

Integrated Shelly Fossil Biostratigraphy and Chemostratigraphy: Applying a Multi-Proxy Toolkit to Correlating the Lower Cambrian of South Australia*

Marissa J. Betts¹, Glenn A. Brock², John R. Paterson³, James B. Jago⁴, and Anita S. Andrew⁵

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Abstract

Despite decades of concerted efforts, the Cambrian Period remains one of the most underdeveloped parts of the International Geological Timescale, with the boundaries of a number of series and stages still awaiting definition and subsequent ratification. A major impediment to the development of the Cambrian timescale and global correlation, particularly in Australia, is the paucity of comprehensive biostratigraphic, lithostratigraphic, and chemostratigraphic data. Hence, there has been increased drive to utilise the stratigraphic ranges of small shelly fossils (SSF) and apply isotopic chemostratigraphic methods to regional studies in an effort to resolve and calibrate the timescale. In South Australia, the lower Cambrian succession in the Arrowie Basin is well preserved, well exposed, and contains rich fossil assemblages. These qualities have been exploited in a new biostratigraphic scheme utilising assemblage zones of SSF and associated mineralised taxa. Shelly fossils have been extracted from ten measured stratigraphic sections and display ranges that are robust and repeatable across the Arrowie Basin. This new scheme correlates well with faunas from the coeval Stansbury Basin; however, endemic and diachronistic taxa hinder effective global application. Chemostratigraphic data, when utilised in concert with biostratigraphy and lithostratigraphy, can allow regional schemes to be put in a global context. Consequently, carbon and oxygen isotope curves have been developed for the Arrowie Basin sections in an effort to provide a more suitable proxy for correlation. This is the first time oxygen and carbon isotopic chemostratigraphic data have been integrated with a robust biostratigraphic scheme for the early Cambrian of Australia, and demonstrates the value of applying a multi-proxy dataset to the problem of stratigraphic correlation.

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Integrated Shelly Fossil Biostratigraphy and Chemostratigraphy: Applying a Multi-Proxy Toolkit to Correlating the Lower Cambrian of South Australia

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4. Environmental Isotopes Pty. Ltd., North Ryde, NSW, Australia.

OUTLINE

- Background and rationale
- Localities and stratigraphic sections
- Shelly fossil biostratigraphy
- Carbon and oxygen chemostratigraphy
- Regional and global correlation



Abundant early Cambrian shelly fauna from Ardrossan, Stansbury Basin

BACKGROUND

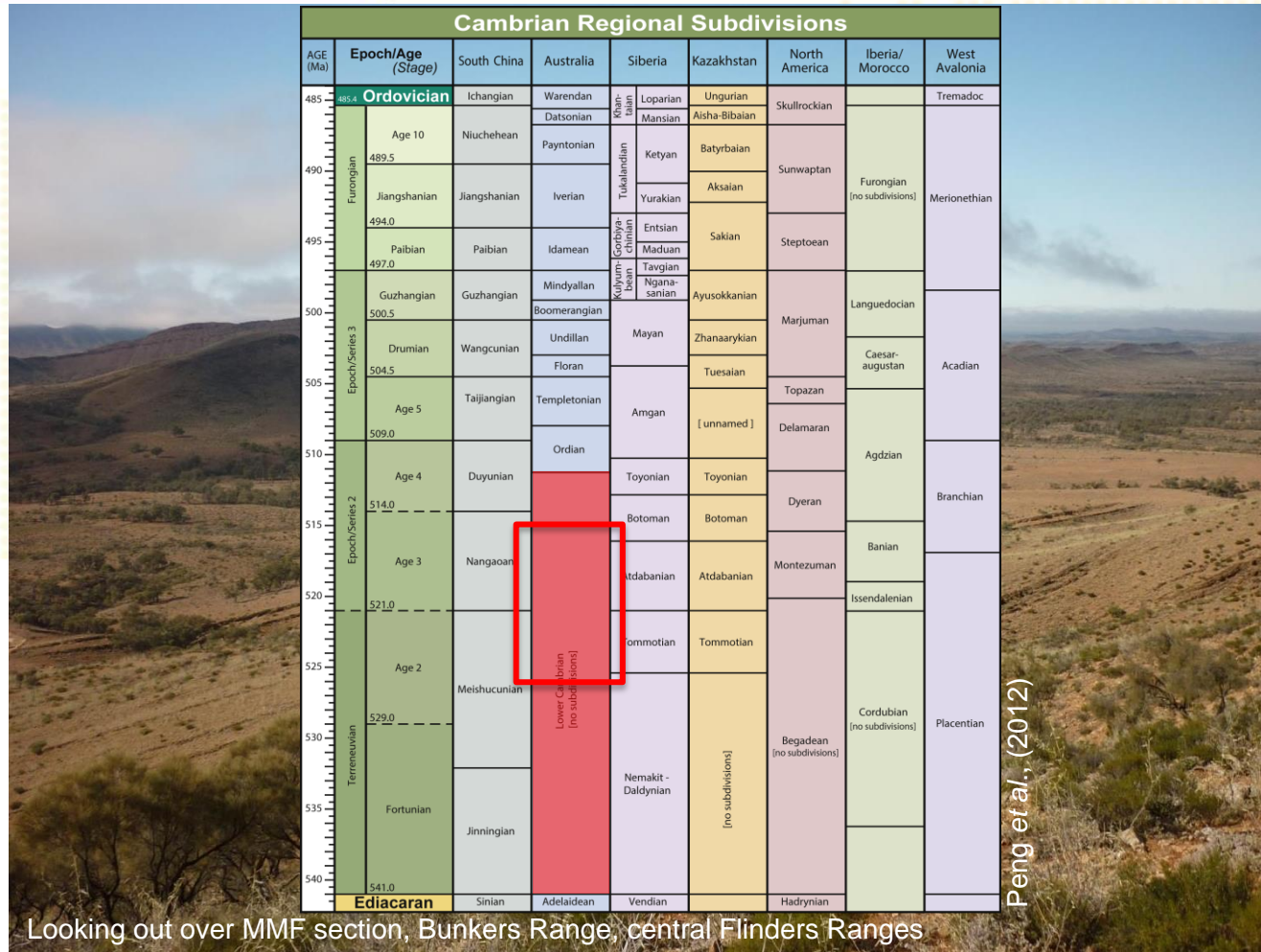
- Early Cambrian in Australia has no stage subdivisions
- Cambrian subdivision hindered by endemism, diachronism, preservation of key fauna
- MULTI-PROXY METHOD
- Current study spans Terreneuvian, Stage 2 to Series 2, Stage 3



Looking out over MMF section, Bunkers Range, central Flinders Ranges

BACKGROUND

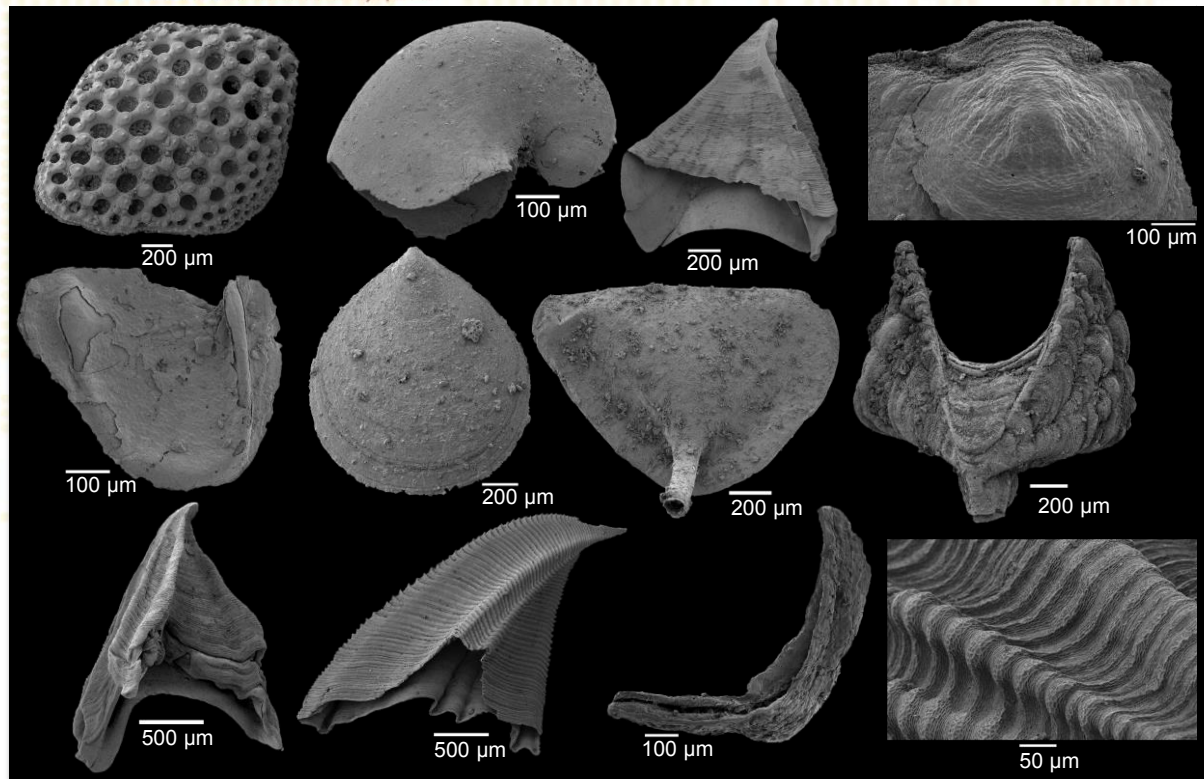
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SMALL SHELLY FOSSILS

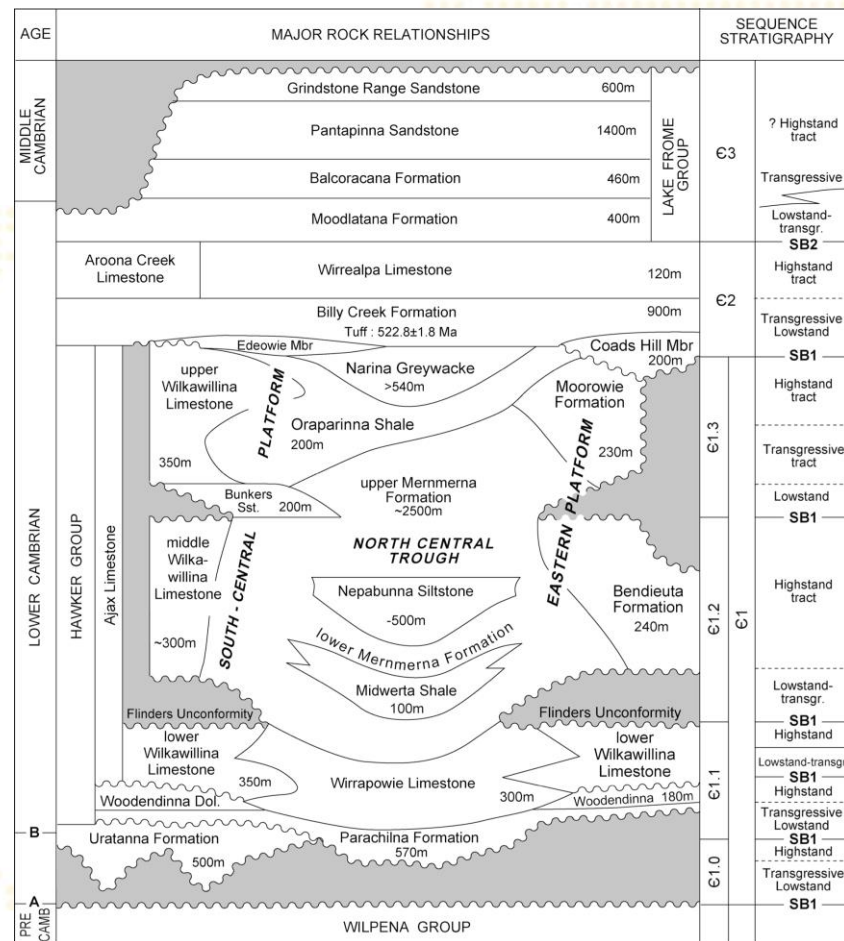
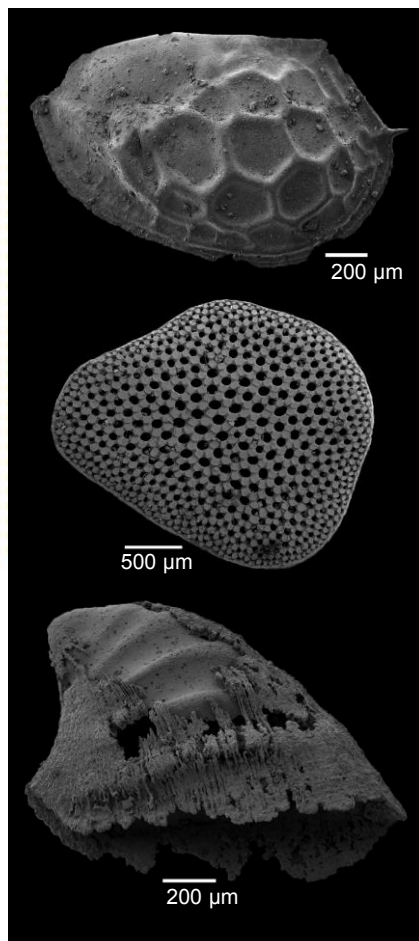
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- Sub-millimetric cap, spine, cone shaped (usually phosphatic) fossils
- Tommotiids, brachiopods, molluscs, bivalved arthropods, lobopodians, and problematic taxa
- First shelly fauna (Cambrian Explosion)
- Great potential for regional biostratigraphic applications



RATIONALE

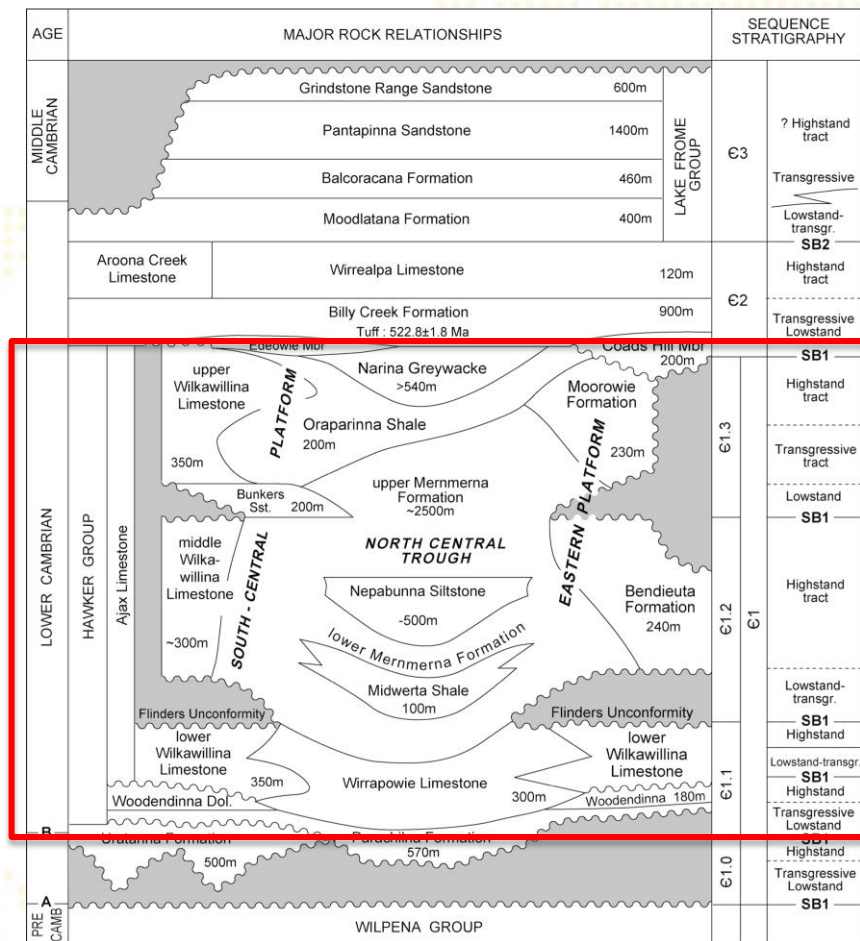
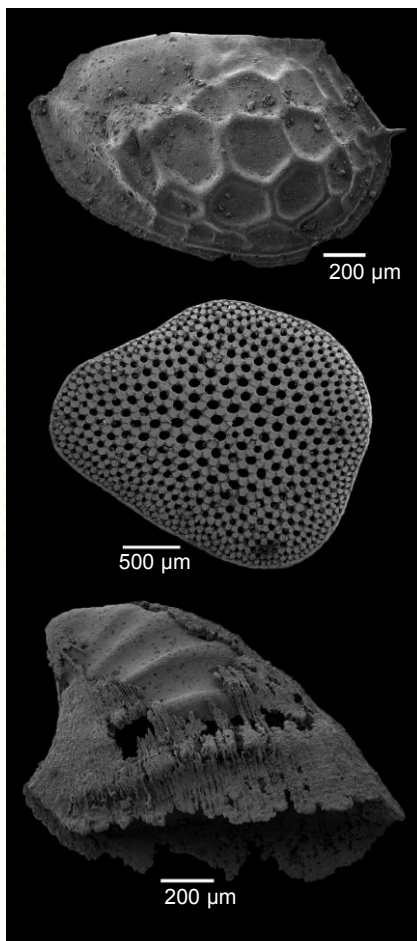
1. Utilise shelly fossils as biostratigraphic tools to subdivide and correlate the early Cambrian successions in South Australia
2. Integration of biostratigraphic and chemostratigraphic data to enable global correlation



Early Cambrian succession, Arrowie Basin, South Australia (Paterson & Brock, 2007)

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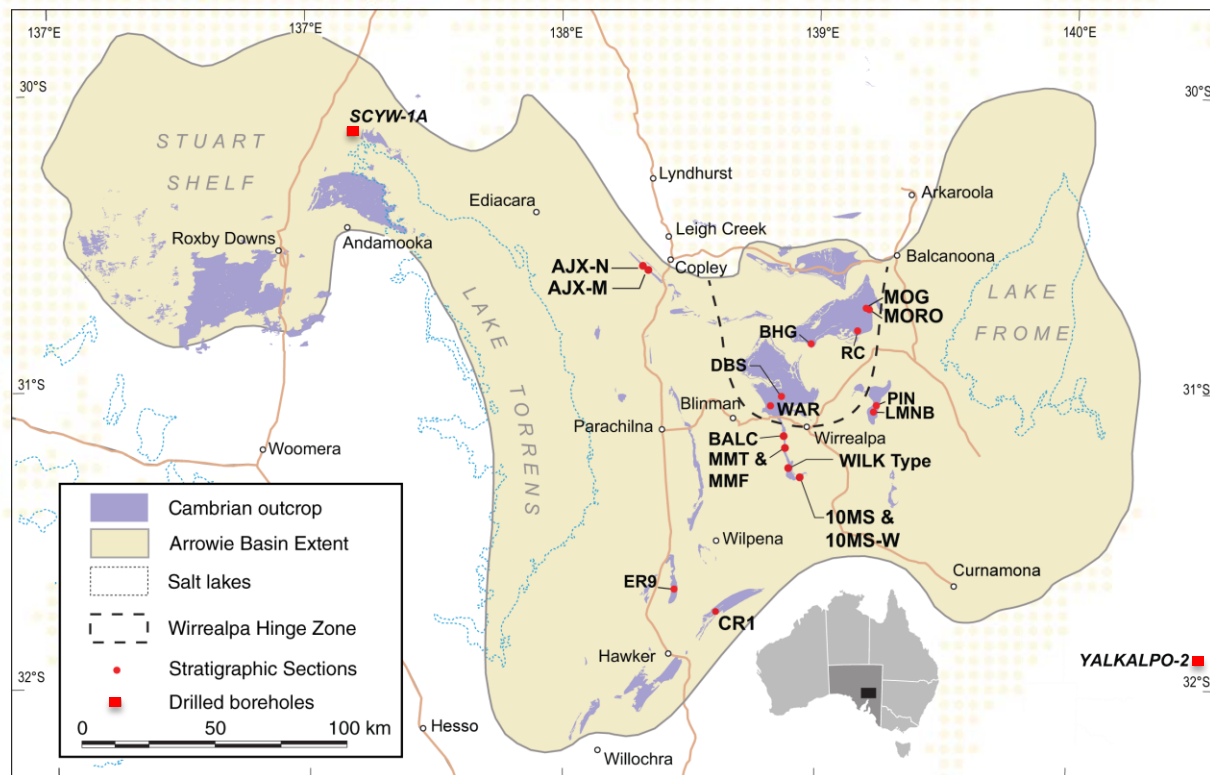


Early Cambrian succession, Arrowie Basin, South Australia (Paterson & Brock, 2007)

Arrowie Basin Sections and Drill Cores

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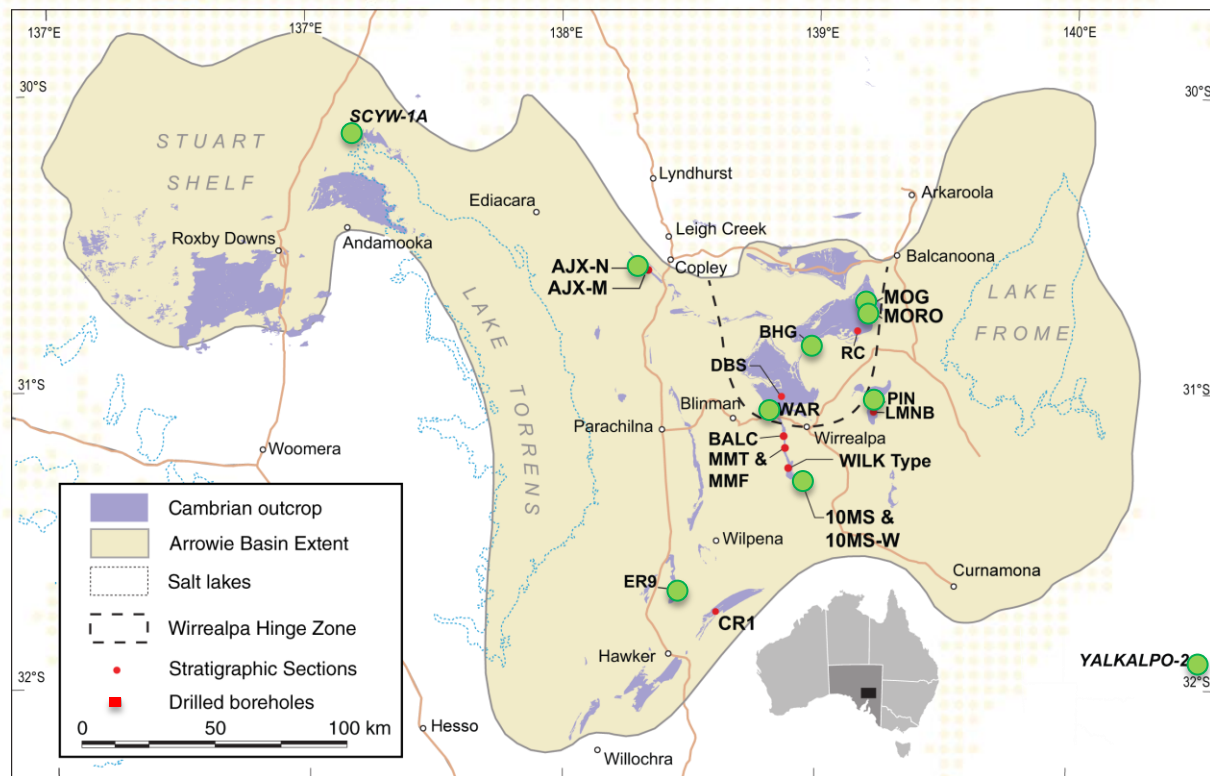
- Biostratigraphic data from 20 sections (inc. 2 drill cores) in Arrowie Basin + Sellick Hill Limestone in Stansbury Basin
- Carbon and oxygen chemostratigraphic data (bulk rock) from 11 sections & drill cores



Arrowie Basin Sections and Drill Cores

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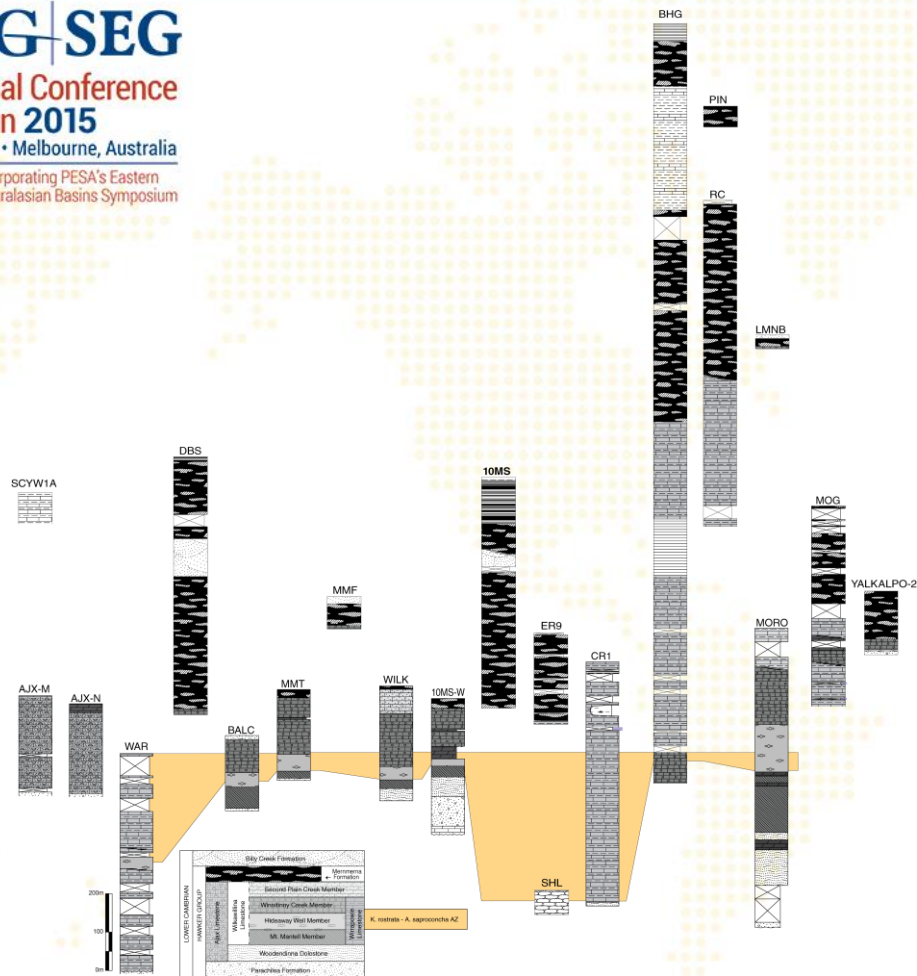
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Figure 1 displays 12 scanning electron micrographs (SEM) of fossilized ostracod specimens, arranged in a grid. Each specimen is shown with a scale bar indicating its size. The specimens exhibit various morphological features, including concentric growth lines, pitting, and distinct shell shapes. The scale bars are as follows:

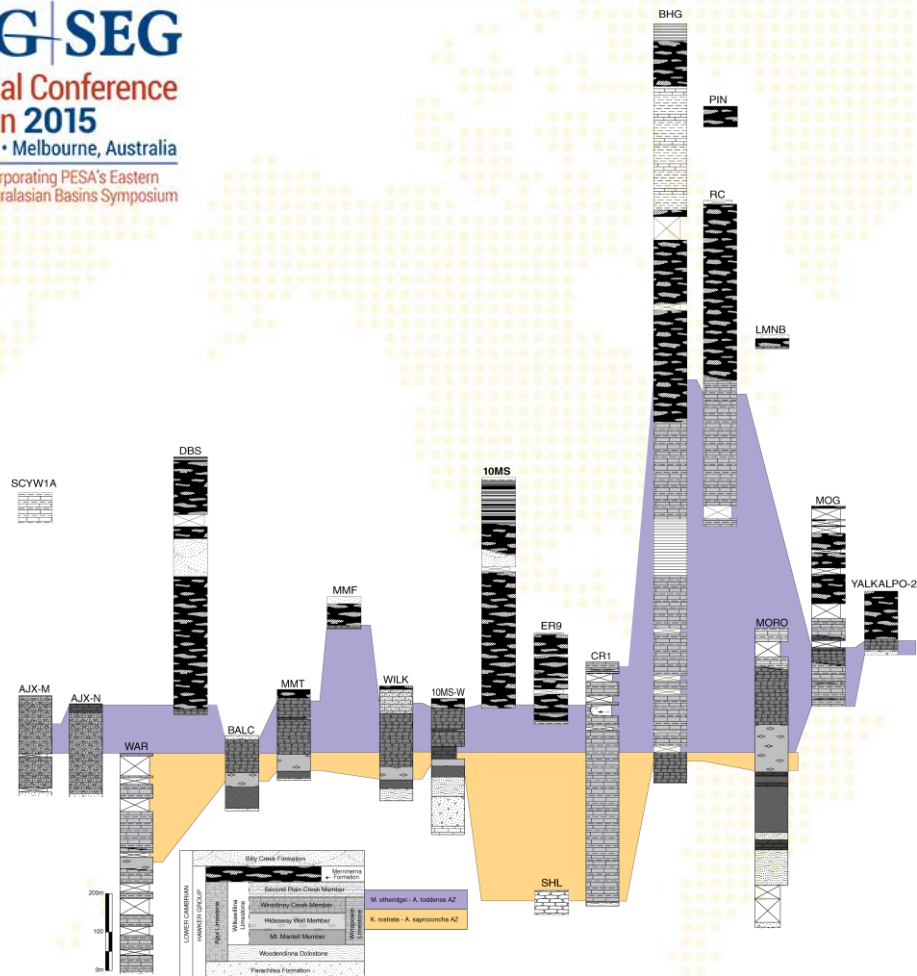
- Top row (left to right): 200 μm , 200 μm , 100 μm , 100 μm .
- Second row (left to right): 1 mm, 1 mm, 1 mm, 500 μm .
- Bottom row (left to right): 500 μm , 200 μm , 100 μm , 200 μm .



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Figure 1 displays 12 scanning electron micrographs (SEM) of fossilized ostracod shells, arranged in a 3x4 grid. Each panel shows a different specimen or view, with scale bars indicating size in micrometers (μm).

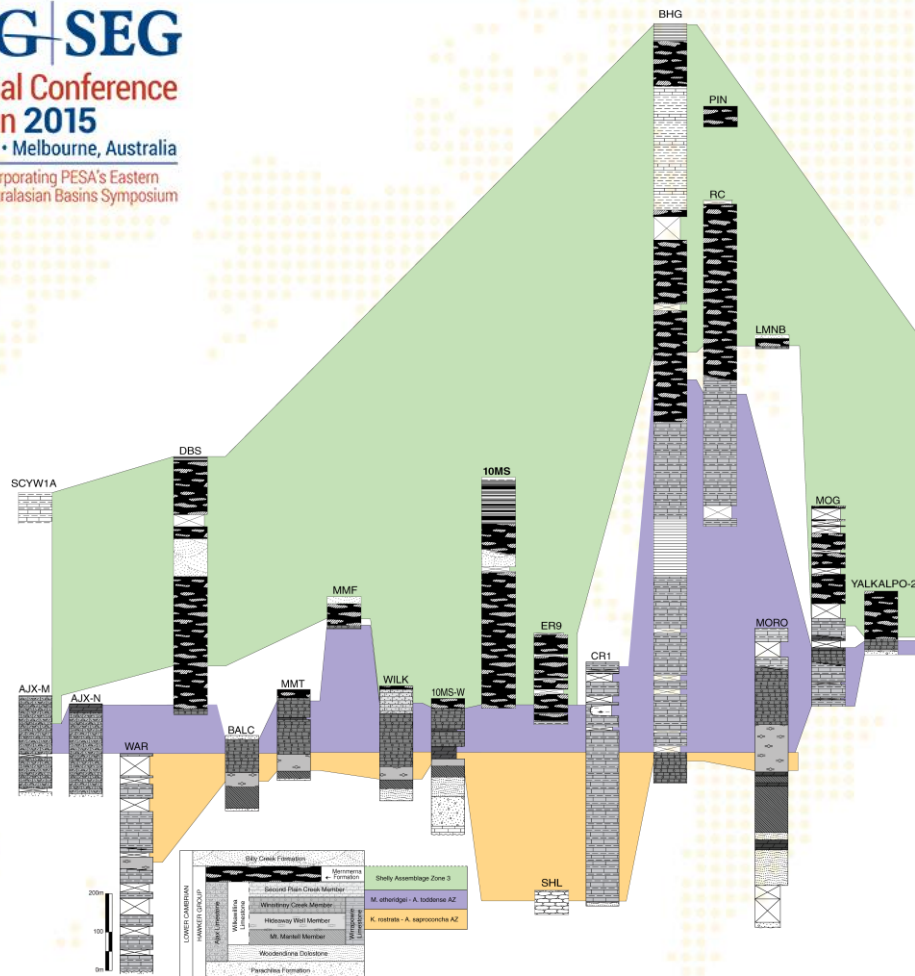
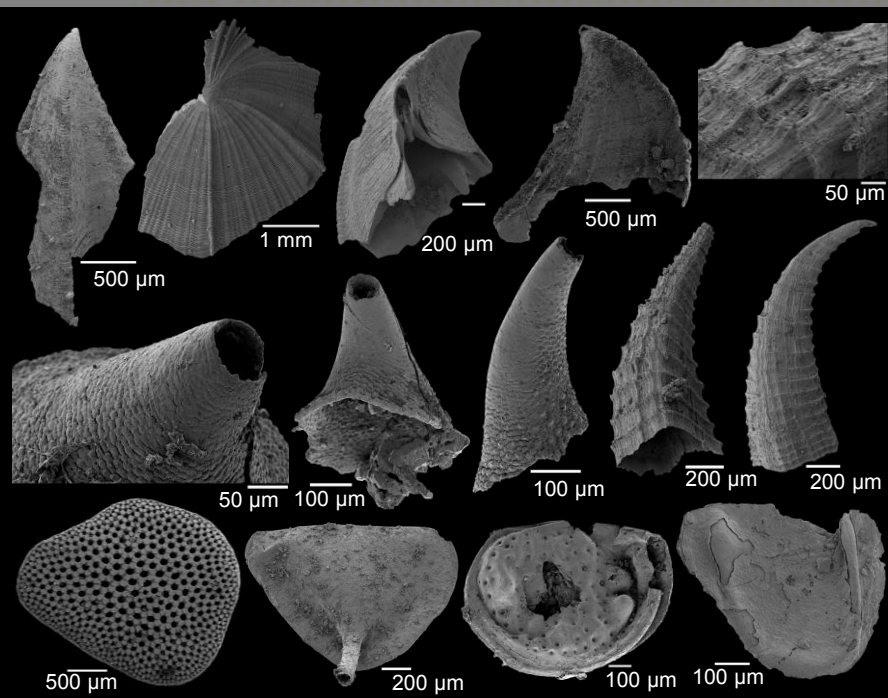
- Panel 1: Dorsal view of a shell with concentric growth lines. Scale bar: 200 μm.
- Panel 2: Ventral view of a shell with concentric growth lines. Scale bar: 200 μm.
- Panel 3: Lateral view of a shell with concentric growth lines. Scale bar: 200 μm.
- Panel 4: Another lateral view of a shell with concentric growth lines. Scale bar: 100 μm.
- Panel 5: Internal view of a valve showing muscle scar areas. Scale bar: 200 μm.
- Panel 6: Internal view of a valve showing muscle scar areas. Scale bar: 100 μm.
- Panel 7: Large, curved valve showing concentric growth lines. Scale bar: 500 μm.
- Panel 8: Smaller, more complex structure, possibly a hinge or muscle scar area. Scale bar: 200 μm.
- Panel 9: Another large, curved valve. Scale bar: 500 μm.
- Panel 10: Internal view of a valve showing muscle scar areas. Scale bar: 200 μm.
- Panel 11: Another internal view of a valve showing muscle scar areas. Scale bar: 100 μm.
- Panel 12: Another internal view of a valve showing muscle scar areas. Scale bar: 100 μm.



Shelly Fossil Biostratigraphy

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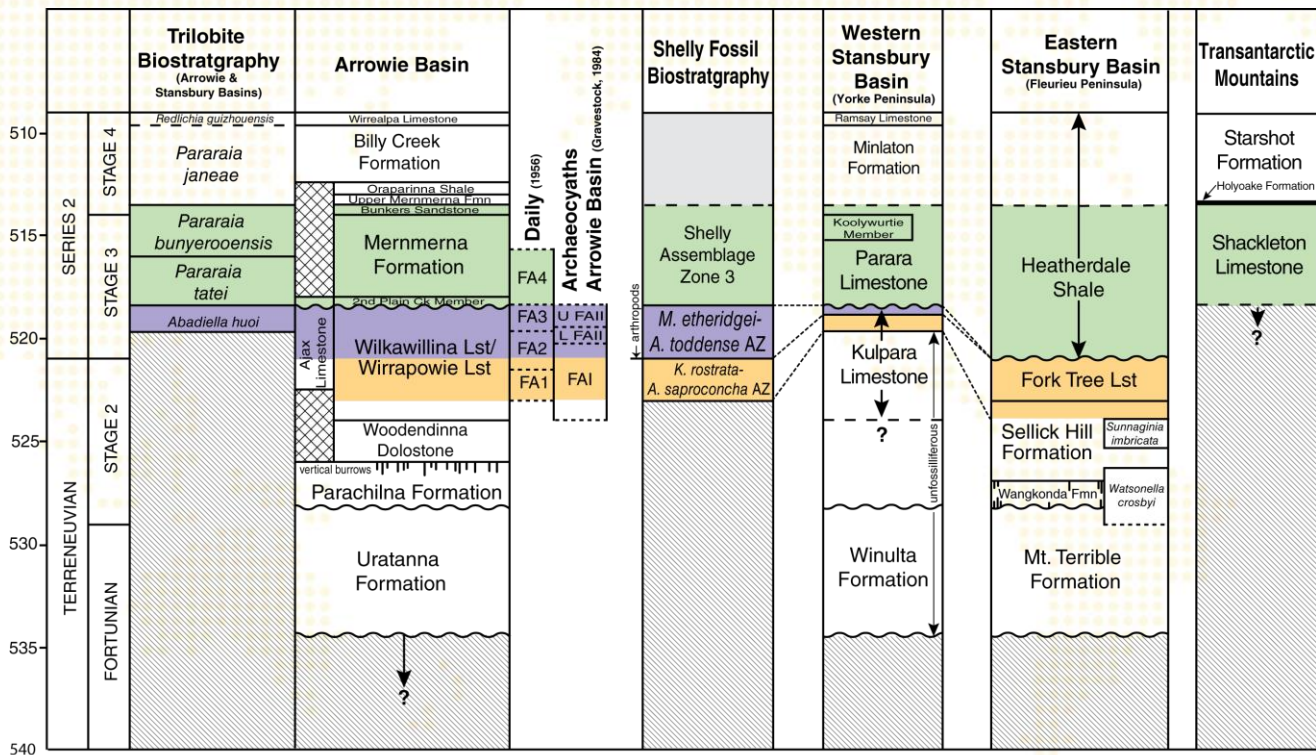
Shelly Assemblage Zone 3



Regional correlation

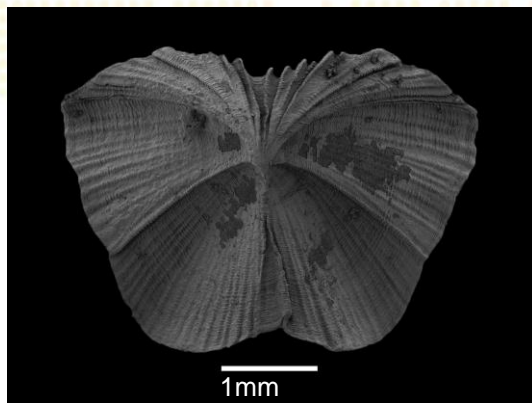
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- Can be correlated with Stansbury Basin and Antarctica based on similar shelly fauna
- Illustrate time-gaps
- Shelly fauna demonstrate that the sections covered span late Terreneuvian, Stage 2 – Series 2, Stage 3



Global correlation

- Can be correlated globally using key cosmopolitan fauna (genera)
- Early Cambrian shelly taxa from Australia are often highly endemic
- **Chemostratigraphy** is applied to regional biostratigraphic schemes to more readily enable **global correlation**



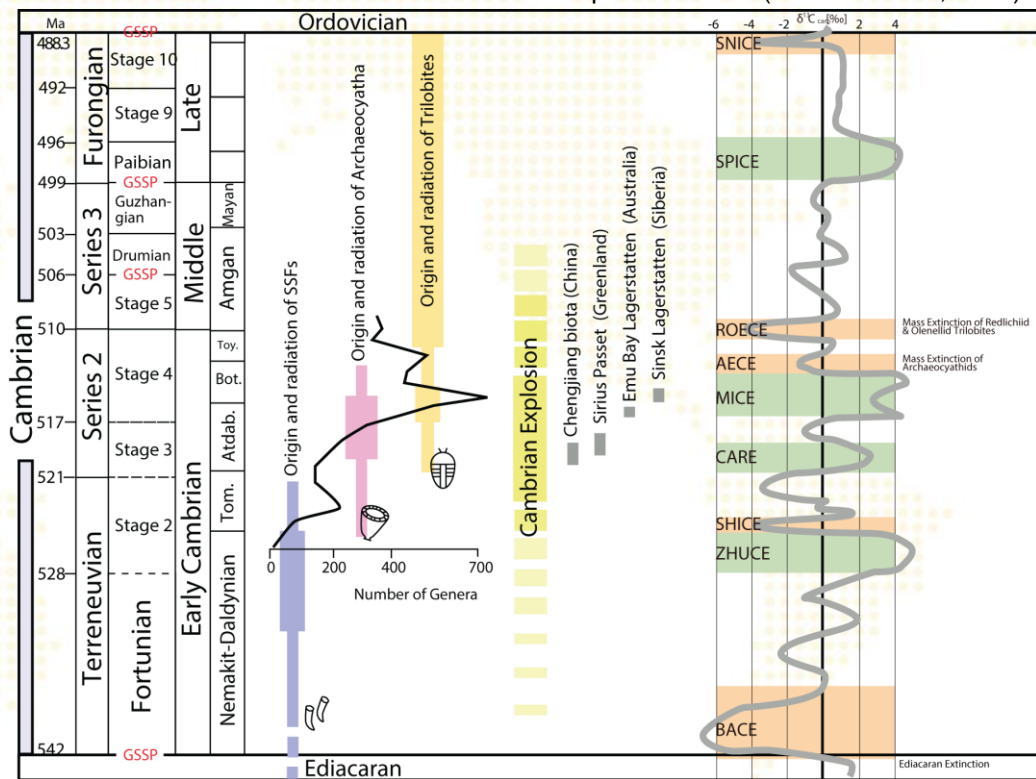
AUSTRALIA (Arrowie Basin)	Trilobites	Shelly Fossils	CHINA (Yangtze Platform)	SIBERIA	AVALONIA	MOROCCO (& West Gondwana)
Bunkers Sandstone	<i>Pararaia janae</i> Biozone					
514.88 Ma	<i>Pararaia bunyeroensis</i> Biozone	Shelly Assemblage Zone 3	Wutingaspis - Eoredlichia Interval Zone Yunnanoccephalus Subzone Rhombocorniculum cancellatum Taxon Range Zone	Pelagiella "lorenzi" Zone	Emyaksin Formation	Camenella baltica Zone (sensu Steiner et al., 2007)
Mernmerna Formation	<i>Pararaia tatei</i> Biozone					
Winnitiny Creek Member	<i>Abadiella huoi</i> Biozone	<i>Micrina etheridgei</i> - <i>Askapasma toddense</i> AZ	<i>Parabadiella huoi</i> Zone			
WIRRAPOWIE LIMESTONE		<i>Kulparina rostrata</i> - <i>Askapasma saproconcha</i> AZ	<i>Sinosachites flabelliformis</i> - <i>Tannuolina zhangwentangi</i> Assemblage Zone	<i>Aldanella operosa</i> Zone		MARCORY FMN (Montagne Noire)
WILKAWILLINA LIMESTONE						
Hideaway Well Member						
Mt. Mantell Member						
Woodendinna Dolostone						
Parachilna Formation						
						AMOUSLEK FMN (Anti Atlas) IGOUDINE FMN (Anti Atlas)
						PARDAILHAN FMN (Montagne Noire)

Carbon Isotope Chemostratigraphy

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- Curves are a reflection of partitioning between organic carbon and carbonate carbon reservoirs
- Carbonate precipitation involves little fractionation of the isotopes + C is resistant to temp changes
- Early Cambrian C isotope curve is characterised by high amplitude excursions

Cambrian carbon isotope excursions (Ishikawa *et al.*, 2014)



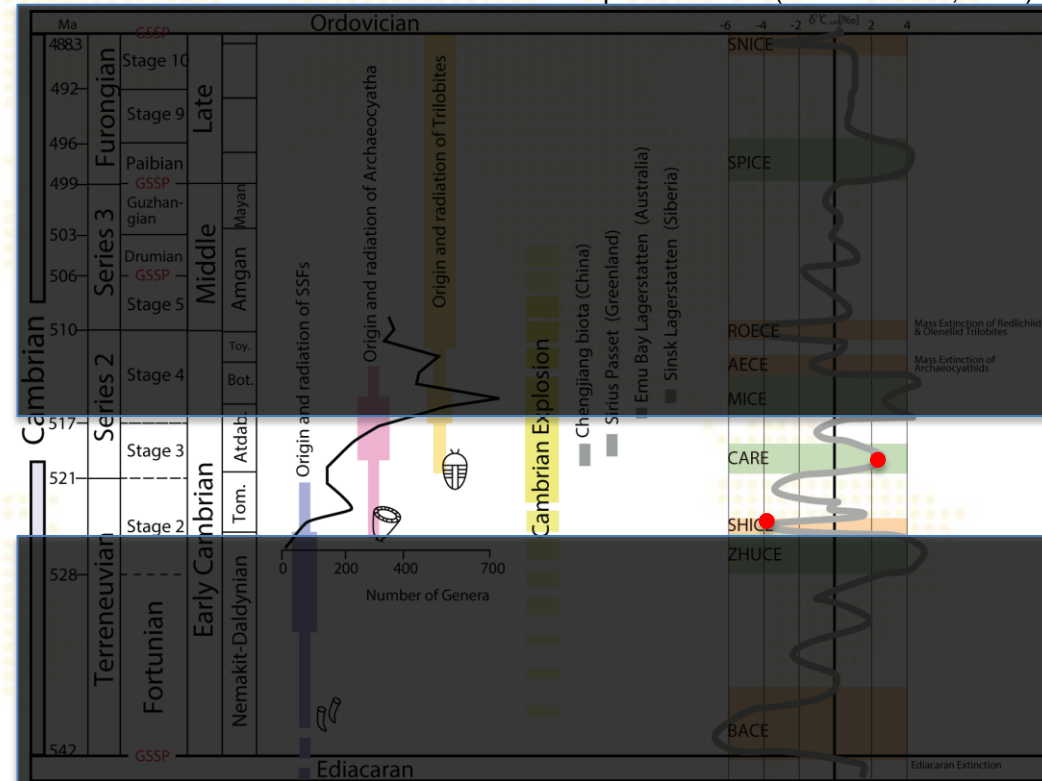
CARE Event (IV)

- Cambrian Arthropod Radiation Event
- Positive excursion near base Stage 3.
- Peak in ^{13}C associated with radiation of arthropods

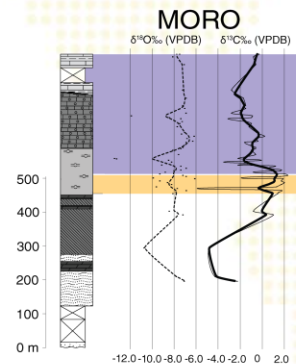
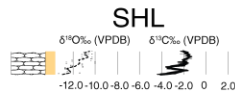
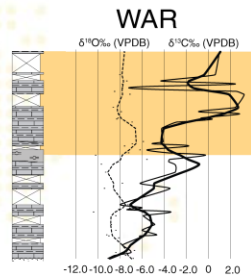
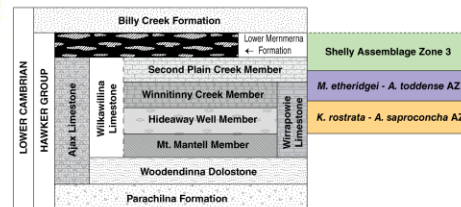
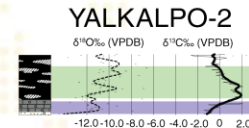
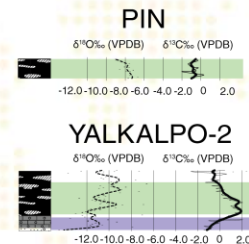
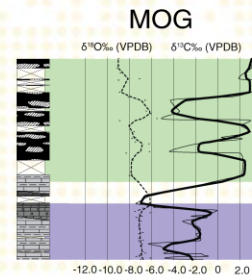
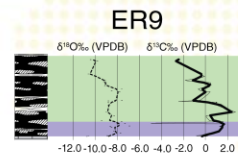
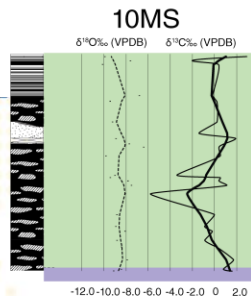
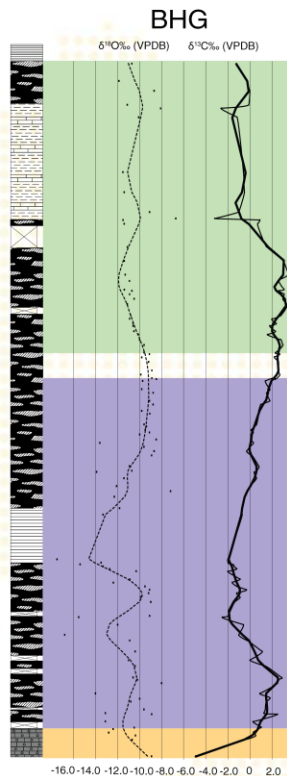
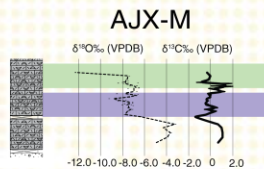
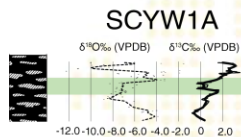
SHICE Event

- **SHI**yantou Carbon isotope Excursion (Zhang et al. 1997)
- Large negative excursion in the middle of Stage 2

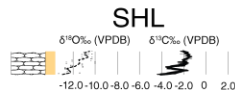
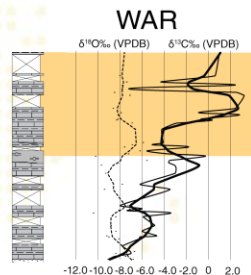
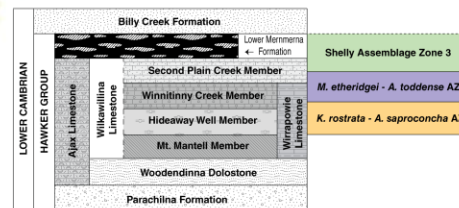
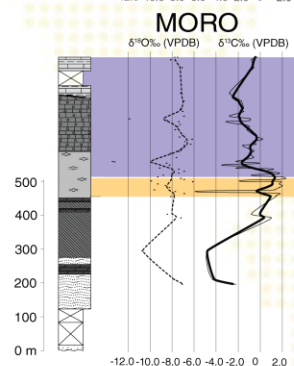
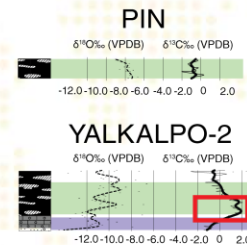
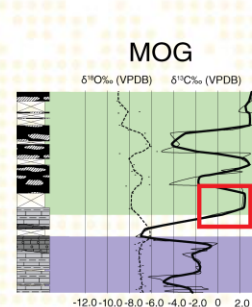
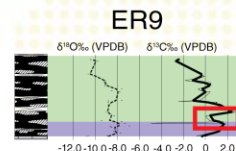
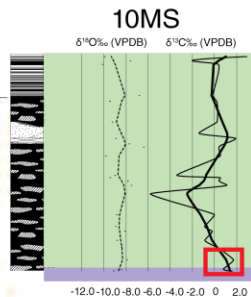
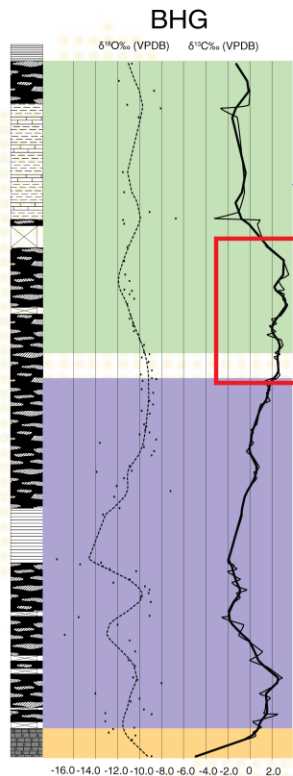
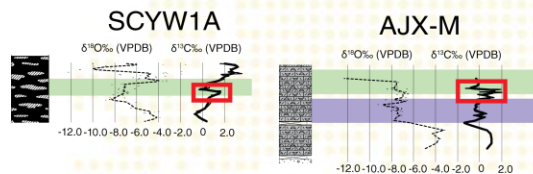
Cambrian carbon isotope excursions (Ishikawa *et al.*, 2014)



CARBON & OXYGEN CURVES

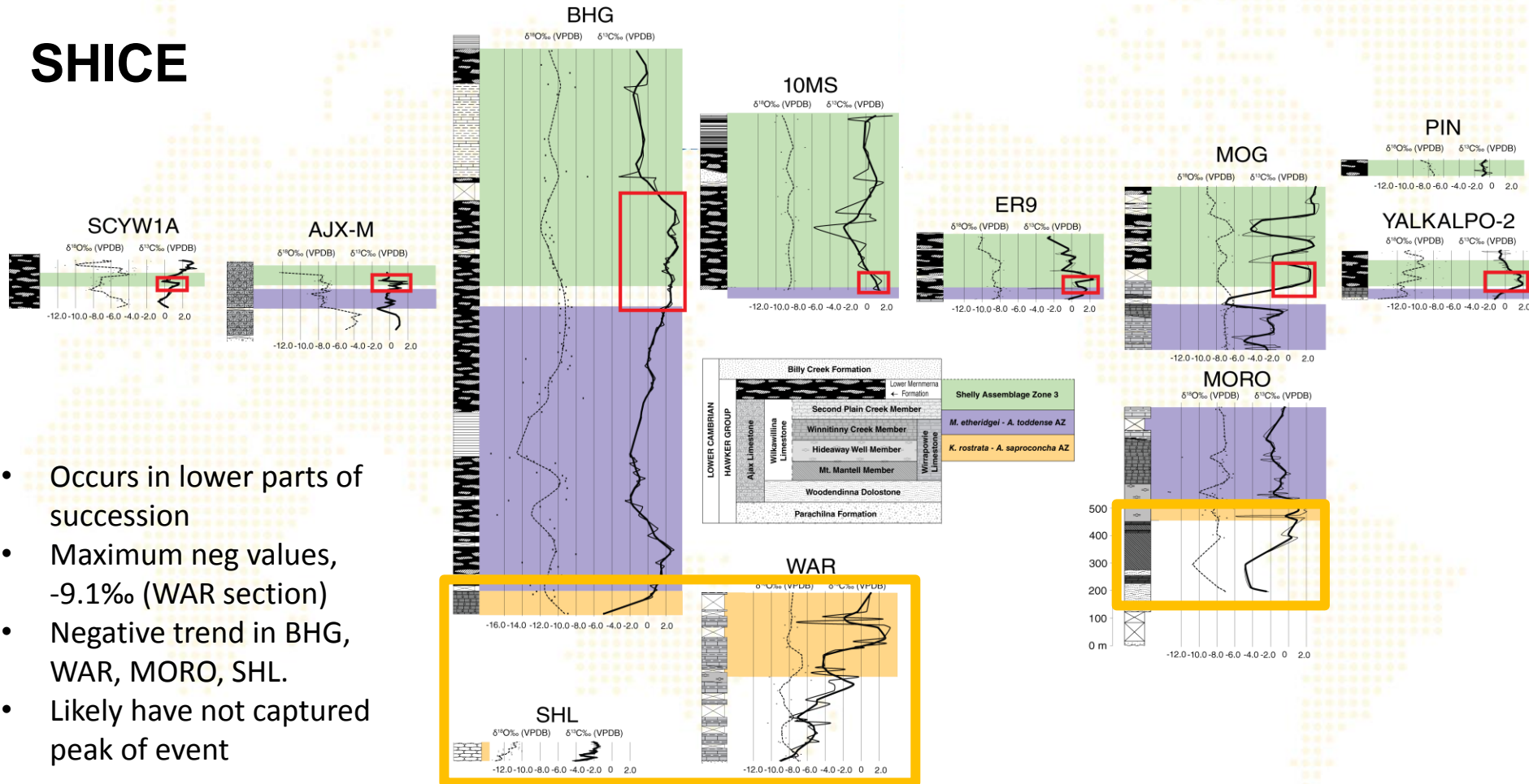


CARE (IV) Arrowie Basin

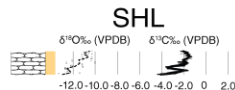
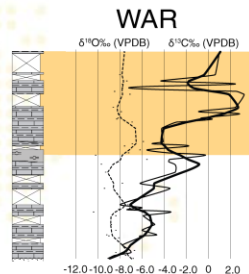
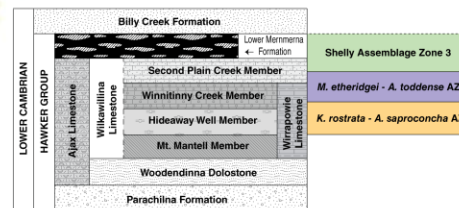
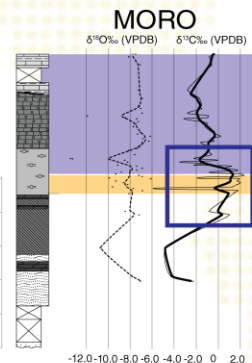
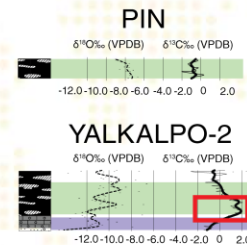
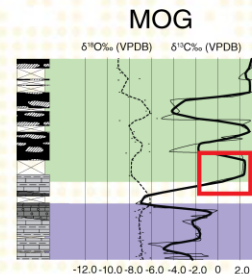
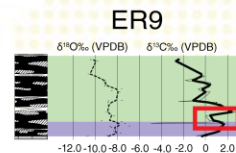
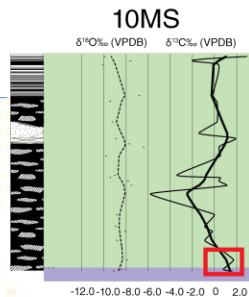
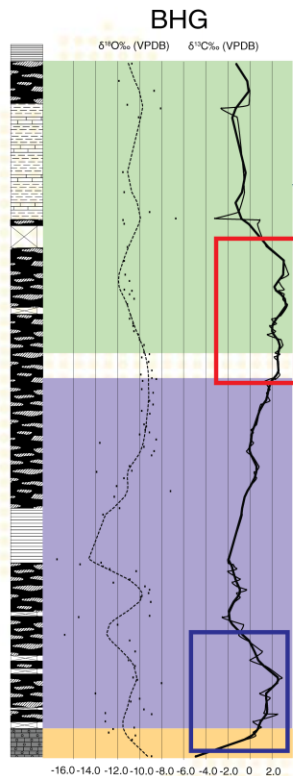
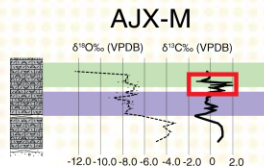
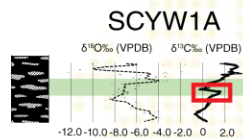


- Values up to +3.5‰, average of +2.3‰
- Correlates with peak arthropod abundance
- Overlaps *M. etheridgei* – *A. toddense* AZ & SAZ 3, peaking in SAZ 3
- Mernmerna Formation, Ajax Limestone & Andamooka Limestone

SHICE



$\delta^{13}\text{C}$ POSITIVE EXCURSION



- Transition between *K. rostrata* – *A. saproconcha* AZ and *M. etheridgei* – *A. toddense* AZ.
- +2.9‰ in BHG
- +2.3‰ in MORO

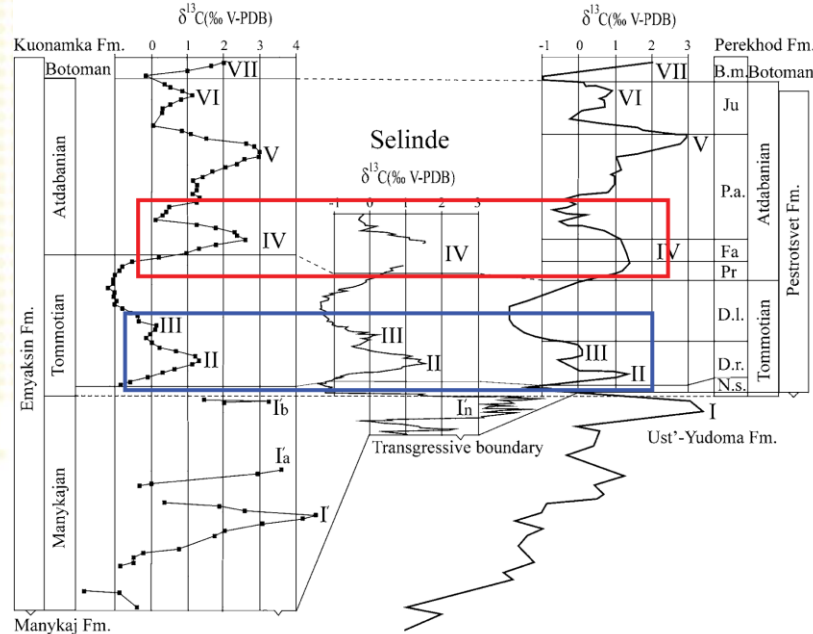
GLOBAL CORRELATION

- Strong global correlation based on two positive C isotope excursions
- CARE (IV) + events II and III
- Australian sequence confidently correlated with Avalonia, Siberia, China, Morocco.

SIBERIA

Northern Siberian platform
Bol'shaya Kuonamka

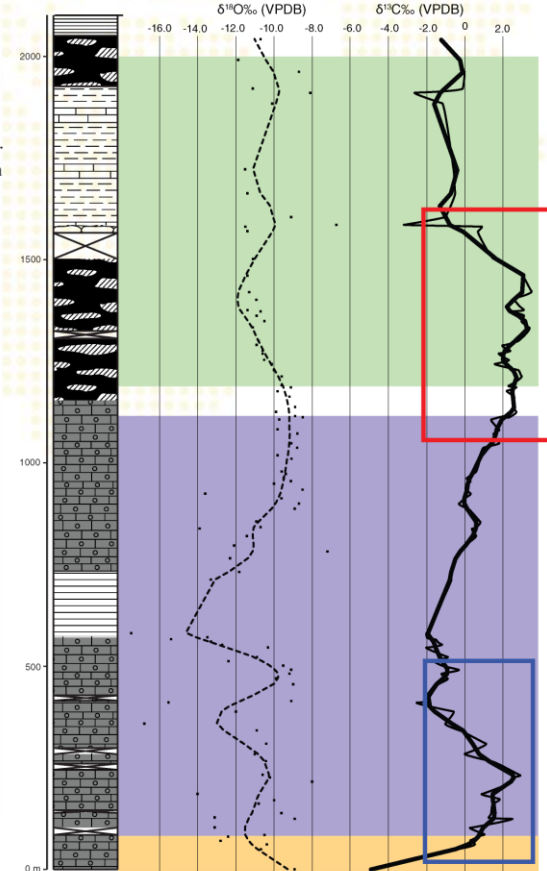
Southeastern Siberian platform
Lena-Aldan



Biozones: B.m. - *Bergeriellus micmaciformis*; D.l. - *Dokidocyathus lenaicus*; D.r. - *Dokidocyathus regularis*; Fa - *Fallotaspis*; Ju - *Judomia*; N.s. - *Nochorocyathus sumnaginicus*; P.a. - *Pagetiellus anabarus*; Pr - *Profallotaspis*.

Kouchinsky *et al.*, (2005)

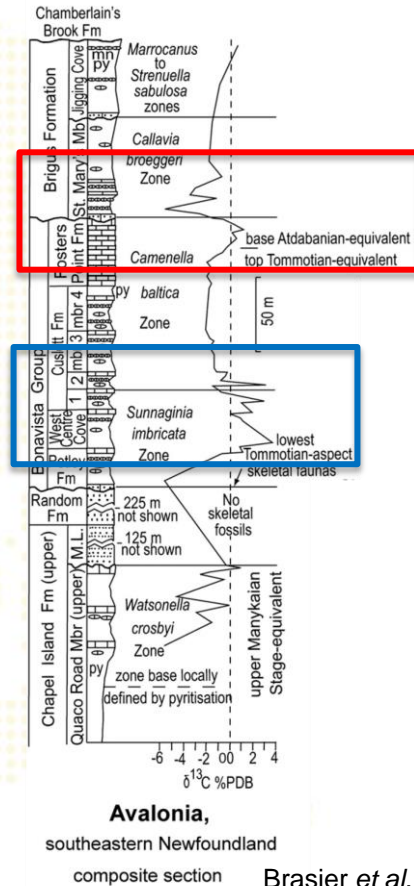
BHG



GLOBAL CORRELATION

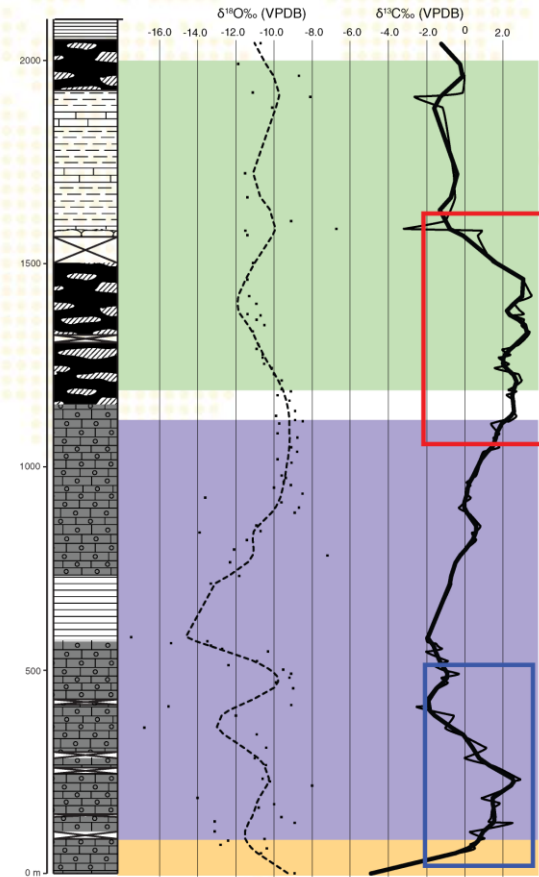
- Strong global correlation based on two positive C isotope excursions
- CARE (IV) + events II and III
- Australian sequence confidently correlated with Avalonia, Siberia, China, Morocco.

AVALONIA



Brasier *et al.*, (1992)

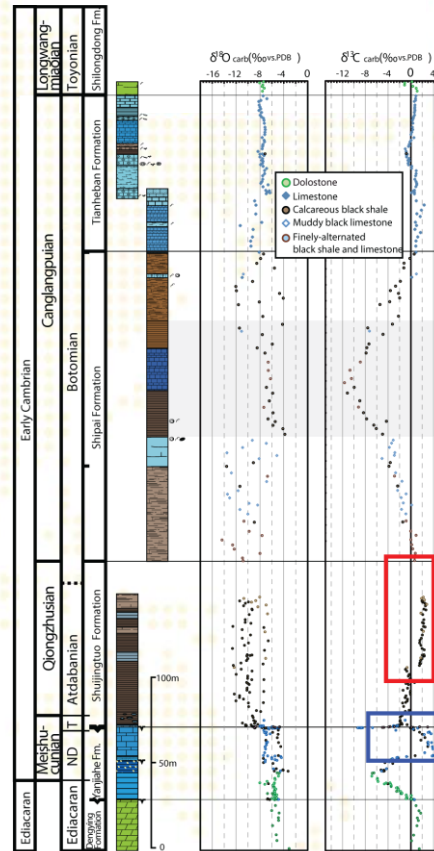
BHG



GLOBAL CORRELATION

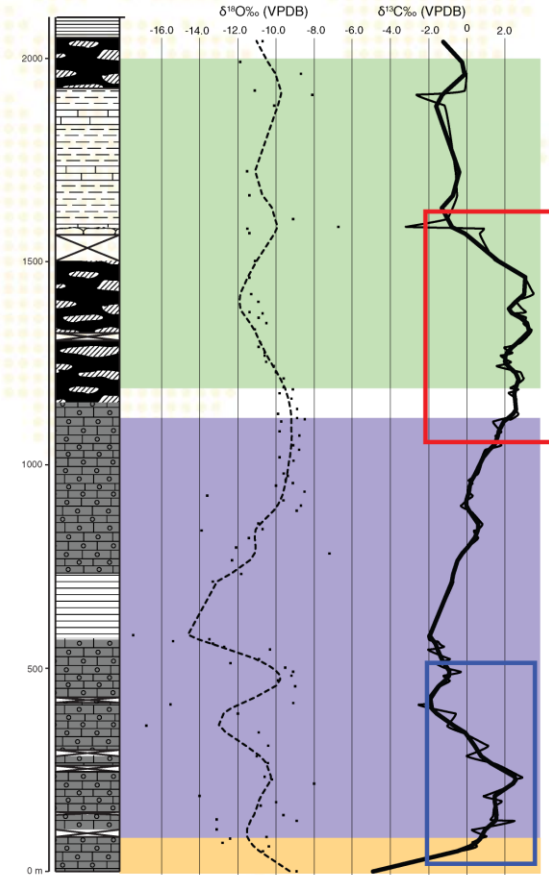
- Strong global correlation based on two positive C isotope excursions
- CARE (IV) + events II and III
- Australian sequence confidently correlated with Avalonia, Siberia, China, Morocco.

SOUTH CHINA



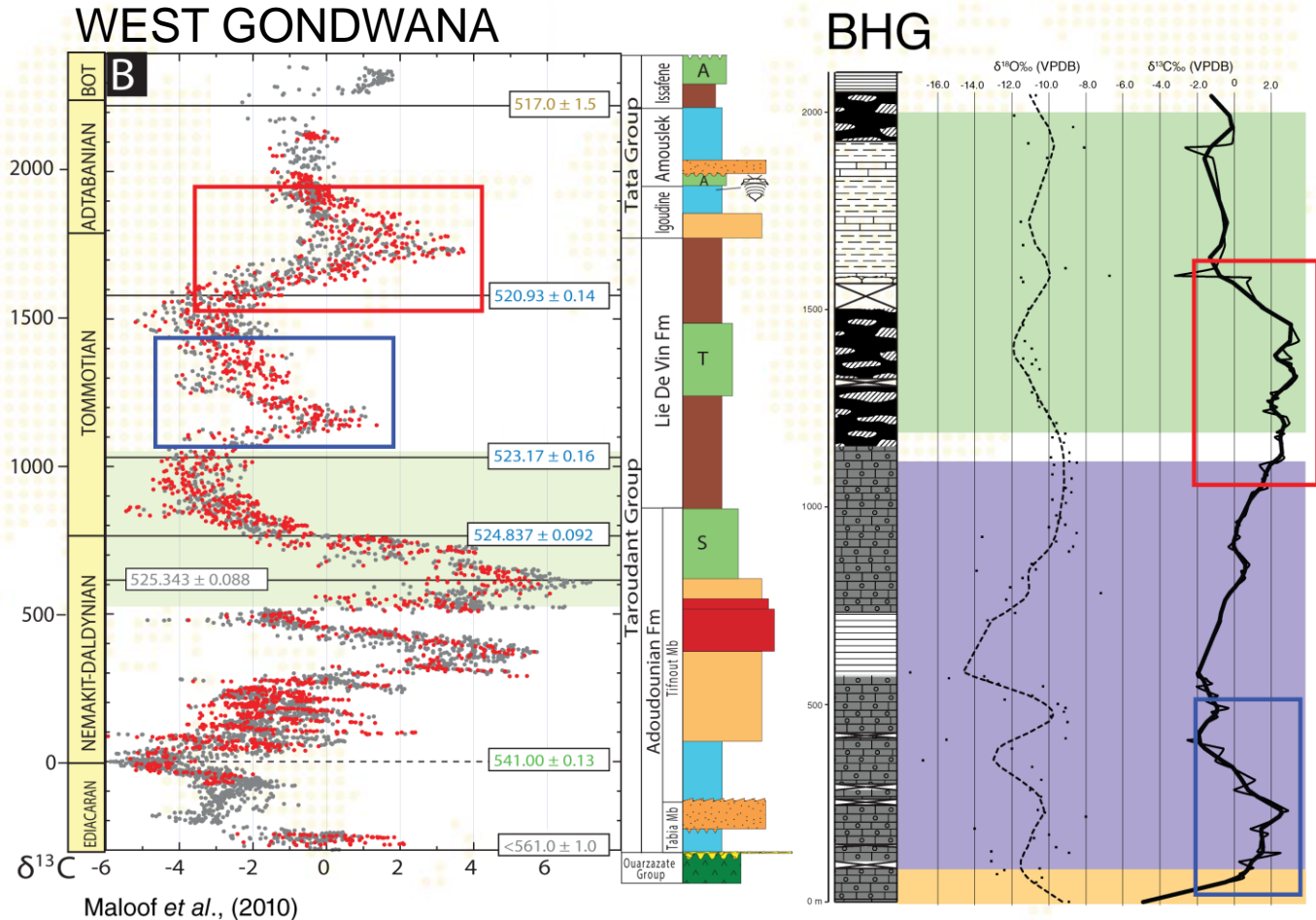
Ishikawa *et al.*, (2013)

BHG



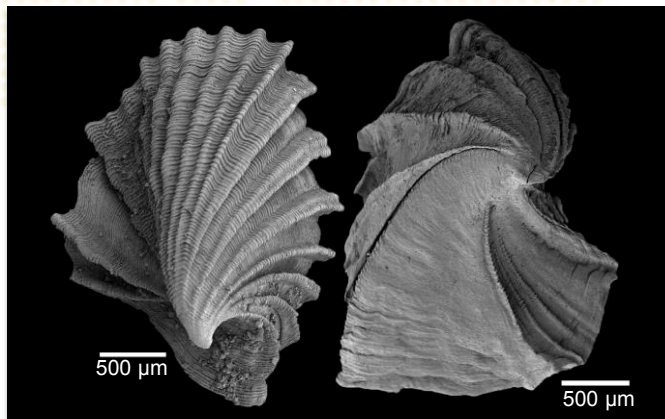
GLOBAL CORRELATION

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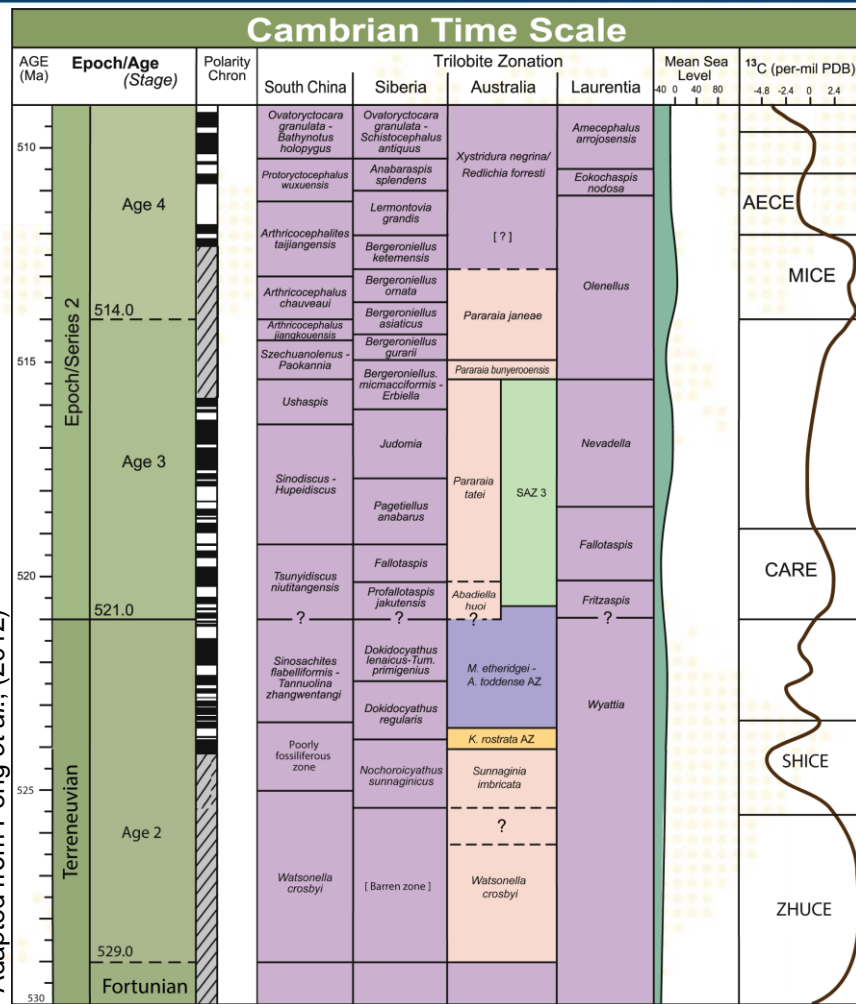


GLOBAL CORRELATION

- First study to integrate shelly fossil biostratigraphy & isotope chemostratigraphy for the early Cambrian of Australia
- Global correlation + provided confident age brackets for Australian succession
- Demonstrates that first occurrence of trilobites in Australia is at/close to base of Series 2, Stage 3



Adapted from Peng et al., (2012)



CONCLUSIONS

AAPG | SEG
International Conference
& Exhibition 2015
13-16 September • Melbourne, Australia
PESA Incorporating PESA's Eastern
Australasian Basins Symposium

- Developed pre-trilobitic biozonation for the early Cambrian of Australia using shelly fossils
- Integrated biostratigraphic and chemostratigraphic data to enable successful global correlation of Australian Cambrian successions
- The most powerful signals for correlation are generated when these methods are applied in concert
- MULTI-PROXY METHOD



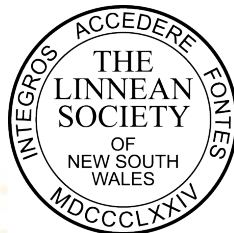
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- IMAGING: Debra Birch & Nicole Vella (MQ)
- THIN SECTIONS: David Keith (UNE)
- ILLUSTRATIONS & MAPS: Dean Oliver Graphics
- Property owners and Adnyamathana People of Nepabunna, Flinders Ranges



MACQUARIE
University
SYDNEY • AUSTRALIA

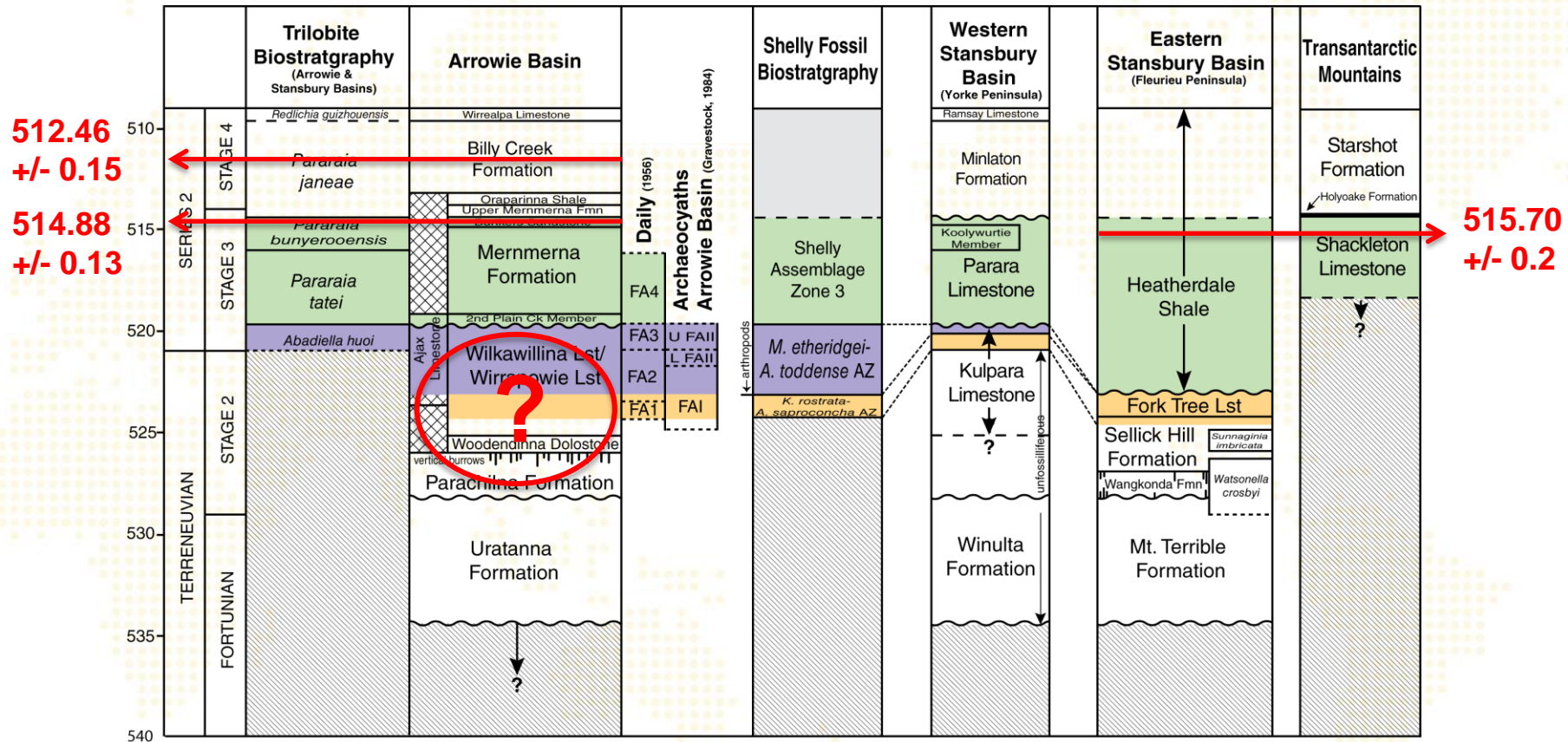


Australian Government

Australian Research Council



Sunset at Angorichina, Flinders Ranges



Unpublished $^{207}\text{Pb}/^{206}\text{Pb}$ TIMS dates for tuffs from the Lower Cambrian of SA (Jagodzinski et al. in prep.)