Resources of the Galilee Basin, Australia: Insights From Burial History and Exhumation Analysis*

Amy I'Anson[1], Adriana Dutkiewcz[2], Dietmar Müller[2] and Ian Deighton[3]

Search and Discovery Article #80506 (2016)**
Posted February 1, 2016

*Adapted from oral presentation at AAPG International Conference & Exhibition, Melbourne, Australia, September 13-15, 2015.

[1]Upstream Gas, AGL, Sydney, NSW, Australia
[2]School of Geosciences, University of Sydney, Sydney, NSW, Australia (dietmar.muller@sydney.edu.au)
[3]TGS, Bradford, United Kingdom

Abstract

The Late Carboniferous - Middle Triassic Galilee Basin in central Queensland covers an area of ~ 250,000 km^2 and is widely considered a frontier for coal seam gas (CSG) exploration. However, relatively little is known about the coal reservoirs, in terms of both their CSG prospectivity and the burial/thermal histories of the host sequences. In this study, we have used a holistic, mixed-method approach on a basin-wide scale that includes the use of seismic interpretation, stratigraphic mapping, reservoir and gas data analysis including carbon isotopes, multivariate statistical analysis of core data, outcrop investigation, 1D basin modelling, and a quantification of regional apparent exhumation from well logs. Our geohistory analysis indicates that relatively slow subsidence rates prevailed in the Galilee Basin from the Carboniferous to the Late Cretaceous, punctuated by two significant exhumation events. The Permian coal measures generated up to 40m^3/t of gas when maximum burial (1.5 to 2 km) was reached in the Late Cretaceous. Rapid subsidence (50 m/Myr compared to a background 5 m/Myr), followed by rebound at 95 Ma, resulted in a kilometer scale uplift and erosion phase. Geohistory models and exhumation analyses provide evidence for a slab detachment event, post-dating the cessation of subduction along eastern Gondwanaland, indicating that subduction dynamics and upper mantle processes had a profound effect on basin evolution and the resource potential of the Galilee Basin. Isotopic evidence suggests the remaining gas is biogenically derived, with a remnant mixed thermogenic signature. The bulk of this thermogenic gas was likely lost as a consequence of the Late Cretaceous exhumation event. It is therefore concluded that burial and exhumation history has had an overriding influence on variations in coal properties on present-day gas contents. Low

gas saturations and distance from market, despite high permeabilities and thick coals, are the major challenges to developing the CSG resources of the Galilee Basin.

Selected References

Australian Department of Resources, Energy, and Tourism (DRET), 2012, Australian Gas Resource Assessment, 2012: DRET, 58p. Website accessed December 14, 2015, http://www.ga.gov.au/webtemp/image_cache/GA21116.pdf.

Deighton, I., J.J. Draper, A.J. Hill, and C.J. Boreham, 2003, A hydrocarbon generation model for the Cooper and Eromanga Basins: APPEA Journal, **v.** 43/1, p. 433-451.

Mavromatidis. A,2006, Quantification of exhumation from sonic velocity data, Cooper Basin, Australia, and implications for hydrocarbon exploration: Surveys in Geophysics, v. 27, p. 277.

Queensland Competition Authority, 2014, Coal Seam Gas Review: Final Report, 155p. Website accessed December 14, 2015, http://www.qca.org.au/getattachment/aaaeab4b-519f-4a95-8a65-911bc46cc1d3/CSG-investigation.aspx.

Sclater, J.G., and P.A.F. Christie, 1980, Continental stretching: An explanation of post mid-Cretaceous subsidence of the Central North Sea: Journal of Geophysical Re-search, v. 85/B7, p. 3711-3739.

EarthByte Building a Virtual Earth

THE UNIVERSITY OF SYDNEY

BGH Basin Genesis Hub

Resources of the Galilee Basin, Australia: Insights from Burial History & Exhumation Analysis

A. I'Anson[1], A. Dutkiewicz[1], R. D. Müller[1], I. Deighton[2]

[1] EarthByte Group, School of Geosciences, The University of Sydney

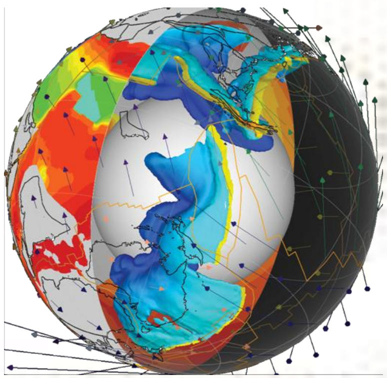
[2]TGS, London

EarthByte | dietmar.muller@sydney.edu.au

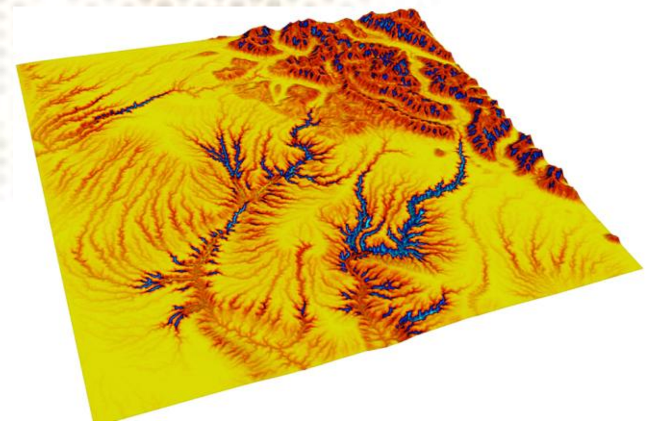
Basin GENESIS Hub

BGH

- 5-year industry linkage project with research focus on Australia, PNG and the Atlantic



Modelling effects of crustal- and mantle-scale processes on basin evolution



Modelling dynamics of surface topography, erosion, sedimentation

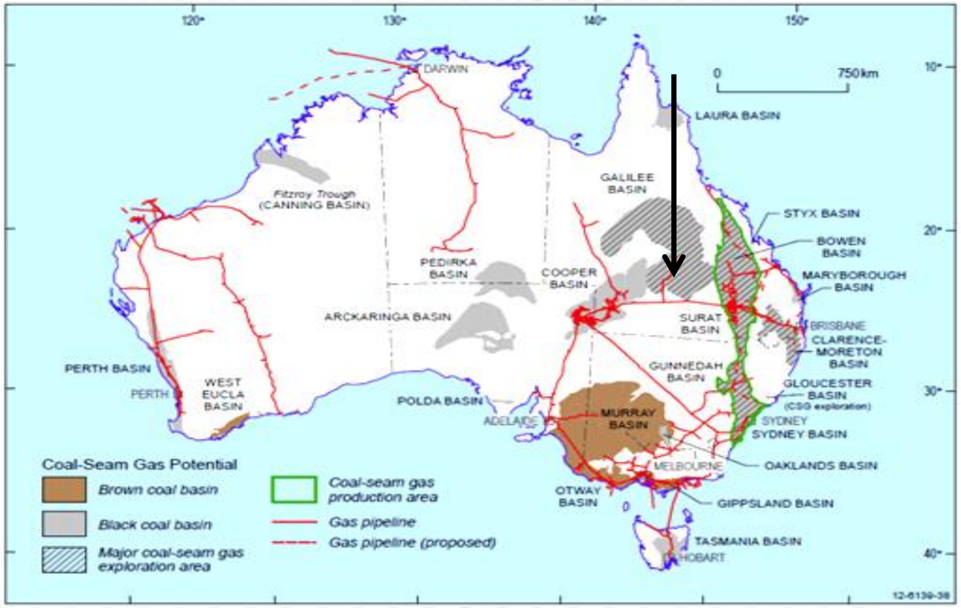
www.earthbyte.org/the-basin-genesis-hub/

Presenter’s notes: Overall objective is to link multiple spatial and temporal scales.

BGH

The Galilee Basin

- The Late Carboniferous-Middle Triassic intracratonic basin, underlying the sequences of the Eromanga Basin
- Historical exploration for conventional oil/gas resources unsuccessful
- Renewed round of exploration for unconventional gas abandoned by all but one player
- Geologically enigmatic

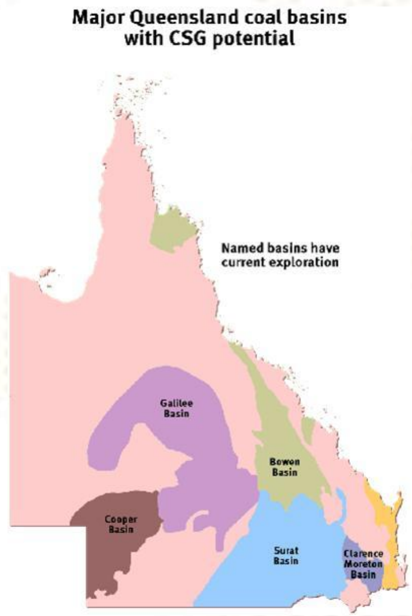


Location of Australian CSG production and exploration areas, Source: DRET (2012)

Presenter's notes: The Galilee Basin of Central Queensland is intracratonic and of Late Carboniferous to Middle Triassic in age; it underlies the sequences of the Eromanga Basin. Exploration for conventional hydrocarbon resources in the Galilee Basin has been historically unsuccessful. The latest round of exploration for unconventional resources in the basin has been abandoned by all but one player (Galilee Energy, who are looking at further work to appraise the deliverability of substantial in-place coal seam gas resource). The Galilee Basin is geologically enigmatic, lying adjacent and coeval with the Cooper Basin, which is the largest onshore oil/gas producer, and the Bowen-Surat Basins where 90% of CSG production occurs.

Aim

- Understand the geological evolution of The Galilee Basin and its resources (or lack thereof)



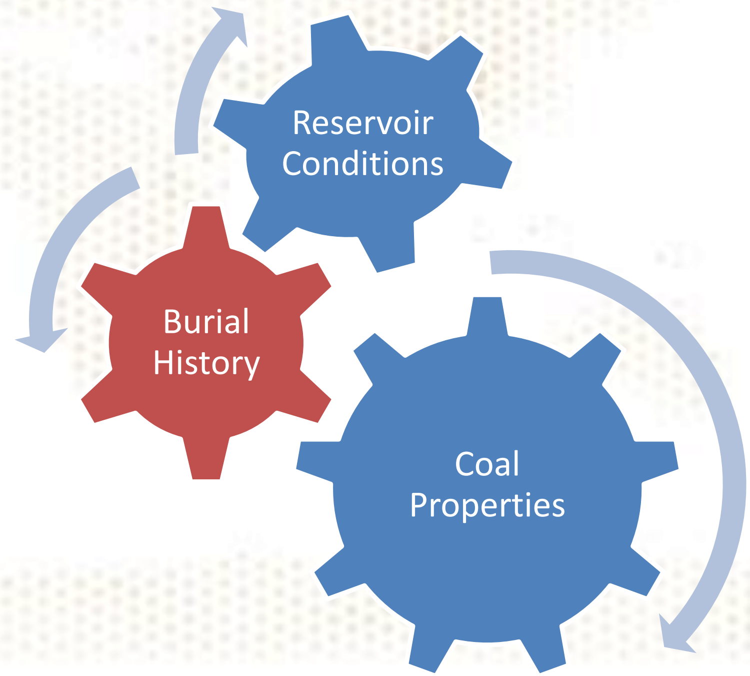
Methods & Data

- 3000 km 2D seismic lines
- Coal & Gas properties
- Quantification of exhumation through well log-derived (over) compaction
- 1D Basin Modelling

Presenter's notes: In order to understand the geological evolution of the GLB and its CSG resources, the study included a thorough review of well logs and formation-top data, interpretation of over 3000 km of seismic lines, statistical analysis of coal and gas properties, and a quantification of exhumation through well log-derived (over) compaction and 1D Basin Modelling.

Gas in Coals

- The gas-bearing coals of The Galilee Basin are undersaturated
- Geohistory Analysis necessary to understand the timing and variability in gas generation and retention



Presenter's notes: The spatial distribution of gas in coals and the resultant prospectivity, is a product of coal properties, burial history, and reservoir conditions. The gas-bearing coals of the Galilee Basin are undersaturated, meaning that they hold LESS gas than they theoretically can (<60%). This presentation will, therefore, focus on the Burial History of the basin in order to understand the timing and variability in gas generation and retention.

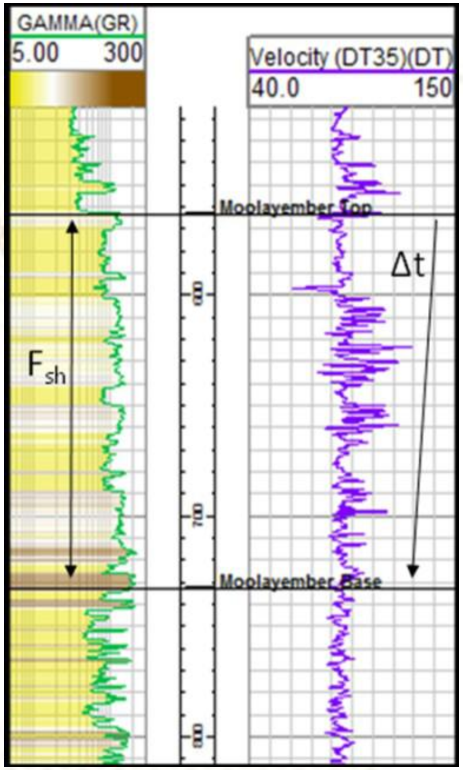
Quantifying Exhumation

- A quantification of exhumation is crucial to successful petroleum exploration and is required for modelling the magnitude of events
- Sonic and Gamma logs are widely run
- Over-compaction can be used to deduce apparent exhumation of sedimentary column

Equation 1 - Porosity transform from sonic and gamma logs

$$\Phi = Fsh\left(\frac{1}{1.57}\right)\left(\frac{\Delta t - 59}{189 - 59}\right) + (1 - Fsh)\left(1 - \frac{55.5^{\frac{1}{1.6}}}{\Delta t}\right)$$

Modification of Hensens shale and Raiga-Clemenceau sand equations, after Mavromatidis (2006), comparable to Sclater and Christie (1980).



Gamma and Sonic log derived variables used in porosity transform; example from Towerhill well.

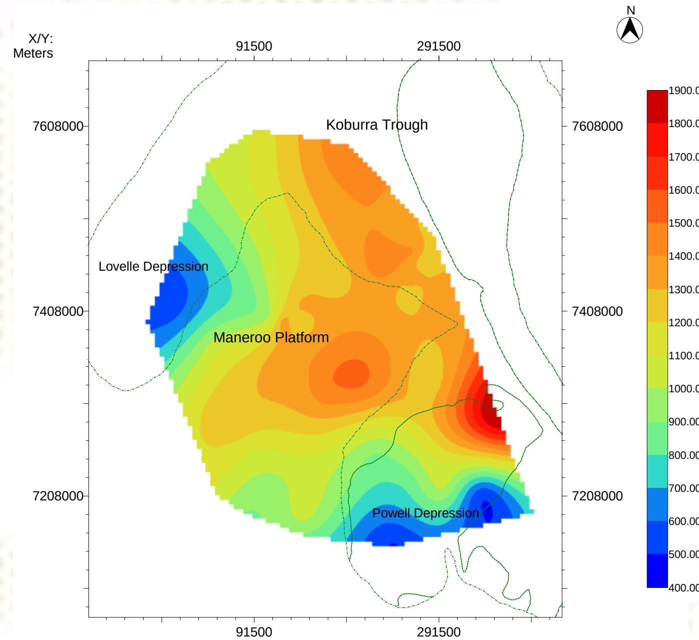
Presenter’s notes: The subsidence history of basins is preserved by the stratigraphic sequence; however, uplift events are expressed only as hiatuses or unconformities. The term “exhumation” describes the displacement of rock with respect to the surface (as opposed to uplift and erosion), the apparent exhumation of a rock column from maximum burial depth to present is crucial to petroleum exploration and of significance in understanding the dynamic driving forces of basin uplift.

The reduction of interval transit time with depth is an appropriate indicator of porosity and can be measured by widely run sonic logs. The degree of over-compaction relative to rock-type porosity-depth trends can then be used to deduce the apparent exhumation of the sedimentary column.

Exhumation Analysis

- Two major exhumation events of interest
  - Late Triassic regional unconformity
  - Late Cretaceous event
- Late K exhumation event in the Galilee basin was in the magnitude of 1000 m (with an E-W orientation 1800-400 m)
- Triassic exhumation was comparatively minor (600 m)

Late Cretaceous exhumation had a magnitude of ~1000 m with an E-W orientation.



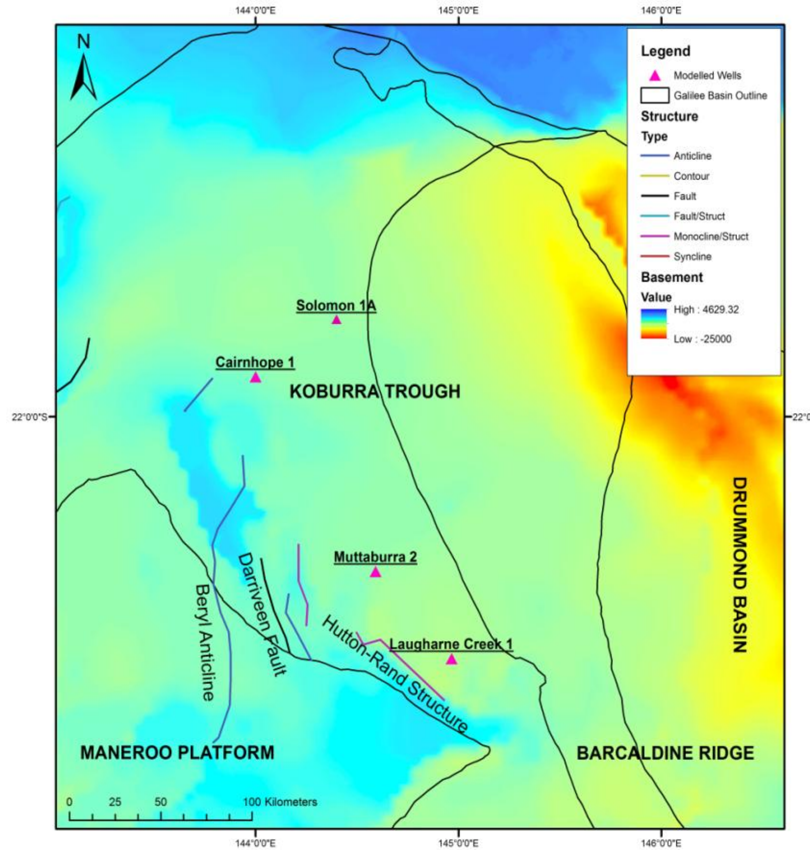
Presenter's notes: Two major exhumation events were of interest in this study, based on observed truncations in the sedimentary sequence in seismic and well data. The oldest unconformity is the Late Triassic event expressed as a regional unconformity that separates the Eromanga and Galilee basins and a younger Late Cretaceous event that separates the Eromanga strata from overlying Tertiary sediments.

This exhumation analysis indicates that the Late Cretaceous exhumation event in the Galilee Basin was ofn the magnitude of 1000 m with an east-west orientation (1800-400 m, respectively), while interpolated Triassic exhumation was comparatively minor, generally <600 m.

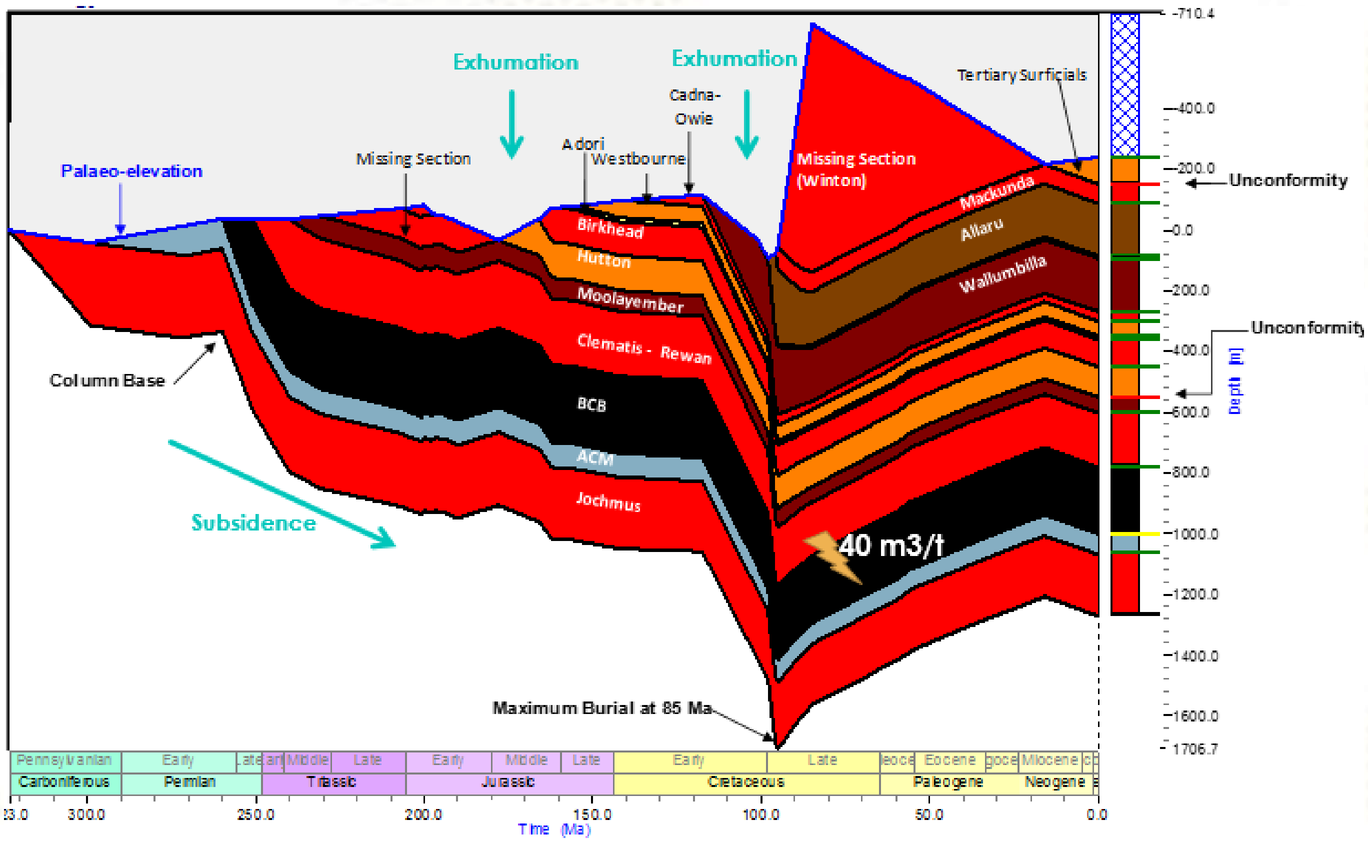
A Powerhouse Emerges: Energy for the Next Fifty Years

Geohistory Analysis

- Exhumation analysis provides a calibration dataset for geohistory modelling, along with variables of lithology, bottom-hole temperature and vitrinite reflectance.
- 4 wells across the Koburra Trough, the depocentre of interest within the basin



Presenter's notes: This exhumation analysis provides a calibration dataset for geohistory modelling, along with variables of lithology, bottom-hole temperature and vitrinite reflectance. Geohistory analysis was conducted for 4 wells across the Koburra Trough in order to understand the timing and variability in gas generation; the results presented here are from the Laugharne Creek 1 well, located proximal to current appraisal efforts.

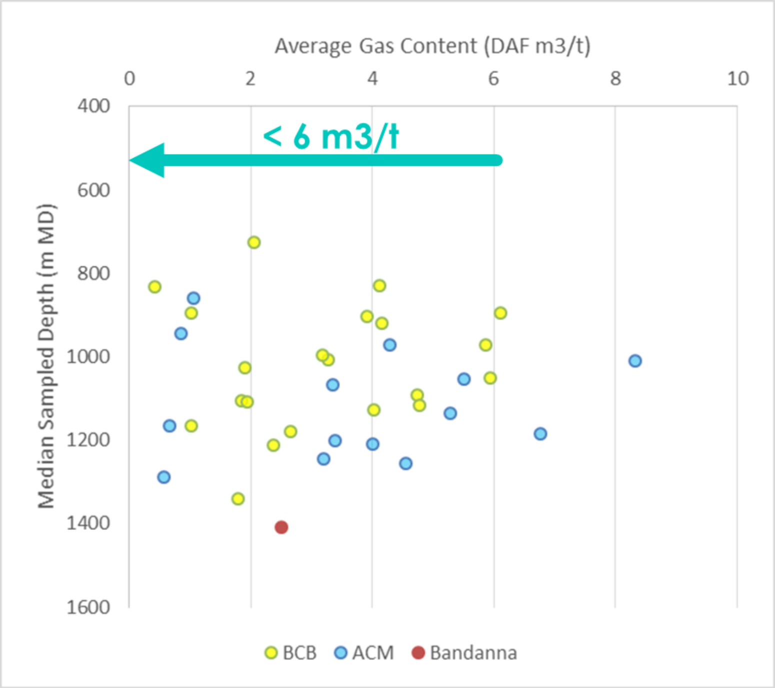


Galilee Basin Geohistory Model

Presenter's notes: This plot shows a geohistory reconstruction though time of the sediment column in the Galilee Basin; it shows 1.7 km of subsidence from the Carboniferous to the Late Cretaceous where maximum burial was achieved. This is segmented by two exhumation events; the second, in the Late Cretaceous, was the larger of the two. The Betts Creek Beds (BCB) and Aramac Coal Measures (ACM) are the Permian coal targets of the Galilee sequence, which is overlain by the Eromanga sequence. Modelling indicates that we have generated up to 40m3/t of gas at maximum burial depth.

Gas in Permian Coals of the Galilee Basin

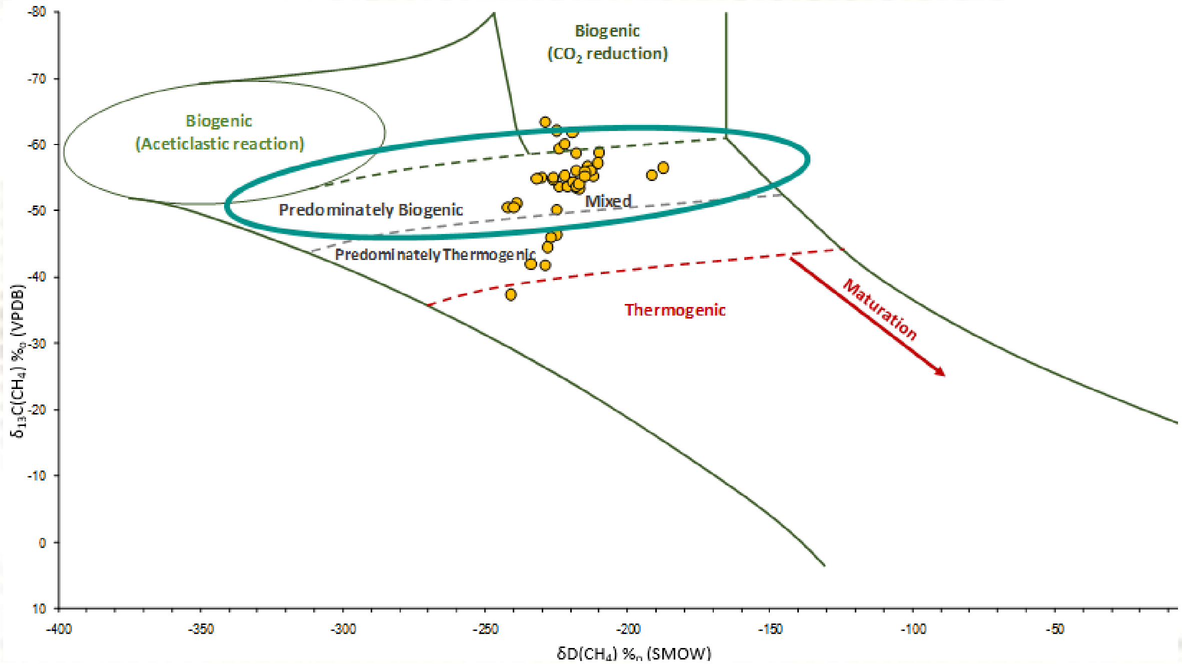
- Late Cretaceous generated volumes up to 40 m^3/t
- Average Gas content of Permian Betts Creek Beds (BCB) and Aramac Coal Measures (ACM) < 6 m^3/t
- Langmuir Volume -Theoretical holding capacity (10-30 m^3/t)
- Low gas contents/saturation explained by loss of gas during exhumation



Presenter's notes: Hydrocarbon generation occurred in the Late Cretaceous, with generated volumes of gas up to 40 m3/t where burial depths are greatest. Average gas contents of the Permian BCB and ACM are <6m3/t, and the theoretical holding capacity of the coal measures (based on coal properties) ranges from 10-30m3/t. This indicates that the mechanism for low gas contents in the Galilee Basin is loss, rather than lack of gas generation.

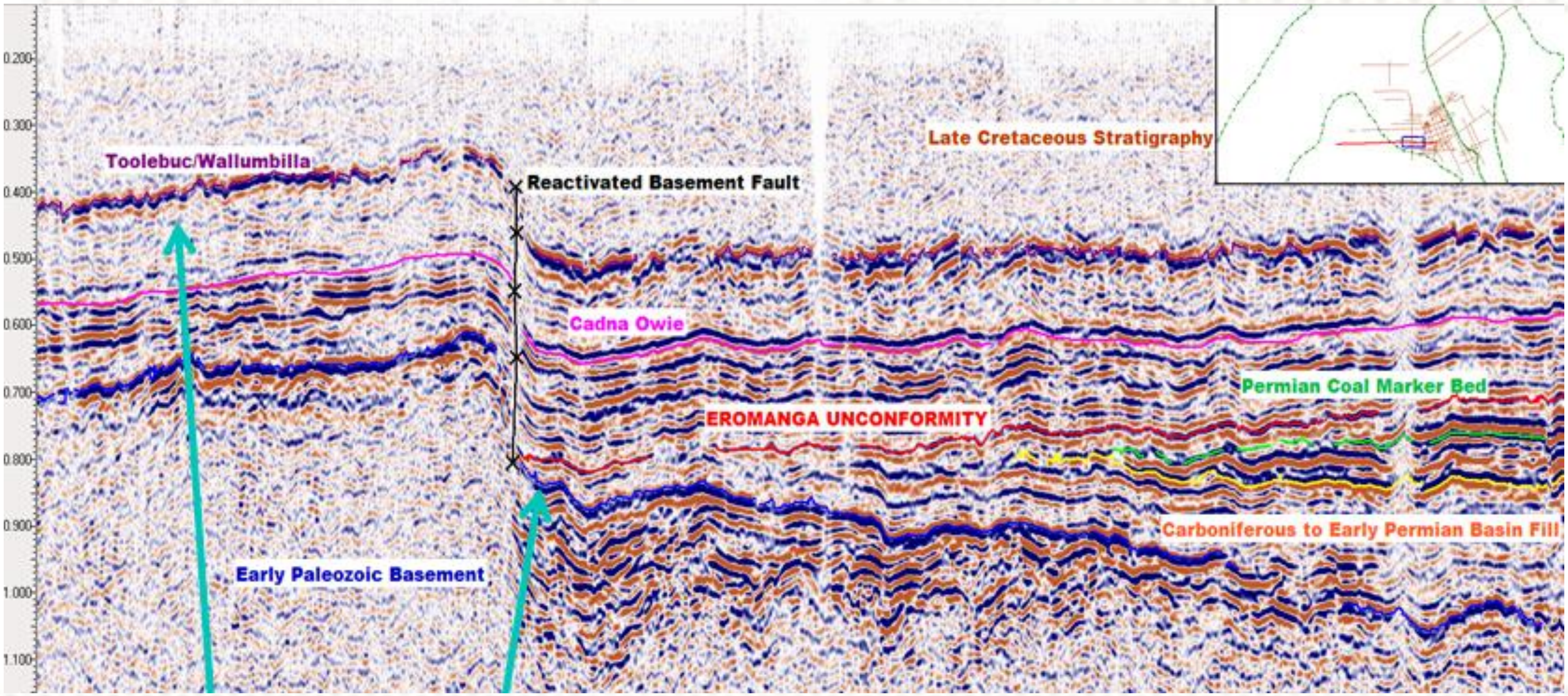
Isotopic evidence demonstrates that the gas within the coals is predominately biogenic in nature

Thermogenic gas sourced from the burial of coals was lost and biogenic methanogens, carried in Great Artesian Basin waters, have generated their own gas



Presenter's notes: The gas that remains today is predominantly BIOGENIC; the Thermogenic gas sourced from the burial of coals was lost, and biogenic methanogens, carried in Great Artesian waters, have generated their own gas.

Thermogenic Gas lost during Cretaceous Uplift

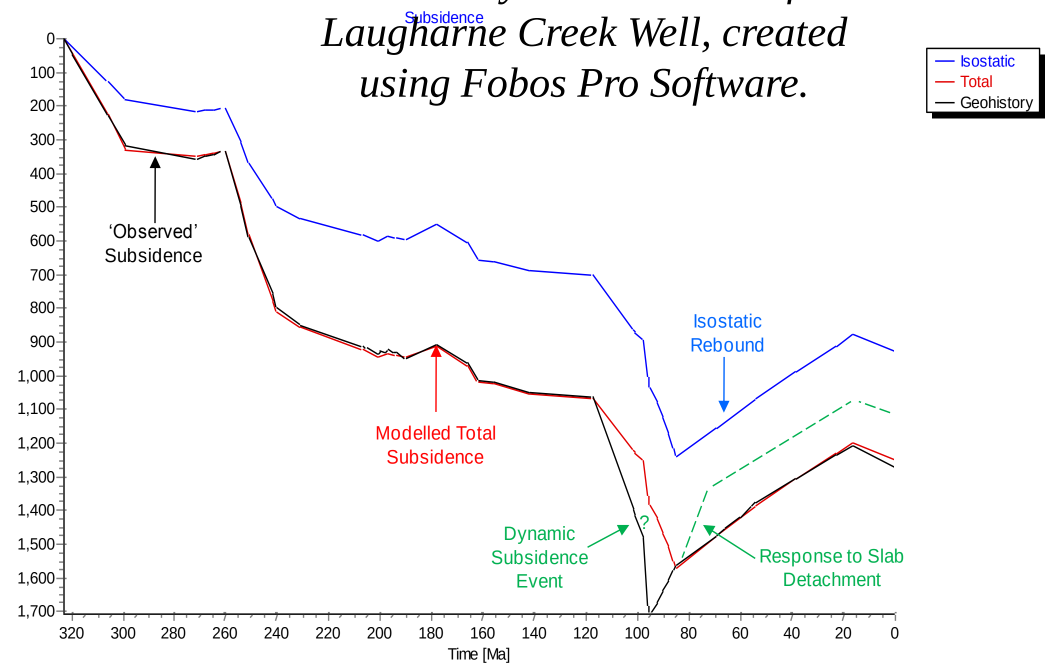


Presenter's notes: Further evidence, from seismic interpretation, includes reactivated basement faults that post-date the Early Cretaceous Toolebuc Formation, which is also heavily faulted and deformed, interpreted to be the consequence of this event.

Geodynamic Implications

- Geohistory models & exhumation analyses provide clear evidence for a slab break-off event, post-dating cessation of subduction along eastern Gondwanaland
- Rapid subsidence (50 m/Myr cf 5 m/Myr) followed by rebound at ~95Ma resulted in an uplift and erosion phase

Geohistory reconstruction for Laugharne Creek Well, created using Fobos Pro Software.



Presenter's notes: In all four models, there is a period of mismatch between the reconstructed 'observed' geohistory and the forward-modelled total subsidence. This period between approximately 120 and 90 Ma must therefore invoke an alternate explanation for observed mid-Cretaceous subsidence.

A dynamic topography model, invoked by Deighton et al. (2003) to explain Cooper-Eromanga tectonic subsidence is considered to be the most likely hypothesis to account for this feature. According to a (Presenter's notes continued on next slide)

(Presenter's notes continued from previous slide)

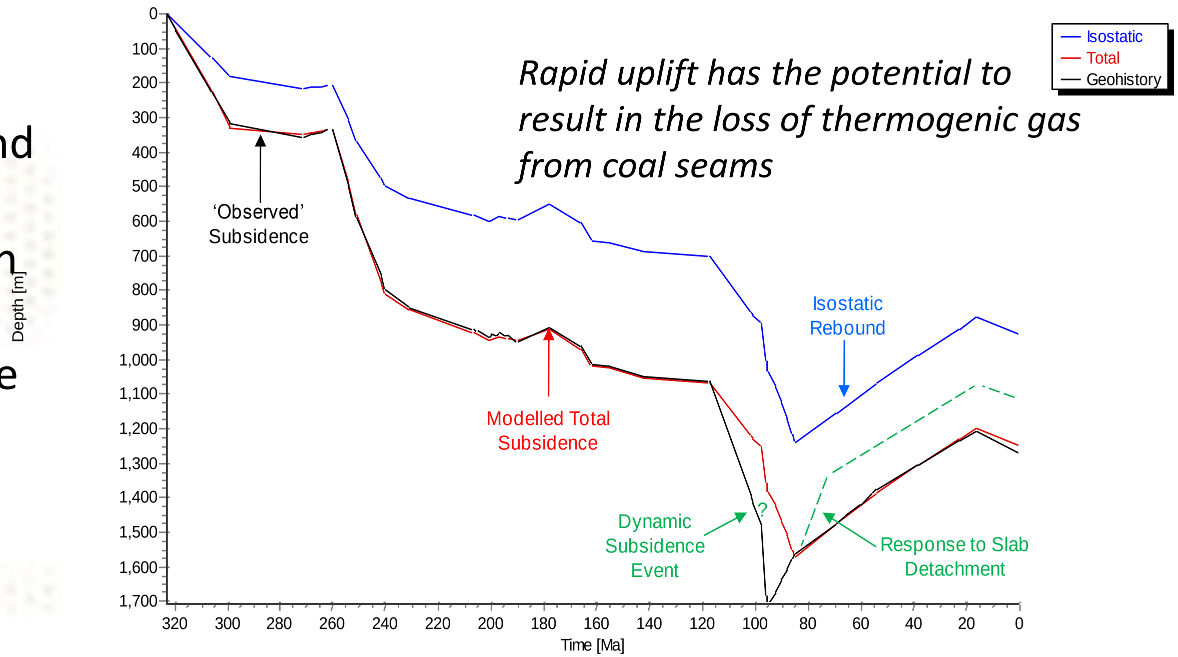
dynamic topography model, at the cessation of the subduction of the Pacific plate under the Australian plate on the eastern Australian margin, the continental platform migrated over a down-going, detached, cold slab, resulting in thermal contraction and subsidence, and inevitably isostatic rebound. At about 95 Ma, subsidence ceased in the Surat and Eromanga basins and the basins became inverted; the cessation of subduction effectively removed the long-wavelength subsidence associated with regional downward tilting to the east.

Geodynamic Implications

- Subduction dynamics and upper mantle processes had a profound effect on basin evolution and the resource potential of the Galilee Basin

When subduction ceased at 100 Ma, the driving force for long-wavelength surface draw-down was removed and the Galilee Basin began to rebound, resulting in uplift and erosion.

Rapid uplift has the potential to result in the loss of thermogenic gas from coal seams



Presenter's notes: If this model is correct, burial depths, then modelled, would have been greater than modelled depths. However, uplift would have been more rapid, having the potential to result in the loss of generated thermogenic gas from the coal seams.

Conclusions

EarthBYTE Building a Virtual Earth

BGH Basin Genesis Hub

- **Slow sedimentation rates with a total subsidence of ~ 2 km from the Carboniferous to the Late Cretaceous, punctuated by two major exhumation events.**
- **The Late Cretaceous exhumation event was about 1800-400 m in magnitude**, while Triassic exhumation was comparatively minor (< 600 m).
- The **Permian coal measures generated up to 40 m^3/t of gas** during maximum burial (1.5-2 km) in the Late Cretaceous, where temperatures were > 100°C.
- Isotopic evidence indicates the **remaining gas is biogenically derived**, with some remnant mixed thermogenic gas
- **Geohistory models and exhumation analyses provided clear evidence for a slab break-off event**, post-dating cessation of subduction along eastern Gondwanaland at ~100 Ma. Rapid subsidence before 100 Ma was followed by rebound at 95 Ma, generating fast uplift and erosion.
- **Subduction dynamics had a profound effect on basin evolution** and the resource potential of the Galilee Basin.

Presenter's notes: Relatively little is published on the geology of the Galilee Basin. This study found that:
- Burial history has an overriding influence on variations in coal properties on present-day gas contents.
- Slow sedimentation rates of Galilee Basin resulted in total subsidence of ~ 2 km from the Carboniferous to the Late Cretaceous, punctuated by two major exhumation events.
- The Late Cretaceous exhumation event was of the magnitude of 1000 m, with an east-west orientation (1800-400 m), while interpolated Triassic exhumation was comparatively minor, generally <600 m. (Presenter's notes continued on next slide)

(Presenter’s notes continued from previous slide)

- The Permian coal measures generated up to 40 m3/t of gas when maximum burial (1.5-2 km) was achieved in the Late Cretaceous where and when temperatures were >100^{o}C.
Isotopic evidence indicates the remaining gas is biogenically derived, with some remnant mixed thermogenic signatures. This thermogenic gas was likely lost as a consequence of the Late Cretaceous exhumation, which, coupled with the effects of pressure and temperature on the methane sorption capacity of the coals, accounts for the undersaturation of the coals at present-day.
- Further, geohistory models and exhumation analyses provide clear evidence for a slab break-off event, post-dating cessation of subduction along eastern Gondwanaland. Rapid subsidence (50 m/Myr cf 5 m/Myr), followed by rebound at 95Ma, resulted in an uplift and erosion phase. This indicates that subduction dynamics and upper mantle processes had a profound effect on basin evolution and the resource potential of the Galilee Basin.
- Low-gas saturations and distance from market, despite high permeabilities and thick coals, pose a the challenge to developing CSG resources in the Galilee Basin.