

RECENT RADIOMETRIC DATING OF SOME CAMBRIAN ROCKS IN SOUTHERN AUSTRALIA: RELEVANCE TO THE CAMBRIAN TIME SCALE

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ABSTRACT

The Cambrian time scale is in a state of flux due to a lack of reliable geochronological dates which can be tied to biostratigraphic scales. Most recent Australian dates relevant to the Cambrian geochronologic scale have been determined from the Early Cambrian successions of South Australia and the Middle and Late Cambrian sedimentary and volcanic rocks of western Tasmania. This work has been based on SHRIMP dates using zircon standard SL13. The reliability of these dates is questionable due to doubts as to the reliability of SL13. An analysis of the Lower Cambrian data from South Australia suggests that depending on the standard used the Botoman/Toyonian boundary may be younger than 532.8 ± 4 Ma or 522.8 ± 1.8 Ma. The base of the Botoman is older than 526 ± 4 Ma and may be several million years older, thus suggesting either that the Tommotian and Atdabanian are quite short or that the recently proposed figures of 534 Ma and 528 Ma for the base of the Tommotian and Atdabanian respectively need to be revised to older dates. The Middle Cambrian/Late Cambrian boundary is more likely to have a date of 505 Ma than 498 Ma. The average time span for a trilobite zone (mainly agnostoid based) in the Middle and Late Cambrian is about 535,000 years. This average time span is such that the error bars of most geochronological dates encompass several trilobite zones. Extremely precise and repeatable geochronological dates with good biostratigraphic links will be required to make significant advances in developing an accurate and reliable Cambrian time scale. Currently biostratigraphic work is much more precise and reliable than geochronology.

Key words: Cambrian time scale, South Australia, Tasmania, biostratigraphy, geochronology, Middle Cambrian/Late Cambrian boundary.

RESUMEN

La escala temporal cámbrica se encuentra cambiando continuamente debido a la falta de dataciones geocronológicas fiables que puedan superponerse con escalas bioestratigráficas. Las dataciones australianas más recientes relevantes para la escala temporal cámbrica han sido determinadas en sucesiones del Cámbrico Temprano de Australia del Sur y en rocas sedimentarias y volcánicas del Cámbrico Medio y Cámbrico Tardío de Tasmania. Este trabajo se ha basado en dataciones SHRIMP que usan el estándar de circón SL13. La exactitud de estas dataciones es cuestionable debido a dudas sobre la fiabilidad del SL13. Un análisis de los datos del Cámbrico Inferior de Australia del Sur sugiere que, dependiendo del estándar usado, el límite Botomense/Toyoniense puede ser más reciente que 532.8 ± 4 Ma o 522.8 ± 1.8 Ma. La base del Botomense es más antigua que 526 ± 4 Ma y puede ser todavía varios millones de años más antigua, lo que sugiere que o bien el Tommotiense y el Atdabaniense son bastante cortos, o bien que las cifras recientemente propuestas de 534 Ma y 528 Ma para las bases de estos respectivos pisos deben ser revisadas hacia dataciones más antiguas. El límite Cámbrico Medio/Cámbrico Tardío es más probable que esté situado en 505 Ma que en 498 Ma. El lapso temporal medio para las zonas de trilobites del Cámbrico Medio y Cámbrico Tardío (principalmente basadas en agnóstidos) es de unos 535.000 años. Dado este lapso temporal medio, resulta que la mayoría de los márgenes de error de las dataciones geocronológicas abarcan varias zonas de trilobites. Para hacer avances significativos en el

desarrollo de una escala temporal cámbrica precisa y fiable, se requerirán dataciones geocronológicas extremadamente precisas y repetibles, con buenos nexos bioestratigráficos. Hoy día, el trabajo bioestratigráfico es mucho más preciso y fiable que la geocronología.

Palabras clave: Escala temporal cámbrica, Australia del Sur, Tasmania, bioestratigrafía, geocronología, límite Cámbrico Medio/Cámbrico Superior.

INTRODUCTION

The Cambrian time scale has been the subject of some discussion in recent years, both in Australia (Shergold, 1995; Young and Laurie, 1996) and elsewhere (e.g., Tucker and McKerrow, 1995; Gradstein and Ogg, 1996). It is in a state of flux (Young and Laurie, 1996) due to a lack of reliable geochronologic dates which can be tied in with the various biostratigraphic scales. The purpose of this paper is to assess critically the value of recent Australian dates used in developing the Cambrian time scale and further to propose modifications, where appropriate, to this part of the time scale.

The two areas of interest are the late Early Cambrian rocks of the Adelaide Fold Belt of South Australia and the late Middle Cambrian Dundas Trough-Mt. Read Volcanics sedimentary-volcanic association of western Tasmania (Figs. 1, 3). The Cambrian geology of these areas, as presently understood, has been described in recent major reviews: the South Australian Cambrian by Gravestock (1995) and the Tasmanian Cambrian in Burrett and Martin (1989). Both areas are important to the understanding of the Neoproterozoic-early Palaeozoic history of the Palaeo-Pacific margin of Gondwana. In particular the dates discussed below for the late Early Cambrian are of considerable significance in trying to understand the timing of events and the sequence of events within the Delamerian Orogeny which affected the Neoproterozoic and Cambrian rocks of the Adelaide Fold Belt. This information will also be relevant to the timing and nature of the Ross Orogeny of the Transantarctic Mountains given the juxtaposition of Australia and Antarctica during the Cambrian.

COMMENT ON SHRIMP DATING

Most of the radiometric dates quoted herein were obtained using the sensitive high mass-resolution ion microprobe (SHRIMP) at the Research School of Earth Sciences, Australian National University. The SHRIMP has proven a very powerful technique for U-Pb dating of zircons through its ability to date single zircon crystals and domains within crystals. However, the SHRIMP technique is totally dependent on the need to compare analytical results with a well-documented, homogeneous standard zircon of known age (for technique details see Compston *et al.*, 1984). The SHRIMP results discussed in this paper have used two different standards; SL13, a 576 Ma gem quality zircon from Sri Lanka, and QGNG, a zircon of Palaeoproterozoic age from the Gawler Craton, South Australia. According to Black *et al.* (1997) SL13,

the dominant standard over the past decade, is now in short supply, and replacement standards are being sought. In dating Tasmanian Cambrian zircons, Black *et al.* (1997) have utilised both SL13 and QGNG, but report that the particular fragments of SL13 used in their study gave inconsistent results suggesting the existence of a poorly understood compositional heterogeneity in the standard. Thus all final ages given by Black *et al.* use QGNG. Black *et al.* (1997) also report that the two standards produce ages which are on average 1.3% different from each other, with QGNG producing relatively older ages. In order to make meaningful comparisons of available Tasmanian and South Australian SHRIMP data, we thus provide appropriate recalculations, depending on the standard used, as suggested by Black *et al.* (1997). This is for comparative purposes only. We wish to make it clear that we make no value judgements as to which standard may be giving the more accurate age. However, this problem highlights the

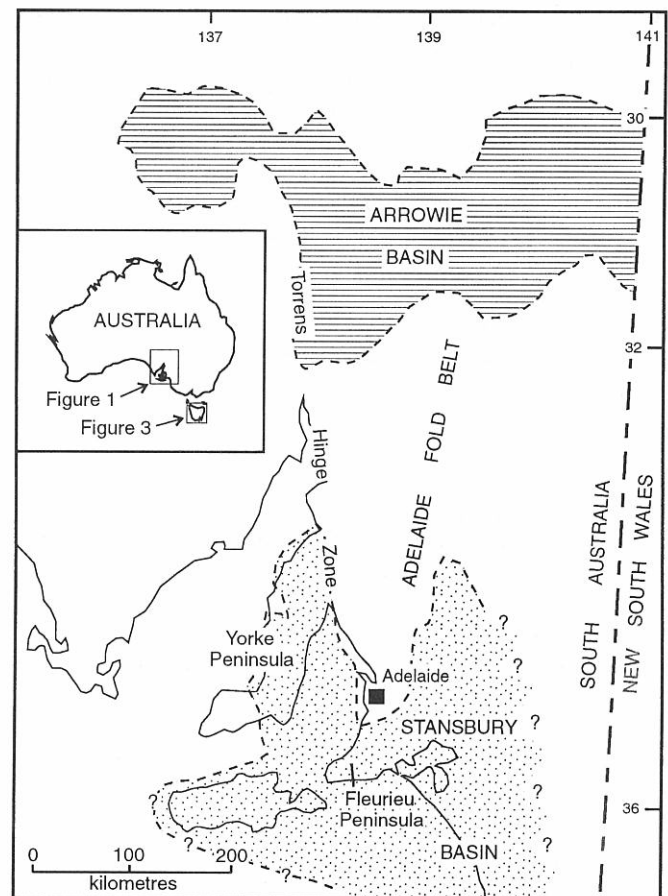


Figure 1. Locality map showing distribution of Cambrian rocks in southern South Australia.

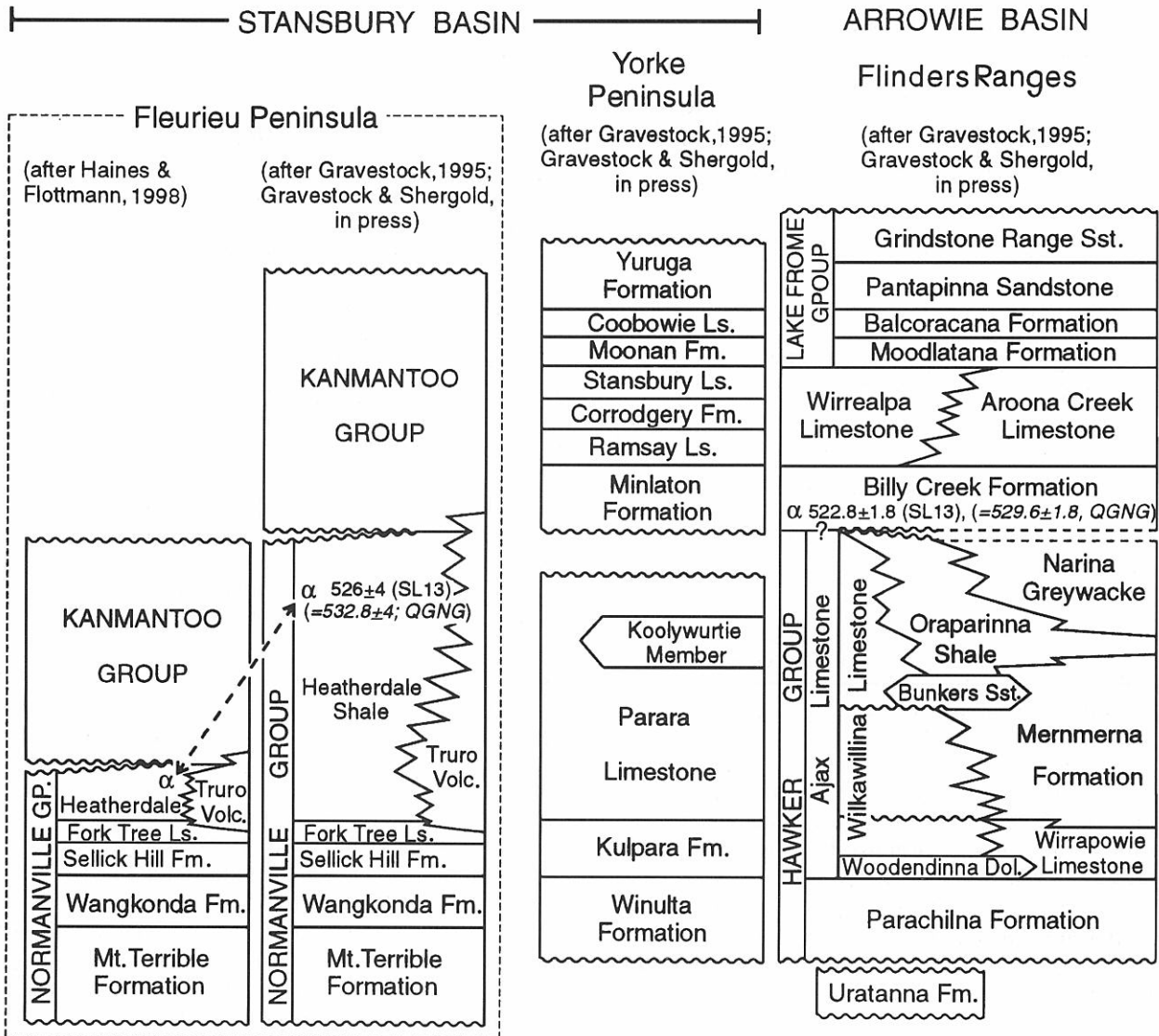


Figure 2. Correlation diagram of the Lower Cambrian successions of Fleurieu Peninsula, Yorke Peninsula and the Flinders Ranges.

potential difficulties of trying to accurately constrain the Australian Cambrian timescale on available radiometric data.

DATES FROM THE EARLY CAMBRIAN SUCCESSION OF THE ADELAIDE FOLD BELT

The Adelaide Fold Belt preserves a thick accumulation of Neoproterozoic to Middle Cambrian sediments. It is generally accepted that deposition began within an intracontinental rift, continued extension of which led to continental break-up in the late Neoproterozoic (the break up of Rodinia) to create the Palaeo-Pacific margin of Gondwana (e.g., Powell *et al.*, 1994; Veevers *et al.*, 1997). During the Cambrian, thick sediments continued to accumulate and are now preserved in two areas of southern South Australia referred to as the Stansbury and Arrowie Basins, although

there was almost certainly some continuity of sedimentation between these areas during deposition. Also beginning in the Cambrian, rocks of the Adelaide Fold Belt east of the Torrens Hinge Zone were deformed by the Early Palaeozoic Delamerian Orogeny (Preiss, 1995). The resulting Delamerian Orogen includes the exposed Adelaide Fold Belt, but extends east beneath cover at least into western Victoria, and may be represented in Tasmania by the Late Cambrian Jukesian Movement. The Delamerian Orogen is generally believed to have once been continuous with the Ross Orogen of the Transantarctic Mountains. Although the Delamerian Orogeny has normally been considered to be Late Cambrian-Ordovician, a recent date of 516 ± 4 Ma (Preiss, 1995), i.e. late Early Cambrian by the time scale of Young and Laurie (1996), has been obtained from what is generally interpreted as an early syn-tectonic granitoid (e.g., Sandiford *et al.*, 1992).

The critical areas of Cambrian rocks for the purposes of this discussion are the Flinders Ranges (Arrowie

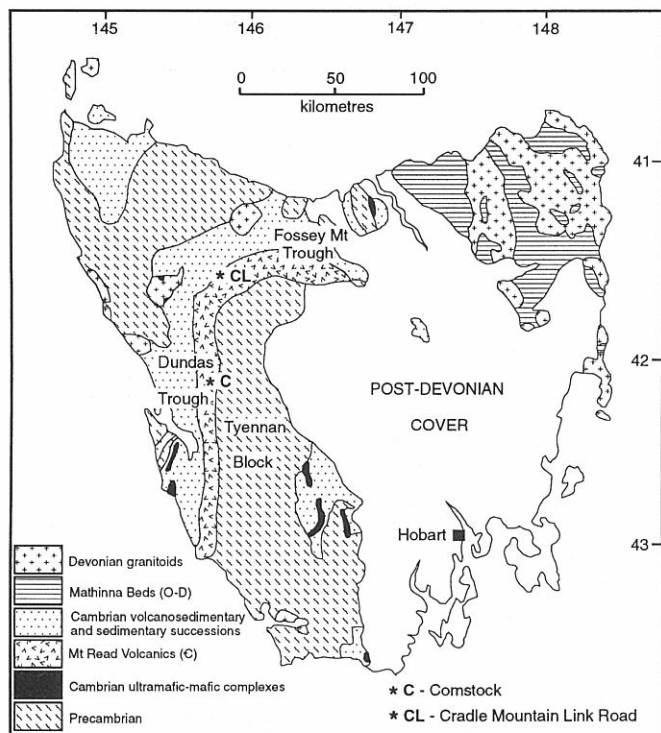


Figure 3. Geological outline of Tasmania.

Basin), Fleurieu Peninsula and Yorke Peninsula (Stansbury Basin). The stratigraphic successions and correlations which have normally been used (e.g., by Gravestock, 1995) are shown in figure 2. A recent alternative view (Fig. 2) has been proposed by Jenkins (1990) and Haines and Flottmann (1998). Of the South Australian successions, the one with the best biostratigraphic control is that in the Flinders Ranges.

Cooper *et al.* (1992) produced a mean $^{206}\text{Pb}/^{238}\text{U}$ SHRIMP age of 526 ± 4 Ma (95% confidence level) with standard SL13 ($=532.8 \pm 4$ Ma with QGNG) on zircons separated from a tuff bed within the upper part of the Heatherdale Shale at Sellicks Hill, Fleurieu Peninsula. However, this age is not very well biostratigraphically constrained in the area of outcrop. The Heatherdale Shale is the top unit of the Normanville Group; it is overlain unconformably by the thick (~8 km) flyschoid sediments of the Kanmantoo Group which contain only a few very poorly preserved, unidentifiable trilobites and brachiopods (Jago and Haines, 1997).

Cooper *et al.* (1992) suggest that the Heatherdale Shale is of early to mid Botoman age. The tuff horizon is quite close to the only known trilobite fauna within the Heatherdale Shale, which comprises a few poorly preserved specimens of *Atops*(?) (Jago *et al.*, 1984; Jenkins and Hasenohr, 1989; Jell *et al.*, 1992). The tuff horizon is over 400 m stratigraphically higher than the only reasonably well constrained biostratigraphic horizon in the Fleurieu Peninsula Cambrian succession. This horizon contains archaeocyaths in the top of the Sellick Hill Formation and the bottom part of the Fork Tree Limestone. Debrenne and Gravestock (1990) considered these archaeocyaths to be "no older than mid-Atdabanian

and arguably Botoman in age", although Zhuravlev and Gravestock (1994) suggest a top Atdabanian age for this fauna.

Gravestock (1995) has used both biostratigraphy and sequence stratigraphy to correlate (Fig. 2) the Cambrian succession on Fleurieu Peninsula with the biostratigraphically better controlled successions of Yorke Peninsula and the Flinders Ranges. Gravestock suggests that the upper part of the Heatherdale Shale should be correlated with the Mernmerna Formation and the Oraparinna Shale in the Central Flinders Ranges, over 400 km to the north.

Jell (1990) and Jell *et al.* (1992) have described a well preserved trilobite fauna from the upper part of the Mernmerna Formation. This fauna includes *Serrodiscus*, *Kootenia*, *Pararaia*, *Atops*, *Paleofossus*, *Redlichia endoi*, *Hsuaspis bilobata*, and others making up what Jell (1990) termed the *Pararaia janeae* Zone which he suggested is probably equivalent to the upper part of the Botoman in the Siberian scheme and probably with the Tsanglangpu Stage of China.

The upper part of the Heatherdale Shale is correlated with the upper part of the Parara Limestone on Yorke Peninsula, where the Koolywurtie Limestone Member, near the top of the Parara Limestone, contains archaeocyaths of the *Syringocnema favus* beds which suggest a middle to late Botoman age (Zhuravlev and Gravestock, 1994). Hence the trilobite and archaeocyath data give the same result, i.e. the figure of 526 ± 4 Ma represents a late Botoman age. This is supported by the work of Zhou and Whitford (1994) who reported a U-Pb SHRIMP age of 525 ± 8 Ma with standard SL13 ($=531.8 \pm 8$ Ma with QGNG) from a felsic tuff within the Cymbric Vale Formation of western New South Wales. Zhuravlev and Gravestock (1994) suggest that archaeocyaths from the top of the Cymbric Vale Formation have a similar mid to late Botoman age to those of the Koolywurtie Limestone. This agrees with the correlation, based on archaeocyaths, of Kruse (1982) of the Cymbric Vale Formation with the Ajax Mine fauna from the upper part of the Ajax Limestone in the Flinders Ranges. Trilobite faunas from near the top of the Cymbric Vale Formation also suggest a mid to late Botoman age (Jago *et al.*, 1997). However, although the New South Wales information supports that obtained from the Heatherdale Shale the details of the Cymbric Vale radiometric age are yet to be published.

Gravestock and Shergold (in press) report a SHRIMP age of 522.8 ± 1.8 Ma (SL13) ($=529.6 \pm 1.8$ Ma with QGNG) from the lower part of the Billy Creek Formation (Fig. 2) which they consider as late Botoman. However, it should be noted that the Billy Creek Formation contains very few fossils; Bengtson *et al.* (1990: 15) record only the emuellid trilobite *Balcoracania flindersi*. The Wirrealpa Limestone, which overlies the Billy Creek Formation contains a small archaeocyathan fauna plus the trilobite *Redlichia guizhouensis* which suggests correlation with the *Redlichia chinensis* Zone of the Chinese Lungwangmiao Stage (Bengtson *et al.*, 1990). This is equivalent to the early Toyonian (Debrenne *et al.*, 1990).

If the ages and correlations discussed above are correct then it would suggest that the Botoman/Toyonian boundary is younger than 526 ± 4 (using SL13) or 532.8 ± 4 (using QGNG) and may be younger than 522.8 ± 1.8 (SL13) or 529.6 ± 1.8 (QGNG).

If it is accepted that the Heatherdale Shale is of mid to late Botoman age then the above discussion suggests that the Atdabanian/Botoman boundary is probably greater than the 525 Ma suggested by Tucker and McKerrow (1995) or the ~526 Ma suggested by Young and Laurie (1996), although the error bars of the geochronology and the unavailability of exact biostratigraphic data do not rule out the possibility that either of these dates is correct.

It is suggested by Tucker and McKerrow that the base of the Tommotian is 534 Ma and the base of the Atdabanian is 530 Ma. However, if the base of the Botoman is older than 526 Ma (and may be several million years older) then it would suggest that either the Tommotian and Atdabanian are quite short or that the figures of 534 and 530 may need to be revised to older dates.

As noted above, on Fleurieu Peninsula the Normanville Group is unconformably overlain by the Kanmantoo Group (Jago *et al.*, 1994). The Kanmantoo Group is intruded by an early syn-tectonic granitoid, known as the Rathjen Gneiss, which has a U-Pb date of 516 ± 4 Ma (Preiss, 1995). Chen and Liu (1996) report a U-Pb zircon date of 510 ± 2 measured at the Royal Ontario Museum from a post-D2 meta-dolerite which intruded Kanmantoo Group rocks.

Due to a lack of diagnostic fossils the biostratigraphic age range of the Kanmantoo Group is unknown. It has generally been argued that the Delamerian Orogeny which folded the Proterozoic-Cambrian sequence of the Adelaide Fold Belt is of Middle to Late Cambrian age with the youngest rocks affected, the biostratigraphically unconstrained Lake Frome Group, being at least in part of Middle Cambrian age (e.g., Gravestock, 1995). This would suggest that the base of the Middle Cambrian would be somewhat older than 510 Ma. However, it has been suggested recently by Haines and Flottmann (1998) that the Delamerian Orogeny is a multistage process with "an outer area", the Fleurieu-Nackara Arc being deformed first and the rest of the Adelaide Fold Belt being deformed later in the Cambrian. If this is the case then neither the 516 nor 510 is of value in determining the Cambrian time scale.

LATE MIDDLE CAMBRIAN DATES FROM WESTERN TASMANIA

Young and Laurie (1996) place the Middle Cambrian/Late Cambrian boundary at about 498 Ma, whereas Gradstein and Ogg (1996), following Tucker and McKerrow (1995), suggest a figure of 505 Ma. Young and Laurie also place the Late Templetonian-Floran/Undillan, Undillan/Boomerangian and Boomerangian/Mindyallan boundaries respectively at

COMSTOCK		CRADLE MOUNTAIN LINK ROAD	
OWEN CONGLOMERATE		OWEN CONGLOMERATE	
ZIG ZAG HILL FORMATION		ZIG ZAG HILL FORMATION	
COMSTOCK FORMATION (=COMSTOCK TUFF)	MOUNT JULIA MEMBER $\alpha_{1,2}$	COMSTOCK FORMATION	⊙ ¹ MOUNT JULIA MEMBER α_3
	LYNCHFORD MEMBER ⊙ ²		LYNCHFORD MEMBER
α_4	Andesites and basalts	SOUTHWELL SUBGROUP ⊙ ³ α_5	QUE RIVER SHALE ⊙ ⁴

BIOSTRATIGRAPHY (⊙)

1. late *L. laevigata* zone fossils
2. late Middle Cambrian fossils
3. *G. nathorsti* - early *L. laevigata* zone fossils in clasts
4. *E. opimus* - *P. punctuosus* zone fossils

GEOCHRONOLOGY (α)

1. 494.4 ± 3.8 (SL13, 1σ); (=500.8 ± 7.6; QGNG, 2σ)
2. 502.5 ± 3.3 ; (SL13, 1σ); (=509.0 ± 6.6; QGNG, 2σ)
3. 505.3 ± 3.6 (QGNG); (=498.9 ± 3.6, SL13)
4. 502.2 ± 3.5 (SL13, 1σ); (=508.7 ± 7.0; QGNG, 2σ)
 501.5 ± 5.7 (40Ar/39Ar, 1σ)
5. 503.2 ± 3.8 (SL13, 1σ); (=509.7 ± 7.6; QGNG, 2σ)

Figure 4. Summary diagram showing biostratigraphic and geochronologic data of the Mount Read Volcanics from the Comstock and Cradle Mountain Link Road areas of western Tasmania (based on White and McPhie, 1996, and Corbett, 1992). In the Cradle Mountain Link Road area, the Zig Zag Hill and Comstock Formations together correspond to the Mt. Cripps Subgroup of Corbett (1992). All the geochronologic dates in the Comstock area and the lower one in the Cradle Mountain Link Road area are from Perkins and Walshe (1993). These are shown both as originally given by Perkins and Walshe with a 1σ error using the SL13 zircon standard and increased by 1.3% and with a 2σ error for comparison with the QGNG zircon standard as used by Black *et al.* (1997). The upper date in the Cradle Mountain Link Road column is from Black *et al.* (1997).

	STAGE	ZONE
ORD	WARENDAN	
	DATSONIAN	
LATE CAMBRIAN	PAYNTONIAN	<i>M. perplexa</i>
		<i>N. quasibilobus</i> - <i>S. nomas</i>
		<i>S. impages</i>
	IVERIAN	<i>R. clarki maximus</i> - <i>R. papilio</i>
		<i>R. bifax</i> - <i>N. denticulatus</i>
		<i>R. clarki prolatus</i> - <i>C. sectatrix</i>
		<i>R. clarki patulus</i> - <i>C. squamosa</i>
		<i>P. tertia</i> - <i>P. quarta</i>
		<i>P. secunda</i> - <i>P. glabella</i>
	IDAMEAN	<i>W. iota</i> - <i>R. apsis</i>
		<i>I. tropica</i>
		<i>S. diloma</i>
<i>E. sentum</i>		
MINDYALLAN	<i>P. cryptica</i>	
	<i>G. reticulatus</i>	
	<i>G. stolidotus</i>	
BOOMERANGIAN	<i>C. quasivespa</i>	
	<i>E. eretes</i>	
	<i>D. torosa</i> - <i>A. janitrix</i>	
	<i>H. arepo</i>	
	<i>P. agra</i>	
UNDILLAN	<i>P. cassis</i>	
	<i>G. nathorsti</i>	
	<i>D. deltoides</i>	
LATE TEMPLETONIAN - FLORAN	<i>P. punctuosus</i>	
	<i>E. opimus</i>	
	<i>A. atavus</i>	
ORDIAN - EARLY TEMPLETONIAN	<i>T. gibbus</i>	
	<i>X. templetonensis</i> - <i>R. chinensis</i>	
EARLY CAMBRIAN		

Figure 5. Australian Middle and Late Cambrian biochronological scale. (Based on Shergold, 1995.)

503, 500 and 498.5 Ma. This work is based essentially on the link between the radiometric ages obtained by Perkins and Walshe (1993) and the biostratigraphy outlined by Jago and Brown (1989) for the Middle and Late Cambrian of Tasmania.

Western Tasmania is a structurally complicated,

geologically diverse, highly mineralized and thickly vegetated area. The known fossiliferous Cambrian rocks are all of Middle and Late Cambrian age. The majority of Tasmanian Middle and Upper Cambrian sediments were deposited in the narrow Dundas Trough, with intermittent volcanism along the neighbouring Mt. Read Volcanic Arc to the east. Further east again are the Precambrian metamorphics of the Tyennan Block (Fig. 3). Most of the sediments were probably deposited in submarine fan complexes, but there are a few shallow water deposits. There is some intercalation of fossiliferous sediments within the Mt. Read Volcanics.

The stratigraphy of the Mt. Read Volcanics has been described by Corbett (1992) and White and McPhie (1996). The terminology shown in figure 4 is based on these workers; where there is a difference in terminology, that of White and McPhie is used. Geochronologic studies by Perkins and Walshe (1993) and Black *et al.* (1997) suggest that the Mt. Read Volcanics were formed over a period of about ten million years in the Middle and Late Cambrian. Perkins and Walshe (1993) obtained eight isotopic dates (mainly SHRIMP U-Pb zircon dates using SL13) from the Mt. Read Volcanics. These ages essentially fall into two groups with two ages between 494 and 495 and five ages between 501.0 and 503.2 Ma. Four of these dates are linked with fossiliferous successions.

One of the Perkins and Walshe dates (sample 92-101) is a SHRIMP U-Pb date of 494.4 ± 3.8 Ma from zircons within volcanoclastic rocks within what they termed the Comstock Tuff, but would now be regarded as occurring low in the Mount Julia Member of the Comstock Formation (Comstock Tuff of Corbett, 1992, and other workers). This sample is stratigraphically above (K. Corbett, pers. comm.) a fossiliferous shallow water limestone of the Lynchford Member (Fig. 4) containing dorypygid and agnostoid trilobites which suggest a late Middle Cambrian age (Jago *et al.*, 1972; Laurie *et al.*, 1995). If the stratigraphic correlation given by White and McPhie (1996) is correct, then the Comstock Formation at Comstock is approximately of early *Lejopyge laevigata* Zone age as shown by Perkins and Walshe. A second SHRIMP U-Pb date given by Perkins and Walshe (1993) for the Mount Julia Member is 502.5 ± 3.3 Ma for volcanoclastics in the Anthony Road area. The fact that both of the above dates are from volcanoclastic rocks means that there is some uncertainty as to the exact age of the zircons.

Perkins and Walshe (1993) give two other dates from just below the Comstock Formation at Comstock. One of these dates, from an andesite, 502.2 ± 3.5 Ma is a SHRIMP U-Pb zircon date using SL13; the other date, 501.5 ± 5.7 Ma is an $^{40}\text{Ar}/^{39}\text{Ar}$ date.

The biostratigraphically best constrained date of Perkins and Walshe (1993) is from a rhyolite lava (their sample 91-278) from what they termed (p.1180) "the Upper rhyolite sequence north of the Cradle Mountain link road" as having a SHRIMP zircon age of 503.2 ± 3.8 Ma (SL13 standard). Although no exact geographic and stratigraphic details are given by Perkins and Walshe, on

their figure 2 they indicate that sample 91-278 came from near the base of the Southwell Subgroup. The Southwell Subgroup is underlain by the Que River Shale which contains a late Floran-early Undillan agnostoid fauna of *Euagnostus opimus* Zone to *Ptychagnostus punctuosus* Zone (Jago, 1977; Laurie *et al.*, 1995). Apparently stratigraphically above sample 91-278, but still within the Southwell Subgroup, is a polymict volcanoclastic conglomerate which contains rare limestone clasts with trilobites which suggest an age of *Goniagnostus nathorsti* Zone to early *Lejopyge laevigata* Zone (Jago and McNeill, 1997).

In the Cradle Mountain Link Road area the Southwell Subgroup is overlain by the Comstock Formation (Fig. 4). There are well preserved trilobites of late *Lejopyge laevigata* Zone age in the upper part of the Mount Julia Member of the Comstock Formation.

There are two problems in using the dates of Perkins and Walshe in relating the geochronologic to the biostratigraphic time scale. The first is that they give their results with a 1σ error, which encompasses a 67% confidence limit, whereas the current convention is to give a 2σ error which encompasses a 95% confidence limit. Thus a more realistic figure for their sample 91-278 would be 503.2 ± 7.6 Ma. The second problem is the use of zircon standard SL13 noted above. The above date when compared with the QGNG zircon standard would be about 509.7 ± 7.6 Ma.

A SHRIMP U-Pb age (standard QGNG) of 505.3 \pm 3.6 Ma was obtained by Black *et al.* (1997) from cogenetic zircons from an ignimbrite which is at the base of the Mount Julia Member on the Cradle Mountain Link Road (K. Corbett, pers comm.). Hence it is stratigraphically above the fossiliferous limestone clasts of *G. nathorsti* Zone to early *L. laevigata* Zone noted above, but below the late *L. laevigata* Zone fossils from the upper part of the Mount Julia Member.

The above data would suggest that the Middle Cambrian/Late Cambrian boundary is more likely to have an age of 505 Ma than 498 Ma, but a precise figure is not possible at this time. Given the data limitations the difference between 505 Ma and 498 Ma may not seem to be particularly significant, but it is of some significance when it is realised that in the tables given by Young and Laurie (1996) there are 28 trilobite zones (Fig. 5) from the base of the Late Templetonian-Floran (506 Ma according to Young and Laurie) to the top of the Payntonian (491 Ma according to Young and Laurie), i.e. the average time span for a trilobite zone over this interval is about 535,000 years using the Young and Laurie time scale.

Because of the problems discussed above with respect to the dating of the late Middle Cambrian part of the time scale, it could be argued the figures 506 Ma and 491 Ma are of little value. However, whatever the figures should actually be, it is quite clear that the average time span of a Middle or Late Cambrian trilobite zone is such that even the error bars of the geochronological dates encompass over ten trilobite zones.

This suggests that extremely precise geochronological dates with good biostratigraphic links in the Middle and

Late Cambrian will be required to make significant advances in developing an accurate and reliable Cambrian time scale. Such precise links are important in developing an understanding of the sequence of events in geologically complex areas such as western Tasmania. The current situation is that biostratigraphic work is much more precise and reliable than geochronology, although it is essential that work proceeds to provide better links between the biostratigraphic and geochronologic scales.

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