Stratigraphic revision of the Warrawoona and Gorge Creek Groups in the Kelly greenstone belt, Pilbara Craton, Western Australia

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Abstract

Mapping in the Kelly greenstone belt in the eastern part of the East Pilbara Granite–Greenstone Terrane of the Pilbara Craton indicates that the stratigraphy of the Warrawoona Group requires significant revision. Four stratigraphic revisions are proposed. The Warrawoona Group now includes the redefined Salgash Subgroup and the newly defined Kelly Subgroup. The felsic volcanic rocks of the c. 3325–3320 Ma Wyman Formation conformably overlie the Euro Basalt and are now included in the Warrawoona Group. The 3324 ± 4 Ma Kelly porphyry, previously thought to be a felsic volcanic interbed in the Euro Basalt, is now recognized as intruding the Euro Basalt and is associated with the overlying Wyman Formation. The Charteris Basalt, previously included in the Gorge Creek Group, is now included with the Kelly Subgroup and it conformably overlies the Wyman Formation. The redefined Warrawoona Group is unconformably overlain by sedimentary rocks of the c. 3308 Ma Budjan Creek Formation and dominantly clastic sedimentary rocks of the 3240–2940 Ma Gorge Creek Group (locally redefined to exclude the Charteris Basalt).

KEYWORDS: Archaean, Pilbara Craton, stratigraphy, East Pilbara Granite–Greenstone Terrane, Kelly greenstone belt.

Introduction

The Archaean Pilbara Craton in the northwest of Western Australia contains well-exposed granite–greenstones that are unconformably overlain by volcanic and sedimentary rocks of the c. 2770–2400 Ma Hamersley Basin, which around the Kelly greenstone belt are part of the 2770–2630 Ma Fortescue Group (Trendall, 1990; Thorne and Trendall, 2001). The granite–greenstones of the Kelly greenstone belt form part of the c. 3655–2830 Ma East Pilbara Granite–Greenstone Terrane (EPGGT) of the northern Pilbara Craton (Hickman, 2001; Fig. 1).

Hickman (1983, 1984) provided a regional lithostratigraphic interpretation of the EPGGT based on 1:250 000-scale reconnaissance geological mapping during the 1970s. Subsequent investigations broadly confirmed the continuity between greenstone belts of the EPGGT, but have also shown that the greenstones are more laterally variable than previously thought (Van Kranendonk et al., 2002). The following review and reinterpretation of the stratigraphy of the Kelly greenstone belt is based on mapping and geochronology resulting from the National Geoscience Mapping Accord (NGMA) projects on the SPLIT ROCK * (Bagas and Van Kranendonk, in prep.), MOUNT EDGAR (Williams and Bagas, in prep.), and NULLAGINE (Bagas, in prep.) 1:100 000 sheet areas.

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* Capitalized names refer to standard 1:100 000 map sheets.

East Pilbara Granite–Greenstone Terrane

The EPGGT is characterized by large ovoid granitoid complexes forming domes that are surrounded by synformal greenstone belts or unconformably overlain by volcanic and sedimentary rocks of the Fortescue Group (Fig. 2). The greenstone belts commonly dip at moderate to steep angles away from granitoid complexes, and are typically metamorphosed to greenschist facies, although higher grades are reached near the complexes.

Table 1 summarizes the former and current stratigraphic nomenclature of the EPGGT, and Table 2 shows the geochronological data for the Kelly greenstone belt.

Stratigraphy of the Kelly greenstone belt

The southern part of the Kelly greenstone belt outcrops between the Corunna Downs Granitoid Complex (CDGC) to the west and

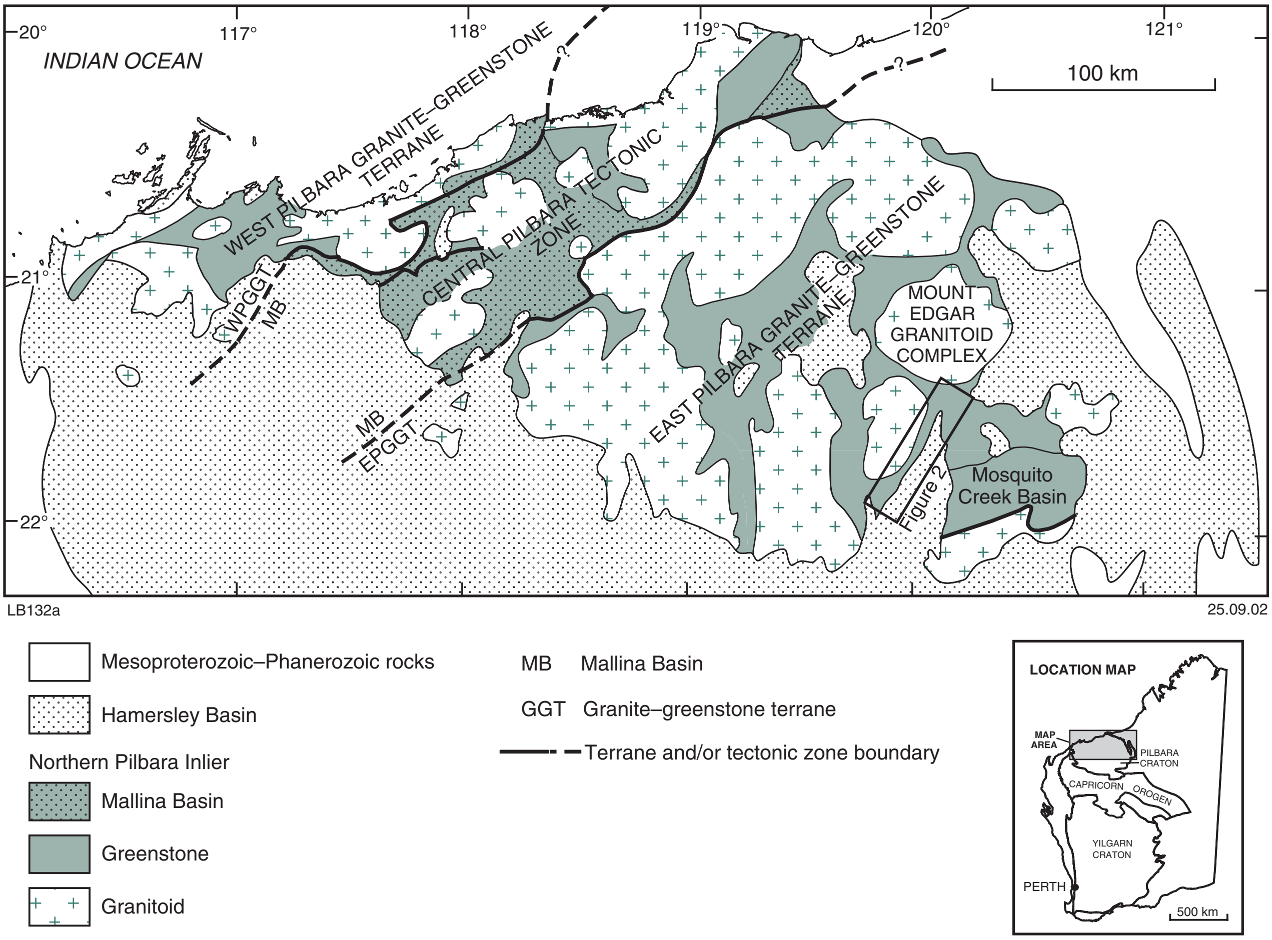


Figure 1. Regional geological setting of the East Pilbara Granite–Greenstone Terrane

the Fortescue Group to the east, and the northeastern part of the belt lies between the McPhee Dome and the Mount Edgar Granitoid Complex (Fig. 2). In both areas the belt comprises dominantly greenschist-facies volcanic rocks of the Salgash and Kelly Subgroups of the Warrawoona Group. The Warrawoona Group is unconformably overlain by the dominantly sedimentary sequences of the Budjan Creek Formation (Noldart and Wyatt, 1962; Lipple, 1975), which in turn is unconformably overlain by the dominantly clastic sedimentary rocks of the Gorge Creek Group (Noldart and Wyatt, 1962; Ryan and Kriewaldt, 1964; Hickman and Lipple, 1978; Hickman, 1983), and the Fortescue Group (Bagas and Van Kranendonk, in prep.; Table 2).

Granitoid rocks in the CDGC (Fig. 2) mostly range in age from about 3317 to 3307 Ma (Nelson, 2001, 2002), and were emplaced approximately contemporaneously with felsic volcanic rocks of the Wyman Formation and the Budjan Creek Formation (Bagas et al., 2002).

Warrawoona Group

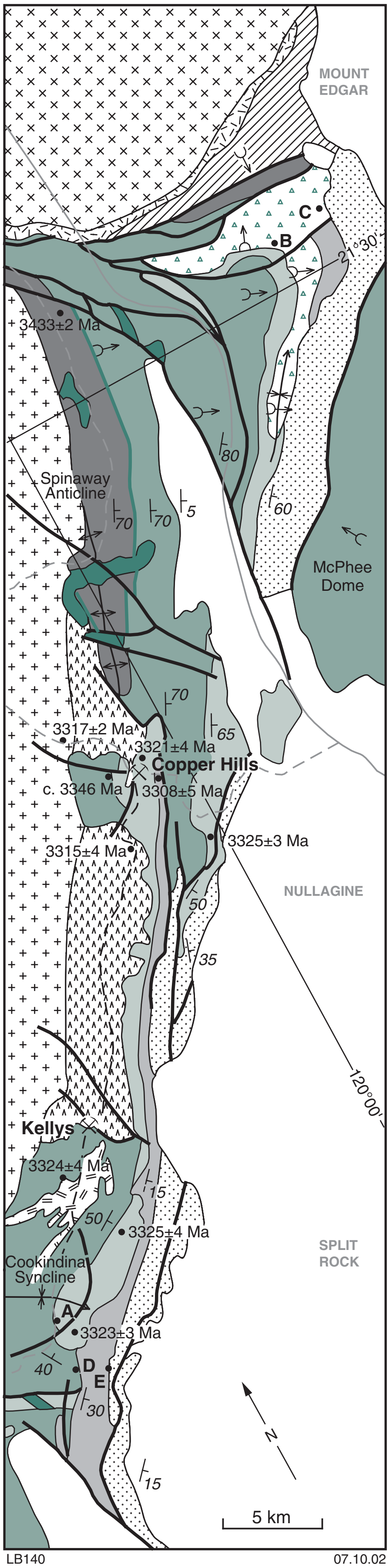
Following detailed mapping and geochronological studies in the Kelly greenstone belt, three major stratigraphic revisions have been made for the Warrawoona Group (Tables 1 and 2):

- The Kelly greenstone belt is now subdivided into the redefined Salgash Subgroup and the newly defined Kelly Subgroup.
- The felsic volcanic rocks of the c. 3325–3320 Ma Wyman Formation conformably overlie the Euro Basalt and are now included in the Warrawoona Group.
- The Charteris Basalt, which was previously included in the Gorge Creek Group, is now included with the Euro Basalt and Wyman Formation in the Kelly Subgroup of the Warrawoona Group.

Another change not shown in Table 1 is that the 3324 ± 4 Ma Kelly porphyry, previously thought to be a correlative of the Panorama Formation (Hickman, 1983) or a felsic volcanic interbed in the Euro Basalt (McNaughton et al., 1993), is now recognized as intruding the Euro Basalt and associated with the overlying Wyman Formation.

Salgash Subgroup

The Salgash Subgroup, which formerly included the Towers Formation, Apex Basalt, Panorama Formation, and Euro Basalt (Hickman 1990), now comprises the Apex Basalt (not in the Kelly greenstone belt), Panorama Formation, and Strelley Pool Chert (Table 1).



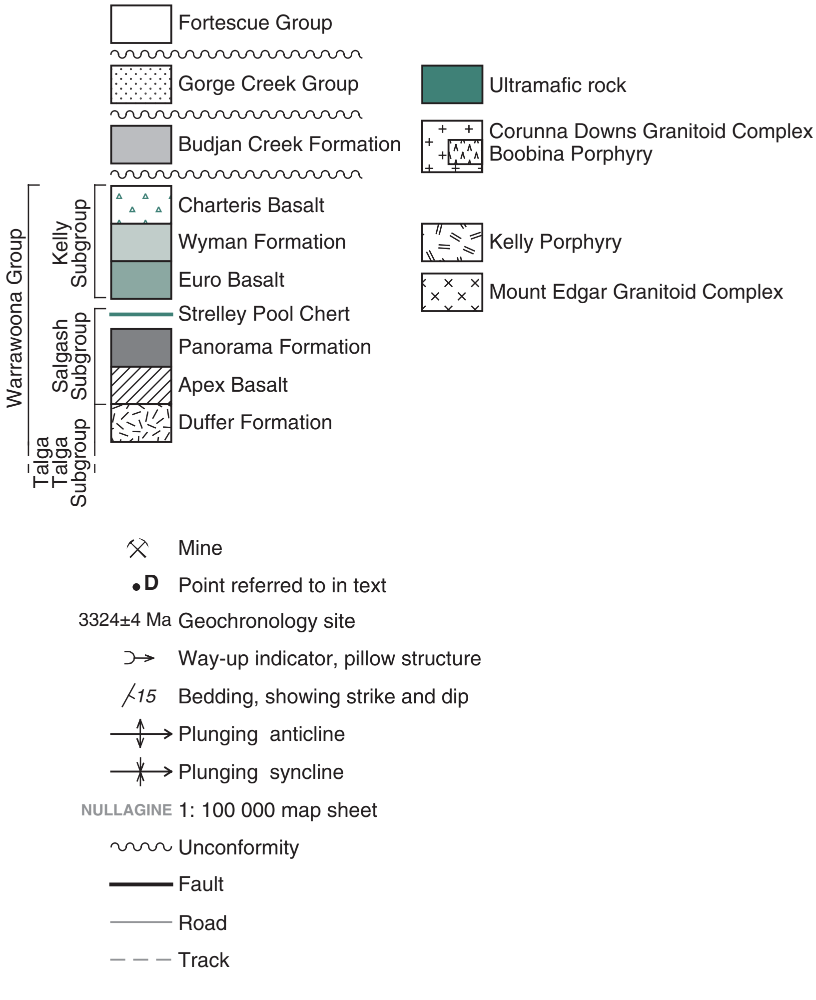


Figure 2. Geology of the Kelly greenstone belt

The Panorama Formation (Lipple, 1975) consists of felsic volcaniclastic rocks, with subordinate felsic lavas and chert. The formation outcrops in the northeastern part of the Kelly greenstone belt and is intruded by granitoid rocks of the CDGC. It was previously interpreted as the c. 3470–3465 Ma Duffer Formation (Hickman, 1983). Three samples of volcanic breccia from the formation at Sandy Creek were dated at 3433 ± 2 Ma (Nelson, 2000), and 3428 ± 4 and 3427 ± 2 Ma (Nelson, 2001). These dates are consistent with the age of the Panorama Formation elsewhere in the EPGGT.

The Strelley Pool Chert (Lowe, 1983) is a discontinuous unit conformably overlying the Panorama Formation in the northeastern part of the Kelly greenstone belt, and was previously interpreted as the Towers Formation (Hickman, 1983). The Strelley Pool Chert consists of silicified chert, sandstone, and intraformational breccia. The chert commonly has pseudomorphs after barite and gypsum, and wavy to domal laminates with local conical stromatolites. The base of the unit shows evidence of relict topography and differential erosion of the underlying Panorama Formation, with a corresponding pinching and swelling of the chert along strike and the filling of palaeochannels in places (Williams and Bagas, in prep.).

Deposition of the Strelley Pool Chert reflects a hiatus in volcanism recognized over 220 km across the EPGGT (Van Kranendonk et al., 2002) and is thought to represent the final hydrothermal phase of

Table 1. Stratigraphy of the East Pilbara Granite–Greentone Terrane. Units in the Kelly greenstone belt are here shown in bold, and the stratigraphic nomenclature for units outside of the belt is taken from Van Kranendonk et al. (2002)

Hickman (1990)

De Grey Group		Lalla Rookh Sandstone
		Budjan Creek Formation
∿∿∿ unconformity ∿∿∿		
Gorge Creek Group		Honeyeater Basalt
		Cleaverville Formation
	Soanesville Subgroup	**Corboy Formation**
		Charteris Basalt
∿∿∿ local unconformity – – –		
Wyman Formation		
∿∿∿ unconformity ∿∿∿		
Warrawoona Group	Salgash Subgroup	**Euro Basalt**
		Panorama Formation
		Apex Basalt
		Towers Formation
	Duffer Formation	
	Talga Talga Subgroup	Mount Ada Basalt
		McPhee Formation
		North Star Basalt

This paper

De Grey Group		Lalla Rookh Sandstone (s)
∿∿∿ unconformity ∿∿∿		
Gorge Creek Group		Pyramid Hill Formation (sh)
		Honeyeater Basalt
	Soanesville Subgroup	**Paddy Market Formation** (sh, BIF)
		Corboy Formation
		Pincunah Hill Formation (sh, BIF)
∿∿∿ local unconformity – – –		
Sulphur Springs Group		Kangaroo Caves Formation (f, an, c)
		Kunagunarrina Formation (u, b)
		Leilira Formation (ss, f)
F———F fault / ∿∿∿ unconformity		
Golden Cockatoo Formation (ss, sh)		
Budjan Creek Formation (cong, ss, sh, f)		
∿∿∿ unconformity ∿∿∿		
Warrawoona Group	Kelly Subgroup	**Charteris Basalt** (b, f)
		Wyman Formation (f, ss)
		Euro Basalt (b, c)
	Salgash Subgroup	**Strelley Pool Chert** (c, ss, cong)
		Panorama Formation (f)
		Apex Basalt (b)
	Towers Formation (c, b)	
	Talga Talga Subgroup	Duffer Formation (f, an)
		Mount Ada Basalt (b)
		McPhee Formation (u, c, f)
		North Star Basalt (b, u)
		Dresser Formation (c, b)
		Double Bar Formation (b)
Coonterunah Group		Coucal Formation (f, c)
		Table Top Formation (b)

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∿∿∿	unconformity	cong	conglomerate
∿∿– –	local unconformity	ss	sandstone
F——F	fault	sh	shale
b	basalt	c	chert
u	ultramafic rock	BIF	banded iron-formation
an	andesite	f	felsic volcanic rocks

felsic volcanism associated with the deposition of the Panorama Formation. Both formations are interpreted to be genetically related (Van Kranendonk, 2000), whereas the overlying ultramafic and mafic rocks of the Euro Basalt mark the beginning of a new volcanic phase. Van Kranendonk et al. (2002) suggested that the Euro Basalt was related to a separate mantle plume than the one they interpreted to have produced the Salgash Subgroup. For this reason the Euro Basalt has been separated from the Salgash Subgroup and included in the overlying Kelly Subgroup (Bagas and Van Kranendonk, in prep.).

Kelly Subgroup

The Kelly Subgroup conformably overlies the Salgash Subgroup and consists of the Euro Basalt, Wyman Formation, and Charteris Basalt.

After deposition of the Strelley Pool Chert, volcanism in the Kelly greenstone belt resumed with deposition of high-Mg basaltic rocks and komatiite of the Euro Basalt. The date at which this volcanism resumed is unknown, but probably occurred at c. 3420–3410 Ma, which is the age of gold mineralization (Thorpe et al., 1992a) and zircon overgrowths (Zegers, 1996; Van Kranendonk, in prep.). The duration of volcanism is a major outstanding problem, but indications are that this succession was deposited over an approximately 100 million-year period from c. 3420 to 3325 Ma, the younger limit being the age of the conformably overlying Wyman Formation in the southeastern part of the Kelly greenstone belt.

Table 2. Ages of units in and around the Kelly greenstone belt

Unit	*Age (Ma)*
Fortescue Group	2770–2630
Gorge Creek Group	3240–2940
Budjan Creek Formation	3308 ± 5
Boobina Porphyry	3315 ± 4
Kelly porphyry	3324 ± 4
Warrawoona Group	c. 3490–3320
Kelly Subgroup	
Charteris Basalt	c. 3320 (inferred)
Wyman Formation	c. 3325–3320
Euro Basalt	3420–3325
Salgash Subgroup	
Strelley Pool Chert	c. 3425 (inferred)
Panorama Formation	3433–3427

In the Kelly greenstone belt the Euro Basalt consists dominantly of tholeiitic pillow basalt, with subordinate interbedded pillowed, ocellar, and occasionally vesicular, high-Mg basalt. The base of the formation typically contains a unit of komatiite or komatiitic basalt up to 500 m thick. The formation is also interbedded with chert that is locally stromatolitic (Williams and Bagas, in prep.). The Euro Basalt has a stratigraphic thickness of about 4 km in the northeastern part of the Kelly greenstone belt. However, this is a minimum thickness for the formation as its top is locally faulted out, and elsewhere in the belt its base is intruded by granitoid rocks of the CDGC.

West of the Copper Hills mine, the Euro Basalt contains several bands of chert interbedded with minor mafic and felsic tuff. Chert in the upper part of the formation contains zircon populations of 3363 ± 6, 3346 ± 6, and 3311 ± 9 Ma (Nelson, 2001). The age of the youngest population (6 of 22 zircons analysed) is within the error margins of the 3315 ± 4 Ma age of the Boobina Porphyry (Barley and Pickard, 1999), which intruded the Euro Basalt about 500 m to the south. The age of the youngest zircon population is therefore interpreted to represent an overgrowth event associated with porphyry intrusion (Bagas and Van Kranendonk, in prep.). The c. 3346 Ma age of the largest population (14 of 22 samples) is interpreted as the depositional age of the tuff, whereas the oldest population is considered to be xenocrystic.

The c. 3325 Ma Wyman Formation conformably overlies the Euro Basalt across a transitional zone of interbedded rhyolite and basalt that is about 50 m thick (e.g. at point A on Fig. 2) and is now therefore included in the Warrawoona Group. The Wyman Formation was excluded from the Warrawoona Group by Hickman (1990) for two reasons. Firstly, geochronological data available in the late 1980s suggested that the contact between the Wyman Formation and underlying Euro Basalt represented a time break of about 125 million years. Recent geochronological data, however, indicate that the upper part of the Euro Basalt is about 3346 Ma. Secondly, mapping in the 1970s suggested that the Wyman Formation unconformably overlies the Salgash Subgroup 7 km southwest of Budjan Creek (Hickman, 1983). New mapping has established that the unconformity in this area is between the Euro Basalt and the Budjan Creek Formation.

The Wyman Formation is about 1 km thick and consists of felsic tuff interbedded with porphyritic rhyolite to rhyodacite, felsic agglomerate and volcaniclastic sandstone, and fine-grained quartz sandstone. The formation has been dated in three places in the Kelly greenstone belt with a conventional zircon age of 3325 ± 4 Ma (Thorpe et al., 1992b; McNaughton et al., 1993), and sensitive high-resolution ion microprobe (SHRIMP) U–Pb zircon ages of 3323 ± 3 Ma (Nelson, 2001), and 3321 ± 4 Ma (Barley and Pickard, 1999). These ages are identical within analytical error to the 3324 ± 4 Ma SHRIMP U–Pb zircon age for intrusive felsic rocks from the informally named Kelly porphyry (McNaughton et al., 1993). The porphyry has been shown to be an intrusive unit by Bagas and Van Kranendonk (in prep.) rather than an extrusive unit as suggested by Hickman (1983) and McNaughton et al. (1993). These data confirm that there is a synchronous relationship between volcanism (Wyman Formation) and subvolcanic intrusions (Kelly porphyry) in the Kelly greenstone belt.

The Charteris Basalt outcrops in the northeastern part of the Kelly greenstone belt, on the northwestern part of NULLAGINE and southwestern part of MOUNT EDGAR (Fig. 2), where it is between 500 and 2000 m thick and consists mainly of pillowed high-Mg and tholeiitic basalt. The basalt lies conformably on the Wyman Formation (e.g. at point B on Fig. 2; Williams and Bagas, in prep.) and is unconformably overlain by clastic sedimentary rocks of the 3240–2940 Ma Gorge Creek Group (e.g. at point C on Fig. 2; Williams and Bagas, in prep.). The Charteris Basalt must therefore be aged between 3320 and 3240 Ma, and has thus been reassigned from the unconformably overlying Gorge Creek Group (Hickman, 1983; Lipple, 1975) to the top of the Warrawoona Group (Table 1).

Rocks similar to the Charteris Basalt within the Wyman Formation about 50 km west of the Kelly greenstone belt in the Warrawoona area (Hickman, in prep.) indicate that the ultramafic and mafic volcanic rocks of the Charteris Basalt do not necessarily represent a new volcanic cycle above the Kelly Subgroup.

Budjan Creek Formation

The Budjan Creek Formation only outcrops in the Kelly greenstone belt where the upward-fining boulder conglomerate at the base of the formation unconformably overlies the Warrawoona Group (e.g. at point D on Fig. 2). The formation grades upward into interbedded sandstone and siltstone, which are overlain across a low-angle unconformity by pebble conglomerate at the base of the Gorge Creek Group (e.g. at point E on Fig 2; Bagas and Van Kranendonk, in prep.). The lower unconformity with the Warrawoona Group was previously equated with the one above the Gorge Creek Group (Lipple, 1975; Hickman, 1983; Hickman, 1990), and the formation was correlated with the Lalla Rookh Sandstone of the De Grey Group (Table 1). The unconformity above the Budjan Creek Formation was not previously recognized and shows that the formation cannot be correlated with the much younger De Grey Group.

The thickness of the Budjan Creek Formation varies along strike from about 1.5 km southeast of the Kelly mine to about 500 m east of the Copper Hills mine. The basal part of the formation southeast of the Kelly mine is an approximately 1 km-thick succession, starting with a boulder conglomerate that fines upward into a pebble conglomerate interbedded with arkosic sandstone, and then into siltstone and shale. The clasts in the conglomerate consist predominantly of vein quartz and chert with rare felsic volcanic rocks, and are consistent with derivation from a local Warrawoona Group source. In addition, the arkosic composition of the sandstone and the rare south- to southeast-trending palaeocurrent direction within the sandstone are consistent with the derivation of at least part of the formation from the CDGC.

The basal clastic unit of the Budjan Creek Formation is conformably and sharply overlain by an approximately 500 m-thick marker horizon, which extends to north of the Copper Hills mine, and consists of lithic wacke, siltstone, minor conglomerate, crystal-lithic felsic tuff and agglomerate, and fine-grained volcanogenic sandstone. Crystal-lithic tuff from 1 km southeast of the Copper Hills mine (Fig. 2) was dated at 3308 ± 5 Ma (Nelson, 2001). This date provides a tight constraint on the age of folding and faulting of the Warrawoona Group in the Kelly greenstone belt.

Gorge Creek Group

The Gorge Creek Group overlies the Budjan Creek Formation with a low-angle unconformity on SPLIT ROCK, disconformably overlies the c. 3240 Ma Sulphur Springs Group on adjoining NORTH SHAW and TAMBOURAH (Van Kranendonk and Morant, 1998), and is unconformably overlain by the c. 2940 Ma De Grey Group (Van Kranendonk et al., 2002). The Gorge Creek Group is therefore between 3240 and 2940 Ma in age.

The Gorge Creek Group on eastern SPLIT ROCK and southern MOUNT EDGAR is at least 750 m thick. Its basal unit consists of a lensoidal, upward-fining, clast- to matrix-supported, cobble to pebble conglomerate that probably correlates lithologically with the Corboy Formation (Table 1). The conglomerate contains clasts of chert, felsic porphyry, and rare mafic volcanic rocks, which are identical to rocks in the underlying Warrawoona Group. The conglomerate is conformably overlain by a succession of silicified and ferruginized shale, banded iron-formation and grey and white layered chert, banded and ferruginous chert, black carbonaceous shale and minor siltstone, and thinly bedded banded iron-formation interbedded with ferruginous chert. This succession is lithologically similar to, and probably correlates with, the Paddy Market Formation (Table 1).

Discussion and conclusion

The volcanic and volcaniclastic rocks of the Warrawoona Group in the Kelly greenstone belt are unconformably overlain by successively younger groups with shallowing dips to the east away from the margin of the CDGC and Mount Edgar Granitoid Complex.

The unconformable relationships between the c. 3325–3320 Ma Wyman Formation of the Warrawoona Group and the 3308 Ma Budjan Creek Formation, and between the Budjan Creek Formation and the c. 3235–2970 Ma Gorge Creek Group have a number of implications. Several different types of tectonic structures formed during the short period between 3320 and 3308 Ma, and between 3308 and c. 3240 Ma (Bagas and Van Kranendonk, in prep.). The first period of deformation may be related to the development of the dome forming around the CDGC, and points to a discernible episode of compression related to the formation of the Spinaway Anticline, Cookindina Syncline, and the CDGC (Fig. 2). The maximum age limit of the first event is slightly older than the granitic rocks near the eastern edge of the CDGC, which decrease in age westward from 3317 ± 2 Ma (Barley and Pickard, 1999) to 3307 ± 4 Ma (Nelson, 2000). These limited geochronological data indicate that granitoid magmatism was synchronous with the older deformation event.

The Budjan Creek Formation and Gorge Creek Group dip at about 30° away from the centre of the CDGC in the same direction as limited palaeocurrents measured in the formations (Bagas and Van Kranendonk, in prep.). This tilting away from the complex is indicative of its upward and outward growth after the earlier deformation event. The Gorge Creek Group overlies the Budjan Creek Formation with a low-angle unconformity on the eastern side of SPLIT ROCK, indicating that tilting was intermittent during the deposition of these units.

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