern Creek 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes.

FERGUSON, K. M., and RUDDOCK, I., 2001, Mineral occurrences and exploration potential of the east Pilbara: Western Australia Geological Survey, Report 81, 114p.

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA, 2004, Compilation of geochronology data, October 2004 update: Western Australia Geological Survey.

GLIKSON, A. Y., and HICKMAN, A. H., 1981, Geochemistry of Archaean volcanic successions, Eastern Pilbara Block, Western Australia: Australia BMR, Record 86/14, 83p.

GROOM, E. E., 1896, Report of a visit to Nullagine, Pilbara district, to examine the country reported to be diamond yielding: Western Australia Department of Mines, Annual Report 1895, p. 27.

HICKMAN, A. H., 1975, Precambrian structural geology of part of the Pilbara region: Western Australia Geological Survey, Annual Report 1974, p. 68–73.

HICKMAN, A. H., 1977, New and revised definitions of rock units in the Warrawoona Group, Pilbara Block: Western Australia Geological Survey, Annual Report 1976, p. 53.

HICKMAN, A. H., 1978, Nullagine, W.A.: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 22p.

HICKMAN, A. H., 1983, Geology of the Pilbara Block and its environs: Western Australia Geological Survey, Bulletin 127, 268p.

HICKMAN, A. H., 1984, Archaean diapirism in the Pilbara Block, Western Australia, *in* Precambrian tectonics illustrated *edited by* A. KRÖNER and R. GREILING: Schweizerbarts'che Verlagsbuchhandlung, Stuttgart, p. 113–127.

HICKMAN, A. H., 1990, Geology of the Pilbara Craton, *in* Third International Archaean Symposium, Excursion Guidebook No. 5: Pilbara and Hamersley Basin *edited by* S. E. HO, J. E. GLOVER, J. S. MYERS and J. R. MUHLING: University of Western Australia, Geology Department and University Extension, Publication no. 21, p. 2–13.

HICKMAN, A. H., 2001, Geology of the Dampier 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 39p.

HICKMAN, A. H., 2004, Two contrasting granite–greenstone terranes in the Pilbara Craton, Australia: evidence for vertical and horizontal tectonic regimes prior to 2900 Ma: Precambrian Research, v. 131, p. 153–172.

HICKMAN, A. H., and LIPPLE, S. L., 1978, Marble Bar, W.A.: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 24p.

HICKMAN, A. H., and VAN KRANENDONK, M. J., 2004, Diapiric processes in the formation of Archaean continental crust, East Pilbara Granite–Greenstone Terrane, Australia *in* The Precambrian Earth: Tempos and events in Precambrian time *edited by* P. G. ERIKSSON, W. ALTERMANN, D. R. NELSON, W. U. MUELLER and O. CATUNEANU: Elsevier, Developments in Precambrian Geology, 12, p. 118–139.

HUSTON, D. L., BLEWETT, R. S., KEILLOR, B., STANDING, J., SMITHIES, R. H., MARSHALL, A., MERNAGH, T. P., and KAMPRAD, J., 2002, Lode gold and epithermal deposits of the Mallina–Whim Creek Basin, Pilbara Craton, Western Australia: Economic Geology, v. 97, p. 801–818.

IDNURM, M., and SENIOR, B. R., 1978, Palaeomagnetic ages of Late Cretaceous and Tertiary weathered profiles in the Eromanga Basin, Queensland: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 24, p. 263–277.

INGRAM, P. A. J., 1977, A summary of the geology of a portion of the Pilbara Goldfield, Western Australia, *in* The Archaean, search for the beginning *edited by* G. J. H. McCALL: Stroudsburg, Pennsylvania, Dowden, Hutchison and Ross, p. 208–216.

JAHN, B. M., GLIKSON, A. Y., PEUCAT, J. J., and HICKMAN, A. H., 1981, REE geochemistry and isotopic data of Archaean silicic volcanics and granitoids from the Pilbara Block, Western Australia: implications for the early crustal evolution: Geochimica et Cosmochimica Acta, v. 45, p. 1633–1652.

KLOPPENBURG, A., 2003, Structural evolution of the Marble Bar Domain, Pilbara granite–greenstone terrain, Australia: the role of Archaean mid-crustal detachments: Faculteit Aardwetenschappen, Universiteit Utrecht, Geologica Ultraiectina, no. 237, The Netherlands, 256p.

KLOPPENBURG, A., WHITE, S. H., and ZEGERS, T. E., 2001, Structural evolution of the Warrawoona greenstone belt and adjoining granitoid complexes, Pilbara Craton, Australia: implications for Archaean tectonic processes: Precambrian Research, v. 112, p. 107–148.

KOJAN, C. J., and HICKMAN, A. H., 1998, Late Archaean volcanism in the Kylena and Maddina Formations, Fortescue Group, west Pilbara: Western Australia Geological Survey, Annual Review 1997–98, p. 43–53.

KRAPEZ, B., and EISENLOHR, B., 1998, Tectonic settings of Archaean (3325–2775 Ma) crustal–supracrustal belts in the West Pilbara Block, Precambrian Research, v. 88, p. 173–205.

KRIEWALDT, M., 1964, The Fortescue Group of the Roebourne region, North-West Division: Western Australia Geological Survey, Annual Report 1963, p. 30–34.

KRIEWALDT, M., and RYAN, G. R., 1967, Pyramid, W.A. (1st edition): Western Australia Geological Survey, 1:250 000 Geological Series, 39p.

Le MAÎTRE, R. W., 1989, A classification of igneous rocks and glossary of terms (Recommendations of the International Union of Geological Subcommission on the systematics of igneous rocks): Oxford, U.K., Blackwell Press, 193p.

LEWIS, J. D., ROSMAN, K. R. J., and de LAETER, J. R., 1975, The age and metamorphic effects of the Black Range dolerite dyke: Western Australia Geological Survey, Annual Report 1974, p. 80–88.

LIPPLE, S. L., 1975, Definitions of new and revised stratigraphic units of the eastern Pilbara Region: Western Australia Geological Survey, Annual Report 1974, p. 58–63.

LOWE, D. R., 1983, Restricted shallow-water sedimentation of Early Archean stromatolitic and evaporitic strata of the Strelley Pool Chert, Pilbara Block, Western Australia: Precambrian Research, v. 19, p. 239–283.

MACKEY, T. E., 1997a, Total magnetic intensity (reduced to pole) with northeast illumination colour pixel-image map of Nullagine/Yarrie, W.A. (1:250 000 scale): Australian Geological Survey Organisation.

MACKEY, T. E., 1997b, First vertical derivative of total magnetic intensity (reduced to pole) greyscale pixel-image map of Nullagine/Yarrie, W.A. (1:250 0000 scale): Australian Geological Survey Organisation.

MACKEY, T. E., 1997c, Airborne gamma-ray spectrometry colour composite pixel-image map of Nullagine/Yarrie, W.A. (1:250 000 scale): Australian Geological Survey Organisation.

MacLEOD, W. N., 1966, The geology and iron deposits of the Hamersley Range area, Western Australia: Western Australia Geological Survey, Bulletin 117, 170p.

McNAUGHTON, N. J., COMPSTON, W., BARLEY, M. E., 1993, Constraints on the age of the Warrawoona Group, eastern Pilbara Craton, Western Australia: Precambrian Research, v. 60, p. 69–98.

MAITLAND, A. G., 1905, Further report on the geological features and mineral resources of the Pilbara Goldfield: Western Australia Geological Survey, Bulletin 20, 127p.

MAITLAND, A.G., 1908, The geological features and mineral resources of the Pilbara Goldfield: with an Appendix by A. Montgomery: Western Australia Geological Survey, Bulletin 40, 437p.

MARSTON, R. J., 1979, Copper mineralization in Western Australia: Western Australia Geological Survey, Mineral Resources Bulletin 13, 208p.

NELSON, D. R., 1998, Compilation of SHRIMP U–Pb zircon geochronology data, 1997: Western Australia Geological Survey, Record 1998/2, 242p.

NELSON, D. R., 2000, Compilation of geochronology data, 1999: Western Australia Geological Survey, Record 2000/2, 251p.

NELSON, D. R., 2001, Compilation of geochronology data, 2000: Western Australia Geological Survey, Record 2001/2, 205p.

NELSON, D. R., 2002, Compilation of geochronology data, 2001: Western Australia Geological Survey, Record 2002/2, 282p.

NELSON, D. R., TRENDALL, A. F., and ALTERMANN, W., 1999, Chronological correlations between the Pilbara and Kaapvaal Cratons: Precambrian Research, v. 97, p. 165–189.

NOLDART, A. J., and WYATT, J. D., 1962, The geology of portion of the Pilbara Goldfield: Western Australia Geological Survey, Bulletin 115, 199p.

PIDGEON, R. T., 1984, Geochronological constraints on early volcanic evolution of the Pilbara Block, Western Australia: Australian Journal of Earth Sciences, v. 31, p. 237–242.

PINK, B. N., 1992, Western Australia Year Book, no. 29: Australian Bureau of Statistics, Perth Office, p. 3.1–3.15.

ROCK, N. M. S., and BARLEY, M. E., 1988, Calc-alkaline lamprophyres from the Pilbara Block, Western Australia: Journal of the Royal Society of Western Australia, v. 71(1), p. 7–13.

RYAN, G. R., and KRIEWALDT, M. J. B., 1964, Facies changes in the Archaean of the West Pilbara Goldfield: Western Australia Geological Survey, Annual Report 1963, p. 28–30.

SMITHIES, R. H., and BAGAS, L., 1997, High pressure amphibolite–granulite facies metamorphism in the Paleoproterozoic Rudall Complex, central Western Australia. Precambrian Research, v. 83, p. 243–265.

SMITHIES, R. H., and CHAMPION, D. C., 1998, Secular compositional changes in Archaean granitoid rocks of the west Pilbara: Western Australia Geological Survey, Annual Review 1997–98, p. 71–76.

SOFOULIS, J., 1958, Report on reconnaissance of the diamondiferous country in the vicinity of Nullagine, Pilbara Goldfield, W.A.: Western Australia Geological Survey, Bulletin 109, p. 91–94.

THOM, R., HICKMAN, A. H., and CHIN, R. J., 1973, Nullagine, W.A. Sheet SF55: Western Australia Geological Survey, 1:250 000 Geological Series.

THORNE, A. M., and TRENDALL, A. F., 2001, Geology of the Fortescue Group, Pilbara Craton, Western Australia: Western Australia Geological Survey, Bulletin 144, 249p.

THORNE, A. M., TYLER, I. M., and HUNTER, W. M., 1991, Turee Creek, W.A. (2nd edition): Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 29p.

THORPE, R. A., HICKMAN, A. H., DAVIS, D. W., MORTENSEN, J. K., and TRENDALL, A. F., 1992a, Constraints to models for Archaean lead evolution from precise U–Pb geochronology from the Marble Bar region, Pilbara Craton, Western Australia, *in* The Archaean: terrains, processes and metallogeny *edited by* J. E. GLOVER and S. HO: Geology Department and University Extension, the University of Western Australia, Publication 22, p. 395–408.

THORPE, R. A., HICKMAN, A. H., DAVIS, D. W., MORTENSEN, J. K., and TRENDALL, A. F. 1992b, U–Pb zircon geochronology of Archaean felsic units in the Marble Bar region, Pilbara Craton, Western Australia: Precambrian Research, v. 56, p. 169–189.

TRENDALL, A. F., 1990a, Hamersley Basin, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 163–191.

TRENDALL, A. F., 1990b, Pilbara Craton — introduction, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 128.

TRENDALL, A. F., NELSON, D. R., de LAETER, J. R., and HASSER, S. W., 1998, Precise zircon U–Pb ages from the Marra Mamba Iron Formation and Wittenoom Formation, Hamersley Group, Western Australia: Australian Journal of Earth Sciences, v. 45, no. 1, p. 137–142.

TYLER, I. M., 1991, The geology of the Sylvania Inlier and southeast Hamersley Basin: Western Australia Geological Survey, Bulletin 138, 108p.

TYLER, I. M., FLETCHER, I. R., de LAETER, J. R., WILLIAMS, I. R., and LIBBY, W. G., 1992, Isotope and rare earth element evidence for a late Archaean terrane boundary in the southeastern Pilbara Craton, Western Australia: Precambrian Research, v. 54, p. 211–229.

VAN HAAFTEN, W. M., and WHITE, S. H., 1998, Evidence for multiphase deformation in the Archean basal Warrawoona Group in the Marble Bar area, East Pilbara, Western Australia: Precambrian Research, v. 88, p. 53–66.

VAN HAAFTEN, W. M., and WHITE, S. H., 2001, Reply to comment on 'Evidence for multiphase deformation in the Archaean basal Warrawoona Group in the Marble Bar area, East Pilbara, Western Australia': Precambrian Research, v. 105, p. 79–84.

VAN KRANENDONK, M. J., 1998, Litho-tectonic and structural map components of the NORTH SHAW 1:100 000 sheet, Archaean Pilbara Craton: Western Australia Geological Survey, Annual Review 1997–98, p. 63–70.

VAN KRANENDONK, M. J., 2000, Geology of the NORTH SHAW 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 86p.

VAN KRANENDONK, M. J., COLLINS, W. J., HICKMAN, A. H., and PAWLEY, M. J., 2004, Critical tests of vertical vs. horizontal tectonic models for the Archaean East Pilbara Granite–Greenstone Terrane, Pilbara Craton, Western Australia: Precambrian Research, v. 131, p. 173–211

VAN KRANENDONK, M. J., HICKMAN, A. H., SMITHIES, R. H., NELSON, D., and PIKE, G., 2002, Geology and tectonic evolution of the Archaean North Pilbara Terrain, Pilbara Craton, Western Australia: Economic Geology, v. 97, p. 695–732.

VAN KRANENDONK, M. J., and MORANT, P., 1998, Revised Archaean stratigraphy of the North Shaw 1:100 000 sheet, Pilbara Craton: Western Australia Geological Survey, Annual Review 1997–98, p. 55–62.

VAN KRANENDONK, M. J., SMITHIES, R. H., HICKMAN, A. H., BAGAS, L., WILLIAMS, I. R., and FARRELL, T. R., 2004, Event stratigraphy applied to 700 million years of Archaean crustal evolution, Pilbara Craton, Western Australia: Western Australia Geological Survey, Annual Review 2003–04, p. 49–61.

WILLIAMS, I. R., 1989, Balfour Downs, W.A. (2nd edition): Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 38p.

WILLIAMS, I. R., 1999, Geology of the Muccan 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 39p.

WILLIAMS, I. R., and BAGAS, L., in prep., Geology of the Mount Edgar 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes.

WILLIAMS, I. S., and COLLINS, W. J., 1990, Granite–greenstone terranes in the Pilbara Block, Australia, as coeval volcano-plutonic complexes; evidence from U–Pb zircon dating of the Mount Edgar batholith: Earth and Planetary Science Letters, v. 97, p. 41–53.

WINGATE, M. T. D., 1997, Testing Precambrian continental reconstructions using ion microprobe U–Pb baddeleyite geochronology and palaeomagnetism of mafic igneous rocks: Australian National University, Canberra, PhD thesis (unpublished).

WINGATE, M. T. D., 1999, Ion microprobe baddeleyite and zircon ages for Late Archaean mafic dykes of the Pilbara Craton, Western Australia: Australian Journal of Earth Sciences, v. 46, p. 493–500.

WINGATE, M. T. D., and GIDDINGS, J. W., 2000, Age and palaeomagnetism of the Mundine Well dyke swarm, Western Australia: Implications for an Australia–Laurentia connection at 755 Ma: Precambrian Research, v. 100, p. 335–357.

WITT, W. K., HICKMAN, A. H., TOWNSEND, D., and PRESTON, W. A., 1998, Mineral potential of the Yilgarn and Pilbara Cratons, Western Australia: Australian Geological Survey Organisation, Journal of Australian Geology and Geophysics, v. 17, p. 201–232.

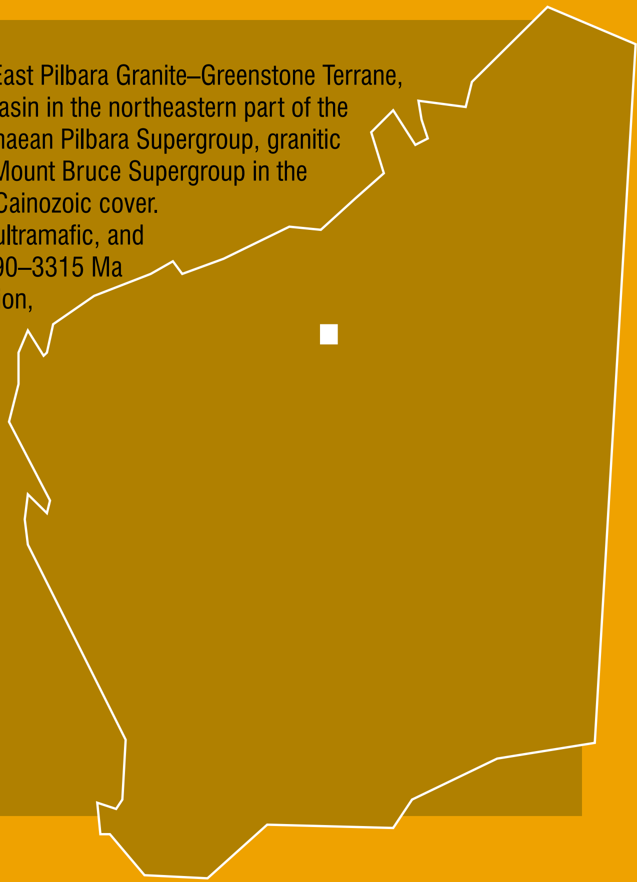
ZEGERS, T. E., NELSON, D. R., WIJBRANS, J. R., and WHITE, S. H., 2001, SHRIMP U–Pb zircon dating of Archean core complex formation and pancratonic strike-slip deformation in the East Pilbara Granite–Greenstone Terrain: Tectonics, v. 20 (6), p. 883–908.

ZEGERS, T. E., WHITE, S. H., de KEIJZER, M., and DIRKS, P., 1996, Extensional structures during deposition of the 3460 Ma Warrawoona Group in the eastern Pilbara Craton, Western Australia: Precambrian Research, v. 80, p. 89–105.

The NULLAGINE 1:100 000 sheet area covers parts of the East Pilbara Granite–Greenstone Terrane, Kurrana Terrane, Mosquito Creek Basin, and Hamersley Basin in the northeastern part of the Archaean Pilbara Craton. The sheet area includes the Archaean Pilbara Supergroup, granitic rocks, the c. 2775 and 2717 Ma Fortescue Group of the Mount Bruce Supergroup in the Hamersley Basin, Palaeoproterozoic intrusive rocks, and Cainozoic cover.

The Pilbara Supergroup includes metamorphosed mafic, ultramafic, and felsic volcanic rocks, and sedimentary rocks of the c. 3490–3315 Ma Warrawoona Group, the <3308 Ma Budjan Creek Formation, the undated Copper Gorge Formation, the poorly constrained c. 3235–2950 Ma Gorge Creek Group, and the De Grey Group. The De Grey Group, which includes rocks of the Mosquito Creek Basin, unconformably overlies or is in faulted contact with the Pilbara Supergroup, and separates the East Pilbara Granite–Greenstone Terrane from the Kurrana Terrane to the south.

There are numerous gold and base metal occurrences on NULLAGINE. Base metal mineralization (dominantly copper) is hydrothermal in origin and probably related to igneous activity associated with the Budjan Creek Formation and contemporaneous magmatism within the Corunna Downs Granitoid Complex. The Mosquito Creek Formation hosts numerous gold prospects and mines in shear zones.



These Explanatory Notes are published in digital format (PDF) and are available online at: www.doir.wa.gov.au/gswa/onlinepublications. Laser-printed copies can be ordered from the Information Centre for the cost of printing and binding.

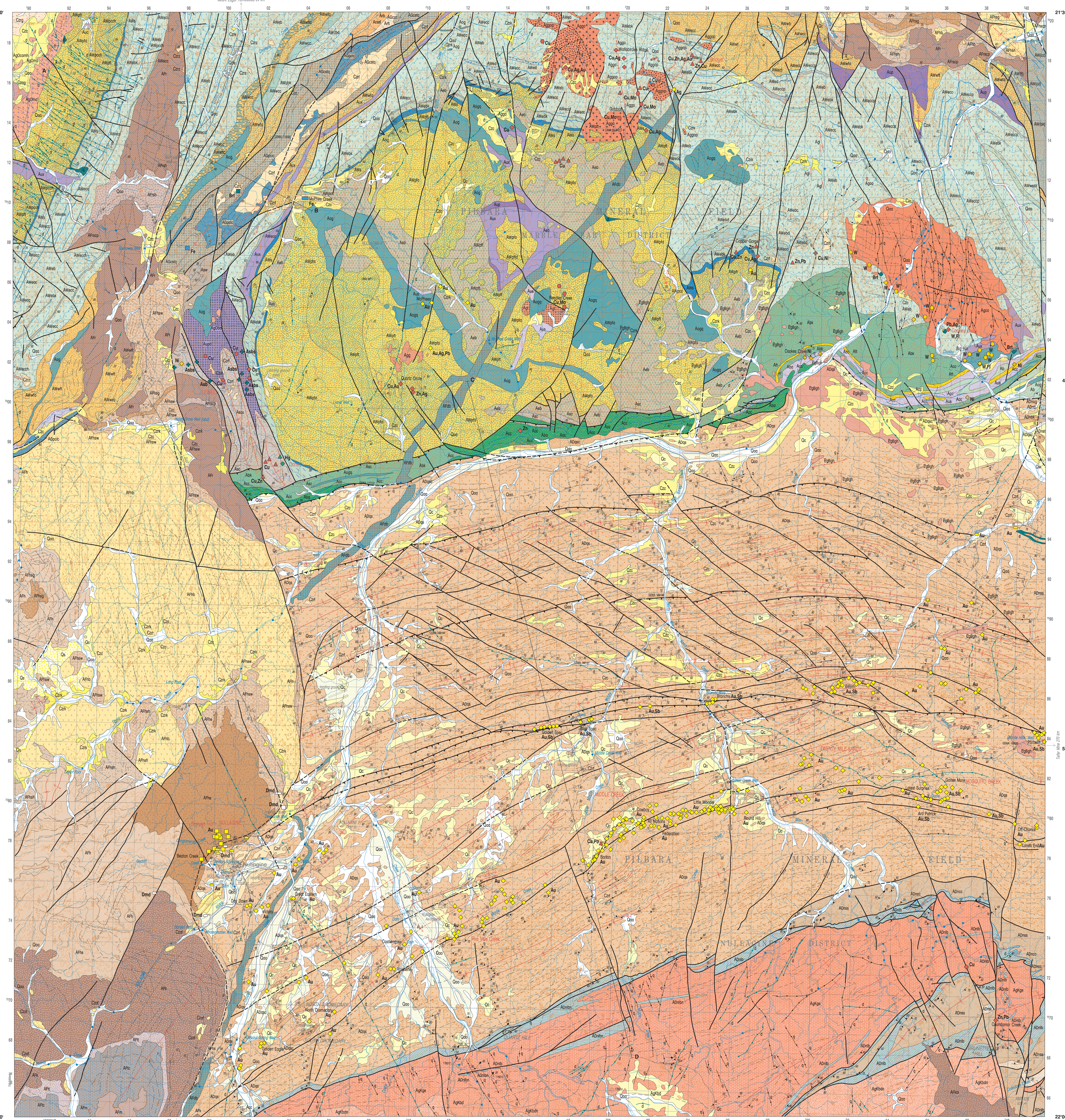
Further details of geological publications and maps produced by the Geological Survey of Western Australia are available from:

Information Centre
Department of Industry and Resources
100 Plain Street
East Perth, WA 6004
Phone: (08) 9222 3459   Fax: (08) 9222 3444

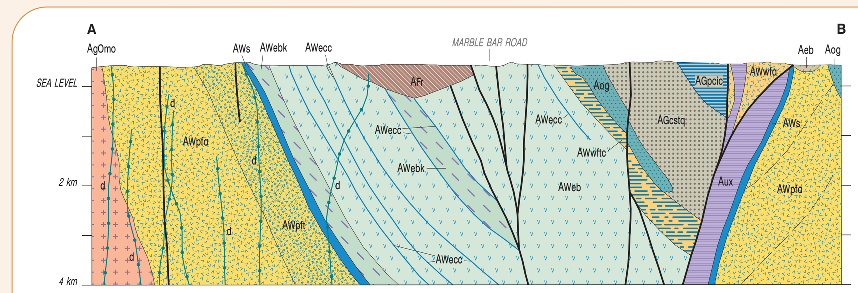
www.doir.wa.gov.au/gswa/onlinepublications

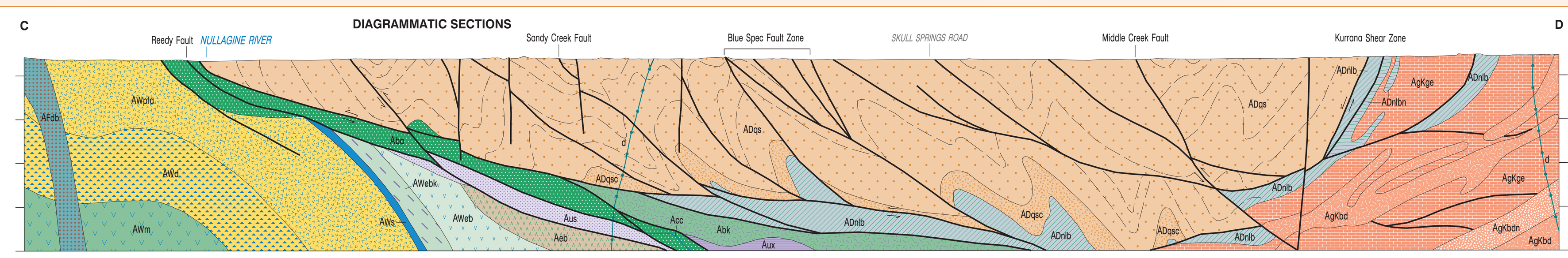
NULLAGINE

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA



DIAGRAMMATIC SECTIONS





Geological legend

PHANEROZOIC — CAINOZOIC — QUATERNARY

Qaa Alluvial sand and gravel in rivers and creeks; clay, silt, and sand in channels on floodplains
Qao Overbank deposits; alluvial sand and silt on floodplains adjacent to main drainage channels; minor clay and gravel
Qw Sheetwash deposits — clay, silt, sand, and pebbles on distal outwash fans; no defined drainage
Qc Colluvium — sand, silt, and gravel on outwash fans; scree and talus
Qs Sandplain deposits — eolian sand in undulating sheets

Czag Alluvial gravel, sand, and silt derived from granitoid rock; consolidated and dissected
Czaf Pisolitic, ferruginous channel deposits; limonite, goethite, and hematite deposits; along palaeodrainage lines dissected by recent drainage; contains fossil wood in places
Czc Colluvium — sand, silt, and gravel on outwash fans; scree, talus; consolidated and dissected

Czrf Ferruginous duricrust; includes massive, pisolitic, and nodular laterite, including some transported material
Czrg Relict eluvium and colluvium; sand, gravel, and silt overlying and derived from granitoid rock; variably consolidated; dissected
Czrk Residual calcrete; massive, nodular, and cavernous limestone; dissected
Czrz Silcrete; siliceous caprock with angular quartz and chert clasts

PROTEROZOIC

Bridget Suite — 1803 Ma [1]
PgBgh Hornblende- and biotite-bearing quartz syenite to quartz monzodiorite; fine grained, porphyritic

d Dolerite dyke
q Quartz vein, various ages; contains barite in veins that intrude **COOKE CREEK MONZOGRANITE**

ARCHAEAN — Mount Bruce Supergroup — Fortescue Group (HAMERSLEY BASIN)

c. 2717 Ma [2] — AFm **MADDINA FORMATION:** massive, vesicular, and amygdaloidal basalt and andesite, with silicified flow tops

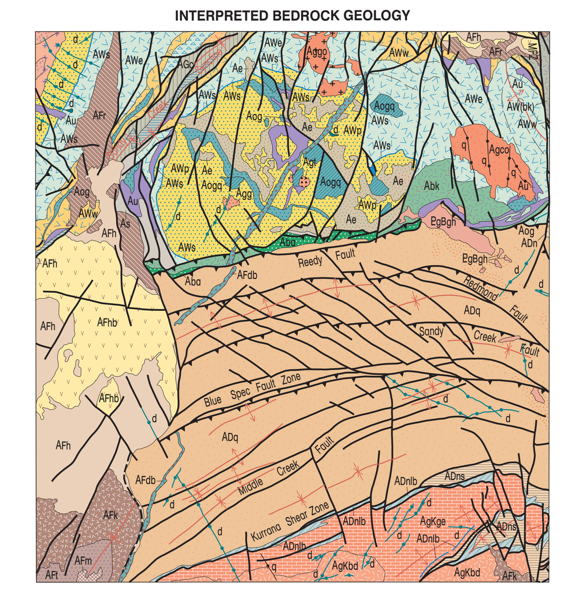
TUMBIANA FORMATION
c. 2719 Ma [3] — AFtt **Mingah Member:** pisolitic mafic tuff, and tuffaceous siltstone and sandstone; thin carbonate units
AFtc **Meentheena Member:** carbonate rock

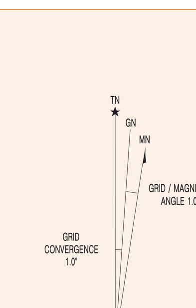
c. 2741 Ma [4] — AFk **KYLENA FORMATION:** massive, vesicular, and amygdaloidal basalt; some pillow lava and columnar jointing; minor basaltic agglomerate
AFkbi Massive and amygdaloidal basaltic andesite; minor basalt and andesite; rare basaltic fragmental rock

HARDEY FORMATION
AFhs Sandstone, conglomerate, shale, felsic tuff, and ooidal and pisolitic beds; rare basalt
2764–2756 Ma [5] — AFh Fine- to coarse-grained sandstone and pebble to cobble conglomerate; commonly arkosic, cross-bedded; minor mudstone, shale, siltstone, and felsic tuff
AFhsg Pebble to cobble conglomerate interbedded with medium- to coarse-grained sandstone
AFhe **Beaton Creek Member:** pebble to cobble conglomerate interbedded with medium- to coarse-grained sandstone
AFhsw Lithic wacke, poorly sorted sandstone, shale, and siltstone
AFhsh Shale, lithic wacke, and minor tuff
c. 2766 Ma [6] — AFhb **Bamboo Creek Member:** porphyritic rhyodacite with quartz phenocrysts; extrusive in part
AFhscp Pebble to cobble conglomerate interbedded with medium- to coarse-grained sandstone

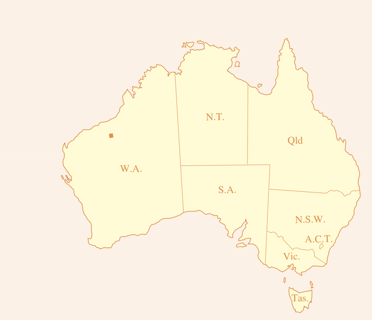
2775–2763 Ma [5,7] — AFr **MOUNT ROE BASALT:** massive, porphyritic, vesicular, and amygdaloidal basalt; some pillow basalt; weakly metamorphosed
c. 2772 Ma [7] — AFdb **Black Range Dolerite suite:** dolerite and medium- to coarse-grained gabbro dykes; weakly metamorphosed
AFrsh Shale, lithic wacke, and minor tuff; weakly metamorphosed
AFrscp Polymictic, poorly sorted and matrix-supported cobble to boulder conglomerate; includes sandstone, siltstone, and wacke; discontinuous thick-bedded shale units in upper parts; weakly metamorphosed

INTERPRETED BEDROCK GEOLOGY

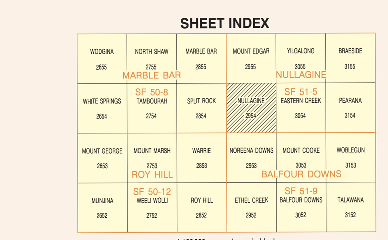




True north, grid north and magnetic north are shown diagrammatically for the centre of the map. Magnetic north is correct for 2003 and moves easterly by about 0.1° in 2 years.



SHEET INDEX



Search for current GSWA map products online www.doir.wa.gov.au/ebookshop

MINERAL OCCURRENCES

Commodity information from non-confidential data held in the WAMIN database. Data points are filtered for clarity on the plotted product; full set of data points available in digital data and GSWA Report 81 Mineral occurrences and exploration potential of the east Pilbara

MINERALIZATION STYLES

- Porphyry, pegmatite, greisen, and skarn
- Orthomagmatic mafic and ultramafic
- Vein and hydrothermal
- Stratabound volcanic and sedimentary
- Stratabound sedimentary and/or sedimentary banded iron-formation
- Regolith hosted

MINERAL AND ROCK COMMODITY GROUPS

- Precious mineral
- Precious metal
- Steel industry metal
- Speciality metal
- Base metal
- Iron
- Industrial mineral

MINERAL AND ROCK COMMODITIES

Antimony	Sb
Asbestos, unknown/uncertain source material	Asb
Asbestos - serpentine	Asbs
Barite	Brt
Copper	Cu
Diamond	Dmd
Fluorite	Fl
Gold	Au
Iron	Fe
Lead	Pb
Mercury	Hg
Molybdenum	Mo
Nickel	Ni
Silver	Ag
Tungsten	W
Zinc	Zn

Mining locaility — Bridget
Battery or treatment plant, abandoned
Mine, abandoned mine, or deposit (names are filtered for clarity) — Cowboy

DATA DIRECTORY

Theme	Data Source	Data Currency	Agency
Geology	GSWA	2002–2003	Dept of Industry and Resources
Structural data	WAROX	OCT 2003	Dept of Industry and Resources
Mineral occurrences (non-confidential)	WAMIN	MAR 2003	Dept of Industry and Resources
Cadastre	TENGRAPH	JUN 2002	Dept of Industry and Resources
Horizontal control	GESMAR	JUN 2002	Dept of Land Information
Topographic nomenclature	GEONOMA	JUN 2002	Dept of Land Information
Topography	DLI and GSWA field survey	2002	Dept of Land Information

Compiled by L. Bagas 2002–2003

Geology by L. Bagas (GSWA) 1999–2002 and O. Beukenhorst and K. Hos (Utrecht University, The Netherlands) 1999

Geochronology by:
(1) D. R. Nelson, 2002, GSWA Record 2002/2, p. 137–144, 174–177.
(2) D. R. Nelson, 1998, GSWA Record 1998/2, p. 133–135.
(3) D. R. Nelson, 2001, GSWA Record 2001/2, p. 129–132, 140–148, 175–177.
(4) T. S. Blake, 2001, Precambrian Research, v. 107, p. 139–177.
(5) N. T. Arndt et al., 1991, Australian Journal of Earth Sciences, v. 38, p. 261–281.
(6) D. R. Nelson, in prep., GSWA Record 2004/2.
(7) M. T. D. Wingate, 1999, Australian Journal of Earth Sciences, v. 46, p. 493–500.
(8) D. R. Nelson, in prep., GSWA Record.
(9) M. E. Barley, and N. J. McNaughton, 1998, Precambrian Research, v. 96, p. 41–62.
(10) D. R. Nelson, 2000, GSWA Record 2002/2, p. 195–198.

Edited by C. Strong and G. Loan

Cartography by G. Wright, B. Williams and K. Greenberg

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

The recommended reference for this map is:
BAGAS, L., BEUKENHORST, O., and HOS, K., 2004, Nullagine, W.A. Sheet 2954: Western Australia Geological Survey, 1:100 000 Geological Series.

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

Geological Survey of Western Australia — TIM GRIFFIN, DIRECTOR

NGA — PRODUCT OF THE NATIONAL GEOSCIENCE AGREEMENT

SCALE 1:100 000

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

Grid lines indicate 1000 metre interval of the Map Grid Australia Zone 51

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

NULLAGINE

SHEET 2954 **FIRST EDITION 2004**
Version 1.0 — June 2004