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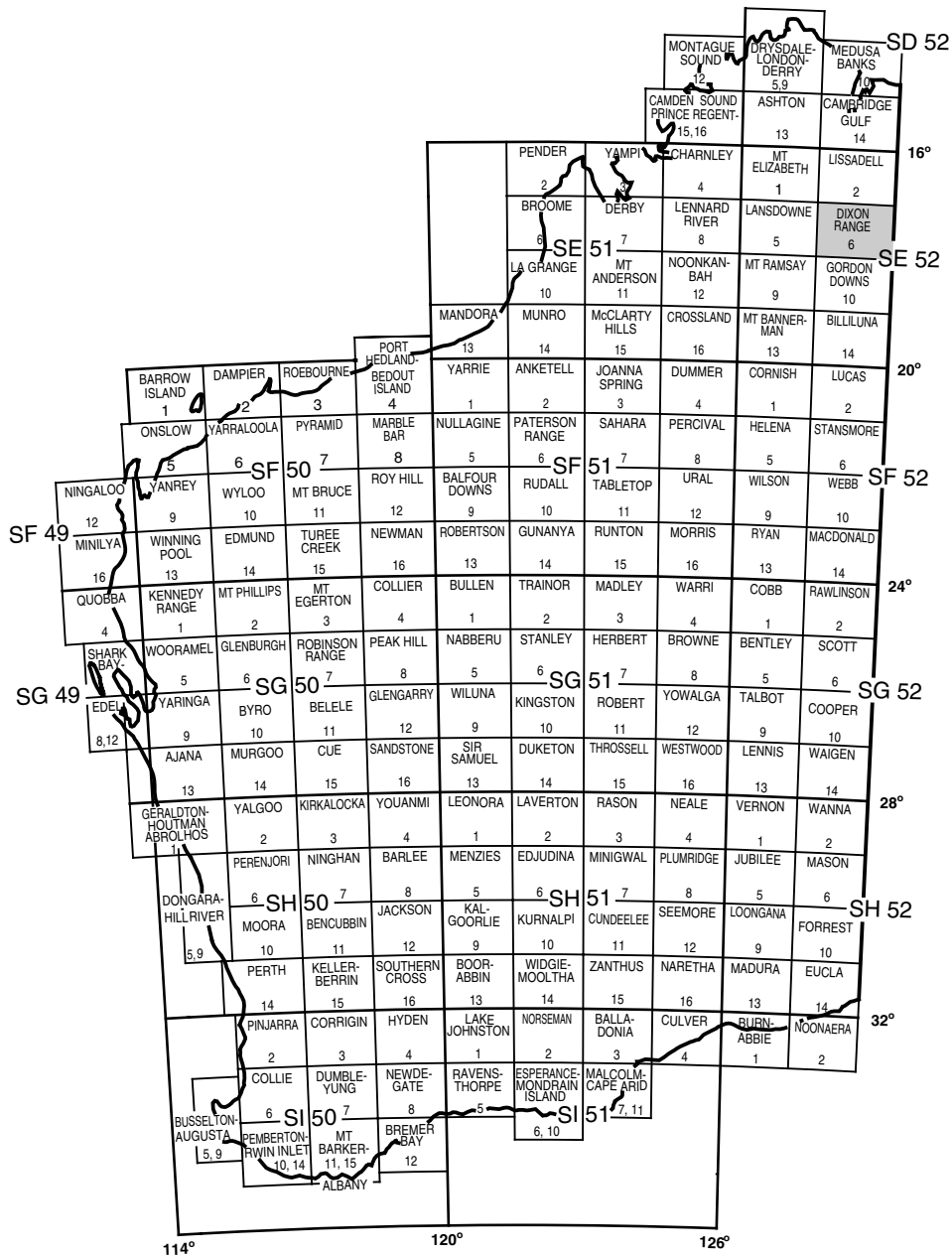
**GEOLOGY OF THE  
DIXON  
1:100 000 SHEET**

by I. M. Tyler

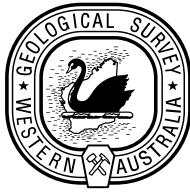
**1:100 000 GEOLOGICAL SERIES**



**Geological Survey of Western Australia**



MOUNT REMARKABLE 4463	TURKEY CREEK 4563	OSMAND 4663
DIXON RANGE SE52-06		
McINTOSH 4462	DIXON 4562	LINACRE 4662



**GEOLOGICAL SURVEY OF WESTERN AUSTRALIA**

**GEOLOGY  
OF THE DIXON  
1:100 000 SHEET**

**by  
I. M. Tyler**

**Perth 2004**

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# Geology of the Dixon 1:100 000 sheet

by  
I. M. Tyler

## Abstract

The DIXON 1:100 000 map sheet (SE 52-6, 4562) lies entirely within the Halls Creek Orogen, a major northeasterly trending orogenic belt developed in the Palaeoproterozoic to Palaeozoic rocks of the east Kimberley region of Western Australia.

The Halls Creek Orogen initially formed in the Palaeoproterozoic between the Kimberley Craton to the northwest and the North Australian Craton to the east. Rocks of the c. 1910 to 1790 Ma Lamboo Complex share many features with convergent Phanerozoic plate margins associated with the subduction of oceanic crust. The Lamboo Complex has been divided into the parallel Western, Central and Eastern zones, with only the Central and Eastern zones outcropping on DIXON.

The oldest rocks on DIXON are the Halls Creek Group in the Eastern zone of the Lamboo Complex, that represent deposition on a passive continental margin. The low-grade mafic metavolcanic and metasedimentary rocks of the c. 1880 Ma Biscay Formation of the Halls Creek Group are overlain by the turbiditic metasedimentary rocks of the Olympio Formation, which include alkaline metavolcanic rocks of the c. 1857 Ma Maude Headley Member. The Halls Creek Group is intruded by the Woodward Dolerite. In the Central zone of the Lamboo Complex on DIXON, sedimentary and volcanic protoliths of the Tickalara Metamorphics were deposited at c. 1865 Ma. At c. 1850 Ma they were intruded by sheets of tonalite and monzogranite, with peak metamorphic conditions, ranging from epidote–amphibolite facies up to the granulite facies transition, reached at c. 1845 Ma. Accompanying deformation produced northeasterly verging recumbent folds. The deformation and metamorphism are consistent with the accretion of an island arc to the eastern edge of the Kimberley Craton.

The Central and Eastern zones of the Lamboo Complex on DIXON were deformed and metamorphosed during the c. 1835 to 1805 Ma Halls Creek Orogeny, reflecting the suturing of the Kimberley and North Australian Cratons at c. 1820 Ma. Large-scale easterly verging folding (including the Black Rock Anticline and the Biscay Anticlinorium) and thrusting was accompanied by mylonite formation along major shear zones.

The c. 1800 Ma sedimentary and mafic volcanic rocks of the Red Rock Formation were deposited in the Red Rock Basin. They are preserved on DIXON as fault-bounded slivers along major strike-slip fault zones that developed during the c. 1000 Ma Yampi Orogeny.

The Lamboo Complex is unconformably overlain by Neoproterozoic sedimentary rocks deposited in the Wolfe Creek Basin. The oldest group is the c. 830 Ma Ruby Plains Group, equivalent to Supersequence 1 of the Centralian Superbasin. These rocks are unconformably overlain by the Duerdin Group, which includes glaciogene rocks correlated with the Marinoan glaciation, and then the Albert Edward Group. These are equivalent to Supersequences 3 and 4 of the Centralian Superbasin.

Sinistral reactivation of the large-scale faults took place during the c. 560 Ma King Leopold Orogeny, deforming the Neoproterozoic sedimentary rocks. This was followed by the eruption of the basaltic rocks of the c. 513 Ma Antrim Plateau Volcanics in the Ord Basin, and deposition of the shallow marine to fluvial Middle to Upper Cambrian Goose Hole Group.

Further sinistral strike-slip faulting and associated thrusting took place during the c. 400 to 300 Ma Alice Springs Orogeny, and was accompanied by the deposition of the fluvial rocks of the Devonian Mahony Group.

An extensive erosion surface, the Sturt Plateau, formed between c. 250 and 24 Ma. Uplift and erosion after 24 Ma has produced the sandstone karst of the Bungle Bungle Range.

Minor occurrences of precious and base metal mineralization are present on DIXON. Mining for gold has taken place in the Halls Creek Group, and in associated alluvial deposits within the present drainage system.

**KEYWORDS:** Halls Creek Orogen, Lamboo Complex, Red Rock Basin, Wolfe Creek Basin, Ord Basin, Tickalara Metamorphics, Halls Creek Group, Ruby Plains Group, Duerdin Group, Albert Edward Group, Antrim Plateau Volcanics, Goose Hole Group, Mahony Group, regional geology

## Introduction

The DIXON\* 1:100 000 map sheet (SE 52-6, 4562) is bounded by latitudes 17°30'S and 18°00'S and longitudes 128°00'E and 128°30'E. The map sheet lies within the DIXON RANGE 1:250 000 sheet in the east Kimberley region of Western Australia.

Tourism and cattle grazing for beef are the main commercial activities in the east Kimberley region, and the northeastern part of DIXON is within the Purnululu National Park. Hoatson et al. (1997) detailed the attractions and facilities within the park, and provided a guide to the rocks, landforms, plants, animals, and human impact. Tourist camping facilities at the Bellburn and Walardi campsites, and an airstrip used for scenic tourist flights were not shown on the published geological map (Tyler et al., 1998d), but are present along 'Bellburn Creek' to the northeast of Blue Hole Yards (see Hoatson et al., 1997, p. 10). The Sophie Downs, Alice Downs, and Mabel Downs pastoral leases extend into the sheet, although none of their homesteads are located on it. The abandoned Turner Homestead is located on the Turner River, at the northwestern end of the Hardman Range. Appendix 1 is a gazetteer of localities on DIXON.

No major roads occur within the map sheet and access is limited to sparse, poorly maintained station tracks within the pastoral leases. Vehicle access in the Purnululu National Park is restricted to tracks to campsites and points of interest between April and September.

Geological investigations prior to 1969 are summarized in the Explanatory Notes for the first edition of DIXON RANGE and in a bulletin on the geology of the east Kimberley region (Dow and Gemuts, 1967, 1969). More recent work is referred to as appropriate in the following Notes.

The present survey was carried out during the remapping of the King Leopold and Halls Creek Orogens that was commenced in 1986 by the Geological Survey of Western Australia (GSWA). The mapping also formed part of a joint project with the Australian Geological Survey Organisation (AGSO, now Geoscience Australia: GA) as part of the National Geoscience Mapping Accord (NGMA) Kimberley–Arunta project. Fieldwork on DIXON was carried out in 1992 and 1993. The Palaeoproterozoic Tickalara Metamorphics and Red Rock Formation rocks in the northwestern part of the sheet were mapped by I. M. Tyler (GSWA), with the Palaeoproterozoic Halls Creek Group rocks in the western part being mapped by R. G. Warren (AGSO), both using 1:25 000 colour aerial photography flown in 1991 and available from the Western Australian Department of Land Information (DLI). The Neoproterozoic rocks of the Ruby Plains, Duerdin, and Albert Edward Groups in the southeastern part of the sheet were mapped and recompiled by R. G. Warren and D. H. Blake (AGSO) using DLI 1:50 000 black-and-white aerial photography flown in 1988. The Phanerozoic rocks of the Antrim Plateau Volcanics, the Goose Hole Group,

and the Mahony Group in the eastern part of the sheet were recompiled on the 1:50 000 black-and-white photographs by A. M. Thorne (GSWA) from the mapping of Mory and Beere (1988). The mapping by R. G. Warren was described in an AGSO record (Warren, 1997).

## Physiography, vegetation, and climate

DIXON lies within the Ordland physiographic division (Beard, 1979). The sheet area includes parts of the Ord Plains province, and the Bow River Hills, the Halls Creek Ridges, and the Albert Edward Range subprovinces of the Lamboo Hills province (Fig. 1). The Bow River Hills and the Halls Creek Ridges occupy the western part of the sheet and consist of low hills and ridges, the summits of which are remnants of the Sturt Plateau, that falls from about 400 m AHD<sup>†</sup> in the south and west to about 260 m near the Ord River (Warren, 1997). The Sturt Plateau is part of a series of ancient subdued land surfaces that were established in the Kimberley region during prolonged subaerial erosion that followed glaciation during the Permian, at c. 280 Ma (Plumb and Gemuts, 1976; Playford, 2001). The Albert Edward Range in the central part of the sheet consists of steep ridges rising to over 540 m, and deep valleys. The Ord Plains occupy the eastern part of the sheet and, at around 200–220 m, generally have little relief other than the prominent Hardman Range, which is an outlier of the Sturt Plateau, and the Dixon Range, which is an extension of the Lamboo Hills (Warren, 1997).

Erosion of the Sturt Plateau took place after 24 Ma, after a relative lowering of sea level by more than 300 m. Creeks and rivers draining into the Joseph Bonaparte Gulf, which generally flow to the north and west as part of the Ord drainage basin, incised the old peneplanation surface (the Wave Hill Surface), and the Early Miocene or younger White Mountain Formation deposited on the surface (Mory and Beere, 1988; Blake, 1996). Warren (1994a) suggested that the major rivers draining the Lamboo Hills, including the westerly flowing upper Ord River and Panton River, were originally headwaters to the inland Sturt drainage basin, but were captured by the northerly flowing Ord River. This period of erosion has produced the spectacular 'beehives' sandstone karst scenery of the Purnululu National Park (Young 1986, 1987; Blake, 1996; Hoatson et al., 1997).

The vegetation of the Kimberley region has been described by Beard (1979). The Lamboo Hills are covered by low-tree savanna and sparse tree steppe comprising spinifex and eucalypts. The vegetation covering the Ord Plain is strongly controlled by the underlying geology. Short-grass, low-tree savanna and tree steppe grow on the basalt of the Antrim Plateau Volcanics, steppe with scattered low trees on the Headleys Limestone, grass savanna on the rest of the Goose Hole Group, and low tree savanna and sparse tree steppe on the sandstones of the Mahony Group.

\* Capitalized names refer to standard 1:100 000 map sheets, unless otherwise indicated.

<sup>†</sup> Australian Height Datum

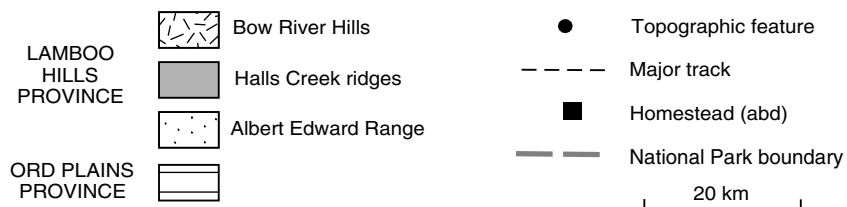
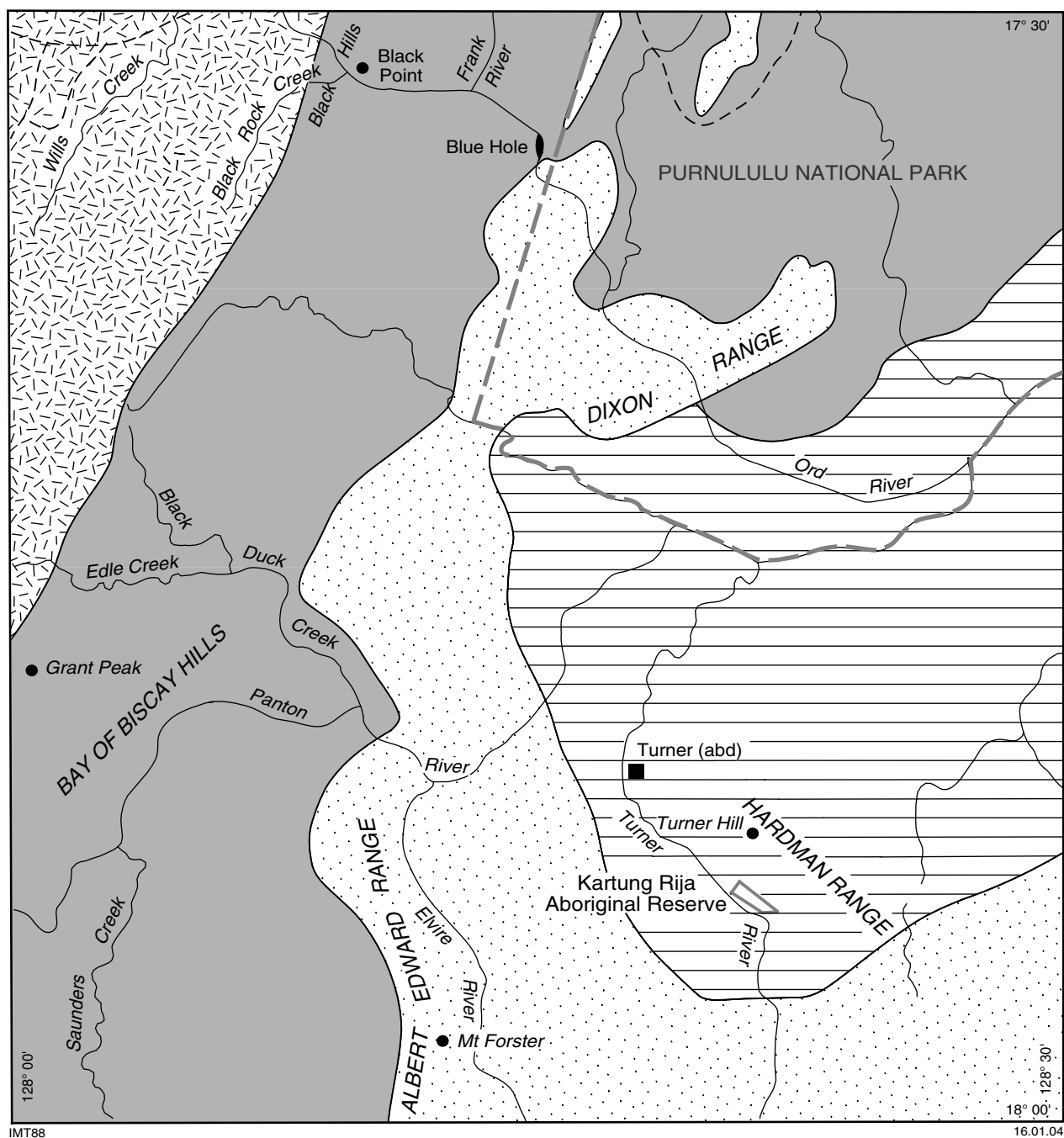


Figure 1. Physiography and drainage sketch map of Dixon (after Warren, 1997)

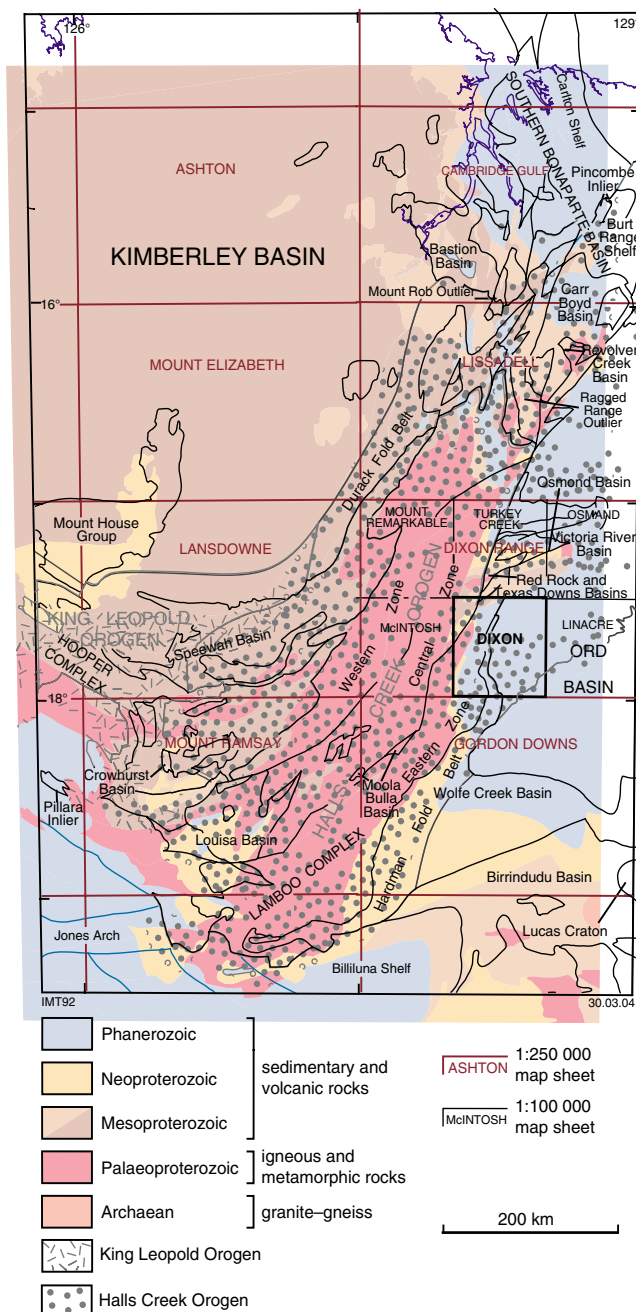
The climate is semi-arid monsoonal having a 'wet' season when temperatures are hot and humidity is high, and a 'dry' season when temperatures are warm to hot and humidity is low. Rainfall averages between 600 and 900 mm per annum, and is mainly generated from thunderstorms and cyclones between November and April. Average daily maximum temperatures vary from 36–39°C in December and January to 27–30°C in June and July.

Watercourses generally only flow after prolonged heavy rain. Permanent pools occur in some of the rivers, however wells and bores provide water supplies for stock.

## Regional geological setting

The regional geological setting and the main tectonic units found on DIXON are shown in Figure 2, and the tectonic units and simplified geology of the map sheet are shown in Figure 3. A summary of the geological history of DIXON is presented in Table 1, geochronology for units on DIXON is summarized in Table 2 and the stratigraphy of the Palaeoproterozoic to Palaeozoic sedimentary rocks is summarized in Table 3. The map sheet lies almost entirely within the Halls Creek Orogen (Fig. 2), a major north-easterly trending orogenic belt developed within the Proterozoic and Palaeozoic rocks of northern Australia (Myers et al., 1996; Tyler et al., 1998c; Tyler and Hocking, 2001). The orogen formed initially in the Palaeoproterozoic during a collision between the Kimberley Craton to the northwest, and a composite Archaean craton to the east, to form the North Australian Craton (Tyler et al., 1995; Myers et al., 1996; Blake et al., 2000; Griffin et al., 2000; Sheppard et al., 1999, 2001). Following collision, the orogen was the locus of repeated sedimentary basin formation, orogenic deformation and associated fault reactivation during the Palaeoproterozoic, Mesoproterozoic, Neoproterozoic, and Phanerozoic (Tyler et al., 1995; Thorne and Tyler, 1996; Blake et al., 2000).

The oldest component of the Halls Creek Orogen is the c. 1910 to 1790 Ma Lamboo Complex, a north-northeasterly trending belt of igneous and low- to high-grade meta-igneous and metasedimentary rocks that underlie the western part of DIXON (Dow and Gemuts, 1969; Griffin and Grey, 1990; Blake et al., 1999, 2000; Griffin et al., 2000; Page et al., 2001). Earlier models for the formation of the Lamboo Complex, and other belts of similar age in northern Australia, proposed extension and crustal thinning, then convergence without subduction of oceanic crust (Hancock and Rutland, 1984; Etheridge et al., 1987; Wyborn, 1988). However Ogasawara (1988) noted that the chemistry of tonalites in the Lamboo Complex is similar to that of tonalites formed by partial melting of basaltic rock above Phanerozoic subduction zones, and suggested that the Halls Creek Orogen may represent the site of a Palaeoproterozoic convergent margin. More recently Tyler et al. (1995, 1999), Griffin et al. (2000), and Sheppard et al. (1999, 2001) have argued that the Lamboo Complex shares many features with convergent Phanerozoic plate margins associated with the subduction of oceanic crust. These authors presented a plate tectonic model for the c. 1910 to 1790 Ma evolution of the Halls Creek Orogen, which involved two orogenic



**Figure 2.** Location of 1:100 000 and 1:250 000 map sheets in the east Kimberley and their relationship to tectonic units

events, the c. 1865 to 1850 Ma Hooper Orogeny and the c. 1835 to 1805 Ma Halls Creek Orogeny.

Before the collision of the Kimberley Craton with the rest of the North Australian Craton, sedimentary rocks were being deposited in the c. 1835 Ma Speewah Basin to the west of the orogen, at the same time as the intrusion of granitic and gabbroic rocks into the Lamboo Complex during the Halls Creek Orogeny (Tyler et al., 1995; Blake et al., 2000; Tyler, 2000). The overlying post-orogenic sedimentary rocks of the c. 1830 to 1790 Ma Kimberley Basin extended across the Lamboo Complex, being equivalent to the rocks of the Red Rock, Texas Downs, and Revolver Creek Basins (Blake et al., 2000; Tyler, 2000).

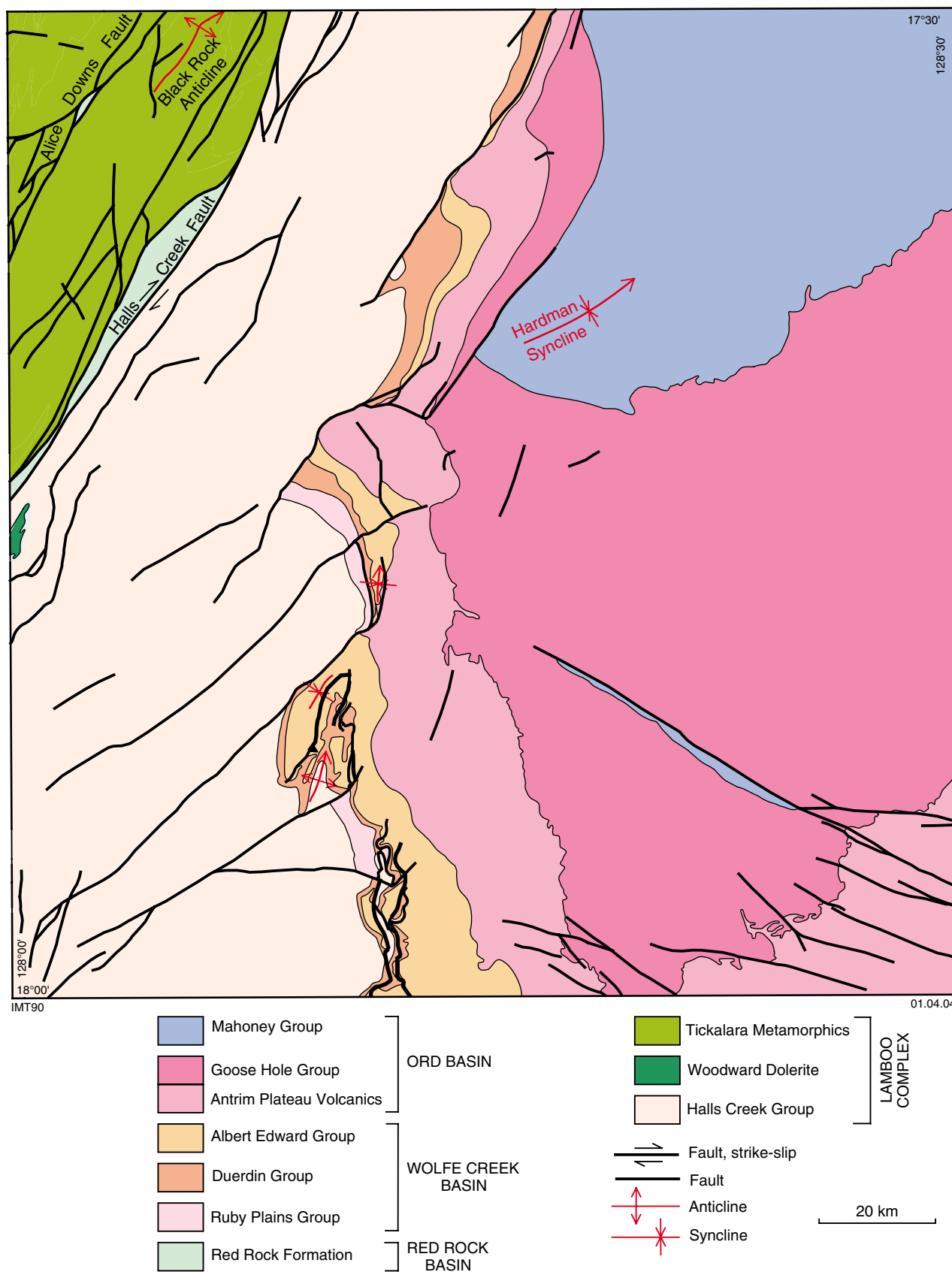


Figure 3. Simplified geological map of Dixon

Table 1. Summary of the geological history of Dixon

Age (Ma)	Lamboo Complex	
	Central zone	Eastern zone
c. 1880 <sup>(a)</sup>		Deposition of the Biscay Formation mafic volcanic and sedimentary rocks
c. 1865 <sup>(b)</sup>	Deposition of the mafic volcanic and siliciclastic and carbonate sedimentary protoliths to the Tickalara Metamorphics	
1863–1850 <sup>(c)</sup>	Early layer-parallel deformation (D <sub>1</sub> ); greenschist facies metamorphism (M <sub>1</sub> )	
<1873–1857 <sup>(d)</sup>		Deposition of the lower Olympio Formation turbiditic sedimentary rocks. Eruption of the Maude Headley Member alkaline volcanic rocks
c. 1850 <sup>(e)</sup>	Intrusion of the Dougalls Tonalite, Monkey Yard Tonalite, and Fletcher Creek Monzogranite as sheet-like intrusions; associated contact metamorphism and metasomatism	
c. 1845 <sup>(f)</sup>	Northeasterly verging recumbent folding (D <sub>2</sub> ); epidote–amphibolite to granulite facies high T/low P metamorphism (M <sub>2</sub> )	
<1847 <sup>(g)</sup>		Deposition of the upper Olympio Formation turbiditic sedimentary rocks Intrusion of Woodward Dolerite
1835–1805 <sup>(e)</sup>	~~~~~ HALLS CREEK OROGENY ~~~~~	
	Formation of upright, SSW-plunging folds (D <sub>3</sub> ) under epidote–amphibolite facies conditions (M <sub>3</sub> ). Formation of the tight to isoclinal, east-facing, NNE-plunging Black Rock Anticline (D <sub>4</sub> ); epidote–amphibolite to greenschist facies mylonitic rocks along major fault zones	Layer-parallel shearing, related to SW-directed extension (D <sub>3</sub> ) Upright to moderately inclined SSE-facing, NNE-plunging open to isoclinal folds and associated thrusts (D <sub>4</sub> ); associated low-grade metamorphism
?1800	Deposition of Red Rock Formation sedimentary and mafic volcanic rocks	<b>Red Rock Basin</b>
c. 1000 <sup>(h)</sup>	~~~~~ YAMPI OROGENY ~~~~~	
	Large-scale sinistral strike-slip faulting, associated folding, and local cleavage development (D <sub>5</sub> )	
c. 830 <sup>(i)</sup>	Deposition of the Ruby Plains Group	<b>Wolfe Creek Basin</b>
c. 610 <sup>(j)</sup>	Deposition of the Duerdin Group and the Albert Edward Group	
c. 560 <sup>(h)</sup>	~~~~~ KING LEOPOLD OROGENY ~~~~~	
	Sinistral strike-slip reactivation of major faults (D <sub>6</sub> )	
c. 513 <sup>(k)</sup>	Eruption of the mafic Antrim Plateau Volcanics	<b>Ord Basin</b>
513–495 <sup>(l)</sup>	Deposition of the Goose Hole Group	
300–400	~~~~~ ALICE SPRINGS OROGENY ~~~~~	
	Sinistral strike-slip reactivation of major faults (D <sub>7</sub> )	
c. 370 <sup>(l)</sup>	Deposition of the Mahony Group	<b>Ord Basin</b>
250–24 <sup>(m)</sup>	Formation of plateau surface	
24–present <sup>(n)</sup>	Uplift and erosion of plateau surface	

NOTES: (a) Blake et al. (1999)  
 (b) Page et al. (1995), Page and Hoatson (2000), Bodorkos et al. (2000a)  
 (c) Page and Hoatson (2000), Page et al. (2001)  
 (d) Page and Sun (1994), Griffin et al. (1998), Blake et al. (1999), R. W. Page in Geoscience Australia's OZCHRON database  
 (e) Page et al. (2001)  
 (f) Oliver et al. (1999), Bodorkos et al. (2000a)  
 (g) Blake et al. (1999), R. W. Page in Geoscience Australia's OZCHRON database

(h) Shaw et al. (1992)  
 (i) Grey and Blake (1999)  
 (j) Grey and Corkeron (1998)  
 (k) Hanley and Wingate (2000)  
 (l) Mory and Beere (1988)  
 (m) Plumb and Gemuts (1979), Playford (2001)  
 (n) Mory and Beere (1988), Blake (1996)



Table 2. Summary of SHRIMP U–Pb zircon and monazite dating of samples relevant to units on Dixon

Unit	Map sheet	Sample	Lithology	AMG coordinates		Age (Ma)	Reference
				Easting	Northing		
Biscay Formation	HALLS CREEK	93526012 (GA)	Foliated felsic fragmental volcanic rock	379200	8000800	1880 ± 3 zircon: igneous crystallization	Blake et al. (1999)
Tickalara Metamorphics	McINTOSH	93525043 (GA)	Garnet-bearing migmatitic metasedimentary rock (palaeosome)	384510	8047730	1865 ± 3 zircon: maximum deposition	Page and Hoatson (2000)
Tickalara Metamorphics	TURKEY CREEK	97SB125	Psammite	410400	8077400	1864 ± 4 zircon: maximum deposition	Bodorkos et al. (2000)
Tickalara Metamorphics	TURKEY CREEK	95SB11	Garnet–sillimanite pelite	398600	8069500	1867 ± 4 zircon: maximum deposition	Bodorkos et al. (2000)
Tickalara Metamorphics	TURKEY CREEK	95SB11	Garnet–sillimanite pelite	398600	8069500	1845 ± 4 zircon: peak high-grade M <sub>2</sub> metamorphism	Bodorkos et al. (2000)
Tickalara Metamorphics	TURKEY CREEK	SM25H	Stromatic migmatite	393700	8086500	1845 ± 3 monazite: peak high-grade M <sub>2</sub> metamorphism	Oliver et al. (1999)
Rose Bore Granite	McINTOSH	113349	Gneissic metagranite	374866	8031584	1863 ± 3 zircon: igneous crystallization	Page and Hoatson (2000)
Dougalls Tonalite	DIXON	93526006	Hypersthene granulite	394800	8063200	1849 ± 3 zircon: igneous crystallization	Page et al. (2001)
Fletcher Creek Monzogranite	DIXON	93526007	Garnet–biotite monzogranite	394500	8064600	1850 ± 2 zircon: igneous crystallization	Page et al. (2001)
Lower Olympio Formation	McINTOSH	93525128B	Feldspathic wacke	388400	8013400	1873 ± 5 zircon: maximum depositional age	OZCHRON
Maude Headley Member	HALLS CREEK	85598001	Porphyritic felsic volcanic rock	386100	8007900	1857 ± 5 zircon: igneous crystallization	Blake et al. (1999)
Upper Olympio Formation	DIXON	92524896	Coarse arkosic sandstone	405800	8038100	1847 ± 6 zircon: maximum deposition	OZCHRON

In the northwestern part of DIXON, sedimentary rock and basalt, which outcrop in fault-bounded slivers along the Halls Creek and Alice Downs Faults, were deposited in the Red Rock Basin (Dow and Gemuts, 1969; Tyler et al., 1995, 1997b; Blake et al., 2000).

Large-scale sinistral strike-slip faulting took place in the Halls Creek Orogen during the Mesoproterozoic Yampi Orogeny (1400–1000 Ma). During this orogeny a pattern of north-northeasterly trending synthetic sinistral faults, and east-northeasterly trending antithetic dextral faults was established (Tyler et al., 1995; Thorne and Tyler, 1996).

In the eastern part of the sheet the Lamboo Complex is unconformably overlain by Neoproterozoic sedimentary rocks of the Wolfe Creek Basin (Shaw et al., 1994; Grey and Blake, 1999), which are part of the Centralian Superbasin. This superbasin was interpreted by Walter et al. (1995) as a broad intracratonic sag-basin that extended throughout much of central Australia between c. 800 Ma and the earliest Cambrian. The c. 560 Ma King Leopold Orogeny affected rocks throughout the King Leopold and Halls Creek Orogens, giving rise to a widespread unconformity at the base of the succeeding c. 515 Ma Lower Cambrian basaltic volcanic rocks and Middle to Upper Cambrian sedimentary rocks in the Ord Basin. The volcanic rocks form part of an extensive continental flood basalt province that originally extended across 300 000 km<sup>2</sup> of northern Australia (Hanley and Wingate, 2000). Devonian sedimentary rocks of the Ord Basin were deposited in sub-basins formed by extensive sinistral strike-slip faulting and associated folding and thrusting related to the c. 400 to 300 Ma Alice Springs Orogeny in central Australia (Mory and Beere, 1988; Thorne and Tyler, 1996). The Hardman Fold Belt (Tyler and Hocking, 2001) formed at this time.

## Palaeoproterozoic Lamboo Complex

### Introduction

Hancock and Rutland (1984) divided the Lamboo Complex into four zones. Griffin and Tyler (1992) amalgamated zones II and III, and Tyler et al. (1994, 1995) and Tyler (2000) subsequently modified their zone boundaries. The three zones (Western, Central and Eastern) trend north-northeasterly (Fig. 2) along the length of the complex and are separated by major fault systems. On DIXON, only the Central and Eastern zones are present, separated by the Halls Creek Fault (Fig. 3). Stratigraphic units cannot be correlated across the zone boundaries, and this is consistent with the zones forming Palaeoproterozoic tectonostratigraphic terranes (Tyler et al., 1995; Fig. 4).

The Western zone of the Lamboo Complex (Fig. 4) is a continuation of the Hooper Complex in the King Leopold Orogen of the west Kimberley region (Griffin et al., 2000). It is composed of low- to high-grade turbiditic metasedimentary rocks of the c. 1870 Ma Marboo Formation, unconformably overlain by felsic

volcanic rocks of the c. 1855 Ma Whitewater Volcanics (Griffin et al., 1993; Tyler et al., 1999; Griffin et al., 2000). The metasedimentary and volcanic rocks were deformed and metamorphosed, and were extensively intruded by granitic and gabbroic rocks of the Paperbark supersuite, as well as by subvolcanic porphyries and by layered mafic-ultramafic intrusions, during the Hooper Orogeny between c. 1865 and 1850 Ma (Tyler and Page, 1996; Tyler et al., 1999; Griffin et al., 2000; Page and Hoatson, 2000; Page et al., 2001).

The Central zone (Fig. 4) is dominated by medium- to high-grade metasedimentary and meta-igneous rocks of the Tickalara Metamorphics, which were intruded by granitic sheet-like intrusions, and deformed and metamorphosed between c. 1865 and 1856 Ma and at 1850–1845 Ma (Tyler and Page, 1996; Bodorkos et al., 1999, 2000a; Blake et al., 2000; Page et al., 2001). In the southern part of the Central zone, low-grade metasedimentary and mafic and felsic volcanic rocks of the Koongie Park Formation were deposited at 1845–1840 Ma (Page et al., 1994). Layered mafic-ultramafic bodies were intruded into the Central zone at c. 1856 Ma, c. 1845 Ma, and c. 1830 Ma (Page and Hoatson, 2000). Large volumes of granite and gabbro of the Sally Downs supersuite intruded the Central zone during the Halls Creek Orogeny at 1835–1805 Ma (Tyler and Page, 1996; Page et al., 2001). The c. 1804 Ma Eastmans Granite intruded the southeastern end of the Central zone (Tyler et al., 1998a; Page et al., 2001).

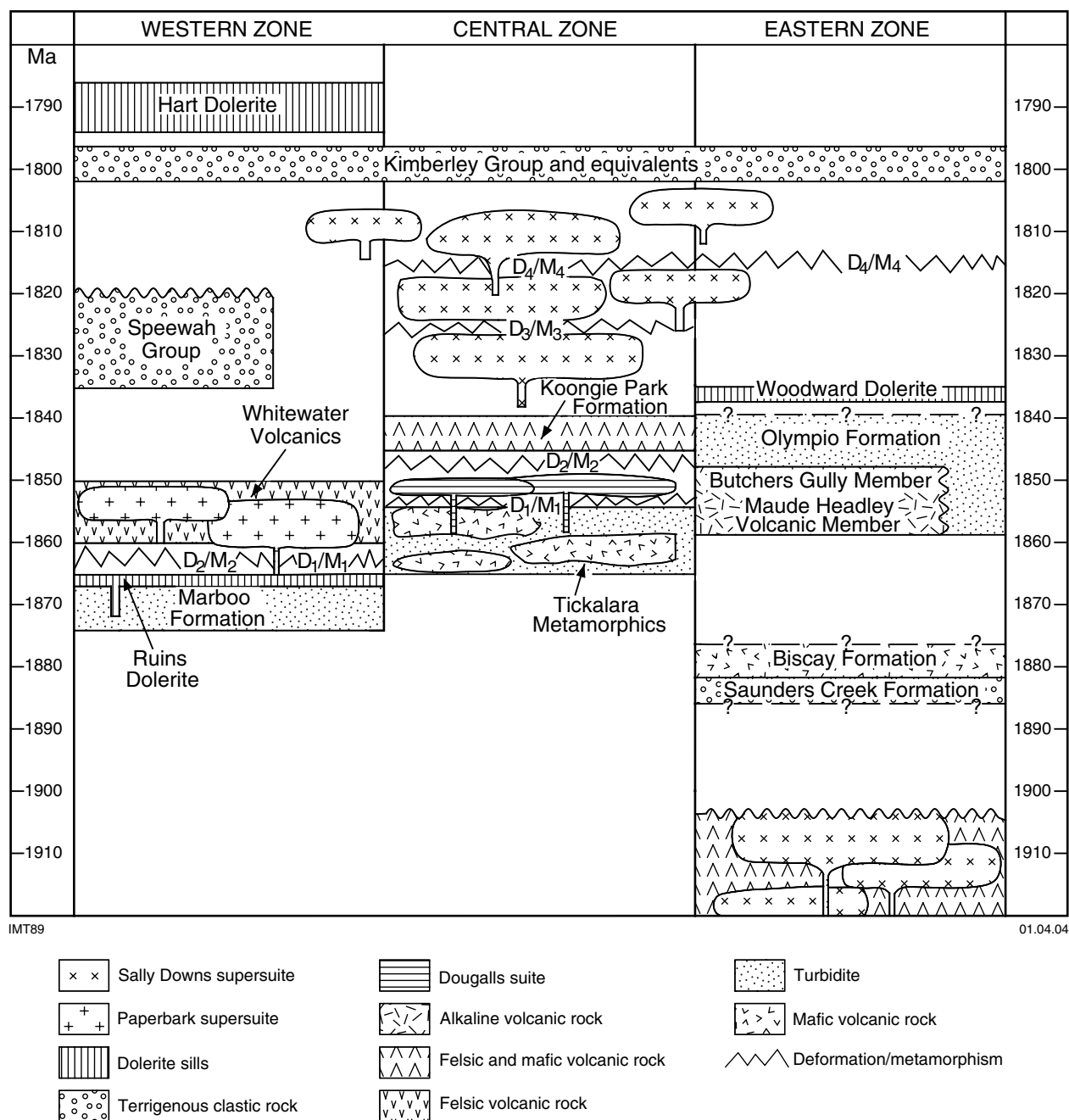
The Eastern zone (Fig. 4) is composed of low-grade metasedimentary and metavolcanic rocks of the Halls Creek Group, which unconformably overlie c. 1910 Ma mafic and felsic volcanic rocks of the Ding Dong Downs Volcanics, together with associated granitic rocks (Tyler et al., 1998b; Blake et al., 1999). Mafic volcanic rocks in the lower part of the Halls Creek Group were erupted at c. 1880 Ma, with alkaline volcanic rocks within turbiditic metasedimentary rocks in the middle and upper part erupted between c. 1857 Ma and c. 1848 Ma (Blake et al., 1999). The Woodward Dolerite forms a series of dolerite sills intruded into the Halls Creek Group. Both the Halls Creek Group and the Woodward Dolerite were deformed and metamorphosed during the 1835–1805 Ma Halls Creek Orogeny, and were intruded by c. 1820 to 1810 Ma granites of the Sally Downs supersuite, and by the c. 1788 Ma San Sou Monzogranite, at the southern end of the Lamboo Complex (Tyler et al., 1998b; Blake et al., 1999; Page et al., 2001).

### Eastern zone

#### Halls Creek Group

On DIXON the Eastern zone lies to the east of the Halls Creek Fault and trends north-northeasterly, occupying most of the western third of the sheet (Fig. 3). The rocks exposed within the zone belong predominantly to the Palaeoproterozoic Halls Creek Group.

The rocks of the Halls Creek Group were defined and described by Dow and Gemuts (1969), and the group was redefined by Griffin and Tyler (1992). The Halls Creek



Group now consists of three formations: the Saunders Creek Formation (not present on DIXON), the Biscay Formation, and the Olympio Formation. The upper part of the mafic volcanic-dominated Biscay Formation is exposed in the southwestern corner of the sheet and is overlain by the extensive turbiditic metasedimentary rocks of the Olympio Formation. Alkaline volcanic rocks of the Maude Headley Member occur in the lower part of the Olympio Formation.

A deformed felsic volcanic rock from the Ilmars copper-lead-zinc prospect on HALLS CREEK gives a

Sensitive High-Resolution Ion MicroProbe (SHRIMP) U–Pb zircon age of  $1880 \pm 3$  Ma (Blake et al., 1999), interpreted as the age of volcanism, for the Biscay Formation, making it the oldest rock unit on DIXON. Page and Hancock (1988) reported a conventional U–Pb zircon age of  $1856 \pm 5$  Ma for a felsic ‘sill’ within ‘Biscay Formation tuffs’ in the northeastern part of HALLS CREEK. Owing to uncertainty as to whether the ‘sill’ was coeval with the surrounding rocks, it was regarded as a minimum age for the Halls Creek Group. Blake et al. (1999) mapped the ‘sill’ as a lava flow, and both the flow and the fragmental volcanics that enclose it belong to the Maude

Headley Member of the Olympio Formation. SHRIMP U–Pb zircon ages of  $1857 \pm 5$  Ma and  $1857 \pm 2$  Ma have been obtained from the same rock and from a pyroclastic rock sampled on McINTOSH respectively (Page and Sun, 1994; Griffin et al., 1998; Blake et al., 1999; R. W. Page in Geoscience Australia's OZCHRON database), providing a depositional age for the lower part of the Olympio Formation.

A detrital zircon population from an Olympio Formation turbiditic sandstone sampled on McINTOSH that underlies the Maude Headley Member gave a SHRIMP U–Pb age of  $1873 \pm 5$  Ma (Blake et al., 1999; R. W. Page in Geoscience Australia's OZCHRON database) providing a maximum depositional age for the lower part of the Olympio Formation. On DIXON a detrital zircon population from an Olympio Formation turbiditic sandstone sampled above the Maude Headley Member gave a SHRIMP U–Pb age of  $1847 \pm 6$  Ma (Table 2; Blake et al., 1999; R. W. Page in Geoscience Australia's OZCHRON database) providing a maximum depositional age for the upper part of the Olympio Formation.

Tight to isoclinally folded rocks of the Halls Creek Group are intruded by the Mount Christine Granitoid on DOCKRELL (Tyler et al., 1998b), the oldest component of which has given a SHRIMP U–Pb zircon age of  $1817 \pm 4$  Ma (Page et al., 2001) providing a minimum depositional age for the Halls Creek Group. Deformation took place during the c. 1835 to 1805 Ma Halls Creek Orogeny. Deformed Halls Creek Group rocks are unconformably overlain by the ?1835–1800 Ma Moola Bulla Formation on HALLS CREEK (Blake et al., 1999).

### **Biscay Formation (Ehr, EHRb)**

The following description is based on Warren (1997) and Blake et al. (1999). The c. 1880 Ma Biscay Formation is in excess of 1000 m thick on HALLS CREEK (Blake et al., 1999), reaching 1500 m further south on DOCKRELL (Tyler et al., 1998b). On DIXON only the upper part of the Biscay Formation is present and consists predominantly of mafic volcanic rocks metamorphosed under low- to medium-grade conditions (Ehr). These were originally fine grained basalt lava flows, mafic volcanoclastic rocks, and volcanogenic sedimentary rocks derived from contemporaneous erosion of the volcanic rocks. Pillow lavas are not preserved on DIXON, but have been recognized in the Biscay Formation on DOCKRELL (Tyler et al., 1998b). Some coarser grained flows have amygdaloidal tops. Cyclic units occur at the top of the Biscay Formation where a basalt lava flow was followed by mafic volcanoclastic rocks and volcanogenic sedimentary rocks capped by thin layers of chert, with or without thin layers and pods of carbonate (EHRb). The uppermost unit in the Dry Creek area on DIXON is a fine grained chert or siliceous volcanoclastic sandstone.

The Biscay Formation may represent mainly shallow-water shelf sedimentation and subaqueous to subaerial volcanism (Blake et al., 1999). Geochemically the metabasalts can be divided into two groups (Sheppard et al., 1999). One group has compositions similar to enriched (E-) MORB, while the second group has lower

TiO<sub>2</sub>, P<sub>2</sub>O<sub>5</sub>, Cr, Y, Nb, and Zr contents, and trace element ratios similar to low-TiO<sub>2</sub> continental flood-basalts. Sheppard et al. (1999) considered that they were erupted on a passive continental margin along the western edge of the North Australian Craton prior to its collision with the Kimberley Craton.

### **Olympio Formation (Eho)**

The following description is based on Warren (1997), Tyler et al. (1998b), and Blake et al. (1999). The Olympio Formation (Eho) is the youngest and most widespread unit of the Halls Creek Group on DIXON. The contact with the underlying Biscay Formation on DIXON is conformable, either with the <1873 Ma lower Olympio Formation turbiditic sedimentary rocks, or with the c. 1857 Ma Maude Headley Member volcanic rocks. The geochronological data suggest that there may be a time gap of up to 20 Ma separating the two formations (Blake et al., 2000). Due to the lack of persistent marker horizons and the possibility of structural repetition, the thickness of the Olympio Formation is difficult to estimate. However, Dow and Gemuts (1969) suggested that the unit was 4000 m (12 000 feet) thick. Hancock and Rutland (1984) and Hancock (1991) give similar thickness estimates for the formation.

The Olympio Formation consists predominantly of thin- to very thick bedded (up to 10 m), fine- to coarse-grained turbiditic mudstone, siltstone, quartz wacke, greywacke, quartz sandstone, lithic sandstone, and arkosic sandstone, with minor pebbly sandstone. Warren (1997) records the presence of a boulder bed exposed in the Ord River, although a precise location is not given. Sandstone layers show graded bedding, with flame structures and rip-up clasts occurring at the contacts with underlying mudstone. Thinner, finer grained sandstone layers show graded bedding and, locally, ripple cross-lamination.

Clasts are commonly angular to subrounded, and consist predominantly of quartz and feldspar in a matrix of quartz, chlorite, and clay minerals. Cubes of iron oxides or cube-shaped voids up to 0.5 cm across after sulfide occur locally. The metamorphic grade of the Olympio Formation on DIXON is very low to low, probably reaching the middle greenschist facies (Dow and Gemuts, 1969). Minor clast components in the sandstones are jasper, vein quartz, chert, microgranite, shale and fine-grained mafic rock, tourmaline, and flakes of detrital muscovite. Locally, clasts of the Maude Headley Member may be seen in the basal part of the upper Olympio Formation. The boulder bed in the Ord River section contains granite clasts and blocks of limestone up to 0.5 m long.

The Olympio Formation has been interpreted as being deposited by turbidity currents as part of a submarine fan system (Dow and Gemuts, 1969; Hancock and Rutland, 1984; Hancock, 1991). Complete Bouma sequences (Walker, 1984) are uncommon, but divisions A, D, and E are usually represented. Hancock (1991) tentatively reported that palaeocurrents obtained from outcrops in the upper Olympio Formation to the northeast of Halls Creek townsite were from the northwest. The petrography of clasts within the sandstone units indicated a continental, largely crystalline source predominantly composed of

granitic rocks, with variable input of felsic volcanic rocks and muscovite-bearing sedimentary rocks (Hancock, 1991). Clast composition on DIXON is also consistent with rapid erosion of a proximal, predominantly granitic source. The detrital zircon ages of c. 1873 Ma for the lower Olympio Formation and c. 1847 Ma for the upper Olympio Formation indicate that they were derived from different source regions. The c. 1847 Ma age from the upper Olympio Formation is too young for derivation from the underlying units of the Halls Creek Group or from the Western zone of the Lamboo Complex. It is also not consistent with a provenance in the Central zone, which includes extensive mafic volcanic rocks and granitic rocks with tonalitic compositions, and from which a more complex detrital zircon population might be expected. The source area does not appear to be exposed within the Halls Creek Orogen at present and was probably removed during possibly contemporaneous strike-slip movements along a proto-Halls Creek Fault system.

#### *Maude Headley Member (PHov)*

The following description is based on Warren (1997) and Blake et al. (1999). The c. 1857 Ma Maude Headley Member of the Olympio Formation consists of alkaline volcanic rocks that either conformably overlie the Biscay Formation, or occur 50–100 m above the base of the Olympio Formation. It ranges from several hundreds to a few tens of metres in thickness.

Lavas range in composition from amygdaloidal trachyte to rhyolite. Pillows in metarhyolite indicate subaqueous eruption from a nearby volcanic centre. A distinctive unit of fragmental volcanics, with flattened and bent porphyritic clasts cemented by a carbonate matrix, forms prominent dark outcrops. The top of the member is marked by laminated chert and carbonate. Northwest of Grant Peak the laminated rocks are capped by 20 m of black carbonate and a thin crystal-rich volcanoclastic sandstone.

Northeast of Dry Creek thin layers of chert or fine-grained siliceous volcanic ashstone occur near the base of the upper Olympio Formation. These may represent very late-stage activity from the Maude Headley Member volcanic centre. Carbonate rocks in the Olympio Formation southwest and north of Black Point had been considered to be high in the Olympio Formation (Dow and Gemuts, 1969). These may actually be low in the succession and could be a northern extension of the Maude Headley Member.

The Maude Headley Member has chemical characteristics of A-type felsic rocks, formed by fractionation of an intraplate mafic magma modified by a minor crustal input (Warren, 1997). The presence of cherty rocks, and carbonates and carbonate-matrix fragmental volcanics may reflect the presence of siliceous and CO<sub>2</sub>-rich volcanic-related fluids.

#### **Woodward Dolerite (*Pdw*)**

The Woodward Dolerite (*Pdw*) on DIXON forms a sill intruded into the uppermost Biscay Formation at the western edge of the sheet, north of Grant Peak. Warren

(1997) described the rock in outcrop as a dark green, medium-grained, even-textured metadolerite. A second sill is present in the Grants Patch area on MCINTOSH and may extend onto DIXON. It has fine-grained margins and a relict ophitic texture.

The Woodward Dolerite forms a series of sills intruded throughout the Halls Creek Group on HALLS CREEK and DOCKRELL, and these may be of different ages ranging from c. 1910 Ma to <1847 Ma (Tyler et al., 1998b; Blake et al., 1999). They have been affected by, and therefore predate, the earliest deformation and metamorphism that affects the Halls Creek Group, and are probably older than c. 1835 Ma.

### **Central zone**

#### **Tickalara Metamorphics (*PmTa*, *PmTan*, *PmTav*, *PmToa*, *PmTpa*, *PmTps*, *PmTpn*, *PmTpc*, *PmTgd*, *PmTgm*, *PmTog*, *PmTgl*, *PmTss*, *PmTgs*)**

The Central zone of the Lamboo Complex occurs in the northwestern part of DIXON to the west of the Halls Creek Fault (Fig. 3). The Tickalara Metamorphics outcrop within the Central zone and consist of interlayered low- to high-grade metavolcanic and metasedimentary rocks, intruded by sheet-like mafic and felsic meta-igneous bodies.

Metamorphosed mafic volcanic rocks interlayered with siliciclastic and calcareous metasedimentary rocks dominate the Tickalara Metamorphics on DIXON. A sequence of turbiditic siliciclastic metasedimentary rocks within the Tickalara Metamorphics on MCINTOSH to the west does not extend onto DIXON. Amphibolite (*PmTa*) may be interlayered with either upper amphibolite to granulite facies migmatitic pelitic, psammitic, and calc-silicate gneisses (*PmTan*), or with amphibolite facies pelite, psammite, calc-silicate rock, and marble (*PmTav*). At low to medium grades in the Tickalara Metamorphics on MCINTOSH, volcanic structures may be preserved including amygdaloids, pillows, and fragmental textures with interstitial carbonate (see also Plumb et al., 1985; Allen, 1986; Blake et al., 2000; Tyler et al., in prep.a). Amygdaloids are preserved in amphibolite on DIXON (Fig. 9). Amphibolite with relict primary layering and gabbroic textures (*PmToa*) is also present. Interlayered pelite and psammite characterized by epidote–amphibolite facies mineral assemblages (*PmTpa*) and by middle amphibolite facies mineral assemblages (*PmTps*), occur with banded iron-formation, calc-silicate rock, marble, and minor amphibolite. Upper amphibolite facies to granulite facies migmatitic pelitic gneiss contain layers and pods of amphibolite and psammitic gneiss (*PmTpn*). Units of calc-silicate rock and marble interlayered with minor banded iron-formation and quartzite (*PmTpc*) are present within the metasedimentary sequence. Sedimentary structures, other than compositional layering that represents original bedding, are not preserved on DIXON.

Sheet-like meta-igneous bodies belonging to the Dougalls suite (Sheppard et al., 1995, 1997a, 2001) consist of the Dougalls Tonalite (*PmTgd*) and the Monkey Yard





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**Figure 5. Inclusion of amphibolite, veined by metamorphosed tonalite and trondhjemite, within the Dougalls Tonalite (AMG 394800E 8063200N)**

Tonalite (*PmTgm*) on DIXON. Also present is amphibolite and dioritic to gabbroic granulite (*PmTog*), which is cut by extensive veins and patches of metamorphosed tonalite and trondhjemite, and occurs as widespread inclusions within the Dougalls Tonalite (Fig. 5; see also Blake et al., 2000, fig. 3.9A). The relationship between the leucocratic and melanocratic phases is complex and the range of structures present is consistent with mingling of two magmas (Sparks and Marshall, 1986; Frost and Mahood, 1987; Blake et al., 2000). The Fletcher Creek Monzogranite (*PmTgl*) represents a separate, more felsic intrusion, which may also contain inclusions of the amphibolite and dioritic to gabbroic granulite veined by tonalite and trondhjemite (Fig. 6).

Mylonites derived from both metasedimentary and meta-igneous rocks (*PmTss*, *PmTgs*) are also present along the Alice Downs and Halls Creek Faults.

A depositional age for the sedimentary and volcanic protoliths of the Tickalara Metamorphics has not been obtained. Nevertheless, detrital zircons from metasedimentary rocks on MCINTOSH and TURKEY CREEK indicate a maximum depositional age of c. 1865 Ma from SHRIMP U–Pb ages (Page et al., 1995; Page and Hoatson, 2000; Bodorkos et al., 2000a). A minimum depositional age is provided by the Rose Bore Granite, a deformed and metamorphosed intrusive granitic sheet exposed on MCINTOSH, which has a SHRIMP U–Pb zircon igneous crystallization age of  $1863 \pm 3$  Ma (Page and Hoatson,

2000), suggesting rapid tectonic evolution of the Central zone at that time. The Dougalls Tonalite and the Fletcher Creek Monzogranite on DIXON (Table 2), have SHRIMP U–Pb zircon igneous crystallization ages of  $1849 \pm 3$  Ma and  $1850 \pm 2$  Ma respectively. Both units intrude the metasedimentary and metavolcanic units of the Tickalara Metamorphics on DIXON (Page et al., 2001).

Previous workers have assumed the metasedimentary and metavolcanic units of the Tickalara Metamorphics to be the metamorphosed medium- to high-grade equivalents of the Halls Creek Group (Dow and Gemuts, 1969; Hancock and Rutland, 1984; Plumb et al., 1985; Allen, 1986), which is exposed within the Eastern zone of the Lamboo Complex (see **Eastern zone** below). However the Biscay Formation, in the lower part of the Halls Creek Group, has been dated at c. 1880 Ma (Page and Sun, 1994; Blake et al., 1999). In the upper part of the Halls Creek Group, felsic volcanic units of the Olympio Formation were erupted between 1857 Ma and 1848 Ma (Blake et al., 1999). The conformably overlying turbiditic sedimentary rocks contain detrital zircons as young as c. 1847 Ma (Blake et al., 1999). Deformation and metamorphism of the Tickalara Metamorphics took place between c. 1863 and 1845 Ma (Tyler and Page, 1996; Bodorkos et al., 1999, 2000a; see **Early deformation and metamorphism in the Central zone** below), and occurred, therefore, while the upper part of the Halls Creek Group was still being deposited. Allen (1986) suggested that quartzose metasedimentary rocks that apparently occur within the Tickalara Metamorphics on DIXON and TURKEY CREEK were part of the Saunders Creek Formation at the base of the Halls Creek Group. However, these outcrops are considered here to be low-strain pods of c. 1800 Ma Red Rock Formation sandstones, strung out within mylonitic rocks along the Halls Creek and Alice Downs Faults (see **Red Rock Formation** below).



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**Figure 6. Inclusion of amphibolite veined by metamorphosed tonalite and trondhjemite, within the Fletcher Creek Monzogranite (AMG 394200E 8063700N)**

Tyler et al. (1995) concluded that the differences between the Tickalara Metamorphics and the Halls Creek Group were consistent with their deposition in geographically separate tectonostratigraphic terranes that were juxtaposed during subsequent tectonism. Sheppard et al. (1999) interpreted the metamorphosed basaltic rocks of the Tickalara Metamorphics as forming in an oceanic island arc/back-arc basin or ensialic marginal basin setting, based on their geochemistry. In contrast they interpreted the basaltic rocks of the Biscay Formation of the Halls Creek Group as being erupted on a passive continental margin. Sheppard et al. (2001) suggested that the geochemical and isotopic composition of the tonalites and trondhjemites of the Dougalls suite resemble crustally derived adakites and low- to medium-K, calc-alkaline rocks from Phanerozoic continental margins and island arcs. They interpreted the suite as the product of melting of a package of mafic volcanic rocks in the deep crust (>40 km depth), implying a substantially tectonically and/or magmatically thickened crust in the Central zone at c. 1850 Ma.

Bodorkos et al. (1999) have pointed out that although the tectonic evolution of the Lamboo Complex has been interpreted in terms of two separate orogenic events, in the Central zone the high temperature/low pressure metamorphism can be attributed to a single long-lived thermal anomaly spanning the two events. This is consistent with the large volumes of mafic magma, as both layered mafic-ultramafic intrusions and gabbroic bodies, that have been intruded into the Tickalara Metamorphics almost continuously over a period from c. 1860 Ma to c. 1830 Ma (Hoatson and Blake, 2000). The maintenance of the anomaly over such a long time period suggests a major mantle perturbation at the base of the crust of the Central zone (Bodorkos et al., 1999), although it is unclear how this was achieved in the interpreted rapidly evolving island arc to plate margin to collisional setting. It may reflect the different nature of the oceanic crust and of subduction processes in the Palaeoproterozoic (Sheppard and Tyler, 2002).

The petrography and the structural and metamorphic history of the Tickalara Metamorphics is described under the **Early deformation and metamorphism in the Central zone and Halls Creek Orogeny** sections below.

### Early deformation and metamorphism in the Central zone

The Hooper Orogeny in the Hooper Complex of the King Leopold Orogen took place between c. 1870 and 1850 Ma (Tyler and Griffin, 1990, 1993; Griffin et al., 1993; Tyler et al., 1999; Griffin et al., 2000). Tyler et al. (1995) noted the similarities in the geological evolution of the Hooper Complex and the Western zone of the Lamboo Complex. Rocks of the Marboo Formation in the Western zone of the Lamboo Complex, and those of the Tickalara Metamorphics within the Central zone are both affected by two early phases of deformation, and Tyler and Page (1996) correlated these events with the Hooper Orogeny. However, zircon and monazite SHRIMP U–Pb ages from the Central zone suggest that, although there is overlap, it has a tectonic history that differs from that of the

Western zone (Bodorkos et al., 1999, 2000a; Oliver et al., 1999).

In the Central zone a maximum age for the first deformation is provided by the c. 1863 Ma Rose Bore Granite on McINTOSH, which pre-dates  $D_1$  (Tyler and Page, 1996). A minimum age for  $D_1$  is provided by the c. 1850 Ma age for the intrusion of the granitoids of the Dougalls suite and the Fletcher Creek Monzogranite, which post-date  $D_1$  but pre-date  $D_2$  (Tyler and Page, 1996).  $D_1$  in the Central zone therefore has similar time constraints to  $D_2$  in the Western zone (Table 1).

$D_2$  in the Central zone post-dates the intrusion of the Dougalls suite and is synchronous with peak metamorphism. Oliver et al. (1999) and Bodorkos et al. (2000a) dated peak  $M_2$  metamorphism in the Tickalara Metamorphics at c. 1845 Ma. This indicates that deformation and metamorphism in the Central zone continued after the Hooper Orogeny in the Western zone had finished. Bodorkos et al. (1999) suggested that peak metamorphism was prolonged with the repeated injection of mafic magma ensuring that the rocks remained very hot ( $\geq 650^\circ\text{C}$ ) for at least 10 m.y., with the Central zone  $M_2$  event merging into  $D_3/M_3$  of the Halls Creek Orogeny.

Sheppard et al. (1999) suggested that the metasedimentary and metabasaltic rocks of the Tickalara Metamorphics represent a c. 1865 Ma intra-oceanic island arc. The Hooper Orogeny in the Western zone and the early deformation and metamorphism in the Central zone may correspond to the accretion of the island arc to the edge of the Kimberley Craton (Myers et al., 1996; Sheppard et al., 1997a). From the relative position of the zones within the Lamboo Complex, subduction of oceanic crust at this time was probably to the southeast (Sheppard et al., 2001). The early deformations in the Central zone were interpreted as being related to large-scale easterly directed thrusting by Hancock and Rutland (1984).

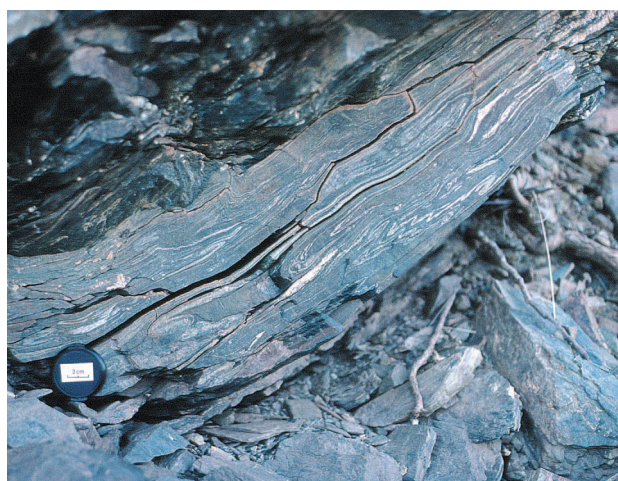
### Deformation ( $D_1/D_2$ )

The earliest deformation ( $D_1$ ) has produced a pervasive layer-parallel foliation to gneissic banding ( $S_1$ ) to the northwest of the Alice Downs Fault. No  $D_1$  folds have been recognized. In carbonate units boudins of more competent layers are wrapped by the  $S_1$  fabric (e.g. Gemuts, 1971, plate 9, figure 1). The  $S_1$  fabric is locally truncated by veins of Dougalls Tonalite and Fletcher Creek Monzogranite.

Large-scale  $D_2$  fold closures are not recognized to the northwest of the Alice Downs Fault, but small-scale  $D_2$  folds are present in metasedimentary rocks (Plumb et al., 1985; Allen, 1986; Bodorkos, 2001). Folds are characterized by a variably developed axial planar foliation ( $S_2$ ) defined usually by aligned biotite, and locally by sillimanite crystals. The Fletcher Creek Monzogranite and the Dougalls Tonalite both contain a well developed  $S_2$  fabric.

To the southeast of the Alice Downs Fault the earliest deformation is not well preserved, with a ubiquitous schistosity probably representing a combined  $S_1/S_2$  fabric. Large scale  $D_1$  folds are not recognized, but  $S_2$  crenulates





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**Figure 7. Small-scale, isoclinal  $D_2$  fold closures in pelitic schist, Tickalara Metamorphics (AMG 398900E 8054500N)**

a layer-parallel  $S_1$  in small-scale, isoclinal  $D_2$  fold closures (Fig. 7). Garnet porphyroblasts, which are wrapped by the crenulation cleavage, preserve earlier straight to sigmoidal inclusion trails of fine-grained quartz or iron oxide (Fig. 8), which are interpreted as the remnants of a low-grade, probably greenschist facies  $S_1$ .

The Monkey Yard Tonalite outcrops within large-scale, elongate, doubly-plunging fold closures around the  $D_4$  Black Rock Anticline, between the Alice Downs and Halls Creek Faults. These structures have been interpreted as originally recumbent, east-verging, isoclinal  $D_2$  folds (Hancock and Rutland, 1984; Bodorkos, 2001), although unfolding  $D_3$  and  $D_4$  as recognized here would suggest a northeasterly vergence.

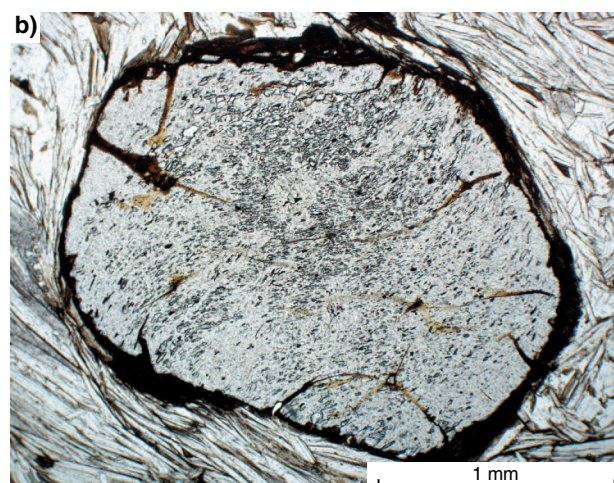
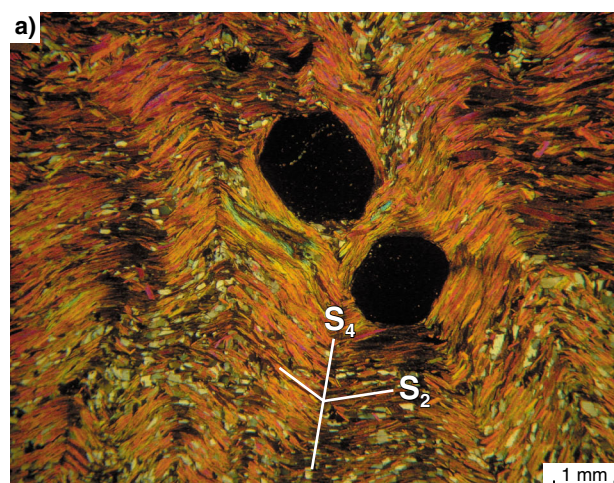
### Metamorphism ( $M_{1/2}$ )

Bodorkos et al. (1999) and Bodorkos (2001) recognized that mineral assemblages representing the highest metamorphic grades in the Tickalara Metamorphics are typical of metamorphism at high temperatures and low pressures (750–800°C at 350–500 MPa). These assemblages grew syn- to post- $D_2$  (c. 1845 Ma) during a single thermal event ( $M_{1/2}$ ) that encompassed both  $D_1$  and  $D_2$ . On DIXON, metamorphic grade increases towards the northwest corner of the map sheet. Between the Halls Creek Fault and the Alice Downs Fault, mineral assemblages are indicative of the epidote–amphibolite facies (Zone B of Gemuts, 1971). To the northwest of the Alice Downs Fault, mineral assemblages represent an increase in grade from the middle amphibolite facies to the amphibolite- to granulite-facies transition (Zone A of Gemuts, 1971).

The Fletcher Creek Monzogranite was intruded at c. 1850 Ma following  $D_1$ , and Magart (1994) and Bodorkos et al. (1999) recognized a narrow (100 m) pyroxene hornfels facies contact aureole in the surrounding calc-silicate rocks and marbles. They inferred that for the aureole to develop, the Fletcher Creek Monzogranite must

have been intruded at a shallow crustal level into relatively cold (300–350°C) country rocks, consistent with the greenschist facies metamorphic conditions for  $D_1$  that are indicated by the fine inclusion trails within later garnet porphyroblasts.

Mineral assemblages within the Tickalara Metamorphics between the Alice Downs and Halls Creek Faults are indicative of epidote–amphibolite facies conditions. Pelitic and psammitic metasedimentary rocks typically consist of biotite, muscovite, and quartz with accessory iron oxides, tourmaline, and zircon. Garnet is often present as subhedral to rounded porphyroblasts up to 10 mm across in pelitic rocks, wrapped by intergrown fine- to medium-grained mica, quartz, and iron oxide defining a well developed schistosity (Fig. 8). Mafic metavolcanic rocks are thoroughly recrystallized, having fine- to medium-grained assemblages of chlorite, epidote, blue-green (edenitic) to green amphibole (hornblende), plagioclase (albite to oligoclase), and quartz with minor



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**Figure 8. (a) Garnet porphyroblast wrapped by the  $S_2$  and  $S_4$  crenulation cleavages. Crossed nicols. (b) Garnet preserves earlier straight to sigmoidal inclusion trails of fine-grained quartz or iron oxide. Plane-polarized light (GSWA 108376)**





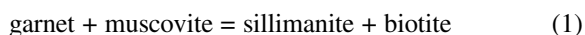
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**Figure 9. Stretched amygdaloides in amphibolite derived from basalt lava in the Tickalara Metamorphics (AMG 404100E 8055700N)**

titanite and iron oxides. Blebs of intergrown quartz and epidote, which may be stretched (Fig. 9), probably represent recrystallized amygdaloides. The Monkey Yard Tonalite is variably foliated, and consists of medium- to coarse-grained quartz, plagioclase (oligoclase), blue-green amphibole, epidote, and K-feldspar, with minor titanite and iron oxides. K-feldspar occurs locally intergrown with plagioclase and quartz, and myrmekite.

To the northwest of the Alice Downs Fault, mineral assemblages are indicative of conditions ranging from the middle amphibolite facies in the south to the amphibolite- to granulite-facies transition in the north. Medium- to coarse-grained pelitic and psammitic rocks in the south consist of biotite, quartz, and iron oxides with or without muscovite, and with sillimanite, garnet, and staurolite occurring in more pelitic lithologies. Plagioclase may also be present intergrown with quartz. Rounded to subhedral garnet porphyroblasts can be up to 10 mm across, wrapped by anastomosing trails of intergrown fibrolitic sillimanite, biotite, and iron oxide (Fig. 10) consistent with the reaction:



Crystalline sillimanite can occur in rounded to elongate patches up to 20 mm across. Locally garnet may be surrounded by sillimanite. Irregular to subhedral crystals of staurolite are intergrown with biotite (Fig. 10) suggesting the operation of reaction 2,

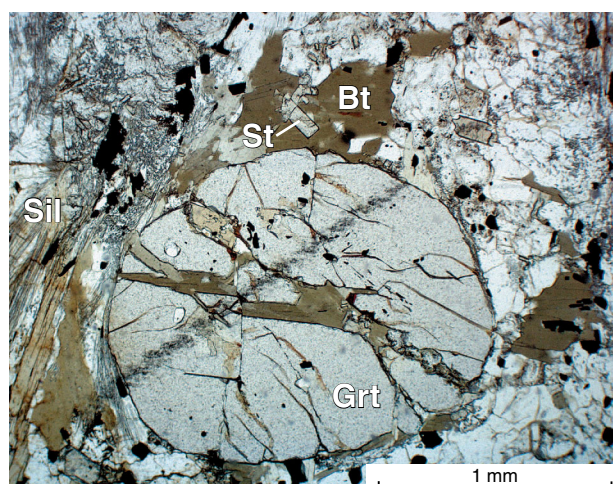


In the north, medium- to coarse-grained pelitic rocks are interlayered with psammite, calc-silicate rocks and marble, and amphibolite, and become migmatitic with anatectic leucosomes developed both parallel to, and crosscutting layering (Bodorkos, 2001). The pelites consist of garnet, biotite, plagioclase, and quartz, with or without cordierite, sillimanite, and K-feldspar, reflecting the locally K-poor nature of the metasedimentary rocks (Plumb et al., 1985; Sheppard et al., 1997b). The appearance of cordierite with garnet is controlled by the reaction:



Calc-silicate rocks interlayered with pelite and psammite typically contain ragged and irregular garnet porphyroblasts up to 5 mm across intergrown with quartz. Depending on how calcareous these rocks are, the porphyroblasts are wrapped by foliations characterized by biotite, quartz, plagioclase (oligoclase-andesine), and iron oxide, or biotite, quartz, epidote, calcite, and iron oxides, together with accessory tourmaline and zircon. Irregular crystals of hornblende may be present locally.

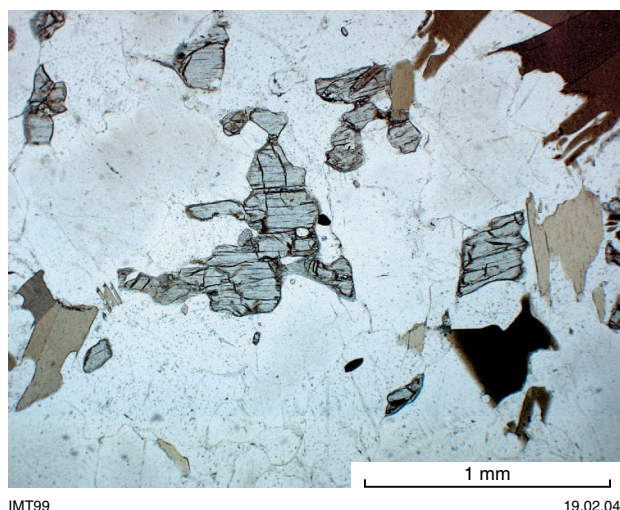
Magart (1994) and Bodorkos (2001) have interpreted calc-silicate rocks, and compositionally layered impure marble associated with pure marble around the Fletcher Creek Monzogranite, as the result of metasomatism due to pervasive infiltration of fluids at high temperatures within a contact aureole. Magart (1994) recognized carbonate-absent, silica-dominated wollastonite-quartz-garnet-clinopyroxene-epidote, and quartz-garnet-clinopyroxene(-scapolite-plagioclase) rocks at the intrusion margins. Associated impure marble is characterized by alternating calcite- and silicate-rich layers, interpreted to represent increasingly channelized fluid flow away from the intrusion. Silicate phases include clinopyroxene, garnet, and scapolite. Unmetasomatized pure marble is characterized by coarse-grained,



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**Figure 10. Garnet (Grt) surrounded by sillimanite (Sil) and irregular to subhedral crystals of staurolite (St) intergrown with biotite (Bt) (GSWA 108361), plane-polarized light**



**Figure 11. Irregular to rounded orthopyroxene in Dougalls Tonalite (GSWA 113593), plane-polarized light**

granoblastic calcite, and silicate phases include olivine (variably altered to serpentine), spinel, garnet, clinopyroxene, plagioclase, scapolite, amphibole, epidote, and titanite.

Amphibolites northwest of the Alice Downs Fault are typically medium to coarse grained with granoblastic textures. Mineral assemblages include green hornblende, plagioclase (andesine to labradorite), quartz, and iron oxides, with or without garnet or clinopyroxene, indicative of the upper amphibolite facies.

The Dougalls Tonalite is metamorphosed and is a medium- to coarse-grained rock consisting of quartz, plagioclase (oligoclase to andesine), biotite, hypersthene, and iron oxides with either hornblende or garnet. Sheppard et al. (1995) suggested that hypersthene might be a relict igneous phase. However, in samples from DIXON (113593 and 108368, Fig. 11) hypersthene has a similar irregular to rounded form to accompanying metamorphic garnet, and is intergrown with biotite and hornblende as well as quartz and plagioclase, suggesting that it has recrystallized during prograde metamorphism, indicating transitional granulite facies conditions. Locally it may be rimmed by iron oxide.

The Fletcher Creek Monzogranite consists of quartz, plagioclase (oligoclase), K-feldspar, garnet, biotite, muscovite, and iron oxides. The garnets are rounded, euhedral to subhedral grains up to 3 mm in diameter, and are relatively rich in Mn (up to 34.2 mol.%; Ogasawara, 1988), consistent with their initial formation as magmatic crystals (Sheppard et al., 1995). Where garnet is present biotite is typically absent.

## Halls Creek Orogeny

Deformation and metamorphism during the Halls Creek Orogeny (Tyler and Page, 1996; Blake et al., 2000) has affected the entire Lamboo Complex. The Halls Creek

Orogeny may be the result of a collision between the combined Central and Western zones and the Eastern zone, the earliest stages of which began at c. 1835 Ma (Page et al., 2001; Sheppard et al., 2001). The collision, which involved the suturing of the Kimberley Craton to the rest of the North Australian Craton, was completed by 1805 Ma (Myers et al., 1996; Tyler et al., 1998c; Sheppard et al., 2001).

## Deformation

Griffin and Tyler (1992) established a sequence of deformation events ( $D_1$  to  $D_7$ ) for the southern part of the Halls Creek Orogen. Their nomenclature is followed here. Deformation that affected the Halls Creek Group in the Eastern zone must have occurred after c. 1847 Ma, the age of the youngest detrital zircons in the Olympio Formation, and has been attributed to  $D_3$  and  $D_4$  (Tyler et al., 1998b), equivalent to  $D_{H1}$  and  $D_{H2}$  of Blake et al. (1999). In the Central zone the intrusion of the c. 1835 Ma Mabel Downs Tonalite was synchronous with  $D_3$  (Bodorkos et al., 2000b). A minimum age for deformation is provided by the c. 1808 Ma age for the Mount Christine Granitoid (Page et al., 2001), which cuts across the trend of  $D_4$  structures in the Halls Creek Group on DOCKRELL (Tyler et al., 1998b).

### First deformation ( $D_3$ )

The first deformation to affect rocks in the Eastern zone ( $D_3$ ) was low-angle normal faulting and layer-parallel shearing (Hancock, 1991; Warren, 1994b, 1997; Tyler et al., 1998b; Blake et al., 1999, 2000). Warren (1997) noted that there were gaps in the expected stratigraphic sequence between the upper Biscay Formation and the Olympio Formation, which corresponded to thin (c. 3 m) zones of laminated or brecciated rock. These were interpreted as bedding-parallel faults, which on a regional scale together form a low-angle normal fault that cuts progressively down-section from north to south and from east to west (Warren, 1994b).

In the Central zone  $D_3$  is characterized by large-scale folding and the local development of shear zones (Plumb et al., 1985; Tyler and Page, 1996; Sheppard et al., 1997b; Bodorkos et al., 1999, 2000b; Bodorkos, 2001). On DIXON, structures attributable to  $D_3$  are present between the Halls Creek Fault and the Alice Downs Fault, and have produced refolding of recumbent  $D_2$  folds around the  $D_4$  Black Rock Anticline to produce elongate basin and dome structures picked out by fold cores of Monkey Yard Tonalite. Unfolding the anticline suggests that the original orientation of  $D_3$  was as upright, north-northeasterly trending structures with gentle plunges to the south-southwest. Locally a crenulation ( $S_3$ ) of  $S_2$  may be recognized, cutting across  $D_2$  fold hinges at an angle to the more widespread  $S_4$  crenulation.

### Second deformation ( $D_4$ )

The second deformation to affect the Eastern zone ( $D_4$ ) was compressional and was marked by the formation of open to tight, upright to overturned, north-northeasterly



trending folds (Warren, 1997). In the southwestern corner of the map sheet the most obvious  $D_4$  structures are a series of anticlines and synclines forming the Biscay Anticlinorium of Dow and Gemuts (1969). The structures forming the anticlinorium plunge gently to moderately to the north-northeast, with the anticlines marked by narrow outcrops of the Biscay Formation and the Maude Headley Member, separated by synclines within the Olympio Formation.

The folds change in style to the north-northeast probably reflecting the more massive nature of the lower Halls Creek Group and its basement, compared with the Olympio Formation (Tyler et al., 1998b). Warren (1997) reported that a cleavage is absent in the southwest, but to the north-northeast the intersection of an axial plane fracture cleavage with bedding in Olympio Formation rocks produces 'pencil slates' (Blake et al., 2000, fig. 3.7B). Beds dip steeply to the west, with the asymmetric folds becoming overturned, facing to the east. Typically, anticlines are preserved with the intervening synclines removed by local thrusting (Warren, 1997). This is consistent with the suggestion by Blake et al. (1999) that  $D_4$  was the result of an easterly verging fold and thrust system.

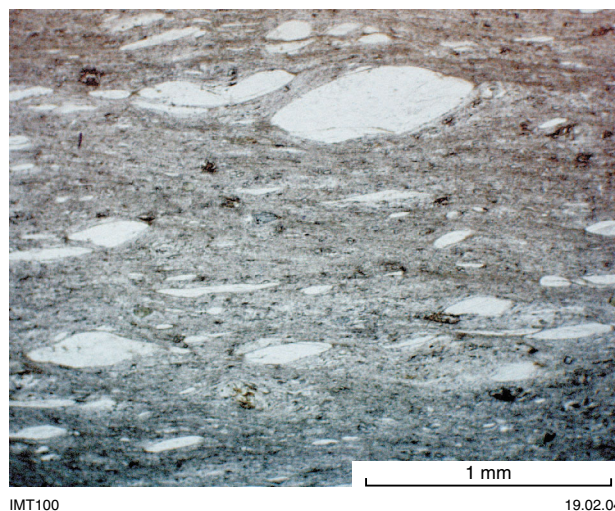
In the Central zone, the regional-scale  $D_4$  Black Rock Anticline lies between the Alice Downs Fault and the Halls Creek Fault. This structure is picked out by metacarbonate, amphibolite layers, and the Monkey Yard Tonalite and is an antiform produced by refolding of recumbent  $D_2$  folds. It was referred to as the Black Rock 'Antiform' by Hancock and Rutland (1984), but Tyler et al. (1998d) retained the original nomenclature of Gemuts (1971) on the published geological map. The 'anticline' is a tight to isoclinal, asymmetric structure, which is locally overturned to the east (Gemuts, 1971, fig. 8). It plunges gently to moderately to the north-northeast, and is parallel to the  $D_4$  structures in the adjacent Eastern zone. A well-developed crenulation is present, axial planar to the fold structure (Fig. 8).

Extensive zones of mylonitic rocks, developed within both metasedimentary and meta-igneous rocks in the Tickalara Metamorphics, are found associated with both the Alice Downs Fault and the Halls Creek Fault on DIXON. Locally the mylonitic fabrics grade into protomylonitic rocks where the fabric can be identified as an  $S_4$  crenulation, consistent with the mylonitization occurring during  $D_4$ . S-C fabrics and asymmetric tails on porphyroclasts typically indicate west-side-up movement on shear zones, consistent with the exposure of higher grade rocks to the west, and with easterly directed thrusting in the Eastern zone to the east.

## Metamorphism ( $M_3$ and $M_4$ )

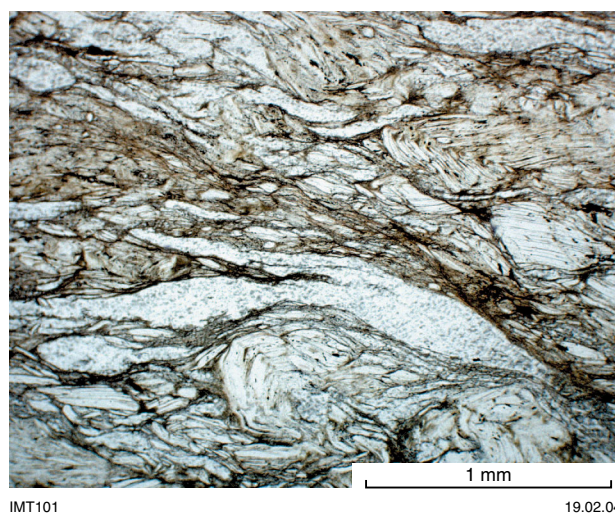
There is little evidence of retrogression of  $M_{1/2}$  mineral assemblages during  $M_3$  on DIXON suggesting that similar epidote-amphibolite facies metamorphic conditions were developed.

During  $D_4$ , extensive recrystallization took place with metamorphic grade ranging from epidote-amphibolite



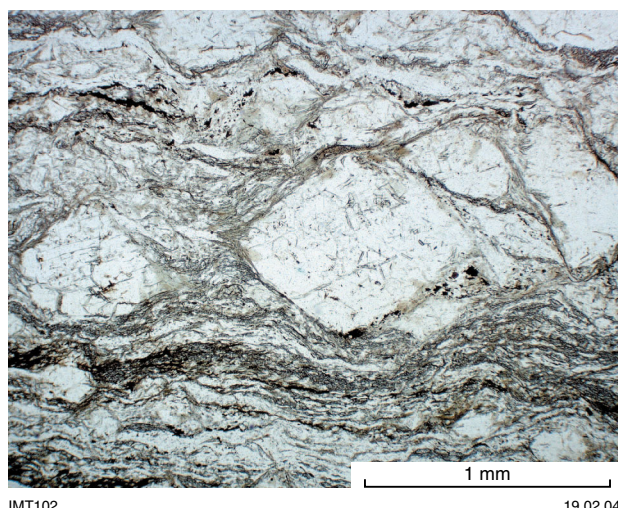
**Figure 12.** Asymmetric 'mica-fish' in mylonitic pelite (GSWA 108355, plane-polarized light). Arrows indicate sense of shear

facies conditions similar to  $M_3$  in the northwest, to greenschist facies adjacent to the Halls Creek Fault. In metasedimentary rocks in the northwest, an  $S_4$  crenulation is typically picked out by muscovite and biotite. In shear zones along the Alice Downs Fault, garnet, epidote, or muscovite porphyroclasts may be present, with muscovite ranging from large (up to 3.5 mm diameter) broken crystals with bent and fractured cleavages, to smaller (1 mm diameter) asymmetric 'mica-fish' (Fig. 12; see Passchier and Trouw, 1996). The porphyroclasts are wrapped by a fine schistose matrix of muscovite, quartz, and iron oxides with or without biotite or epidote. At lower strains, transposed isoclinal, small-scale  $D_2$  fold hinges may be preserved, wrapped by a strong schistosity (Fig. 13). In metatonalitic rocks, lozenge-shaped porphyroclasts of quartz and plagioclase



**Figure 13.** Transposed, isoclinal, small-scale  $D_2$  fold hinges wrapped by a strong schistosity in mylonitic pelite (GSWA 108358, plane-polarized light)





**Figure 14. Lozenge-shaped porphyroclasts of quartz and plagioclase in metatonalitic rocks wrapped by an asymmetric, finely schistose to laminated mylonitic fabric (GSWA 108353, plane-polarized light)**

(oligoclase, sieved by fine muscovite, epidote, and biotite) up to 15 mm in diameter are wrapped by an asymmetric, finely schistose to laminated mylonitic fabric with strings and ribbons of garnet, epidote, quartz, iron oxides, titanite, and biotite with muscovite or chlorite (Fig. 14).

In mylonitic metatonalite along the Halls Creek Fault, rounded to angular (often broken) porphyroclasts of quartz and plagioclase (oligoclase) are wrapped by a fine, schistose matrix of chlorite, muscovite, quartz, epidote, calcite, and iron oxide. Adjacent pelitic rocks have retrograde greenschist facies assemblages with an  $S_4$  schistosity picked out by chlorite, muscovite, and quartz, wrapping ovoid patches up to 5 mm across consisting of sericite intergrown with iron oxide and some relict garnet. Curvilinear trails of iron oxide may be preserved from an original  $M_{1/2}$  garnet porphyroblast (Fig. 15). Biotite is preserved in some chlorite grains.

## Palaeoproterozoic Red Rock Basin

### Red Rock Formation (*Pk*, *Pkc*, *Pkb*)

Fault-bounded strips of conglomerate, sandstone, mudstone, siltstone, metabasalt, and carbonate occur along the Halls Creek Fault and the Alice Downs Fault on DIXON, MCINTOSH, and TURKEY CREEK (Tyler et al., 1997a, 1997b, 1998d). At one locality on TURKEY CREEK, conglomerate and sandstone unconformably overlie the Tickalara Metamorphics (Tyler et al., 1997b). These rocks are correlated with the Red Rock Formation (*Pk*), which was deposited in the Red Rock Basin, and which is now exposed in the Osmand Range on TURKEY CREEK (Tyler et al., 1997b). The Red Rock Formation and the Texas Downs Formation are probably equivalent to the c. 1800 Ma Kimberley Group to the west, but the

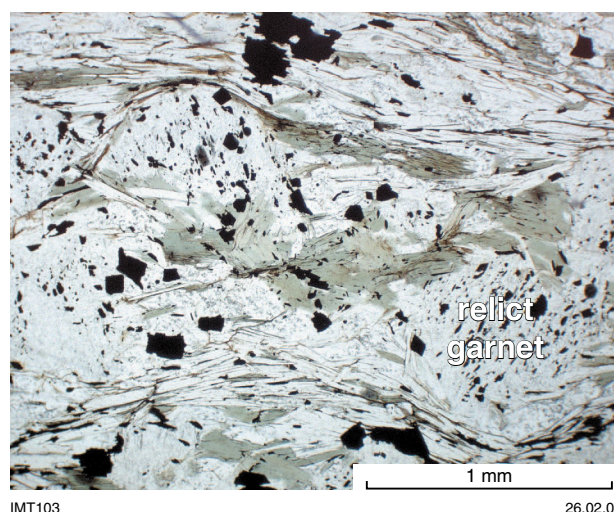
differences in stratigraphy and provenance may reflect contemporaneous activity along a proto-Halls Creek Fault (Tyler et al., in prep.b).

Outcrops of variably deformed sandstone, conglomerate, siltstone, and mudstone (*Pk*) occur as strips along the Alice Downs Fault in the northwestern corner of DIXON. These are up to 2 km long, and 300 to 400 m wide. A 21 km-long strip of massive to amygdaloidal basalt and basaltic breccia (*Pkb*) reaches up to 2 km in width along the Halls Creek Fault. A layer of carbonate (*Pkc*) is present within the basalt unit, adjacent to the Halls Creek Fault at the western edge of DIXON.

## Mesoproterozoic Yampi Orogeny

The Mesoproterozoic Yampi Orogeny was recognized in the King Leopold Orogen in the west Kimberley region by Tyler and Griffin (1990, 1993) and by Griffin et al. (1993), and is equivalent to  $D_5$  of Griffin and Tyler (1992) in the Halls Creek Orogen. Structures assigned to this event were referred to by Warren (1997) as  $D_3$  and by Blake et al. (1999) as  $D_Y$ .

The system of regional-scale, north-northeasterly trending sinistral faults and easterly trending dextral faults in the Halls Creek Orogen affects rocks as young as Devonian (Dow and Gemuts, 1969; Plumb and Gemuts, 1976; Tyler et al., 1995; Thorne and Tyler, 1996). However, Dow and Gemuts (1969) noted that younger rocks were displaced less than older rocks, suggesting that the faults have long, complex histories. Direct dating of  $D_3$  faults in the Halls Creek Orogen is not available, but K–Ar dating by Shaw et al. (1992) placed constraints of between  $1475 \pm 12$  Ma and  $999 \pm 9$  Ma on the Yampi Orogeny in the King Leopold Orogen.



**Figure 15.  $S_4$  schistosity wrapping ovoid patches of sericite intergrown with iron oxide and relict garnet. Curvilinear trails of iron oxide may be preserved from an original  $M_{1/2}$  garnet porphyroblast (GSWA 108407, plane-polarized light)**

Tyler et al. (1995) suggested that the pattern of strike-slip faulting was controlled by major northeasterly trending structures that developed during the Palaeoproterozoic, and whose position is now marked by the zone boundaries in the Lamboo Complex. The current fault pattern was interpreted to have developed first as ductile structures in the Mesoproterozoic, accompanying northeasterly directed folding and thrusting in the King Leopold Orogen. Later Neoproterozoic and Palaeozoic reactivations of the faults were more brittle.

In the Halls Creek Group in the Eastern zone, Warren (1997) recognized northerly trending, steeply dipping faults. On their eastern side are narrow zones, up to 1 km wide, of open to tight folds with axial surfaces parallel to the faults, and with variable plunges. D<sub>3</sub> and D<sub>4</sub> structures are overprinted, with their lineations reoriented and the earlier fabrics crenulated to produce pencil slates. In the vicinity of Grants Peak, Warren (1997) suggested that large-scale sheath folding could be related to strike-slip movements between two northerly to north-northeasterly trending D<sub>5</sub> faults. Small-scale sheath folds are present locally in the Maude Headley Member. Warren (1997) also reported that metamorphic grade may be higher near D<sub>5</sub> faults with an increase in grain size and the development of phyllites from fine-grained sedimentary rocks. A zone of quartz–chlorite–calcite veins occurs adjacent to a D<sub>5</sub> fault near the Slinkey Hill prospect.

## Neoproterozoic Wolfe Creek Basin

Neoproterozoic rocks form a narrow strip running north–south through the central part of DIXON, and are represented by the Ruby Plains, Duerdin, and Albert Edward Groups, all of which were deposited in the Wolfe Creek Basin (Shaw et al., 1994; Tyler and Hocking, 2001; equivalent to the ‘Wolfe Basin’ of Blake et al., 1997, 1999). On DIXON, the Ruby Plains Group unconformably overlies the Palaeoproterozoic Halls Creek Group, while the glaciogenic Duerdin Group unconformably overlies either the Halls Creek Group or the Ruby Plains Group. The Albert Edward Group conformably overlies the Duerdin Group, and is overlain unconformably by the Cambrian Antrim Plateau Volcanics. The Ruby Plains Group has been equated with the c. 830 Ma Supersequence 1 of the Centralian Superbasin of Walter et al. (1995), following identification within it (Grey and Blake, 1999) of the stromatolite *Linella avis* (Krylov 1967). Previously the rocks now mapped as Neoproterozoic Ruby Plains Group on DIXON had been correlated with the Mesoproterozoic Mount Parker Sandstone and Bungle Bungle Dolomite (Dow and Gemuts, 1967).

Coates and Preiss (1980) equated the combined Duerdin and Albert Edward Groups with the c. 610 Ma Marinoan Glaciation in South Australia. However, Grey and Corkeron (1998), on the basis of stromatolite biostratigraphy, suggested that the Marinoan Glaciation is represented by the Fargoo and Moonlight Valley Tillites only, with the Duerdin Group and the lower Albert Edward Group equivalent to Supersequence 3 of the

Centralian Superbasin (Walter et al., 1995; Plumb, 1996; Corkeron et al., 1996; Grey and Corkeron, 1998; Corkeron and George, 2001). Rocks in the upper part of the Albert Edward Group, above and including the Boonall Dolomite, may represent at least the lower part of Supersequence 4 (Grey and Corkeron, 1998).

## Ruby Plains Group

The Ruby Plains Group consists of three formations: the Mount Kinahan Sandstone, the Eliot Range Dolomite, and the Illjarra Sandstone (Blake et al., 1997, 1999). Only the lower two units are exposed on DIXON (Table 3). They are equivalent to the c. 830 Ma Supersequence 1 of the Centralian Superbasin and probably represent intertidal, fluvial, lacustrine, and shallow marine sediments (Walter et al., 1995; Grey and Blake, 1999; Blake et al., 1999).

### Mount Kinahan Sandstone (*EPk*)

Outcrops of the Mount Kinahan Sandstone (*EPk*) are discontinuous and are restricted to a zone between two sets of northeasterly trending faults in the central part of the southern half of DIXON. Previously these outcrops were mapped as either Mount Parker Sandstone or as Mount Forster Sandstone (Dow and Gemuts, 1967). Stromatolite biostratigraphy indicates that the unit cannot be correlated with the Mount Parker Sandstone in the Osmand Range to the north (Grey and Blake, 1999). The most northerly outcrop is overlain by the Moonlight Valley Tillite, and therefore cannot be the stratigraphically higher Mount Forster Formation (Warren, 1997). A third exposure is within a fault-bounded thrust sheet 3.5 km north of Mount Forster. Other exposures of ‘Mount Parker Sandstone’ shown by Dow and Gemuts (1967) have been identified as Olympio Formation by Warren (1997).

The Mount Kinahan Sandstone forms prominent cuestas unconformably overlying tightly folded Olympio Formation rocks. On HALLS CREEK to the south it has a maximum thickness of 150 m (Blake et al., 1999). On DIXON it consists of up to 200 m of medium-grained, medium- to thick-bedded, cross-bedded, quartz sandstone.

### Eliot Range Dolomite (*EPi*)

Carbonate rock of the Eliot Range Dolomite (*EPi*) outcrops within a thrust slice, 4 km north of Mount Forster. Blake et al. (1999) described the unit on HALLS CREEK as consisting of thin- to thick-bedded and locally brecciated dolomitic mudstone, siltstone, and sandstone with thin bands and lenses of nodular black chert present in places. Stromatolites are common locally.

### Illjarra Sandstone (*EPj*)

The Illjarra Sandstone (*EPj*) is not exposed on DIXON, but is shown on the cross section. It is exposed on HALLS CREEK to the south where it consists of lithic sandstone, with siltstone and dolomitic sandstone and mudstone as minor components (Blake et al., 1999).

Table 3. Stratigraphy of the Palaeoproterozoic to Palaeozoic sedimentary rocks on Dixon<sup>(a)</sup>

<i>Basin</i>	<i>Group</i>	<i>Formation</i>	<i>Thickness (m)</i>	<i>Lithology</i>
Ord Basin	Mahony Group	Glass Hill Sandstone ( <i>DMg</i> )	200	Pebbly quartz sandstone, conglomerate, siltstone
		~~~~~unconformity/disconformity~~~~~		
	Goose Hole Group	Elder Subgroup		
		Overland Sandstone ( <i>EGo</i> )	190	Lithic arkose
		Eagle Hawk Sandstone ( <i>EGe</i> )	10	Feldspathic sandstone, siltstone
		Negri Subgroup		
		Panton Formation ( <i>EGp</i> )	24	Siltstone and mudstone; feldspathic sandstone and limestone
		Linnekar Limestone ( <i>EGl</i> )	124	Limestone, shale; chert; stromatolites and macrofossils
		Nelson Shale ( <i>EGn</i> )	100	Siltstone and mudstone; feldspathic sandstone
		Headleys Limestone ( <i>EGh</i> )	50	Limestone; chert; stromatolites
		~~~~~		
		Antrim Plateau Volcanics ( <i>Ca</i> )	340	Massive and amygdaloidal, locally porphyritic basalt and basaltic breccia; sandstone, siltstone; stromatolitic chert
		Blackfella Rockhole Member ( <i>Car</i> )	<130	Basalt and basaltic breccia
		Bingy Bingy Member ( <i>Cab</i> )	<140	Glomeroporphyritic basalt
		~~~~~unconformity/disconformity~~~~~		
Wolfe Creek Basin	Albert Edward Group	Nyuleless Sandstone ( <i>ELy</i> )	40	Quartz sandstone, lithic sandstone; siltstone and conglomerate
		Timperley Shale ( <i>ELj</i> )	1 000	Mudstone, siltstone; sandstone
		Boonall Dolomite ( <i>ELb</i> )	30–60	Laminated dolomite, dolorudite; mudstone
		Elvire Formation ( <i>ELe</i> )	60	Mudstone; quartz sandstone
		Mount Forster Sandstone ( <i>ELo</i> )	100	Quartz sandstone; pebbly sandstone and conglomerate
		~~~~~disconformity~~~~~		
	Duerdin Group	Ranford Formation ( <i>PEo</i> )	650	Siltstone and mudstone; feldspathic wacke, lithic sandstone, quartz sandstone, dolomitic sandstone and dolomite
		Jarrad Sandstone Member ( <i>PEoj</i> )	60	Dolomitic sandstone, and quartz sandstone, siltstone, and mudstone
		Moonlight Valley Tillite ( <i>PEm</i> )	0–>10	Matrix-supported, polymictic pebble to boulder conglomerate, sandstone; larger clasts polished and striated locally
		~~~~~unconformity/disconformity~~~~~		
		Fargoo Tillite ( <i>PEf</i> )	52	Matrix-supported pebble to boulder conglomerate, sandstone; clasts polished and striated locally
		~~~~~unconformity/disconformity~~~~~		
	Ruby Plains Group	Illjarra Sandstone	–	Lithic sandstone, minor siltstone and dolomite (subsurface only)
		Eliot Range Dolomite ( <i>EPe</i> )	–	Dolomitic mudstone, siltstone and sandstone
		Mount Kinahan Sandstone ( <i>EPk</i> )	200	Quartz sandstone
		~~~~~unconformity~~~~~		
Red Rock Basin		Red Rock Formation ( <i>EK, EKc, EKb</i> )	–	Lithic quartz sandstone, feldspathic quartz sandstone, pebbly sandstone, conglomerate, siltstone, mudstone, basalt, basaltic breccia

SOURCE: (a) after Dow and Gemuts, 1969; Mory and Beere, 1988; Blake et al., 1997, 1999)

## Duerdin Group

The Duerdin Group on DIXON consists of three formations: the Fargoos Tillite, the Moonlight Valley Tillite and the Ranford Formation (Dow and Gemuts, 1969; Table 3). The Ranford Formation contains the Jarrad Sandstone Member. The group consists of glaciogene rocks that are equivalent to the c. 610 Ma Marinoan Glaciation and it is correlated with the lower part of Supersequence 3 of the Centralian Superbasin (Plumb, 1996; Walter et al., 1995; Grey and Corkeron, 1998).

Dow and Gemuts (1969) considered that the Fargoos Tillite and the overlying Moonlight Valley Tillite were deposited in a marine environment from a floating ice sheet. However Plumb and Gemuts (1976) considered that the main tillites were subglacial deposits onto bedrock at or near the edge of a marine basin. Plumb (1981) presented a model involving marine transgression accompanying glacial retreat.

### Fargoos Tillite (*PEf*)

The Fargoos Tillite (*PEf*) on DIXON outcrops to the west of the Dixon Range where it unconformably overlies tightly folded Olympio Formation. In this area the Fargoos Tillite is disconformably overlain by the Moonlight Valley Tillite. Sedimentation and subsequent erosion may have been controlled by an adjacent northeasterly trending fault (Warren, 1997). The unit here is 52 m (170 feet) thick and consists of 3 m of a basal medium-grained quartz sandstone, overlain by 12 m of boulder conglomerate, 6 m of dolomitic sandstone, and 31 m of interbedded shale, siltstone, and quartz sandstone, which may be equivalent to the Frank River Sandstone (Dow and Gemuts, 1969). The boulder conglomerate is composed of well-rounded boulders of quartz, quartzite, dolomite, and chert, which are rarely polished and striated, set in a matrix of dolomitic sandstone.

The Fargoos Tillite in the Osmand Range to the north of DIXON has been interpreted as the deposit of a terrestrial, or at least grounded, mountain-fed glacier. It is overlain there by the probably fluvio-glacial Frank River Sandstone (Plumb, 1981). Clasts were derived from the adjacent Lamboo Complex, which was probably ice-capped land.

### Moonlight Valley Tillite (*PEm*)

The Moonlight Valley Tillite (*PEm*) outcrops discontinuously, resting unconformably on the Olympio Formation and stepping onto the Mount Kinahan Sandstone and the Fargoos Tillite across northeasterly trending faults. This relationship suggests a period of active faulting and erosion prior to its deposition. It is overlain conformably by the Ranford Formation. Warren (1997) reported the occurrence of a fragment of glaciated pavement on the underlying Olympio Formation near AMG 315900E 8046000N. The tillite is poorly exposed, with its presence indicated by a thin veneer of rounded quartzite cobbles, and by the distinctive 'cap dolomite', a less than 10 m-thick, cream or pale pink flaggy dolomite at the top of the tillite (Warren, 1997). North of Blue Hole

Yards, a sandstone with a calcareous matrix replaces the dolomite. In outcrop the tillite consists of predominantly quartzite clasts in a clay matrix (Warren, 1997). Other clasts include lithologies recognizable as coming from the Olympio Formation.

The Moonlight Valley Tillite has been interpreted by Plumb (1981) as being deposited in hollows on an irregular surface from ablation of a grounded, and locally floating, retreating ice sheet. Ice movement was from ice-capped land to the north or northeast with clasts being derived from rocks in the Victoria River Basin. The widespread deposition of the unit, which extends from Kununurra to south of Halls Creek, suggests a broad, low-relief continental ice sheet.

### Ranford Formation (*PEo*)

The Ranford Formation (*PEo*) either conformably overlies the Moonlight Valley Tillite or steps onto the underlying Mount Kinahan Sandstone or the Olympio Formation. On DIXON it is conformably overlain by the Mount Forster Sandstone of the Albert Edward Group. It can consist of 650 m of thin-bedded siltstone, shale, mudstone, and fine-grained quartz sandstone, with thin beds of dolomitic sandstone and dolomite, and thin- to thick-bedded greywacke (Dow and Gemuts, 1969; Blake et al., 1999). Load casts, graded bedding, convolute bedding, ripple-marks, and low-angle cross-bedding are common. Sheppard et al. (1999) reported palaeocurrents from north to south on Bow.

The Ranford Formation represents a deepening marine shelf or lake, following melting of the ice sheets (Plumb, 1993).

### Jarrad Sandstone Member (*PEoj*)

The Jarrad Sandstone Member (*PEoj*) overlies the Moonlight Valley Tillite north of the Ord River. One outcrop on the published map (Tyler et al., 1998d; AMG 421500E 8060000N) has been wrongly labelled as *PLj*. It consists of 60 m of dolomitic sandstone, with rare glacial erratics in sandstone lenses near the base (Dow and Gemuts, 1969). It probably represents a migrating delta fan (Plumb, 1993; Blake et al., 1999).

## Albert Edward Group

The Albert Edward Group consists of five formations: the Mount Forster Sandstone, the Elvire Formation, the Boonall Dolomite, the Timperley Shale, and the Nyuleless Sandstone (Dow and Gemuts, 1969; Table 3). Glaciogene rocks are not present, nevertheless the Boonall Dolomite is correlated with the glaciogene Egan Formation of the Louisa Downs Group on the MOUNT RAMSAY 1:250 000 map sheet to the southwest (Plumb, 1996; Grey and Corkeron, 1998; Tyler et al., 1998a). The group is equivalent to the upper part of Supersequence 3 and at least the lower part of Supersequence 4 of the Centralian Superbasin (Walter et al., 1995; Grey and Corkeron, 1998).

## Mount Forster Sandstone (*PLo*)

On DIXON, the Mount Forster Sandstone (*PLo*) overlies the Ranford Formation disconformably, and is conformably overlain by the Elvire Formation, and unconformably overlain by the Antrim Plateau Volcanics. It consists of 100 m of fine- to coarse-grained quartz sandstone with abundant ripple marks and ubiquitous cross-bedding, and quartz pebble conglomerate, which forms prominent strike ridges and cuestas (Dow and Gemuts, 1969; Blake et al., 1999). Sheppard et al. (1999) reported palaeocurrents on Bow indicating that sediment transport was dominantly towards the south-southwest. Plumb (1993) interpreted deposition as taking place on a shallow marine shelf, passing up into tidal and alluvial flats.

## Elvire Formation (*PLe*)

The Elvire Formation (*PLe*) conformably overlies the Mount Forster Sandstone and is overlain conformably by the Boonall Dolomite. It consists of 60 m of maroon and chocolate-brown shale and siltstone, with minor thin beds of fine- to medium-grained quartz sandstone representing deposition on a flood plain (Dow and Gemuts, 1969; Blake et al., 1997, 1999).

## Boonall Dolomite (*PLb*)

The Boonall Dolomite (*PLb*) forms low cuestas on the eastern side of the Albert Edward Range. It conformably overlies the Elvire Formation and is conformably overlain by the Timperley Shale. It consists of between 30 and 60 m of fine-grained dolomite with minor dolomitic conglomerate and dolomitic breccia, and may contain poorly preserved stromatolitic structures, including algal mats (Dow and Gemuts, 1969; Blake et al., 1999).

The unit is regarded as equivalent to the Egan Formation in the Louisa Downs Group, which represents deposition on a shallow, warm-water carbonate platform that was interrupted by glaciation (Corkeron and George, 2001).

## Timperley Shale (*PLj*)

The Timperley Shale (*PLj*) conformably overlies the Boonall Dolomite, and is overlain conformably by the Nyuleless Sandstone, and unconformably by the Antrim Plateau Volcanics. It consists of 1000 m of thinly bedded, green or dark-grey shale, siltstone, and mudstone deposited in a below-wave-base marine or lacustrine environment (Dow and Gemuts, 1969; Plumb, 1993; Blake et al., 1999).

## Nyuleless Sandstone (*PLy*)

The Nyuleless Sandstone (*PLy*) on DIXON is restricted to the southern edge of the sheet where it conformably overlies the Timperley Shale. The unit is unconformably overlain by the Antrim Plateau Volcanics. It consists of 40 m of fine- to medium-grained quartz sandstone deposited by braided streams (Dow and Gemuts, 1969; Plumb, 1993).

## Neoproterozoic King Leopold Orogeny

The King Leopold Orogeny (Tyler and Griffin, 1993; Griffin et al., 1993) produced extensive, well-exposed, west-northwesterly trending folding and thrusting in the King Leopold Ranges, along the southwestern margin of the Kimberley Basin (Griffin and Myers, 1988; Tyler and Griffin, 1990), together with the reactivation of shear zones in the Hooper Complex (Tyler et al., 1991; Shaw et al., 1992). Deformation affected Neoproterozoic glaciogene rocks, and Shaw et al. (1992) obtained K–Ar ages of c. 560 Ma from reactivated shear zones and interpreted this date as the age of deformation. Coates and Preiss (1980) and Plumb (1981) recalculated and reinterpreted Rb–Sr data from Bofinger (1967) and reported ages of 568 Ma and  $576 \pm 80$  Ma from the McAlly Shale of the Louisa Downs Group, equivalent to the Timperley Shale of the Albert Edward Group. These ages were interpreted as reflecting a metamorphic cleavage-forming event, which was correlated by Shaw et al. (1992) with the King Leopold Orogeny. Thrusting in the west Kimberley region was linked to sinistral strike-slip faulting in the east Kimberley region (Tyler and Griffin, 1990; Tyler et al., 1991). Deformation occurred at about the same time as the Paterson Orogeny at the eastern edge of the Pilbara Craton and the Petermann Ranges Orogeny in central Australia (Myers et al., 1996; Tyler et al., 1998c).

Small-scale structures that can be attributed to the King Leopold Orogeny ( $D_6$ ;  $D_L$  of Blake et al., 1997, 1999, 2000) have not been recognized on DIXON. On HALLS CREEK and RUBY PLAINS to the south, large-scale fold interference patterns are present within Neoproterozoic rocks between generally west-northwesterly trending King Leopold Orogeny structures and northeasterly trending late Palaeozoic Alice Springs Orogeny structures (Blake et al., 1997, 1999, 2000). The King Leopold Orogeny structures appear to die out in intensity northwards. Plunge reversals of  $D_4$  folds in the Olympio Formation across west-northwesterly trending axes (Fig. 3) may be related to  $D_6$ . Uplift and erosion at this time is indicated by the unconformity at the base of the Cambrian Antrim Plateau Volcanics.

## Palaeozoic Ord Basin

Palaeozoic sedimentary and volcanic rocks belonging to the Ord Basin are exposed in the eastern half of DIXON. The Ord Basin lies to the east of the Halls Creek Fault and contains rocks of latest Early to ?Late Cambrian and Late Devonian age. The following descriptions are based on the work of Mory and Beere (1985, 1988) who extensively revised and redefined the stratigraphy from that of Dow and Gemuts (1967).

## Lower Cambrian Antrim Plateau Volcanics (*€a*)

The Antrim Plateau Volcanics (*€a*) unconformably overlie the Neoproterozoic Albert Edward Group rocks, progress-



ively stepping down from the Nyuleless Sandstone to the Mount Forster Sandstone from north to south across DIXON. They are conformably overlain by the Middle Cambrian Headleys Limestone. On DIXON the Antrim Plateau Volcanics include the Blackfella Rockhole Member and the Bingy Bingy Member. The unit is 340 m thick south of the abandoned Turner Homestead and thins to the southeast (Mory and Beere, 1988). Hanley and Wingate (2000) gave a SHRIMP U–Pb zircon date of  $513 \pm 12$  Ma for a dolerite dyke in the west Kimberley, which they interpreted as a feeder to the Antrim Plateau Volcanics. They suggested that lava flows must have originally extended across at least part of the Kimberley Basin. The Antrim Plateau Volcanics are part of the Kalkarinji continental flood basalt province, Australia's largest, which originally covered an area of 300 000 km<sup>2</sup> and extended as far east as the Northern Territory – Queensland border (Hanley and Wingate, 2000; Glass, 2002). The thickest sections are in the Osmand Range, suggesting that the major eruptive centres may have been to the north of DIXON.

The unit consists predominantly of fine- to medium-grained, massive, vesicular, amygdaloidal and porphyritic tholeiitic basalt, interbedded with minor basaltic breccia, siltstone, sandstone, tuff, and stromatolitic chert (Bultitude, 1971; Mory and Beere, 1988). Lava flows range from 5 to 80 m thick, averaging 25 to 35 m. The lavas consist of plagioclase, clinopyroxene, and opaques, within a matrix of devitrified glass. Flow tops are highly vesicular or amygdaloidal, with amygdales filled with coarse quartz, chert, calcite, agate, chlorite, prehnite, and pumpellyite. Pipe vesicles may occur at the bottoms of flows. The presence of prehnite and pumpellyite suggests depths of burial for the lavas of between 5 and 7 km (Mory and Beere, 1988).

### Bingy Bingy Member (€ab)

The Bingy Bingy Member (€ab) outcrops within the Antrim Plateau Volcanics in the southeastern corner of DIXON. It consists of a massive fine- to medium-grained glomeroporphyritic basalt flow with clots of plagioclase crystals up to 1 cm in diameter. The unit reaches a maximum thickness of 130 m to the northeast of DIXON near Chara Rockhole on LINACRE (Mory and Beere, 1988).

### Blackfella Rockhole Member (€ar)

The Blackfella Rockhole Member (€ar) occurs at or near the top of the Antrim Plateau Volcanics on DIXON. It consists of a number of very fine grained lava flows with basaltic breccias at their tops. The unit reaches a maximum thickness of 140 m to the northeast of DIXON near Chara Rockhole on LINACRE (Mory and Beere, 1988).

## Middle to Upper Cambrian Goose Hole Group

The Goose Hole Group (Mory and Beere, 1985, 1988) incorporates all sedimentary rocks within the Ord Basin that conformably overlie the Antrim Plateau Volcanics and are considered to be of Cambrian age. On DIXON it is

exposed in the eastern half of the map sheet, and comprises the Middle Cambrian Negri Subgroup, which includes the Headleys Limestone, the Nelson Shale, the Linnekar Limestone, and the Panton Formation, and the overlying Upper Cambrian Elder Subgroup, which includes the Eagle Hawk Sandstone and the Overland Sandstone. It is unconformably overlain by the Upper Devonian Glass Hill Sandstone of the Mahony Group. The entire group is 630 m thick west of the Dixon Range, with the Negri Subgroup being 440 m thick and the Elder Subgroup 190 m thick (Mory and Beere, 1988, fig. 14).

The Negri Subgroup was deposited in laterally continuous intertidal to shallow subtidal environments in an intracratonic basin on a stable basement. The upper part of the Linnekar Limestone represents a basin-wide marine incursion. A second marine incursion from the northwest occurred during the deposition of the Panton Formation but did not reach the southwestern part of the basin, which includes DIXON. The Elder Subgroup was deposited on intertidal sand and mudflats that were succeeded by a braided fluvial system flowing from a low-relief hinterland to the northeast.

## Negri Subgroup

### Headleys Limestone (€Gh)

The Headleys Limestone (€Gh) on DIXON conformably overlies the Antrim Plateau Volcanics and is conformably overlain by the Nelson Shale. The unit consists of 50 m of grey, laminated or massive micrite with chert nodules, and locally contains simple, non-branching stromatolites.

### Nelson Shale (€Gn)

The Nelson Shale (€Gn) conformably overlies the Headleys Limestone, and is overlain conformably by the Linnekar Limestone. On DIXON it consists of 100 m of purple siltstone with minor thin beds of sandstone and micrite. The cyanobacteria or calcimicrobe *Girvanella* has been recorded from the Nelson Shale (Dow, 1980).

### Linnekar Limestone (€Gl)

The Linnekar Limestone (€Gl) conformably overlies the Nelson Shale and is conformably overlain by the Panton Formation. On DIXON it consists of 24 m of fossiliferous limestone and shale. The presence of the trilobite *Redlichia forresti* has been interpreted as indicating an early Middle Cambrian age (Öpik, 1967). *Girvanella*, the narrow, conical shell of the holoplanktonic mollusc *Biconulites hardmani*, and unnamed stromatolites are also present (Mory and Beere, 1988).

### Panton Formation (€Gp)

The Panton Formation (€Gp) conformably overlies the Linnekar Limestone and is conformably overlain by the Eagle Hawk Sandstone of the Elder Subgroup, or unconformably overlain by the Glass Hill Sandstone of the Upper Devonian Mahony Group. On DIXON it consists of 124 m of purple siltstone, flaggy sandstone, and limestone

(Mory and Beere, 1988). Locally the Pantan Formation may be highly fossiliferous, containing the Middle Cambrian assemblage of the trilobites *Redlichia* and *Xystridura* (documented by Öpik, 1967; Jell, 1983). Also present (Traves, 1955) are the brachiopods *Billingsella* and *Wimanella*, girvanellids, stromatolites, and *Biconulites hardmani*.

## Elder Subgroup

### **Eagle Hawk Sandstone (€Ge)**

The Eagle Hawk Sandstone (€Ge) conformably overlies the Pantan Formation, and is conformably overlain by the Overland Sandstone, or unconformably overlain by the Glass Hill Sandstone of the Upper Devonian Mahony Group (Mory and Beere, 1988). On DIXON it consists of 190 m of red, fine-grained, trough cross-bedded to parallel laminated, medium- to thin-bedded, micaceous, arkosic sandstone and minor siltstone and mudstone. Trilobite tracks are present on bedding planes, which also show wave-generated ripples and sand-filled desiccation cracks.

### **Overland Sandstone (€Go)**

The Overland Sandstone (€Go) conformably overlies the Eagle Hawk Sandstone and is unconformably overlain by the Glass Hill Sandstone of the Upper Devonian Mahony Group. On DIXON its outcrop is restricted to the east of the Ord River. It consists of up to 10 m of white to fawn, fine- to medium-grained, clayey, lithic arkose and sandstone. Lithic fragments make up to 20% of the rock and include quartz-mica schist, fine-grained metasedimentary rock, and quartzite. The sandstone is medium to thin bedded and trough cross-bedded, planar cross-bedded or parallel laminated.

## Upper Devonian Mahony Group

The Mahony Group (Mory and Beere, 1985, 1988) on DIXON consists of the Glass Hill Sandstone, which unconformably overlies the Elder Subgroup, and locally the Negri Subgroup of the Cambrian Goose Hole Group. Correlation of the Mahony Group with the Cockatoo Group in the Bonaparte Basin to the north suggests a Late Devonian, Frasnian age (Mory and Beere, 1988).

Sediment in the Mahony Group was derived mainly from a highland in the Osmand Range. Initially braided streams and rivers flowed to the southwest, parallel to the highland. Contemporaneous eolian sandstone indicates an arid climate. Later movement on the east-northeasterly trending Osmond Fault in the Osmand Range resulted in the development of alluvial fans passing southwards into alluvial plain deposits, and then fluvial deposits where broad, shallow rivers flowed southeast, transverse to the fans.

### **Glass Hill Sandstone (DMg)**

The Glass Hill Sandstone (DMg) on DIXON unconformably overlies the Eagle Hawk and Overland Sandstones of

the Elder Subgroup, and locally the Pantan Formation of the Negri Subgroup of the Cambrian Goose Hole Group (Mory and Beere, 1985, 1988). Overlying strata are not known; however, the interpretation of the Piccaninny Structure to the north as a deeply eroded meteorite impact structure (Beere, 1983), implies the erosion of several kilometres of strata from above the Glass Hill Sandstone forming the Bungle Bungle Range on TURKEY CREEK.

The Glass Hill Sandstone is the only formation of the Mahony Group outcropping on DIXON. It is 200 m thick at its type section at the south end of the Dixon Range, and it is dominated by pebbly quartz sandstone, with minor siltstone and conglomerate. Pebbly sandstone is friable, medium to fine grained, and well sorted. Pebbles generally comprise from 1% to 5% of the rock. They are up to 3 cm in diameter with rare cobbles up to 15 cm, and consist of quartzite and locally abundant shale intraclasts. Medium trough and planar cross-bedding are dominant with minor, thick parallel bedding and low-angle cross-bedding. Siltstone occurs as thin lenses and is massive, rippled and contains mudcracks. Conglomerate is parallel and trough cross-bedded in thin to medium lenses.

## Palaeozoic Alice Springs Orogeny

The youngest phase of major faulting and folding (D<sub>7</sub>; D<sub>A</sub> of Blake et al., 1997, 1999, 2000) in the east Kimberley region is attributed to the Late Devonian to Carboniferous (400–300 Ma) Alice Springs Orogeny (Shaw et al., 1991; Tyler et al., 1995; Thorne et al., 1999). On DIXON, the Cambrian rocks of the Antrim Plateau Volcanics and the Goose Hole Group, and the Devonian rocks of the Glass Hill Sandstone, are folded into a gentle to open, large-scale, northeasterly plunging syncline, which represents the southwesterly closure of the regional-scale Hardman Syncline (Fig. 3). The fold is bounded by thrusting within the Osmand Range to the north and can be related to a compression direction consistent with regional-scale sinistral strike-slip movements on the Halls Creek Fault system (Thorne and Tyler, 1996). The folding represents the final stages of deformation. Initially a depositional basin was produced by flexural subsidence to the south of the Osmond Fault, with the Late Devonian alluvial fan, alluvial plain, and braided stream deposits of the Mahony Group being deposited in response to the initiation of southeasterly directed thrusting (Mory and Beere, 1988; Thorne and Tyler, 1996).

In the Albert Edward Range and to the west of the Dixon Range, west-southwesterly directed folding and thrusting is developed, which becomes more intense towards an easterly trending dextral fault on HALLS CREEK to the south (Blake et al., 1999). The folding and thrusting occurs locally between easterly to north-northeasterly trending faults that show dextral offset. The deformation may reflect compression between originally easterly trending dextral fault structures, antithetic to regional-scale sinistral movement on the Halls Creek Fault. The faults were rotated during continued sinistral movements.

## Quartz veins (*q*)

Quartz veins (*q*) are not widespread on DIXON. A large mass of vein quartz forms a prominent outcrop adjacent to a splay of the Halls Creek Fault within the Tickalara Metamorphics (AMG 403400E 8056600N). Quartz veins are present along a fault within the Olympio Formation southeast of the Bay of Biscay Hills.

## Cainozoic surficial deposits

Semiconsolidated low-angle slope deposits, scree and rubble (*Czc*) outcrop below scarps and in valleys, and consist of sand, gravel, conglomerate, and sedimentary breccia. Colluvial sand and gravel (*Czcv*) forms dissected valley-fill deposits above the present-day alluvium-filled drainage channels (*Qa*). Semiconsolidated and unconsolidated silt, sand, and gravel (*Czs*) covers valley floors and plains. Treeless black soil plains (*Czb*) formed by clay and silt cover broad flood plains adjacent to the larger creeks and rivers. These plains consist of black and dark grey-brown soils and expanding clays that produce cracking soils, and are largely developed over the Antrim Plateau Volcanics, the Nelson Shale, and the Pantom Formation. A landslide breccia (*Czx*) occurs below a scarp of Mount Forster Sandstone in the Albert Edward Range.

Calcrete (*Czk*) is restricted to an outcrop within alluvium and colluvium forming an older, dissected flood plain of the Ord River. Massive and pisolitic ferruginous duricrust (*Czl*) overlies outcrops of the Nelson Shale in the southeastern part of DIXON. Extensive consolidated and partly consolidated sandplain deposits (*Czn*) surround the outcrops of the Glass Hill Sandstone in the northeastern part of DIXON.

## Economic geology

The mineral occurrences and exploration potential of the east Kimberley region have been documented in detail by Sanders (1999) and by Hassan (2000). The following brief summary is based on open file exploration reports held in the WAMEX database (<http://www.doir.wa.gov.au/wamex/>) and summarized by Hassan (2000). Most of the occurrences described here do not appear on the published map sheet (Tyler et. al., 1998d), but they are shown on the 1:500 000 map accompanying Hassan (2000).

### Precious metal

#### Vein and hydrothermal — undivided

Warren (1994b,c, 1997) has suggested that gold in the Halls Creek Orogen may have been sourced from the A-type volcanics of the Maude Headley Member, with fluids circulating through reactivated  $D_{5/6/7}$  faults reconcentrating gold at favourable structurally controlled sites. Typically these sites are close to the Maude Headley Member, in the vicinity of the Biscay Formation —

Olympio Formation contact. Occurrences such as Slinkey Hill may be situated in the Olympio Formation just above the Maude Headley Member in a culmination produced by the interference of  $D_4$  folds with cross-folding produced during  $D_6$ .

At Slinkey Hill (AMG 407000E 8045500N) gold mining took place within the sandstones, siltstones, and mudstones of the Olympio Formation of the Halls Creek Group. Mineralization is present at the intersection of ladder-like quartz veins and the Slinkey Hill Fault, associated with chlorite–hematite–sericite–carbonate alteration. At Black Duck Creek D (AMG 408700E 8032800N) low-grade gold mineralization occurs in a large quartz vein and quartz stockwork associated with a northerly trending fault.

In the Dry Creek area a number of abandoned gold workings on quartz veins are present in sedimentary rocks of the Olympio Formation (Dry Creek 1 to 6, around AMG 394500E 8015400N) and in volcanic rocks of the Maude Headley Member (Kangaroo Hole, AMG 394700E 8015500N).

Gold and silver mineralization at Wills Creek B2 (AMG 401600E 8062600N) occurs within a pegmatitic quartz breccia vein in the Tickalara Metamorphics. At Wills Creek C2 (AMG 401100E 8060200N) gold mineralization occurs in thin limonitic quartz veins within amphibolite of the Tickalara Metamorphics.

### Regolith — alluvial to beach placers

Alluvial gold has been worked in the Dry Creek area. A number of other deposits and occurrences are known on DIXON, principally to the north of Slinkey Hill, and along creeks and rivers draining from areas of known bedrock mineralization in the Halls Creek Group.

### Base metal

#### Orthomagmatic mafic and layered mafic–ultramafic

The geology, mineralization, and economic potential of the mafic–ultramafic layered intrusions in the Lamboo Complex have been discussed in detail by Hoatson and Blake (2000). Copper, nickel, and gold mineralization occurs in the Tickalara Metamorphics at Wills Creek D (AMG 401900E 8062600N). Minor malachite staining and gossanous veins are associated with massive biotite pods in amphibolite after gabbro.

### Skarn

Base metal occurrences classified as skarns on DIXON are within calc-silicate and marble units of the Tickalara Metamorphics. These include copper as chrysocolla, malachite staining, and disseminated chalcopyrite at Sally Downs A (AMG 398600E 8063100N) and Wills Creek B4 (AMG 397800E 8052900N), zinc and silver in gossan at Wills Creek B5 (AMG 397800E 8052200N), and copper

and silver as malachite and chalcopyrite in association with quartz and tonalite veins at Wills Creek B6 (AMG 397000E 8051300N).

### **Stratabound volcanic and sedimentary — undivided**

The Antrim Plateau Volcanics form part of the Kalkarinji continental flood basalt province and have potential for the discovery of Noril'sk type nickel–copper sulfides and platinum group elements (Naldrett and Lightfoot, 1993).

At the Panton–Elvire copper prospect (AMG 416800E 8026100N), segregations of cuprite and chrysocolla up to 30 cm wide occur in a 5 m-thick zone in basaltic agglomerate. Mineralization occurs over a strike length of 5 km within the Antrim Plateau Volcanics.

At Panton River (gossan) 1 (AMG 394400E 8012900N) zinc mineralization occurs associated with gossanous carbonate rock in the upper part of the Biscay Formation.

### **Stratabound sedimentary — undivided**

Copper, zinc, lead, silver, (tin) mineralization was reported in a gossan in metasedimentary rocks of the Tickalara Metamorphics at Wills Creek A (AMG 401300E 8061500N).

### **Vein and hydrothermal — undivided**

Copper and zinc are associated with gossanous stringers within metasedimentary rocks of the Tickalara Metamorphics at Wills Creek B3 (AMG 402100E 8060400N). Finely disseminated sulfides and associated malachite staining occur within amphibolites at Ord (copper).

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## Appendix

### Gazetteer of localities on Dixon

<i>Locality</i>	<i>AMG coordinates</i>	
	<i>Easting</i>	<i>Northing</i>
Airstrip/helipad (Purnululu National Park)	426000	8058500
Bay of Biscay Hills	397500	8028000
Bellburn campsite (Purnululu National Park)	424700	8061000
Black Hills	410000	8062000
Black Point	411500	8062000
Blue Hole	420500	8058000
Blue Hole Yards	421500	8059100
Dixon Range	427000	8046000
Dry Creek	394500	8015400
Dry Swamp Yard	439500	8059500
Eight Mile Yard	431900	8020200
Grant Peak	395000	8032200
Hardman Range	431500	8024100
Monkey Yard	397300	8058000
Mount Forster	415100	8014100
Piccaninny Yard	437500	8049200
Seven Mile Yard	445300	8028100
Slinkey Hill	407000	8045500
The Island	437000	8039500
The Island Yard	430900	8041800
Turner Hill	431500	8024100
Turner Homestead (abandoned)	425000	8028000
Walardi campsite (Purnululu National Park)	425400	8062100



The Dixon 1:100 000 sheet lies within the central southern portion of the Dixon Range 1:250 000 sheet in the East Kimberley region. The mapped area falls within the Halls Creek Orogen, a major northeasterly trending orogenic belt developed in Palaeoproterozoic to Palaeozoic rocks. The oldest components lie within the Central and Eastern zones of the Lamboo Complex. Successively younger Neoproterozoic and Palaeozoic basins are exposed in the eastern and northeastern parts of the sheet, each separated from the previous basin suite by four successive orogenies. These Notes describe the lithology, geological history, and relationships of these successions, and the deformation and metamorphism associated with the four orogenies. Mineralization in the sheet area is also briefly outlined.

**These Explanatory Notes are published in digital format (PDF) and are available online at: [www.doir.wa.gov.au/gswa](http://www.doir.wa.gov.au/gswa).**

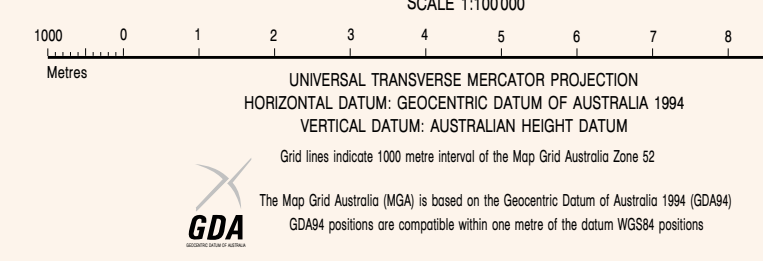
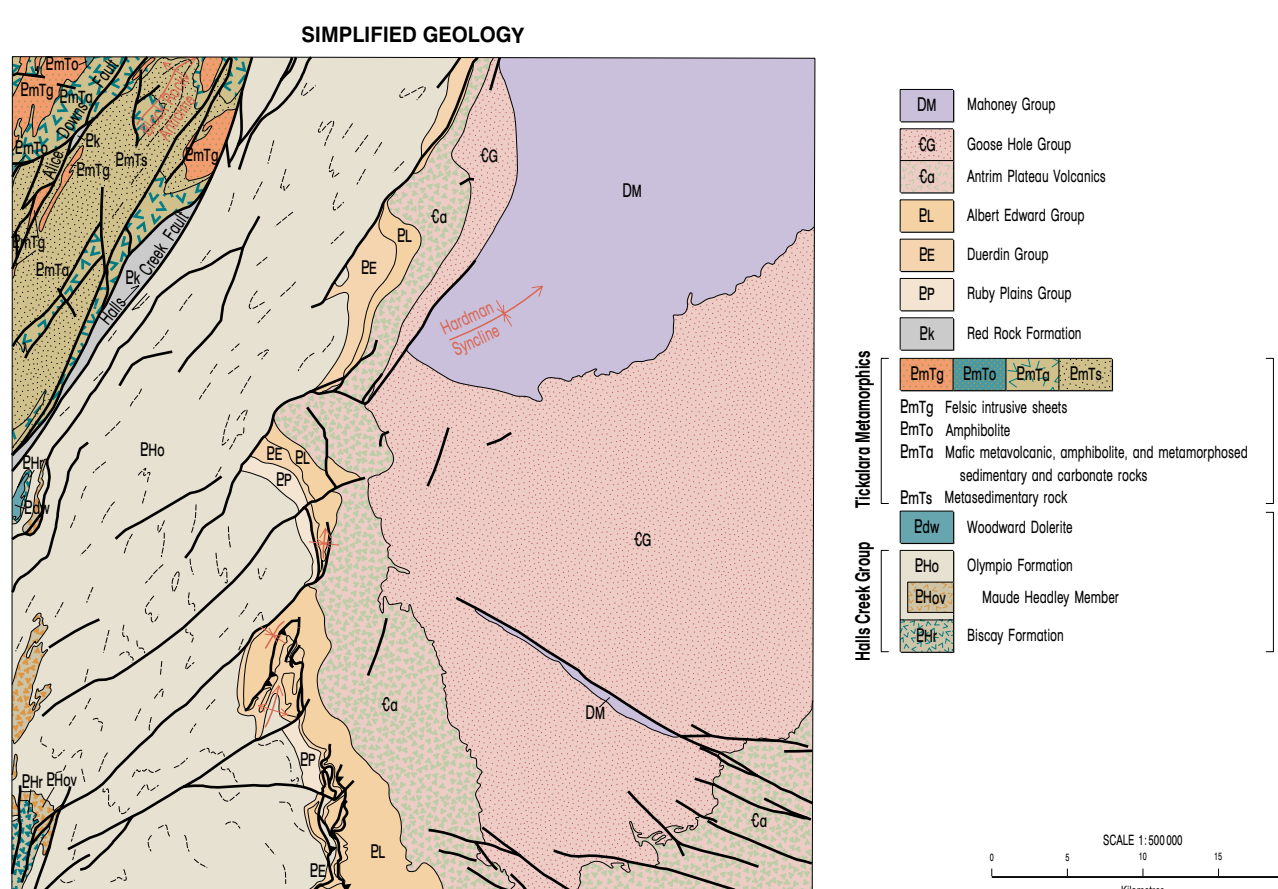
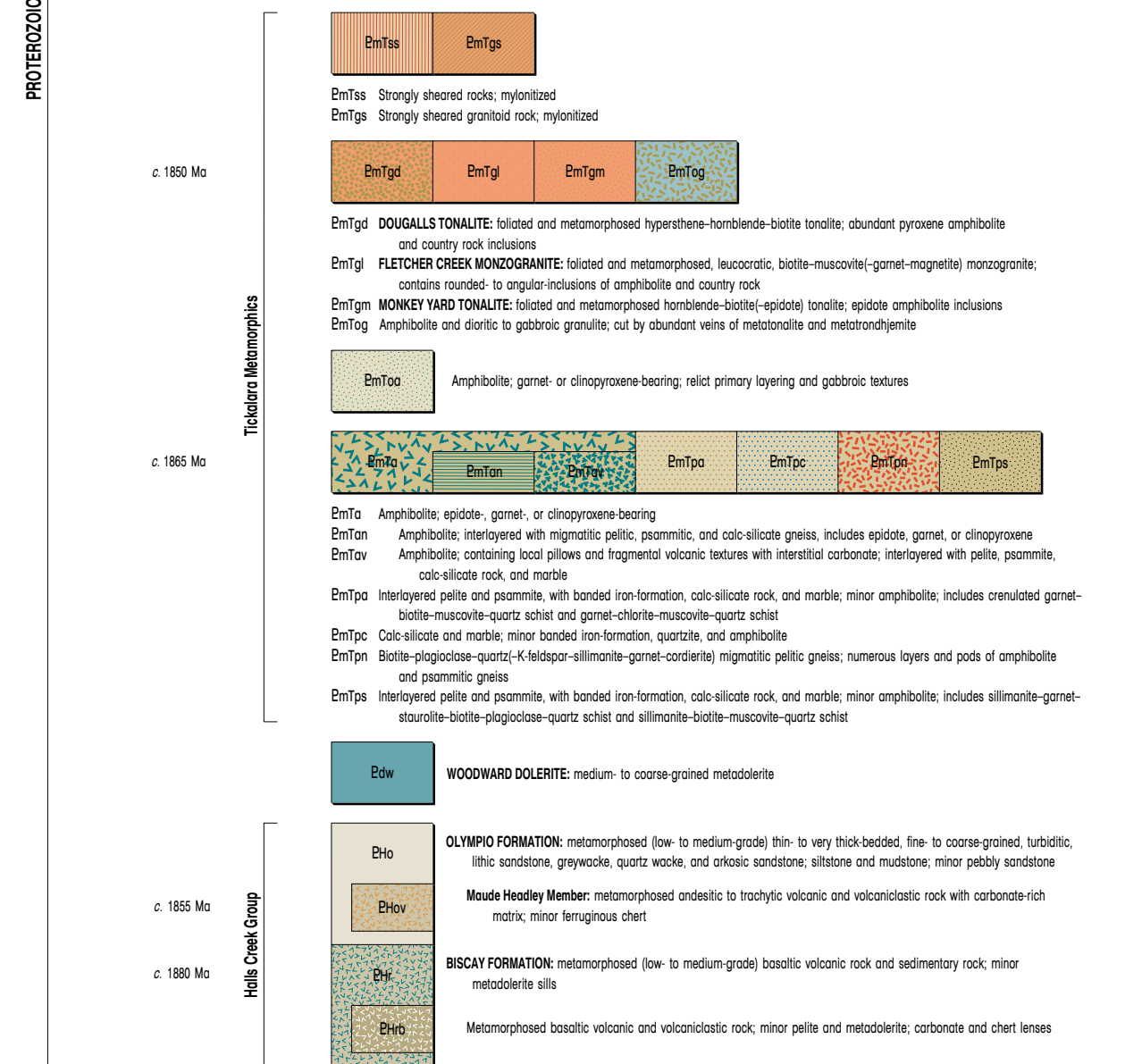
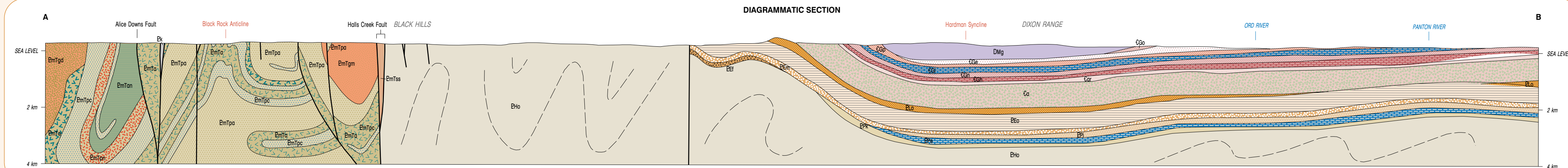
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**J. A. M. Thomas**, 1995-1997

Geology by **R. G. Warren** (AGSO), **M. T. Tyler** and  
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by **R. G. Warren** modified from **MGR**, **A. J. and BEERIE**, G., 1987,  
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 by **N. T. Taylor** and **L. Loon**

Topography by **E. Owen** and **C. Smith**

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by **LEIGH L. M. WARRISON** (AGSO) and **BLAKE**, D. H. 1968, DSO,  
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