1 **Stratigraphy of the Late Palaeoproterozoic (~2.03 Ga) Woolly**
2 **Dolomite, Ashburton Province, Western Australia: a**
3 **carbonate platform developed in a failed rift basin**

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12 **Keywords**

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18 **ABSTRACT**

19 This paper describes the sequence stratigraphy of the ~2.03 Ga Woolly Dolomite, the uppermost
 20 stratigraphic unit of the Horseshoe Basin, strata of which unconformably overlie the 2772-2410 Ma
 21 Hamersley Province, unconformably truncate folded ~2210 Ma dolerite sills and post-date the
 22 2195-2145 Ma Ophthalmia Orogeny. The Horseshoe Basin was an intracontinental rift that initiated
 23 at ≤ 2.05 Ga with deposition of ≤ 360 m of fluvial and shallow-marine siliciclastic sandstones
 24 (Beasley River Quartzite), followed by eruption of ~2.7 km of flood basalt (Cheela Springs Basalt),
 25 and culminated with deposition of ≥ 325 m of platformal carbonates and associated volcanoclastic
 26 and siliciclastic sediments (Woolly Dolomite). The three formations of the Horseshoe Basin stack
 27 conformably, with tectonically driven unconformities developed only at a late stage, within the
 28 Woolly Dolomite. Depositional systems of the Woolly Dolomite appear to have been
 29 compartmentalized, but connected to an ocean. Five depositional sequences are identified.
 30 Depositional Sequence 1, which developed conformably on the Cheela Springs Basalt, records the
 31 establishment of a carbonate platform coeval with volcanoclastic sedimentation, but it was
 32 developed only in the southeastern-most sector of the basin. Resedimented tuffs (volcanoclastic
 33 siltstones) are present in all of the depositional sequences, but are most abundant in DS1.
 34 Depositional Sequence 2 cuts deeply into the Cheela Springs Basalt, and has a lower section of
 35 siliciclastic sedimentary rocks that is overlain by carbonate-platform deposits. The Wyloo Dome, at
 36 an interpreted rift triple-junction, was an uplifted area until the late stage of DS2, implying that
 37 accommodation generation was also fault compartmentalized. Depositional Sequences 3, 4 and 5
 38 have predominantly carbonate-platform deposits, and are also unconformity bound, whereas DS4
 39 and DS5 preserve a shelf-slope transition. Subsidence in the Horseshoe Basin ended with basin
 40 inversion during the D₁ (Panhandle) deformation event, which predated emplacement of an ~2008
 41 Ma dolerite dyke swarm. A subsequent rifting event, recorded by the McGrath Basin, led to a rift-
 42 drift transition that finally initiated a west-facing Atlantic-type continental margin.

43

44 **1. Introduction**

45 How and when the Archaean Pilbara and Yilgarn cratons of Western Australia came together has
 46 been long debated, although the most favoured tectonic model involves a protracted period of north-
 47 south convergence from 2450 Ma to 1800 Ma (e.g., Tyler and Thorne, 1990). Most attention has
 48 been focussed on the southern margin of the Pilbara Craton, where the 2770-2410 Ma Hamersley
 49 Province is succeeded, after a long hiatus, by the 2050-1680 Ma Ashburton Province (Krapež,,
 50 1999). Two discrete orogenic events were recognised within the protracted (~650 myr-long) period
 51 of convergence proposed originally by Tyler and Thorne (1990): the older Ophthalmia Orogeny and
 52 the younger Capricorn Orogeny. The older (2195-2145 Ma; Rasmussen et al., 2005) Ophthalmia
 53 Orogeny affected only the southern margin of the Pilbara Craton, but the younger (~1770 Ma)
 54 Capricorn Orogeny resulted in the tectonic amalgamation of the Pilbara and Yilgarn cratons, with
 55 the Capricorn Orogen recorded on both the northern margin of the Yilgarn Craton and the southern
 56 margin of the Pilbara Craton (Fig. 1).

57 There is continuing debate regarding which stratigraphic sequences of the Ashburton Province
 58 (Fig. 1) are tied tectonogenetically to the Ophthalmia Orogeny (e.g., Tyler and Thorne, 1990;
 59 Thorne and Seymour, 1991; Martin et al., 1998, 2000; Powell et al., 1999; Martin and Morris, 2010)
 60 and which stratigraphic sequences post-date that orogeny and initiate a new tectonic cycle that
 61 ultimately culminated in the Capricorn Orogeny (e.g., Krapež, 1999; Taylor et al., 2001; Müller et
 62 al., 2005). The earliest work, by Tyler and Thorne (1990), tied all of the Wyloo Group of the
 63 Ashburton Province tectonogenetically to the protracted Pilbara-Yilgarn collision, but with only the
 64 Lower Wyloo Group of the Horseshoe Basin (Fig. 2) involved in the Ophthalmia Orogeny. Almost
 65 all other stratigraphic studies have followed that scenario, although the latest work, by Martin and
 66 Morris (2010), now puts the upper stratigraphic boundary of the Ophthalmia cycle at the base of the
 67 Wooly Dolomite, at the top of the Lower Wyloo Group (Fig. 2). In their tectonostratigraphic
 68 scenario, there must be a 180 myr hiatus prior to deposition of the Wooly Dolomite, within the
 69 Lower Wyloo Group and therefore also within the Horseshoe Basin (Fig. 2).

Martin et al. (1998, 2000), Powell et al. (1999) and Martin and Morris (2010) interpret the Lower Wyloo Group to have been deposited in a foreland basin, whereas Krapež (1999), Taylor et al. (2001) and Müller et al. (2005) favour an intracontinental rift-basin. Foreland and rift basins have different predictions for subsidence history and basin architecture (e.g., Busby and Ingersoll, 1995), the distinction being readily determined by stratigraphic analysis. Although there have been detailed stratigraphic studies of most of the Lower Wyloo Group that defines the Horseshoe Basin (e.g., Tyler and Seymour, 1991; Goddard, 1992; Martin and Morris, 2010; Müller, 2005), the stratigraphy of the Woolly Dolomite is virtually unknown other than at a reconnaissance level (Daniels, 1970; Seymour et al., 1988; Thorne and Seymour, 1991), and yet it is key to understanding the chronostratigraphic and tectonostratigraphic records of the Horseshoe Basin (cf. Krapež, 1999; Martin and Morris, 2010). The Woolly Dolomite was recognised only as a locally developed stratigraphic unit by Thorne and Seymour (1991), whereas our field mapping recognises it to have regional extent. The aims of this paper are therefore to establish the sequence stratigraphy and tectonic setting of the Woolly Dolomite, and thereby resolve the chronostratigraphic and tectonostratigraphic affinities of the Horseshoe Basin.

2. Regional geology

2.1. Depositional basins

The Ashburton Province comprises an ~32 km-thick Late Palaeoproterozoic sedimentary and volcanic succession, which is considered by Tyler and Thorne (1990), and Thorne and Seymour (1991) to record a single foreland basin. In contrast, Krapež (1999) recognised 13 second-order (i.e., basin-scale) sequences within the estimated 370 myr (2050-1680 Ma) history of the province (Figs 2 and 3). The lowermost second-order sequence, defining the Horseshoe Basin (Fig. 2), comprises three formations: (i) the ≤360 m-thick Beasley River Quartzite, a fluvial and tidally influenced siliciclastic succession; (ii) the ~2.7 km-thick Cheela Springs Basalt, a flood-basalt succession; and (iii) the >325 m-thick Woolly Dolomite, a shale-dolostone succession. The Beasley

95 River Quartzite overlies the Hamersley Province (2772-2410 Ma; Krapež, 1999) of the Pilbara
 96 Craton (Fig. 1) with angular unconformity (Goddard, 1992).

97 Sandstones and shales of the Mt McGrath Formation (McGrath Basin on Fig. 2) unconformably
 98 overlie the Beasley River Quartzite, Cheela Springs Basalt and Woolly Dolomite, and are
 99 unconformably overlain by dolostones and shales of the Duck Creek Basin. The Duck Creek Basin
 100 and conformably overlying turbidites of the Mininer and Wandarray basins collectively define a
 101 divergent-margin succession (Krapež, 1999). Change from divergence to convergence is marked by
 102 uplift and erosion of the divergent-margin succession, followed by development of deep-water
 103 volcanic basins. Deep erosion occurred in the northwest, where basalts of the June Hill Basin
 104 unconformably overlie strata of the Duck Creek and Mininer basins (Figs 2 and 3). The June Hill,
 105 Mininer and Duck Creek basins are unconformably overlain by volcanosedimentary rocks of the
 106 Stuart Basin, which are in turn unconformably overlain by siliciclastic turbidites of the Cane River
 107 Basin. The equivalent of the June Hill Basin in the southeast is the Boggola Basin (Fig. 2), which is
 108 unconformably overlain by turbidites of the Pingandy Basin, the equivalent of the Stuart and Cane
 109 River basins (Krapež, 1999).

110 ***2.2. Deformation history and geochronology***

111 Six regional deformation events (D_1 to D_6 on Fig. 2) are recorded in the Ashburton Province
 112 (Krapež, 1999). With the exception of D_1 (locally known as the Panhandle Event; see Taylor et al.,
 113 2001) and D_5 (which were high-level strike-slip events), each event involved tectonic burial, and the
 114 development of pervasive axial-plane and shear cleavages. Strata of the Horseshoe Basin are
 115 deformed by F_1 folds but truncate folds and fabrics related to the Ophthalmia Orogeny, which
 116 deformed sills of dolerite emplaced at ~2210 Ma (Müller et al., 2005). Craton-scale alteration
 117 associated with the Ophthalmia Orogeny spans ~2195 Ma to ~2145 Ma (Rasmussen et al., 2005).
 118 Strata of the McGrath Basin post-date F_1 folds and are also younger than a suite of dolerite dykes
 119 dated at ~2008 Ma (Müller et al., 2005) that intrude strata of the Horseshoe Basin and post-date D_1
 120 (Fig. 2).

121 Folds, fabrics and faults related to D₂ and D₃ are the principal structures of the Ashburton
 122 Province, with D₃ being related to sinistral transpression (Krapež, 1999). D₂ was preceded and
 123 succeeded by uplift, erosion and sea-floor volcanism associated with convergence. Sircombe (2003)
 124 dated pre-D₂ rhyodacitic volcanoclastic rocks in the basalt-rhyodacite sequence at Mt Boggola at
 125 1829 ± 5 Ma, whereas Krapež (1999) correlated that sequence to the basaltic sequence at June Hill
 126 (respectively the Boggola and June Hill basins; Figs 2 and 3). Evans et al. (2003) questioned that
 127 correlation based on the 1786 ± 11 Ma age of a felsic porphyry, and on the 1799 ± 11 Ma maximum
 128 depositional age (13 analyses on 13 detrital zircon grains, out of a total of 18 analyses on 15 grains)
 129 of a volcanoclastic sandstone. Both dates come from strata of the Stuart Basin, which
 130 unconformably overlie turbidites of the Mininer Basin (supposedly represented by the felsic
 131 porphyry) and basalts of the June Hill Basin (supposedly represented by the volcanoclastic
 132 sandstone). The sample with the maximum depositional age of 1799 ± 11 Ma is from an olistolith-
 133 bearing lithic sandstone overlying an unconformity that truncates D₂ folds and axial-plane cleavage
 134 in June Hill basalts, and therefore is not the syneruptive age of the June Hill Volcanics. Wilson et
 135 al. (2010) report a maximum depositional age of 1795 ± 7 Ma (11 analyses on 11 detrital zircon
 136 grains out of a total of 26 analyses on 26 grains) from the same sandstone dated by Evans et al.
 137 (2003), which they similarly misinterpret to be the syneruptive age of the June Hill Volcanics.

138 Returning to the age of the Horseshoe Basin, Martin et al. (1998) dated the youngest detrital
 139 zircon age-population from a conglomerate near the top of the Cheela Springs Basalt at 2209 ± 15
 140 Ma (9 analyses on 7 grains, 3 analyses discordant, from a total of 27 analyses on 12 grains), which
 141 they interpreted to be the age of basaltic volcanism. That detrital zircon age-population is
 142 considerably older than the syneruptive zircon age of 2031 ± 6 Ma (37 analyses on 37 grains, no
 143 analyses discordant, out of a total of 53 analyses on 53 grains) of a volcanoclastic siltstone, from the
 144 Woolly Dolomite, that conformably overlies the Cheela Springs Basalt (Müller et al., 2005). Based
 145 on the available geochronology, and the observation that strata of the Horseshoe Basin are younger
 146 than the 2195-2145 Ma Ophthalmia Orogeny, the interpretation that the eruptive age of the Cheela

147 Springs Basalt is ~2209 Ma (Martin et al., 1998) is incorrect; rather, it must be close to the ~2031
 148 Ma age of the base of the Wooly Dolomite. In summary therefore, the maximum age of the
 149 Horseshoe Basin is ~2145 Ma and its minimum age is ~2008 Ma.

150 **2.3. Tectonic settings**

151 The different tectonic settings that have been proposed for strata of the Horseshoe Basin were
 152 based on conflicting interpretations of the relative timing of the Ophthalmia Orogeny, which
 153 produced a NE-verging fold-thrust belt along the southern margin of the Pilbara Craton (Fig. 1).
 154 Martin et al. (1998, 2000) and Powell et al. (1999) inferred a foreland-basin continuum from the
 155 Turee Creek Group (the uppermost unit of the Hamersley Province) to the Wooly Dolomite, linking
 156 the foreland basin to the Ophthalmia Orogeny, in accord with Tyler and Thorne (1990). The basis of
 157 the interpretation was recognition of a common axial-plane cleavage in the Turee Creek Group and
 158 basal Beasley River Quartzite in the Hardey Syncline (Fig. 3). However, the unit interpreted by
 159 Martin et al. (1998) and Powell et al. (1999) to be the basal Beasley River Quartzite is an
 160 unconformity-bound sequence at the top of the Turee Creek Group (un-named quartzite 3 of
 161 Trendall, 1979, and Goddard, 1992; the upper Kazput Formation of Thorne et al., 1995). The
 162 Beasley River Quartzite *sensu stricto* truncates Ophthalmia folds and their axial-plane cleavage in
 163 the Turee Creek Group of the Hardey Syncline (Goddard, 1992).

164 Alternatively, Krapež (1999) proposed an intracontinental rift superposed on the Ophthalmia
 165 Orogen as the tectonic setting of the Horseshoe Basin (Fig. 4). Krapež (1999) also envisaged that
 166 the Wyloo Dome (Fig. 3) was the site of a rift triple-junction, with the Ashburton Province
 167 representing two (ESE-trending and N-trending) arms of a fossil rift, the west-facing (i.e., N-
 168 trending) arm of which evolved into a divergent continental margin. The ESE-trending arm, which
 169 defines the structural trend of the Ashburton Province, developed into a Benue-like trough. The
 170 third (SW-trending) arm, represented by the Gascoyne Province (Figs 1 and 3), also developed into
 171 a west-facing ocean margin but was rotated anticlockwise during sinistral transform collision
 172 between the Yilgarn and Pilbara cratons at ~1770 Ma (D₃ on Fig. 2), and thrust onto the Ashburton

Province (Krapež, 1999). The resulting orogen, which comprises the Ashburton, Gascoyne, Glenburgh and Nabberu provinces, is the Capricorn Orogen (Fig. 1).

2.4. Woolly Dolomite

Initially mapped by Daniels (1970) as part of the Turee Creek Group, the Woolly Dolomite was placed in the Wyloo Group by Seymour et al. (1988) after they identified a type section on the southern flank of the Wyloo Dome (Fig. 3). From that type section, Thorne and Seymour (1991) described a 325 m-thick succession of shallow-marine dolostones and dolomitic mudrocks, but did not recognise the formation elsewhere. Fieldwork carried out for this study establishes that the Woolly Dolomite is a regional stratigraphic unit lying above the Cheela Springs Basalt, but in many sections it has been eliminated below the basal unconformity of the McGrath Basin. The Woolly Dolomite is best exposed: i) at Mt Olympus, ii) at Miningee Well, Anthiby Well and Bloodwood Bore, iii) along the southern flank of the Wyloo Dome; iv) at Urandy Creek Outcamp; v) in the headwaters of Cane River, and vi) at Red Hill (Fig. 3).

3. Sequence stratigraphy

3.1. Lithofacies

Sixteen lithofacies are recognised (Table 1), making up three lithofacies associations, namely: i) volcanoclastic, ii) siliciclastic, and iii) carbonate. Unconformities and the vertical stacking of lithofacies define five mappable stratigraphic units, which are herein referred to as depositional sequences. These depositional sequences are equivalent to the unconformity-bounded depositional sequences described by Mitchum (1977), although conventional systems tract nomenclature has not been rigidly applied.

Volcanoclastic lithofacies are conformable with the Cheela Springs Basalt, and define the basal depositional sequence (DS1) of the Woolly Dolomite. The temporal change within and between the five depositional sequences records a progression from: i) a volcanic and volcanoclastic environment, to ii) a fluvial and shallow-water siliciclastic environment, to iii) a carbonate shelf and

slope environment, consistent with drowning of the flood-basalt province. The unconformity-bound character of each depositional sequence conforms to the tectonically influenced development of a carbonate platform in a fault-segmented rift (cf. Bosence et al., 1998; Merino-Tomé et al., 2012).

3.1.1. *Volcaniclastic association*

Most of the sedimentary rocks in this association are silt- and mud-grade (MIT), and have a chloritic composition reflecting their basaltic provenance. Nevertheless, there are fine-grained, cross-laminated sandstone units (SMT) that contain rounded quartz, and also preserve starved ripples. Graded beds are common in SMT and MIT, but there is no evidence that they are primary pyroclastic deposits. Rather, the beds are interpreted to be volcaniclastic sediments, with depositional processes being dominated by current settling and reworking, as well as potential storm reworking. There are numerous layers of rhyodacitic volcaniclastic sandstone and siltstone, some of which preserve shards, angular quartz fragments and embayed quartz grains (Fig. 5A), and there are shard-rich volcaniclastic siltstones (Fig. 5B) of basaltic provenance. There are also interbeds of dolomitic mudstone and organic-rich (black) shale. Ribbon-shaped bodies cut through the volcaniclastic beds and are filled with carbonate debris, most of which consists of fragmented stromatolites (Fig. 5C), although some of them preserve *in situ* stromatolites (Fig. 5D). The ribbon-shaped bodies resemble gutter casts (Myrow, 1992) and were probably cut and filled by offshore-directed storm surge. An alternate view is that they relate to earthquake-induced tsunamis (cf. Pratt, 2001), which is possible given the rift-basin setting. Collectively, the lithofacies imply that carbonate sedimentation was contemporaneous with volcaniclastic sedimentation and flood-basalt volcanism.

3.1.2. *Siliciclastic association*

Although all lithofacies in this association contain detrital quartz, clasts in most conglomerates (Gm) are predominantly of basaltic composition. Other clast types are banded chert, which is typically red coloured, and various fine-grained metasedimentary rocks such as yellow siltstone and black shale. Clasts are typically rounded to well-rounded, implying that they are of epiclastic origin.

224 There are also conglomerates with clasts composed dominantly of vein quartz. Sandstones are
 225 variably quartzose, quartzolithic and lithic, with the lithic component being basaltic in composition.
 226 Lithofacies associations of conglomerate (Gm), plane-bedded sandstone (Sh) and trough cross-
 227 bedded sandstone (St) suggest a fluvial depositional system. There are few well-preserved plan
 228 views of trough cross-bedded sets, such that there has not been a definitive palaeocurrent analysis.
 229 Nevertheless, where observed, the trend of trough axes is unimodal and indicates palaeocurrents to
 230 the southwest and west. Associations with finer-grained lithofacies (Sr, SM, MI and Mb) are
 231 interpreted to represent a transition to a shallow-marine environment, although some may record an
 232 overbank fluvial environment.

233 Volcaniclastic and siliciclastic facies in the Woolly Dolomite were temporally exclusive, with the
 234 first appearance of basalt-pebble conglomerate recording erosion of DS1 and of the Cheela Springs
 235 flood basalts. Similar conglomerates are interlayered with flood basalts in the Cheela Springs
 236 Basalt, for example, the unit from which Martin et al. (1998) dated detrital zircon, and several units
 237 dated by Müller (2005). Whether interlayered with or unconformably overlying basalt,
 238 conglomerates and sandstones are quartz-bearing and have similar polymodal detrital-zircon age-
 239 spectra, establishing that their provenance was beyond the original areal extent of the flood basalts.

240 3.1.3. Carbonate association

241 Carbonate lithofacies and lithofacies associations of the Woolly Dolomite define shelf and slope
 242 environments. Solitary, domal and columnar stromatolites are present in all sections (Figs 6A, 6B
 243 and 6C), whereas oncolitic grainstones (Figs 6D, 6E and 6F) are particularly abundant on the
 244 southern flank of the Wyloo Dome. Figure 6E shows an example in which original oncolites
 245 developed into small conical stromatolites. Soft-sediment deformation is common and although
 246 soft-sediment deformed beds could be due to sediment loading, there are sets of bed-specific soft-
 247 sediment deformation structures (Fig. 7A) that are better related to synsedimentary earthquake
 248 shock (cf. Hempton and Dewey, 1983), which is not unexpected in a rift basin. Pre-compaction
 249 nodules of manganese oxide (Fig. 7b) are present at a few locations, particularly near Urandy Creek

Outcrop (Fig. 3), where they are hosted by dolomitic mudstones. Boulders and megaclasts in diamictites (DX) with a black-shale matrix (Figs 7C and 7D), and enclosed within dolomitic mudstones (DI), are present only on the southern flank of the Wyloo Dome (Fig. 3), where they probably record debris flows emplaced in a slope setting, thereby defining the slope between platformal and basinal facies. The debris-flow deposits may relate to storm-induced destruction of the shelf edge, but similar to many other features of the Woolly Dolomite, they could also relate to seismic events.

Although much petrographic detail is not preserved because of silicification and weathering, the range of lithofacies is consistent with a shelf environment dominated by wave and storm reworking.

3.2. Depositional sequences

There is no single section of the Woolly Dolomite in which the five depositional sequences are preserved. Correlation throughout the region depends on overall lithostratigraphic characteristics, but the southern flank of the Wyloo Dome (Fig. 3) is different from all other areas. The depositional sequences are described below from the key sections.

3.2.1. Mount Olympus

Green, red and black mudrocks, sandstones and dolostones that conformably overlie the Cheela Springs Basalt in the core of an F₃ anticline at Mt Olympus (Figs 3 and 8), and which lie unconformably below black and red shales of the Mt McGrath Formation, are the Woolly Dolomite rather than the Mt McGrath Formation as mapped by Thorne and Seymour (1991). In the hinge of the anticline, basalt is overlain by interbedded siltstones (MIT, SMT), dolostones (Dm, Dh, DI) and breccias (Db) that are collectively designated DS1 of the Woolly Dolomite (Figs 8 and 9). The top of the basalt locally preserves interlayered dolomitic mudstone, jigsaw-fit hyaloclastite and amygdaloidal basalt (Fig. 10; location PP at 594,762 mE, 7,409,253 mN on Fig. 8; coordinates for all localities are Australian Map Grid, Zone 50), thereby establishing a continuum between flood-basalt volcanism and marine sedimentation. Siltstones and sandstones in DS1 are of volcanoclastic origin (Figs 5a and 9), with a volcanoclastic siltstone (sampled at 598,794 mE, 7,408,360 mN; Fig.

276 8) giving a syneruptive SHRIMP U-Pb zircon age of 2031 ± 6 Ma (Müller et al., 2005). Dolostone
 277 lithofacies comprise stromatolitic breccias, and plane-bedded or cross-bedded dolostones, and gutter
 278 casts are abundant (Figs 5c and 5D).

279 To the south (SF on Fig. 8), a different succession is developed above the Cheela Springs Basalt.
 280 There, a ≤ 80 cm-thick unit of MIT is truncated by an ~ 15 m-thick package of St, with intercalated
 281 quartz-pebble conglomerate (Gm), that cuts down to the Cheela Springs Basalt. The St-Gm package
 282 is the base of DS2. About 5 metres of dolomitic mudrock (DI) with thin beds of plane-bedded
 283 dolostone (Dh) overlie that basal unit and pass up into an ~ 30 m-thick body of recrystallised
 284 dolostone (at 595,322 mE, 7,407,135 mN). Some sections preserve better details, and show that the
 285 recrystallised dolostone (Dm) originally comprised alternating thickly and thinly bedded Dh, but
 286 preserved clastic textures are rare. The top of the Dm body is incised below shales of the Mt
 287 McGrath Formation. Along strike, the basal unconformity of the Mt McGrath Formation cuts down
 288 to the Cheela Springs Basalt. The base of DS2 is traced to the hinge of the anticline, where it lies at
 289 ~ 100 metres above the base of the measured section (Fig. 9). Further to the west, the Cheela Springs
 290 Basalt, Woolly Dolomite and Mt McGrath Formation are poorly exposed, tightly folded and
 291 segmented by strike-slip faults (see Section A-B on Fig. 8).

292 3.2.2. *Miningee Well, Anthiby Well and Bloodwood Bore*

293 A well-exposed contact between the Cheela Springs Basalt and the Woolly Dolomite is located
 294 north of Miningee Well, east of the Wyloo Dome (Fig. 3). The basalt surface is incised several
 295 metres and overlain by a fining-upwards package of epiclastic sedimentary rocks that begins with
 296 ≤ 2 metres of channelised Gm containing clasts of basalt, chert and dark-grey siltstone (Fig. 11A).
 297 The top of the Gm unit is a planar surface overlain by ~ 3 metres of weakly laminated to plane-
 298 laminated, medium-grained sandstone (Sh) with pebble lags and siltstone interbeds. Parasequences
 299 from 3 to 8 m thick of finely laminated dolomitic siltstone and mudstone (DI), capped by beds of
 300 tabular dolostone (Dm), overlie the basal Gm-Sh package. Most dolostone beds, particularly those
 301 associated with dolostone breccias, are silicified with rare preservation of stromatolites. The upper

302 part of the section passes from black shale to alternating beds of dolostone and dolomitic mudstone,
 303 but few primary sedimentary details are preserved. Irregularly shaped, laterally linked stromatolites
 304 are preserved in some beds.

305 The contact between the Cheela Springs Basalt and the Woolly Dolomite can be traced for
 306 several kilometres, with sections correlating well with the section at Miningee Well. An erosion
 307 surface on basalt is exposed north of Anthiby Well (Fig. 3), where it is overlain by ~6 metres of
 308 interbedded quartzose sandstone and laminated mudstone (Fig. 11B). The overlying interbedded Ml
 309 and Dm pass gradationally up into weathered shales and then into an upper ~10 m-thick unit of Dm
 310 below shales of the Mt McGrath Formation. Dolomitic mudstones and tabular dolostones have the
 311 yellow weathering colour and box-work textures that are characteristic of oxidised sphalerite,
 312 whereas white-weathered shales are distinctive of the presence of pyrite, indicating that much of
 313 this section is mineralised (Fig. 11B). Similar evidence for sulphidic mineralisation is present in the
 314 Miningee Well area (Fig. 11A). In contrast, there is no evidence for stratabound sulphide
 315 mineralisation in DS2 at Mt Olympus.

316 North of Bloodwood Bore (Fig. 3), yellow- to pink-coloured dolostones are sporadically exposed
 317 above silicified amygdaloidal basalt and below steeply dipping beds of quartzose sandstone of the
 318 Mt McGrath Formation. The unconformity below the Mt McGrath Formation cuts down to the
 319 Cheela Springs Basalt.

320 3.2.3. *South Wyloo Dome*

321 The Woolly Dolomite crops out over ~30 km along the southern flank of the Wyloo Dome, and is
 322 cut out to the west and east by the unconformity at the base of the Mt McGrath Formation, but re-
 323 emerges to the east in the Miningee Well-Anthiby Well-Bloodwood Bore sections through a series
 324 of fault-bounded blocks (Fig. 3). Stratigraphic correlation between the Miningee Well and South
 325 Wyloo Dome sections is not obvious because other than the unconformity on the Cheela Springs
 326 Basalt and the overlying unconformity with the Mt McGrath Formation, there are no features in
 327 common between the sections.

Two sections have been measured: i) the Type Section being from the locality illustrated by Thorne and Seymour (1991); and ii) the Main Section to the west, in which a maximum thickness of ~350 metres is exposed (Figs 12, 13 and 14). The lowermost 11 metres of the Main Section are tentatively correlated to the top of DS2 of the Miningee-Anthiby sections, based on the interpretation that the base of the overlying dolomitic mudstone records a transgressive surface and the start of a new transgressive-regressive cycle. The entire Type Section is interpreted to be DS3. Onlap onto a palaeotopographic high is interpreted from the absence of most of DS2 that is preserved in other areas. Third, fourth and fifth depositional sequences (DS3, DS4 and DS5) are recognised in the Main Section, with the boundaries to the fourth sequence being prominent erosion surfaces (Fig. 14). Dh and Dm make up highstand sections and thick units of stromatolitic dolostone define bioherms. Black shales and dolomitic shales are the major components of transgressive sections. The transgressive part of DS5 contains lenses of DX (Figs 7C and 7D). Plane-bedded, oncolitic dolostones (Dho) are a significant component of the Type Section, where DS2 onlaps the Cheela Springs Basalt. Oncolitic dolostones (Figs 6D, 6E and 6F) are interbedded with wave-rippled dolostones.

The vertical profile (Fig. 14) gives only a rudimentary picture of the depositional architecture, whereas map patterns establish lateral changes. Figure 15 is interpreted from field mapping, and shows down-palaeoslope (i.e., to the SW) changes in lithofacies. A platform edge is identified from the three-dimensional architecture of the base of DS4, on which accreted a channel and bioherm complex. The edge of that complex is a three-dimensional scarp, as shown by the base of DS5 (Figs 14 and 15), defining well both the unconformity-bound character of DS4 and basin deepening to the southwest. That scarp was onlapped by black shales, with lenses of dolostone diamictite of DS5 (Figs 7C and 7D), recording drowning of the carbonate platform. Re-establishment of a carbonate platform is recorded by the upper part of DS5.

3.2.4. *Urandy Creek Outcamp*

353 Dolostones at Urandy Creek Outcamp (Figs 3 and 16) were assigned to the Mt McGrath
 354 Formation by Thorne and Seymour (1991), but are unconformably overlain by that formation, and
 355 are here designated as the Wooly Dolomite. There are close similarities to the section at Miningee
 356 Well, such that the Wooly Dolomite at Urandy Creek Outcamp is interpreted to be a more-complete
 357 section of DS2. From the field geology, DS2 comprises an incised lowstand section of epiclastic
 358 sedimentary rocks that passes gradually upwards into a transgressive section that culminates in
 359 black shales, which are overlain by highstand dolostones and dolomitic mudstones with chert and
 360 manganese nodules (Figs 7B, 16 and 17). Mineral-exploration drilling in the vicinity of Urandy
 361 Creek Outcamp intersected galena and sphalerite mineralisation in dolostones and shales of the
 362 transgressive section.

363 To the east of Urandy Creek Outcamp (Figs 16 and 17), basalt is overlain by a conglomerate unit
 364 that is ≤ 6.5 m thick, and by coarse-grained lithic sandstone or silicified mudstone. Clasts in the
 365 conglomerate are almost all of basalt, but are well-rounded and up to cobbles in size. Overlying
 366 sandstone beds are plane-bedded and tabular, contain lags of pebbles and cobbles of basalt, and are
 367 lithic-rich. The uppermost sandstones are weathered yellow, indicating the oxidation of sphalerite.
 368 The overlying ~65 metres of laminated siltstone, mudstone and bedded chert preserve widespread
 369 gossanous breccias establishing that the entire section is mineralised (Fig. 17). The uppermost unit
 370 is a 2 to 3 m-thick body of silicified dolostone (Dm).

371 Depositional Sequence 2 is well-preserved in the northwest, although block-faulting makes
 372 detailed correlation difficult (Fig. 16). There, the top of the Cheela Springs Basalt is incised and
 373 overlain by a composite body of conglomerate, sandstone and siltstone (Fig. 17). Conglomerate
 374 beds comprise well-rounded cobbles and pebbles of basalt in a coarse-grained matrix of lithic
 375 sandstone. Sandstone beds are lithic-rich, plane-bedded or trough cross-bedded, whereas siltstones
 376 are plane-laminated. The overlying section comprises fine- to medium-grained, plane-laminated and
 377 cross-laminated quartzolithic sandstone, and plane-laminated and cross-laminated siltstones that are
 378 highly weathered and stained yellow, again implying the oxidation of sphalerite. Solitary beds of

379 basaltic volcanoclastic siltstone are present (Fig. 5B). The overlying mudstone section is poorly
 380 exposed, comprising laminated mudstone, silicified mudstone and bedded chert. Gossans are less
 381 conspicuous, but much of the section is nevertheless weathered yellow. Siliciclastic mudstones
 382 grade upwards into dolomitic mudstones with thin beds of laminated dolostone and then into
 383 dolostone, much of which is stromatolitic. Small channels are preserved in laminated dolostones,
 384 whereas stromatolites vary from large, laterally linked domes to solitary domes enclosed in
 385 intraclast breccias.

386 The upper part of DS2 is exposed west of Urandy Creek Outcamp (Fig. 16), where alternating
 387 dolomitic breccias, stromatolitic dolostones, dolomitic mudstones and black shales make up a
 388 highstand complex (Fig. 17). Upward-shallowing parasequences of dolomitic mudstones to
 389 dolostones are ~5 m thick, and mudstones are wavy bedded with starved ripples. The top of the
 390 sequence is unconformably overlain by quartz-pebble conglomerate of the Mt McGrath Formation.

391 The upper part of DS2 is also exposed south of Urandy Creek Outcamp (Fig. 16), where thinly
 392 bedded dolostones with rare stromatolites and dolostone breccias are intercalated with wavy bedded
 393 dolomitic mudstones (Fig. 17). Metre-scale, soft-sediment folds are preserved in the dolostones.
 394 The upper surface is overlain by quartz-pebble conglomerate of the Mt McGrath Formation.

395 3.2.5. *Cane River*

396 Although poorly exposed, DS2 is preserved in low-lying exposures along the upper reaches of
 397 the Cane River (426,277 mE, 7,539,866 mN; see Fig. 3). There, basalt is abruptly overlain by ~2
 398 metres of trough cross-bedded and plane-bedded lithic sandstone with lags of basalt pebbles (Fig.
 399 18). The overlying beds fine upwards from plane-bedded and cross-laminated lithic sandstone to
 400 plane- and cross-laminated siltstone and plane-laminated mudstone, and then into intercalated
 401 dolomitic mudstone and thinly bedded dolostone, some of which is stromatolitic. Yellow-
 402 weathering mudstones indicate oxidation of sphalerite. About 10 metres of recrystallised dolostone
 403 (Dm) are exposed unconformably below the base of the Mt McGrath Formation.

404 3.2.6. *Red Hill*

405 Shales and dolostones above the Cheela Springs Basalt east of Red Hill (Figs 3 and 19) were
 406 mapped as the Mt McGrath Formation by Thorne and Seymour (1991), but are here identified as the
 407 Woolly Dolomite (Fig. 20). Exposures are complicated by: i) NNE-trending, sinistral strike-slip
 408 faults that repeat the succession, ii) NW-trending block faults that have produced wedge-shaped
 409 horsts and gräben, and iii) incision on the basal unconformity of the Mt McGrath Formation to the
 410 north, south and east (Fig. 19). Sulphidic shales have been intersected in drill holes. The succession
 411 comprises lower (sandstone-mudrock-dolostone) and upper (mudrock-dolostone) members, which
 412 are respectively transgressive and regressive components of DS2. Beyond the northern and southern
 413 limits of the mapped area, the Mt McGrath Formation lies unconformably on the Cheela Springs
 414 Basalt.

415 The base of DS2 is an erosion surface on basalt and basaltic hyaloclastite. Above the
 416 unconformity there is a ≤ 11 m-thick unit of trough cross-bedded (St) and plane-bedded (Sh),
 417 coarse- to medium-grained lithic sandstone in bedsets up to 2 m thick (Fig. 20). The overlying
 418 section is poorly exposed, but one exposure in the eastern structural block shows an upwards
 419 transition from the basal sandstone to shale through 8 metres of interbedded, normally graded,
 420 plane-laminated fine-grained lithic sandstone, siltstone and mudstone (Ml), with sandstone beds 1 to
 421 5 cm thick. The lower mudrock is silicified, but soft-sediment deformation structures are preserved.
 422 In some exposures, ~10 metres of black shale are preserved at the base, passing up into 10 to 20
 423 cm-thick, normally graded beds of fine-grained sandstone, siltstone and mudstone from which
 424 gossanous breccias, after sulphidic mineralisation, are developed. The lower mudrock is overlain by
 425 a bed of silicified stromatolitic dolostone, up to 1.5 m thick, that can be traced through the western
 426 structural blocks (lower dolostone on Fig. 20). Large domal stromatolites are developed in that bed,
 427 forming either 20 to 30 m-long bioherms or solitary domes. Stromatolitic breccias are abundant in
 428 the southwestern structural block. Black shales at the base of the upper mudrock drape over
 429 individual domes, preserving pre-compaction geometries.

The upper mudrock is present only in the western structural blocks (Fig. 19), where exposure is fairly good. Black shales, up to 25 m thick, are overlain by ~30 metres of dolomitic shales, which contain tabular beds up to 10 cm thick of Dm at the top of small-scale, upward-shallowing parasequences. Up to 40 metres of the upper dolostone are preserved beneath the unconformity at the base of the Mt McGrath Formation. A 2 m-thick bed of dolomitic sandstone is locally developed at the base of the upper dolostone, but most of the unit comprises horizontally stratified dolostone (Dh) alternating with <10 cm-thick beds of silicified dolomitic mudrock (DI). Domal stromatolites are present in massive portions of the unit, whereas small digitate stromatolites are preserved in thin-bedded portions, and desiccation cracks are preserved in interbedded mudstones.

4. Basin architecture

Interpretation of the three-dimensional stacking pattern of the depositional sequences of the Woolly Dolomite is complicated by palaeotopography developed on the Cheela Springs flood basalts, by open folding prior to incision on the basal unconformity of the Mt McGrath Formation, and by the fact that not all the depositional sequences are preserved in one section. Figure 21, which attempts to establish the three-dimensional architecture, is drawn with the horizontal at the maximum flooding surface within DS2, that is, between the lower and upper members of DS2. Depositional Sequence 1 is present only in the vicinity of Mt Olympus, where it was deposited contemporaneously with flood-basalt volcanism. The implication is that DS1 was not removed elsewhere by the erosion that produced the unconformity at the base of DS2, but that it accumulated only in a southeastern segment of the rift system (see Fig. 4). This interpretation is consistent with the Wyloo Dome being a topographic high during the deposition of DS1 and much of DS2.

Depositional Sequence 2 records erosion of the flood-basalt province, and then offlap of siliciclastic lithofacies followed by onlap. Because most clastic sedimentary rocks are of siliciclastic composition, solitary beds of volcanoclastic siltstone, representing resedimented tuffs, probably record ongoing volcanism elsewhere in the basin. The massive sulphide mineralisation and Mn

455 nodules in dolomites of the transgressive section of DS2 are interpreted to relate to hydrothermal
 456 activity in the rift basin.

457 The upper part of DS3 records development of a regional carbonate platform, and therefore
 458 drowning of the volcanic province. A palaeotopographic high appears to have been maintained in
 459 the vicinity of the southern Wyloo Dome, possibly representing a separate fault-bounded block,
 460 until at least the late-stage of DS2. Depositional Sequences 3, 4 and 5 record the development of a
 461 regional-scale carbonate platform, but with a platform edge in the vicinity of the southern margin of
 462 the Wyloo Dome (Fig. 15). Resedimented volcanoclastic siltstones of mafic composition, preserved
 463 within DS3 and DS5, record ongoing but distal volcanism. The unconformity-bound character of
 464 DS4 implies that the transgressive-regressive nature of depositional sequences was probably
 465 influenced by periods of uplift and subsidence within fault-bounded blocks.

466 From the perspective of the entire Horseshoe Basin, the oldest preserved sediments, of the
 467 Beasley River Quartzite, record fluvial and tidal influences (e.g., Thorne and Seymour, 1991;
 468 Goddard, 1992; Krapež, 1999), although conflict between designating lithofacies of fluvial versus
 469 tidal origin has led to contrasting interpretations (e.g., Martin et al., 2000; Martin and Morris, 2010).
 470 Eruption of ~2700 metres of flood basalt, probably over a time span of <2 million years (cf. Self et
 471 al., 2014) could have disrupted sedimentary dispersal patterns, but it is clear from interlayered
 472 sedimentary rocks that fluvial and tidal influences prevailed (Thorne and Seymour, 1991; Martin et
 473 al., 2000; Martin and Morris, 2010). This was certainly the case for the Woolly Dolomite. To
 474 maintain a shallow-marine environment, subsidence must have matched volcanic eruption rates,
 475 which is consistent with the dominantly subaqueous emplacement of the flood basalts (Müller,
 476 2005). The implication is that the Horseshoe Basin was connected to an ocean via an
 477 intracontinental gulf (Fig. 4).

478 The tectonic interpretation of Krapež (1999) is consistent with the palaeocurrent and
 479 palaeoenvironmental aspects of the Lower Wyloo Group/Horseshoe Basin documented by Thorne
 480 and Seymour (1991), but conflicts with their interpretation of a foreland basin in front of a NE-

481 verging fold and thrust belt. Martin et al. (2000) and Martin and Morris (2010) infer a similar
 482 foreland basin, despite significantly different documentation of dispersal systems. The foreland-
 483 basin interpretation paid no significance to fluvial and tidal signals in all stratigraphic units of the
 484 Wyloo Group along the N-trending arm of the Ashburton Province (see left-hand column on Fig. 2
 485 and also Figs 3 and 4), which support offshore environments deepening to the west and sediment
 486 provenance from the east or northeast (Krapež, 1999). That palaeogeography is not what would be
 487 expected from a foreland basin migrating to the NE in front of an orogenic belt. The upwards
 488 change from fluvial (Beasley River Quartzite) to carbonate (Woolly Dolomite) depositional systems
 489 is also inconsistent with the progradational stratigraphic architecture predicted for a foreland basin.

490 A foreland-basin setting, whatever its architecture, is similarly inconsistent with the thickest
 491 stratigraphic component of the Horseshoe Basin being flood basalt, which implies lithospheric
 492 extension and decompression melting of the asthenosphere (Self et al., 2014), tectonic conditions
 493 that are incompatible with crustal shortening. The foreland basin model and its associated
 494 palaeogeographic interpretation (Thorne and Seymour, 1991; Martin et al., 2000, Martin and
 495 Morris, (2010) are not supported by the fact that the Horseshoe Basin is significantly younger than
 496 the Ophthalmia fold-thrust belt. The most likely scenario is that the Horseshoe Basin was linked to
 497 an ocean to the west, along the N-trending and originally SW-trending arms of the triple-junction
 498 (Fig. 4).

499 At the current level of geochronological documentation, it is impossible to determine the precise
 500 duration of the Horseshoe Basin and in particular of Woolly Dolomite deposition. The Lower
 501 Jurassic Djebel Bou Dahar platform of Morocco is a strikingly similar example in which a
 502 carbonate platform developed on basalt in a segmented rift basin (Merino-Tomé et al., 2012). There,
 503 six depositional sequences developed between 201.6 Ma and 190 Ma, giving a nominal duration of
 504 1.93 myr per sequence. The depositional sequences of the Woolly Dolomite probably record similar
 505 depositional cycles of nominal duration ~2 myr. Given that the Cheela Springs flood basalts may

506 have been erupted over ~2 myr, the Cheela Springs-Wooly package probably spans ~14 myr,
 507 thereby placing initiation of the Horseshoe Basin at <2050 Ma (cf. Krapež, 1999).

508 Development of a rift-drift unconformity on the Wooly Dolomite was thwarted by the strike-slip
 509 D₁ event that deformed the Horseshoe Basin (Krapež, 1999). The McGrath Basin (Fig. 2) records a
 510 second rift basin, albeit with no evidence for synrift volcanism. A rift-drift unconformity is
 511 preserved at the stratigraphic boundary between the McGrath and Duck Creek basins (Fig. 2), such
 512 that the base of the Duck Creek Basin is locally an angular unconformity best developed around the
 513 western part of the Wyloo Dome at the former site of the rift triple-junction. The combined Duck
 514 Creek, Mininer and Wandarray basins (Fig. 2), that record the development of a west-facing
 515 Atlantic-type continental margin, ended at least 450 myr of intracontinental tectonics that began at
 516 ~2450 Ma (Krapež, 1999).

517 **6. Conclusions**

518 The Wooly Dolomite records a carbonate platform that developed within a failed-rift basin at the
 519 end of flood-basalt eruption (represented by the Cheela Springs Basalt) at ~2.03 Ga in the
 520 Ashburton Province of Western Australia. Five transgressive-regressive depositional sequences are
 521 identified. The basin appears to have been segmented into uplifting and subsiding compartments,
 522 such that for all but the base of Depositional Sequence 1 (DS1), stratigraphic boundaries are
 523 unconformities. That stratigraphic architecture is consistent with the development of a carbonate
 524 platform within a fault compartmentalized rift basin.

525 The transgressive section of DS1 is dominantly volcanoclastic, but gutter casts, possibly of storm
 526 origin, are filled with stromatolitic debris eroded from shallow-water settings. The base of DS1 is
 527 conformable on basalt with interlayering between dolomitic mudstone, basaltic hyaloclastite and
 528 amygdaloidal basalt establishing that basaltic volcanism (Cheela Springs Basalt) was
 529 contemporaneous with marine sedimentation (Wooly Dolomite). The lowermost transgressive
 530 section of DS2 is siliciclastic, with fluvial and shallow-marine facies preserved. Depositional

Sequences 3, 4 and 5 are composed dominantly of carbonate-platform facies, but DS5 preserves carbonate debris flows of a slope environment. Stromatolitic bioherms were extensively developed in DS3, DS4 and DS5, whereas DS4 preserves a shelf-edge architecture, establishing basin deepening to the southwest. There is no evidence for a restricted shelf environment, such as bedded or diagenetic evaporites, and black shales are not common. Basin architecture and depositional facies indicate that the basin was connected to an ocean to the west.

Comparison to carbonate-platform sequences of Mesozoic age that were developed in a similar rift-basin setting suggests that the five Woolly Dolomite sequences each record depositional cycles of nominal period ~2 myr, such that the combined Cheela Springs Basalt and Woolly Dolomite possibly span ~14 myr, which is compatible with the development of the Horseshoe rift basin at ≤ 2050 Ma. Reassessment of the structural and stratigraphic evolution clearly shows that the Horseshoe Basin post-dated the 2195-2145 Ma Ophthalmia Orogeny, and has no tectonostratigraphic affinity with a pre-Ophthalmia foreland basin (i.e., the Turee Creek Group).

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- 630

631 **FIGURE CAPTIONS**

632 **Fig. 1.** Location of the Ashburton Province and the Capricorn Orogen within late Palaeoproterozoic
633 PalaeoAustralia (after Krapež, 1999).

634 **Fig. 2.** Basin-rank sequence stratigraphy of the Ashburton Province (after Krapež, 1999).

635 **Fig. 3.** Map distributions of the basin-rank sequences of the Ashburton Province (modified from
636 Krapež, 1999).

637 **Fig. 4.** Tectonic reconstruction of the Horseshoe Basin at ~2.03 Ga (after Krapež, 1999).

638 **Fig. 5.** Photomicrographs and field photographs of the Woolly Dolomite: A) photomicrograph of
639 volcanoclastic siltstone from Mt Olympus, showing glassy shard (arrowed) and clear volcanic
640 quartz; B) photomicrograph of shard-rich volcanoclastic siltstone from near Urandy Creek Outcamp;
641 C) cross-sectional view of a gutter cast with stromatolitic debris incised into volcanoclastic
642 siltstones, Mt Olympus, hammer is 33 cm long; D) cross-sectional view of stromatolite-filled gutter
643 cast from Mt Olympus, with an ~1 cm-thick lining (arrowed) of calcite on the margin, hammer is 33
644 cm long.

645 **Fig. 6.** Field photographs and photomicrograph of the Woolly Dolomite: A) solitary stromatolite
646 enclosed in clastic dolostone from near Urandy Creek Outcamp, hammer is 33 cm long; B) large
647 domal stromatolite from near Urandy Creek Outcamp, hammer is 33 cm long; C) top surface of
648 columnar stromatolites near Urandy Creek Outcamp, hammer is 70 cm long; D) tabular bed of
649 oncolitic grainstone with large clasts, from the southern flank of the Wyloo Dome; hammer is 33
650 cm long; E) photomicrograph of oncolitic dolostone, from the southern flank of the Wyloo Dome,
651 showing small-scale stromatolites developed from oncolites; F) columnar stromatolites draped by
652 oncolitic grainstone, from the southern flank of the Wyloo Dome, scribe is 13 cm long.

653 **Fig. 7.** Field photographs of the Woolly Dolomite: A) a bed of soft-sediment deformed dolomitic
654 mudstone enclosed in undeformed dolomitic mudstones, from the southern flank of the Wyloo
655 Dome, scribe is 13 cm long; B) manganese nodule in dolomitic mudstones, showing compaction-
656 related deformation, from near Urandy Creek Outcamp, pencil is 16 cm long; C) and D) dolostone

657 megaclasts (highlighted) in diamictite with black shale matrix, from the southern flank of the
 658 Wyloo Dome, hammer is 70 cm long.

659 **Fig. 8.** Geological map of the Mt Olympus area, showing the location of drill-holes; refer to Fig. 3
 660 for the location.

661 **Fig. 9.** Measured stratigraphic section of the Wooly Dolomite at Mt Olympus; refer to Fig. 8 for the
 662 location.

663 **Fig. 10.** Field-sketch of interlayered dolomitic mudstone, jigsaw-fit hyaloclastite and basalt at Mt
 664 Olympus (refer to PP on Fig. 8 for location).

665 **Fig. 11.** Measured stratigraphic sections of the Wooly Dolomite at A) Mininee Well, and B)
 666 Anthiby Well; refer to Fig. 3 for the location.

667 **Fig. 12.** Geological map of the southern flank of the Wyloo Dome; refer to Fig. 3 for the location.

668 **Fig. 13.** Measured stratigraphic section of the Wooly Dolomite at the Type Section, southern flank
 669 of the Wyloo Dome; refer to Fig. 12 for the location.

670 **Fig. 14.** Measured stratigraphic section of the Wooly Dolomite at the Main Section, southern flank
 671 of the Wyloo Dome; refer to Fig 12 for the location and to Fig. 13 for the legend.

672 **Fig. 15.** Reconstructed stratigraphic profile of the Wooly Dolomite based on field mapping along
 673 the Main Section, southern flank of the Wyloo Dome; refer to Fig. 12 for the location.

674 **Fig. 16.** Geological map of the area around the Urandy Creek Outcamp; refer to Fig. 3 for the
 675 location.

676 **Fig. 17.** Measured stratigraphic sections of the Wooly Dolomite, Urandy Creek Outcamp at A)
 677 western section and B) eastern section; refer to Fig. 16 for locations.

678 **Fig. 18.** Measured stratigraphic section of the Wooly Dolomite in the headwaters of the Cane River;
 679 refer to Fig. 3 for the location.

680 **Fig. 19.** Geological map of the area around Red Hill; refer to Fig. 3 for the location.

681 **Fig. 20.** Composite measured stratigraphic section of the Wooly Dolomite around Red Hill; refer to
 682 Fig. 19 for the general location.

683 **Fig. 21.** Reconstructed stratigraphic geometry of the Woolly Dolomite drawn with the boundary
684 between the transgressive and regressive parts of DS2 as the horizontal; refer to Fig. 3 for the
685 general locations of the columns.

686

687 **TABLES**

688 **Table 1.** Summary of the lithofacies of the Woolly Dolomite.

Table 1. Summary of the lithofacies of the Wooly Dolomite.

Codes	Lithology	Structure	Composition	Interpretation
Gm	Pebble-cobble conglomerate, rare boulders	Clast-supported, massive or horizontally stratified	Pebbles of basalt, vein quartz, chert, & fine-grained metasedimentary rocks	Fluvial channels & bars
Sh	Coarse- & medium-grained sandstone, pebble lags	Horizontally stratified	Quartzose, quartzolithic & lithic, pebbles of vein quartz & basalt	High-flow regime in fluvial channels & on gravel bar tops
St	Medium- & fine-grained sandstone, pebble lags	Trough cross-stratification	Quartzose, quartzolithic & lithic, pebbles of vein quartz & basalt	Megaripples in fluvial channels, & compound sand bars (cosets)
Sr	Fine-grained sandstone	Plane- & cross-laminated	Quartzose, quartzolithic & lithic	Overbank & shelf sediments
SM	Sandstone, siltstone, mudstone	Graded beds, starved ripples	Quartzose, quartzolithic & lithic	Shelf siliciclastic sediments
SMT	Sandstone, siltstone, mudstone	Graded beds, starved ripples	Volcaniclastic, quartz-bearing	Shelf volcaniclastic sediments
MI	Siltstone, mudstone	Plane- & cross-laminated	Quartzose, quartzolithic & lithic	Shelf & fluvial siliciclastic sediments
MIT	Siltstone, mudstone	Plane & cross-laminated, graded beds	Volcaniclastic, quartz-bearing, some calcareous mudstone	Shelf volcaniclastic sediments
Mb	Organic-rich (black) shale	Laminated	Locally silicified (black-white chert)	Offshore & basinal sediments
Tf	Volcaniclastic siltstone	Massive or laminated	Rhyodacitic & basaltic	Reworked ashes
DX	Diamictite	Lenoid within Mb & DI	Dolostone clasts, black shale matrix	Slope debris flows
Dm	Dolostone	Tabular, crystalline	Rare stromatolites	Recrystallised shelf carbonates
Dh	Dolostone	Horizontally stratified, some wavy bedding (Dhw)	Recrystallised, rare grainstone & packstone textures, oncolitic (Dho)	Clastic shelf carbonates
Dt	Dolomitic sandstone	Trough cross-bedding	Grainstone textures preserved	Carbonate sands in tidal channels
Dstrom	Dolostone	Massive	Abundant stromatolites	Bioherms & local baffles
Db	Dolomitic breccia	Clast-supported, lenoid	Rudstone textures, stromatolites	Storm reworked shelf carbonates
DI	Dolomitic mudrock	Plane- or cross-laminated	Often interbedded with black shale	Shelf and slope carbonate muds

Figure 1

Figure

FIGURE 2

Lithological legend for Figure 2

Figure

FIGURE 3

Figure

Figure 4

Figure 5

Figure 6

Figure 7

FIGURE 8

Figure

Figure 9

FIGURE 10

FIGURE 11

Figure

FIGURE 12

FIGURE 13

Figure

FIGURE 14

FIGURE 15

Figure

FIGURE 16

Figure

FIGURE 17

LEGEND for Figure 17

Sphalerite-rich massive sulphide mineralisation

Soft-sediment deformation

Domal stromatolites

Lithofacies

Mb
MI
Sh
Gm

Dh - thinly bedded
Dt
Dm - silicified
Dm - recrystallised

DI
Db
Dhw

Legend to FIGURE 17

FIGURE 18

Figure

Legend

FIGURE 19

FIGURE 20

FIGURE 21