The breakup of the Rodinia Supercontinent and its impact on petroleum systems in the Amadeus and Georgina Basins

Executive Summary

- **Global correlations of Late Neoproterozoic and Middle Cambrian source rock sequences from the Amadeus, Georgina and Wiso basins suggest their potential is very much underestimated considering the prolific hydrocarbon production from equivalent petroleum systems in Oman and on the Siberian Platform in Russia, and to some extent in China.**

- **In particular, the Amadeus Basin is still a generation behind world standards in terms of areal seismic and drilling coverage/density and Centrals exploration drilling program this year will be the first since 1992. Current drilling density is only one well per 5200 km2 and less than 10% of the entire basin has reasonable seismic coverage.**

- **Middle Cambrian source rocks in the Georgina Basin, and probably in the Wiso Basin, offer a very rich algal/bacterial petroleum system which correlates with commercially productive petroleum systems located on the Siberian Platform. In the Amadeus Basin similar age petroleum systems are believed to have commercial potential given excellent oil shows in Alice-1 and comparable elog facies to the Georgina Basin, but more work is required to confirm this system.**

- **The global correlations from central Australian basins to Russia, Oman and China are discussed in terms of the breakup of the Supercontinent Rodinia and most of the discussion is based on work by li et al (2008), and for the Middle Cambrian the main reference is Boreham and Ambrose (2007).**

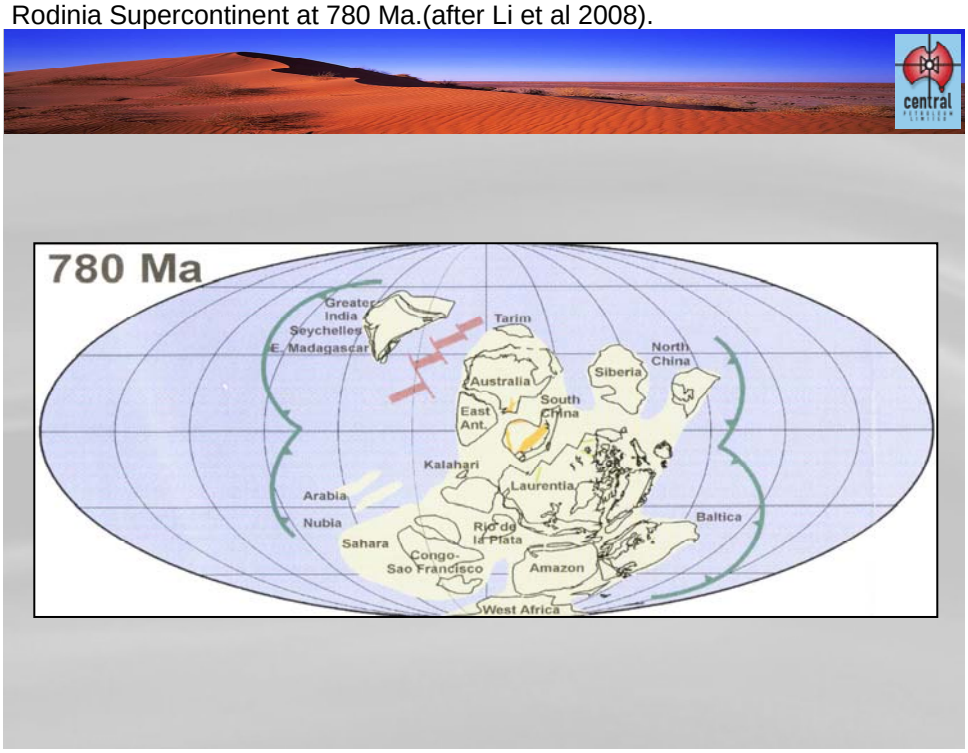
Introduction

By definition the Earth's geodynamic system periodically pushes almost all continents together to form a single landmass – a supercontinent. The youngest is Pangea which existed between 320 and 170 million years ago and the oldest is Rodinia which existed between 900 and 1000 Ma and is relevant to petroleum exploration in the Amadeus Basin. The name 'Rodinia' comes from the Russian word 'rodit' meaning to 'give birth'. Rodinia is the supercontinent that spawned all subsequent continents, while the edges (continental shelves) of Rodinia hosted the the creation of life (animals) as we know it today. Earlier formed, primitive life such as bacteria and algae evolved much earlier in the Proterozoic and provide vast petroleum source rocks developed in the Rodinia supercontinent which formed commercial oil and gas deposits found in Siberia, China, Oman and to a lesser extent Australia. Central believes the latter can be greatly expanded in the Amadeus Basin and this note provides some background.

Rodinia assembled through world wide orogenic events between 1300 and 900 Ma with all continental blocks known at this time being involved. The assembly of the Rodinia supercontinent featured the accretion (or collision) of continental blocks during this period; the breakup of Rodinia occurred over a period of 150 Ma after its assembly.

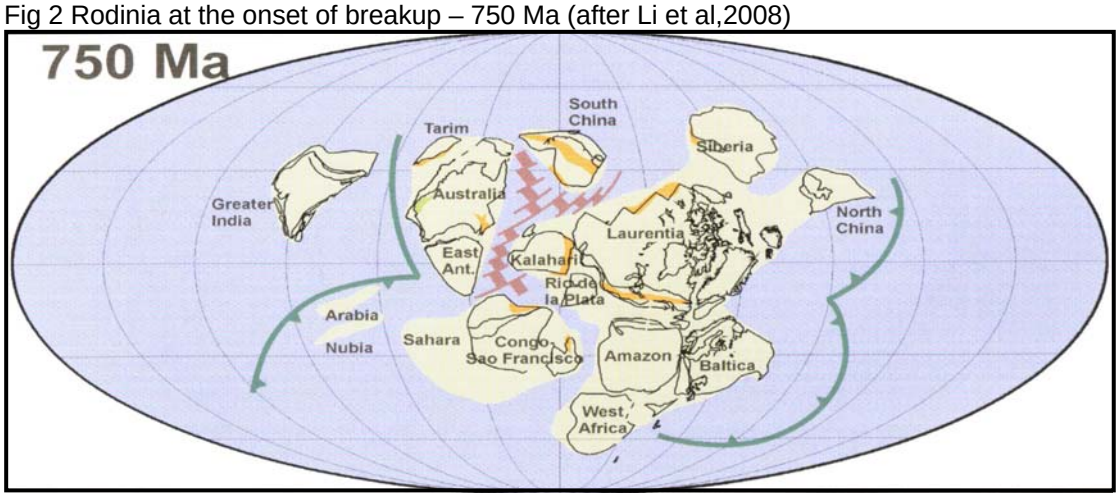
It is widely accepted that Rodinia broke apart during the latter half of the Neoproterozoic era (1000-542 Ma) and that some fragments re-assembled by the Early Cambrian (~ 530 Ma) to form Gondwanaland. As the rifting, or pull apart process took place new oceans formed in basinal areas intervening between the spreading continental masses and this is depicted in Figures 1 and 2. Figure1 which shows the mid-stage of the breakup (rifting) of the

Fig. 1 Rodinia Supercontinent at 780 Ma.(after Li et al 2008).



Rodinia supercontinent. Note the proximity of the Australian continent (including the Amadeus Basin) to analogous basins formed in Siberia, south China and the Tarim Area of northern China. The key to Neoproterozoic petroleum systems is the extension of Sturtian lacustrine shales present in Australian basins (including the Amadeus Basin) onto the continental masses of Siberia, China and Oman. These source rocks, in part hold the key to prolific hydrocarbon production from the Neoproterozoic / Early Cambrian sequences developed in the last three areas and there are analogies with similar age sequences in central Australia

Fig 2 Rodinia at the onset of breakup – 750 Ma (after Li et al,2008)



It is believed the breakup of Rodinia resulted from the activity of mantle plumes or of a mantle super plume beneath the supercontinent which thinned and thermally weakened the lithosphere resulting in widespread continental rifting and eventually breakup.

Global Correlations of Petroleum Systems

The most powerful criteria for reconstructing the continental distribution within the Rodinia Supercontinent comes from palaeomagnetics and tectonostratigraphic correlations. Glacial episodes are particularly useful correlation tools. Study of these criteria indicate the Tarim craton of northwest China was first joined to northwestern Australia at the beginning of the Neoproterozoic. The Tarim Basin in NW China also has many similarities with the Len-Tunguz Basin developed in eastern Siberia and it is believed the two areas were once connected. In this area the majority of discoveries, which are gas condensates and more rarely light oil, occur in fractured carbonates of Cambrian and Late Neoproterozoic reservoirs.

The Tarim Basin has at least two (possibly three) glacial episodes and these can be correlated via the Kimberley of NW Australia to the basins of Central Australia (including the Amadeus and Georgina basins) and southwards to the Adelaide Geosyncline. Cambrian mafic volcanic units of NE Tarim correlate with the Antrim Plateau Volcanics found in the Northern Territory and elsewhere.

A model proposed by Li et al., for the distribution of basinal areas which made up Rodinia has the southeast China Block connected to southeastern Australia (Adelaide Geosyncline, Amadeus Basin and Georgina Basin etc). To the west lay Siberia where correlative source rocks (petroleum systems) approximate the Aralka Formation and Pertatataka Formation in the Amadeus Basin of central Australia.

The relevance to petroleum exploration is manifested in the correlation of petroleum source rocks common to the basins mentioned above.
The Tarim Basin is a prolific oil/gas province with reserves exceeding 300 million tonnes of oil which is dominant over gas condensate. Traps occur in large dome like structures, the

reservoirs being fractured carbonates of lower Palaeozoic age (Ordovician) age. There are 10 petroleum systems in all with hydrocarbon production present from Sinian to Tertiary reservoirs.The main petroleum systems are discussed below:

1) Prolific oil prone petroleum systems of Cambrian age (algal-bacterial organic matter) occur in the Tarim Basin.
2) Glacio-lacustrine shales directly overlying "Sturtian" diamictites are good source rocks in the Tarim Basin of which is a prolific oil province.

Prolific oil and gas production in the **Tarim Basin** in China, in **Oman** and in the **Lena-Tunguska area** on the Siberian Platform, all lend credence to the prospectivity of correlative sequences in the Amadeus Basin in Australia.

Proterozoic Petroleum Systems (Amadeus Basin) –Global Correlatives.

The main petroleum systems active in the Amadeus Basin are the Gillen Member (Willouran), the Aralka Formation (Sturtian), the Pertatataka Formation (Marinoan), the Chandler Formation (Early Cambrian) and the Giles Creek/Shannon Formation (Middle Cambrian). In terms of global correlations reflecting the breakup of Rodinia the standout petroleum systems are the Aralka Formation, the Pertatataka Formation, and the Giles Creek/Shannon Formation. These three petroleum systems, and their global correlatives are discussed in more detail below:

1) **The Sturtian Aralka Formation**: on a regional scale this unit directly overlies Sturtian diamictites, and was recently defined as the richest source in the Amadeus Basin. It was at this time that Rodinia began to break up and a "sag basinal" phase was emplaced. This phase corresponds to the Tapley Hill Formation in the Adelaide Geosyncline which corresponds to the Aralka Formation in the Amadeus Basin.

   Correlations with northwest China: In the Tarim Basin of northwest China glacio-lacustrine shales, directly overlying what are believed to be "Sturtian" equivalent diamictites, provide good source rocks. This is a prolific oil province with reserves exceeding 300 million tonnes of oil which is dominant over gas/condensate. Traps occur in large dome like structures, the reservoirs being fractured carbonates of lower Palaeozoic age (Ordovician) age. There are 10 petroleum systems in all with hydrocarbon production present from Sinian to Tertiary reservoirs. Cambrian algal-bacterial source rocks are also very important source rocks in the basin.

   Correlations with southwest China: Neoproterozoic strata deposited in southern China sometimes record the diagnostic Sturtian diamictite-carbononaceous shale sedimentary couplet in a number of sub-basins eg in the Central Hunan Basin. In the latter, 130 m of carbonaceous shales overlie 155 m of glacial marine diamictite. Overall the Rodinian rock record in South China shows similarities to that of eastern Australia, both featuring four major phases of rifting during in the ca 830-700 ma. The two regions are believed to abutted each other during Rodingan time but broke apart about 750 Ma.

   Correlations with the Len-Tunguz Basin: This basin is developed in eastern Siberia and has many similarities with the Tarim Basin in China and it is believed the two areas were once connected. In this basin the majority of discoveries, which are gas condensates and more rarely light oil, occur in fractured carbonates of Cambrian age. It is also believed equivalents of the Aralka Fm source rocks have sourced oil and gas production in the basin. Stratigraphically equivalent source rocks, hosting oil and gas shows, also appear to occur on the Central Russian Platform and in the Volga-Ural region.

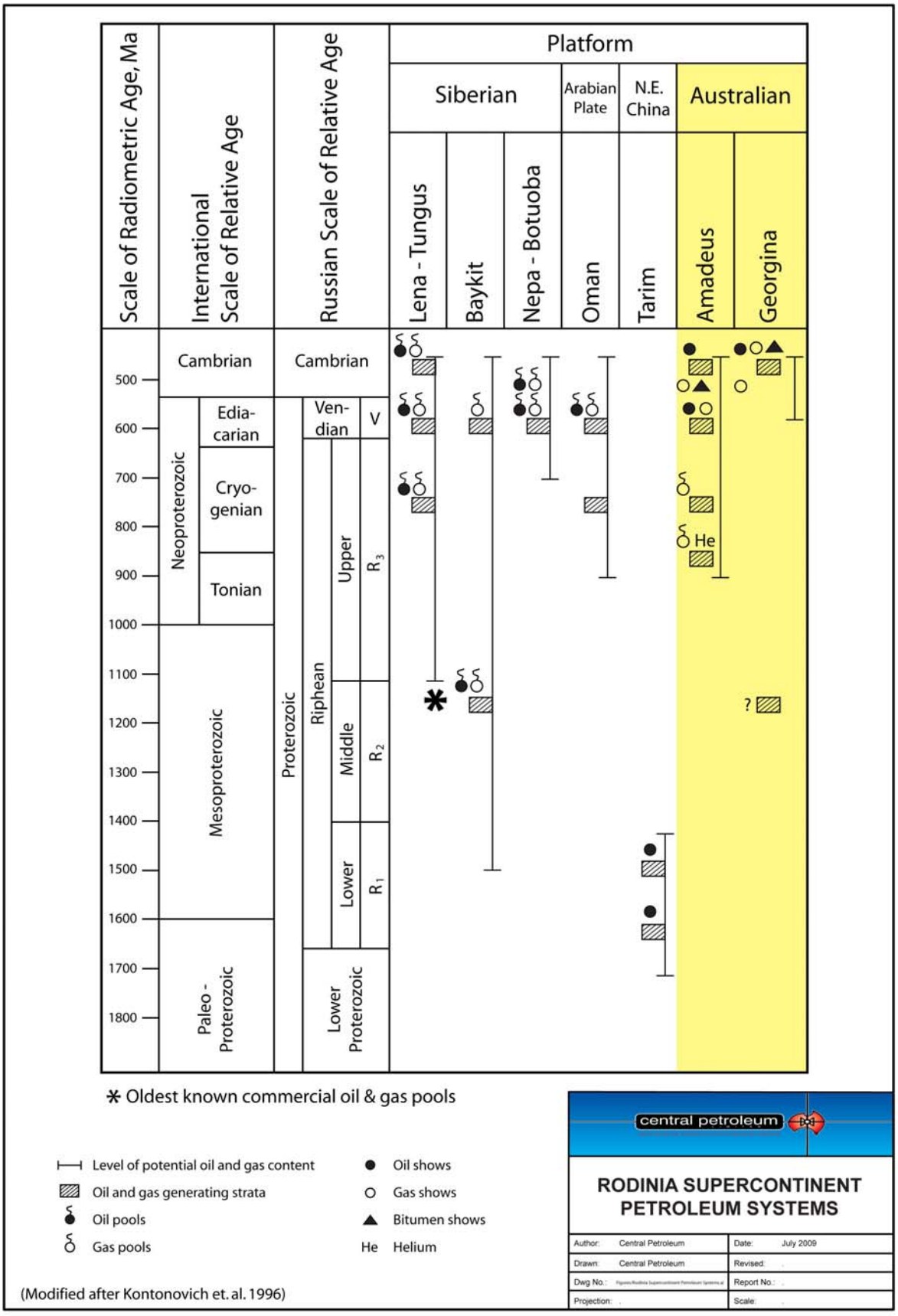


Table 1 Rodinia Supercontinent – Correlation of Petroleum Systems

Correlations with Oman geology: On the Arabian Plate (Oman) organic rich, oil-prone shales (Abu Mahara Formation) are prolific source rocks responsible for considerable commercial production. The shales directly overlie glacial diamictites of Sturtian age (Ghubrah Fm) and are thus believed to be equivalent to the Aralka Formation. A sample of an oil stain from Aralka shales in the western Amadeus Basin has very unusual geochemical characteristics including acyclic isoprenoids>C2 which were unusually abundant and included C40 carotenoids.Very unusual diahopanes and farrihopanes were also present. These analyses show a close affinity with source rock/oil geochemical signatures from Cryogenic source rocks formed in the producing Proterozoic provinces of the eastern Siberian Platform and Oman. Thus it has emerged that the Aralka Formation Petroleum System may be very important in the Amadeus Basin as is the case in the afore-mentioned basins which are analogous both in terms of their stratigraphic context and unique hydrocarbon geochemical signature.

2) **The Marinoan Pertatataka Formation**: this is a basin sag shale-siltstone facies and is the source of gas in the Dingo and Orange fields in the Amadeus Basin. No equivalent units have been defined in SE China. However, Table 1 based on the work of Kontorovich (2005), indicates source rocks of similar age (~ 600 Ma) occur on the Siberian Platform in the following basins:(Tunguska-oil and gas production, Baykit-gas production, Nepa Botuba- oil and gas production, and in Oman- oil and gas production).

The Pertatataka Fm. is widespread in the Amadeus Basin and is in the oil/gas window at shallow depths suggesting regional basin unroofing. Little maturation modelling has been undertaken but the sequence probably entered the gas window during the early part of the Alice Springs Orogeny (Devonian-Carboniferous), prior to the main phase of folding and this could explain why Dingo field is not filled to spill. However, fields sourced from younger source rocks (Ordovician Horn Valley Siltstone- Mereenie and Palm Valley fields) entered the gas window post the main phase of folding and are hence filled to spill.

Central believes the Pertatataka petroleum system, given the major fields discovered in Siberia and Oman at the same level, has far more potential than previously envisaged. This view is enhanced by recent studies indicating the Pertatataka/Arumbera/Chandler (source-reservoir-seal tripartite system) is widespread in the southern Amadeus Basin where it was previously interpreted to be largely absent.

3) Middle Cambrian Petroleum Systems: Giles Creek Fm/Jay Creek Limestone/ Shannon Formation

Middle Cambrian marine oil-prone petroleum source rocks have been described on a global scale including in Siberia and Australia. In Australia the Georgina Basin lies at the heart of a series of intracratonic basins on the Australian continent that share their origin in the breakup of the supercontinent Rodinia. Their wide geographic distribution in Central Australia includes Central Petroleum's holdings in the Amadeus, Georgina and Wiso basins. These basins were linked in Proterozoic time prior to the breakup of Rodinia, which began at about 750 Ma.

Thus basin connections were severed from the early Cambrian onwards, following tectonic fragmentation associated with the Petermann Ranges Orogeny. Later,from the early Middle Cambrian through to the Late Middle Cambrian, a combination of sedimentary facies and organic input from algal bacterial sources saw important source rocks developed in the Georgina Basin. Lack of core data has inhibited correlations with analogous sequences in the Amadeus and Wiso basins but suggested correlations occur below:

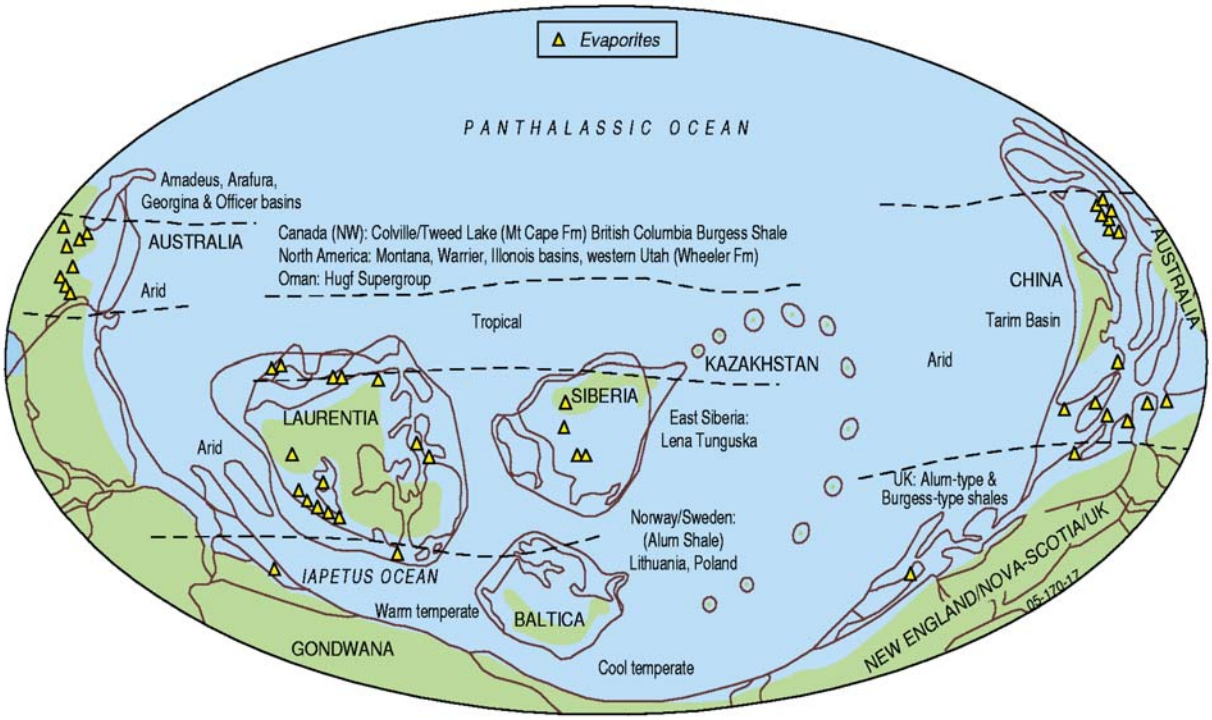


Fig.3 Middle – late Cambrian Palaeogeographic Map; Distribution of oils and organic – rich Black shales

Table-1 Middle Cambrian Correlations in Central Australia

	Early Middle Cambrian	**Middle Cambrian**
Georgina Basin	Thorntonia Limestone	Arthur Creek Formation
Amadeus Basin	Chandler Formation	Giles Creek / Shannon Fm.
Wiso Basin	Montejinni Limestone	Point Wakefield Beds

Incursion of oxygen-deficient bottom waters over broad passive margins linked to restricted seaways occurred on a global scale during the Middle Cambrian. This, in combination with tropical conditions and transgressive episodes (Gaines and Droser, 2005), resulted in worldwide deposition of organic rich potential source rocks during the Early to Late Cambrian. Some important source rocks in Central Petroleum's basins, particularly in the Georgina Basin, are Middle Cambrian in age (Arthur Creek Formation). Analogous, organic rich shales of similar age occur in North America (Burgess Shale), Scandinavia/UK (Alum Shale) and northwest Canada (Mount Cap Formation). Some of these sequences are now being investigated for their unconventional reservoir potential. Organic rich shales of Early Cambrian age, **which are related to commercial production, occur on the Siberian Platform and in Oman (Huqf Supergroup).**

Conclusions

The Rodinia Supercontinent assembled during the Mesoproterozoic between 900-1300 Ma by accretion of continental blocks during this period. The breakup of Rodinia saw up to four phases of rifting during the Neoproterozoic (Adelaidean) with final breakup commencing at about 750 Ma. During this time characteristic source rock facies developed in Central's frontier basins including the Amadeus, Georgina and Wiso basins. Correlation with analogous source rocks on Siberia, China and Oman are summarised below.

Australia

Aralka Formation: correlatives in Northern and Southern China, Siberian Platform, Oman
Pertatataka Fm: correlatives on the Siberian Platform and in Oman.
Middle Cambrian: correlatives on Siberian Platform and Oman.

Reconstruction of the Rodinia supercontinent leads to conclusions which enhance the prospectivity of the Adelaidean rift and Middle Cambrian sequences in the Amadeus and Georgina Basins and allows expanded global source rock correlations. The main inference is that commercially productive source rocks (petroleum systems) in Siberia, China and Oman have been more thoroughly explored than similar domains in Australia, and have yielded considerable commercial production. In contrast, equivalent Australian basins are very sparsely explored. However, given geological commonality with these other producing areas, Central believes commercial production will result from exploration drilling over the next two years ending a drilling hiatus that goes back to 1992.