EXPLANATORY NOTES

GOVERNMENT OF WESTERN AUSTRALIA

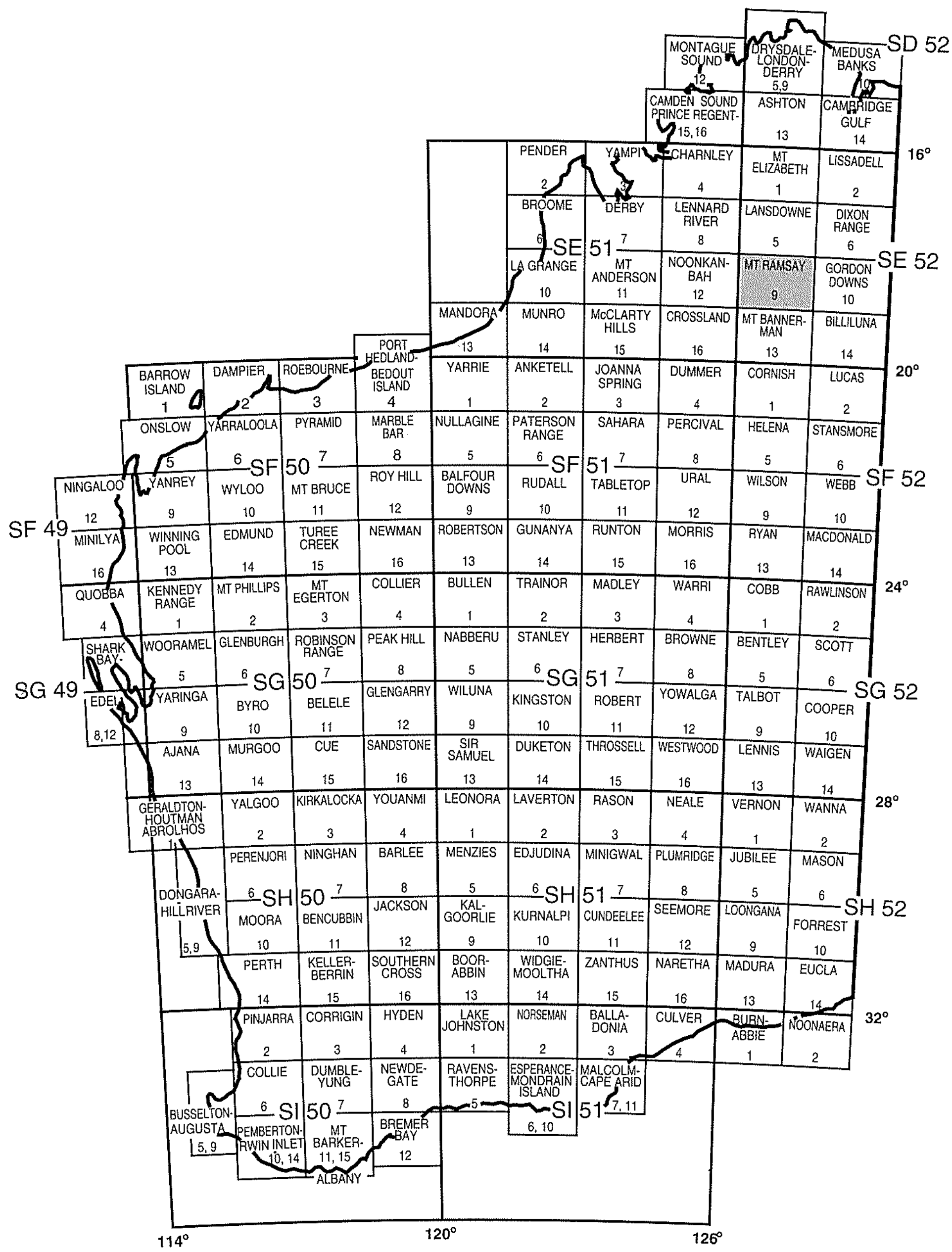
GEOLOGY OF THE ANGELO 1:100 000 SHEET

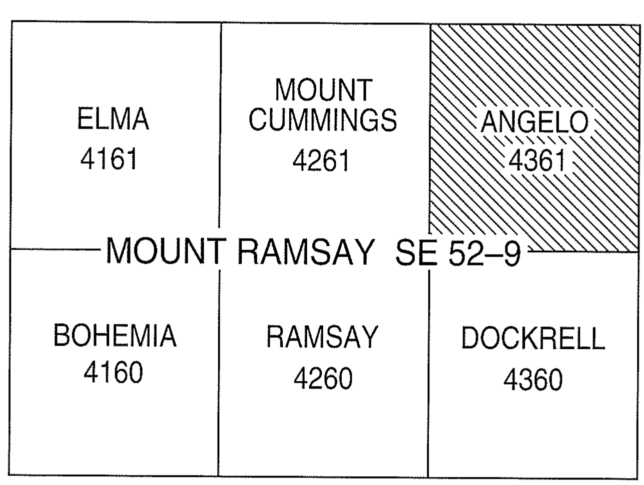
by T. J. Griffin, I. M. Tyler, K. Orth, and S. Sheppard

1:100 000 GEOLOGICAL SERIES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY





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by
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Cover photograph:

Thin quartz–feldspar veins developed within high-grade Marboo Formation hornfels, adjacent to the Neville Granodiorite. These may represent the onset of in situ partial melting within the contact aureole.

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Geology of the Angelo 1:100 000 sheet

by

T. J. Griffin, I. M. Tyler, K. Orth[1] and S. Sheppard

Abstract

The ANGELO 1:100 000 map sheet (SE52-9-4360) is bounded by latitudes 18°00' and 18°30'S and longitudes 127°00' and 127°30'E. The sheet lies entirely within the Halls Creek Orogen, a major north-easterly trending orogenic belt developed within the Proterozoic and 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. Palaeoproterozoic rocks of the c. 1910 to 1790 Ma Lamboo Complex share many features with convergent Phanerozoic plate margins associated with subduction of oceanic crust. In the Western zone of the Lamboo Complex, the c. 1870 Ma turbiditic metasedimentary rocks of the Marboo Formation were deformed and metamorphosed during the Hooper Orogeny, reflecting accretion of an island arc to the edge of the Kimberley Craton, before being intruded and contact metamorphosed by granitoid and gabbroic rocks of the c. 1865 to 1850 Ma Paperbark supersuite. The c. 1843 Ma felsic and mafic volcanic rocks of the Koongie Park Formation, which host significant VMS Zn–Pb–Cu(–Ag) deposits, occur in the Central zone of the Lamboo Complex. The Koongie Park Formation is intruded by the Lamboo Ultramafics. Turbiditic metasedimentary rocks forming the upper part of the c. 1880 to <1847 Ma Halls Creek Group occur in the Eastern zone of the Lamboo Complex.

The Western and Central zones of the Lamboo Complex on ANGELO were intruded by granitoid and gabbroic rocks of the c. 1835 to 1805 Ma Sally Downs supersuite. Deformation and metamorphism of the Marboo Formation and Paperbark supersuite granitoids produced the Amhurst Metamorphics in the Western zone during the Halls Creek Orogeny. This event reflects suturing of the Kimberley and North Australian Cratons at c. 1820 Ma, and also affects some of the granitoids, and the Koongie Park Formation in the Central zone, and the Halls Creek Group in the Eastern zone.

The c. 1800 Ma Kimberley Group was deposited in the Kimberley Basin, and unconformably overlies both the Western and Central zones of the Lamboo Complex. The Moola Bulla Formation, which may be equivalent to the Kimberley Group in part, unconformably overlies the Koongie Park Formation in the Central zone.

Large-scale, north-northeasterly trending sinistral strike-slip faults developed during the Mesoproterozoic Yampi Orogeny. These structures may have controlled gold mineralization in the Central zone.

The Lamboo Complex and Kimberley Basin succession are unconformably overlain by c. 610 Ma Neoproterozoic glacigene rocks of the Louisa Downs Group deposited in the Louisa Basin. Sinistral reactivation of the strike-slip faults occured during the c. 560 Ma King Leopold Orogeny deforming the glacigene rocks. This was followed by the eruption of the basaltic rocks of the Antrim Plateau Volcanics in the Ord Basin. Further sinistral strike-slip faulting and associated folding took place during the c. 400 to 300 Ma Alice Spring Orogeny.

An extensive lateritized plateau surface formed between the Late Cretaceous and Early Miocene.

KEYWORDS: Halls Creek Orogen, Lamboo Complex, Moola Bulla Basin, Kimberley Basin, Louisa Basin, Ord Basin, Marboo Formation, Paperbark supersuite, Koongie Park Formation, Sally Downs supersuite, Louisa Downs Group, Antrim Plateau Volcanics, regional geology

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Introduction

The ANGELO* 1:100 000 map sheet (SE52-9-4361) is bounded by latitudes 18°00' and 18°30'S and longitudes 127°00' and 127°30'E, and lies within the MOUNT RAMSAY 1:250 000 sheet in the Kimberley region of Western Australia.

Cattle grazing for beef is the main commercial activity in the Kimberley region and the Moola Bulla, Mount Amhurst (an outstation of Moola Bulla), Lamboo, Margaret River, and Koongie Park pastoral leases extend into the sheet. Lamboo Homestead is located in the southeastern corner of the sheet, and Moola Bulla Homestead near the eastern margin.

The sealed Great Northern Highway traverses the southeastern corner of the sheet, linking Fitzroy Crossing and Halls Creek. Access within the rest of the sheet is via graded roads and station tracks.

Geological investigations prior to 1968 are summarized in the explanatory notes for the first edition of the MOUNT RAMSAY 1:250 000 geological sheet (Roberts et al., 1965, 1968). More recent work will be referred to as appropriate in the following notes.

The present survey by the Geological Survey of Western Australia (GSWA) continues the remapping of the King Leopold and Halls Creek Orogens that commenced in 1986. Fieldwork was carried out mainly in 1990 and 1991 using 1:25 000 colour aerial photography flown by the Western Australian Department of Lands Administration (DOLA). The mapping forms part of a joint project with the Australian Geological Survey Organisation (AGSO), carried out as part of the National Geoscience Mapping Accord Kimberley–Arunta project.

Physiography, vegetation and climate

ANGELO lies across the boundary between the North Kimberley and the Ordland physiographic divisions (Beard, 1979, fig. 7). The central and southeastern parts of the sheet are within Ordland and consist of dissected, sand-covered plateaus with intervening areas of low hills and stony plains. This area forms part of the Louisa Ranges, Bow River Hills, and Halls Creek ridges subprovinces of the Lamboo Hills province (Fig. 1). In the northwestern part of the sheet high, rocky sandstone strike ridges and intervening valleys belong to the Kimberley foothills and the Mount Cummings plateau subprovinces of the Kimberley Foreland Province. The highest point within ANGELO is in excess of 640 m AHD† on the eastern flanks of Mount Amhurst, whose summit lies on MOUNT CUMMINGS to the west. Creeks and rivers flow predominantly to the southwest, and form part of the Fitzroy River basin that drains to the Indian Ocean.

The vegetation of the Kimberley region has been described by Beard (1979). The dissected plateau country is covered by low-tree savanna with patches of spinifex, whereas the intervening low hills and stony plains are covered by low-tree savanna with spinifex and short grasses. Sparse tree steppe occurs in the southeastern corner of the sheet. The high sandstone ridges in the northwestern part of ANGELO are covered by low-tree savannah with spinifex, and the intervening valleys with savannah woodland.

The climate is semi-arid monsoonal with most rainfall, commonly between 350 and 400 mm per annum, occurring during the 'wet' season between November and April when temperatures are hot (often >40°C) and humidities are high. In the 'dry' season temperatures are warm to hot, and humidities are low.

Watercourses flow only after prolonged heavy rain although permanent pools lie in some of the rivers. Water supplies for stock are provided by wells and bores.

Regional geological setting

The main tectonic features of ANGELO and neighbouring sheets are shown in Figure 2, and the geological history of rocks within the sheet area is summarized in Table 1. The sheet lies entirely within the Halls Creek Orogen (Fig. 2), a major northeasterly trending Proterozoic orogenic belt in northern Australia (Rutland, 1981; Griffin and Grey, 1990). Five tectonic units are present on ANGELO (Fig. 3). In the northwestern and southeastern parts of the sheet, the Palaeoproterozoic (c. 1910 to 1790 Ma) Lamboo Complex of metasedimentary and igneous rocks is unconformably overlain by mainly clastic sedimentary rocks deposited in the Palaeoproterozoic (c. 1800 Ma) Kimberley Basin. In the southeastern part of the sheet the complex is overlain by clastic sedimentary rocks deposited in the Moola Bulla Basin. Neoproterozoic (c. 610 Ma) glacigene rocks outcrop in the Louisa Basin at the western margin of the sheet against the Lubbock Range Fault, and at the southern margin against the Ramsay Range Fault, where they are overlain by Cambrian deposits of the Ord Basin. An outlier of Neoproterozoic to Early Palaeozoic rocks also outcrops in the central part of the sheet.

The Halls Creek Orogen (Fig. 2) initially formed in the Palaeoproterozoic between the presumed Archaean rocks of the Kimberley Craton, underlying the Kimberley Basin to the northwest, and a composite Archaean craton to the east (Tyler et al., 1995). Earlier models for the formation of the orogen, 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 the similarity of some tonalites in the Halls Creek Orogen to those formed by partial melting of basaltic rock above subduction zones. He suggested that the Halls Creek Orogen may represent the site of an early Proterozoic convergent margin. Griffin and Tyler (1992), Griffin et al. (1994), Tyler et al. (1995) and Sheppard

* Capitalized names refer to standard map sheets.

† Australian Height Datum

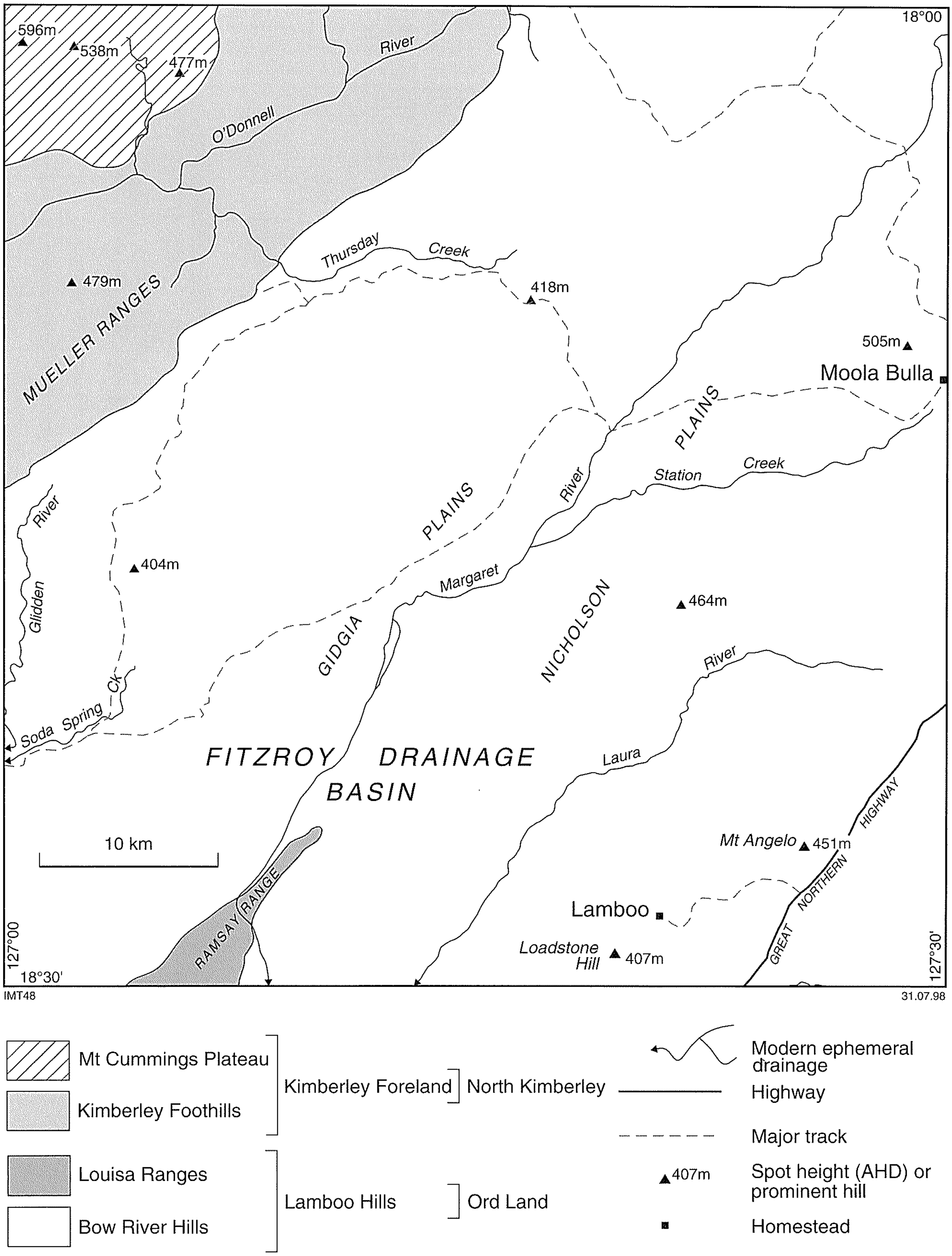


Figure 1. Physiographic and drainage sketch map of Angelo

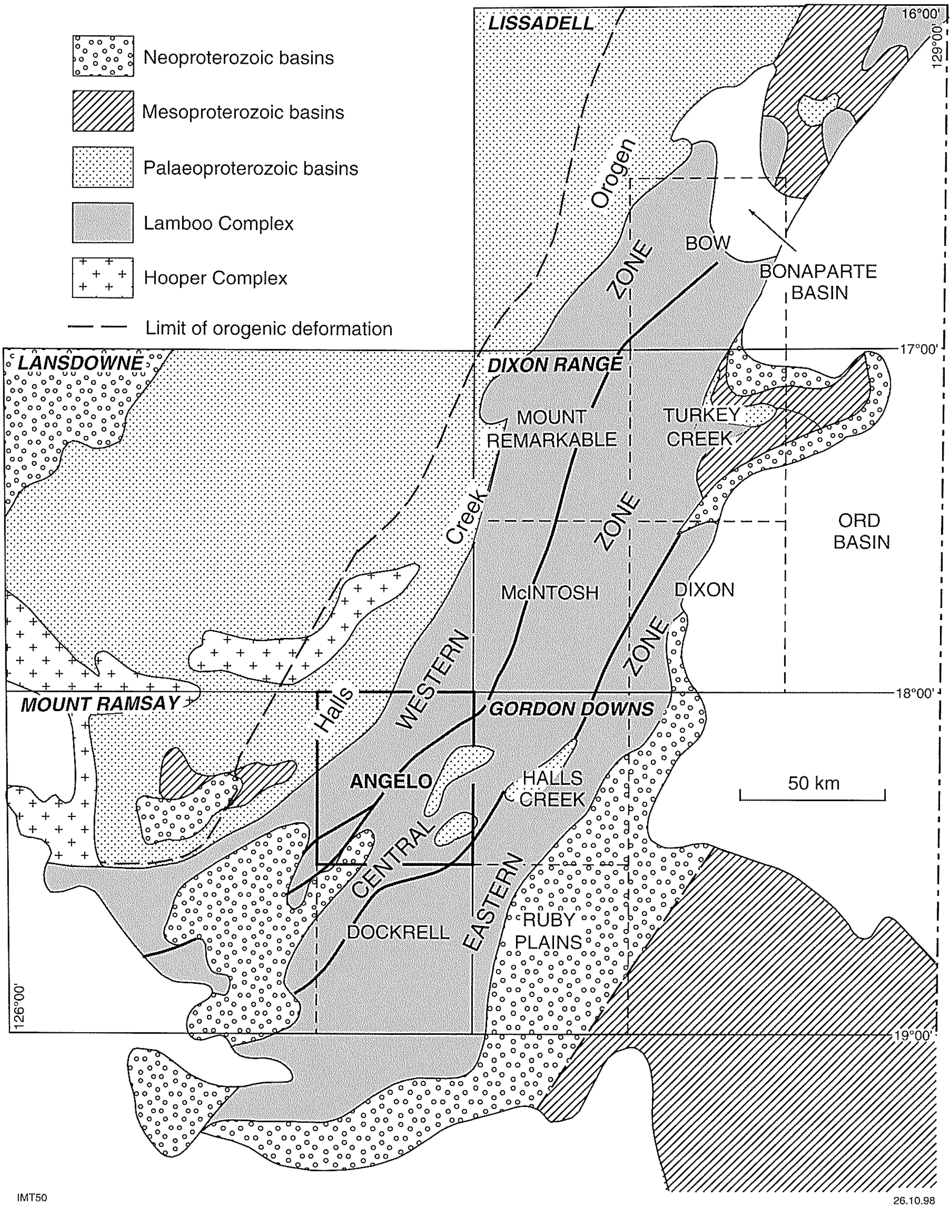


Figure 2. Location of 1:100 000 and 1:250 000 map sheets in the East Kimberley and their relationship to the tectonic zones in the Lamboo Complex

Table 1. Summary of the geological history of Angelo

Age (Ma)	*Kimberley Basin*	*Lamboo Complex* *Western zone*	 *Central zone*	 *Eastern zone*
?>2500	Unexposed Kimberley Craton			
c. 1870		Deposition of Marboo Formation		
1865–1850		----------	**Hooper Orogeny**	----------
c. 1865			Deposition of protoliths of the Tickalara Metamorphics	
		D_1 recumbent folding D_2 upright folding		
c. 1860		Intrusion of Neville and Gnewing granodiorites. Contact metamorphism of Marboo Formation		
<1847				Deposition of Olympio Formation of Halls Creek Group
c. 1845			Deposition of Koongie Park Formation. Intrusion of the granophyric Angelo Microgranite	
1835–1805		----------	**Halls Creek Orogeny**	----------
?c. 1830			Intrusion of Lamboo Ultramafics into Koongie Park Formation ?Upright, tight to isoclinal folding	Early layer-parallel shearing (D_3) related to a southwesterly directed extension
c. 1827			Intrusion of Loadstone Monzogranite	
				Upright to moderately inclined, open to isoclinal (D_4). Accompanied by very low- to low-grade metamorphism
1835–1805		Intrusion of gabbroic rocks, including Emull Gabbro Metamorphism of Marboo Formation and Neville Granodiorite to form Amhurst Metamorphics		
1820–1805		Intrusion of the Mount Christine Granitoid, and the Dillinger and Grimpy Monzogranites	Deposition of the Moola Bulla Formation in the Moola Bulla Basin	
c. 1800	Deposition of Kimberley Group in the Kimberley Basin			
c. 1790	Intrusion of the Hart Dolerite sills into the Kimberley Group			
?c. 1000	----------	**Yampi Orogeny**	----------	----------
	Large-scale sinistral strike-slip faulting and associated folding (D_5). Greenschist facies metamorphism. Intrusion of dolerite and porphyry dykes			
c. 610	Deposition of the Louisa Downs Group by a mountain glaciation from the north, followed by a marine transgression			
c. 560	----------	**King Leopold Orogeny**	----------	----------
	Northwesterly directed folding and thrusting of Kimberley Group rocks c. 560 Ma. ?Sinistral strike-slip faulting on ancestral Ramsay Range – Springvale Fault (D_6)			
		Deposition of the Lally Conglomerate, and eruption of the continental flood basalts of the Antrim Plateau Volcanics in the Ord Basin		
400–300	----------	**Alice Springs Orogeny**	----------	----------
	Sinistral strike-slip faulting and associated north-northeasterly trending folding			
70–50		Formation of plateau surface		
20–present		Uplift and dissection of plateau surface		

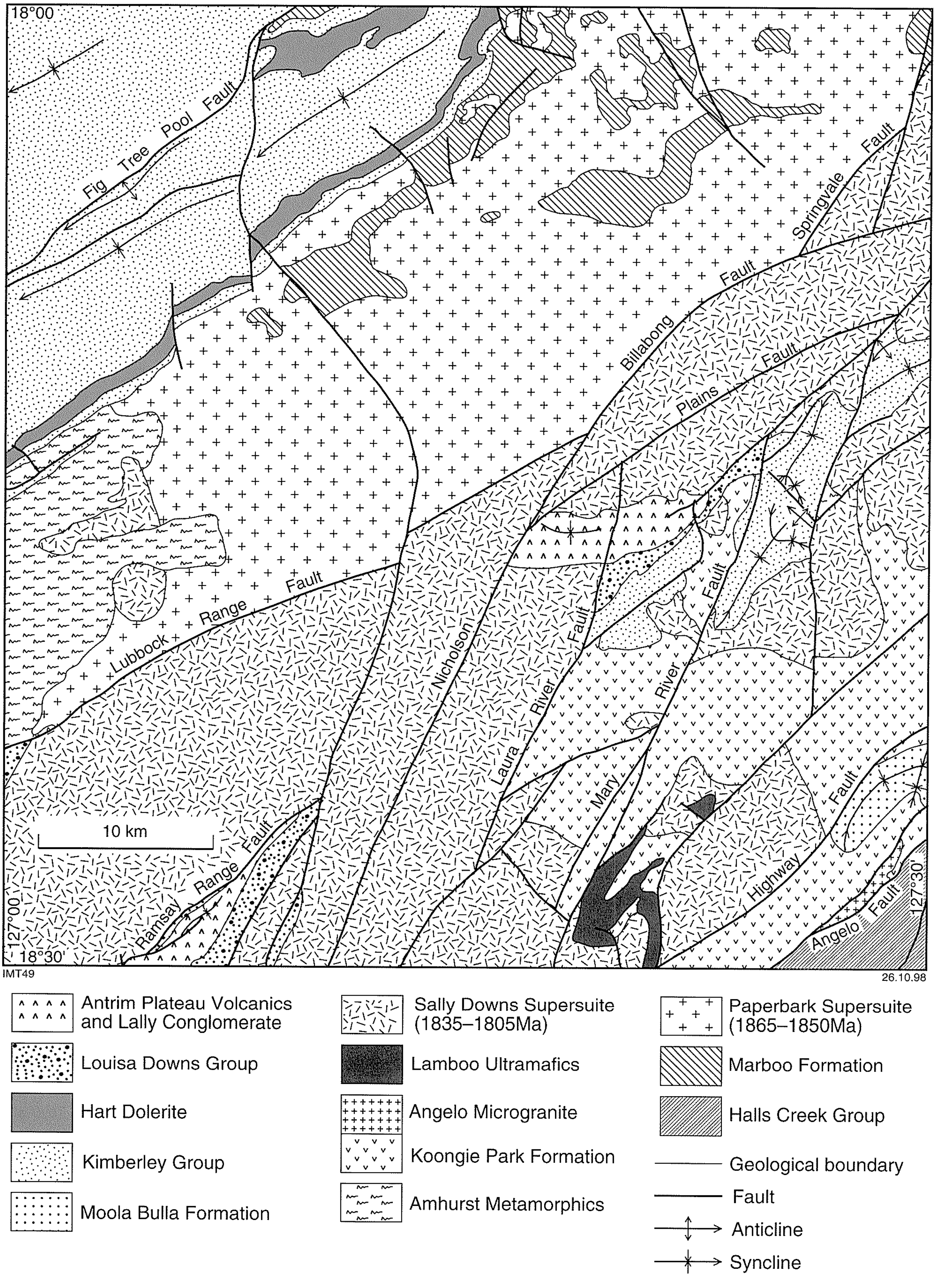


Figure 3. Simplified geological map of Angelo

et al. (1995, 1997b) have recently argued that the Halls Creek Orogen shares many features with convergent Phanerozoic plate margins associated with subduction of oceanic crust.

Major sinistral strike-slip faulting in a transpressive regime reactivated pre-existing fault zones, affecting rocks up to and including Palaeozoic volcanic and sedimentary successions in the Louisa Basin. Thorne and Tyler (1996) suggest that most movement occurred in the latest Proterozoic and the Palaeozoic.

Palaeoproterozoic Lamboo Complex

The Lamboo Complex on ANGELO consists of Palaeoproterozoic (c. 1910 to c. 1790 Ma) low- to high-grade metasedimentary rocks, and mafic and felsic intrusive and extrusive igneous rocks. It is unconformably overlain by rocks of the Moola Bulla Basin and the c. 1800 Ma Kimberley Basin succession, and by Neoproterozoic rocks deposited in the Louisa Basin.

Griffin and Tyler (1992) recognized three northeasterly trending zones within the Lamboo Complex: the Western zone, Central zone, and Eastern zone (Fig. 2). These corresponded roughly to subdivisions established by Hancock and Rutland (1984). The boundary between the Central and Western zones was modified by Tyler et al. (1994, 1995).

All three zones are present within the ANGELO sheet area. The Angelo Fault marks the boundary between the Central and Eastern zones, and the boundary between the Central and Western zones is a combination of the Ramsay Range, Billabong and Springvale Faults (Figs 2 and 3). On ANGELO, granitoids of the c. 1835 to 1805 Ma Sally Downs supersuite (see below) intrude both the Central and Western zones.

Western zone

The Western zone of the Lamboo Complex on ANGELO is confined to the area northwest of the Springvale, Billabong, and Lubbock Range Faults (Figs 2 and 3). The granitoids in the Halls Creek Orogen were considered by Dow and Gemuts (1967) and Gemuts (1971) to be part of a single batholith and most were included in the Bow River Granite (equivalent to the Bow River Granitoid Suite of Ogasawara, 1988). However, recent geochemical studies and U–Pb SHRIMP* dating indicates that the granitoids form two supersuites (not shown on map): the 1865–1850 Ma Paperbark supersuite, and the 1835–1805 Ma Sally Downs supersuite (Page and Sun, 1994; Page et al., in prep.a; Sheppard et al., 1995, 1997a,b). The Paperbark supersuite is restricted to the Western zone, and is dominated by 1865–1850 Ma granitoid and gabbro together with felsic volcanic rocks and subvolcanic porphyry. The igneous rocks either intrude, or unconformably overlie low- to high-grade turbiditic metasedimentary rocks of the c. 1870 Ma Marboo Formation.

Marboo Formation (*Ꝑm, Ꝑms, Ꝑmm*)

Turbiditic metasedimentary rocks outcrop in the northern and northwestern part of ANGELO, at the southeastern margin of the Kimberley Basin. These rocks were placed initially within the Olympio Formation of the Halls Creek Group by Roberts et al. (1965, 1968; *see also* Hancock and Rutland, 1984; Hancock, 1991). However, although the rocks are lithologically similar to those of the Olympio Formation, they have been deformed prior to being intruded by granitoid rocks that have been dated at c. 1860 Ma (Page et al., in prep.a), and are therefore older than the Olympio Formation, which was still being deposited after c. 1850 Ma (Tyler et al., 1995; Blake et al., in press a). Griffin and Tyler (1992) correlated these metasedimentary rocks with the Marboo Formation in the King Leopold Orogen. The Marboo Formation there was also deformed and metamorphosed prior to the intrusion of granitoid plutons at c. 1860 Ma, but was no older than c. 1871 Ma, the age of the youngest population of detrital zircons within it (Tyler et al., in prep.e).

The rocks that make up the Marboo Formation on ANGELO typically consist of variably deformed and metamorphosed interbedded mudstone, siltstone, greywacke and quartz wacke. The top of the unit is not seen, and no base or basement has been recognized. Griffin et al. (1993) estimated the thickness of the Marboo Formation on LENNARD RIVER to be in excess of 7000 m, although this may have been tectonically thickened by layer-parallel shearing and isoclinal folding. Marboo Formation rocks to the north and northeast, on LANSDOWNE, were described by Hancock (1991).

The thinly bedded nature of the Marboo Formation rocks on ANGELO is consistent with the upper part of the unit (Griffin and Tyler, in press). The sandstone beds are typically less than 1 m thick, have flute and load casts occurring locally on their bases, develop graded bedding, and pass up into siltstones and mudstones. They are interpreted as representing deposition by turbidity currents, with partial preservation of Bouma cycles (units ADE — Walker, 1984). Hancock (1991) recorded palaeocurrent data on LANSDOWNE that indicated a depositional slope from the north and northeast. This contrasts with data from the Olympio Formation, where depositional currrents came from the northwest (Hancock, 1991). The provenance of the arenite component of the Marboo Formation was a 'mature quartzose to quartzo-feldspathic hinterland with some acid volcanic material interlayered with or overlying granite' (Hancock, 1991, p. 214).

Paperbark supersuite

The older granitoids on ANGELO (the c. 1860 Ma Gnewing Granodiorite and Neville Granodiorite of Griffin and Tyler, 1994) belong to the c. 1865–1850 Ma Paperbark

* Sensitive High Resolution Ion Microprobe

supersuite of the Bow River batholith[*] (Sheppard et al., 1995; 1997a,b). Overall the supersuite is dominated by medium- to coarse-grained, I-type porphyritic biotite monzogranite and granodiorite. Granitoids of the supersuite are coeval, and probably cogenetic, with felsic volcanic rocks of the Whitewater Volcanics (Page and Sun, 1994; Sheppard et al., 1995), and subvolcanic porphyries on Dixon Range and Lissadell. As in the c. 1835–1805 Ma Sally Downs supersuite, granitoids of the Paperbark supersuite are also spatially and temporally associated with extensive areas of unlayered gabbros (Sheppard et al., 1997a; Tyler et al., in prep.a).

Neville Granodiorite (Ᵽgnv)

The Neville Granodiorite is a very large, east-north-easterly trending intrusion at the southern end of the Bow River batholith. It is almost 70 km long and about 8–10 km wide, with the bulk outcropping on Angelo. A sample collected about 2 km east of Neville Gorge has given a SHRIMP U–Pb zircon age of 1860 ± 3 Ma (Page et al., in prep.a). Most of the pluton consists of medium-grained and medium- to fine-grained, even-textured or weakly porphyritic tonalite and granodiorite. Medium-grained, porphyritic biotite monzogranite is widespread east of Duchess Dam (AMG 052917)[†], where it intrudes finer grained tonalite and granodiorite. The pluton also includes minor biotite diorite, and biotite–hornblende quartz diorite. The Neville Granodiorite intrudes the Marboo Formation, and high-grade metasedimentary rock inclusions are abundant adjacent to the contacts. The western margin of the intrusion is overlain by Palaeoproterozoic sedimentary rocks of the Kimberley Basin.

The tonalites and granodiorites are composed of subhedral granular plagioclase, biotite and minor microperthite, with phenocrystic and interstitial quartz, and accessory apatite, zircon, allanite and rare opaque minerals. Extinction angles on plagioclase twins indicate weak normal zoning from andesine to oligoclase. Most of the accessory minerals form euhedral inclusions in biotite, although fine-grained tonalites commonly contain abundant acicular apatite within quartz. Fine-grained diorites and quartz diorites are composed of plagioclase, hornblende or actinolite, biotite and quartz, with minor amounts of opaque minerals, and accessory apatite and zircon.

Small mafic clots, less than 3 cm in diameter, are widespread in the Neville Granodiorite. They are composed of intergrowths of decussate plagioclase–biotite(–accessories). Mafic clots in hornblende-bearing quartz diorites also contain hornblende, suggesting that the clots represent early crystallized cognate material. Fine-grained quartz diorite and tonalite inclusions are sparse, but consist of fine-grained (0.3–0.5 mm) plagioclase and biotite crystals enclosed in oikocrysts of quartz up to 3 mm in diameter. Quartz crystals also contain numerous inclusions of acicular apatite.

Alteration and metamorphism in many samples is evident from epidote replacement of magnetite, prehnite lamellae in biotite cleavage planes, and minor sericitization of plagioclase. Where hornblende is replaced by actinolite, adjacent plagioclase is altered to a fine-grained mixture of sericite and clinozoisite.

About 3 km southwest of Cameron Dam (AMG 251028), the Neville Granodiorite is intruded by a dyke of strongly porphyritic microtonalite containing coarse phenocrysts of plagioclase and oval-shaped quartz, and microphenocrysts of hornblende and biotite in a fine-grained, subhedral granular groundmass.

Gnewing Granodiorite (Ᵽgfm)

The Gnewing Granodiorite is a poorly exposed, elongate pluton which outcrops over about 250 km^2 in the northeast corner of Angelo. It trends roughly north-northeast, parallel to the Neville Granodiorite. The Gnewing Granodiorite is composed of coarse-grained, strongly porphyritic biotite–hornblende granodiorite and tonalite. The rocks have a granular texture with abundant dark-brown biotite, sparse quartz phenocrysts, and plagioclase with strong oscillatory zoning. Contacts between the Gnewing Granodiorite and other rock units are not exposed on Angelo.

Hooper Orogeny

The Hooper Orogeny was recognized first in the Hooper Complex of the King Leopold Orogen (Tyler and Griffin, 1993; Griffin et al., 1993; Griffin and Tyler, in press) and took place between c. 1865 and 1850 Ma. Tyler et al. (1995) noted the similarities in the geological evolution of the Hooper Complex and the Western zone of the Lamboo Complex. Events of similar age are also present in the Central zone, which may represent an island arc (Tyler and Page, 1996). From the relative position of the zones within the Hooper Complex, subduction of oceanic crust (Ogasawara, 1988; Griffin and Tyler, 1992; Griffin et al., 1994; Tyler et al., 1995; Sheppard et al., 1995, 1997b) probably took place to the northwest, beneath the Kimberley Craton (Tyler and Page, 1996). The Hooper Orogeny may have occurred as a response to the accretion of the island arc to the edge of the Kimberley Craton (Myers et al., 1996; Sheppard et al., 1997b)

Deformation and metamorphism

Hancock (1991) recognized upright medium-scale (1–100 m wavelength) trending folds in Marboo Formation rocks on Lansdowne to the northeast. However, he also recognized downward-facing structures there locally, and he concluded that the upright folds were a second generation (D_2) refolding an earlier recumbent fold phase (D_1). D_1 fold closures were not identified.

* The recognition of the Paperbark and Sally Downs supersuites is based on geochemical and geochronological studies carried out after the map sheet (Griffin and Tyler, 1994) was published. 'Bow River batholith' (Dow and Gemuts, 1969) has precedence over 'Bow batholith' used on map.

† Localities are specified by the Australian Map Grid (AMG) standard six-figure reference system whereby the first group of three numbers (eastings) and the second group (northings) uniquely define position, on this sheet, to within 100 m.

Marboo Formation rocks between Duchess Dam and the northern margin of ANGELO have undergone low-grade (greenschist facies) regional metamorphism, producing phyllitic pelitic rocks consisting of quartz, sericite, fine-grained biotite and iron oxides. Although downward-facing structures have not been recognized on ANGELO, the rocks have been deformed by northwesterly trending open to tight, upright, small-scale (<1 m wavelength) to medium-scale folds, which are correlated with the D_2 structures recognized by Hancock (1991). The folds have an axial planar cleavage (S_2) and a bedding–cleavage intersection lineation (l_2) oriented parallel to subhorizontal to moderately inclined axes. Large-scale (>100 m wavelength) fold closures are not recognized.

Contact metamorphism

Marboo Formation rocks in the northern part of ANGELO have been contact metamorphosed by the Neville Granodiorite. To the northeast of Duchess Dam, Marboo Formation rocks adjacent to the granodiorite are medium- to coarse-grained hornfelses, and may contain randomly oriented, subhedral andalusite porphyroblasts up to 5 cm long. The highest grade hornfelses consist of andalusite, cordierite, biotite, muscovite, plagioclase, and quartz. In some samples sillimanite is present in the form of fibrolite. Within approximately one hundred metres of the contact with the granodiorite, lower grade hornfelses are fine- to medium-grained and may be spotted, with the development of poikiloblastic cordierite and andalusite porphyroblasts.

In some areas a spaced foliation (<3 mm) has developed during metamorphism, and is picked out by fibrolite and biotite wrapping cordierite porphyroblasts. This may be related to local deformation accompanying the intrusion of the granodiorite.

To the north of Cameron Dam and Egan Dam (around AMG 260060) higher grade coarse-grained, migmatitic metasedimentary granofels and gneiss *(Emn)* occurs as extensive xenoliths within Neville Granodiorite. The migmatites are undeformed and the typical mineral assemblage is sillimanite, cordierite, biotite, muscovite, K-feldspar, plagioclase, and quartz, with relict andalusite, consistent with partial melting in situ under high temperature, low pressure metamorphic conditions (e.g. Thompson, 1982). Sillimanite may occur as needles up to 1.5 cm long or, where relict andalusite is preserved, as felts of fibrolite. These rocks are also interpreted as the product of contact metamorphism by the Neville Granodiorite.

In the northeastern corner of ANGELO a foliated medium-grade metasedimentary rock *(Ems)*, which consists of sillimanite, relict andalusite, biotite, muscovite and pinite after cordierite, may represent a deformed hornfels. It is veined by foliated granitoid.

The hornfelses show extensive alteration with pinitization of cordierite and chloritization of biotite.

Central zone

In the Central zone on ANGELO and HALLS CREEK, felsic and mafic volcanic rocks and associated metasedimentary rocks had been regarded as part of the Biscay and Olympio Formations of the Halls Creek Group (Roberts et al., 1968; Gemuts and Smith, 1967). However, Griffin and Tyler (1992) proposed that they be redefined as the Koongie Park Member, a component of the Tickalara Metamorphics. U–Pb SHRIMP dating of zircons from two rhyolite samples and a microgranite from HALLS CREEK give a pooled age of 1843 ± 2 Ma (Page et al., 1994). This is younger than the age of deformation and peak metamorphism of the Tickalara Metamorphics, which are exposed in the Central zone to the northeast (Page and Hancock, 1988; Page and Sun, 1994; Tyler et al., 1995). The unit was therefore raised to formation status, and the Koongie Park Formation is regarded as a unit separate from both the older Tickalara Metamorphics and the units of the Halls Creek Group.

The Koongie Park Formation is intruded and contact metamorphosed by granitoids, and mingled gabbro–granite of the 1835–1805 Ma Sally Downs supersuite.

For the ANGELO map sheet, Griffin and Tyler (1994) included all of the low-grade metasedimentary and mafic metavolcanic rocks in the Central zone in the Tickalara Metamorphics, and they were given the map codes '*ETs*' and '*ETa*'. There is no evidence for an unconformity or structural break between those units and the c. 1843 Ma felsic metavolcanic rocks of the Koongie Park Formation. It is now recognized that the rocks mapped on ANGELO as Tickalara Metamorphics actually form part of the Koongie Park Formation, and they are described as such here.

Koongie Park Formation (*ETa, ETs, Ee, Eec*)

The Koongie Park Formation occurs in the southeastern part of ANGELO where it is poorly exposed and locally deeply weathered. The unit consists of metamorphosed low-grade mafic volcanic rocks, felsic volcanic and volcaniclastic rocks, turbiditic sandstone, laminated siltstone and mudstone, and thin chert horizons interlayered with red, shaly siltstone and mudstone, carbonate, and iron-formation. South of the Sandiego Zn–Cu prospect, mafic volcanic rocks are interbedded with sandstone and argillite and underlie felsic volcaniclastic rocks interlayered with thin iron-formation layers. This, together with a change in provenance of sandstone from typically quartz-rich for those interlayered with the mafic volcanic rocks, to volcanic fragment-bearing lithic sandstone interlayered with the felsic volcanic rocks, suggests that the Koongie Park Formation may be subdivided into a lower mafic volcanic-dominated part and an upper felsic volcanic-dominated part.

No base or basement to the Koongie Park Formation has been recognized on ANGELO, and the thickness of the unit is difficult to estimate owing to extensive folding, faulting, and poor exposure. Estimates based on cross sections suggest that it is at least 2000 m thick.

The Koongie Park Formation is intruded by both the Loadstone and Dillinger Monzogranites. In the south-eastern corner of the map sheet it occurs also within a fault slice bounded by splays of the Angelo Fault, where it is intruded by the Angelo Microgranite. It is unconformably overlain by the Palaeoproterozoic Moola Bulla Formation and Kimberley Group, and by the Neoproterozoic Louisa Downs Group.

The Koongie Park Formation was probably deposited in a rift setting, with the lower package of mafic rocks having MORB*-like geochemical signatures. This indicates either that they have ascended rapidly through thinned continental crust, or that they may be ocean-floor type basalt erupted in a localized back-arc basin setting. The latter is more consistent with evidence for a oceanic island-arc setting for the mafic volcanic rocks of the Tickalara Metamorphics in the Central zone to the north, and with the geochemistry of the felsic intrusive rocks throughout the Lamboo Complex (Sheppard et al., 1995, 1997b). Proximity to a nearby continental margin is indicated by the presence of continentally derived sediments, which include clasts of metamorphic rock and granite. A-type felsic volcanism increases in importance during the evolution of the unit, which may represent rifting of the pre-existing volcanic arc.

Mafic metavolcanic rocks (₽Ta)

Metamorphosed mafic volcanic rocks are best exposed to the north and west of the Sandiego Zn–Cu prospect. They form pods and larger bodies amongst turbiditic metasedimentary rocks, and one large body of fine-grained metabasalt covers an area of 2.5 km^2 (around AMG 390760). Pillow structures up to 1 m in diameter occur near the margin of this body. More enigmatic arcuate fractures outlined by silicified fine-grained margins are also present. Amygdales filled with quartz, epidote or carbonate are common. Elongate pseudo-breccia layers up to 1 m thick and 50 m long have been formed by sericite–quartz and chlorite–albite–quartz alteration infiltrating the basalt along perlitic fractures. Thin beds of silicified granule conglomerate containing felsic volcanic fragments, together with beds of carbonate, are interlayered with the basalt.

The mafic rocks have been extensively recrystallized, and primary igneous minerals are not preserved. Patches of green actinolite, pale-green tremolite and blue-green hornblende pseudomorph large pyroxene crystals. Amphiboles also form small scattered crystals, or radiating fans of needle-like crystals in a matrix of plagioclase, carbonate, albite, opaques (mostly ilmenite), epidote, minor clinozoisite/zoisite, and scattered titanite. Minor quartz is present in many of the samples.

* Mid-Ocean Ridge Basalt

Metasedimentary rocks (₽Ts)

This unit comprises metamorphosed turbiditic quartz-rich sandstone and laminated siltstone and mudstone, thin chert beds and iron-rich, red shaly siltstone and mudstone. In limited creek exposures, which may be up to 100 m long, individual beds are between 0.03 and 0.3 m thick with infrequent beds and lenses of graded, medium- to coarse-grained sandstone between 0.4 and 1 m thick characterized by sharp bases and tops. Rare rip-up intraclasts are incorporated into the bases of some of these thicker beds. Bouma sequence divisions A3, B2, C, D, E are the most commonly present. Locally, small channel-like scours reach a depth of 2 m and are filled with medium- to coarse-grained graded sandstone.

Isolated outcrops of yellow or black chert are associated with red shaly siltstone and mudstone and contain contorted chert layers less than 0.3 m thick.

West and southwest of the Sandiego Zn–Cu prospect, metamorphosed mafic volcanic rocks occur interlayered with the metasedimentary rocks. These form irregular lens-like bodies that may be as small as 20 m in diameter, some of which contain amygdales filled with quartz and chlorite. Metabasalt is commonly relatively coarse-grained and, as boundary relationships with the surrounding metasedimentary rocks are not seen, it is uncertain as to whether the metabasalt represents lava flows or intrusions. Cross-cutting relationships between coarse-grained mafic rocks and metasedimentary rocks have been observed on HALLS CREEK to the east (Orth, 1997), indicating that some intrusive mafic rocks are present.

In thin section the metasandstone comprises mainly angular to subrounded, well- to moderately sorted grains of quartz, with lesser amounts of lithic fragments composed of volcanic to subvolcanic, sedimentary, and low-grade metamorphic material, including large kinked muscovite plates, and grains of opaques and tourmaline. The matrix is composed of sericite and fine-grained quartz, clay and iron oxides. In some cases these may reflect a pseudomatrix. Metamorphosed laminated siltstone and mudstone contains similar components but with a more abundant matrix and fewer obvious rock fragments. A cleavage may be defined by aligned sericite and clays.

Felsic metavolcanic rocks and associated metasedimentary rocks (₽e)

The felsic metavolcanic rocks encompass a lithologically diverse sequence consisting of felsic volcanic rocks, and volcaniclastic rocks, and are associated with granule conglomerate, sandstone, shale, ironstone, chert, and carbonate that have undergone greenschist facies metamorphism.

Aphyric, quartz-phyric, and less abundant quartz–feldspar-phyric rhyolite to rhyodacite are massive to featureless in outcrop, apart from broad-scale jointing. One aphyric body 100 m to the north of the Sandiego Zn–Cu prospect (AMG 398685) is 500 m long and 100 m wide and contains spherulites 5 to 10 mm in diameter associated with patches of vesicular rhyolite near the margin. South of the Sandiego prospect quartz-phyric bodies contain embayed and rounded quartz grains less than 1 mm in diameter together with minor vesicles.

The felsic volcanic rocks are interbedded with metamorphosed quartz-bearing sandstone, granule conglomerate, laminated siltstone and mudstone, and minor iron-formation. Below the weathering profile at the Sandiego Zn–Cu prospect, thin beds of turbiditic grey siltstone, black laminated mudstone, carbonate, and normally graded, coarse-grained quartz–feldspar volcaniclastic rock can be seen in drillcore. These are intruded by blue quartz-bearing rhyolite sills.

Aphyric rhyolite or rhyodacite and an open framework, quartz-bearing volcaniclastic unit are also associated with the Mount Angelo North copper prospect.

In thin section the matrix of the granule conglomerate and sandstone contains a pseudomatrix of felsic volcanic, laminated siltstone and mudstone, sandstone, and chert clasts. Minor amounts of metamorphic rock and granite fragments, together with detrital tourmaline grains, are also present. Alteration is common around the Sandiego Zn–Cu prospect with chlorite, actinolite and talc abundant. The metamorphosed rhyolite and rhyodacite bodies may contain small (<2 mm) rounded and embayed quartz grains, and euhedral feldspar grains set in an open framework, the matrix of which consists of quartz, albite, iron oxides, kaolinite (in weathered samples), chlorite, biotite, sericite, carbonate, and minor ilmenite. Quartz and albite form spherulites, which in weathered samples are rimmed by a dusting of iron oxide.

Minor highly altered metadolerite dykes have been recognized only in drillcore. Their identification is based on their sharp, cross-cutting, intrusive relationships with the surrounding felsic metavolcanic and metasedimentary rocks. No relict or pseudomorphed phenocrysts are preserved in what are now carbonate–chlorite rocks. These intrusions were not observed during surface mapping.

Chert and iron-formation (Ɇec)

Sequences of metamorphosed chert, iron-formation, red shaly siltstone and mudstone, and carbonate occur at different stratigraphic levels interlayered with the felsic metavolcanic rocks. At the Sandiego prospect they host the primary Zn–Cu mineralization. One unit occurs to the west of the Mount Angelo copper prospects (around AMG 360610), near the top of the formation, where it was eroded prior to deposition of the overlying Moola Bulla Formation.

At the surface, carbonate is silicified and may be difficult to recognize; however, it is recrystallized and massive in drillcore. Calc-silicate with abundant needle-like talc, chlorite, and actinolite are also present. Iron-formation can display 1–30 mm banding of magnetite or hematite alternating with chert, and is associated with massive white and black chert, together with laminated, black, chloritic mudstone, and chert nodules. Chert and iron-formation layers are often highly contorted, but display no foliations. In contrast the interbedded shales display little folding, but may have least two foliations.

Angelo Microgranite *(Ɇgan)*

The Angelo Microgranite is a small, elongate intrusion about 5 km long by 1 km wide, which outcrops along the western side of the Angelo Fault, in the southeast corner of the map sheet. The intrusion is poorly exposed and, for the most part, deeply weathered. It is composed of altered, medium- to fine-grained, granophyric and granular microgranite. Adjacent to the Angelo Fault, the rocks are well foliated and may be extensively veined by quartz. Disseminated malachite is common, occuring along joint surfaces and foliation planes. The Angelo Microgranite intrudes low- to medium-grade metasedimentary and felsic metavolcanic rocks of the Koongie Park Formation. Its close spatial association with, and the similarity of the whole-rock compositions to, the felsic rocks of the Koongie Park Formation suggest that the Angelo Microgranite is the intrusive equivalent of the felsic volcanic rocks (Sheppard et al., 1995).

In thin section the Angelo Microgranite consist of medium- and fine-grained, strongly recrystallized leucocratic monzogranite with a granophyric texture. Granophyric intergrowths of quartz and K-feldspar constitute up to 50% of the rock, commonly with an anhedral quartz grain at the core. The remainder of the rock consists of recrystallized quartz, albite with abundant sericite inclusions, and commonly less than 5% chlorite and epidote in very fine grained clots. More strongly deformed samples are composed of very fine grained granular quartz and feldspars. One strongly altered sample from material adjacent to the Angelo Fault contains abundant acicular edenitic hornblende and granular epidote in a matrix of very fine grained, granular quartz and feldspar.

Lamboo Ultramafics (*Ɇal*)

The Alice Downs Ultrabasics on ANGELO (Roberts et al., 1965, 1968) are renamed the Lamboo Ultramafics. They were previously grouped with ultramafic rocks in the Alice Downs area, about 80 km to the northeast, on MCINTOSH. However, there is no evidence to suggest that these two groups of ultramafics are related to each other and, therefore, they have been separated.

The Lamboo Ultramafics form a north-northeasterly trending elliptical intrusion about 6 km long and 2–3 km wide, with a smaller exposure (~1 km^2) about 3 km to the northeast. The ultramafic rocks are poorly exposed and are commonly covered by a silcrete cap, although primary igneous layering has been recognized at the southern margin and dips at about 60° to the south (Gemuts, 1971). The ultramafic rocks probably formed sill-like intrusions into low- to medium-grade metasedimentary and metavolcanic rocks of the c. 1843 Ma Koongie Park Formation. The intrusion was folded before being intruded by the c. 1827 Ma Loadstone Monzogranite, which has produced local hornfelsing.

The intrusion has been the target of exploration for Cr, PGE, Au, Ni, and Cu mineralization. Detailed mapping within the intrusion has been carried out at various times by Kennecott/BHP, Union Oil Corporation, and Hunter Resources, and the results have been summarized from open-file WAMEX reports by Sanders (in prep.).

The intrusion consists of a 500 m-thick basal unit of serpentinized, cumulus peridotitic–dunite overlain by 900 m of a mixed gabbro to anorthosite unit. Quartz diorite to monzogranite has been interpreted as an upper granophyric zone, but could also be part of the Loadstone Monzogranite. The lower contact of the intrusion is with felsic volcanic rocks and metasedimentary rocks of the Koongie Park Formation.

The western and central parts of the intrusion were originally thought to form the limbs of a north-northeasterly plunging syncline (e.g. Griffin and Tyler, 1994); however, the primary igneous layering is more consistent with a south-southwesterly plunging anticline. The concealed eastern part of the intrusion forms the eastern limb of a succeeding syncline.

Eastern zone

The Eastern zone, which lies to the east of the Halls Creek–Angelo Fault system (Tyler et al., 1995), consists of low- to medium-grade metasedimentary rocks, and mafic and felsic volcanic and intrusive igneous rocks. The oldest rocks outcrop on HALLS CREEK and DOCKRELL, and belong to the predominantly mafic c. 1910 Ma Ding Dong Downs Volcanics, and the associated high-level granitoid intrusions. These are unconformably overlain by the c. 1880 to younger than 1847 Ma Halls Creek Group, the upper part of which outcrops in the southeastern corner of ANGELO. Elsewhere, the Halls Creek Group is intruded by extensive mafic sills forming the Woodward Dolerite.

Halls Creek Group

The Halls Creek Group, as redefined by Griffin and Tyler (1992), consists of three formations: the Saunders Creek Formation, the Biscay Formation, and the Olympio Formation. Only the Olympio Formation outcrops in the southeastern corner of ANGELO.

A deformed felsic rock from the Ilmars Cu–Pb–Zn prospect on HALLS CREEK gives a SHRIMP U–Pb zircon age of c. 1880 Ma (Tyler et al., 1995) for the Biscay Formation. Page and Hancock (1988) reported a conventional U–Pb zircon age of 1856 ± 5 Ma for a felsic 'sill' within 'Biscay Formation tuffs'. Owing to uncertainty as to whether the 'sill' date was coeval with the surrounding rocks, they regarded the date as a minimum age for the Halls Creek Group. Blake et al. (in press a) mapped the 'sill' as a lava flow, and both the flow and the tuffs that enclose it belong to the Maude Headley Member of the Olympio Formation. A SHRIMP U–Pb zircon age of c. 1857 ± 5 Ma has been obtained from the same rock (Page and Hancock, 1988; Page and Sun, 1994), and a SHRIMP age of 1857 ± 2 Ma has been obtained from a pyroclastic rock on MCINTOSH to the north (Page et al., in prep.b), providing a depositional age for the lower part of the Olympio Formation.

Taylor et al. (1995a) obtained a SHRIMP U–Pb zircon age of 1870 ± 4 Ma for the mineralized 'Niobium Tuff' within the Butchers Gully Member of the Olympio Formation (Griffin and Tyler, 1992) at the Brockman rare metals prospect on HALLS CREEK. However a SHRIMP U–Pb zircon age of c. 1848 ± 3 Ma has been obtained also from a pillow lava from the same area (Page et al., in prep.b). The older indicated age from the 'tuff' was taken as that of the youngest coherent zircon fraction analyzed from the rock, but may be a maximum age reflecting either detrital or inherited zircons. The youngest ages obtained from detrital zircons from Olympio Formation turbidites sampled below the Butchers Gully Member on MCINTOSH were c. 1870 Ma, while those above the volcanic rocks give ages as young as c. 1847 Ma (Page et al., in prep.b), thus providing maximum ages for deposition.

Tight to isoclinally folded Halls Creek Group rocks are unconformably overlain by the Moola Bulla Formation to the east on HALLS CREEK.

Olympio Formation (ⱣHo, ⱣHoq)

The Olympio Formation (*ⱣHo*) consists of a monotonous sequence of weakly metamorphosed, thin- to medium-bedded (≤2 m) mudstone, siltstone, and fine-, medium-, and coarse-grained, typically matrix-supported quartz wacke, greywacke, and arkose. Thicker (2–4 m), metamorphosed coarse-grained to pebbly, clast-supported quartz sandstone units (*ⱣHoq*) are also present. The top of the formation is not seen.

Due to the lack of persistent marker horizons within the Olympio Formation, and the possibility of structural repetition, it is not possible to gave an accurate estimate of the thickness of the unit. However, Dow and Gemuts (1969) estimated that the unit was some 4000 m (12 000 feet) thick (*see also* Hancock and Rutland, 1984; Hancock, 1991).

The unit has been interpreted as the deposits of a submarine fan system (Dow and Gemuts, 1969; Hancock and Rutland, 1984; Hancock, 1991). Complete Bouma sequences are not usually seen, although graded bedding is developed in most of the arenaceous units. These pass up into laminated siltstones and mudstones to represent divisions ADE of a Bouma sequence. Within the coarser quartz sandstone units, siltstone and mudstone are generally absent with only repeated occurrence of Bouma sequence division A being observed. Other sedimentary structures, such as bottom structures, and convolute and ripple lamination, which have been reported from the Olympio Formation elsewhere (Dow and Gemuts, 1969; Hancock, 1991), occur less commonly in Olympio Formation rocks on ANGELO.

The general absence of bottom structures and ripple laminations from the arenaceous units on ANGELO means that sediment transport directions are not known.

Hancock (1991) tentatively reported palaeocurrents indicating flow from the northeast, observed from areas to the northeast of Halls Creek. The petrography of the typically subangular to subrounded clasts within the coarser arenaceous units is dominated by quartz, K-feldspar, and plagioclase, together with detrital muscovite, tourmaline, and a variety of lithic fragments. Hancock (1991) concluded that the petrography of clasts within the arenaceous units indicated that the source area was largely crystalline, predominantly composed of granitic rocks, with variable inputs of felsic volcanics and muscovite-bearing metasedimentary rocks.

Sally Downs supersuite

On ANGELO, granitoid, massive gabbro, and mingled gabbro–granite outcrop in the southern half and northeastern corner of the mapped area. Contacts between granitoid and gabbro are commonly complex and are indicative of coeval mafic and felsic magmas. Granitoid and gabbro plutons have intruded and contact metamorphosed the Koongie Park Formation and are therefore younger than c. 1843 Ma Koongie Park Formation. They are regarded as belonging to the 1835–1805 Ma Sally Downs supersuite (Sheppard et al., 1995, 1997a,b).

Although granitoid and gabbro of the Sally Downs supersuite are confined to the Central zone on HALLS CREEK, on ANGELO they intrude rocks in the Western zone, whereas on DOCKRELL, to the south, they intrude rocks in the Eastern zone (Tyler et al., in prep. a).

Many granitoids of the Sally Downs supersuite are characterized by higher Na_2O, P_2O_5, Sr and Y, and lower K_2O, FeO, Rb, and LREE than granitoids of the Paperbark supersuite (Sheppard et al., 1995). The Loadstone, Grimpy and Dillinger Monzogranites, and the Mount Christine Granitoid, belong to the Sally Downs supersuite.

Gabbroic rocks

In the Lamboo Complex, field relationships indicate that many of the unlayered gabbros in the Central zone, and c. 1835–1805 Ma granitoids of the Sally Downs supersuite, are broadly coeval (Blake and Hoatson, 1993; Sheppard et al., 1997a; Tyler et al., in prep. a). Evidence for this includes net-veined complexes along the contacts between many gabbros and granitoids and, locally, numerous mafic inclusions in granitoids with features consistent with magma-in-magma relationships (e.g. Vernon, 1991). Furthermore, large areas containing 'intimate mixtures of granite, gabbro and metamorphic rock' recorded on the first edition MOUNT RAMSAY (Roberts et al., 1968), DIXON RANGE (Dow and Gemuts, 1967) and GORDON DOWNS (Gemuts and Smith, 1967) 1:250 000 map sheets have features indicative of magma mingling. Although the unlayered gabbros are the product of a tholeiitic magmatic event separate to that of the granitoids, they are considered to be an integral part of the Sally Downs supersuite.

Emull Gabbro (Ᵽoe)

The Emull Gabbro is a north-northeasterly trending, elongate intrusion about 15 km long by 7 to 8 km wide that outcrops on ANGELO and DOCKRELL. About two-thirds of the intrusion outcrops on ANGELO. The Emull Gabbro comprises medium- to fine-grained, subophitic and subhedral granular gabbro, xenocrystic quartz gabbro and tonalite. The tonalite typically forms irregular veins cutting the various gabbro types. Locally, some of the coarser grained gabbros have a weak layering. In proximity to the Dillinger Monzogranite, the gabbros commonly contain rounded xenocrysts of plagioclase and quartz with fine-grained reaction rims. The Emull Gabbro is extensively veined and intruded by medium- to fine-grained leucocratic biotite monzogranite of the Dillinger Monzogranite. The occurrence of net-veined complexes and limited hybrid magmas along the contact imply that the granite and gabbro were, in part, coeval.

Most samples are recrystallized and consist of edenitic amphibole or green hornblende and plagioclase (cores of labradorite zoned to rims of andesine), with some 5% reddish-brown biotite, minor interstitial quartz, and minor amounts of opaque minerals. Amphibole commonly contains cores of clinopyroxene and rare orthopyroxene, and locally plagioclase cores contain abundant secondary epidote. The gabbros have been metamorphosed under epidote–amphibolite to amphibolite facies conditions.

Undivided gabbro (Ᵽo)

The undivided gabbro unit includes a range of basic and intermediate intrusive rocks which form several small exposures scattered over a wide area in the Central zone. The exposure south of Eagle Hawk Crossing Gorge (around AMG 030540) is part of a larger intrusion which extends southwards onto DOCKRELL. Gabbro also intrudes rocks of the Western zone north of Soda Spring and north-northeast of Gnewing Bore. This unit comprises rock types that are xenocrystic to even-textured, medium- to fine-grained gabbro and diorite, with locally abundant tonalite veins. Rocks mapped as undivided gabbro on ANGELO and DOCKRELL (Griffin and Tyler, 1994; Tyler and Griffin, 1994) are equivalent to the gabbro and comingled gabbro and granite units (*ᵽgSob* and *ᵽgSog*) on HALLS CREEK, MCINTOSH and MOUNT REMARKABLE (Blake et al., in press a; Tyler et al., in prep. a; Sheppard et al., 1997a).

North of Dusty Bore (around AMG 270740), undivided gabbro intruded metasedimentary and mafic metavolcanic rocks of the Koongie Park Formation. In the same area gabbro is extensively veined and intruded by the Dillinger Monzogranite, and is overlain by the Palaeoproterozoic Kimberley Group, the Neoproterozoic Louisa Downs Group, and basalts of the Cambrian Antrim Plateau Volcanics.

Most of the gabbros and diorites have been variably recrystallized and metamorphosed under greenschist to amphibolite facies conditions. Least-altered samples consist of medium-grained, subophitic gabbro and norite with small amounts of strongly fractured, anhedral olivine, or reddish-brown biotite.

Inclusion-rich granitoids (*Єgx*)

There are two main exposures on ANGELO of granitoids rich in inclusions of mafic rock; one along the eastern margin of the Dillinger Monzogranite west of Loadstone Hill (~2 km^2 around AMG 180550), and the second, on the eastern edge of the Grimpy Monzogranite immediately northwest of Eagle Hawk Crossing Gorge (>3 km^2 around AMG 010580). There are also a number of other occurrences too small to show on the map. These are equivalent in part, to the net-veined complexes of Sheppard et al. (1997a) and Tyler et al. (in prep.a) on MOUNT REMARKABLE and MCINTOSH.

Loadstone Monzogranite (*Єgst*)

The Loadstone Monzogranite is a large, poorly exposed pluton, which outcrops extensively on ANGELO and extends onto HALLS CREEK (Blake et al., in press a). Many of the exposures are deeply weathered and lateritized. The intrusion is quite homogenous, consisting almost entirely of medium- to coarse-grained, weakly porphyritic biotite monzogranite and syenogranite. Most of the rocks are massive and undeformed. However, in north-northeasterly trending shear zones, which may be several metres wide and are commonly associated with quartz veining, the granites have been strongly recrystallized to form fine-grained cataclastic rocks with plagioclase porphyroclasts. The intrusion is distinguished from most others in the Sally Downs batholith by the presence of microcline, rather than microperthite, as the K-feldspar. Angular inclusions of microgabbro and metasedimentary rock are sparse. The Loadstone Monzogranite intrudes the Lamboo Ultramafics, and medium- and low-grade metasedimentary rocks of the Koongie Park Formation, and has given a SHRIMP U–Pb zircon age of 1827 ± 2 Ma (Page et al., in prep.a).

Most rocks are composed of subhedral granular quartz (20–35%), microcline (30–35%), and plagioclase (40–25%) 3–7 mm long, with minor interstitial chocolate-brown biotite (≤5%), and microcline phenocrysts (~5%) up to 10 mm long. Amphibole is rare, and may contain cores of orthopyroxene. Strongly porphyritic samples contain microcline phenocrysts up to 15 mm long in a groundmass of quartz, plagioclase, and minor biotite. Microcline commonly contains small euhedral inclusions of plagioclase, and minor biotite and quartz. Smaller plagioclase crystals are commonly unzoned, but larger crystals may have oscillatory zoned cores with or without narrow, normally zoned rims. Accessory minerals consist of opaques, apatite, and zircon. Alteration generally consists of chloritization of biotite and weak to moderate sericite and clinozoisite replacement of plagioclase cores or calcic zones.

Grimpy Monzogranite (*Єggy*)

The Grimpy Monzogranite is a large (~15 × 40 km), elongate north-northeasterly trending intrusion, most of which outcrops on ANGELO, but which extends to the south-southwest beyond the sheet boundary (Tyler et al., in prep.c). The bulk of the Grimpy Monzogranite outcrops in the Central zone, but medium- to coarse-grained granodiorite and monzogranite some 10 km northwest of Watson Dam (around AMG 935785) in the Western zone are also included in the Grimpy Monzogranite. A sample from this area has geochemical similarities to the Grimpy Monzogranite, but is dissimilar to the Neville Granodiorite (Sheppard et al., 1995). The Grimpy Monzogranite is composed of medium- to fine-grained, even-textured or weakly porphyritic biotite granodiorite and tonalite, with lesser biotite monzogranite. Most of the rocks are massive, but strongly foliated samples also occur. Along the southeast margin of the pluton, rounded and flattened mafic inclusions are abundant.

Contacts between the Grimpy Monzogranite and country rock are rare owing to poor exposure. Grimpy Monzogranite in the Western zone probably intruded medium- and high-grade metasedimentary rocks and granitic gneisses of the Amhurst Metamorphics. Along the western edge of the sheet, Grimpy Monzogranite is overlain by Neoproterozoic sedimentary rocks of the Louisa Downs Group.

The granodiorites and tonalites of the Grimpy Monzogranite are composed of 0–10% tabular microperthite phenocrysts up to 10 mm long in a groundmass of 25–30% quartz, 50–60% plagioclase, 5–15% biotite, rare hornblende (≤1%) and accessory apatite, opaques, zircon, and monazite. Plagioclase displays weak normal zoning, commonly in conjunction with pronounced oscillatory zoning. Most samples show sericite and clinozoisite alteration of plagioclase cores, some chloritization of biotite, and epidote and sphene rimming magnetite and ilmenite respectively. Both altered and fresh biotite grains commonly contain lamellae of prehnite, or rarely epidote, oriented along their cleavage planes. These secondary minerals are not accompanied by quartz and feldspar recrystallization and may reflect static metamorphism or hydrothermal alteration.

Dillinger Monzogranite (*Єgdi*)

The main part of the Dillinger Monzogranite outcrops over an area of about 25 × 10 km in the southern part of ANGELO and the northern part of DOCKRELL (Tyler and Griffin, 1994). However, scattered exposures southwest and north of Dusty Bore on ANGELO suggest that it extends farther north underneath an extensive plain of colluvium. South of Emull Bore, the pluton is reasonably well exposed, but to the north it consists only of scattered, deeply weathered exposures. The Dillinger Monzogranite is a homogeneous intrusion composed of medium-grained, even-textured or weakly porphyritic, leucocratic biotite monzogranite, and minor syenogranite. Fine-grained mafic inclusions are abundant only in proximity to gabbros. The Dillinger Monzogranite intruded the Emull Gabbro in the south of the sheet, and undivided gabbro north of Dusty Bore.

The rocks consist of up to 10% microperthite phenocrysts, in a groundmass of granular 2–3 mm quartz, microperthite and plagioclase, with minor biotite, and accessory magnetite, apatite, zircon, and allanite.

Extinction angles in plagioclase suggest weak normal zoning from cores of around An_{20} to rims of about An_{10}. Fine-grained, granophyric textures are widespread; they range from incipient development at grain boundaries, to complete recrystallization of quartz and feldspars.

Mount Christine Granitoid (*Ꝑgch*)

The Mount Christine Granitoid is a very large (~40–50 km long and 20 km wide) north-northeasterly trending intrusion, the bulk of which outcrops on DOCKRELL (Tyler and Griffin, 1994). On ANGELO, the Mount Christine Granitoid is represented by a few small (≤0.5 km^2) scattered exposures on the southern edge of the sheet, although it may extend for another 15 km or more to the north beneath a large colluvium and alluvium covered plain. Two samples collected from DOCKRELL have been dated. A foliated granodiorite phase, which intrudes a northwesterly trending strip of migmatite and amphibolite northeast of Mount Christine, gave a SHRIMP U–Pb zircon age of 1819 ± 4 Ma. A sample of porphyritic biotite hornblende granodiorite, typical of exposures in the Mount Christine area, gave an age of 1808 ± 3 Ma (Page et al., in prep.a).

Contact relationships are not exposed on ANGELO, but on DOCKRELL the Mount Christine Granitoid intrudes recrystallized high-grade migmatitic Tickalara Metamorphics, undivided gabbro, and the younger massive phase also intrudes the Halls Creek Group of the Eastern zone (Tyler et al., in prep.b).

The Mount Christine Granitoid is mainly composed of medium- to coarse-grained, biotite monzogranite, and medium-grained hornblende–biotite monzogranite and granodiorite. Many samples of the Mount Christine Granitoid are only weakly deformed and recrystallized. Nevertheless, alteration of plagioclase to sericite and clinozoisite, replacement of magnetite by epidote, and chlorite alteration of biotite is widespread in the Mount Christine Granitoid.

Contact metamorphism

The metamorphic grade of many of the metasedimentary rocks and the mafic metavolcanic rocks of the Koongie Park Formation increases towards the contact with the granitoid intrusions and they may be converted to fine-grained hornfels or granofels. Muscovite and biotite appear first, with spotting and andalusite laths becoming common within the last 50–75 m. Mafic volcanic rocks are converted to amphibolites within this zone. Retrogression has affected some of these higher grade rocks with andalusite being pseudomorphed by sericite/muscovite and quartz.

Halls Creek Orogeny

The earliest deformation in the Eastern zone affected rocks within the Olympio Formation and therefore is no older than c. 1847 Ma, the age of detrital zircons in the upper part of that unit (see above). On DOCKRELL the Mount Christine Granite intrudes the Halls Creek Group, post-dating two deformations (Tyler et al., in prep.b), and has given a SHRIMP U–Pb zircon age of 1808 ± 3 Ma (Page et al., in prep.a). This provides an upper limit on the earliest deformations to affect the Halls Creek Group, and suggests that they correspond to the 1835–1805 Ma Halls Creek Orogeny and therefore to the regional D_3 and D_4 events recognized in the Central zone (Griffin and Tyler, 1992; Tyler and Page, 1996; Sheppard et al., 1997a). These events are younger than the D_1 and D_2 events in the Central and Western zones, which developed during the 1865–1850 Ma Hooper Orogeny (Tyler et al., 1995, fig. 3; Tyler and Page, 1996) and with which they were correlated on the map sheet (Griffin and Tyler, 1994).

The Halls Creek Orogeny has been interpreted as the result of a collision between the Eastern zone and the combined Central and Western zones, representing the final suturing of the Kimberley Craton on to the North Australian Craton by 1805 Ma (Tyler and Page, 1996; Myers et al., 1996).

The first deformation (D_3)

The first deformation to affect rocks in the Eastern zone of the Lamboo Complex was a layer-parallel shearing event, and is ascribed to D_3. Folding related to this event is not recognized, although zones of phyllonite and associated quartz veining (2–5 cm thick) occur typically along bedding planes. Tyler et al. (in prep.b) noted that shear criteria within D_3 shear zones on DOCKRELL consistently gave a top to the southwest sense of shear. At the top of the Biscay Formation on MCINTOSH, Warren (1994) has noted a D_3 shear zone that has removed the upper part of that unit and the lower part of the overlying Olympio Formation, including the Maude Headley Member. This relationship is consistent with southerly directed low-angle extensional faulting.

This early extensional deformation has not been recognized in the Central zone on ANGELO. The oldest deformation recognized there affected rocks of the c. 1843 Ma Koongie Park Formation and formed medium-scale tight to isoclinal upright folds with an axial planar cleavage, which have been refolded by later deformation (Orth, 1997). These structures were correlated initially with the second deformation of the Hooper Orogeny, and have been shown on the map sheet as 'D_2' (Griffin and Tyler, 1994). However, as they affected the Koongie Park Formation they must be younger than c. 1843 Ma. About 3 km north of Dusty Bore the axial planar cleavage is overprinted by contact metamorphic andalusite adjacent to the Dillinger Monzogranite, and deformation is regarded as predating the intrusion of the Loadstone Monzogranite at c. 1827 Ma, as well as the deposition of the unconformably overlying Moola Bulla Formation. These relationships suggest that this deformation is similar in age to the D_3 deformation recognized in the Tickalara Metamorphics farther north (Plumb et al., 1985; Griffin and Tyler, 1992; Tyler and Page, 1996).

The second deformation (D_4)

The second deformation to affect the Eastern zone of the Lamboo Complex on ANGELO produced pervasive tight to isoclinal, east-northeasterly to northeasterly trending folds at all scales. Axial surfaces are upright to moderately inclined to the southeast. Plunges are subhorizontal to moderate and either to the southwest or northeast. Folds generally develop a good axial planar cleavage (S_4), which is either a slaty cleavage with a bedding–cleavage intersection lineation (l_4), or where S_3 is present, a crenulation cleavage with a crenulation hinge lineation.

On HALLS CREEK, D_4 folds are tighter and were originally recumbent adjacent to the Angelo – Halls Creek Fault system, forming part of an easterly verging fold and thrust system (Griffin and Tyler, 1992; Blake et al., in press a).

D_4 folds in the Eastern zone predate the deposition of the Moola Bulla Formation, which unconformably overlies folded Olympio Formation rocks on HALLS CREEK. The relationship between the apparent D_3 folds in the Central zone and the D_4 folds in the Eastern zone is not certain. D_3 folds of the Tickalara Metamorphics farther north within the Central zone were originally oriented north-northwest before being refolded about north-northeasterly to northeasterly trending D_4 folds (Sheppard et al., 1997a). The D_4 structures are oriented parallel to D_4 folds in the Eastern zone, and may represent the same event. However, Orth (1997) and Blake et al. (in press a) did not recognize a second deformation affecting the Koongie Park Formation prior to the deposition of the Moola Bulla Formation.

On DOCKRELL, SHRIMP U–Pb zircon ages from a deformed phase and an undeformed phase within the Mount Christine Granitoid suggest that an episode of deformation did affect the Central zone between c. 1820 Ma and c. 1808 Ma (Tyler et al., in prep.b), similar to the age constraints for D_4 (Tyler et al., 1995). The difference in styles of deformation events of apparently the same age between the Central and Eastern zones during the Halls Creek Orogeny may reflect their development within separate tectonostratigraphic terranes. The first event that can be correlated unequivocably between the different zones is the intrusion of the younger phase of the Mount Christine Granitoid at c. 1808 Ma.

Metamorphism

In general, rocks in the Eastern zone of the Lamboo Complex on ANGELO have been metamorphosed under lower greenschist facies metamorphic conditions. Fine-grained chlorite and muscovite occur extensively within Olympio Formation rocks.

The metasedimentary rocks in the Koongie Park Formation are composed of quartz, albite, sericite, and chlorite with or without biotite, and with minor amounts of opaque minerals and rutile. Metabasaltic rocks are composed of actinolite or a blue-green edenitic amphibole, plagioclase (albite or oligoclase), clinozoisite, epidote, and sphene. Both types of metamorphic assemblages are consistent with greenschist or epidote–amphibolite facies metamorphism that was coincident with the formation of the cleavage associated with the early, possibly D_3 folds described above.

Mineral assemblages containing biotite and quartz occur in metasedimentary rocks at the Sandiego Zn–Cu prospect. However, chlorite is also common in many of the metasedimentary rocks, together with actinolite and talc. Either these minerals are part of a retrogressive event or biotite is present at lower than normal conditions because the original rocks contained more K-feldspar than normal pelites.

Amhurst Metamorphics (ꞒAm, ꞒAgm)

The Amhurst Metamorphics outcrop at the western margin of ANGELO, to the north of the Mount Amhurst Fault. They consist of a mixture of high-grade para- (*ꞒAm*) and orthogneisses (*ꞒAgm*) that were intruded by c. 1835 to 1805 Ma granitoids of the Sally Downs supersuite. Inclusions of paragneiss occur extensively in the younger granitoid. The metamorphic rocks can be interpreted as Marboo Formation and c. 1860 Ma Neville Granodiorite that originally had an outcrop pattern similar to that seen to the northwest of Duchess Dam (AMG 052917). The rocks were then overprinted by a high-grade metamorphic event between 1860 and 1805 Ma.

The paragneiss consists of medium- to coarse-grained, interlayered pelitic and psammitic rocks, with the pelitic units typically consisting of granofels containing quartz, plagioclase, biotite, cordierite, and garnet. Cordierite is typically pinitized.

The orthogneisses are banded and coarse grained and consist of biotite–hornblende granodiorite gneiss and biotite–andalusite–garnet–cordierite monzogranite gneiss. Garnet and cordierite grains may be up to 2 cm across. Cordierite typically forms subhedral grains that may show alteration at their margins, although fresh cores are generally preserved. Zircon occurs extensively throughout the rock.

Within the granitic orthogneiss there are rounded melanocratic inclusions that probably represent mafic inclusions within the original granitoid intrusion. These are coarse-grained and a relict subophitic igneous texture is preserved, but the rock now consists of sericite and epidote replacing feldspar, and amphibole replacing pyroxene. Quartz and apatite are also present.

The Amhurst Metamorphics on ANGELO are not migmatitic, and are characterized by the presence of andalusite rather than sillimanite. The mineral assemblages within the orthogneisses could be interpreted as reflecting a primary S-type granitoid, although the textures reflect recystallization of the original granitic rock during a subsequent metamorphic event. The presence of andalusite with garnet and cordierite indicates that metamorphism took place under low-pressure/medium- to high-temperature conditions (e.g. Hess, 1969). Farther to the southwest on MOUNT CUMMINGS, there are higher grade, sillimanite-bearing migmatitic rocks (Tyler et al., in prep.c).

Although the orthogneiss on ANGELO is banded, textures in thin section from both ortho- and paragneiss are typical of static metamorphism. However, metamorphism is not restricted to local contact aureoles (as is the case with metamorphism around the Neville Granodiorite northeast of Duchess Dam), and a regional-scale heat source may be centred farther to the southwest (Tyler et al., in prep.c). Metamorphism could be related to a major c. 1835–1805 Ma mafic intrusion at depth.

Palaeoproterozoic Moola Bulla Basin

Sediment deposited into the Palaeoproterozoic Moola Bulla Basin is preserved as sedimentary rock of the Moola Bulla Formation (Gemuts and Smith, 1967; Dow and Gemuts, 1969; Plumb and Gemuts, 1976). Rocks in the southeastern corner of ANGELO that were previously mapped as part of the Olympio Formation of the Halls Creek Group (Roberts et al., 1965, 1968) have been correlated with the Moola Bulla Formation (Griffin and Tyler, 1992, p. 12). They overlie the c. 1843 Ma Koongie Park Formation, apparently disconformably (see below). On HALLS CREEK (Blake et al., in press a) the Moola Bulla Formation lies unconformably on deformed Halls Creek Group rocks, and is overlain with minor angular discordance by rocks mapped as King Leopold Sandstone of the Kimberley Group. Dow and Gemuts (1969) suggested that the Moola Bulla Formation may be equivalent in part to the c. 1834 Ma Speewah Group (Dow and Gemuts, 1967, 1969; Griffin and Tyler, 1992; Page and Sun, 1994), which unconformably overlies the Western zone of the Lamboo Complex to the west of the Greenvale Fault.

The Moola Bulla Formation on HALLS CREEK has been interpreted as a fluvial and sandy braid-delta complex that drained from a granite and metasedimentary source area to the southwest (Blake et al., in press a). Because of the limited extent of the present day outcrop area and the lack of diagnostic criteria such as tide-generated structures, it is not known if this delta complex was associated with a lacustrine or marine environment. The differences in stratigraphy and provenance suggest that the Moola Bulla Formation was deposited in a basin separate from the Speewah Basin, whose outcrop is restricted to the west of the Greenvale Fault (Dow and Gemuts, 1969; Plumb and Gemuts, 1976; Sheppard et al., 1997a). The absence of the Speewah Group in the northwestern part of ANGELO has been attributed by Griffin and Tyler (in press) to syn- to post-Speewah Group uplift of the Lamboo Complex. The deposition of the Moola Bulla Formation may have been controlled by active faulting during this uplift.

Table 2 outlines the stratigraphy of the sedimentary rocks on ANGELO, from the Palaeoproterozoic to the Palaeozoic, within the Moola Bulla, Kimberley, Louisa, and Ord Basins.

Moola Bulla Formation (*Pl*)

The Moola Bulla Formation outcrops in a refolded syncline on the southeastern side of the Highway Fault (around AMG 370620), and as a thin sliver of the basal sandstone farther north against this fault. The maximum thickness of the unit, which consists of two sandstone units and an intervening shale unit, is 1350 m. A similar stratigraphy is recognized in the sequence found farther northeast on HALLS CREEK (Dow and Gemuts, 1969; Blake et al., in press a).

Folded banded iron-formation of the Koongie Park Formation occurs beneath the contact with the overlying Moola Bulla Formation at AMG 359615, suggesting an unconformable relationship. In the hinge area of the synform, the basal unit consists of 1000 m of sandstone and granule conglomerate that near the base contain abundant fragments of shale and chert ripped up from the underlying Koongie Park Formation. Heavy-mineral bands and trough cross-bedding, as well as normally graded sandstone beds, occur also near the base. Coarse-grained sandstone beds are up to 1 m thick. The overlying 320 m-thick argillite-dominated unit is composed of red to pink fine-grained sandstone and mudstone with occasional iron-rich red beds. Overlying the fine-grained sequence are several beds of sandstone that may reach a thickness of 700 m in the syncline core.

Along strike, facies changes are apparent from photo-interpretation. The lowermost unit identified in the southern area of the fold thins northward on both sides of the syncline. The middle unit changes character around the fold. Shale and fine- to medium-grained sandstone is dominant on its northern side, but is not apparent in the hinge area or at the southern edge of the fold, where there are more abundant medium- to coarse-grained sandstone lenses. The upper very coarse grained sandstone unit becomes prominant in the northern portion of the fold. Here it appears to form large outcrop-scale cross-bedded sandstone and abundant, parallel-bedded, coarse-grained sandstone beds.

The sandstones are moderately well sorted to poorly sorted with fragments displaying low sphericity and ranging from angular to subrounded. Very few well-rounded fragments occur. This, as well as the rock-fragment components, indicates that the rocks are submature to immature (Folk, 1974).

Fragment types include quartz and feldspar from a granitic source, abundant low-rank metamorphic fragments, and Koongie Park Formation volcanic and sedimentary clasts such as spherulitic rhyolite and chert. These indicate a provenance from an unroofed granitic and metamorphic terrane, and uplifted Koongie Park Formation. More quartz and fewer lithic fragments occur in the upper sandstone than in the rest of the formation.

Table 2. Stratigraphy of the Palaeoproterozoic to early Palaeozoic sedimentary rocks on ANGELO

Basin/Group	*Formation*	*Thickness (m)*	*Lithology*
ORD BASIN	Antrim Plateau Volcanics (*Ꞓa*)	>1 500	Massive, vesicular, and amygdaloidal basalt, minor sandstone
	Lally Conglomerate (*Ꞓl*)	33	Medium- to coarse-grained sandstone, quartz cobble conglomerate
~ ~ ~	~ ~ ~	*unconformity/disconformity*	~ ~ ~
LOUISA BASIN			
Louisa Downs	Lubbock Formation (*Ꝑll*)	1 830	Medium-grained quartz wacke, siltstone
Group	Tean Formation (*Ꝑlt*)	120	Fine- to medium-grained feldspathic sandstone, quartz sandstone, quartz wacke, conglomerate, siltstone, and mudstone
	McAlly Shale (*Ꝑlm*)	1 500	Mudstone, minor siltstone and fine-grained sandstone
	Yurabi Formation (*Ꝑly*)	125	Medium-grained sandstone, siltstone, mudstone, dolomitic siltstone, silty or sandy dolomite
	Egan Formation(*Ꝑle*)	40	Tillite, coarse-grained arkose, dolomite, algal dolomite, siltstone
~ ~ ~	~ ~ ~	*unconformity*	~ ~ ~
KIMBERLEY BASIN			
Kimberley Group	Pentecost Sandstone (*ꝐKp*)	900	Fine- to medium-grained sandstone, coarse-grained quartz sandstone, pebble and cobble conglomerate, siltstone, mudstone
	Elgee Siltstone (*ꝐKe*)	250	Mudstone, siltstone, sandstone, dolomite, dolomitic siltstone
	Teronis Member (*ꝐKet*)		Dolomite, stromalolitic dolomite, mudstone, siltstone, quarrtz sandstone
	Warton Sandstone (*ꝐKw*)	300	Fine- to medium-grained quartz sandstone
	Carson Volcanics (*ꝐKc*)	400	Metabasalt, quartz sandstone, feldspathic sandstone, siltstone
	King Leopold Sandstone (*ꝐKl*)	200	Medium- to coarse-grained quartz sandstone, thin pebble conglomerate bands
~ ~ ~	~ ~ ~	*unconformity/disconformity*	~ ~ ~
MOOLA BULLA BASIN	Moola Bulla Formation (*Ꝑl*)	1 350	Coarse feldspathic sandstone, pebble conglomerate, fine-to coarse-grained sandstone, siltstone, mudstone

When unfolded, the overall shape of the Moola Bulla Formation in this area indicates that it was deposited in a broad depression between topographic highs in the surrounding Koongie Park Formation. Palaeocurrent measurements indicate a transport direction from the west-southwest, consistent with the transport direction found in the Moola Bulla Formation on HALLS CREEK (Blake et al., in press a).

Palaeoproterozoic Kimberley Basin

Sedimentary rocks deposited in the Kimberley Basin, and which make up the Kimberley Group, are exposed in the northwestern corner of ANGELO, and as an outlier in the central and eastern part of the sheet. The Kimberley Group lies unconformably on the Lamboo Complex in both areas. The rocks were described in detail by Roberts et al. (1965). The Speewah Group, deposited in the Speewah Basin (Sheppard et al., 1997a) and which underlies the Kimberley Group elsewhere (Dow and Gemuts, 1969; Plumb and Gemuts, 1976; Griffin et al., 1993), is absent from ANGELO.

A lower limit on the age of the Kimberley Group is provided by the c. 1834 Ma age of the Speewah Group. An upper age limit is provided by a SHRIMP U–Pb zircon age obtained from granophyre from the Hart Dolerite, which was intruded into the Kimberley Group at 1790 ± 4 Ma (Page, R. W., 1994, pers. comm.).

The Kimberley Group has been interpreted by Plumb et al. (1981) as having been deposited within a broad, semi-enclosed, shallow marine basin. Palaeocurrents were from the north-northwest.

Kimberley Group

King Leopold Sandstone (*ꝐKl*)

The King Leopold Sandstone is the basal unit of the Kimberley Group (Table 1). An unconformity with the underlying Marboo Formation is exposed at the south-eastern end of One Palm Tree Gorge (AMG 141033). Elsewhere it unconformably overlies the Neville Granodiorite, and the Amhurst Metamorphics.

The unit has been described by Roberts et al. (1965, 1968) and consists of 200 m of white, blocky to massive, thick-bedded, medium- to coarse-grained quartz sandstone. Pebble bands are present, and trough cross-bedding is commonly developed.

Carson Volcanics (*ĿKc, ĿKcs*)

The Carson Volcanics conformably overlies the King Leopold Sandstone, and also unconformably overlies the Amhurst Metamorphics at the western margin of the sheet. The unit consists of 400 m of interlayered metabasalt, quartz sandstone, feldspathic sandstone, and siltstone.

The metabasalt includes rocks with amygdaloidal textures, and consists of laths of altered plagioclase, interstitial subhedral to anhedral clinopyroxene grains, and magnetite (Roberts et al., 1965). The clinopyroxene is altered to chlorite. Partially altered olivine phenocrysts are present in some samples in a matrix of tremolite–actinolite, clinozoisite, and opaque minerals.

Warton Sandstone (*ĿKw*)

The Warton Sandstone, which lies conformably on the Carson Volcanics, consists of 300 m (1000 feet) of white to purple, massive to blocky, thin-bedded, fine- to medium-grained quartz sandstone (Roberts et al., 1965). Siltstone and flaggy sandstone characterize the top and bottom of the unit. Trough cross-bedding features are abundant.

Elgee Siltstone (*ĿKe*)

The Elgee Siltstone lies conformably on the Warton Sandstone. It consists of 250 m of maroon mudstone and siltstone, interbedded with thin sandstone, dolomite, and dolomitic siltstone (Roberts et al., 1965). The Teronis Member lies at the base of the unit.

Teronis Member (ĿKet)

In the Mueller Ranges the Teronis Member of the Elgee Siltstone consists of 140 m of interbedded dolomite, mudstone, siltstone, and quartz sandstone (Roberts et al., 1965). Some dolomite beds contain abundant stromatolites.

Pentecost Sandstone (*ĿKpl, ĿKpm, ĿKpu*)

The Pentecost Sandstone is the uppermost unit of the Kimberley Group on Angelo, and lies conformably on the Elgee Siltstone. It is at least 900 m thick and can be divided into three sub-units, forming the lower, middle and upper parts of the formation.

The lower part consists of medium- to coarse-grained, thinly bedded to laminated quartz sandstone, whereas in the middle part the sandstones are interbedded with thin sequences of fine-grained sandstone, mudstone, and siltstone (Roberts et al., 1965, 1968). Ripple marks are common, as is cross-bedding. The upper part consists of massive and blocky, trough cross-bedded, coarse-grained quartz sandstone, and pebble to cobble conglomerate.

Hart Dolerite (*Ŀdh*)

The Hart Dolerite consists of a series of massive tholeiitic dolerite sills and less extensive granophyre which intrude the lower parts of the Kimberley Basin succession. The sills have a combined thickness of up to 3000 m, and underlie an area of about 160 000 km^2 (Plumb and Gemuts, 1976). The Hart Dolerite is exposed as a single sill, about 200–300 m thick, in the northwest corner of Angelo. It intruded the Carson Volcanics, or the contact between the Carson Volcanics and underlying King Leopold Sandstone. At the western edge of the sheet, a small sill, probably less than 50 m thick, intruded the unconformity between the King Leopold Sandstone and crystalline rocks of the Lamboo Complex.

On Angelo, the Hart Dolerite is a massive medium- to coarse-grained, ophitic dolerite that shows little vertical zoning (Roberts et al., 1965). Sparse phenocrysts of altered plagioclase are set in a groundmass of plagioclase and clinopyroxene, with disseminated opaque minerals. Minor chloritized ?olivine present in most samples, and brown biotite, apatite and sphene are common accessory minerals (Gellatly et al., 1975).

Mesoproterozoic Yampi Orogeny

In the Halls Creek Orogen large-scale, north-northeasterly trending sinistral strike-slip faults and easterly trending dextral faults developed after deposition in the Kimberley Basin had ceased. Displacements of up to 200 km have been suggested (Dow and Gemuts, 1969; Plumb and Gemuts, 1976; Plumb et al., 1985; Tyler et al., 1994, 1995; Thorne and Tyler, 1996). The faults affect rocks as young as Devonian; however, Dow and Gemuts (1969) noted that younger rocks showed smaller displacements than older rocks, suggesting that the faults have long, complex histories.

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 within the Lamboo Complex. The current fault pattern developed first as ductile structures in the Mesoproterozoic, accompanying the northeasterly directed folding and thrusting developed during the Yampi Orogeny in the King Leopold Orogen (Tyler and Griffin, 1993, 1994; Griffin et al., 1993). Later reactivations of the faults were more brittle. Griffin and Tyler (1992) referred to the initial, more ductile deformation as D_5, as it post-dated the Palaeoproterozoic D_1 to D_4 events recognized in the Central zone (Plumb et al., 1985; Sheppard et al., 1997a).

On Angelo, extensive faulting has taken place (Fig. 3), and three phases of folding have produced large-scale refolded fold patterns in the outliers of Kimberley Group and Moola Bulla Formation rocks in the eastern part of the sheet. The earliest fold phase (D_5) occurs as two curved, open to tight, upright folds of Elgee Siltstone and

Pentecost Sandstone to the south of Station Creek (AMG 332821 and AMG 325786), that now trend northwesterly. These are Type 2 fold-interference patterns (Ramsay and Huber, 1987) and have been refolded by D_6 and D_7. Their original orientation was as upright, shallowly plunging north-northeasterly oriented folds. The syncline of Moola Bulla Formation adjacent to the Angelo Fault also formed initially as a D_5 structure, as did the faulted syncline formed by King Leopold Sandstone and Carson Volcanics to the south of Pick and Shovel Bore (around AMG 250750). The latter structure is unconformably overlain by the Neoproterozoic glacigene rocks of the Louisa Downs Group, placing a minimum age on deformation, which probably formed in a sinistral transpressive regime that developed in the Halls Creek Orogen during the Yampi Orogeny. The age of deformation is poorly constrained by K–Ar ages from sheared granitoid rocks from the Hooper Complex to between 1475 ± 12 Ma and 999 ± 9 Ma (Shaw et al., 1992).

A cleavage is developed in Moola Bulla Formation rocks axial planar to the D_5 fold east of Mount Angelo. This cleavage was originally mapped as S_4 and is labelled as such on the ANGELO map sheet (Griffin and Tyler, 1994). However, from relationships in the Tickalara Metamorphics to the north, the D_4 event predated the deposition of rocks that are probably in part equivalent to the Moola Bulla Formation (Tyler et al., in prep.d). Cleavages also attributed to D_5 are found within rocks of both the Koongie Park Formation, and the Olympio Formation, where locally they crenulate S_3 or S_4. S_5 occurs also as a foliation in granitoids of the Sally Downs batholith.

The Angelo, Highway, Lamboo, and Woodward Faults, and the ancestral Ramsay Range – Springvale Fault were probably all active at this time. Fault zones are marked by zones of disrupted bedding, which may be several metres wide, and by the development of phyllonite, and quartz veins. Within the fault zones, the granitoids are substantially recrystallized and igneous minerals are partly replaced by greenschist-facies assemblages. This includes alteration of plagioclase cores to sericite and clinozoisite, chloritization of biotite, and replacement of magnetite and ilmenite by epidote and sphene respectively. Development of widespread microperthite and the possible replacement of igneous hornblende by biotite and epidote (e.g. Wyborn and Page, 1983), are also related to metamorphism accompanying D_5 (M_5). In the Koongie Park Formation, partial recrystallization of earlier-formed greenschist-facies assemblages took place during D_5 and M_5.

Mesoproterozoic dolerite dykes (*d, po*)

North-northwesterly to northerly trending dolerite dykes (*d*) cut the Neville Granodiorite and, to a lesser degree, the Marboo Formation and Gnewing Granodiorite in the northern part of the sheet. The dykes are up to 6 km long, and typically about 1.5–4 m wide. They stand out on the aerial photographs as narrow, dark, resistant ridges. Two dykes, up to about 100 m thick, cut across the Hart Dolerite and the base of the Kimberley Basin succession north of Neville Gorge. The dolerites have an ophitic or intergranular texture, and are locally weakly porphyritic. Clinopyroxene is partly replaced by chlorite and actinolite, plagioclase cores are altered to clinozoisite, and magnetite is commonly pseudomorphed by epidote. A northerly trending andesite to rhyolite porphyry dyke (*po*), containing coarse K-feldspar, quartz, and plagioclase, cuts the Neville Granodiorite 3.5 km west of Cameron Dam.

Neoproterozoic Louisa Basin

Louisa Downs Group

Neoproterozoic glacigene rocks outcrop extensively throughout the Kimberley region (Dow and Gemuts, 1969; Coates and Preiss, 1980; Plumb, 1981). The Louisa Downs Group outcrops against the Lubbock Range Fault, against the Ramsay Range Fault, and in the central part of ANGELO, where it unconformably overlies granitoid rocks of the Lamboo Complex, and sedimentary rocks of the Kimberley Basin. Elsewhere on MOUNT RAMSAY it unconformably overlies the Crowhurst Group, the Colombo Sandstone, and the Glidden Group (Roberts et al., 1968; Tyler et al., in prep.c). West of Louisa Downs, in the Kuniandi Range, it disconformably overlies the Kuniandi Group, also regarded as a Neoproterozoic glacigene sequence (Roberts et al., 1965).

Dow and Gemuts (1969) suggested that the tillite was a subaqueous deposit from a grounded ice sheet. Plumb (1981; 1993, pers. comm.) points out that the tillite interfingers with fluvioglacial outwash material occurring to the north and suggests that the deposits represent a palaeoglacier that passed southwards into a subaqueous, marine or lacustrine environment. Ice movement was from the north. Glaciation was followed by a marine transgression.

Coates and Preiss (1980) correlated the Louisa Downs Group with the Mount House Group, and with both the Duerdin Group and the overlying Albert Edward Group, and equated all three successions with the Maranoan Glaciation in South Australia, dated at c. 670 Ma. This was consistent with an age of 666 Ma for deposition of the McAlly Shale interpreted from the Rb–Sr data of Bofinger (1967) by Coates and Preiss (1980).

Plumb (1996) disputes this correlation, preferring to correlate the Louisa Downs Group with the Albert Edward Group; and the Mount House Group and the Duerdin Group with the Kuniandi Group. He regards the Louisa Downs Group as the product of a local, mountain glaciation that is not known elsewhere in Australia, but which has been identified just below the base of the Cambrian elsewhere in the world. Recent identification of the stromatolite *Tungussia julia* from carbonate near the base of the group confirms this correlation, and suggests that the glacigene rocks of the Kimberley region all belong to Supersequence 3 of the Centralian Basin (Walter et al., 1995; Corkeron et al., 1996.).

The Louisa Downs Group was divided into five formations which have a maximum combined thickness of some 4000 m (13 000 feet; Roberts et al., 1965, 1968, 1972). The following descriptions are based on the detailed measured sections of Roberts et al. (1965) with additional data from Coates and Preiss (1980), and Plumb (1981).

Egan Formation (*Ele*)

The Egan Formation is the basal unit of the Louisa Downs Group. It unconformably overlies gabbroic rocks of the Central zone of the Lamboo Complex at the southern margin of the sheet, and granitic rocks and the King Leopold Sandstone of the Kimberley Group southwest of Moola Bulla Homestead. It has been described in detail by Roberts et al. (1965, 1968, 1972), and on ANGELO consists of 40 m of tillite, coarse-grained quartz sandstone and arkose, fine- to medium-grained dolomitic sandstone and siltstone, and laminated dolomite.

Yurabi Formation (*Ely*)

The Yurabi Formation on ANGELO varies in thickness from 30 to 100 m, disconformably overlies the Egan Formation (Roberts et al., 1965), and lies directly on the Kimberley Group rocks southwest of Moola Bulla Homestead. It consists of fine- to medium-grained, ripple-laminated quartz sandstone interbedded with siltstone, mudstone, laminated dolomitic siltstone, and silty or sandy dolomite.

McAlly Shale (*Elm*)

The McAlly Shale conformably overlies the Yurabi Formation and consists of 1500 m of finely laminated mudstone, interbedded near its base with finely laminated siltstone and fine-grained sandstone.

Tean Formation (*Elt*)

The Tean Formation conformably overlies the McAlly Shale, and is 120 m thick. The unit consists mainly of fine- to medium-grained feldspathic sandstone and quartz wacke, interbedded with conglomerate, fine- to medium-grained quartz sandstone, and laminated siltstone and mudstone.

Lubbock Formation (*Ell*)

The Lubbock Formation conformably overlies the Tean Formation. It is at least 1830 m thick, and consists of interbedded ?turbiditic, medium-grained quartz wacke and siltstone. The quartz wackes may show graded bedding.

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 glacigene rocks. Shaw et al. (1992) obtained K–Ar ages of c. 560 Ma from reactivated shear zones, and these were interpreted as the age of deformation. Coates and Preiss (1980) and Plumb (1981) reported Rb–Sr ages of 568 and 576 ± 80 Ma respectively from the McAlly Shale of the Louisa Downs Group, both reinterpreted from the data of Bofinger (1967). These 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 was linked to sinistral strike-slip faulting in the east Kimberley (Tyler and Griffin, 1990; Tyler et al., 1991). Deformation occurred at about the same time as the Paterson Orogeny, and the Petermann Ranges Orogeny in central Australia (Myers et al., 1996).

In the central and southeastern parts of ANGELO, uplift and erosion of the Louisa Downs Group is indicated by the Cambrian Lally Conglomerate and Antrim Plateau Volcanics lying unconformably on lower Louisa Downs Group and Lamboo Complex rocks to the south of Pick and Shovel Bore (around AMG 260780). D_5 folds are refolded about upright, open to tight, northwesterly plunging D_6 folds, again producing Type 2 refolded fold patterns (Ramsay and Huber, 1987). Folds in this orientation affect the Neoproterozoic glacigene rocks in the King Leopold Range, and the Lubbock Range and Kuniandi Range farther to the west on MOUNT RAMSAY (Tyler et al., in prep.c), and on RUBY PLAINS to the southeast (Blake et al., in press b).

Cambrian Ord Basin

Supposed Cambrian strata, which consist of the Lally Conglomerate and the overlying basalts of the Antrim Plateau Volcanics, outcrop adjacent to the Lubbock Range and Ramsay Range faults at the western edge of the sheet. They overlie the Lubbock Formation of the Louisa Downs Group in this area with apparent conformity. However, this contact is regarded as a disconformity (Roberts et al., 1965) as the Lally Conglomerate unconformably overlies the Lamboo Complex, and the Yurabi Formation and McAlly Shale to the south of Pick and Shovel Bore. Uplift presumably took place during the King Leopold Orogeny and provides a c. 560 Ma maximum age for the deposition of the Lally Conglomerate and the Antrim Plateau Volcanics. In the Ord Basin on DIXON RANGE the Antrim Plateau Volcanics are overlain by Middle Cambrian strata (Mory and Beere, 1988).

Neoproterozoic to early Cambrian mafic volcanic rocks exist throughout central and northern Australia (Shaw et al., 1991). They represent a period of widespread continental extension that may have occurred in a back-arc setting along the eastern margin of Australia, adjacent to a Palaeo-Pacific Ocean (Myers et al., 1996).

Lally Conglomerate (Ꞓl)

The Lally Conglomerate has been described by Roberts et al. (1965, 1968). In the Ramsay Range the Lally Conglomerate is less than 33 m thick and consists of massive, cross-bedded medium- to coarse-grained sandstone, with local lenses of quartz-cobble conglomerate.

Antrim Plateau Volcanics (Ꞓa)

The Antrim Plateau Volcanics on ANGELO were described by Roberts et al. (1965, 1968). They conformably overlie the Lally Conglomerate and consist of massive, vesicular, and amygdaloidal basalt, with occasional sandstone interbeds.

Bultitude (1971) described the Antrim Plateau Volcanics from nine stratigraphic drillholes in the Victoria River District of the Northern Territory. The succession consists of feldspar-phyric, tholeiitic olivine to quartz basalt lava flows, which average 36 m in thickness. The lava flows are interlayered with local bands of agglomerate, as well as sandstone, siltstone, limestone, and chert beds. Individual flows have a central massive, medium-grained interior grading into an altered, fine-grained, vesicular zone in the upper, and generally also the basal part. Vesicles are filled with chlorite, quartz, calcite, chalcedony, agate, prehnite, and pumpellyite.

Late Devonian to Carboniferous Alice Springs Orogeny

On ANGELO, the Louisa Downs Group, Lally Conglomerate, and the Antrim Plateau Volcanics are folded into an open, large-scale, gently southwesterly plunging syncline against the Ramsay Range Fault. A throw of some 3.5 to 4 km (combined thickness of the Louisa Downs Group and Cambrian strata), down to the southeast, is suggested by the juxtaposition of Antrim Plateau Volcanics against Palaeoproterozoic granitoid. The structure may have formed as a hangingwall synform (*see* Ramsay and Huber, 1987, fig. 23.25) produced by local normal movement of the Ramsay Range Fault. Kimberley Group rocks to the north of the Laura River are folded by open to tight, north-northeasterly and south-southwesterly plunging large-scale folds, which refold D_5 and D_6 structures, and are therefore regarded as D_7. Refolding of the D_5 syncline of Moola Bulla Formation rocks about a north-northeasterly trending syncline is also attributed to D_7.

Kimberley Group rocks in the northwestern part of the sheet are folded by large-scale, open to tight, northeasterly trending folds such as the O'Donnell Syncline, associated with northwesterly directed thrusting on the Fig Tree Pool Fault. These structures deform Neoproterozoic glacial rocks to the southwest (Tyler et al., in prep.c).

Thorne and Tyler (1996) have pointed out that Upper Devonian sedimentation within the northern part of the Halls Creek Orogen shows many features associated with active strike-slip faulting in a sinistral transpressive environment. The pattern of synthetic north-northeasterly trending sinistral faults, such as the Mary River and Laura River Faults, antithetic northwesterly trending faults, and north-northeasterly to northeasterly trending folding and thrusting that post-dates Cambrian rocks may represent the effects the Upper Devonian to Carboniferous (400–300 Ma) Alice Springs Orogeny on ANGELO (Shaw et al., 1992; Tyler et al., 1995).

Cainozoic geology

Laterite (*Czl*) occurs extensively throughout the central part of ANGELO, forming a dissected high plateau. The laterite is generally regarded as having formed between the Late Cretaceous and Early Miocene (Hocking and Cockbain, 1990). Colluvial and alluvial deposits (*Czs*), consisting of partially consolidated silt, sand and gravel, overlie the laterite and also cover floodplains adjacent to drainage channels. Partly consolidated colluvial deposits (*Czc*) occur as valley-fill, and also overlie Halls Creek Group rocks in the southeastern part of the sheet.

Unconsolidated alluvium (*Qa*), consisting of silt, sand and gravel, lies along present drainage channels. Area of black soil plain (*Qb*) are often developed over mafic rocks.

Economic geology

The following descriptions of mineral deposits and occurrences on ANGELO are based on a summary of both published information and that contained within open-file WAMEX reports compiled by Sanders (in prep.), covering the whole of the East Kimberley.

Chromium and platinum group elements

The Lamboo Ultramafics host significant, but currently uneconomic deposits of chromium and platinum group elements (PGE) mineralization.

Chromium mineralization is best exposed in the western and central parts of the Lamboo mafic–ultramafic intrusion. It occurs within two poorly exposed 20 to 30 m-thick chromitite zones, separated by a 60 to 80 m interval of serpentinized peridotite, in the upper part of the lower ultramafic unit. The upper chromitite zone is mostly covered by recent deposits, which contain peridotite, chromitite and laterite float. As many as six chromitite layers ranging in thickness from 0.2 to 1.5 m may be present in the upper zone, and they may be locally thickened by folding and faulting.

The lower zone contains as many as seven chromitite layers of thicknesses similar to those in the upper zone.

These are magnetic and include very magnetic 0.1 to 0.25 m-thick peridotite bands containing up to 60% interstitial coarse chromite and magnetite grains.

The concealed eastern part of the Lamboo intrusion is marked by a magnetic feature, and can be traced southwards beneath Cainozoic deposits until it is truncated by the Highway Fault on DOCKRELL (Tyler and Griffin, 1994). Small chromitite outcrops and linear zones of chromitite float pick out a 5 to 25 m-wide zone containing up to five narrow (5–72 cm thick) chromitite seams which can be followed for nearly 4 km.

The chromitite layers may contain up to 80% non- to slightly magnetic chromite as disseminated subhedral to euhedral grains (0.2–0.5 mm) within a fine-grained serpentine matrix. Analysed chromitite contains between 41.9 and 47.1% Cr_2O_3, and 0.05 to 0.3 ppm Pt.

Significant PGE mineralization is apparently confined to chromitite from the lower ultramafic unit of the intrusion. In the western and central parts of the intrusion values of 0.30 ppm Pt and 42 ppm Pd have been obtained from chromitite in drillcore. In the eastern part values of between 0.1 and 0.52 ppm combined Pt and Pd (with the relative amounts of Pt and Pd being subequal) have been obtained from rock-chip sampling of the thin chromitite layers.

Gold

Since 1994 Nicholsons Find (AMG 261633), which has an inferred resource of 279 000 t at 5.54 g/t Au, has been developed as an opencut gold mine by Precious Metals Australia. Ore is being trucked to their Palm Springs mine, east of Halls Creek, for processing. Several other smaller prospects are also present in the area.

Mineralization is restricted to northerly trending quartz veining within strongly oxidized and kaolinized felsic volcaniclastic rocks of the Koongie Park Formation. A north-northeasterly trending sheared contact with the Loadstone Monzogranite lies immediately to the east. Deformation may have taken place initially during the Mesoproterozoic Yampi Orogeny.

Mineralization occurs over a strike length of 140 m and varies in width within this zone from 1 to 7 m. The quartz veins are massive to fractured and vuggy in places, with limonite present in cavities (after sulfide, with some remnant pyrite). Mineralization also occurs as disseminations, and fracture coatings. Thin (<2 cm) ferruginous, silicified and epidote-bearing alteration selvedges occur adjacent to the quartz veins, and as fracture coatings. The quartz veins may be capped by a zone of gold enrichment, which is often underlain by a zone of gold depletion. Gold values are higher in association with limonite replacing sulfide in the quartz veins. Samples from the deposit also have anomalous values of Pb, Ag, and As.

At the Gnewing Bore prospect (AMG 363018) a northwesterly trending, 50 m-long, gossanous outcrop is strongly anomalous in Au, Ag, As, and Pb. The mineralization has developed over quartz veins within migmatitic pelitic metasedimentary rocks of the Marboo Formation. Limonite after pyrite boxwork is evident in some of the quartz veins and locally in the ferruginous metasedimentary rock.

Gold mineralization is present in the hangingwall of the Sandiego Zn–Cu prospect (see below) associated with copper. The best gold intersection is 6 m at 2.4 g/t Au.

The Soda Spring prospects (AMG 675934) are associated with east-northeasterly trending quartz veins in the Grimpy Monzogranite that are oriented parallel to the Glidden Fault. The quartz veins are also parallel to thin, foliated doleritic dykes. Narrow (<1 m) epidote alteration selvedges are typically developed adjacent to both the quartz veins and the doleritic dykes.

Gold values up to 15 g/t Au have been reported from the veins. Malachite, chrysocolla, chalcopyrite, and galena are also present, and analysed samples are strongly anomalous in Cu, Ag and Au and moderately anomalous in Pb and Zn.

Nickel–copper

Soil sampling over the lower ultramafic zone in eastern part of the Lamboo mafic–ultramafic intrusion delineated several low PGE–Au–Ni–Cu anomalies coincident with, or very close to, thin chromitite layers. The correlation of elevated Ni with Cu and precious metals over areas underlain by dunite is consistent with a magmatic sulfide origin.

Zinc–lead–copper(–silver)

A number of significant but as yet subeconomic Zn–Pb–Cu(–Ag) deposits occur within felsic metavolcanic rocks and associated metamorphosed chert, iron-formation, red shaly siltstone and mudstone, and carbonate of the c. 1843 Ma Koongie Park Formation. These have been interpreted as stratabound volcanic-associated massive sulfide deposits.

The Sandiego prospect (AMG 398686) is the largest of the known deposits, and has a primary-zone indicated resource of 4.3 Mt at 7.9% Zn, 1.0% Pb, 0.51% Cu and 31 g/t Ag, and a supergene demonstrated resource of 300 000 t at 6.71% Cu, 290 g/t Ag, with Au grades locally >2 g/t. The oxide zone extends to approximately 100–120 m below surface.

The mineralization occurs in steeply southward-plunging, discontinuous sulfide gossans hosted by carbonate-rich chlorite schists and cherts over a strike length of 350 m along the western limb of a fold. Massive sulfide shoots are aligned parallel to the plunge of the fold axes of tight folds, suggesting a later, possibly local structural control on mineralization.

The primary sulfides exhibit a crude zonation with massive sphalerite, pyrrhotite and accessory galena, overlain by a hangingwall stringer zone of chalcopyrite and pyrite. Magnetite is an important minor mineral in much of the deposit and contributes to the prominent magnetic signature. The supergene sulfides consist of chalcocite and unidentified silver minerals. Carbonate, chlorite, and talc dominate the alteration mineralogy.

The Hanging Tree prospect (AMG 382655), located 3.5 km to the southwest of the Sandiego prospect, consists of three discrete gossans with the largest outcroping over a strike length of 150 m. Mineralization occurs in a silicified and brecciated carbonate horizon that contains graphitic interbeds. The main gossan has maximum grades of 0.37% Cu, 0.57% Pb, and 0.9% Zn. Percussion and diamond drillholes intersected stringer and disseminated sphalerite, galena and chalcopyrite in shale units that are intruded by dolerite.

The Mount Angelo North Cu–Ag prospect (AMG 403603) occurs within the Koongie Park Formation between two splays of the Angelo Fault. Two prominent limonitic copper gossans 60 m long and up to 18 m wide, occur 150 m apart. Boxworks are common and secondary copper minerals (malachite, azurite, cuprite) are apparent just below the surface.

Copper and silver mineralization is hosted in the lower part of a zone of interbedded volcanogenic metasedimentary rocks, carbonate, chert, and iron-formation, and consists of two lenses of massive chalcopyrite, with lesser amounts of pyrrhotite, magnetite, arsenopyrite, and galena, together with associated stringer zones. A pyritic halo surrounds the mineralized zone.

The deposit has a primary sulfide resource of 200 000 t at 2.0% Cu, with resources of 76 000 t at 1.0% Cu and 9.6 g/t Ag in the carbonate gossan, 35 000 t at 1.1% Cu and 45.0 g/t Ag in the silver enrichment zone, and 11 000 t at 7.7% Cu and 19.1 g/t Ag in the copper enrichment zone (Ferguson, in press).

The Emull prospect (AMG 204617) has total demonstrated resources of 4.7 Mt grading 4.5% Zn, 0.33% Cu, 0.2% Pb, and 19 g/t Ag.

The deposit is located near the contact between the Emull Gabbro and poorly exposed, lateritized metasedimentary rocks originally assigned to the Tickalara Metamorphics (Griffin and Tyler, 1994) but now regarded as forming part of the Koongie Park Formation. The Laura River Fault is 2 km to the east of the deposit.

The main mineralized zone has a strike length of 500 m and trends at 290°, dipping to the south at approximately 70°. It consists of a series of en echelon lenses or pods of disseminated to massive Zn-rich sulfides hosted by 'serpentinite' (silicified in outcrop) and calc-silicate rocks within gabbro, which also contains disseminated low-grade mineralization (pyrrhotite and pyrite, with minor chalcopyrite and sphalerite). The 'serpentinite' and calc-silicate rocks were probably derived by metasomatism of the enclosing gabbro (suggesting that mineralization is secondary) following intrusion of the gabbro, and is possibly related to granitoid intrusion.

A strongly oxidized limonitic (?pseudo) gossan at Dusty Bore (AMG 281643) contains 0.61% Cu, 0.63% Pb, 0.70% Zn, and 6 ppm Ag.

The Blackfellow Creek Pb–Cu–Ag prospect (AMG 984917) occurs within the Hart Dolerite at the south-eastern margin of the Kimberley Basin. Galena and malachite are present in an easterly trending quartz vein that extends along strike for approximately 90 m.

Uranium–copper

The Amphitheatre U–Cu prospect (AMG 263747) occurs within metasedimentary rocks of the Koongie Park Formation that are immediately below an angular unconformity with overlying quartz sandstone of the King Leopold Sandstone. The sandstones are at the base of an outlier of Palaeoproterozoic Kimberley Group rocks to the southwest of Moola Bulla Homestead.

The metasedimentary rocks of the Koongie Park Formation have been locally metamorphosed to high grade, probably by contact metamorphism with an adjacent gabbroic intrusion.

The uranium mineralization occurs as (yellow) carnotite closely associated with limonite in a ferruginous quartz–muscovite–clay (kaolin–montmorillonite–illite) rock. The highest radioactivity (>15 000 cps) was recorded over a very narrow carnotite-bearing ferruginous and clay-rich zone that assayed 0.27% U. Mineralization is controlled by both bedding and local faulting.

Copper minerals including malachite, azurite, bornite, and ?chalcopyrite occur in dolomite and calc-silicate rock in the vicinity of the main U mineralization. One surface sample assayed 1.08% Cu.

References

BEARD, J. S., 1979, The vegetation of the Kimberley area: Vegetation Survey of Western Australia, 1:1 000 000 Vegetation Series, Explanatory Notes to Sheet 1: Perth, University of Western Australia Press, 118p.

BLAKE, D. H., and HOATSON, D. M., 1993, Granite, gabbro, and migmatite field relationships in the Proterozoic Lamboo Complex of the east Kimberley region, Western Australia: AGSO Journal of Australian Geology and Geophysics, v. 14, p. 319–330.

BLAKE, D. H., TYLER, I. M., GRIFFIN, T. J., THORNE, A. M., and WARREN, R. G., in press a, The geology of the Halls Creek 1:100 000 geological sheet, Western Australia: Australian Geological Survey Organisation, Record.

BLAKE, D. H., TYLER, I. M., and SHEPPARD, S., in press b, The geology of the Ruby Plains 1:100 000 geological sheet, Western Australia: Australian Geological Survey Organisation, Record.

BOFINGER, V. M., 1967, Geochronology of the east Kimberley area of Western Australia: Australian National University, PhD thesis (unpublished).

BULTITUDE, R. J., 1971, The Antrim Plateau Volcanics, Victoria River District, Northern Territory: Australia BMR Geology and Geophysics, Record 1971/69, 74p.

COATES, R. P., and PREISS, W. V., 1980, Stratigraphic and geochronological reinterpretation of late Proterozoic glaciogenic sequences in the Kimberley Region, Western Australia: Precambrian Research, v. 13, p. 181–208.

CORKERON, M., GREY, K., LI, Z. X., PLUMB, K. A., POWELL, C. McA., and von der BORCH, C. C., 1996, Neoproterozoic glacial episodes in the Kimberley region, northwestern Australia: Geological Society of Australia, Abstracts, v. 41, p. 97.

DOW, D. B., and GEMUTS, I., 1967, Dixon Range, W.A., 1:250 000 geological series explanatory notes: Australia BMR Geology and Geophysics, 15p.

DOW, D. B., and GEMUTS, I., 1969, Geology of the Kimberley Region, Western Australia: The East Kimberley: Western Australia Geological Survey, Bulletin 120, 135p.

ETHERIDGE, M. A., RUTLAND, R. W. R., and WYBORN, L. A. I., 1987, Orogenesis and tectonic process in the early to middle Proterozoic of Northern Australia, *in* Proterozoic lithospheric evolution *edited by* A. KRONER: Geodynamic Series 17, American Geophysical Union, Washington D.C., p. 131–147.

FERGUSON, K. M. in press, Lead, zinc and silver deposits of Western Australia: Western Australia Geological Survey, Mineral Resources Bulletin 15.

FOLK, R. L., 1974, Petrology of sedimentary rocks: Austin, Hemphill, 182p.

GELLATLY, D. C., DERRICK, G. M., and PLUMB, K. A., 1975, The geology of the Lansdowne 1:250 000 sheet area, Western Australia: Australia BMR, Report 152, 100p.

GEMUTS, I., 1971, Metamorphic and igneous rocks of the Lamboo Complex, East Kimberley Region, Western Australia: Australia BMR, Bulletin 107, 71p.

GEMUTS, I., and SMITH, J. W., 1967, Gordon Downs, W.A., 1:250 000 geological series explanatory notes: Australia BMR, 23p.

GRIFFIN, T. J., and GREY, K., 1990, King Leopold and Halls Creek Orogens, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 232–253.

GRIFFIN, T. J., and MYERS, J. S., 1988, Geological Note: A Proterozoic terrane boundary in the King Leopold Orogen, Western Australia: Australian Journal of Earth Sciences, v. 35, p. 131–132.

GRIFFIN, T. J., SHEPPARD, S., and TYLER, I. M., 1994, Geochemical constraints on the tectonic evolution of the Early Proterozoic orogens in the Kimberley region of Western Australia: Geological Society of Australia, Abstracts, v. 37, p. 151–152.

GRIFFIN, T. J., and TYLER, I. M., 1992, Geology of the southern Halls Creek Orogen — a summary of field work in 1992: Western Australia Geological Survey, Record 1992/17, 28p.

GRIFFIN, T. J., and TYLER, I. M., 1994, Angelo, W. A. Sheet 4361: Western Australia Geological Survey, 1:100 000 Geological Series.

GRIFFIN, T. J., and TYLER, I. M., in press, The Geology of the King Leopold Orogen: Western Australia Geological Survey, Bulletin.

GRIFFIN, T. J., TYLER, I. M., and PLAYFORD, P. E., 1993, Lennard River W.A. (third edition): Western Australia Geological Survey, 1:250 000 Series Explanatory Notes, 56p.

HANCOCK., S. L., 1991, Tectonic development of the Lower Proterozoic basement in the Kimberley district of northwestern Western Australia: University of Adelaide, PhD thesis (unpublished).

HANCOCK, S. L., and RUTLAND, R. W. R., 1984, Tectonics of an Early Proterozoic geosuture — The Halls Creek orogenic subprovince, northern Australia: Journal of Geodynamics, v. 1, p. 387–432.

HESS, P. C., 1969, The metamorphic paragenesis of cordierite in pelitic rocks: Contributions to Mineralogy and Petrology, v. 24, p. 191–207.

HOCKING, R. M., and COCKBAIN, A. E., 1990, Regolith *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 591–602.

MORY, A. J., and BEERE, G. M., 1988, Geology of the onshore Bonaparte and Ord Basins: Western Australia Geological Survey, Bulletin 134, 184p.

MYERS, J. S., SHAW, R. D., and TYLER, I. M., 1996, Tectonic evolution of Proterozoic Australia: Tectonics, v. 15, p. 1431–1446.

OGASAWARA, M., 1988, Geochemistry of the Early Proterzoic granitoids in the Halls Creek orogenic subprovince, northern Australia: Precambrian Research, v. 40/41, p. 469–486.

ORTH, K., 1997, Notes on the Geology of the Koongie Park Formation southwest of Halls Creek, Western Australia: Australian Geological Survey Organisation, Record 1997/25, 18p.

PAGE, R. W., BLAKE, D. H., and TYLER, I. M., in prep. b, Geochronology of the Halls Creek Group and associated rocks in the East Kimberley, Western Australia.

PAGE, R. W., BLAKE, D. H., TYLER, I. M., GRIFFIN, T. J., and THORNE, A. M., 1994, New geological and geochronological constraints on VMS prospectivity near Halls Creek, W. A.: AGSO Research Newsletter 20, p. 5–7.

PAGE, R. W., and HANCOCK, S. L., 1988, Geochronology of a rapid 1.85–1.86 Ga tectonic transition — Halls Creek Orogen, northern Australia: Precambrian Research, v. 40/41, p. 447–467.

PAGE, R. W., SHEPPARD, S., GRIFFIN, T. J., and TYLER, I. M., in prep. a, Geology and SHRIMP geochronology of Palaeoproterozoic granites in the Lamboo Complex of the Halls Creek Orogen, Western Australia: Journal of the Geological Society of London.

PAGE, R. W., and SUN, S-s, 1994, Evolution of the Kimberley Region, W.A. and adjacent Proterozoic inliers — new geochronological constraints: Geological Society of Australia Abstracts, v. 37, p. 332–333.

PLUMB, K. A., 1981, Late Proterozoic (Adelaidian) tillites of the Kimberley–Victoria River region, Western Australia and Northern Territory, *in* Earth's pre-Pleistocene glacial record *edited by* M. J. HAMBREY and W. B. HARLAND: Cambridge, Cambridge University Press, p. 528–530.

PLUMB, K. A., 1996, Revised correlation of Neoproterozoic glacial successions from the Kimberley region, northwestern Australia: Geological Society of Australia, Abstracts, v. 41, p. 344.

PLUMB, K. A., ALLEN, R., and HANCOCK, S. L., 1985, Proterozoic evolution of the Halls Creek Province, Western Australia: Australia BMR, Record 1985/25, 87p.

PLUMB, K. A., DERRICK, G. M., NEEDHAM, R. S., and SHAW, R. D., 1981, The Proterozoic of Northern Australia, *in* Precambrian of the southern hemisphere *edited by* D. R. HUNTER: Developments in Precambrian geology 2, Amsterdam, Elsevier, p. 205–307.

PLUMB, K.A., and GEMUTS, I., 1976, Precambrian geology of the Kimberley region, Western Australia: 25th International Geological Congress Excursion Guide no. 44C, 69p.

RAMSAY, J. G., and HUBER, M. I., 1987, The techniques of modern structural geology, Volume 2: Folds and Fractures: London, Academic Press, 392p.

ROBERTS, H. G., GEMUTS, I., and HALLIGAN, R., 1972, Adelaidean and Cambrian stratigraphy of the Mount Ramsay 1:250 000 sheet area, Kimberley region, Western Australia: Australia BMR, Report 150, 72p.

ROBERTS, H. G., HALLIGAN, R., and GEMUTS, I., 1965, Geology of the Mount Ramsay 1:250 000 sheet area, E/52-9, Western Australia: Australian Geological Survey Organisation, Record 1965/156, 209p.

ROBERTS, H. G., HALLIGAN, R., and PLAYFORD, P. E., 1968, Mount Ramsay, W.A., 1:250 000 geological series explanatory notes: Australia BMR, 24p.

RUTLAND, R. W. R., 1981, Structural framework of the Australian Precambrian, *in* Precambrian of the southern hemisphere *edited by* D. R. HUNTER: Developments in Precambrian Geology 2, Amsterdam, Elsevier, p. 1–32.

SANDERS, T., in prep., Mineral occurrences of the Halls Creek Orogen, East Kimberley District, Western Australia: Western Australia Geological Survey, Report.

SHAW, R. D., ETHERIDGE, M. A., and LAMBECK, K., 1991, Development of the late Proterozoic to mid- Palaeozoic, intracratonic Amadeus Basin in Central Australia: A key to understanding tectonic forces in plate interiors: Tectonics, v. 10, p. 688–721.

SHAW, R. D., TYLER, I. M., GRIFFIN, T. J., and WEBB, A., 1992, New K–Ar constraints on the onset of subsidence in the Canning Basin, Western Australia: Australia BMR, Journal of Australian Geology and Geophysics, v. 13, p. 31–35.

SHEPPARD, S., GRIFFIN, T. J., and TYLER, I. M., 1995, Geochemistry of felsic igneous rocks from the southern Halls Creek Orogen: Western Australia Geological Survey, Record 1995/4, 81p.

SHEPPARD, S., TYLER, I. M., and HOATSON, D. M., 1997a, The geology of the Mount Remarkable 1:100 000 geological sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 27p.

SHEPPARD, S., GRIFFIN, T. J., and TYLER, I. M., 1997b, The tectonic setting of granites in the Halls Creek and King Leopold Orogens, Northwest Australia: Australian Geological Survey Organisation, Record 1997/44, p. 107–109.

TAYLOR, W. R., PAGE, R. W., ESSLEMONT, G., ROCK, N. M. S., and CHALMERS, D. I., 1995a, Geology of the volcanic-hosted Brockman rare-metals deposit, Halls Creek Mobile Zone, northwest Australia, Part I — Volcanic environment, geochronology and petrography of the Brockman volcanics: Mineralogy and Petrology, v. 52, p. 209–230.

TAYLOR, W. R., ESSLEMONT, G., and SUN, S-s, 1995b, Geology of the volcanic-hosted Brockman rare-metals deposit, Halls Creek Mobile Zone, northwest Australia, Part II — Geochemistry and petrogenesis of the Brockman volcanics: Mineralogy and Petrology, v. 52, p. 231–255.

THOMPSON, A. B., 1982, Dehydration melting of pelitic rocks and the generation of H_2O-undersaturated granitic liquids: American Journal of Science, v. 282, p. 1567–1595.

THORNE, A. M., and TYLER, I. M., 1996, Mesoproterozoic and Phanerozoic sedimentary basins in the northern Halls Creek Orogen: constraints on the timing of strike-slip movement on the Halls Creek Fault system: Western Australia Geological Survey, Annual Review 1995–96, p. 156–168.

TYLER, I. M., and GRIFFIN, T. J., 1990, Structural development of the King Leopold Orogen, Kimberley Region, Western Australia: Journal of Structural Geology, v. 12, p. 703–714.

TYLER, I. M., and GRIFFIN, T. J., 1993, Yampi, W.A. (second edition): Western Australia Geological Survey, 1:250 000 Series Explanatory Notes, 32p.

TYLER, I. M., and GRIFFIN, T. J., 1994, Dockrell, W. A. Sheet 4360: Western Australia Geological Survey, 1:100 000 Geological Series.

TYLER, I. M., GRIFFIN, T. J., and SHAW, R. D., 1991, Early Palaeozoic tectonism and reactivation of pre-existing basement structures at the margins of the Kimberley Craton, Western Australia: Geological Society of Australia, Abstracts, v. 31, p. 70–71.

TYLER, I. M., GRIFFIN, T. J., PAGE, R. W., and SHAW, R. D., 1994, The Halls Creek fault zone: repeated reactivation of a major north Australian tectonic boundary: Geological Society of Australia, Abstracts, v. 36, p. 167–168.

TYLER, I. M., GRIFFIN, T. J., PAGE, R. W., and SHAW, R. D., 1995, Are there terranes in the Lamboo Complex of the Halls Creek Orogen: Western Australia Geological Survey, Annual Review 1993–94, p. 37–46.

TYLER, I. M., and PAGE, R. W., 1996, Palaeoproterozoic deformation, metamorphism and igneous intrusion in the central zone of the Lamboo Complex, Halls Creek Orogen: Geological Society of Australia, Abstracts, v. 41, p. 450.

TYLER, I. M., HOATSON, D. M., SHEPPARD, S., BLAKE, D. H. and WARREN, R. G., in prep. a, The geology of the McIntosh 1:100 000 geological sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes.

TYLER, I. M., GRIFFIN, T. J and SHEPPARD, S., in prep. b, The geology of the Dockrell 1:100 000 geological sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes.

TYLER, I. M., GRIFFIN, T. J., HOCKING, R. M., and PLAYFORD, P. E., in prep. c, Explanatory notes on the the Mount Ramsay 1:250 000 Sheet SE/52-9, Western Australia (second edition): Western Australia Geological Survey, Record.

TYLER, I. M., THORNE, A. M., HOATSON, D. M., and BLAKE, D. H., in prep. d, The geology of the Turkey Creek 1:100 000 geological sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes.

TYLER, I. M., PAGE, R. W., and GRIFFIN, T. J., in prep. e, Depositional age and provenance of the Marboo Formation from SHRIMP U–Pb zircon geochronology: Implications for the Palaeoproterozoic tectonic evolution of the Kimberley region, Western Australia: Precambrian Research.

VERNON, R. H., 1991, Interpretation of microstructures of microgranitoid enclaves, *in* Enclaves and granite petrology *edited by* J. DIDIER and B. BARBARIN: Developments in Petrology, 13, Amsterdam, Elsevier, p. 277–291.

WALKER, R. G., 1984, Turbidites and associated coarse clastic deposits, *in* Facies models (second edition) *edited by* R. G. WALKER: Geoscience Canada, Reprint Series 1, p. 171–188.

WALTER, M. R., VEEVERS, J. J., CALVER, C. R., and GREY, K., 1995. Late Proterozoic stratigraphy of the Centralian Superbasin, Australia. Precambrian Research, v. 73, p. 173–195.

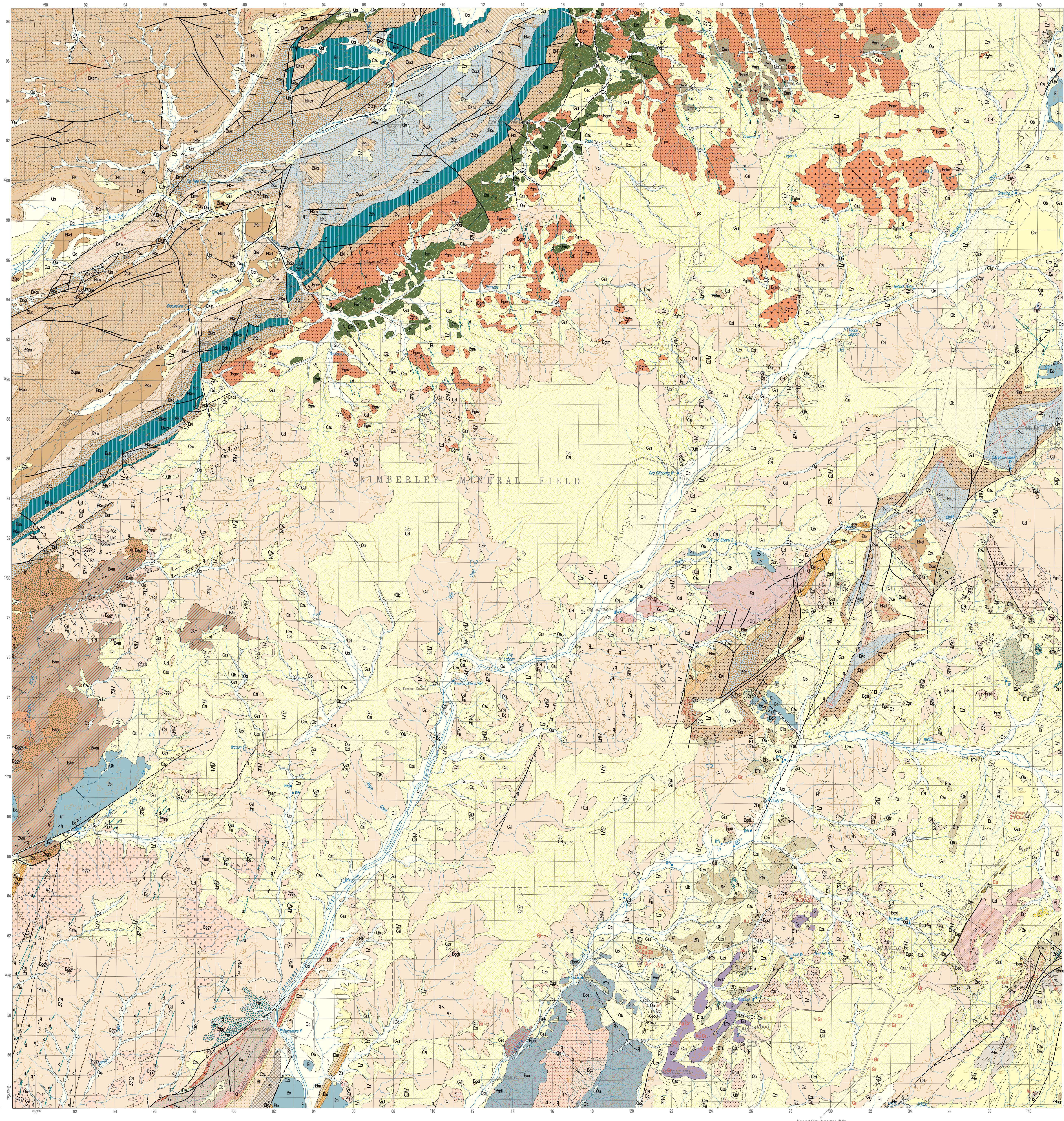
WARREN, R. G., 1994, Role of early extensional faults in the Grants Patch district, east Kimberley, Western Australia: Geological Society of Australia, Abstracts, v. 37, p. 453–454.

WYBORN, L. A. I., 1988, Petrology, geochemistry and origin of a major Australian 1880–1840 Ma felsic volcano-plutonic suite: a model for intracontinental felsic magma generation: Precambrian Research, v. 40/41, p. 37–60.

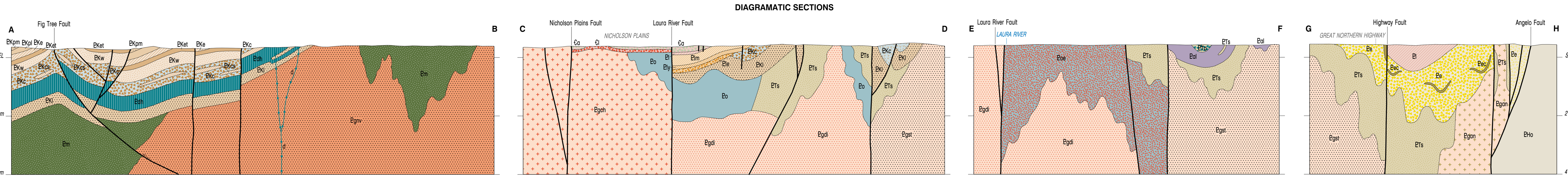
WYBORN, L. A. I., and PAGE, R. W., 1983, The Proterozoic Kalkadoon and Ewen batholiths, Mount Isa Inlier, Queensland: source, chemistry, age, and metamorphism: BMR Journal of Australian Geology and Geophysics, 8, p. 53–69.

ANGELO

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA



DIAGRAMATIC SECTIONS



PHANEROZOIC

CAINOZOIC — QUATERNARY

Qa Alluvium—unconsolidated silt, sand, and gravel
Qb Black soil—clay and silt

Czs Colluvium and alluvium—partly consolidated silt, sand, and gravel; adjacent to drainage; sand plain on laterite surface
Czc Colluvium—partly consolidated scree and valley-fill deposits
Czl Laterite—massive and pisolitic ferruginous duricrust; forms plateaus overlying weathered rock (₽g—granitoid, ₽A—Amherst Metamorphics, ₽T—Ticklara Metamorphics); steep breakaways commonly form at the margins

q Quartz veins, of various ages; youngest generation postdates Cambrian units

PALAEOZOIC — CAMBRIAN

Ꞓa **ANTRIM PLATEAU VOLCANICS:** dark grey vesicular and amygdaloidal basalt; generally deeply weathered

Ꞓl **LALLY CONGLOMERATE:** medium- to coarse-grained quartz sandstone, and cobble conglomerate

PROTEROZOIC

c. 670 Ma — Louisa Downs Group

₽ll **LUBBOCK FORMATION:** grey, green, or purple siltstone and shale; interbedded with fine- and medium-grained quartz wacke

₽lt **TEAN FORMATION:** feldspathic sandstone, quartz wacke, quartz sandstone, pebble conglomerate, siltstone, and shale; minor dolomite

₽lm **McALLY SHALE:** black, grey, and green shale; minor siltstone and fine- to very fine-grained sandstone

₽ly **YURABI FORMATION:** flaggy to blocky quartz sandstone and feldspathic sandstone; grey and purple siltstone, shale, dolomitic siltstone, and sandy dolomite

₽le **EGAN FORMATION:** tillite, arkose, dolomite, limestone, sandstone, siltstone, and shale

d Dolerite dyke
po Andesite to rhyolite porphyry dyke; coarse phenocrysts of K-feldspar, quartz, and plagioclase

c.1800 Ma

₽dh **HART DOLERITE:** dark grey dolerite

Kimberley Group (KIMBERLEY BASIN)

PENTECOST SANDSTONE:
₽Kpu Upper unit: medium- to coarse-grained quartz sandstone and pebbly quartz sandstone
₽Kpm Middle unit: white, fine- to coarse-grained quartz sandstone; purple, fine-grained sandstone, siltstone, and shale
₽Kpl Lower unit: quartz sandstone and siltstone

₽Ke **ELGEE SILTSTONE:** red-brown and grey siltstone and shale; minor quartz sandstone

₽Ket **Teronis Member:** stromatolitic dolomite, sandy dolomite, oolitic dolomite, shale, micaceous siltstone, and fine-grained sandstone

₽Kw **WARTON SANDSTONE:** white to purple, massive to blocky, quartz sandstone; minor feldspathic sandstone

₽Kc **CARSON VOLCANICS:** green to black basalt, amygdaloidal basalt, and basaltic volcaniclastic rocks; interbedded quartz sandstone, feldspathic sandstone, and laminated siltstone and mudstone

₽Kcs Pale yellow-brown, laminated to massive, quartz- and felspar-rich sandstone and siltstone

₽Kl **KING LEOPOLD SANDSTONE:** white to pale brown, medium- to coarse-grained quartz sandstone and pebbly quartz sandstone

₽l **MOOLA BULLA FORMATION:** lithic quartz sandstone and granule to pebble conglomerate; minor argillite

c. 1820 Ma (LAMBOO COMPLEX)

₽gch **MOUNT CHRISTINE GRANITOID:** coarsely porphyritic to medium-grained biotite monzogranite
₽gdi **DILLINGER MONZOGRANITE:** medium- to fine-grained, locally porphyritic, leucocratic biotite monzogranite; minor syenogranite; abundant mafic inclusions adjacent to contacts with gabbro
₽ggy **GRIMPY MONZOGRANITE:** weakly porphyritic, fine-grained biotite monzogranite
₽gst **LOADSTONE MONZOGRANITE:** weakly porphyritic biotite monzogranite and syenogranite; minor microgranodiorite
₽gx Granitoid rocks rich in inclusions of angular, rounded and flattened, mafic rock

₽o Undivided porphyritic to even-grained, medium- to fine-grained gabbro, quartz gabbro, and tonalite; extensively veined by granitoid rocks locally
₽oe **EMULL GABBRO:** medium- to fine-grained gabbro, quartz gabbro, and tonalite; extensively veined by the DILLINGER MONZOGRANITE, aplite, quartz-feldspar porphyry, and pegmatite

₽gan **ANGELO MICROGRANITE:** altered medium- to fine-grained granophyric microgranite; disseminated malachite locally present

c.1840 Ma

₽e **KOONGIE PARK FORMATION:** metamorphosed felsic volcanic and volcaniclastic rocks; minor chert, banded iron-formation, and carbonate
₽ec Metamorphosed chert; banded, and locally iron-rich

Veins and dykes: p—muscovite-rich pegmatite; g—medium- to fine-grained granitoid dyke; a—aplite dyke

Amhurst Metamorphics

₽Agn Inclusion-rich, biotite-hornblende granodiorite gneiss, and garnet-cordierite-andalusite-sillimanite-biotite monzogranite gneiss; inclusions of metasedimentary and mafic igneous rocks; metamorphosed, possible equivalent of NEVILLE GRANODIORITE
₽Am Medium- to high-grade metasedimentary rocks, and granitoid rocks; quartz-muscovite-biotite-andalusite-garnet-cordierite-K-feldspar-plagioclase granofels and schist; metamorphosed equivalents of MARBOO FORMATION

c. 1860 Ma (Bow batholith)

₽gfm **GNEWING GRANODIORITE:** coarsely porphyritic, biotite-hornblende granodiorite and tonalite; contains mafic inclusions
₽gnv **NEVILLE GRANODIORITE:** medium- to fine-grained biotite granodiorite and tonalite; minor monzogranite; metasedimentary rock inclusions are abundant adjacent to contacts with metasedimentary rock

₽al **LAMBOO ULTRAMAFICS:** partly serpentinized ultramafic and mafic intrusive rocks

Tickalara Metamorphics

₽Ts Metamorphosed interbedded psammite and pelite; minor metamorphosed felsic and mafic volcaniclastic rocks; includes carbonate locally
₽Ta Metamorphosed basaltic volcanic and volcaniclastic rocks; minor metadolerite sills, thin interbedded metapelite, and metamorphosed carbonate and chert lenses

c. 1860 Ma — Halls Creek Group

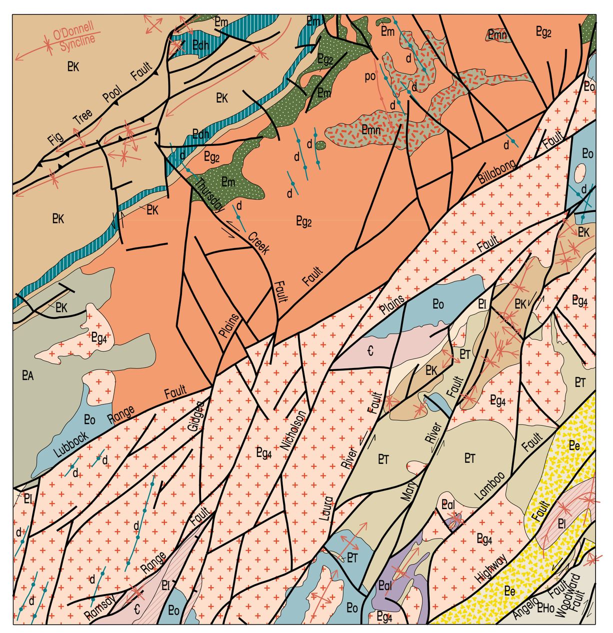
₽Ho **OLYMPIO FORMATION:** very low- to low-grade, thin- to medium-bedded mudstone, siltstone, turbiditic quartz wacke, greywacke, and arkosic sandstone

₽Hoq Metamorphosed thick-bedded, turbiditic quartzitic sandstone, and minor pelite

>1880 Ma

₽m **MARBOO FORMATION:** low-grade, turbiditic metasandstone; quartz-chlorite-muscovite phyllite; narrow zones of medium- to high-grade quartz-muscovite-biotite-andalusite-cordierite hornfels occur adjacent to granitoid intrusions
₽ms Medium-grade, quartz-muscovite-biotite-sillimanite-andalusite(-cordierite) schist (possibly after hornfels)
₽mn High-grade, migmatitic quartz-muscovite-biotite-sillimanite-andalusite-cordierite-K-feldspar-plagioclase granofels and gneiss

TECTONIC SKETCH MAP



Ꞓ Antrim Plateau Volcanics
₽l Louisa Downs Group
d Dolerite dyke
po Porphyry dyke
₽dh Hart Dolerite
₽K Kimberley Group — KIMBERLEY BASIN
₽l Moola Bulla Formation — KIMBERLEY BASIN
₽g4 Granitoid rocks c.1820 Ma — LAMBOO COMPLEX
₽o Gabbroic rocks
₽g3 Granitoid rocks c.1840 Ma
₽e Koongie Park Formation
₽A Amherst Metamorphics
₽g2 Bow batholith c.1860 Ma
₽al Lamboo Ultramafics
₽T Tickalara Metamorphics
₽Ho Olympio Formation of Halls Creek Group
₽m Marboo Formation
₽mn Migmatitic granofels and gneiss

Fault
Thrust fault
Strike-slip fault
Normal fault

Geological boundary
- accurate
- inferred

Fault
- accurate
- concealed
- reverse
- shear zone

Fold, showing direction of plunge
- anticline; inferred
- syncline; inferred

Small-scale folds showing strike and dip of axial surface, direction of plunge, and nature of vergence (S, Z, or M profile)
- D_2
- D_5

Bedding, showing strike and dip
- inclined
- vertical
- horizontal
- overturned
- strike and dip estimated from aerial photography
  - horizontal
  - 0 – 15°
  - 15 – 45°
  - 45 – 90°
  - trend of bedding (also visible through surficial deposits)

Igneous layering
- inclined

Way-up indicator
- top of bed

Foliation, showing strike and dip
- D_2: inclined; vertical
- D_5: inclined; vertical

Strongly sheared rock

Cleavage, showing strike and dip
- D_2: inclined; vertical
- D_4: inclined
- D_5: inclined; vertical

Lineation, showing direction of plunge
- bedding—cleavage intersection

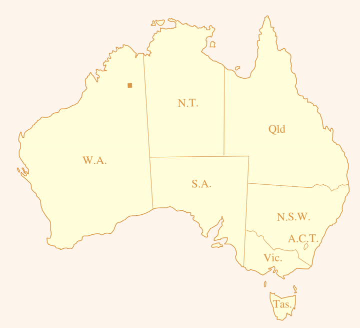
Air photo lineament

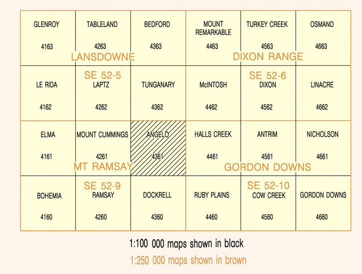
Highway with national route marker
Formed road
Track
Fence, generally with track
Homestead — Moola Bulla
Building; yard — Yd
Microwave repeater station
Horizontal control, major
Contour line, 20 metre interval — 320

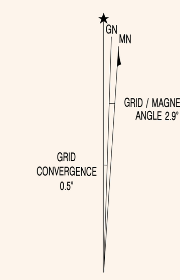
Watercourse, ephemeral
Bore — B
Well — W
Windpump
Dam — D
Tank — T
Spring — S
Waterhole — WH

Quarry
Prospect — Emull
Mineral occurrence
- Chromium — Cr
- Copper — Cu
- Gold — Au
- Lead — Pb
- Nickel — Ni
- Uranium — U
- Zinc — Zn

Industrial minerals
- Asbestos (amphibole) — Aa
- Gravel — Gr







True north, grid north and magnetic north are shown diagrammatically for the centre of the map. Magnetic north is correct for 1993 and moves easterly by about 0.1° in 6 years.

PRODUCT OF THE NATIONAL GEOSCIENCE ACCORD

DEPARTMENT OF MINERALS AND ENERGY
HON. GEORGE CASH, J.P., M.L.C.
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PIETRO GUJ
DIRECTOR, GEOLOGICAL SURVEY
OF WESTERN AUSTRALIA

SCALE 1:100 000

1000 0 1 2 3 4 5 6 7 8 9 10
Metres — Kilometres

TRANSVERSE MERCATOR PROJECTION
Grid lines indicate 1000 metre interval of the Australian Map Grid Zone 52

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ANGELO

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