Laboratory experiments at reservoir pressure and temperature of the biogenic methane potential of coal seam reservoirs

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12 February 2015

CSIRO ENERGY
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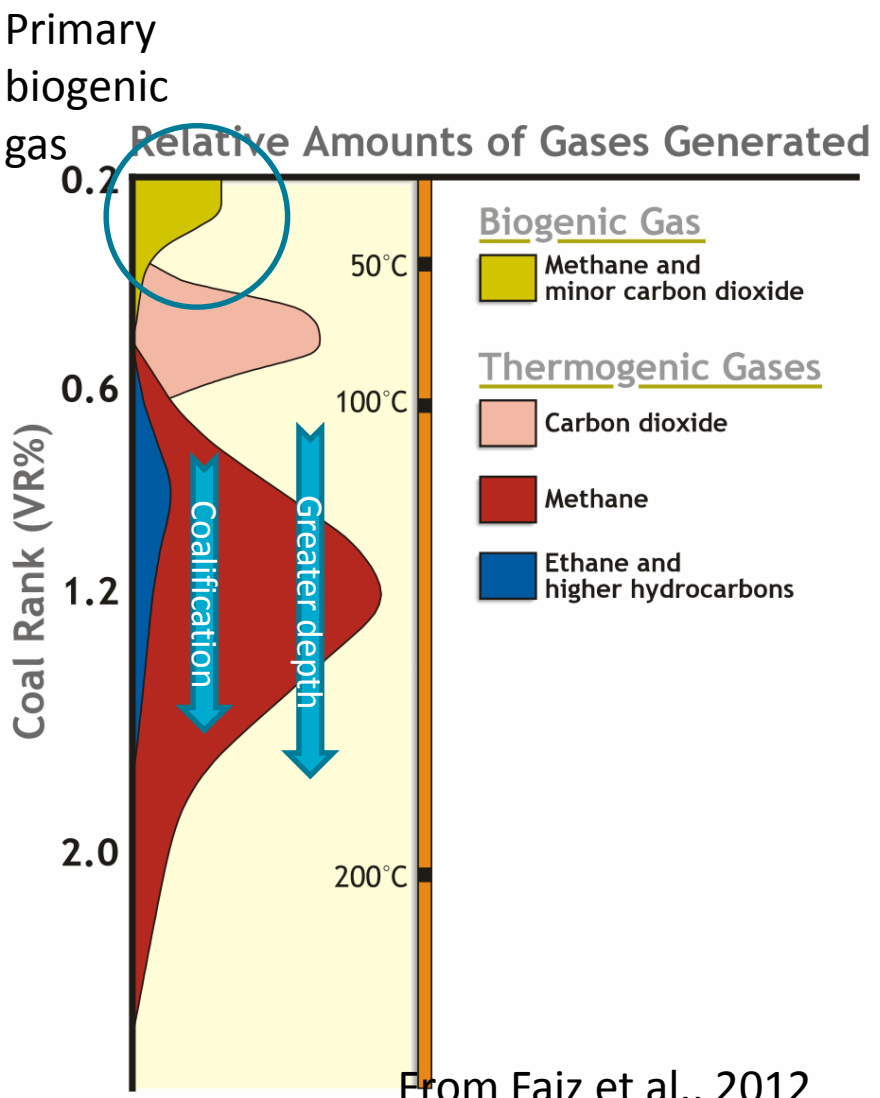
Objectives and Acknowledgments

- Microbially Enhanced Coal Seam Methane (MECSM) project research undertaken jointly with industry.
- Supported and sponsored by Santos Ltd, APLNG, AGL Energy and QGC
- Objective to improve recovery from CSG fields by enhancing the biogenic process
- The Sponsors and CSIRO have agreed to collaborate recognizing the mutual benefit of combining their expertise and resources to conduct the research in pursuit of the Objective
- Phase 1 successfully investigated the potential for microbial enhancement of coal seam gas production from key Australian basins
- Phase 2 is underway. Methane has been successfully generated from core flooding. Current work is focused on upscaling and modelling for potential field trial phase
- This presentation is on the core flooding which formed a component of the program of work under MECSM phase 2

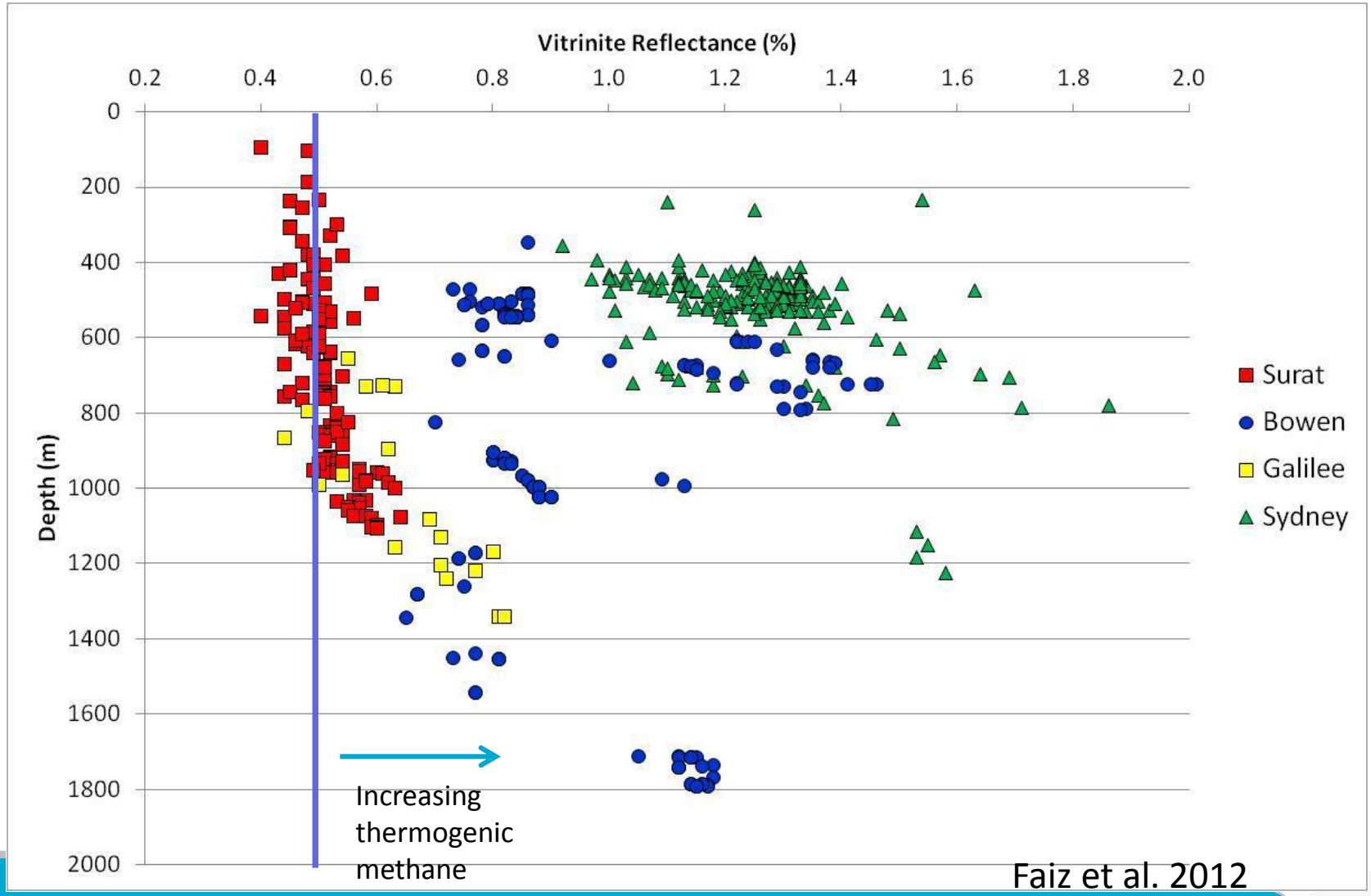
Origins of gas in coal

- Coal seam gas usually the result of degradation of coal
- Two main routes
  - Thermogenic – produced during coalification due to heat and pressure over time
  - Biogenic – derived through microbial processes
- Biogenic
  - Primary – at an early stage of coalification
  - Secondary – after coalification with the uplift of coal



From Faiz et al., 2012

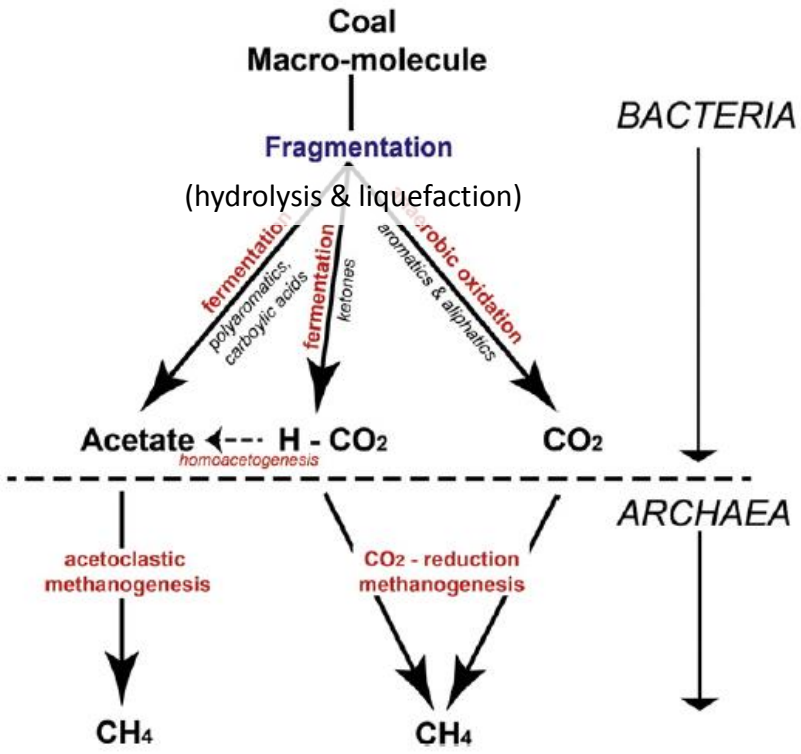
Coal rank for Australian basins



Faiz et al. 2012

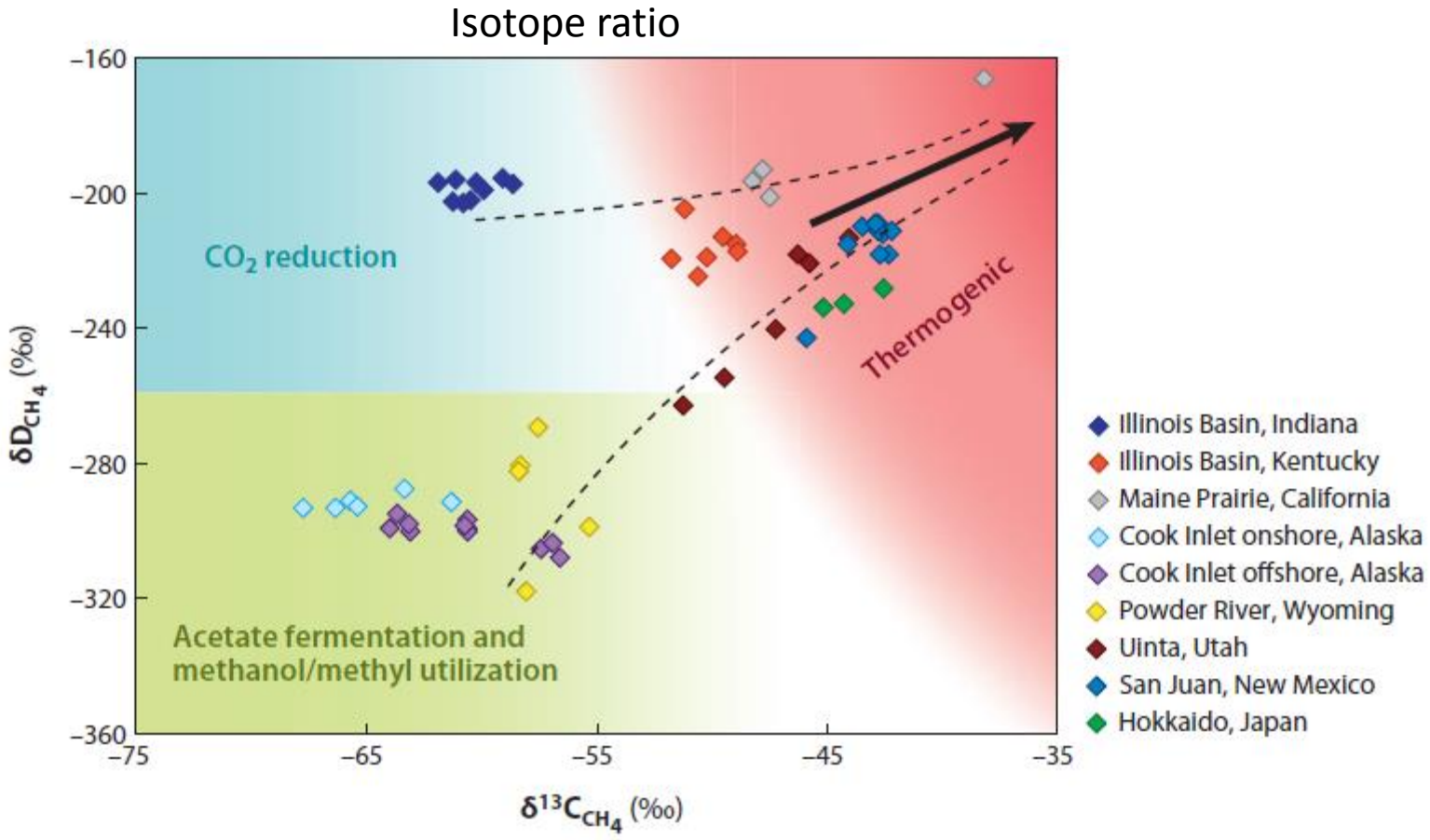
Biogenic methanogenesis

- Anaerobic degradation of the coal to methane occurs through a microbial consortia following a chain of inter-mediate organic compounds and microbes
- Similar process to bio-degradation of other organic materials
- The last step is performed by the archaea



From Moore, 2012

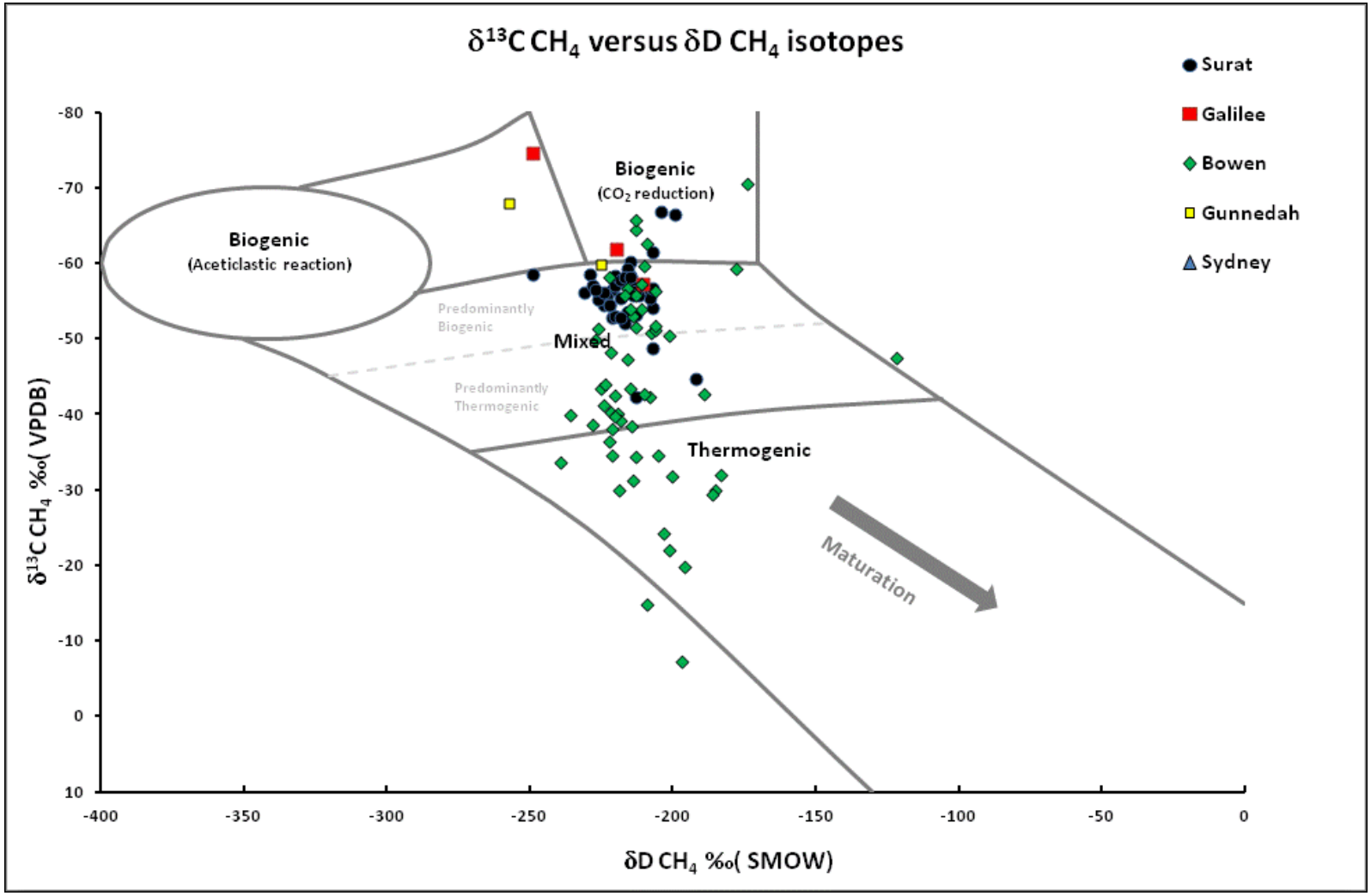
Origins of coal seam methane: US data



Deuterium-hydrogen and carbon 13 isotope ratios

From Strąpoć et al, 2011

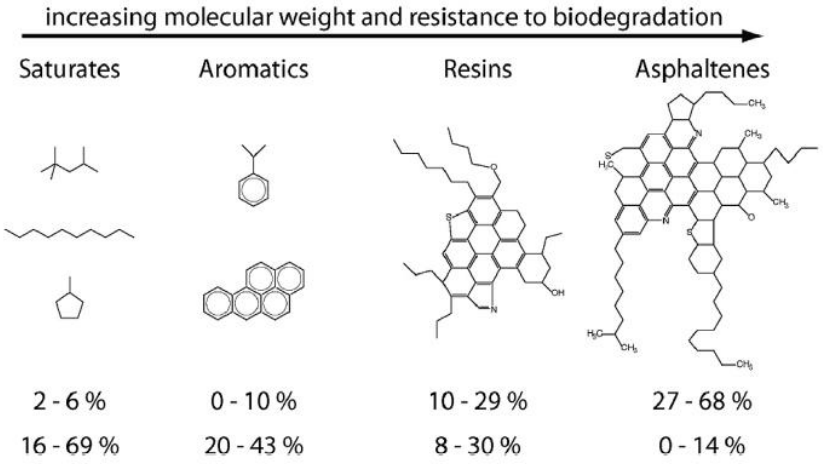
Origins of coal seam methane: Australian data



Faiz et al. 2012

Biogenic methanogenesis from coal

- Not all of the coal is bio-available

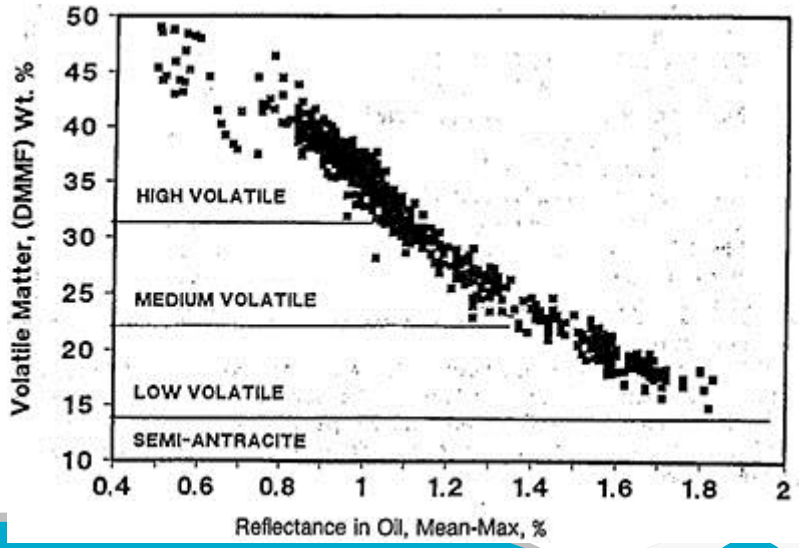


	Saturates	Aromatics	Resins	Asphaltenes
Coal	2 - 6 %	0 - 10 %	10 - 29 %	27 - 68 %
Oil	16 - 69 %	20 - 43 %	8 - 30 %	0 - 14 %

From Mesle et al, 2013

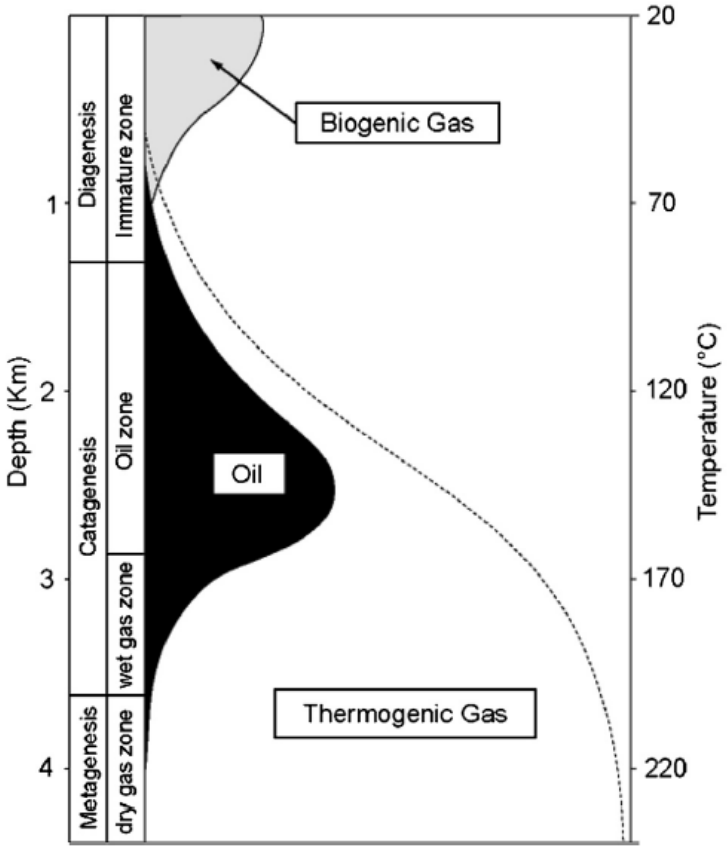
These compounds will make up the volatile fraction of coal

- A proportion of the volatile fraction may be degraded
- But this can represent a significant fraction of the coal depending on rank
  - Access of microbes to the coal micro-porosity will be an important factor as well



Biogenic methanogenesis and temperature

- Limited by temperature – meso to thermo-philic range is 20 °-70°C with microbial activity decreasing above this – upper limit 110°C
- Cover the depths of interest for coal seam gas production



From Mesle et al, 2013

Nutrients and Biogenic methane

- Coal seams contain the organic matter to sustain microbial communities
- Nutrients are also required (nitrogen, phosphorus and potassium)
- Nutrients from surface in groundwater recharge are depleted with flow in the sub-surface

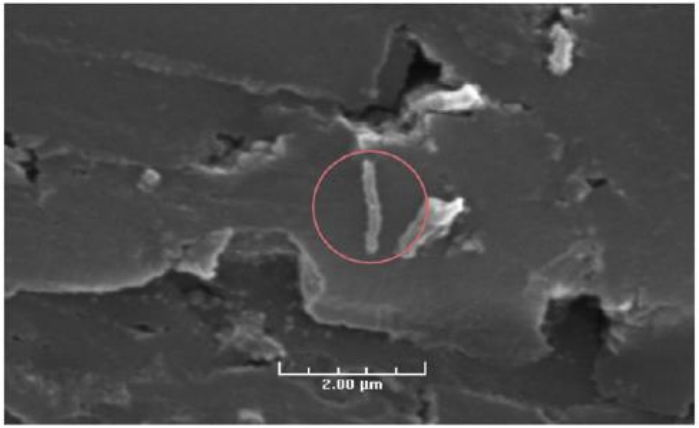
- Shallow coal seams
  - may receive sufficient nutrients via groundwater flow

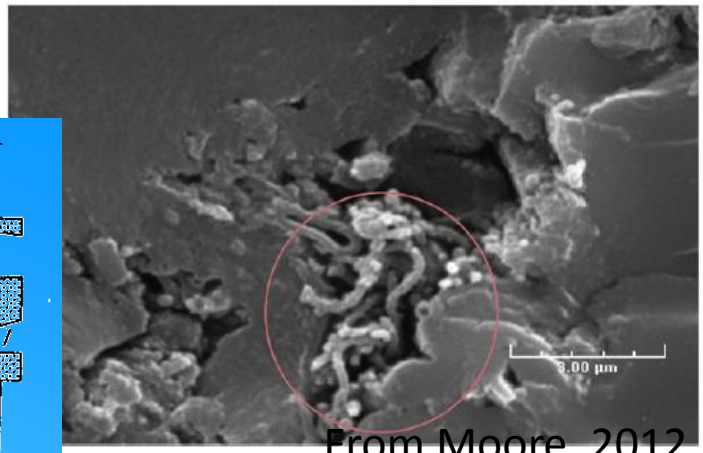
- For deeper coal seams
  - groundwater will be very low in nutrients
  - Under insitu conditions the nutrients required for microbial growth derived from the coal during degradation
  - Natural rates of biogenic methanogenesis within deeper coals very low – nutrient limited?

- Adding nutrients to coal seam reservoir formation waters could stimulate in-situ methanogenesis - biostimulation

Coal physical structure

- Fractured rock with dual porosity structure
  - Cleats - the macro-porosity and coal matrix - the micro-porosity
- Bulk flow occurs in fracture system
- Dissolved nutrients could diffuse into micro-porosity but size of bacteria could restrict them to cleat surfaces

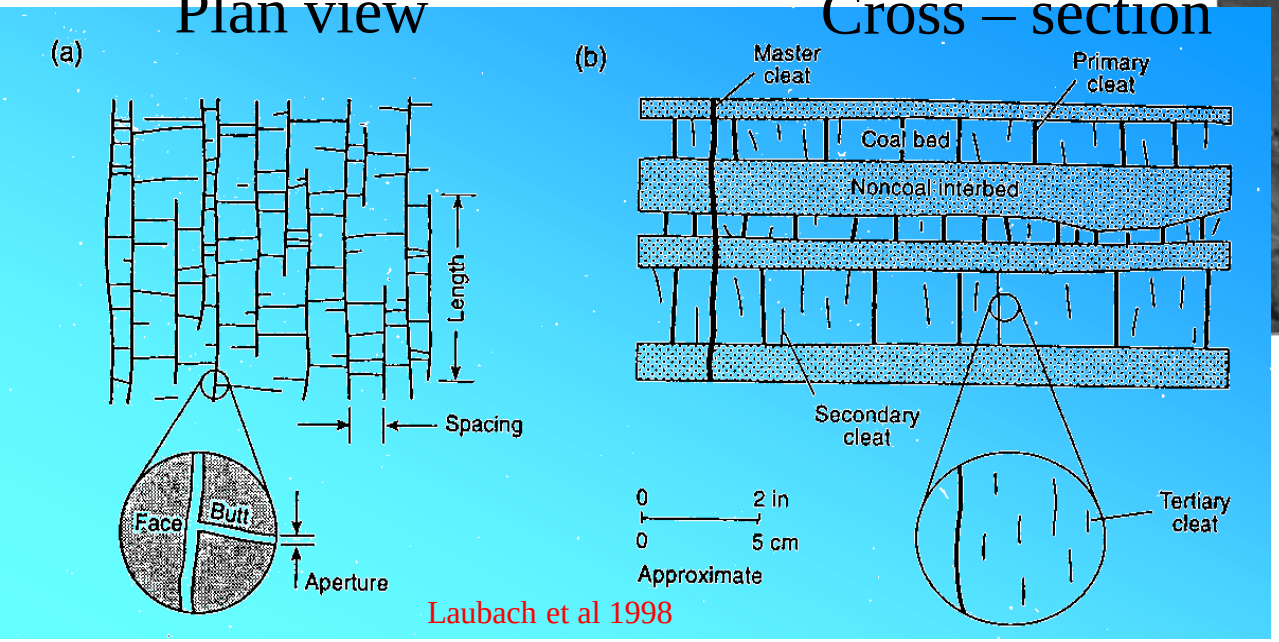




From Moore, 2012

Plan view

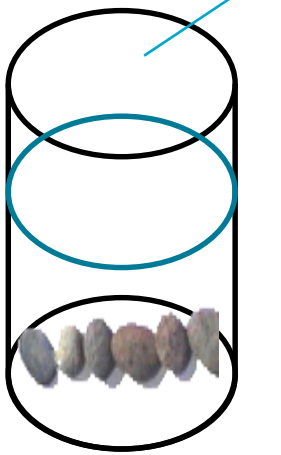
Cross – section



Laubach et al 1998

Biostimulation of coal methanogenesis

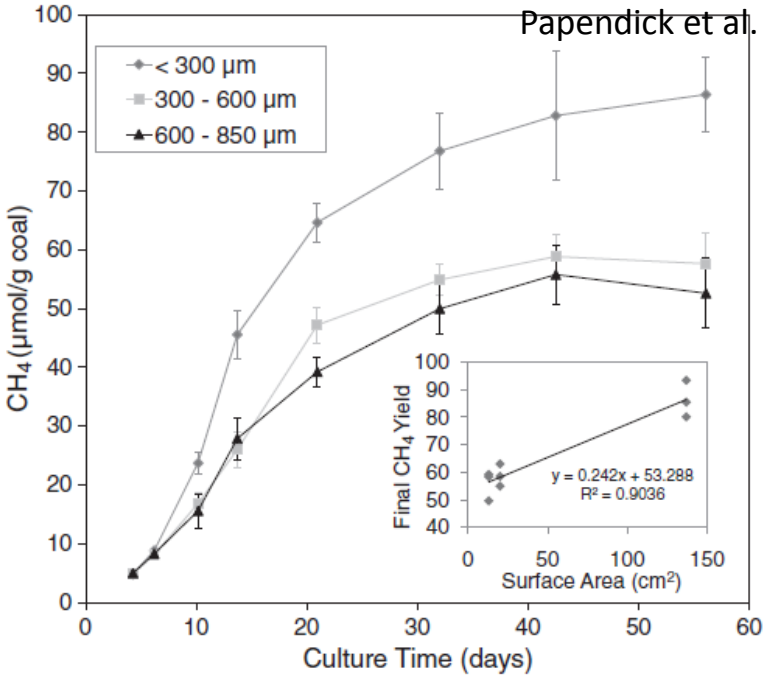
- A number of studies have demonstrated stimulation of biogenic methanogenesis from coal through nutrient amendment of formation waters

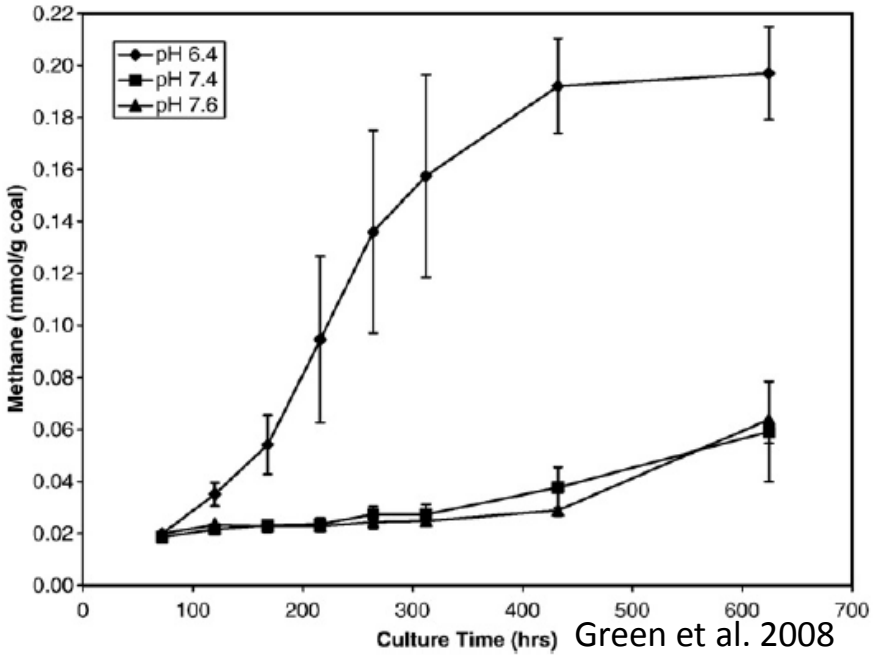


Anaerobic bioreactor @ atmospheric pressure

Previous studies: Example results

Papendick et al. 2011





Green et al. 2008

- Gas generation varied significantly; a function of
  - coal, the endemic microbial community and various experimental conditions including particle size, pH, nutrient concentrations, temperature etc
- Plateau in gas generation commonly observed
  - could be due to depletion of readily degradable coal, accumulation of toxic organics, depletion of nutrients

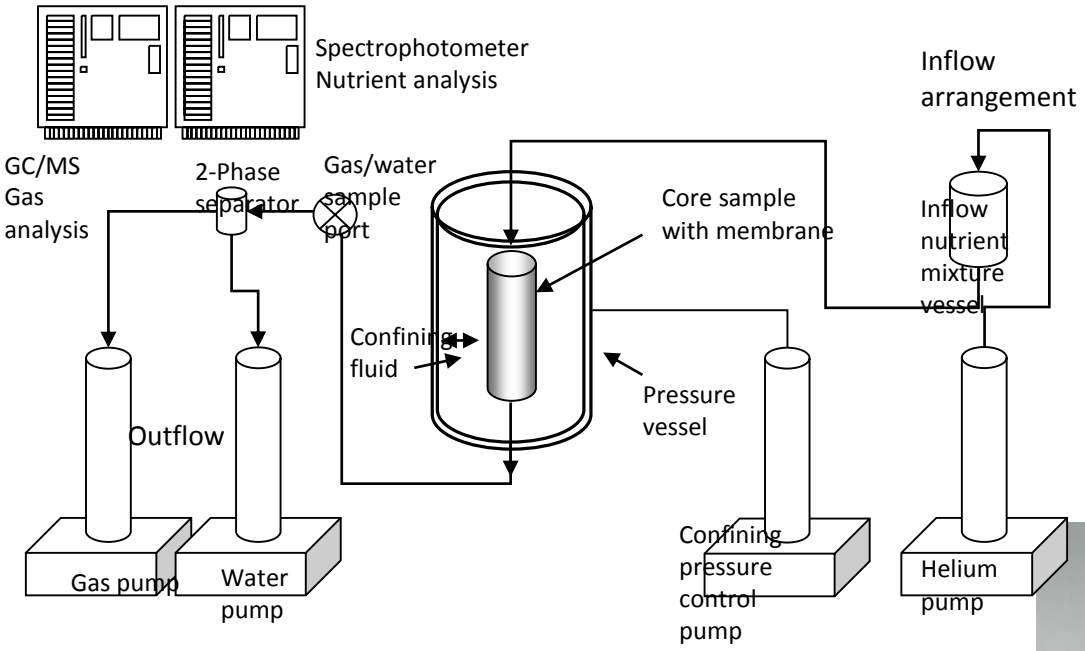
Laboratory studies under reservoir conditions

- Previous work has used crushed coal at atmospheric pressure and reservoir temperature
- Good gas generation rates observed
- How does this translate to reservoir pressure and intact coal?

- Core flooding experiments using intact coal replicate many of the key reservoir conditions

- This study conducted core flooding experiments
  - under anaerobic conditions
  - using nutrient amended formation waters
  - with coal core
  - at reservoir pressure and temperature

Core flooding rig



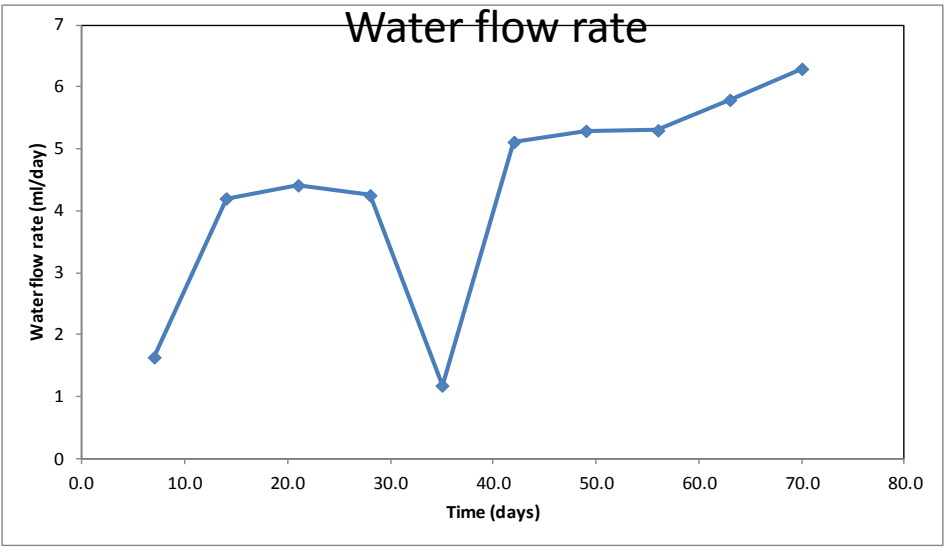
- High pressure syringe pumps provide precise pressure and volume control and measurement

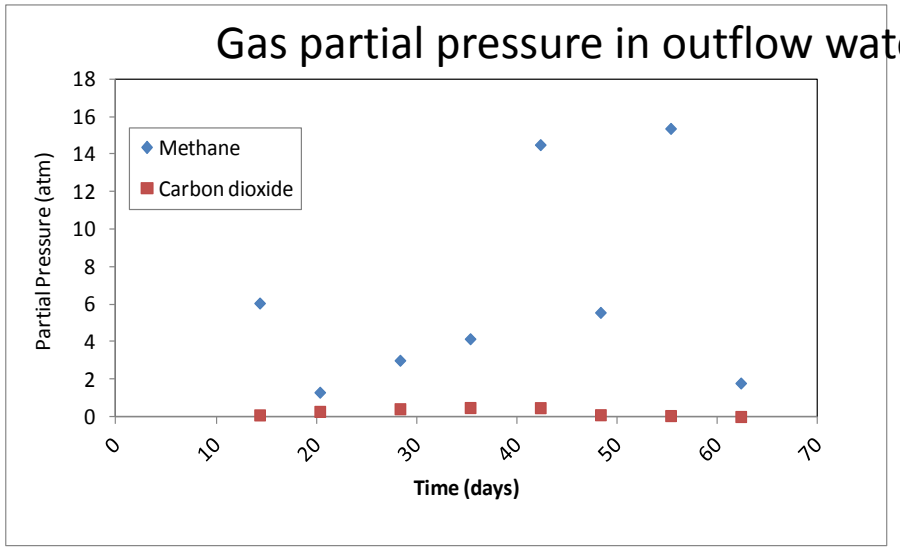
- Two phase separator on outflow to monitor gas or water flow

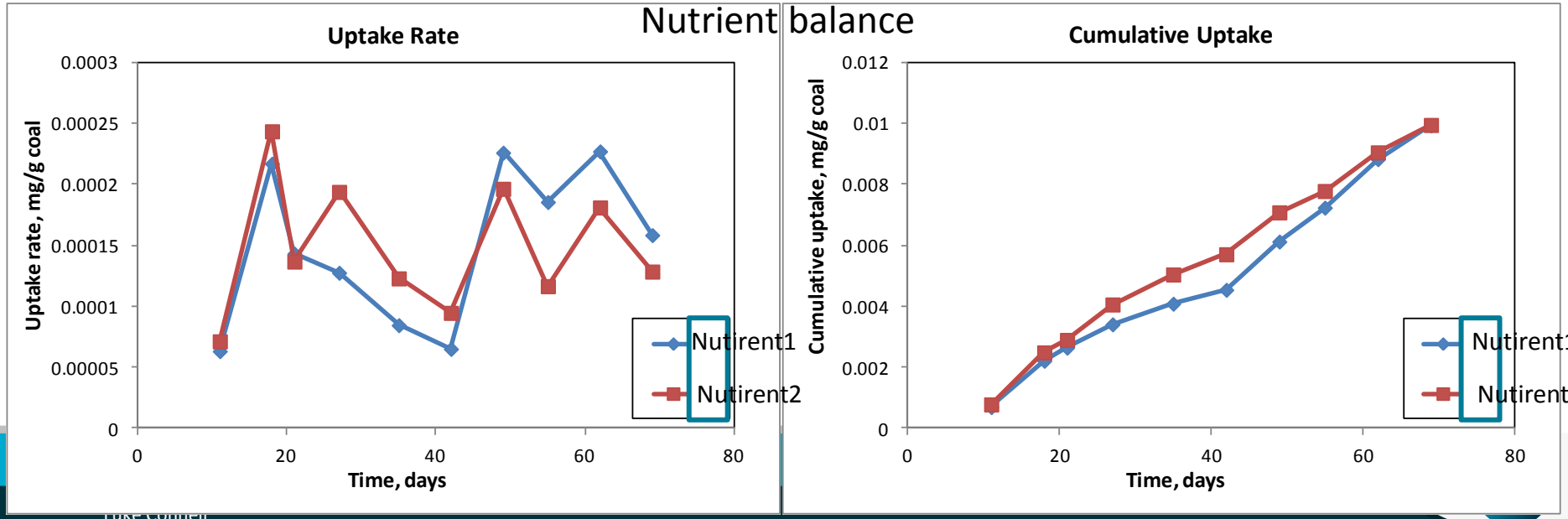
Methodology

1. Degassing of coal core before flood & determination of any residual gas pressure
2. Core flood with nutrient augmented formation water
   - Periodic water sampling and analysis of
     - Nutrient concentration inflow and outflow
     - Dissolved gas partial pressure
   - Pore pressure - 5 MPa
   - Generated gas is adsorbed no gas outflow during experiment
3. Degassing of core sample
   - Decrease pore pressure
   - Helium flood - composition analysed
   - Vacuuming stage for <1 atm pressures

Example experimental observations: core flood#1

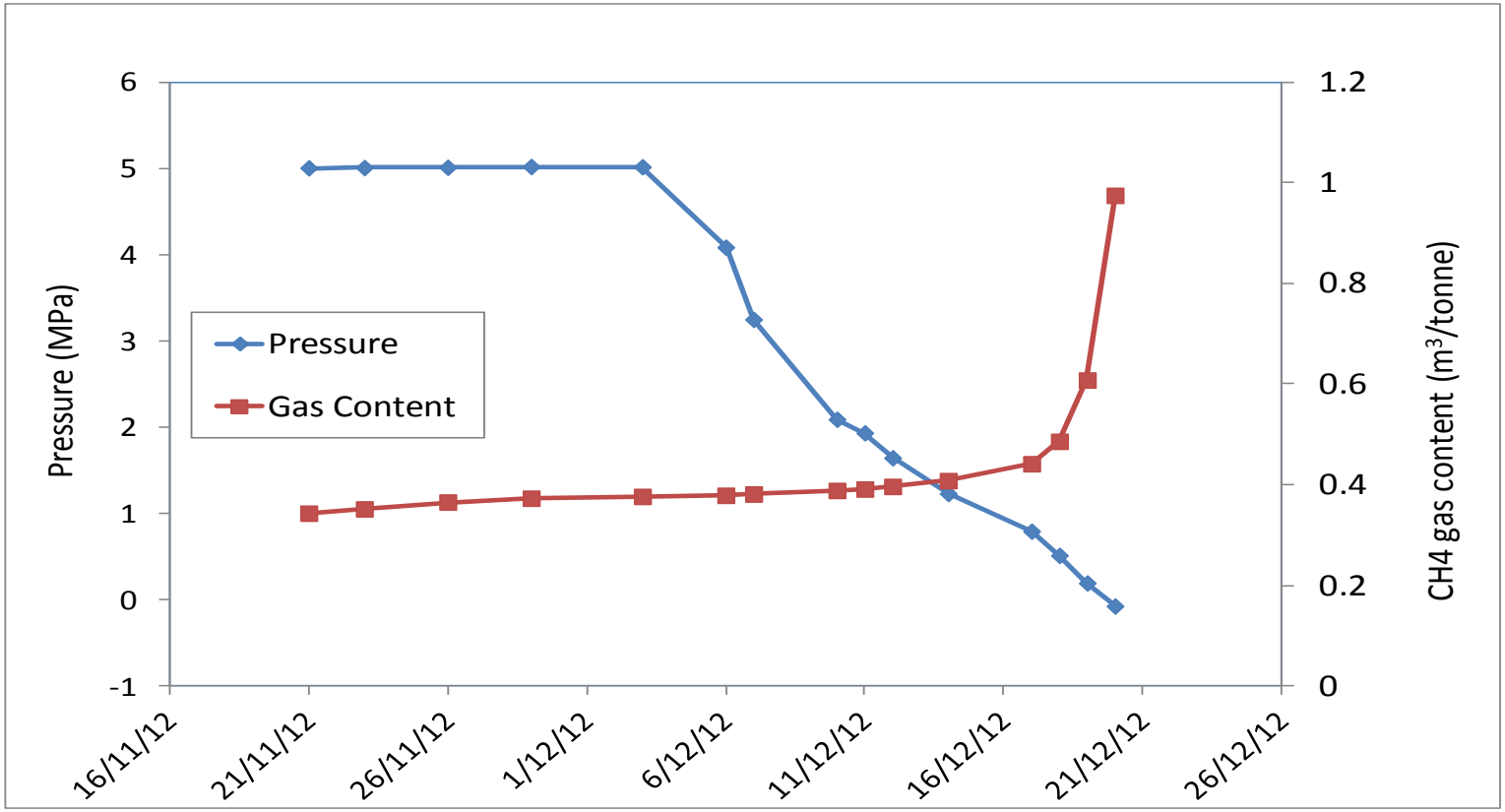




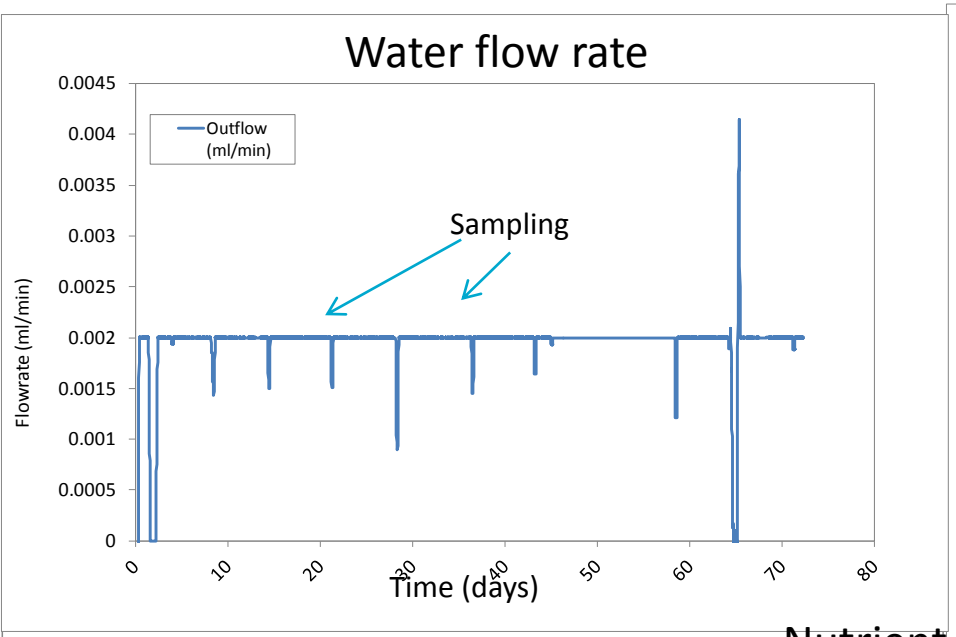


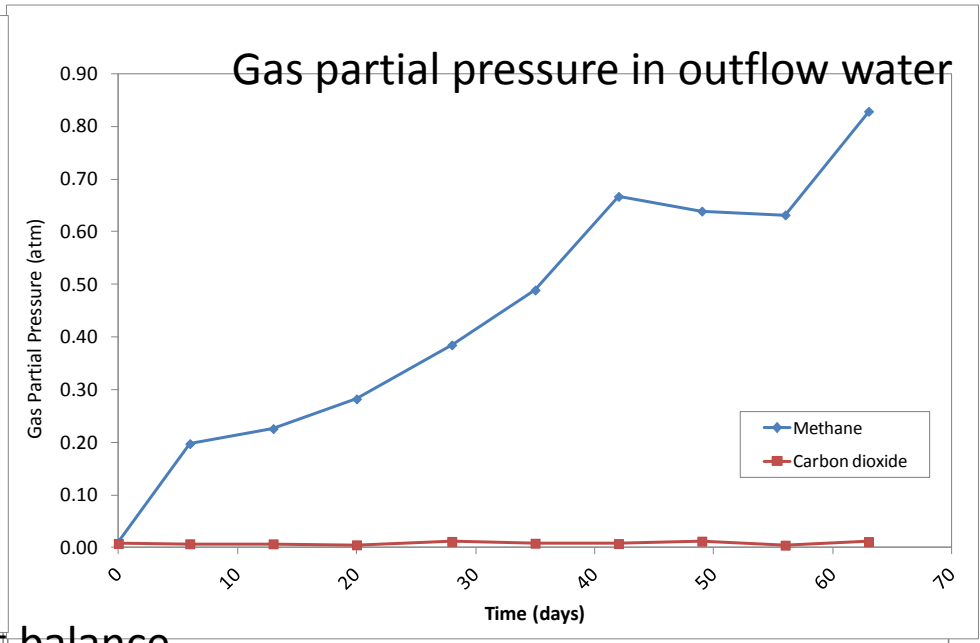
Gas generation: core flood #1

- Gas recovered from core at end of core flood

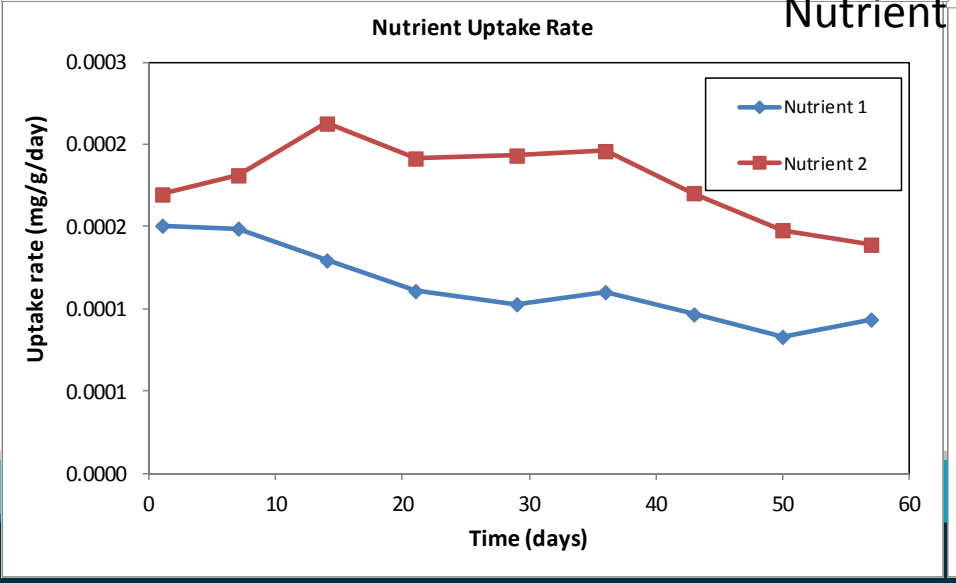


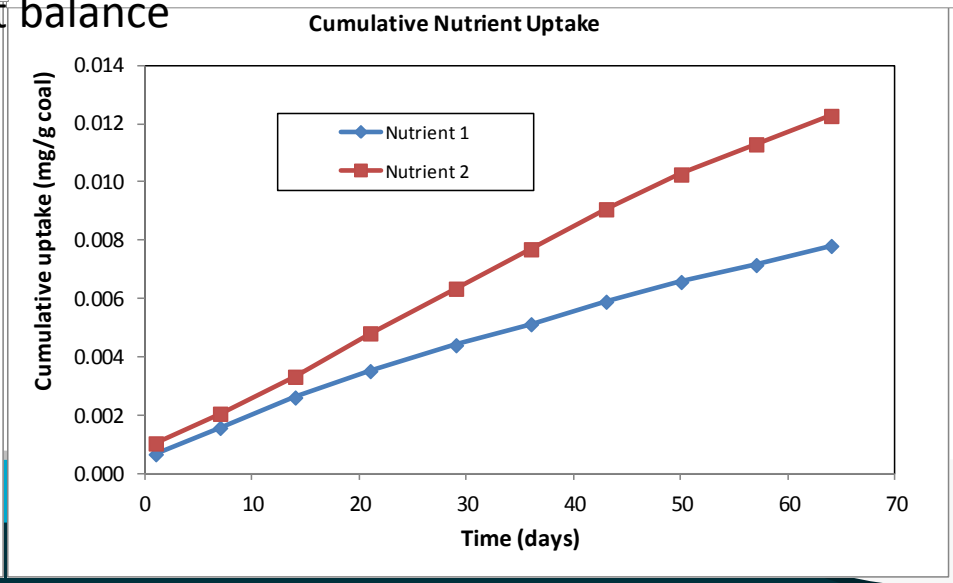
Example core flood#2



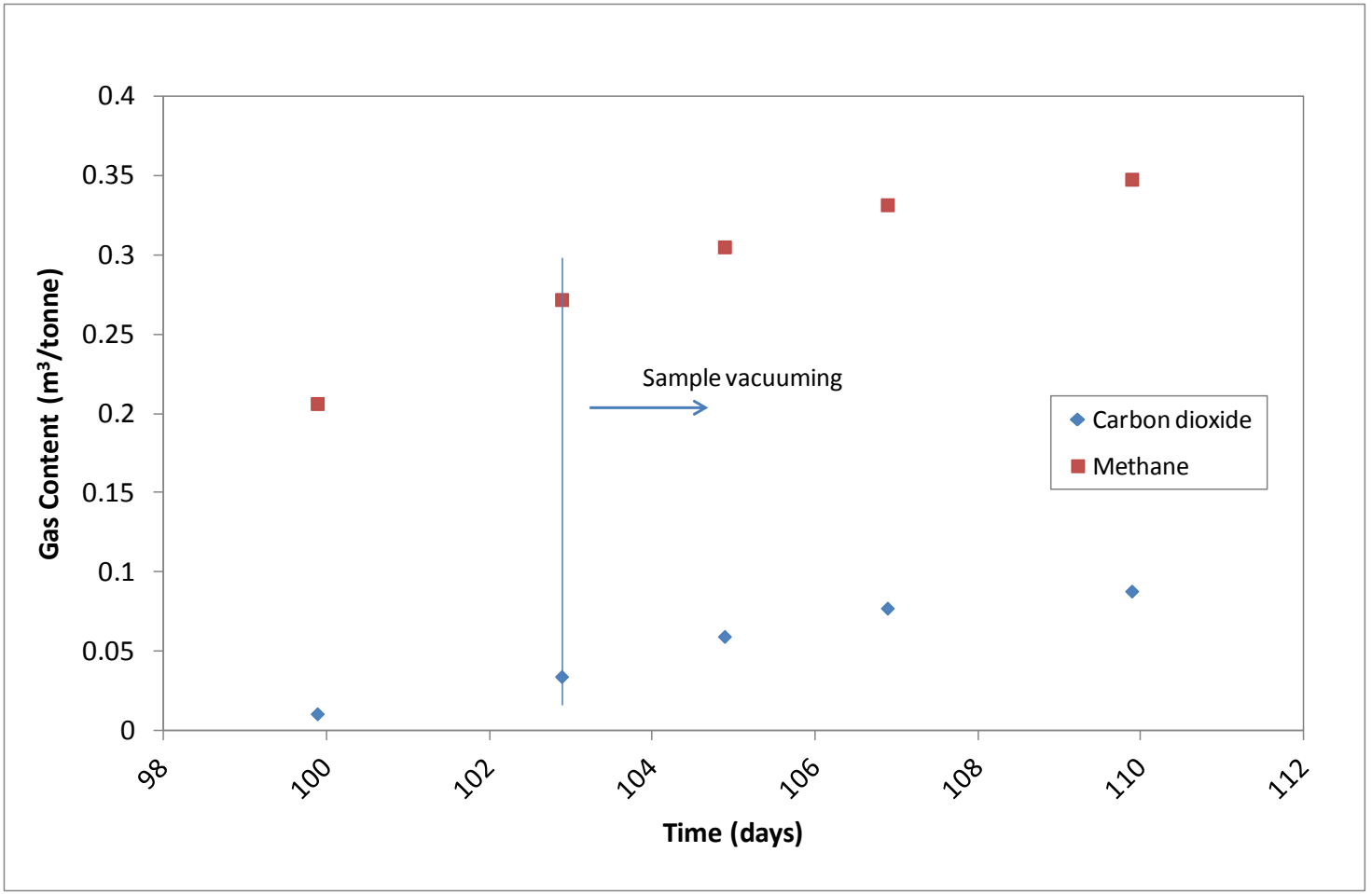


Nutrient balance





Gas generation: core flood #2



Conclusions

- Enhancement of biogenic methanogenesis successfully demonstrated at reservoir pressure and temperature on intact coal core
- Up to 1 m^3/tonne generated over ten week period
- Further work being conducted to refine nutrient management and optimise gas generation