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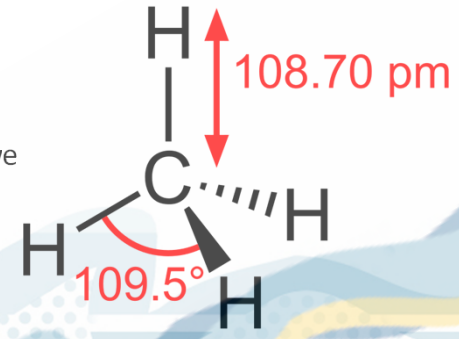
CSG and Geophysics

A Rare Conundrum

"What we do now, and what we will do in the future"



Prepared by: Scott Thomson

26th February 2012

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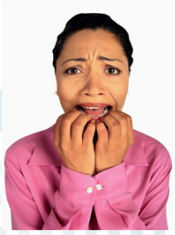
Objectives …

- Provide an introduction to the CSG industry for those geophysicists interested, but not necessarily working in the sphere …
- Provide an open forum to discuss experiences of geophysics with CSG.
- Provide some basic science on 'gas in coal' relevant to all geoscientists (even those familiar with CSG).
- Examine the 'state of the art' for geophysics in CSG.
- Identify the pros and cons and the opportunities.
- Delve into futuristic scenarios.



Who are we?

- CoalBed formed in 1998
- Consultants to mining companies and CSG industry
  - Geologists, project managers, land access
- Emphasis on coal seam gas, from CSG development and appraisal, mine safety & GHG perspective
- Have been in the Australian CSG scene from the beginning …
- Due diligence, IER's, training!
- International alliances with partner consulting organisations
- To learn more, see
  - **www.coalbed.com.au**

Contributors to course

Scott Thomson

- Geologist with over 30 years experience
- B. Sc., M.Sc. and M.B.A.
- Out of the mining industry and into the CSG one
- Still actively involved in both sectors

- Managing Director of CoalBed Energy Consultants
- Active participant in a number of ACA Research Projects, and has written a number of papers on CSG

Contributors to course

Duncan Thomson

- Project manager and geologist with 10 years field experience
- B. Sc. and M. Mining Eng. Mining & CSG experience
- Currently project managing exploration projects for junior CSG players & coal miners
- Drilling and completion emphasis

Contributors to course

Kate Thomson

- Land Access Consultant
- B. Development Studies.
  Currently undertaking M. Business & Technology
- Three years experience in project development, stakeholder management, and legislation and policy advice
- Currently working with stakeholders, including landowners, directly impacted by CSG development in the Surat Basin

Contributors to course

Steve Hennings

- Long term colleague based in North America
- Worked extensively in Australia with ST, and overseas
- Reservoir engineer with extensive conventional and CSM experience
- Specialist in reservoir characterisation, development planning, and field evaluations for gas, coal and oil development projects
- Co-author with ST of "Stefanko Award" winning paper 'A Petroleum Approach to Coal Mine Gas Drainage'
- Principal of Source Rock Engineering LLC based out of Denver, CO

Introduction

- What is CSG?
- Background to the industry.
- Some perspective …

Some key points we all need to understand about CSG …

- There are 4 essentials to make a CSG project work. They are:
  - Net coal, saturation, perm, and gas content.
  - How does this impact upon the commerciality of CSG engineering decisions?
  - What are the techniques we use to extract CSG?
- What role for geophysics in characterising any of the above???
- *…Anything you specifically would like to discuss???*

Now let's start at the beginning …

" A rose by any other name …"

- **Coal Bed Methane (CBM)**
- **Coal Seam Methane (CSM)**
- **Coal Seam Gas (CSG)**

- Coal Bed Natural Gas (CBNG)
- Coal Mine Methane (CMM)
- Abandoned Mine Methane (AMM)

All nuances to describe the same thing …

Glossary

- **Coal:** A combustible sedimentary rock, commonly found throughout the world.
- **Coal Seam Gas:** Mainly methane, found in the micropores of coal.
- **Thermogenic:** Gas formed from the actions of heat and pressure over geological time.
- **Biogenic:** Gas formed from the action of microbes in groundwater, over relatively recent geological time.
- **Rank:** The degree of "cooking" (i.e. heat and pressure) that a particular coal has been subjected to.
- **Permeability:** A measure of the ability of a particular coal to flow gas or water. High permeability is usually good for CSG production.
- **Saturation:** The amount of gas that a particular coal actually holds relative to its theoretical capacity. High saturation is usually good for CSG production.

Glossary (continued)

- **Hydraulic fracturing:** A production and completion (P & C) method that involves the fracturing of coal under high pressure at depth, and the injection of usually water, sand and chemicals into the coal fractures.
- **Barefoot completion:** A simple P & C method involving a vertical well, and a simple reamed cavity in the coal formation. The cheapest and simplest P & C method.
- **MRD SIS:** A directional drilling P & C method that involves long steered lateral boreholes drilled horizontally in coal seams.
- **Footprint:** The amount of surface impact of a particular P & C method.

Some simple terms … and conversions

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- Gas production from single wells usually cited as "X Mcfd", e.g. 300 Mcfd (300 thousand cubic feet per day). 300 Mcfd is ~ 0.3 TJ's, or 300 GJ's. ***A well flowing at 1 TJ per day is a good well.***
- Reserves and resources are usually referred to as X PJ's or occasionally, as X Bcf. ***A field with reserves of 20,000+ PJ's would be considered pretty large. A PJ is ~ equivalent to a BCF*. Huge fields are expressed as X Tcf (1000 Bcf's, e.g. "11 Tcf").***

** 1.055 Bcf = 1 PJ*

Energy units used in natural gas are:

(A Joule is the primary measure of energy in the metric system, and an average household consumes ~55 Gj's per annum in Australia).

- GigaJoule [GJ] = 10^9 J *(1 billion joules) … ~ MCF*
- TeraJoule = 10^{12}J *(1000 Gigajoules) … ~ MMCF*
- PetaJoule [PJ] = 10^{15} J *(1,000,000 Gigajoules) … ~ BCF*

One PJ is the heat energy content of about 43,000 tonnes of black coal or 29 million litres of petrol.

Coal Seam Gas 101

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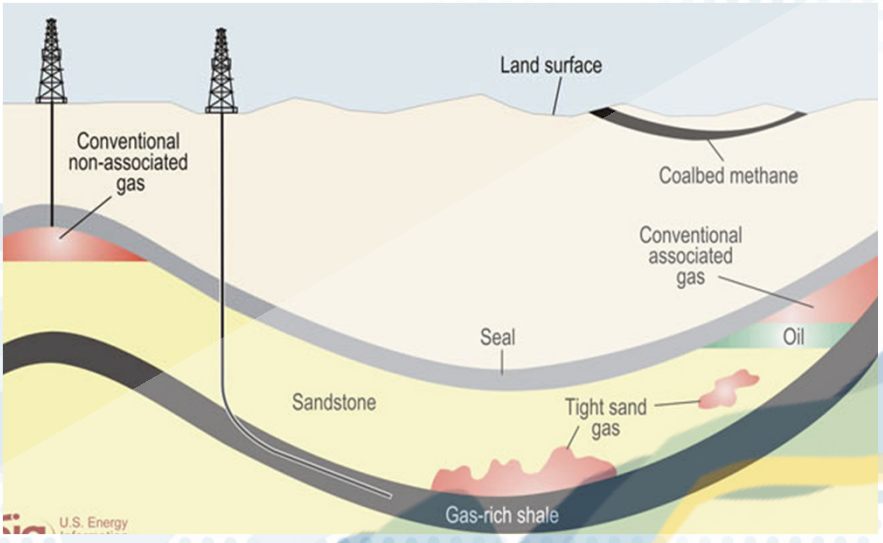
- History and perspective …
- Coal, and why gas is in it *(and what kind of gas) …*
- Reservoir characterisation essentials – the essentials of a Coal Seam Gas play

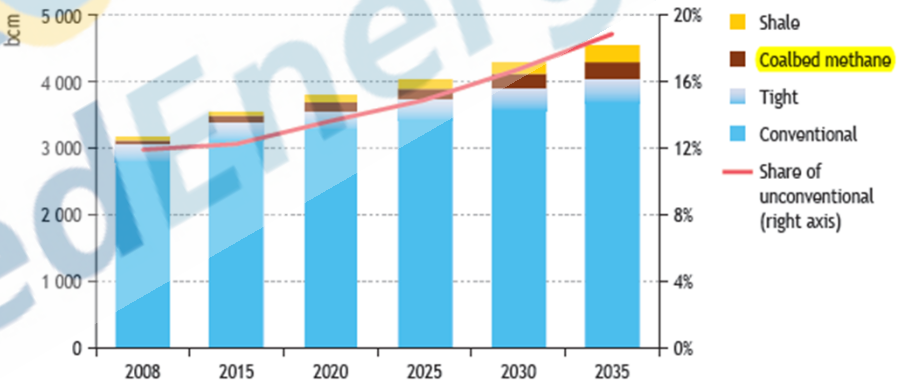
What you need to know about CSG … and were afraid to ask … !!!

CSG gas & conventional gas

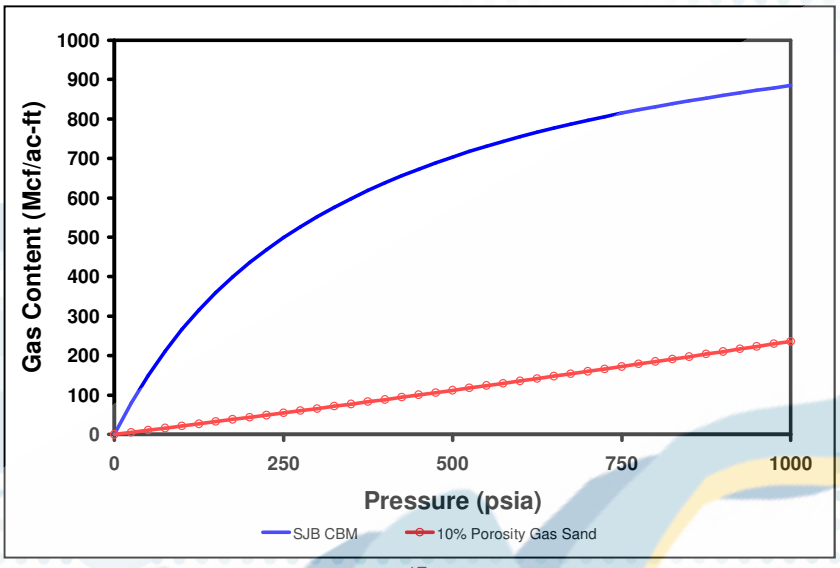


We'll be cooking with gas in the future …

World natural gas production by type



Gas Storage for Coal Gas vs. Conventional Reservoirs



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What do I think are the key gas concepts that you should understand?

- **Basic coal geology**
  - What is coal, and why gas is in it.
- **Gas content and the saturation relationship**
  - The relationship between water and gas in coal, and the surrounding strata.
- **The concept of permeability**
  - Determines how fast gas will flow to the wellbore and *what spacing of drilling will be required to make the project work.*
- **Hydrology**
  - Subsurface water, how it all works, and the issues.
- **Gas Composition**
  - Coal Seam Gas. Is it all methane, and is it toxic?
- **Production and completion methods**
  - What are the options, and what drives the choice of methods?
  - Implications of that choice.

But first … some background, and perspective …

Where is the gas?

Country	Estimated CBM Resource Base (trillion cubic metres)
Canada	17 to 92
Russia	17 to 80
China	30 to 35
Australia	8 to 14
USA	4 to 11
Source: IEA CCC 2005	

In 2006 it was estimated that of global resources totalling 143 trillion cubic metres, only 1 trillion cubic metres was actually recovered from reserves.

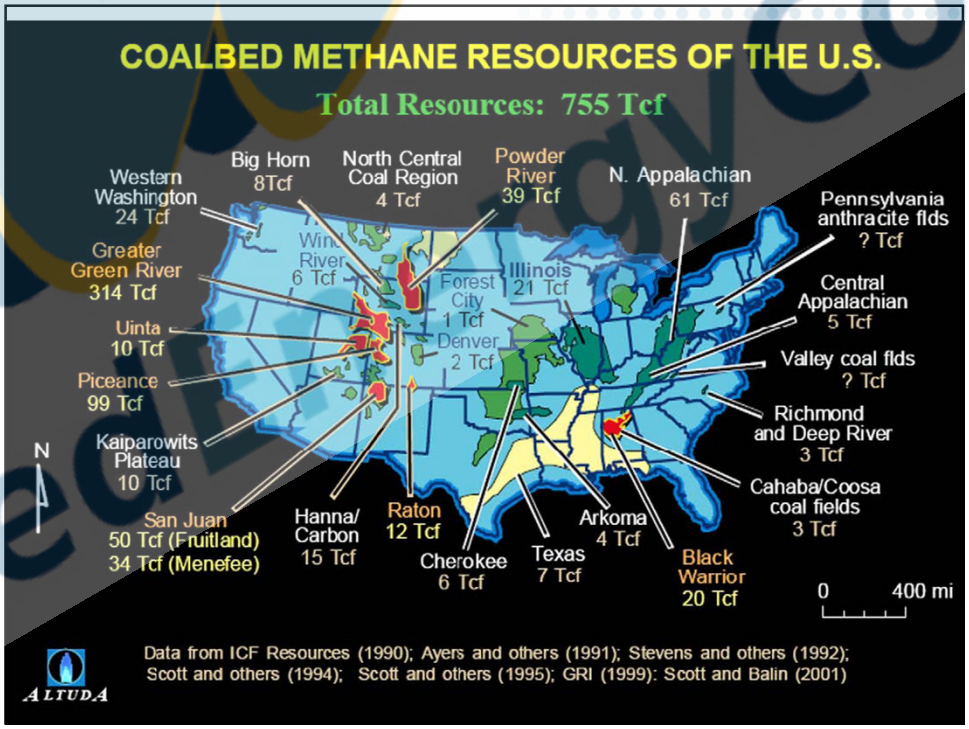
Why?

Some background to the CSG industry …

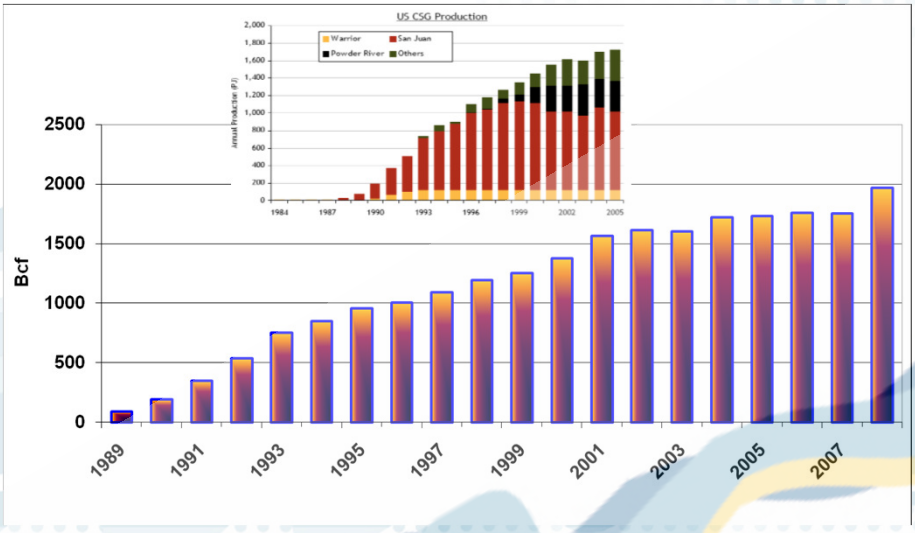
Any idea where this photo was taken?

Where did it all start?

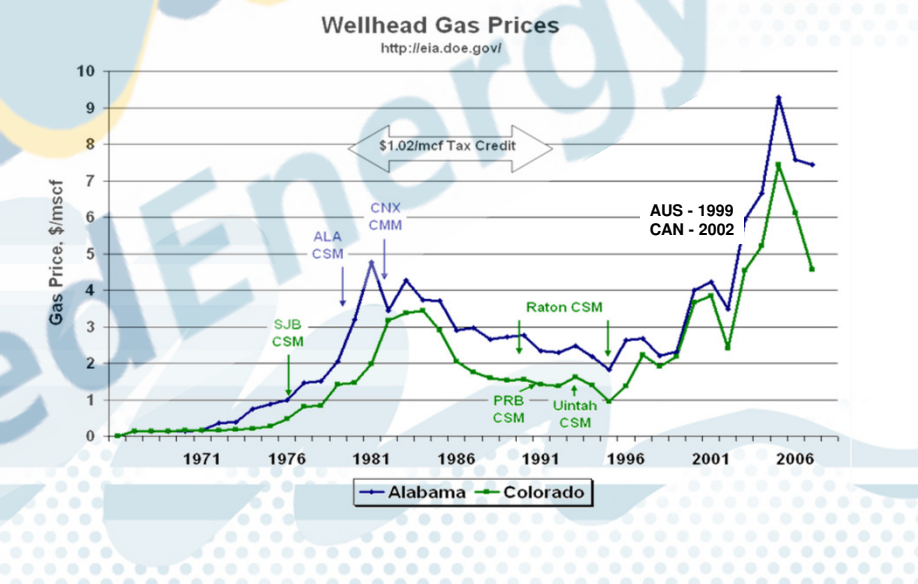
- The USA
- Spurred by tax incentive. "Internal Revenue Code Section 29" provided a tax credit for sale of CBM from wells drilled between 1980 and 1992 inclusive.
- Most of this gas came out of San Juan Basin, with the Powder River Basin and Black Warrior also contributing.
- Currently the US produces 1.73 Tcf per year, approximately 9% of total US gas production.
- By comparison, Australia now produces 215 PJ's (0.21 Tcf), approximately 13% of total Australian gas production, but this is growing.



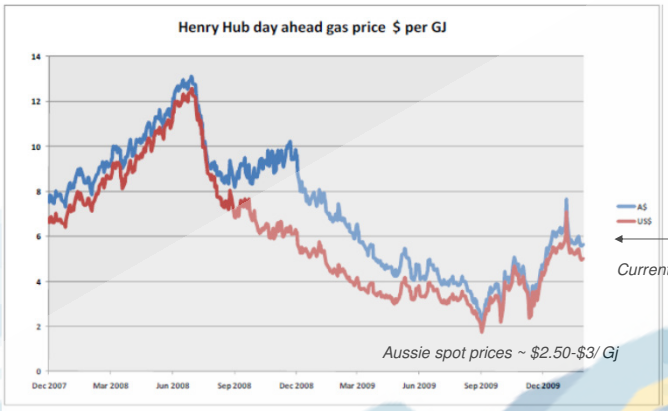
U.S. Annual Coal Gas Production



Variability in Coal Gas Projects
Historical US Gas Prices



Current gas price …



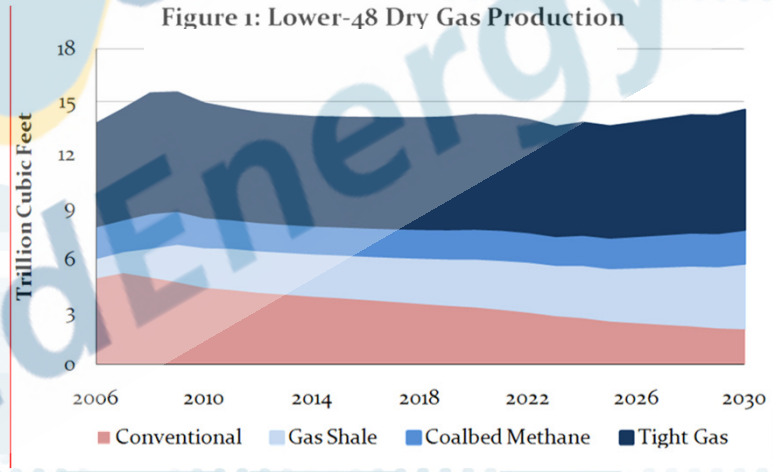
Currently around $6/ Gj

Aussie spot prices ~ $2.50-$3/ Gj

Source: ICE Global Markets

Henry Hub is the pricing point for natural gas futures traded on the NYMEX. It is a point on the natural gas pipeline system in Erath, Louisiana.

U.S Gas Sources



http://energypolicyinfo.com/2009/05/unconventional-gas-mirage-or-oasis/

Current status of US "CBM" Industry

- Pretty flat. Mature, still producing about 8% of US gas supply, but probably in long term decline.

ANY THOUGHTS ON WHY?

- Prosperity dependent upon high gas prices.
- What has been learned from US CBM?
  - Production and completion techniques
  - The problems with CSG
  - Some of the solutions

Where is the rest of the world in CSG?

- Australia a long way 2nd to North America (USA, Canada) but leading the rest
- Canada doing reasonably well, out of the Rocky Mountain coals – potentially huge resources (~300 – 500 TCF)
- India and China have lots of coal but little to show in the way of CSG success thus far
- Eastern Europe and Russia likewise
- "Green" efforts in AMM happening slowly in the old coal mining nations (UK, Germany, France)
- NZ has a CSG industry "of sorts" emerging …
- Activity in Asia (Indonesia, Vietnam) tipped to rise

Any thoughts on why Australian industry took time to develop …???

International gas prices

- USA Henry Hub ~$5 / Gj
- Australia ~$3 / Gj
- Japan, Korea, Taiwan ~ $10 / Gj
- Russia ~ $6 / Gj
- UK ~$5 / Gj

The gold lies in Asia …

What is going on in Australia?

- Our crude oil production is in decline - is now about 15 percent lower than 10 years ago.
- **Australia produced 54 percent of its demand for oil last year, down from 98 percent in 2000.**
- **Australian CSG production is increasing - now about 215 PJ representing around 8 per cent of total gas production** (2010 figures).
- Queensland mandated 13% of the state's electricity be sourced from gas and 18% by 2020. Originally set as an incentive to build the Papua New Guinea gas pipeline, which has been cancelled.

CSG sector has been actively traded …

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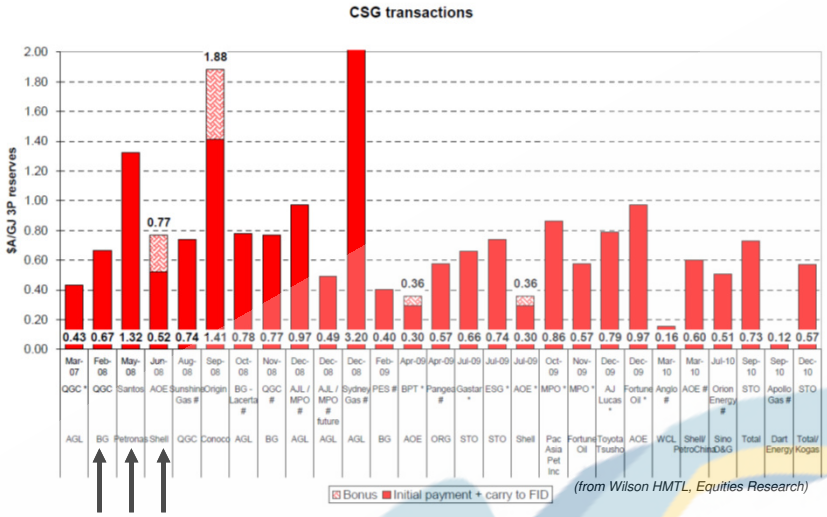

(from Wilson HMTL, Equities Research)

LNG projects

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Australia / PNG LNG project summary

Project	Location	LNG participants	Date FID / RFSU	# Trains	Output Mtpa	Capex to S/U b$US	Capex Lifetime b$US	Capex to S/U k$US/tpa	Capex Lifetime k$US/tpa	2P PJ	3P PJ	2C PJ	Contract gas PJ	2P life years	3P life years	3P+2C life years	Reserves	Sales Buyer / Mtpa / First LNG / Duration (Years)
CSG																		
GLNG	Curtis Is Gladstone	STO 30% Petronas 27.5% Total 27.5% Kogas 15%	13 Jan 11 2015	2	7.8	16.0	16.0	2.1	2.1	1,503 1,377 1,377 751 5,009	2,304 2,112 2,112 1,152 7,680	1,120 1,026 1,026 560 3,732	0	10.5 10.5 10.5 10.5 10.5	16.1 16.1 16.1 16.1 16.1	24.0 24.0 24.0 24.0 24.0	Surat Basin Bowen Basin	Petronas / 3.5 / 2015 / 20 Kogas / 3.5 / 2015 / 20
Qld Curtis LNG	Curtis Is Gladstone	BG 95% CNOOC 5%	31 Oct 10 2014	2→3	8.5→12.75	17.4	20.0	2.1	1.6	7,245	10,710	7,196	678	13.3	20.4	23.3	Surat Basin Bowen Basin	CNOOC / 3.6 / 2014 / 20 Singapore* / 3 / 2014 / 20 Chile* / 1.7 / 2014 / 21 Tokyo Gas* / 1.2 / 2015 / 20
Australian-Pacific LNG	Laird Pt Curtis Is	ORG 50% ConP 50%	Feb 2011 ? late 2014	2→4	8→16	13.6	28.0	1.7	1.8	5,072 5,072 10,143	7,299 7,299 14,598	2,422 2,422 4,844	1,370 1,370 2,740	15.2 15.2 15.2	16.2 16.2 16.2	17.1 17.1 17.1	Surat Basin Bowen Basin	
Gladstone LNG (unlikely to proceed)	Fisherman's Landing	AOE 0% LNG 100%	2Q10 (?) 2012 (?)	1→2	1.5→3	0.5	0.8	0.3	0.3	0	0	0	0	0.0	0.0	0.0	Surat Basin	Toyota Tsusho* / 1.5 / 2012 / 12
"Shell LNG"	Curtis Is Gladstone	Shell 50% PetroChina 50%	2012 2014/15 (?)	1→4	8→16	10.0		1.3	0.0	2,636 2,636 5,271	4,129 4,129 8,259	13,134 13,134 26,268	0 0 0	10.8 10.8 10.8	11.3 11.3 11.3	35.4 35.4 35.4	Surat Basin Bowen Basin	
Southern Cross LNG	Curtis Is Gladstone	Impel 100%	tba	2→3	1.4→5.1	4.0		2.9	0.0	0	0	0	0	0.0	0.0	0.0		
Abbot Point	Abbot Point Mackay	EWC 100%	tba 2012 (?)	4→10	2→5	1.6		0.8	0.0	0	0	0	0	0.0	0.0	0.0	Cooper Basin Bowen Basin	
LNGN	Newcastle NSW	ESG 100%	1Q2012 2014	1→7	1→4	1.2	0.9	1.2	0.2	968	1,818	2,285	400	9.6	9.3	15.2	Gunnedah Basin Gunnedah Basin	

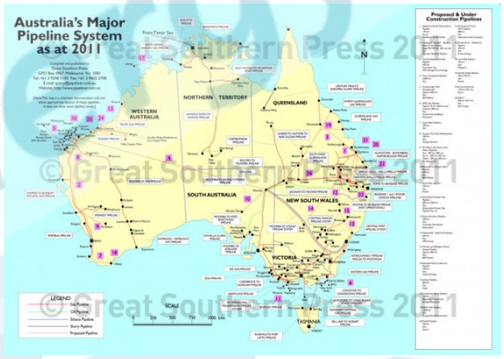
LNG example: APLNG (Origin)

- Gas coming from Talinga, Lauren, Fairview
- US$220M drilling & workover contract awarded to US company Savannah Energy
- Agreements with GCLNG for Argyle, Lauren, Kenya
- Will sell 190 PJ of gas over initial ramp up period of 2 yrs, and then 25 PJ/a over 18 years.

GLNG plans for 200 PJ/a over 20 years … *(Santos)*
QCLNG plans for 400 PJ/a … *(BG Group)*
FLLNG plans for 90 PJ/a … *(Shell / Arrow)*

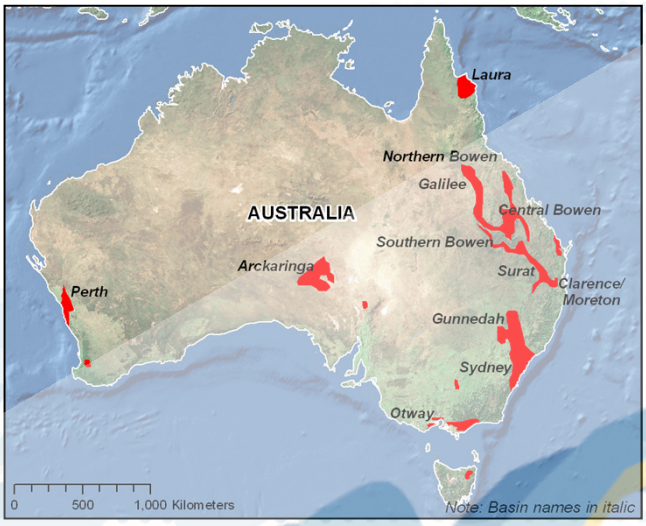
Gas pathways in Australia

- Cooper Basin in decline
- Exports of gas growing in WA and Qld
- Bowen & Surat providing significant CSG to mix
- NSW producing very little
- Otway & Bass in decline but still v. significant



http://pipeliner.com.au/pipeline_map_of_australia/

Australian CSG Basins – where is the coal?



Where is Australian CSG located?

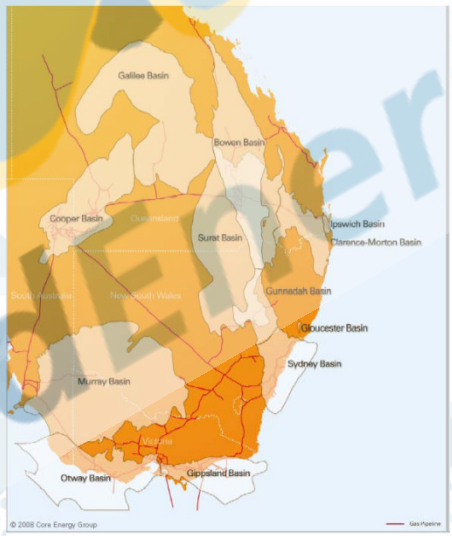
- Almost exclusively in eastern states.
- Queensland in particular.
- Now driven by LNG demand (export to Asia).

Conundrum: Why Queensland?

Australia CSG Summary

- Origin Energy, Santos and Arrow Energy were among Australian CSG producers that boosted output last year to meet rising demand from power generators.
- BG Group, Malaysia's Petroliam Nasional and ConocoPhillips have all bought stakes in Australian CSG companies or projects, with the aim of using the fuel for export ventures.
- BG is the biggest holder of CSG reserves in Australia, followed by Origin Energy, ConocoPhillips and Santos.
- Australia's 1P and 2P reserves of CSG have doubled over the past year, to 17,451 PJ, while conventional gas reserves in eastern Australia have declined.
- Most CSG development has been with vertical wells, either with "natural" or cavitation completions. Hydraulic frac completions have become very popular over the past few years and horizontal drilling activity is also increasing.

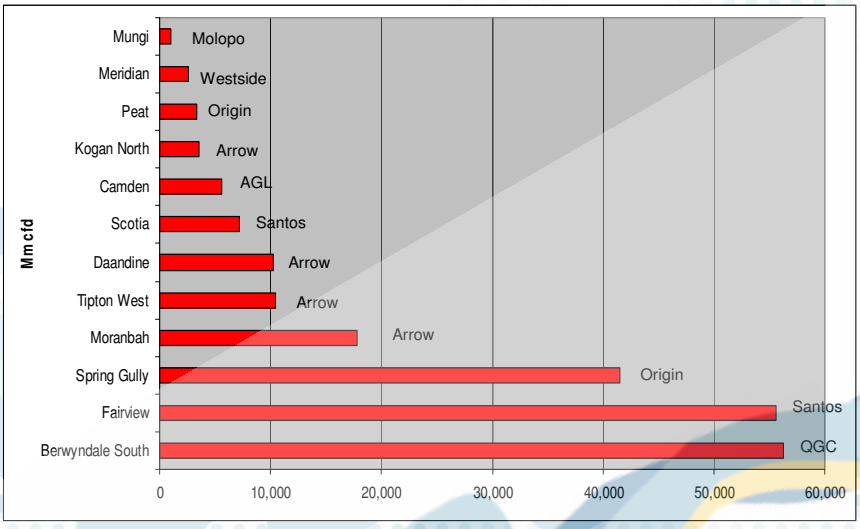
Qld is where most of the action is …



Source: Core Energy Group; 2009.

- Bowen and Surat Basins dominate CSG production
- Moura, Dawson Valley, Fairview, Spring Gully, Talinga, Berwyndale South, Peat & Scotia are key developments
- Sydney, Galilee, Clarence-Moreton, Murray, Gunnedah Basins at various stages of evaluation and / or development

2010 Production statistics

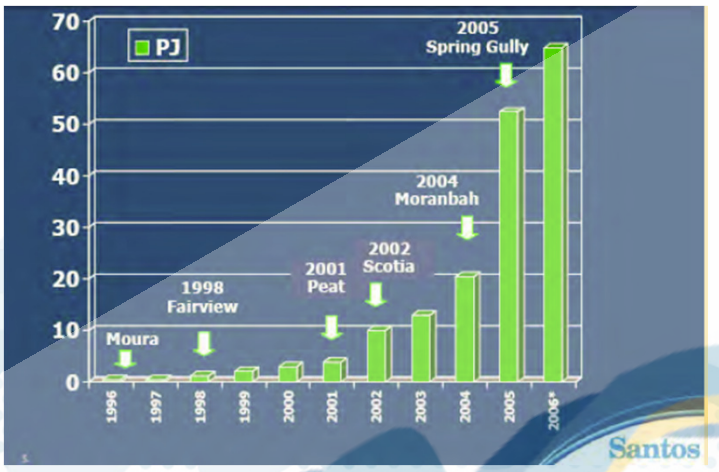


Source: APPEA

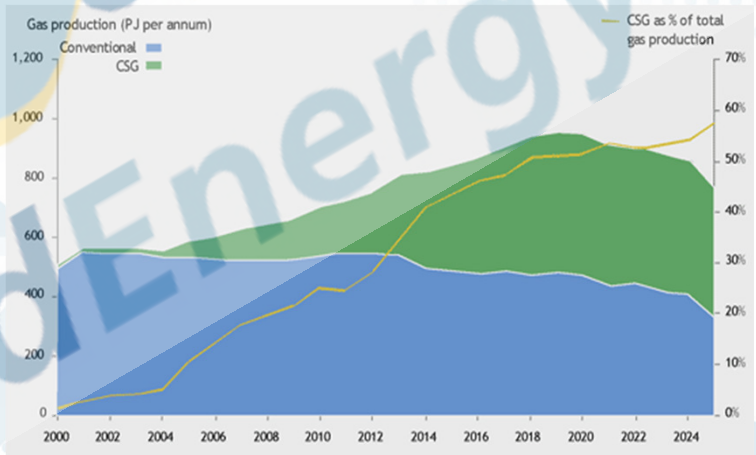
What do the "winners" have in common?

- Located on **structural relaxation zones … e.g.**
  - The Undulla Nose
  - The Comet Ridge
- **HIGH PERM**
- Close to **SATURATED.**

Historical … Bowen Basin development of CSG



CSG Production in Australia



Source: Wood Mackenzie's Eastern Australia Gas and Power Outlook

LNG from CSG

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- Cost of producing LNG from CSG is estimated to be around $2.60 per gigajoule while Asian customers are expected to pay between $8 and $11per gigajoule.

• Gladstone is targeted to be the first site in world for using coal seam gas to source LNG plants. CSG will be piped to the proposed liquefaction plants in Gladstone where it will be super-cooled to create liquefied natural gas (LNG).

• The LNG process reduces the natural gas to 1/600th of its original volume so that it can be transported by specially-built LNG tankers to global markets.

• The average CSG contains 98% methane and 1% nitrogen and 1% carbon dioxide. These two minor gases do not burn and are difficult to liquefy so they must be removed ahead of the LNG plants.

• Australia is already the world's #5 LNG exporter, exporting product worth around US$2 billion per year. Japan purchases about 93% of Australia's LNG with small amounts delivered to the U.S., Spain and South Korea.

• Cost to build one of the mid-size LNG plant is roughly $8 billion.

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Australian CSG Development – summary …

- Dominated by **BIG players**
- **LNG** focus
- **Queensland** focus
- There are going to be **lots of holes** drilled to satisfy demand
- Domestic power from gas will take back seat to LNG
- NSW remains an enigma

Eastern Australian Gas Reserves by Basin

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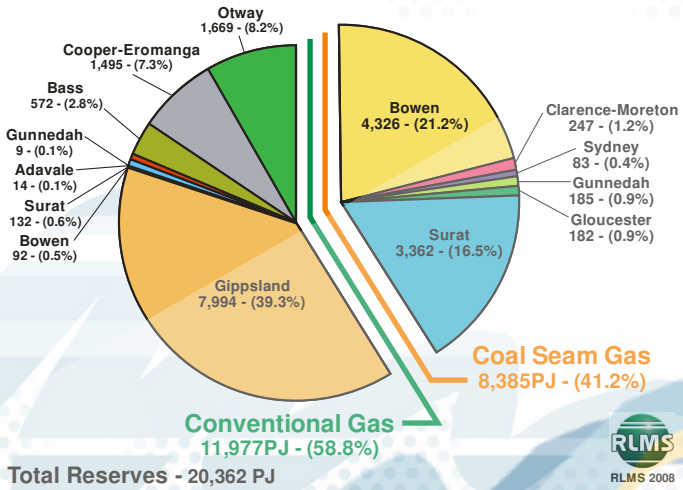
Eastern Australia 2P Gas Reserves by Basin in PJs
(04 March 2008)



Coal Seam Gas
8,385PJ - (41.2%)

Conventional Gas
11,977PJ - (58.8%)

Total Reserves - 20,362 PJ

RLMS
RLMS 2008

Some specifics on current activity in Qld – where is the drilling activity?

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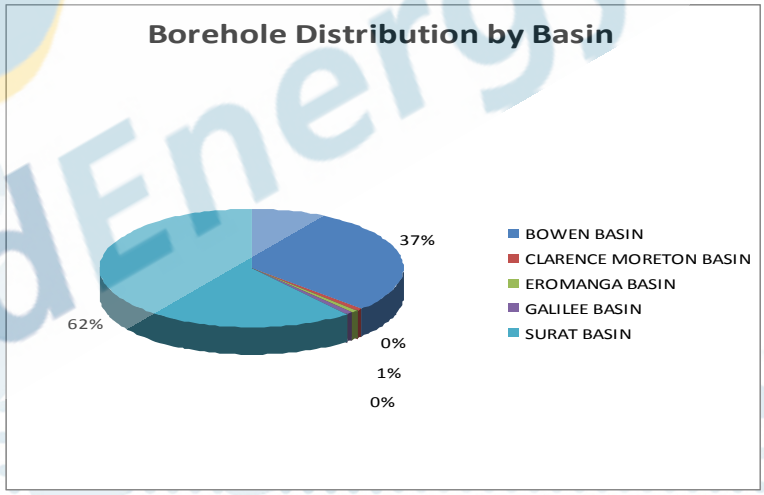
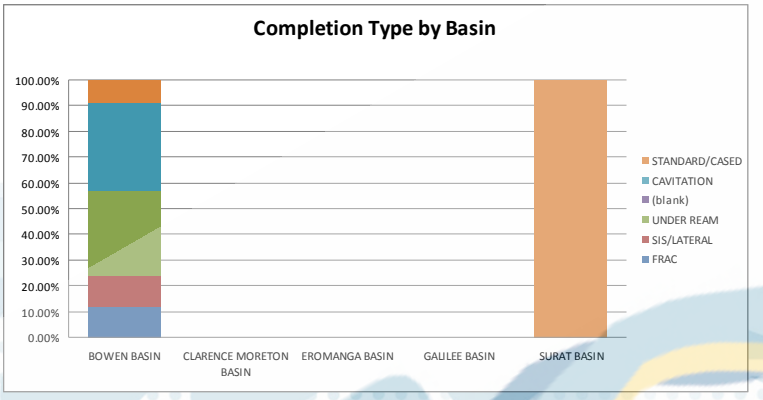
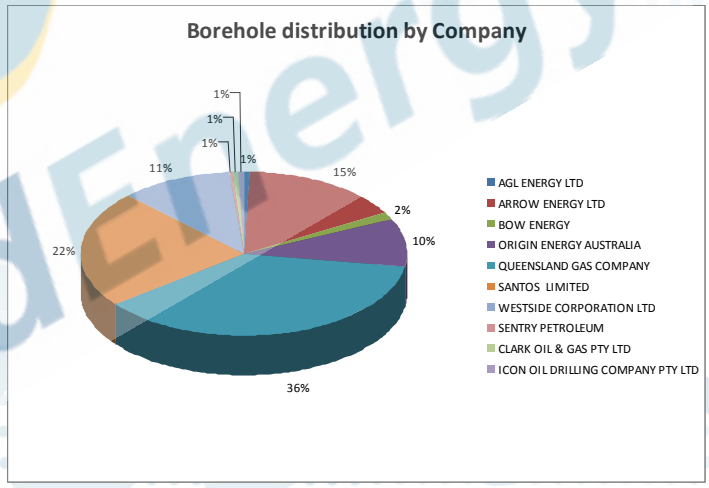
Borehole Distribution by Basin



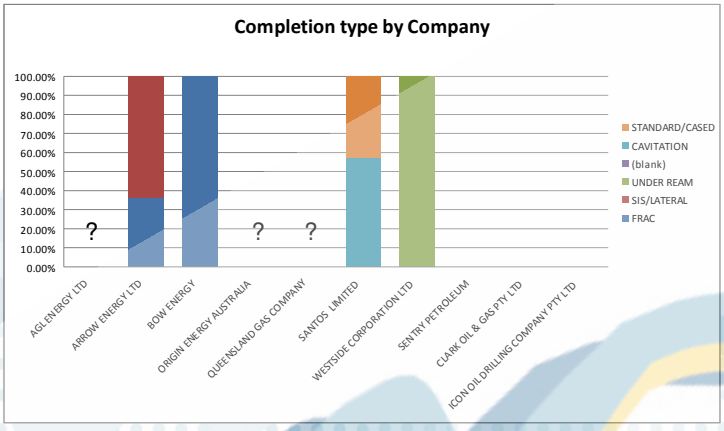
What completions?



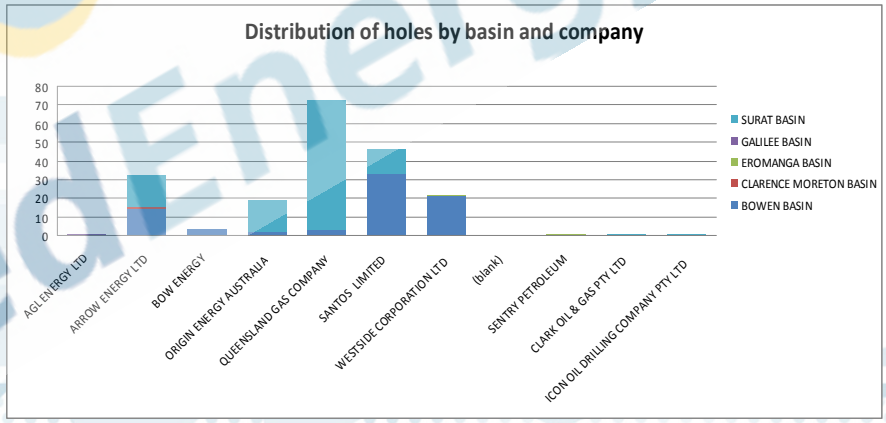
Who is doing all the drilling?



What P & C method is favoured by each company?



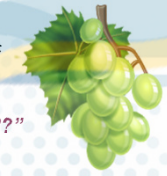
Distribution of holes by company and basin



Summary of where we are at …

- The Australian CSG industry has exploded in the past decade, and is on the cusp of a major expansion phase.
- Much of the work will be about production & completion, and ensuring consistent supply.
- There will be many thousands of holes drilled.
- 'Ramp up' gas an issue.
- Water disposal is likely to be a major issue.

- The US industry is probably slightly in decline.
- "Other" areas getting all the attention.
- CSG still has a long way to go internationally.
- The "easy" projects are already discovered, it will be a game of margins.

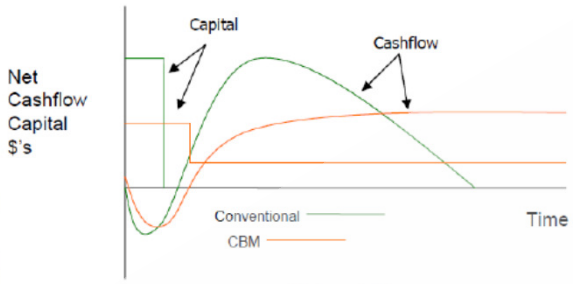


"Low hanging fruit already gone ???"

A few words on CSG economics

- CSG costs less to establish but requires an ongoing commitment to drilling new wells
- Sometimes hard for conventional players to get their heads around the marginal nature of CSG …
- Any thoughts? Anyone coming from conventional to CSG care to comment?

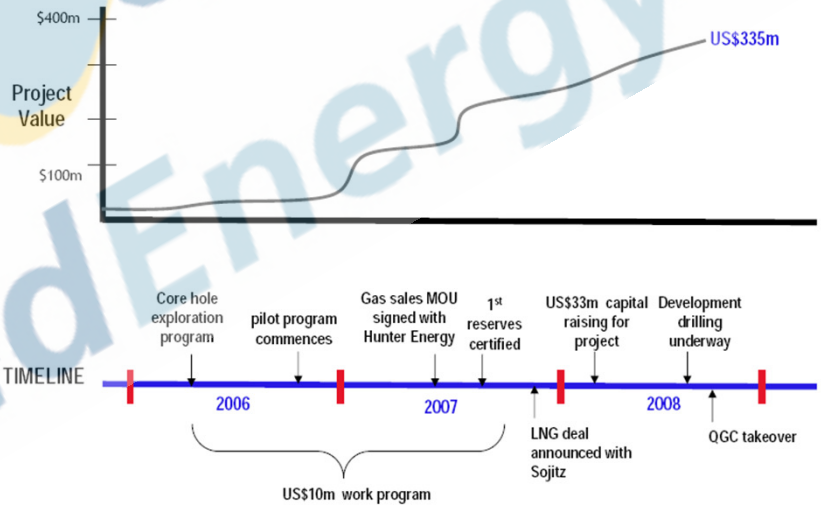
The economics of CBM v. Conventional Gas



Net cash Flow profile

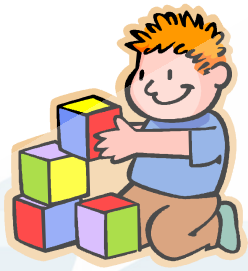
- Less upfront capital.
- More ongoing capital.
- Cash flow is less in short – medium term but keeps on going for years.
- Note: cost to achieve certification is LOW compared to conventional.

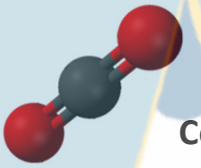
A typical project timeline …



(Example based on Sunshine Energy Lacerta Project, public domain information)

OK, let's get down to the basics …





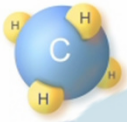
Coal Seam Gas can be dangerous!

- Only small % in atmosphere is a potentially explosive mix (~5-15%).
- Can cause asphyxiation if replaces O_2.
- Coal dust and a spark is all that is needed, miners are ***very wary*** of methane, or "firedamp".
- Methane is however **not toxic**!
- CO2 is **not toxic**, but very dangerous to health in confined spaces.
- CSG reservoir pressure a factor in coal outbursts – "pressure bumps" – highly dangerous to underground workers.
- Most of this not a problem for CSG operators – only miners.

- ***What are the issues with methane around CSG sites?***

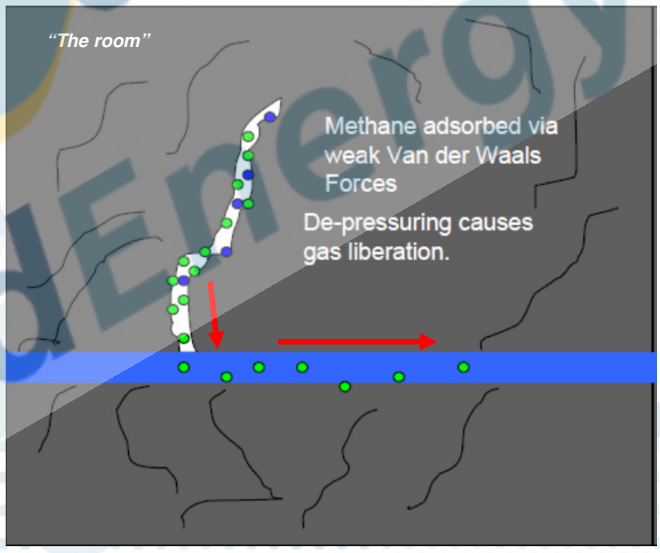
What EXACTLY is Coal Gas?

- Coal gas is a colourless and odourless gas – usually a mixture.
- Initial gas production from CSG wells is usually Methane (CH_4)
  - Occasional Ethane (propane, butane …)
  - Usually a few percent carbon dioxide (CO_2) but it sometimes involves 10% to 40% CO_2 (in Australia, CO2 can be 90%+)
  - Usually a small percent nitrogen (N_2) but it sometimes involves 6+% N_2
  - sometimes other "contaminants"

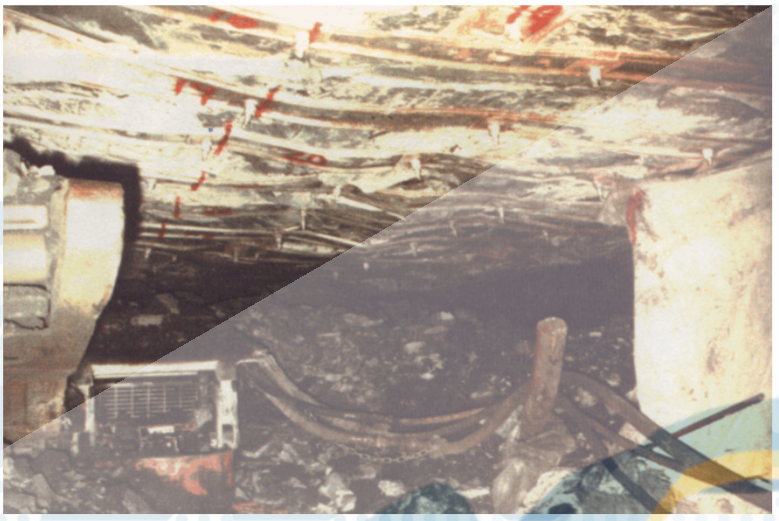


Coal provides the source, reservoir and trap for coal seam gas.

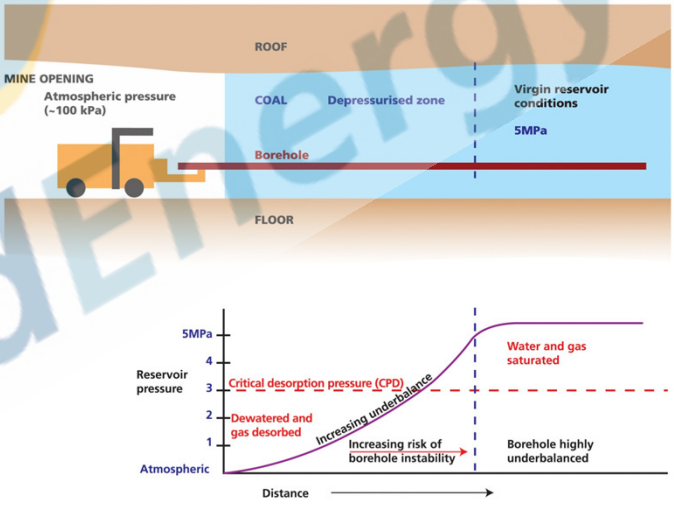
Gas is trapped in coal micropores



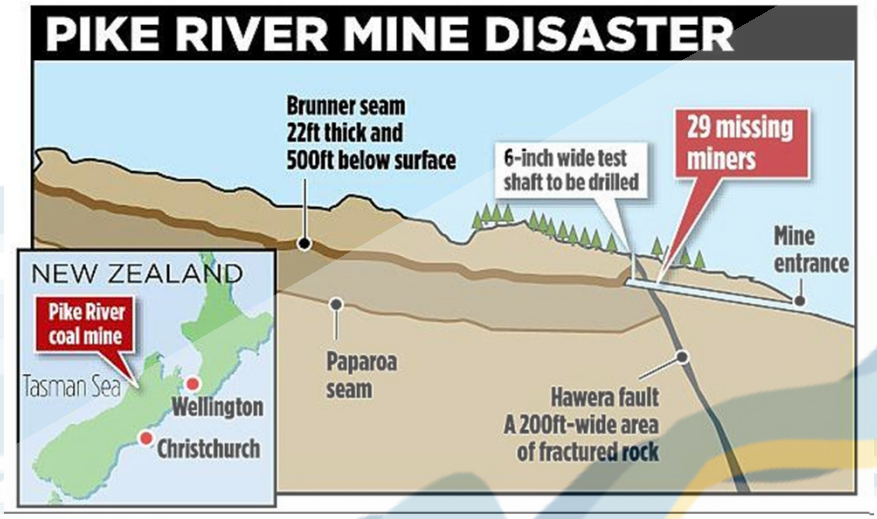
The danger of gas in confined spaces: 1) outbursts



What they do in mining to lessen the risk …



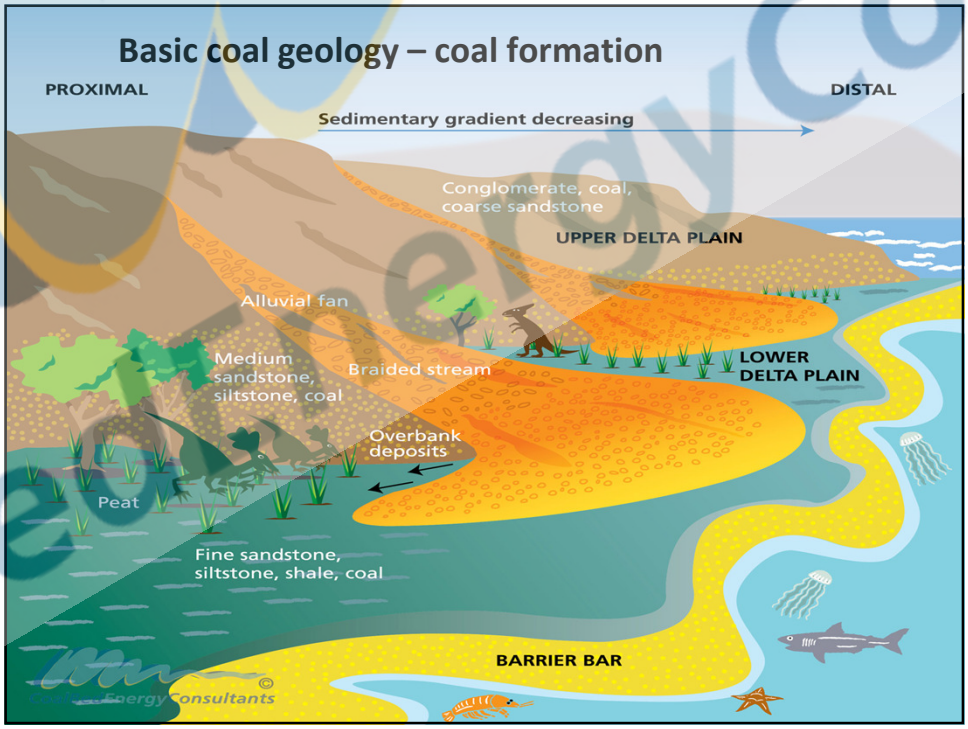
The danger of gas in confined spaces: 2) explosion



Mining & CSG

- **Totally different headspace …**
- **To miners gas is a pest, and a hazard**
- **To CSG operators it is the main game**

- Draining gas from mining rarely results in utilisation of methane, but this view is slowly changing
  - Miners always do it in a rush & care little about completion
- Miners don't really like coexisting with CSG operations
  - Unsure of impact of water depletion
  - Might need to put water back in to control dust
  - Hate the idea of committing to gas drainage years in advance
  - Are uncertain of their supply capability & do not want to be locked in
  - Greenhouse story has changed the game, and miners are trying to work out whether CSG is an asset after all …

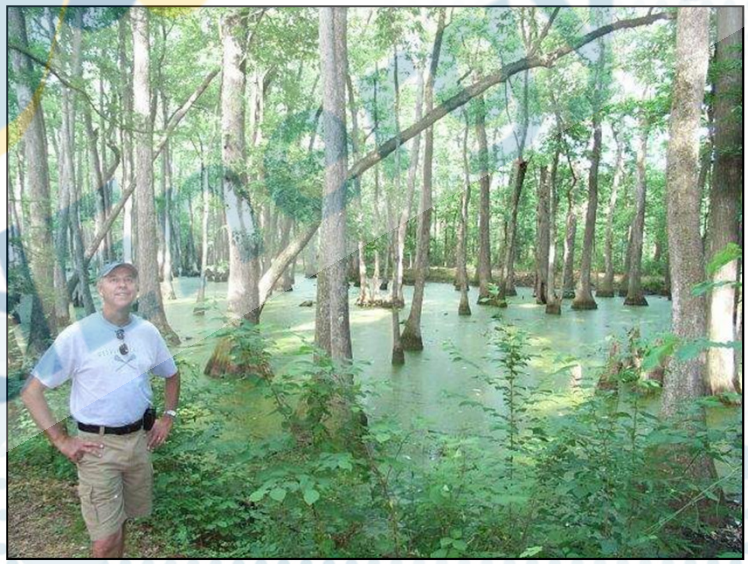


Coal is …

- A combustible sedimentary rock formed from the lithification of plant material.
- It is made up of largely carbon.
- Is abundant in the Earth's subsurface.
- Is the host for "Coal Seam Gas".

Coal is essentially the wonder fuel that drove the Industrial Revolution *… e.g. Carnegie's steel that "practically built America", or the Krupp Works steel were used to construct Hitler's panzers …* ***is it's day close to an end?***
What do you think?

The Coal Forming Environment



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Peat …the first result in the geologic drying and cooking process.

Just for your interest … China's energy mix *(now & 2030)*

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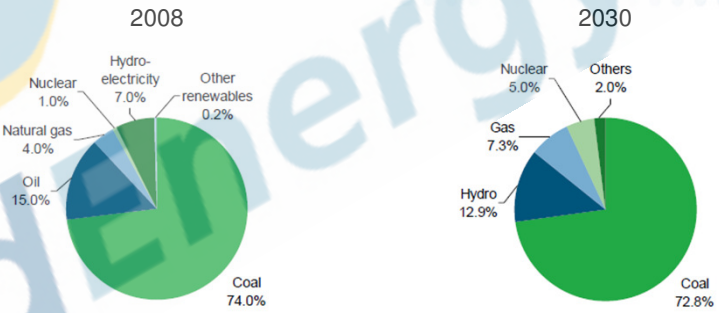
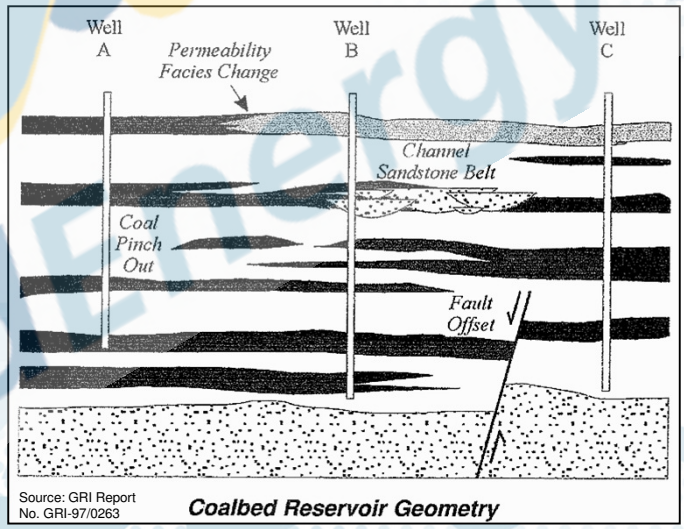


"China's electricity generation cost remain the lowest worldwide across all energy sources. With **abundant coal supplies**, it remains the most commonly used fuel feedstock for power generation, reaching 74% of total energy consumption in 2008, while natural gas made up only 4% of the total energy consumption".

India loves coal too …

"You can almost see the gas desorbing …".

Coal Continuity



Implications for CSG production?

Coal is …

- Layered, and usually horizontal.
- Made up of discrete 'seams'.
- Usually only about 10% of the total "coal measure sequence" (the rest is sandstone, shale etc.).
- Terrestrial – i.e. formed on land.

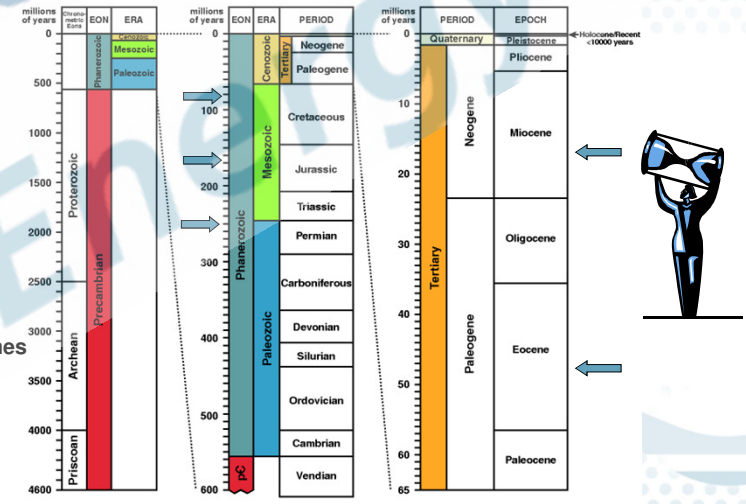
Not safe!

Geology can be complex!

This is right next door to a CSG play …

And it can be simple …

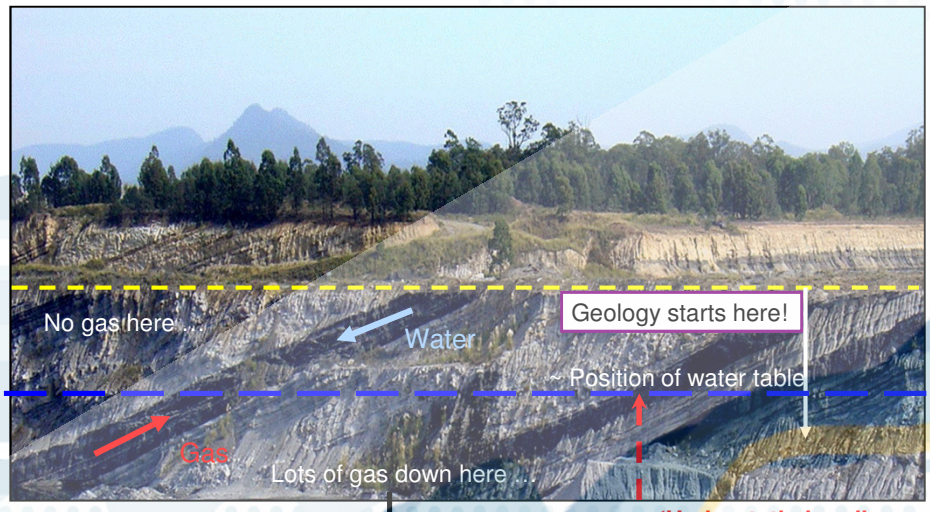
CSG and geological time …



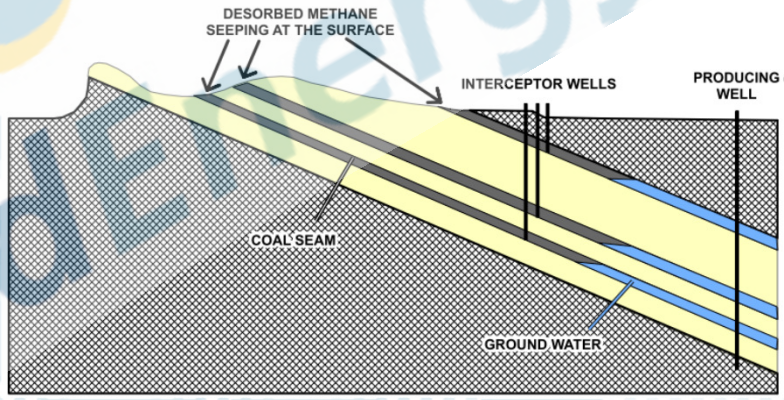
Coal forming times
In Australia

What age are the coals from your workplace?

The relationship between gas, water and the surface …



The concept of 'fugitive emissions' …and gas migration

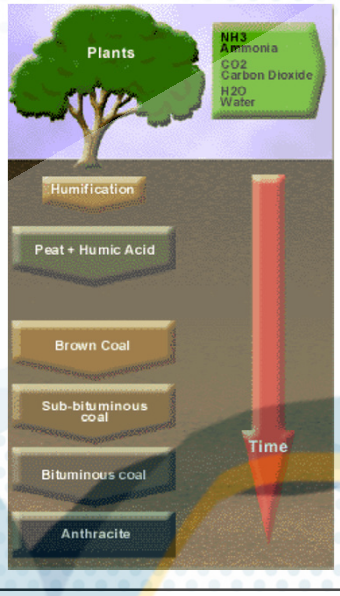


From: **Draft baseline and monitoring methodology "Interception, recovery and use of methane from CBM seeps that would otherwise be released to the atmosphere"**
Version 6, 21 September 2010

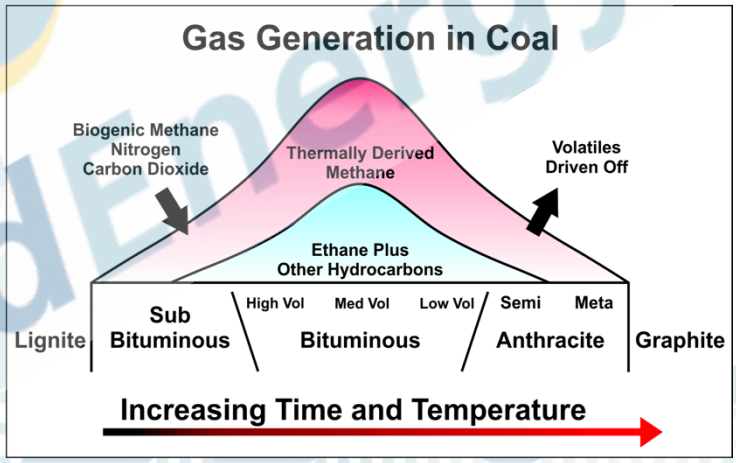
The origin of gas in coal

- Process is governed by heat & pressure & time variables
- Essentially, the more heat & pressure the greater the coal gas storing capacity
- Burial history a big factor in whether a coal contains gas or not (but not the only one)

Key concept: "rank"



Most gas is generated at a certain 'rank'



Gas Generation by Rank

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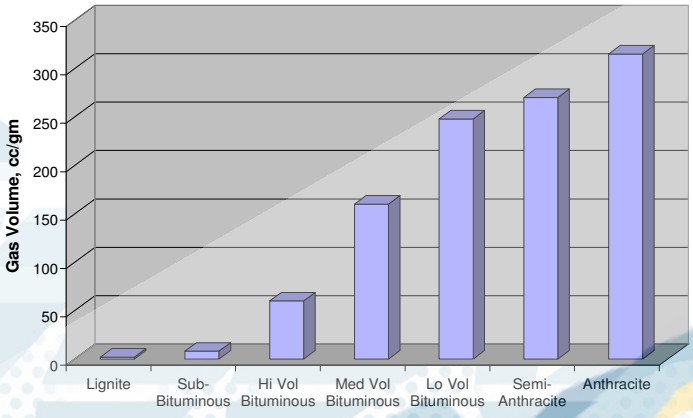
Cumulative Gas Generation versus Rank



Ref: Rightmire, 1984

We can generate so much… but why is it no longer there?

The "oil window" … and gas …

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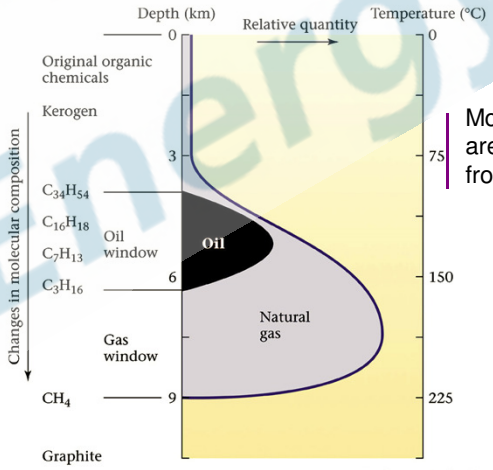

Most of the gas we are interested in is from about here …

FIGURE 14.5

Earth: Portrait of a Planet, 2nd Edition
Copyright (c) W.W. Norton & Company

Coal is variable & banded

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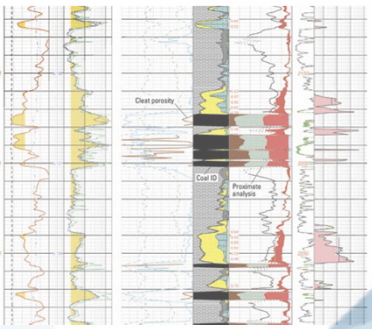
- Has partings, and varies in quality



- Ash & moisture affect coal seam gas holding capacity
- Variability impacts upon CSG production.

The banding in coal means anisotropy = potential drilling difficulties

Classification by Rank of Coal

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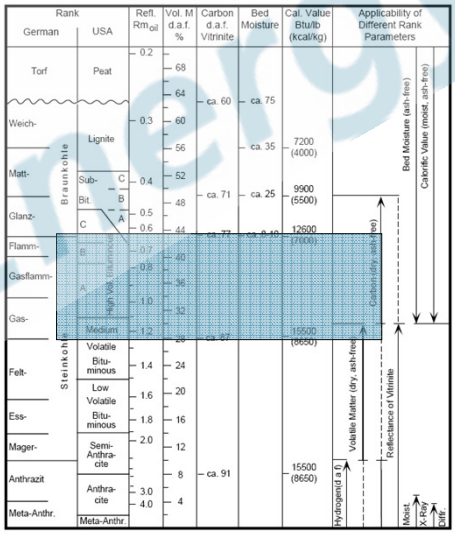
Thermogenic



(from Stach et al., 1982)

Also may be prospective … see Powder River Basin

Focus area: sufficient "cooking" for gas generation …

What are the P & C implications of changing rank?

Do you think miners and CSG operators are interested in the same resource?

To find gas we need to drill …

And measure the gas that 'desorbs' from the coal

Desorbing Coal at 450m

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Measuring Gas Content …

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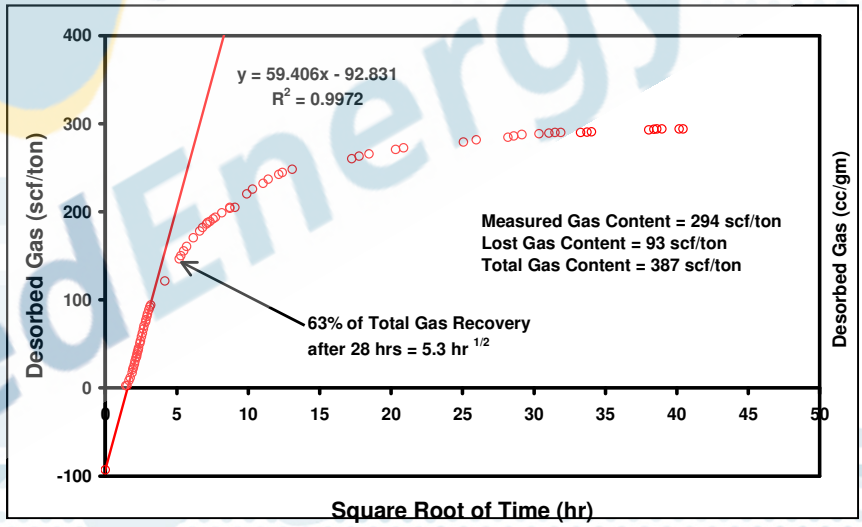


Gas content in the ground …

- **Hard to estimate – needs to be measured**
- **Involves coring, and sampling**
- **Essentially 2 ways to do it**
  - **Slow method (USBM)**
  - **Fast method (Quick Crush)**

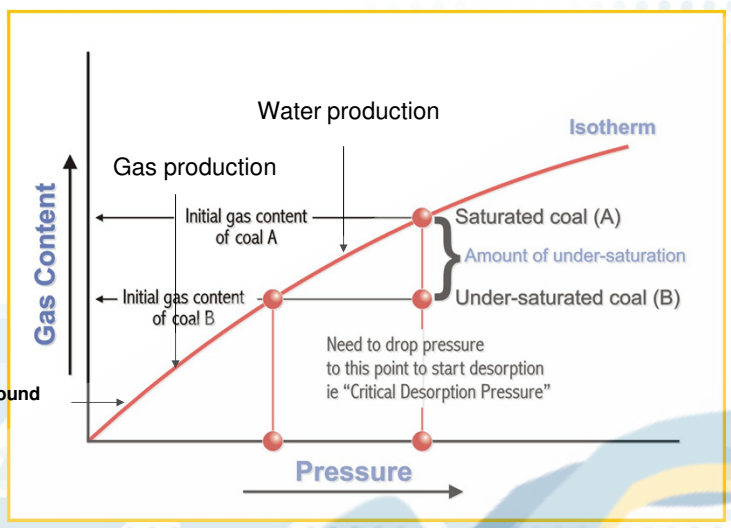
Miners use 'fast' method, CSG companies the 'slow' method – why?

The Adsorption Isotherm

- The adsorption isotherm is a property of the coal itself
- Different coals have different isotherms, which is usually (strongly) a function of coal rank
- While the gas content tells us how much gas a coal does hold, an isotherm tells us how much gas a coal can hold
- Two methods:
  - Gravimetric: measure weight of coal during adsorption testing
  - Volumetric: measures volume of gas adsorbed, in adsorption container

"How full is my coal of gas …"

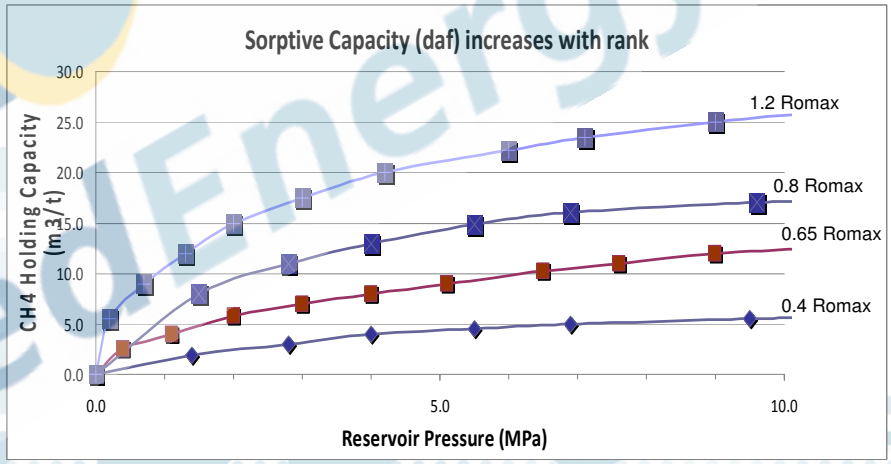
Gas Content & the Saturation Relationship



Red line is the "***adsorption isotherm***".

Key Coal Properties Example Adsorption Isotherms

Any idea of the rank of your coals?



Note the important link between rank & the isotherm …

Rank vs. Gas Content … *another way of looking at it*

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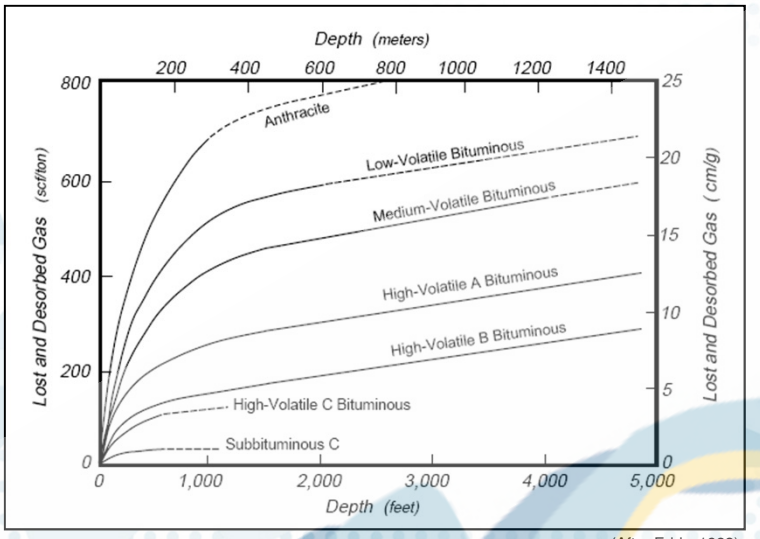

(After Eddy, 1982)

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Gas saturation – some generalities

- Adsorption Isotherms define the **maximum storage capacity** of a coal.
- **Many coals hold less gas** than their total storage capacity.
- Gas Contents define the **actual volume of gas** in the coal.
- The pressure at which 'first gas' is encountered is the **critical desorption pressure**. This is achieved by reducing reservoir pressure (pumping water).
- If the desorption pressure is **less than the current pressure** in the coal, then the coal is under-saturated.

"The Surat is actually terrific coal. The wells are so over saturated that they flow gas from day one" … *(CEO of gas company that shall remain nameless).*

A few words on reservoir pressure … sometimes called 'seam pore pressure'

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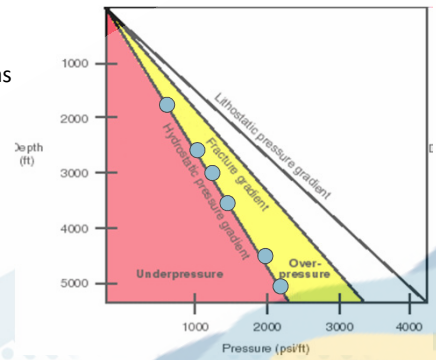
Rhetorical questions for you:

- Is reservoir pressure always constant in the same seam?
- If not, then what are the implications for gas content?
- What about implications for Critical Desorption Pressure?
- What would be the implications of mining encroachment on the reservoir pressure?
- What about if the pressure was reduced by pumping for other reasons … e.g. water for agriculture?



Expected depth pressure relationship

Real life isotherm example …

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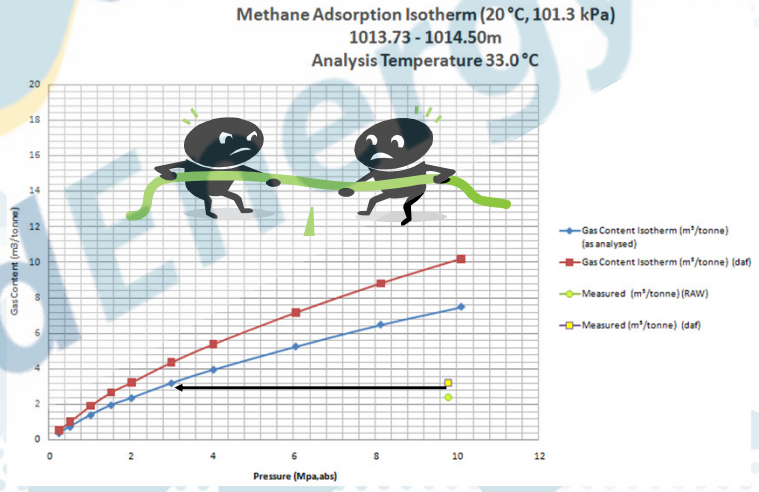
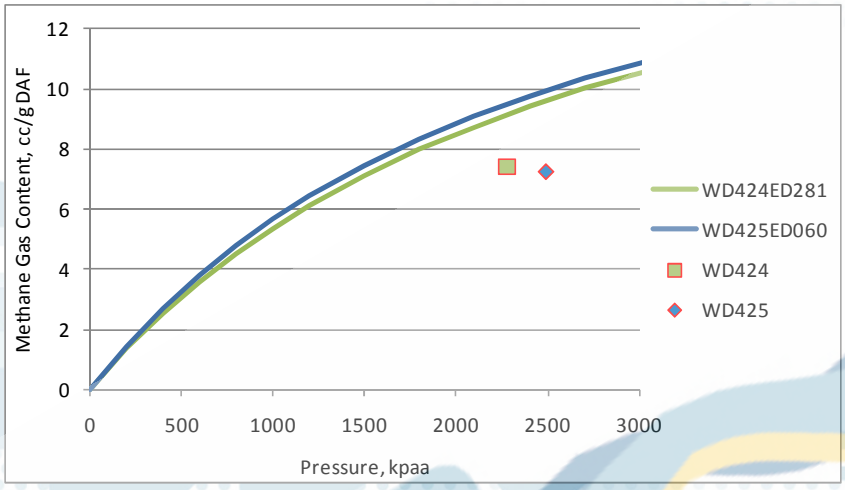


A highly undersaturated coal … would you invest?

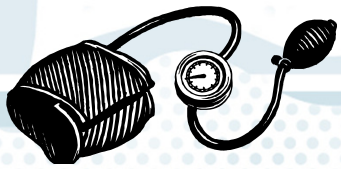
A little undersaturated …



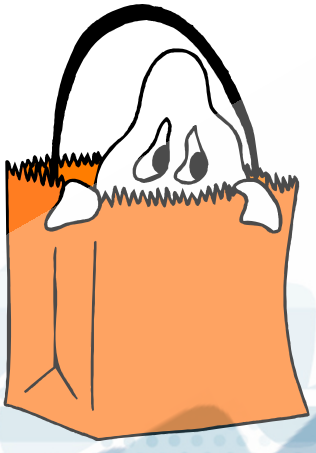
Promising?

Rhetorical questions …

- If a coal is **under**saturated is that good for CSG production?
- What are the implications?
- Can a coal be **over**saturated?
- Any thoughts on the lateral / vertical **controls** on something like saturation? Is it likely to vary much?
- What if a coal is significantly **under**pressured?
- What if it is significantly **over**pressured?



Exercise: Langmuir Isotherms



Permeability

"Permeability measures the ability of fluids to flow through rock (or other porous media)".

- What controls permeability?
- How do we measure it?
- Anisotropy of perm
- Is it a static property?
- What bearing on production and completion strategy?

Mr. Darcy

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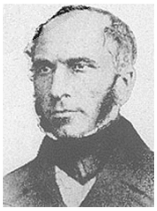
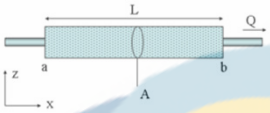


No! This Mr. Darcy

- BAD perm … anything less than 1mD.
- MARGINAL perm … from 1-5 mD.
- MARGINAL but BETTER … from 5-10 mD.
- GOOD perm … 10-50 mD.
- SENSATIONAL perm … >50 mD.
- UNBELIEVABLE perm … 5 D etc.

$$Q = \frac{-kA}{\mu}\frac{(P_b - P_a)}{L}$$



Implications?

In CSG, perm is often the project killer

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"**Perm**" … is influenced by current stress field, pre-existing discontinuities, and imposed stress field

Any ideas on the history behind this photograph? Where is it?

Coal seam gas character with depth: the gas / perm tradeoff …

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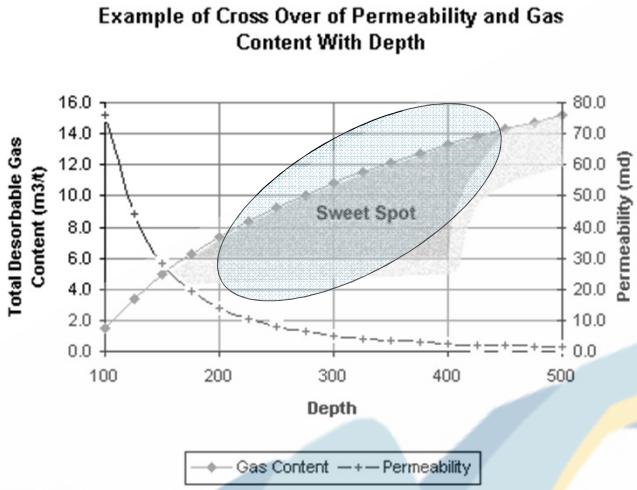

(from Thomson & MacDonald, 2003, modified from Williams 1999)

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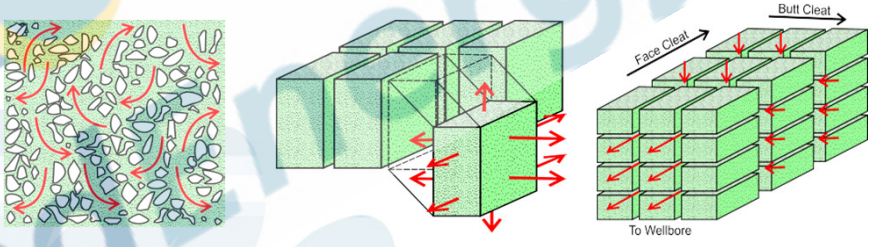
Gas Transport Mechanisms in Coal



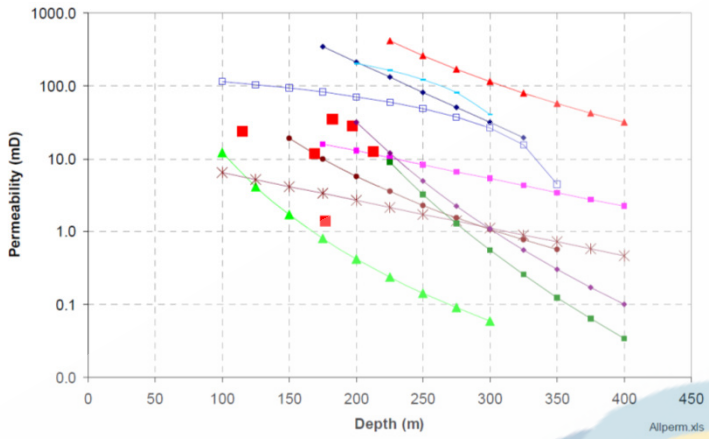
Molecular Diffusion Through the Coal Matrix

Gas Desorption from Cleat Surfaces

Fluid Production from Natural Fractures

Source: GRI – A Guide to CBM Reservoir Engineering

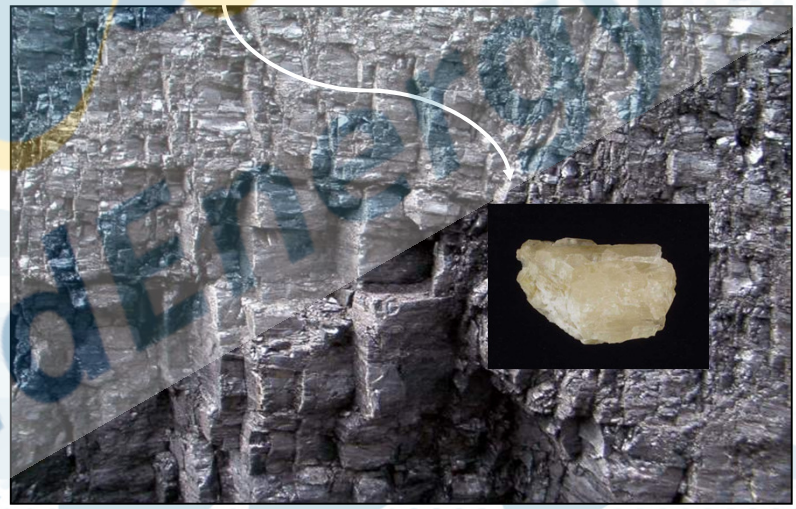
Actual perm gradients …



(from Williams, 2004)

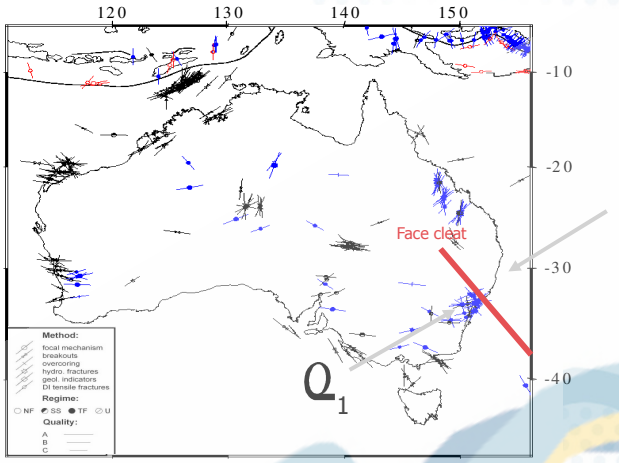
What is it like where you are extracting CSG?

Perm has a lot to do with coal cleats
- and what is in them!



Gas is stored on the coal surfaces and produced through the cleats …

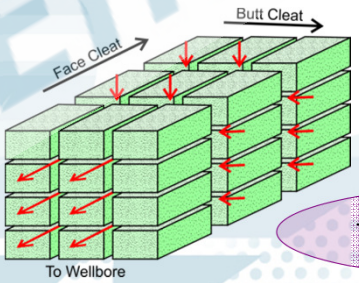
And stress … compression responsible for tightening up of perm …



Stress Map of Australia
(after Mueller et al., 2000)

Directional Permeability

- A good first approximation is that a coal will have a higher permeability in the direction of the predominant "face" cleats, and lower permeability in the direction of the secondary "butt" cleats.
- Maximum permeability direction can be altered by fracture systems and by insitu stresses.



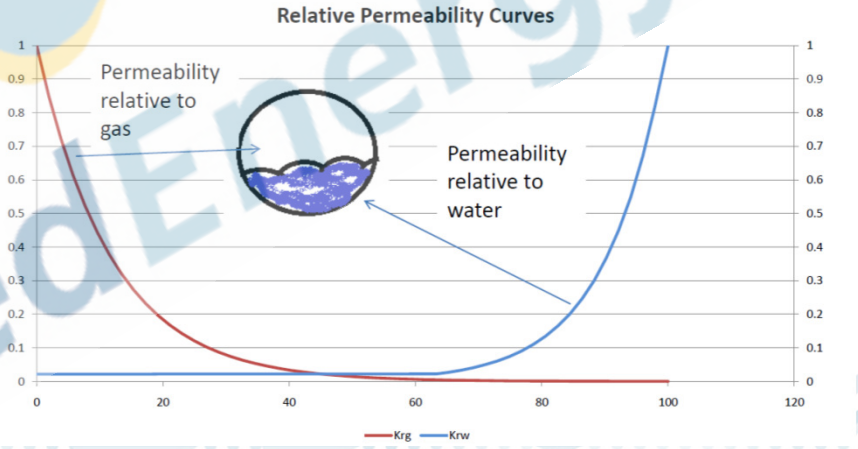
This is a gross oversimplification!

Implications of directional anisotropy?

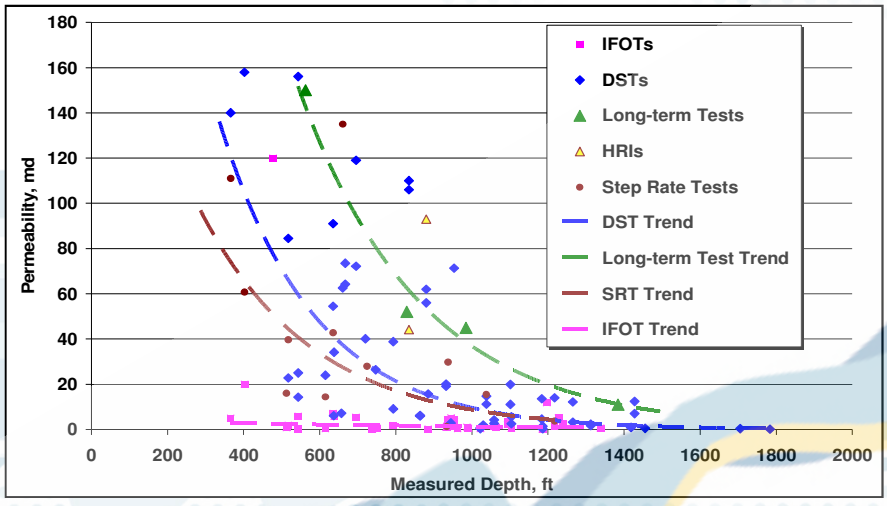
Measuring perm

1. **Expensive** process, and never enough data
2. All methods involve **well testing**, and rig time
3. Effectively, **injecting water** into formation or measuring water flow out of formation (or a combination)
4. **How representative** is the data?
5. **Relative permeability** effects (we are measuring water, but what about the gas?)

The concept of relative permeability



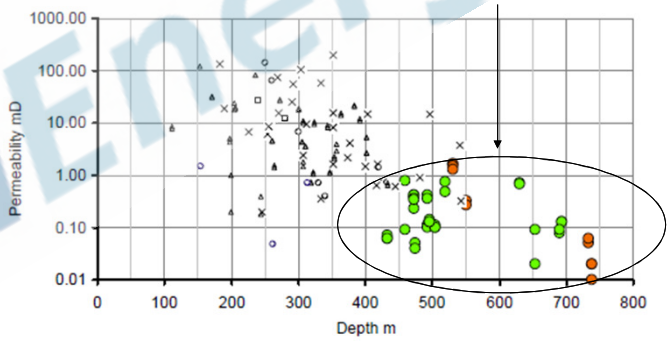
Perm data from a single field



Highly variable …

Bowen Basin perm data …

Is this good or bad?
Implications?



Implications for production & completion

- Spacing
- Timing
- Gathering systems

- What about the 'footprint' of CSG development?

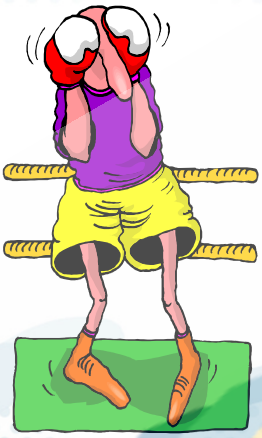
What Environmental Statement Does Your Company Want to Make?

Think horizontal, underbalanced, multilateral CBM technology

(apologies, stolen from Weatherford ad …)

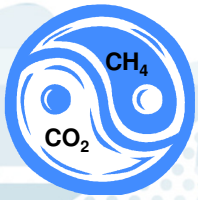
"Footprint" may be a serious issue …

Exercise: Bonnie Hills

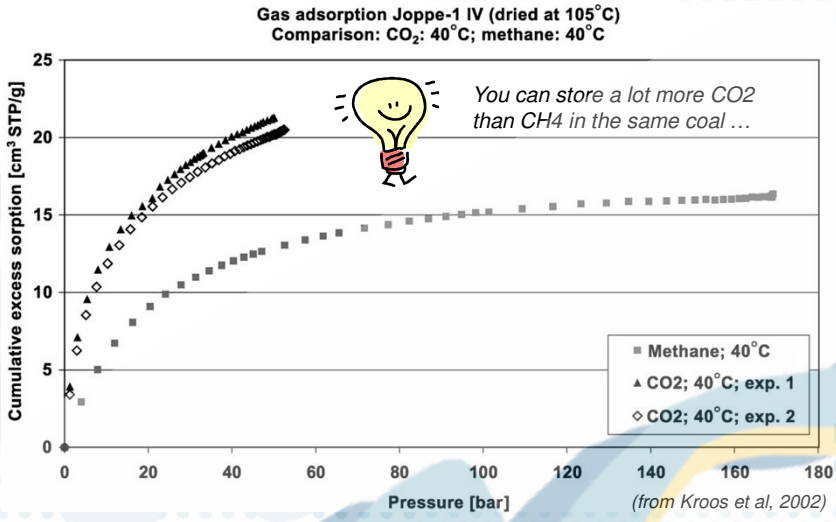


Some thoughts on gas composition

- What is the main coal seam gas in your area?
- Is there anything other than methane?
- What are the implications of more CO2?
  - From production perspective?
  - From OH & S perspective?



The methane & CO2 isotherm

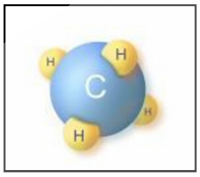


(from Kroos et al, 2002)

Other stuff I think you should know about gas …

Origins of gas in coal

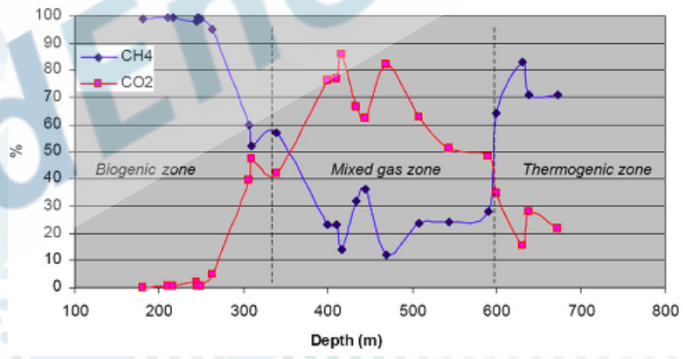
- Primary biogenic
- Thermogenic
- Magmatic
- Secondary biogenic



- Forget about primary biogenic gas – this is long gone …
- "Thermogenic gas (methane) is the primary gas making up most CSG projects" … ***well, maybe …***
- Secondary biogenic gas is important, and increasingly is being recognised as such … ***I think so …***
- Magmatic activity (ancient volcanism) is primarily responsible for all the CO2 found in some CSG projects. ***Probably acknowledged, but not well understood …***

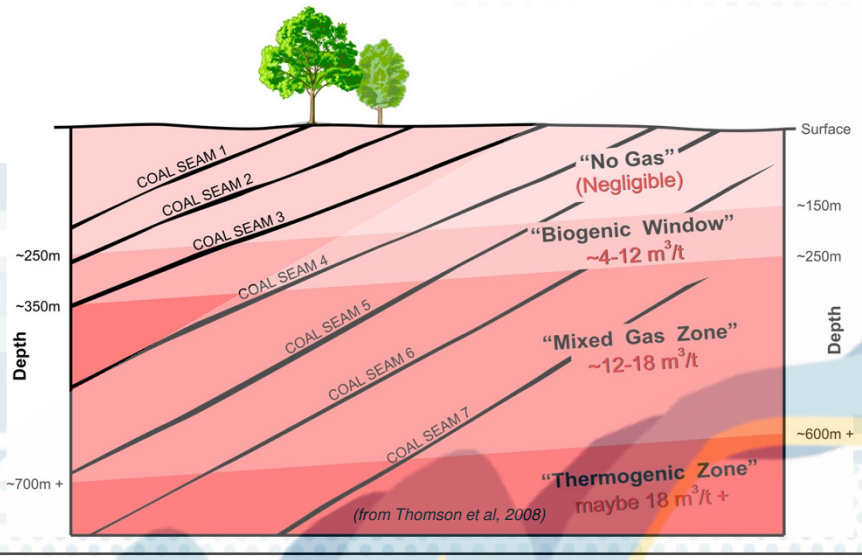
The layering of gases with depth

- First noticed this relationship in Permian coals of Hunter Valley … suggest the 'sweet spot' is all about the "biogenic window"
- But what of the 'Mixed Gas Zone'?
- Why does methane kick back at depth?

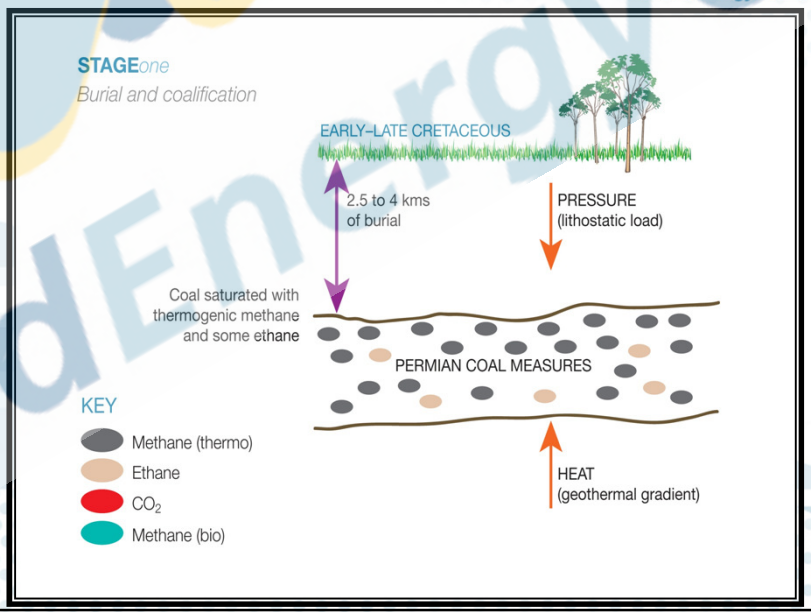


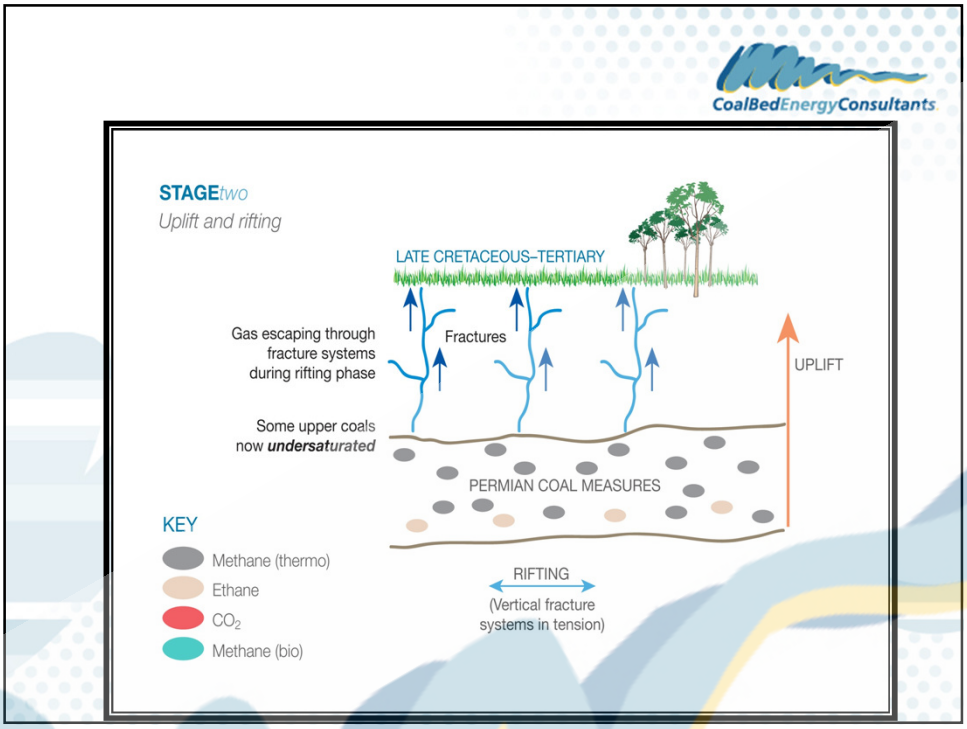
(from Thomson et al, 2008)

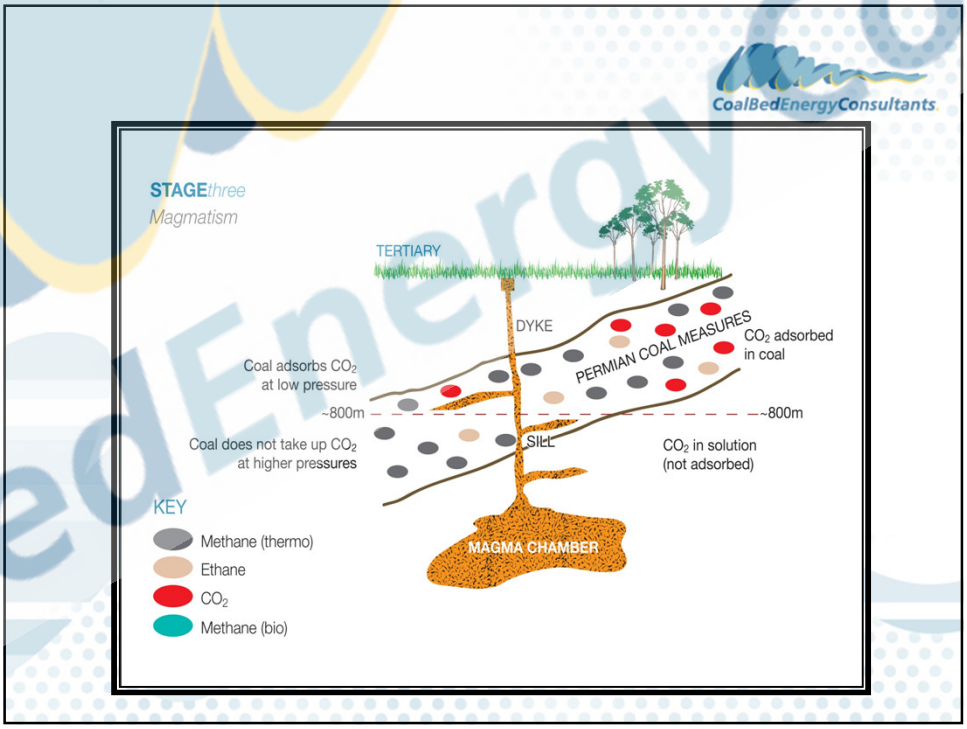
Summary of layering … what does it look like in subsurface?

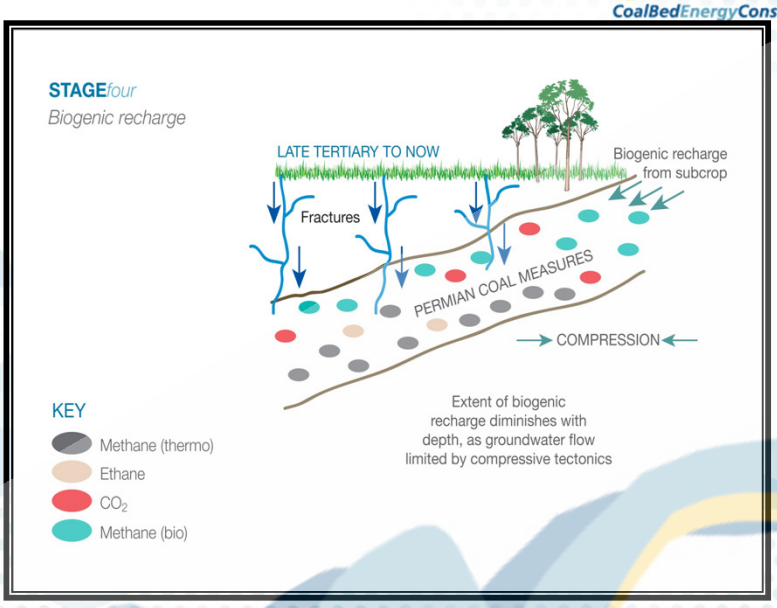


Why is it so?




CoalBedEnergyConsultants
STAGEtwo
Uplift and rifting
LATE CRETACEOUS–TERTIARY
Gas escaping through fracture systems during rifting phase
Fractures
UPLIFT
Some upper coals now undersaturated
PERMIAN COAL MEASURES
KEY
Methane (thermo)
Ethane
CO2
Methane (bio)
RIFTING
(Vertical fracture systems in tension)


CoalBedEnergyConsultants
STAGEthree
Magmatism
TERTIARY
DYKE
PERMIAN COAL MEASURES
CO2 adsorbed in coal
Coal adsorbs CO2 at low pressure
~800m
~800m
Coal does not take up CO2 at higher pressures
SILL
CO2 in solution (not adsorbed)
KEY
Methane (thermo)
Ethane
CO2
Methane (bio)
MAGMA CHAMBER



Some truisms … and conundrums

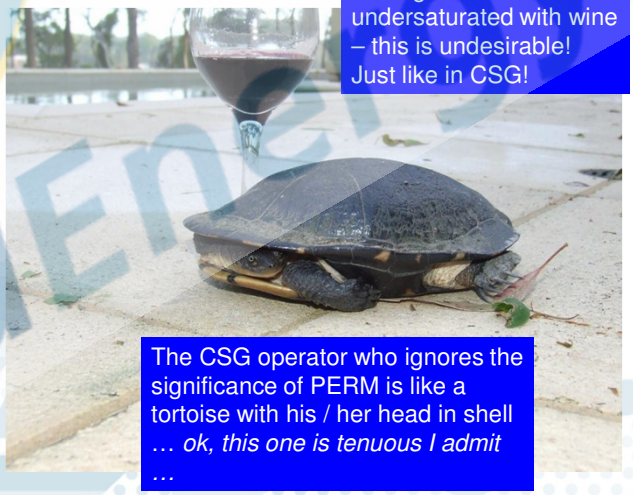
If coal is present, is gas there too?

- Generally … but coal must be of sufficient **RANK**.
- Some gas may have escaped in geological time.
- A lot of low rank coal contains very little gas.
- Even if gas is present, can you get it out at commercial rates? Maybe … but what is the **PERM**?
- What do we do with the water we produce?

Enough background on gas … let's talk P & C …

… but first, a small exercise … (or two) …

The significance of the tortoise and the glass of wine …



Wine glass is undersaturated with wine – this is undesirable! Just like in CSG!

The CSG operator who ignores the significance of PERM is like a tortoise with his / her head in shell … *ok, this one is tenuous I admit …*

Exercise: Wildcat, Bull & Bear

End of Module 1

Questions?