Middle Cambrian Chemostratigraphy and Biostratigraphy in the Southern Georgina Basin: Correlating the Arthur Creek "Hot Shale"*

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Search and Discovery Article #51208 (2015)
Posted January 18, 2016

*Adapted from oral presentation given at AAPG/SEG International Conference & Exhibition, Melbourne, Australia, September 13-16, 2015

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Abstract

The Georgina Basin is a Neoproterozoic to Lower Devonian sedimentary basin covering 325,000 km^2 of western Queensland and the Northern Territory. It is a northwest-southeast-trending extensional basin, with prospective conventional and unconventional hydrocarbon targets within Cambrian and Ordovician carbonate and siliciclastic rock units in the southern depocentres. Recent biostratigraphic work has highlighted an age discrepancy in the prospective organic-rich 'hot shale' in the base of the Middle Cambrian Arthur Creek Formation. This unit is present in the two major southern depocentres, the Dulcie and Toko synclines, where it has previously been considered as correlative. Recent results, however, suggest that the basal 'hot shale' is either significantly younger in the Toko Syncline than in the Dulcie Syncline, or represents a very condensed section in the former. Middle Cambrian carbon isotope excursions have been correlated across a number of Australian basins and can be used to test correlative models across the Georgina depocentres. In the current study, high resolution sampling across this Middle Cambrian section has been carried out in a number of wells in the Dulcie Syncline and in the Undilla Sub-basin, where the age equivalent Inca Shale is penetrated. Carbon isotopes from organic carbon (kerogen) as well as carbon and oxygen isotope ratios of four carbonate mineral phases (calcite, ankerite, dolomite and siderite) were analysed. These new data are compared with the existing carbon isotope stratigraphy from the Dulcie and Toko synclines. Initial results corroborate the new biostratigraphic interpretation. This work provides a detailed understanding of Middle Cambrian isotope signatures and correlates this prospective unit across the southern Georgina Basin.

Selected References

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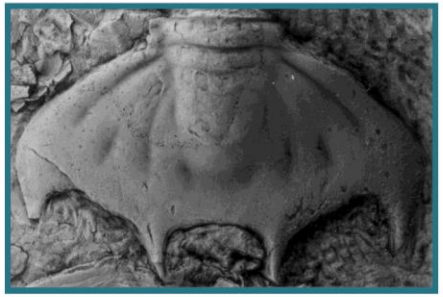
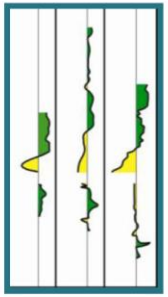
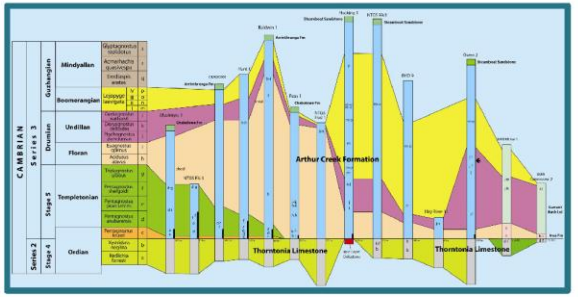




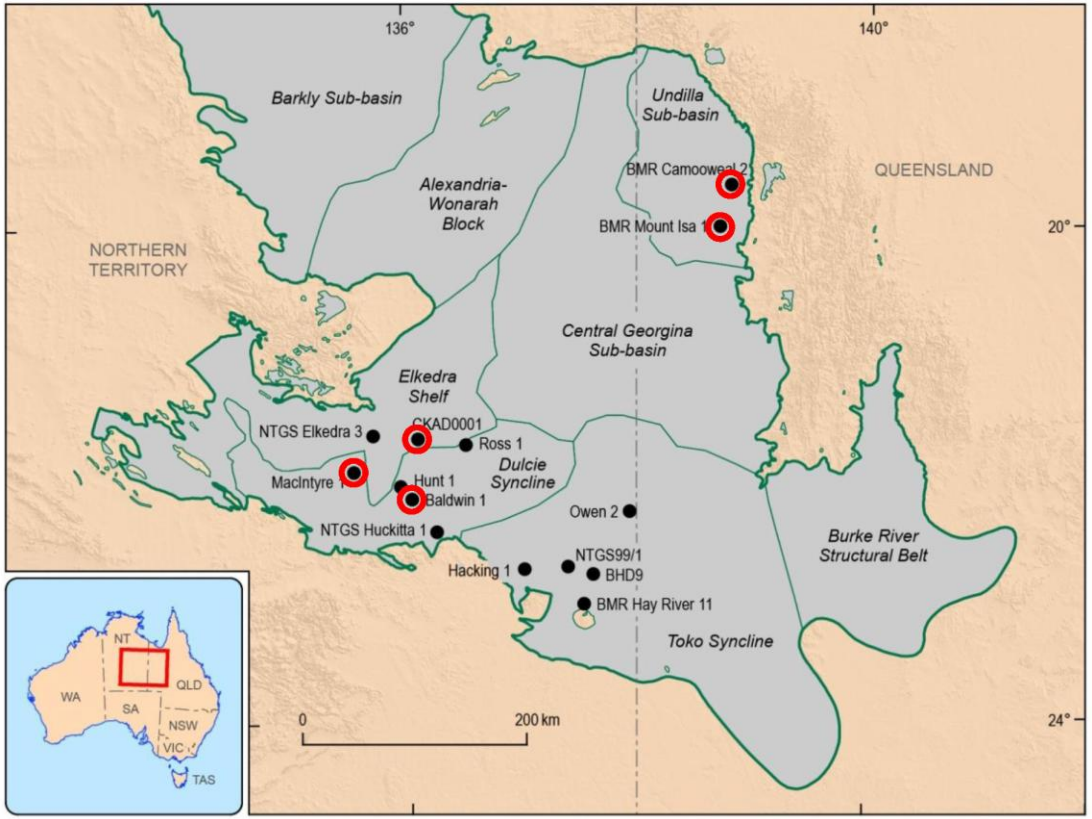
Tegan E. Smith, **John R. Laurie** and Dianne E. Edwards.

AAPG-ICE September 2015

Presenter's notes: This paper is a short overview of the geochemical and biostratigraphic work undertaken in the Georgina Basin over recent years by Geoscience Australia and its impact on the understanding of the stratigraphy of the southern part of the basin

Georgina Basin

- 325 000 km^2
- NT and QLD
- Neoproterozoic to Devonian
- Thick Cambrian to Ordovician sections in the southern synclines (Dulcie and Toko)
- Prospective middle Cambrian Arthur Creek 'Hot Shale'



Presenter's notes: The Georgina Basin is a large Neoproterozoic to Devonian basin in the NT and QLD. The southern part of the basin, in the Dulcie and Toko synclines, contains a thick Cambrian succession, which is prospective for unconventional hydrocarbons. Of particular interest is the middle Cambrian Arthur Creek Formation which has the prospective 'hot shale' at its base. In some places, this 'hot shale' has TOC values as high as 16%

The black dots on this map show most of the wells that have been used for my biostratigraphic work and the ***('click')*** red circles are those for which Tegan has undertaken chemostratigraphic analyses.

Georgina Basin

- 'Hot shale' present at the base of Arthur Creek (black) in Dulcie and Toko synclines
- Considered coeval in both synclines by Ambrose et al. (2001)

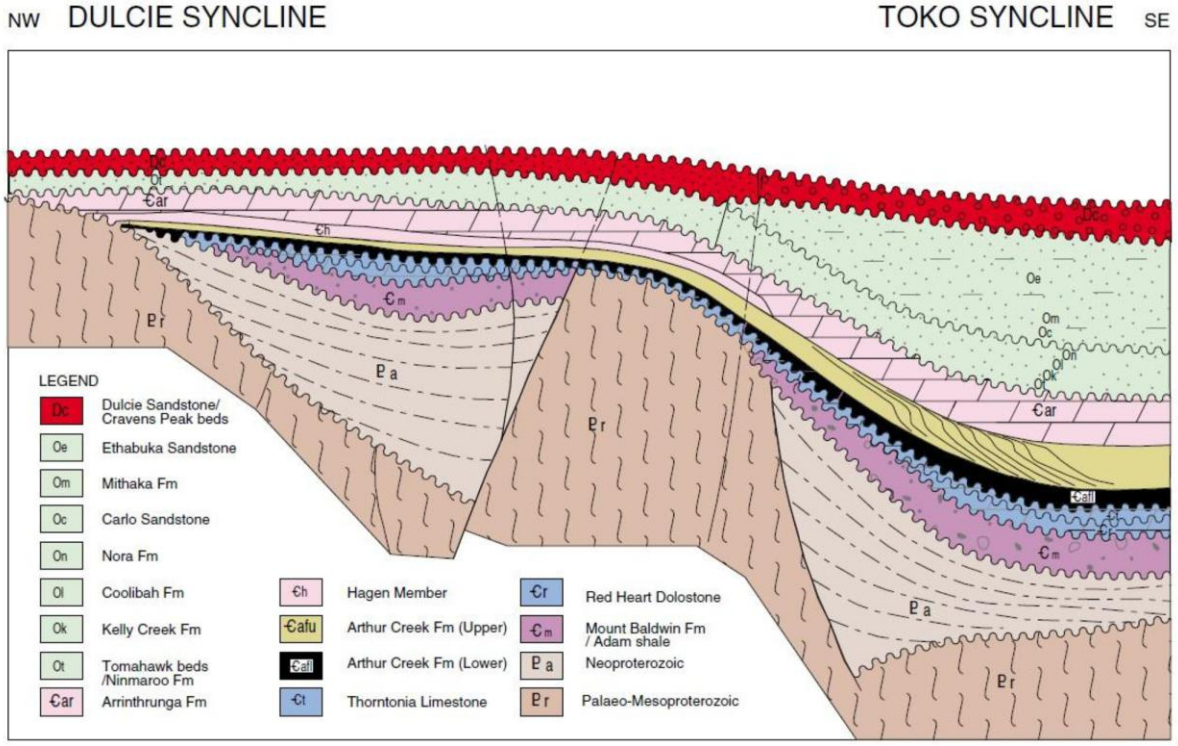


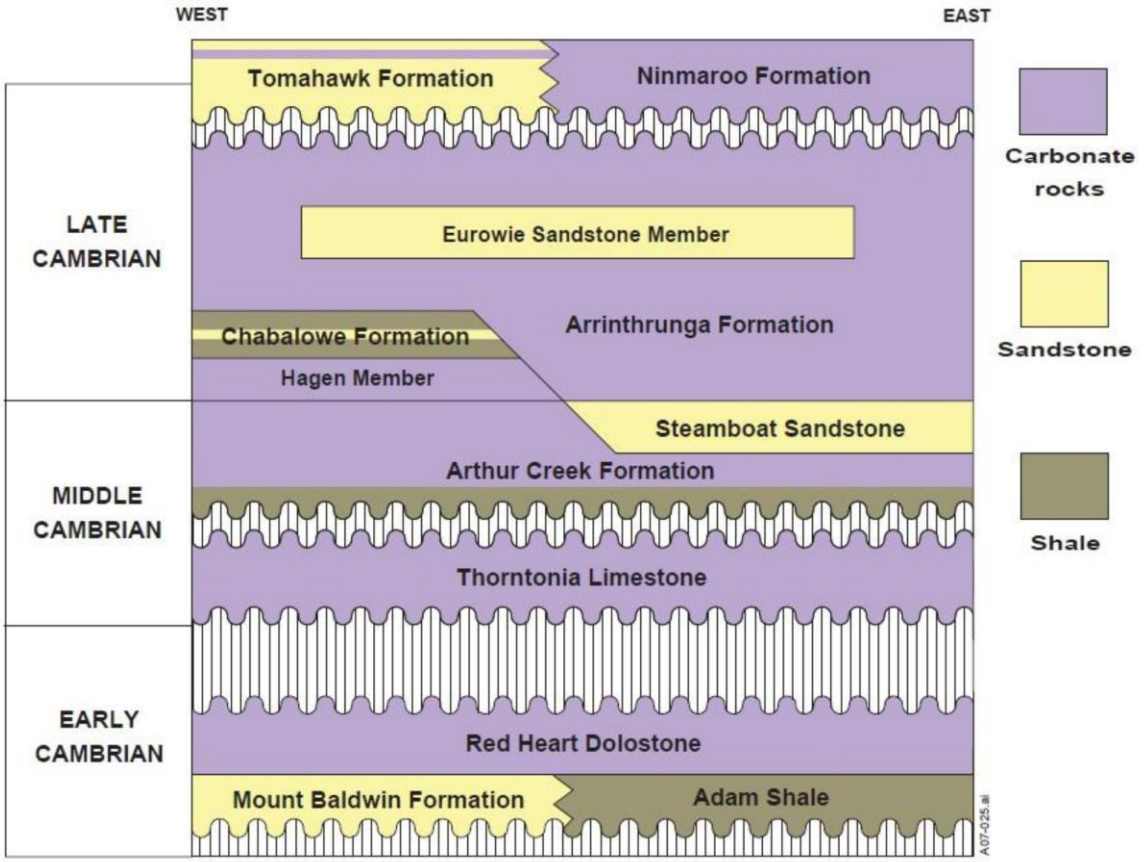
Figure from Ambrose et al. 2001

Presenter's notes: The prospective Arthur Creek 'hot shale' has long been identified in both the Dulcie and Toko synclines. This figure is from the work of Ambrose and others and is a schematic cross section from West to East from the Dulcie Syncline to the Toko Syncline. In this diagram, the upper part of the Arthur Creek Formation is buff coloured, while the lower Arthur Creek, which includes the 'hot shale' is shown in black. As you can see in this diagram, it was assumed to be coeval across both synclines.

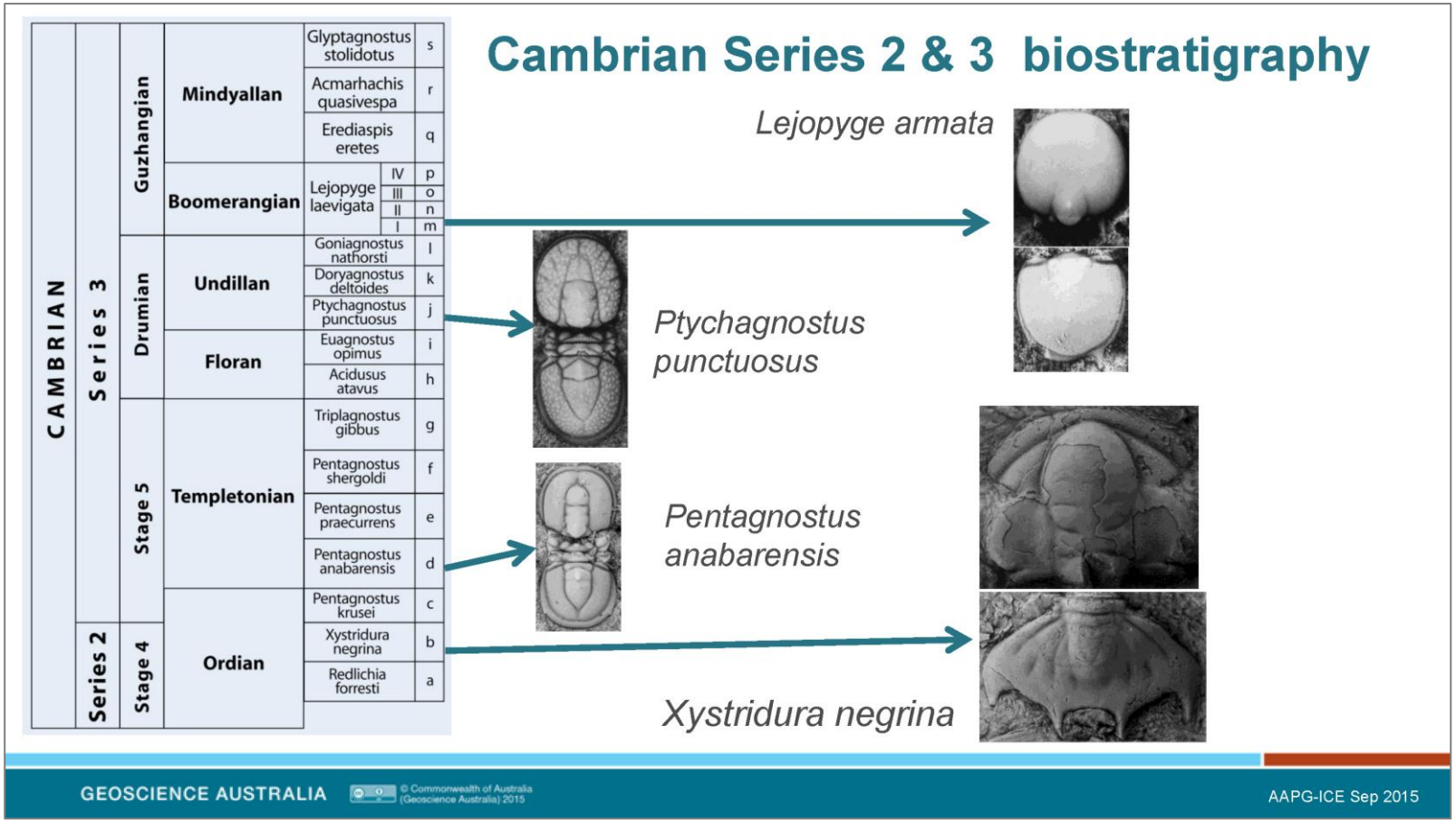
Georgina Basin

- 'Hot shale' present at the base of Arthur Creek in Dulcie and Toko synclines.
- Considered coeval in both synclines by Dunster et al. (2007)

Dunster et al. 2007

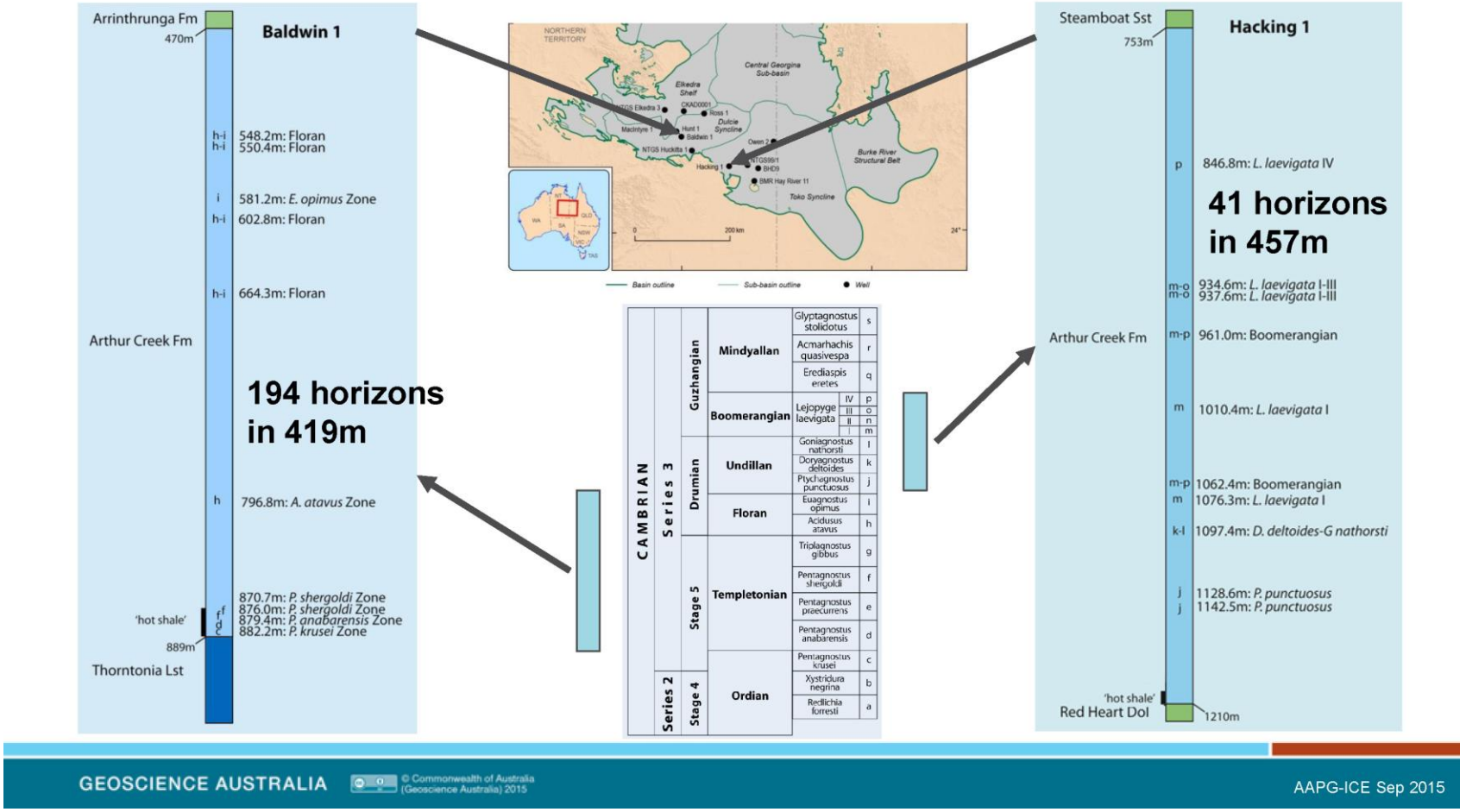


Presenter's notes: In a more recent compilation on the NT section of the southern Georgina Basin by Dunster and others, the basal 'hot shale' is represented here by the greenish colour in the lower part of the Arthur Creek section. As you can see, here it is also assumed to be coeval across the southern Georgina, from the Dulcie Syncline in the West to the Toko Syncline in the East.



Presenter's notes: The middle Cambrian biostratigraphic scheme used in the Georgina Basin was mostly compiled by Öpik in the 1960s, with several subsequent updates based on much more recent work in the Georgina and other basins. It consists mostly of a zonation based on trilobites and agnostids. Here the current zonation is presented against the Australian stages such as the Ordian and Templetonian, and the standard global stages some of which are yet to be named. Some of the taxa used are illustrated here.

One of the good things about agnostids is they are small (rarely longer than 8 mm) and consequently lend themselves to analysis in core. Indeed, in some of the core samples taken, there are occasionally as many as 100 specimens belonging to several taxa on a single bedding plane in a single piece of core.



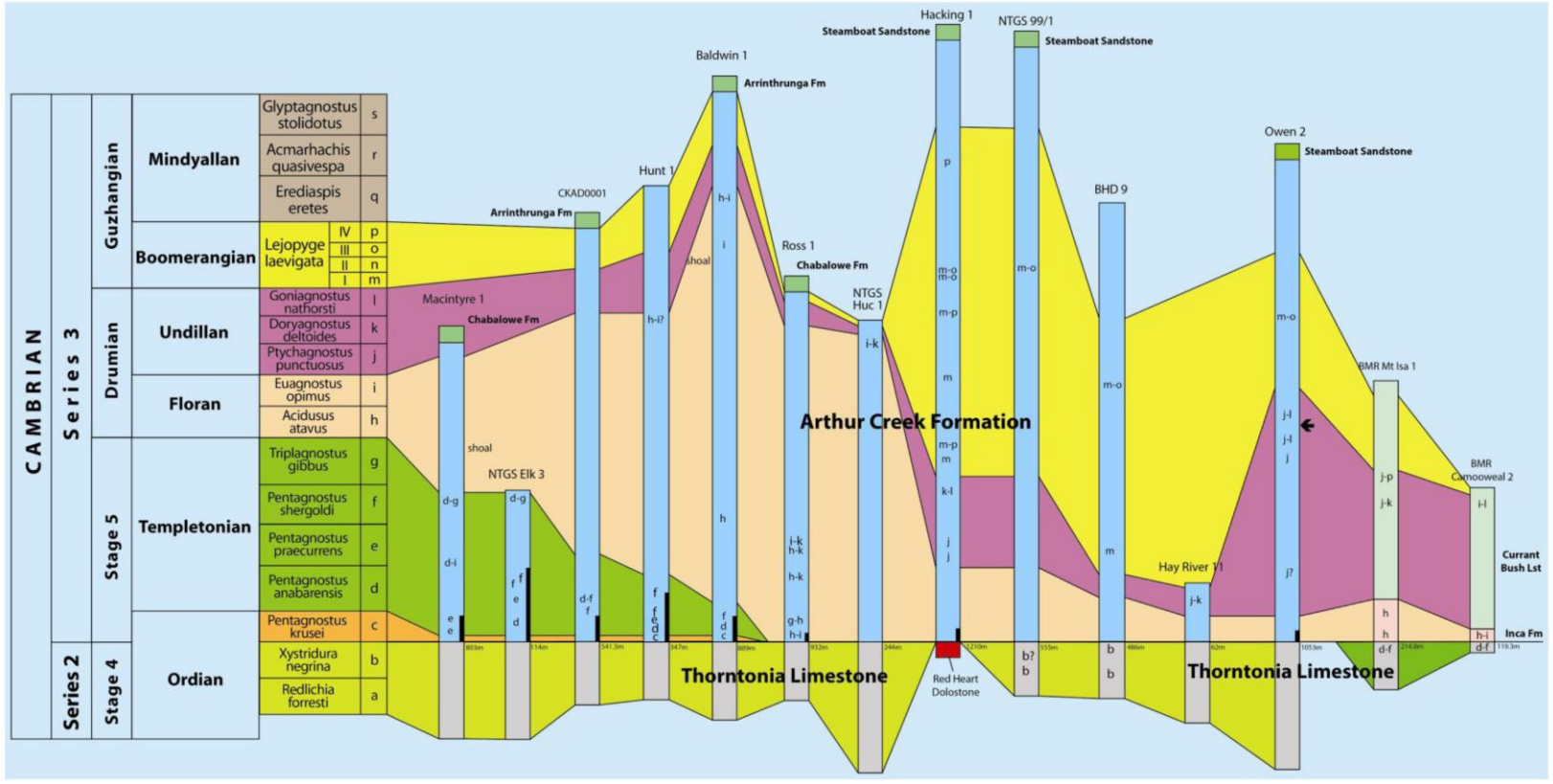
Presenter's notes: I first presented some of the biostratigraphic evidence indicating that this correlation may be incorrect back at CABS in 2012.

Detailed sampling of material from nearly 20, mostly fully cored holes in the southern part of the basin, was undertaken in association with the NTGS and, as you can see, some of the core was very fossiliferous. For instance, *(Presenter's notes continued on next slide)*

(Presenter's notes continued from previous slide)

in Baldwin 1, the Arthur Creek Formation is about 419 m thick and that interval gave us 194 fossiliferous horizons. From this well, we obtained a couple of thousand specimens. Hacking 1 was less fossiliferous, but a similar thickness to that in Baldwin 1, still gave us over 40 fossiliferous horizons.

The two examples given here also clearly show that in the Baldwin 1 well in the Dulcie Syncline, almost all the succession is latest Ordian to Floran in age. Conversely, the succession in Hacking 1 well in the Toko Syncline, is almost all Undillan and Boomerangian in age. As more wells were studied, it became clear that the succession in the two synclines differed considerably.



Presenter's notes: This figure shows this pattern more clearly, and is an updated version from the one I presented at Central Australian Basins Symposium in 2012. As you can see, in the several wells examined from the Dulcie Syncline, the Arthur Creek Formation mostly contains sediments of Templetonian and Floran age, with very little Boomerangian, while in the Toko Syncline, the formation mostly contains sediments of Undillan and Boomerangian age. *(Presenter's notes continued on next slide)*

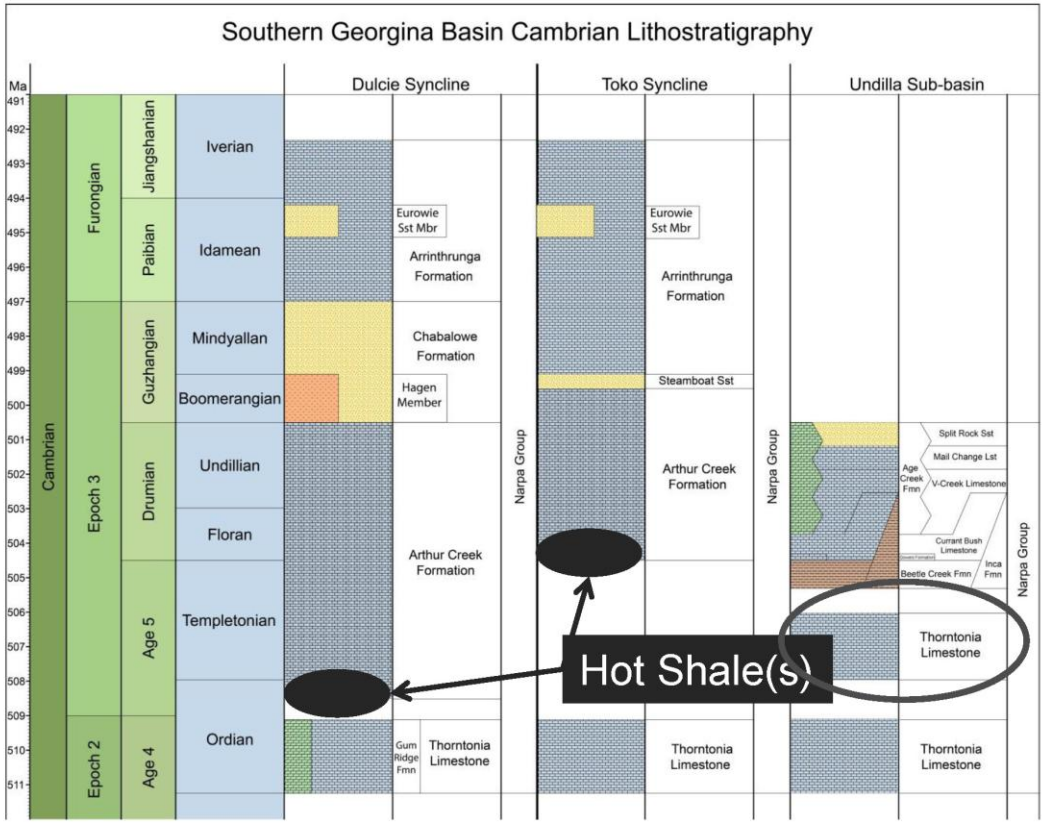
(Presenter's notes continued from previous slide)

In this diagram, the recorded intervals of hot shales in the various wells are given by a thick black line at the base of the Arthur Creek. Determinations of particular zones are shown as letters in the core representations.
In addition, the two wells from the Undilla Sub-basin (those to the right in this diagram), despite having a different lithostratigraphic nomenclature, have a similar age profile to that of the Arthur Creek in the Toko. However, the intersected part of the Thorntonia Limestone is, in fact, not coeval with the Thorntonia in the Dulcie and Toko synclines, but is coeval with the lower part of the Arthur Creek in the Dulcie Syncline.

Updated lithostratigraphy

- Base of Arthur Creek Ordian in Dulcie Syncline, but Floran in Toko Syncline
- Templetonian Thorntonia Limestone in Undilla Sub-basin

Smith et al. 2013



Presenter's notes: The revised stratigraphy resulting from this work was presented in a poster presentation at APPEA 2013, by Smith and others.

Two of the main stratigraphic revisions include:

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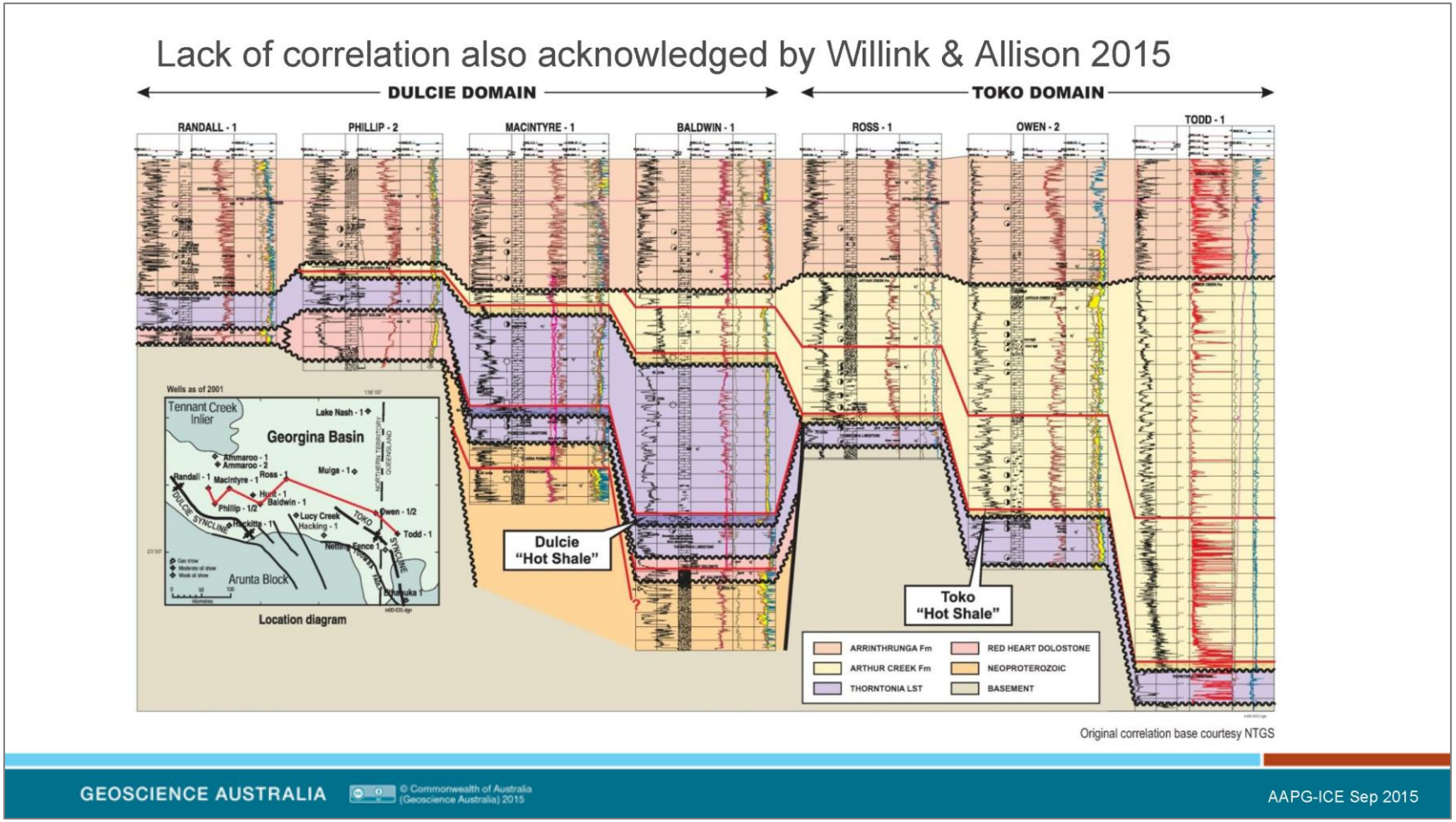
- The non-correlative base of the Arthur Creek Formation, ***('click')*** indicating an age difference of several million years between the hot shales in each of the two synclines, and making the Toko hot shale equivalent in age to the Inca Formation present in the Undilla Sub-basin.
- And the Thorntonia Limestone in the Undilla Sub-basin ***('click')*** includes a Templetonian interval, equivalent in age to the lower Arthur Creek formation in the Dulcie Syncline, in addition to the more familiar early Ordian interval, which it comprises throughout the southern Georgina Basin.



Presenter's notes: The lack of correlation between the 'hot shales' in the Dulcie and Toko synclines has also recently been shown by Willink and Allison from Central Petroleum, who presented their interpretation at APPEA this year. This is clearly shown in this figure.

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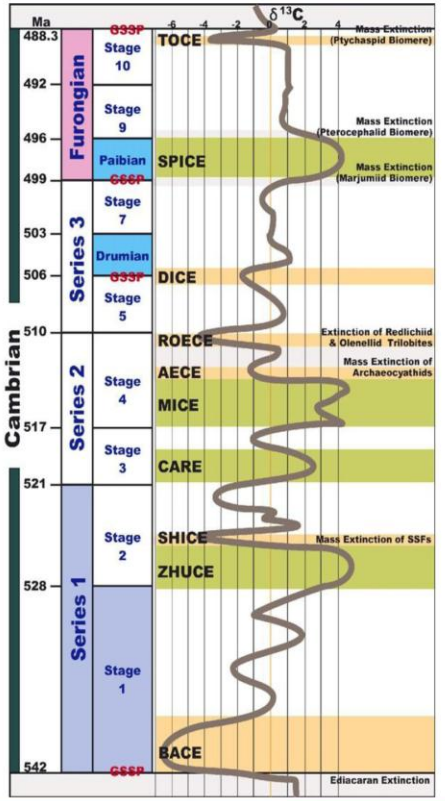
(Presenter's notes continued from previous slide)

The Dulcie 'hot shale' is represented by the darker purple interval, while the Toko 'hot shale' is represented by the pale orange interval. This Toko 'hot shale' has also been identified higher in the section in the Dulcie wells, well above the Dulcie 'hot shale'. Willink and Alison place everything beneath the Toko 'hot shale' in an expanded Thorntonia, but we believe that the hiatus between the Toko 'hot shale' and the 'Arthur Creek' below it is insignificant compared to the hiatus beneath the Dulcie 'hot shale'. This latter hiatus is also the level of one of the major extinction events in the Cambrian, and is characterised by the demise of the Redlichiid and Olenellid trilobites.

Cambrian chemostratigraphy

- Global Cambrian carbon isotope curve ($\delta^{13}C$ ‰)
- Numerous distinct negative and positive excursions
- Can potentially be used to tie local stratigraphy and biozones to the International Timescale
- Chemostratigraphy also useful for local and regional correlation

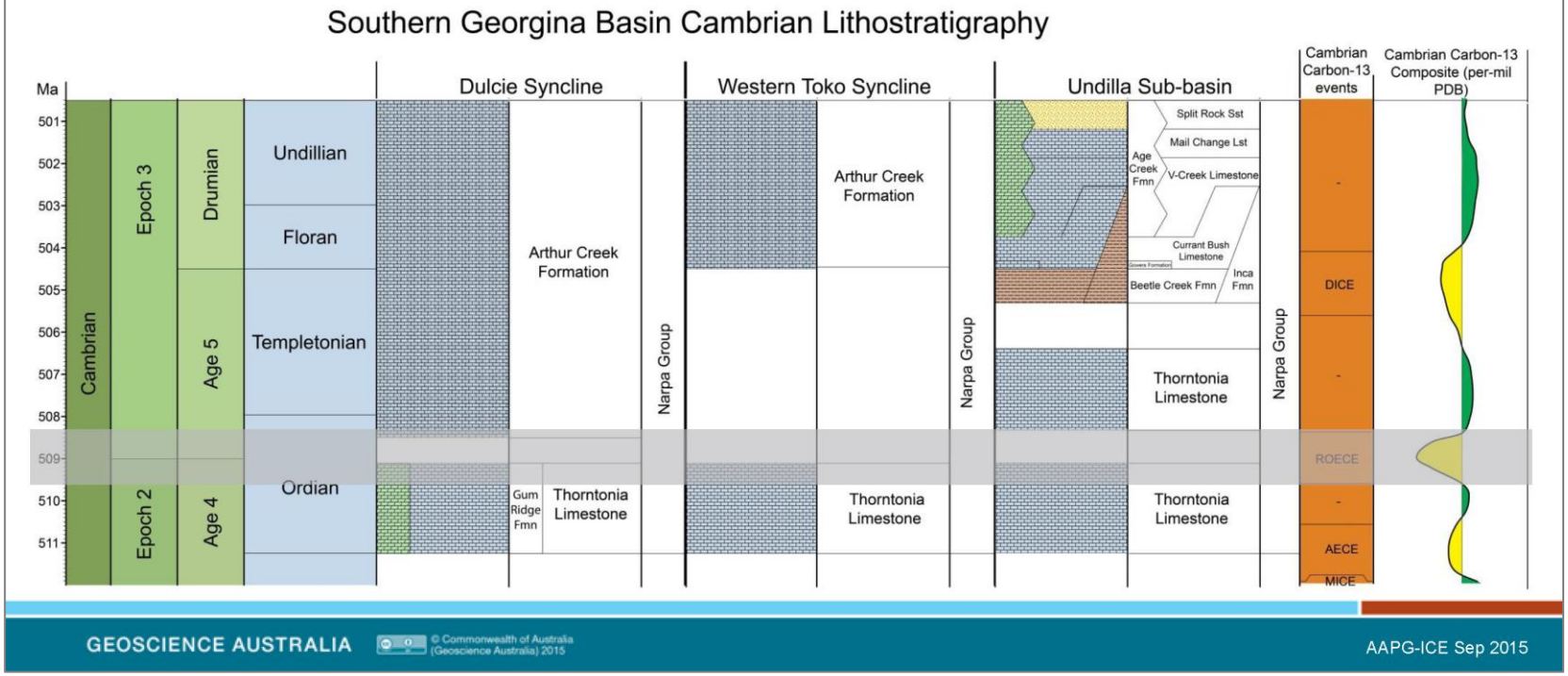
Zhu et al. 2006



Presenter's notes: Now onto the geochemistry
This figure shows a portion of the global carbon isotope curve for the Cambrian. Significant positive or negative excursions have been highlighted and are given names (such as SPICE – Steptoean Positive Carbon Isotope Excursion, DICE – Drumian Carbon Isotope Excursion etc.)

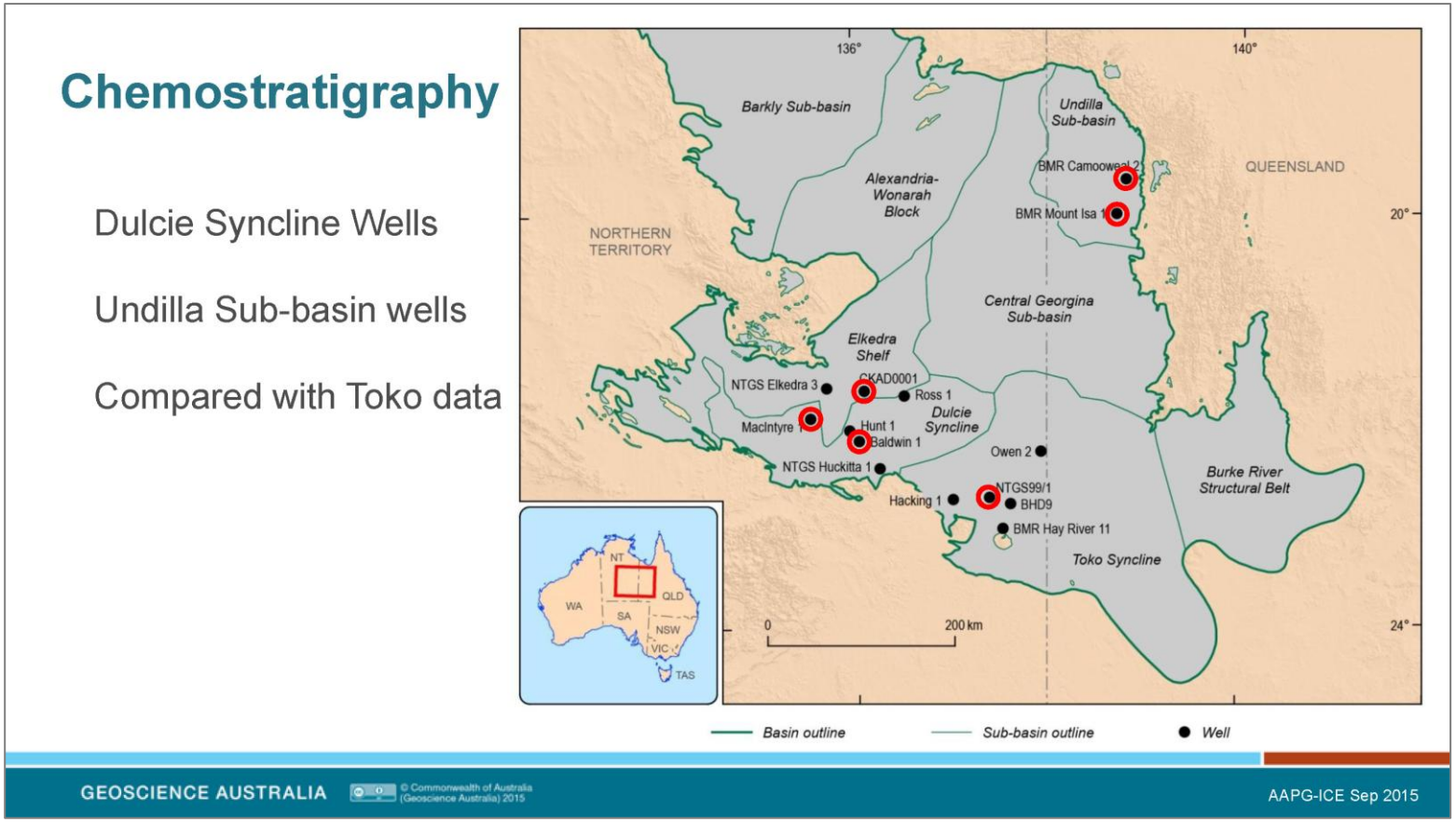
Where these excursions are identifiable in local stratigraphy, they can provide a method to tie the local stratigraphy and the associated biozones to the International Timescale.
Even when global events aren't recognised, chemostratigraphy can still be useful for local and regional correlation.

Chemostratigraphy



Presenter's notes: While my work has been biostratigraphic, Tegan and Dianne have concentrated on the carbon isotopes. Here we can see a short interval of the global curve, given by Zhu and others, alongside some of the stratigraphic successions in parts of the Georgina Basin.

The largest negative peak in the curve here is the ROECE – Redlichian-Olenellid Extinction Carbon isotope Excursion. It occurs near the base of Stage 5, which is in the uppermost Ordian…we wanted to know if we could find evidence of this excursion in the uppermost Ordian rocks of the Georgina Basin – in the Dulcie Syncline and possibly the Undilla Sub-basin.

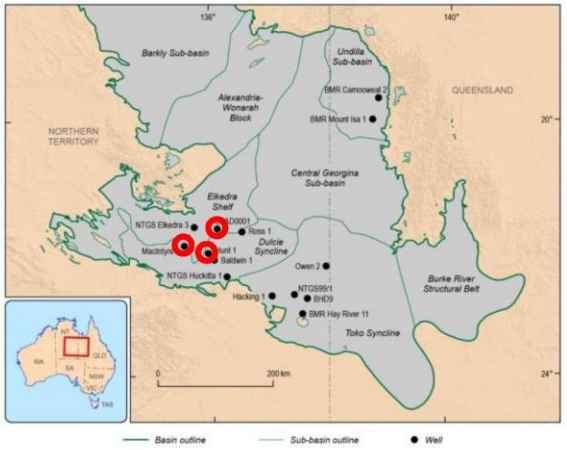


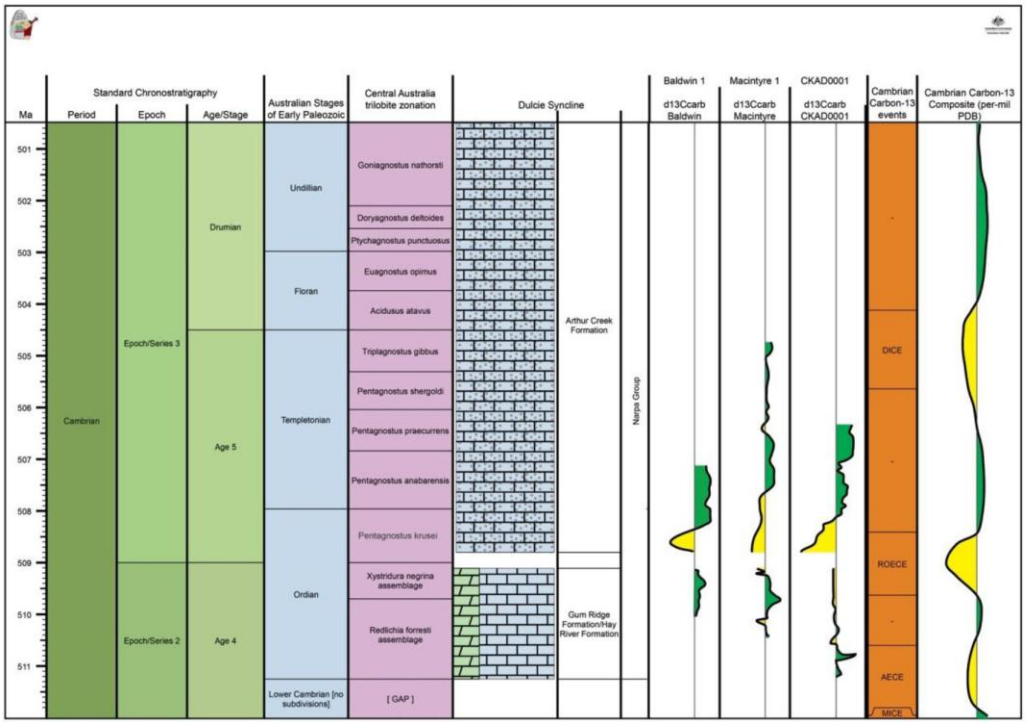
Presenter's notes: High resolution sampling (from 5m to <1m intervals) was carried out in three wells from the Dulcie Syncline, across the Arthur Creek – Thorntonia Boundary: These were Macintyre 1, Baldwin 1 and CKAD0001 (which we call 'skadoo 1' for obvious reasons).

In addition, two wells in the Undilla Sub-basin, Mt Isa 1 and Camooweal 2, were sampled across the Current Bush Limestone, Inca Shale and Thorntonia Limestone

We also have data for the stratigraphic well NTGS 99/1 in the Toko syncline, published by Creveling and others 2013, which we used for comparative purposes.

Chemostratigraphic results – Dulcie Syncline





Presenter's notes: These are the results for carbonate carbon isotope values in the Dulcie Syncline wells Baldwin 1, MacIntyre 1 and Skadoo 1. The well data have been converted to age using the biostratigraphic data from each of the wells.

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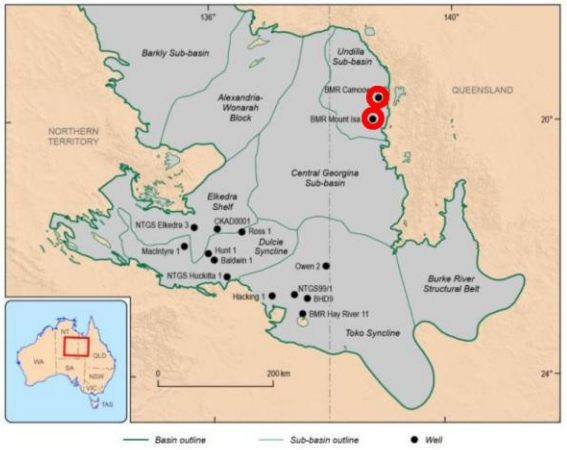
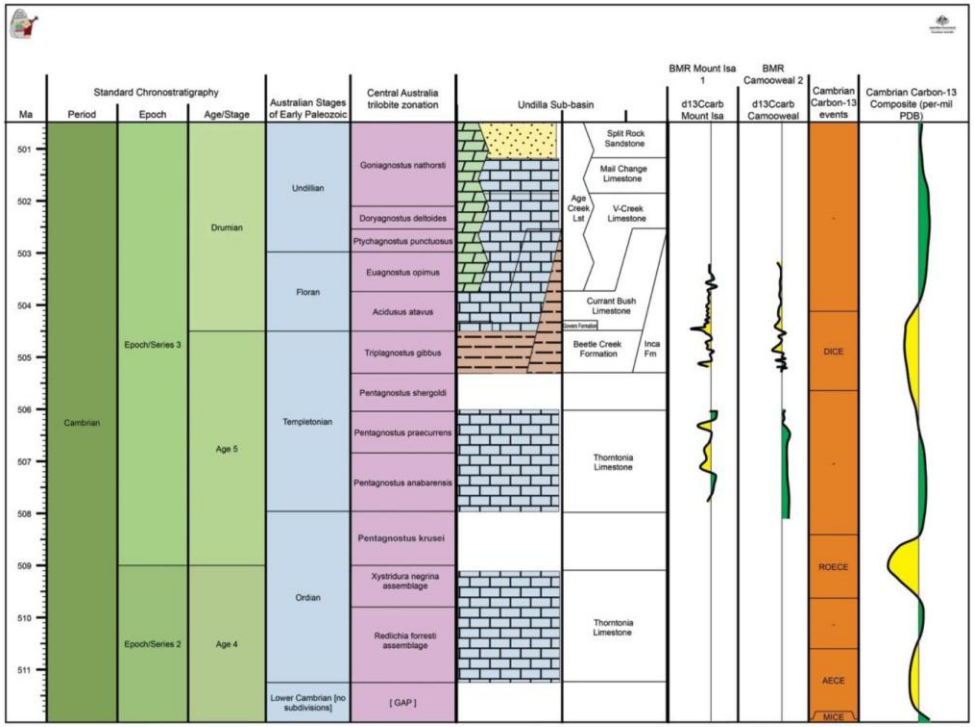
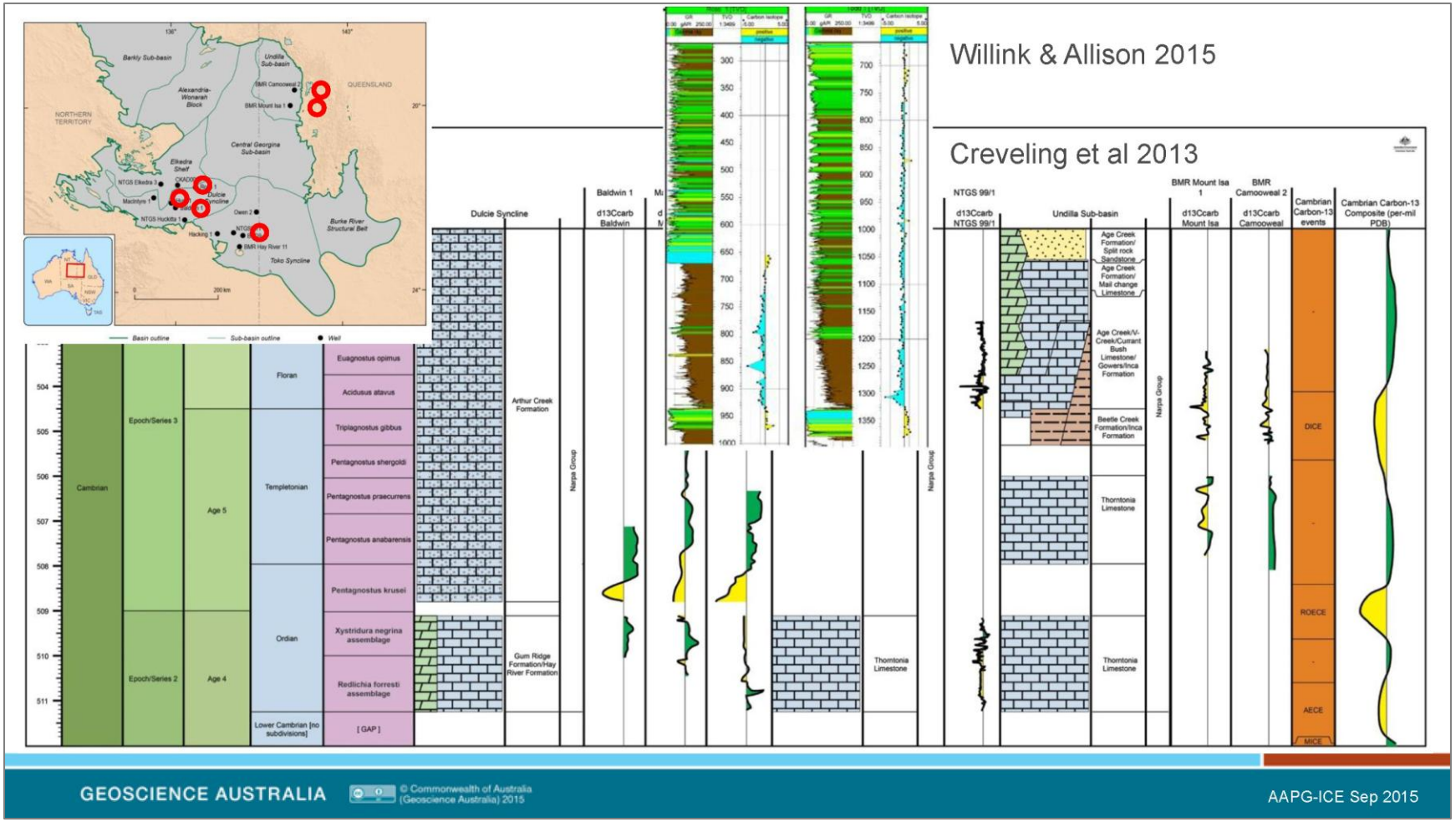
A strong negative carbon isotope excursion occurs at the base of the Arthur Creek formation in all three of the analysed wells, and it is most likely the global ROECE excursion. This excursion is not evident in the upper part of Thorntonia Limestone at all, and has probably been 'cut-off' by the disconformity. This dates the disconformity to about the base of Stage 5.
The slight offset between the global curve and that in the Dulcie Syncline is caused by uncertainty in the definition of the base of Stage 5. While the Australian Scheme (in the blue and purple) is fairly well developed in itself, how that correlates to the global scheme (green) is a little unclear.

Chemostratigraphic results – Undilla Sub-basin





Presenter's notes: The other location with rocks of similar age is the Templetonian portion of the Thorntonia in the Undilla Sub-basin. Here, a strong negative excursion is also absent, suggesting that these rocks are indeed Templetonian only, and probably do not extend down into the Ordian as does the Arthur Creek in the Dulcie Syncline.



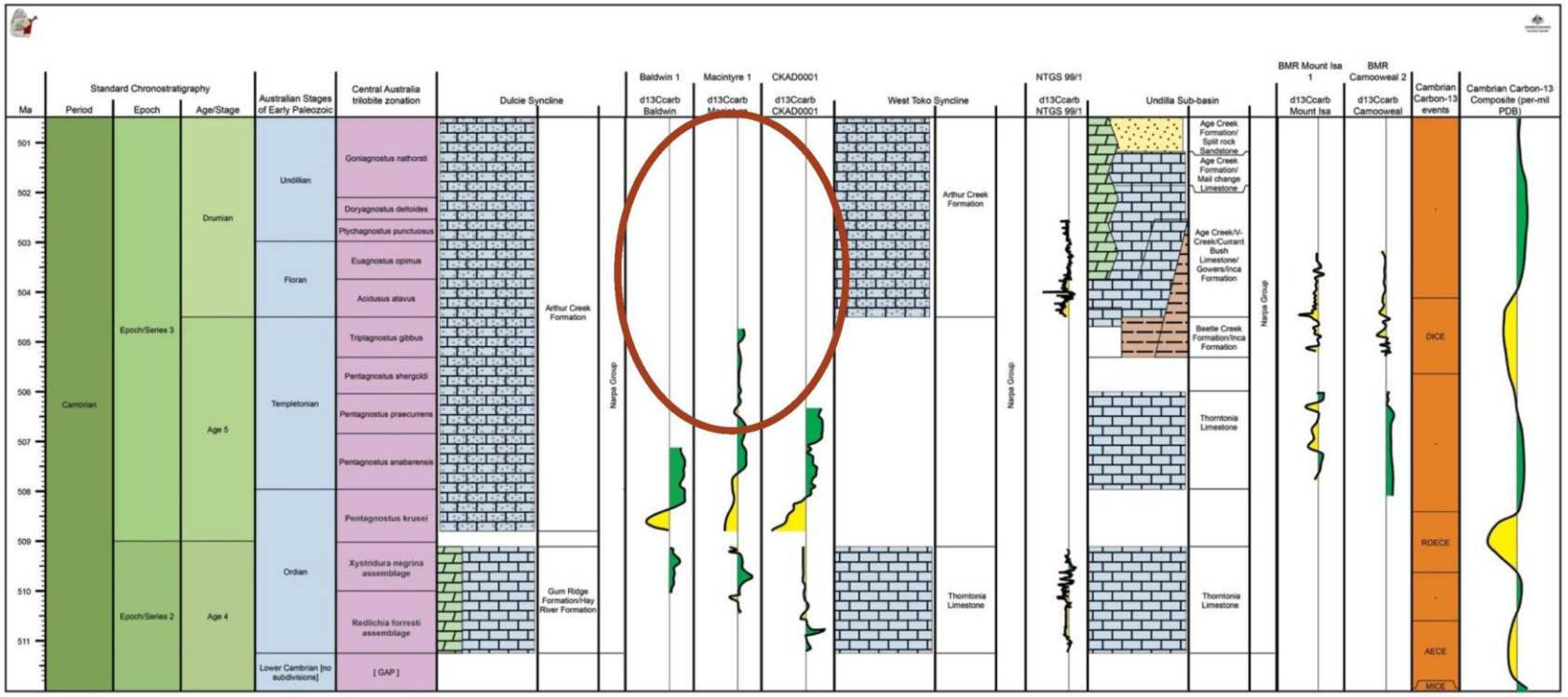
Presenter's notes: Here you can see the results just presented, alongside data from NTGS 99/1 in the Toko Syncline, given by Creveling and others.

The hot shale at the base of the Arthur Creek formation in this Toko well provides a consistently weak negative carbon isotope signal, which is more like that from the Inca Formation, and unlike the strong negative signal seen in the Dulcie hot shale with which it was previously correlated. *(Presenter's notes continued on next slide)*

(Presenter's notes continued from previous slide)

Data from other Toko Syncline wells, such as Ross 1 and Todd 1, which were presented by Willink and Allison at APPEA this year, also show a consistent weak negative carbon isotope signal at the base of the Arthur Creek formation. I should also note that the data from Willink & Allison are shown by depth, not age.

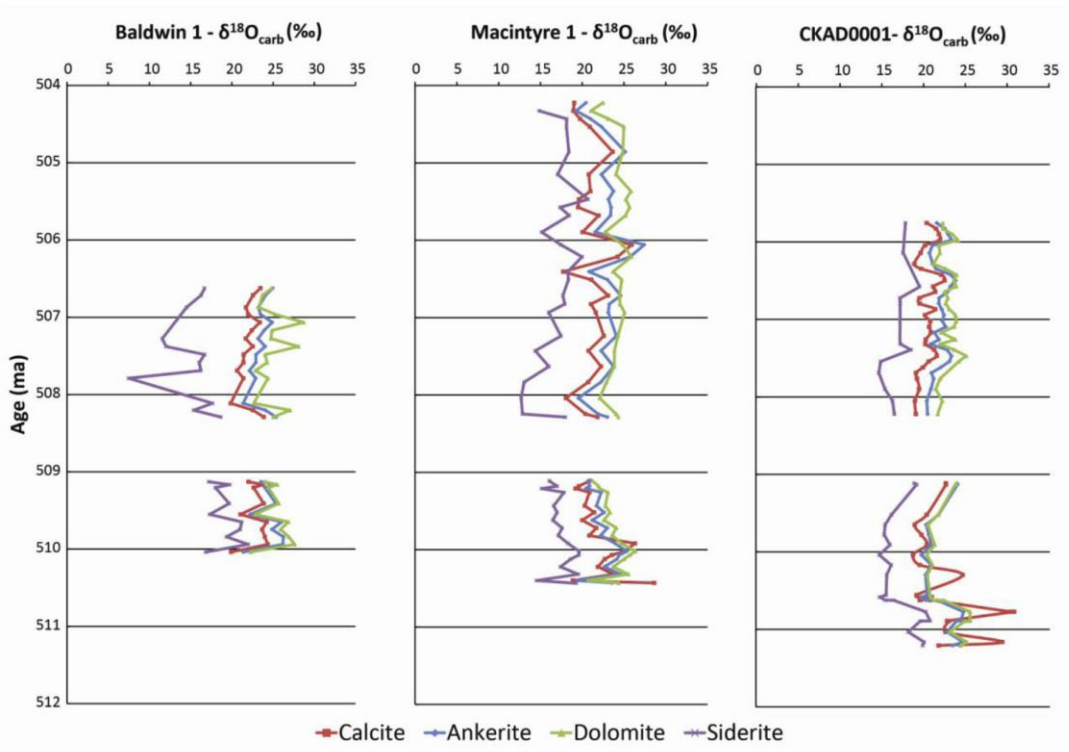
Next steps



Presenter's notes: Next, we'd like to do some fill-in sampling of the Dulcie wells to go higher up the Arthur Creek Formation, with the intention of intersecting the portion of the wells equivalent to the Toko Syncline 'Hot Shale', thus allowing for a more direct comparison of this interval across the two synclines.

Next steps

- Measured $\delta^{13}C$ and $\delta^{18}O$ of separate carbonate phases

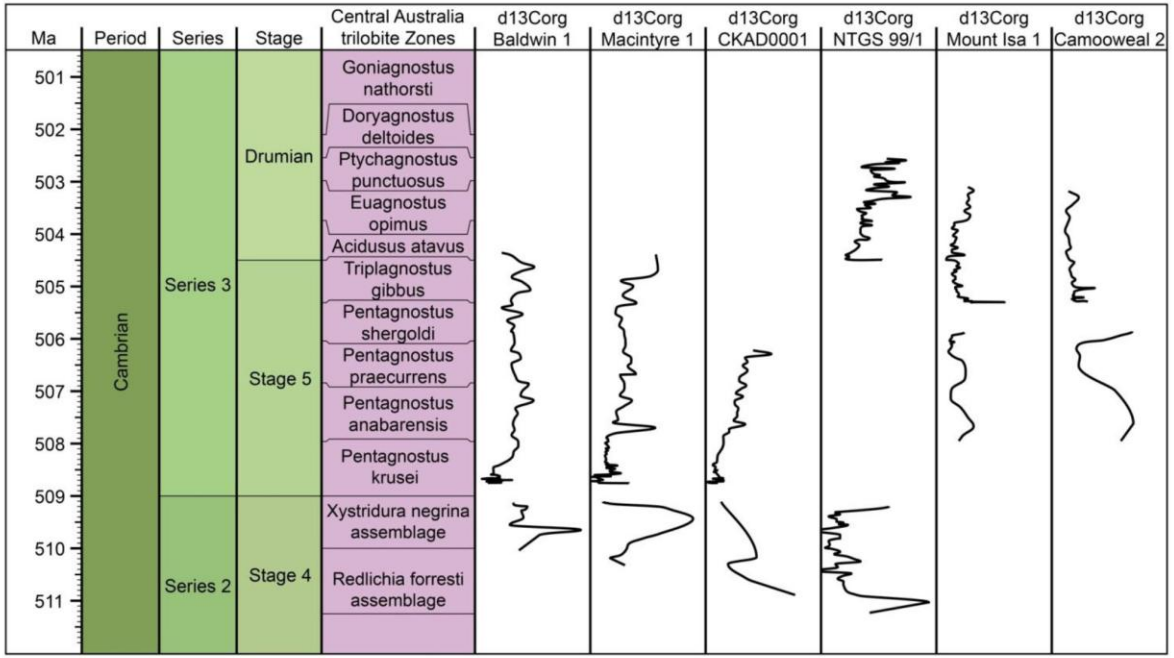


Presenter's notes: We also have a lot of other data still to investigate:

We utilised a stepped digestion method to analyse the carbon and oxygen isotope ratios of four separate carbonate phases: calcite, ankerite, dolomite and siderite. While the results for carbon isotopes do not vary systematically, those for oxygen do.

Next steps

- Measured $\delta^{13}C$ of organic (kerogen) materials



Presenter's notes: We also measured carbon isotope ratios in kerogen from the same set of samples, creating organic carbon isotope profiles.

We have not yet attempted the interpretation of these data, but all of it is available in a Destructive Analysis Report from GA.

Conclusions

- Hot shales in Dulcie and Toko synclines are not coeval
  - Ordian to early Templetonian in Dulcie Syncline, Floran in Toko Syncline
  - Chemostratigraphy corroborates biostratigraphic evidence

- Global ROECE negative isotope excursion may be present in latest Ordian of Georgina Basin
  - About *Pentagnostus krusei* Agnostid Zone
  - Dates the disconformity between Arthur Creek Formation and Thorntonia Limestone in Dulcie Syncline.

Presenter's notes: The first conclusion is simply reiterating a point that has now been made in a number of fora, and not just by GA: that the hot shale units in the Dulcie and Toko synclines are not coeval. It is younger in the Toko syncline, and chemostratigraphic evidence is not inconsistent with the biostratigraphic evidence.

Secondly, it appears that the global ROECE negative isotope excursion is present in the uppermost Ordian of the Georgina Basin. These rocks belong to the *Pentagnostus krusei* agnostid zone, thus providing a tie for this local zone to the International Timescale, and dating the unconformity between the Arthur Creek Formation and Thorntonia Limestone in the Dulcie Syncline.
Finally, I'm sure you all want to know why Tegan isn't presenting this talk and why you are stuck with an old fossil like me.