CSG & Geophysics (fundamentals)

CoalBedEnergyConsultants

Module 3: What is going on elsewhere?

Prepared by: Scott Thomson

26th February 2012

CoalBedEnergyConsultants

Literature reviews

- Derived from SPE, Science Direct & the internet in general.
- Anecdotal evidence from CoalBed contacts around the world …
- You tell me your opinion too!

What are the things we are looking for?

- Better coal characterisation. Particularly coal quality and coal continuity. **Wireline logs, seismic.**
- Nasty water bearing non-coal units. **Wireline logs.**
- Crossovers – gas bearing sands. **Wireline logs (neutron / density).**
- Regional dip. Structure. **Seismic (2D v. 3D?), maybe magnetics, maybe some gravity.**
- Intrusions. **Airborne magnetics.**
- Staying inseam. **LWD technologies.**
- Groundwater movement. **Resistivity? EM? Tomography?**

- ***The weird and the wonderful …***
  - ***Microseismic*** *– for hydraulic fracturing characterisation.*
  - ***Low frequency EM*** *– for dewatering and depressurisation studies.*
  - ***Cross well seismic*** *– same as above.*
  - ***Wireline other than gamma, density*** *– for characterisation of coal and interburden.*

A typical approach to exploration for CSG

- Review all petroleum, stratigraphic, coal & water wells in prospect.
  - Holes may open holed through sequence of interest, be too shallow or not logged.
- Review any regional seismic available, basin structural studies, regional topographic or satellite images.
- Do they have geophysical logs through the target coals?
  - (as an example, early on - the Walloons did not – at least in part, and sonic was used instead of density to estimate coal thickness).
- Can coals be correlated?
- Look for references to gas 'shows'.
- **Drill wells of your own! Exploration holes (quantify gas resource), then a couple of pilots (prove production potential) …**

Historical challenges

- Accurate estimation of Gas-In-Place (gas content, composition, net coal etc.) … ***role of geophysics?***
- Estimation of saturation (isotherms)
- Estimation of permeability
  - Initial absolute perm of system
  - Selection of appropriate relative perm curves
  - Changes in perm with depletion (effective stress, matrix shrinkage)
- Gas composition changes with depletion
- Accounting for multilayer behaviour … commingling?
- Accurate prediction of hydraulic fracturing or cavitation properties … ***role of geophysics?***

- **"Accurate estimation of basic reservoir and geomechanical properties remains challenging".**

from (Clarkson & Bustin, 2011)

The role of seismic

- Coal seam depth and structure!
- Structural relaxation zones – targets.
- Need accompanying log data from boreholes.

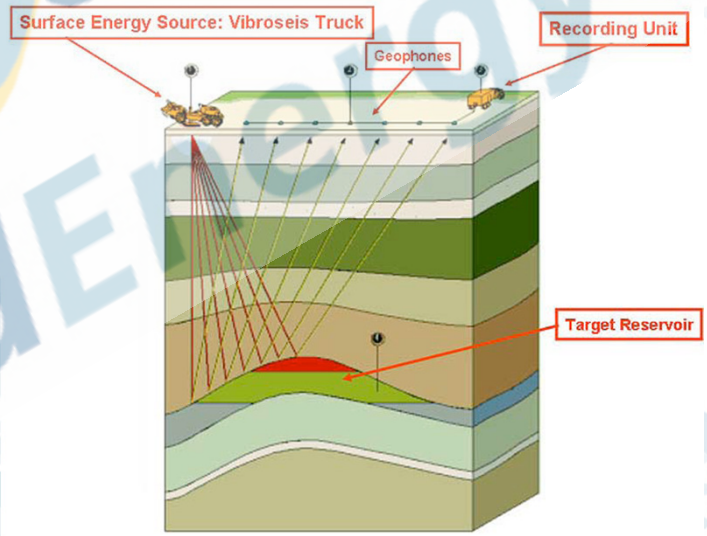
Probably the most important geophysical technology to be used in association with CSG exploration!

2D or 3D? Relative merits for CSG?

Seismic and coal

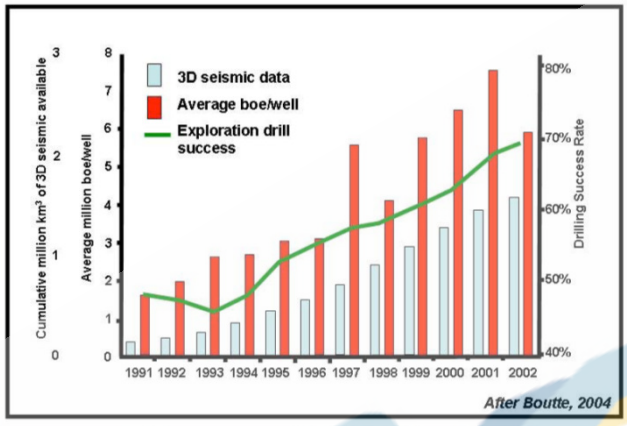
- Coal has strong contrast in seismic velocity and density with bounding strata.
- Although coal seams are extremely thin relatively to seismic wavelength, their large impedance contrast with surrounding rocks results in distinct reflections.
- Bulk density and seismic velocity may change after dewatering and gas injection (e.g. sequestration site).

Surface based seismic



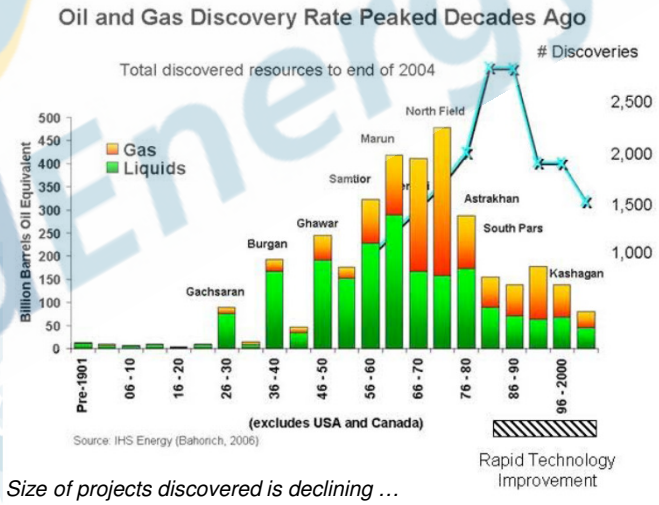
(Courtesy of Apache Corp)

Seismic (3D) has had a big impact upon exploration success in oil & gas industry



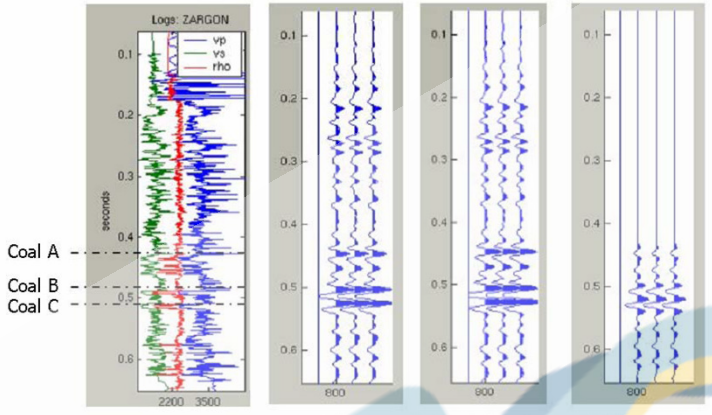
Now we are looking for the subtle features …
Has technology become a substitute for thinking ???

However, discovery rate is slowing …



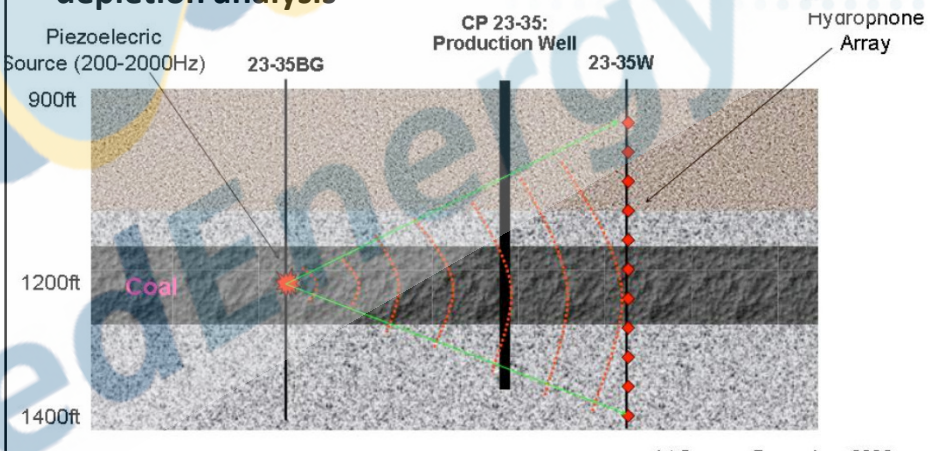
Size of projects discovered is declining …

Examples of dewatering change in seismic properties



(from Richardson, 2003)

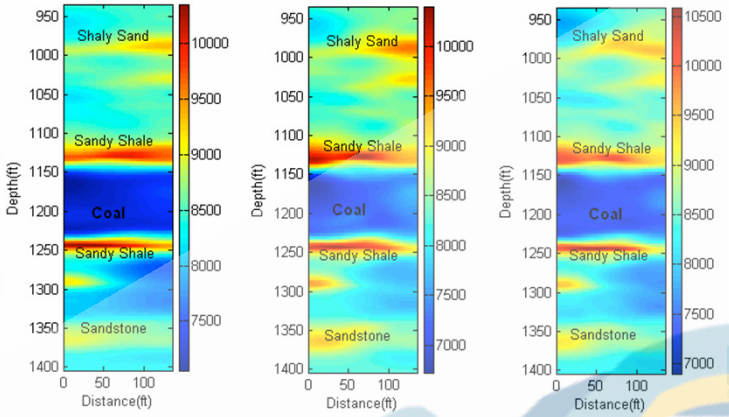
Crosswell seismic for pressure depletion analysis



1st Survey : December, 2002
2nd Survey : July, 2003
3rd Survey: June, 2004

(from Akintude, 2006)

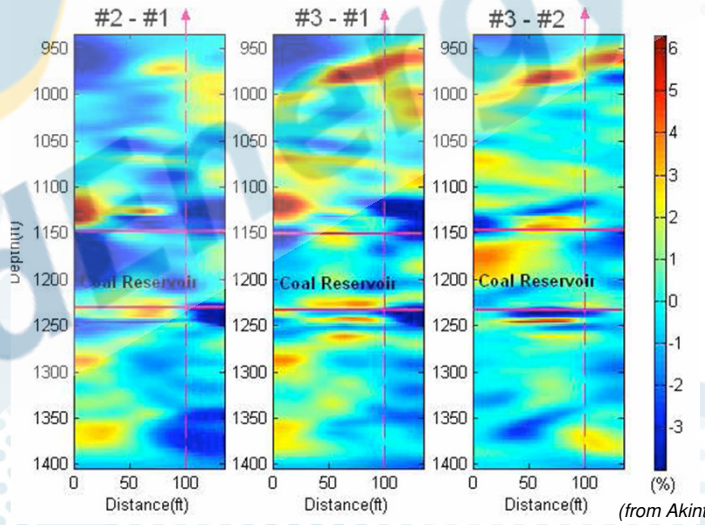
Baseline & repeat tomograms



... looks the same to me ...

(from Akintude, 2006)

Measured difference tomograms from time-lapse surveys



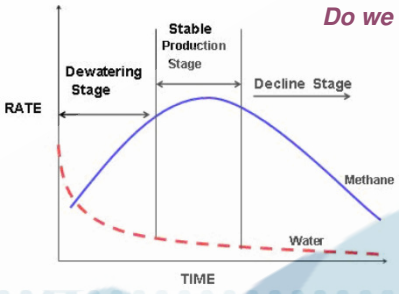
(from Akintude, 2006)

Now I see something! *(Scale ... 50m apart)*

"Dewatering or depressurization of coal beds during CBM production **perturbs the reservoir**, causing **changes in seismic and petrophysical properties**. Our results have demonstrated the usefulness of high resolution cross-well seismic in characterizing the CBM reservoir and mapping production-induced changes in seismic and reservoir properties. Quantitative estimation of these changes favors effective monitoring and **optimization of the CBM production process**".

(from Harris et al, 2004)

Do we believe this claim?



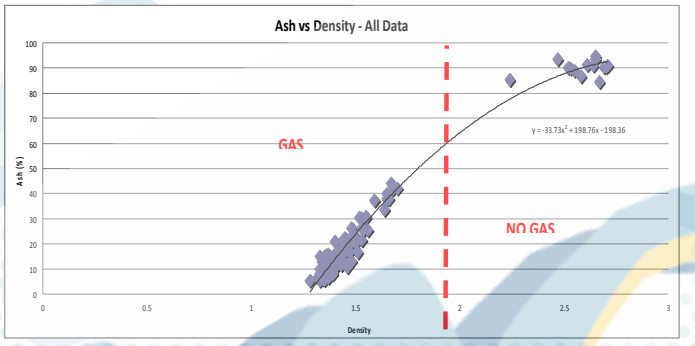
What has been achieved?

- Characterised production induced changes in P wave velocity in PRB's Big George Coal using time lapse cross-well seismic.
- Changes are small & non-uniform.
- Pressure drawdown from overlying sandy shale & is not spatially efficient in coal. Hmmm ….

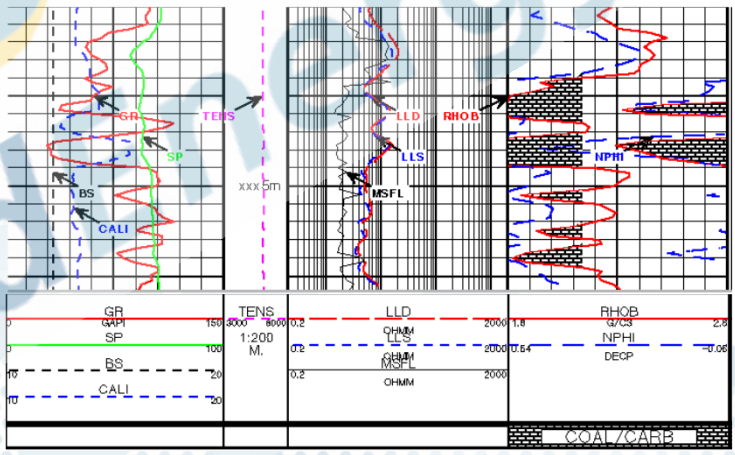
Methinks this cumbersome …

Wireline logs … how helpful?

- Important in all stages of CSG project evaluation.
- Delineation of coal layers, and coal quality.
- Essentials: density, gamma, caliper.
- Good to haves: temperature, neutron, resistivity, micro imaging tools, sonic.

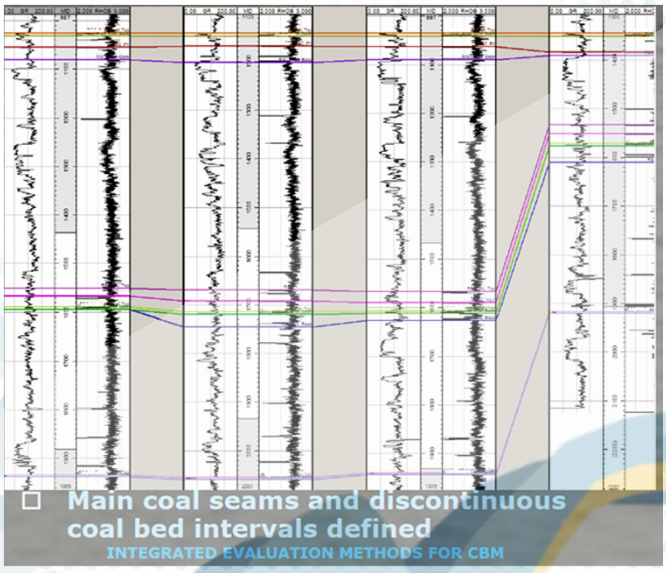


The value of logging …



(from Rao & Chakraborty)

Coal correlation & continuity analysis



- Main coal seams and discontinuous coal bed intervals defined

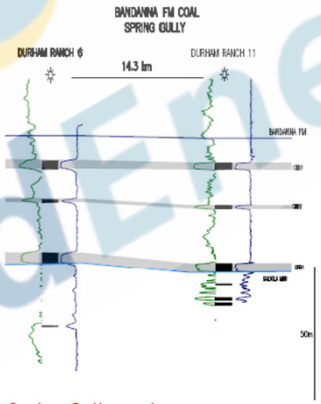
INTEGRATED EVALUATION METHODS FOR CBM

(from Phillips, 2006)

Let's discuss … !!!

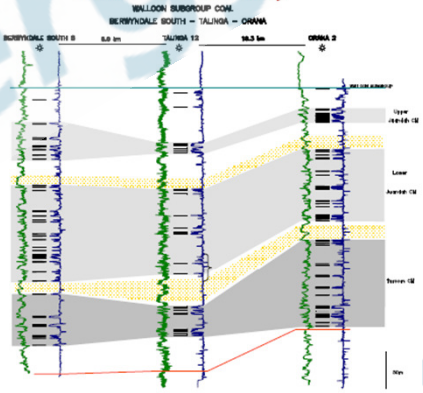
- What are the issues?

Spring Gully Coal Continuity



Spring Gully coal seams are continuous over many ten of kms

Walloon Coal Variability



Walloons coal seams are thinner and the packages which contain the seams vary in thickness across the area

CSG and fracture detection

- Cleat direction likely determines preferential direction for optimal placement of horizontal wells. Cleat aperture width and stress condition important – **perm is king!**
- Can we work out cleat direction from electrical images in vertical well bores? Yes. Borehole imaging technology works in vertical wells.
- What about the horizontal wells?
- Resistivity, gamma, neutron porosity, density porosity do not cut it when it comes to cleat identification.
- What about horizontal wells? (In principle, good … but risks re wellbore stability). High angle wireline data acquisition not easy.
- Compact memory shuttle a winner. (E.g. Compact Micro Imager)

Delineation of faults, fractures

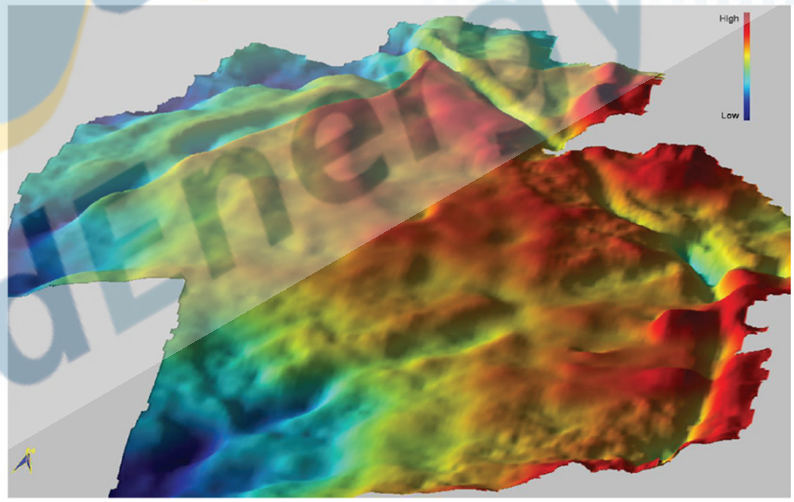


Figure 6: Base Mannville coal time structure map (3D view).

(from Hyland et al, 2010)

Positive curvature to show flexure

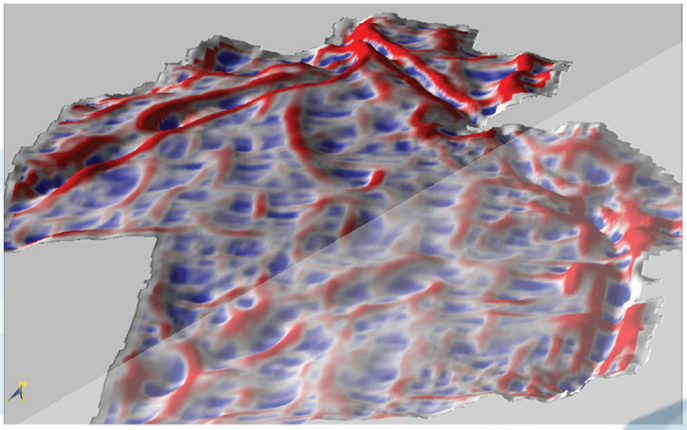


Figure 7: Base Mannville coal most positive curvature map; the red color shows positive flexure zones where secondary fracturing is caused by local stress variation.

(from Hyland et al, 2010)

Petrel's 'ant tracking'

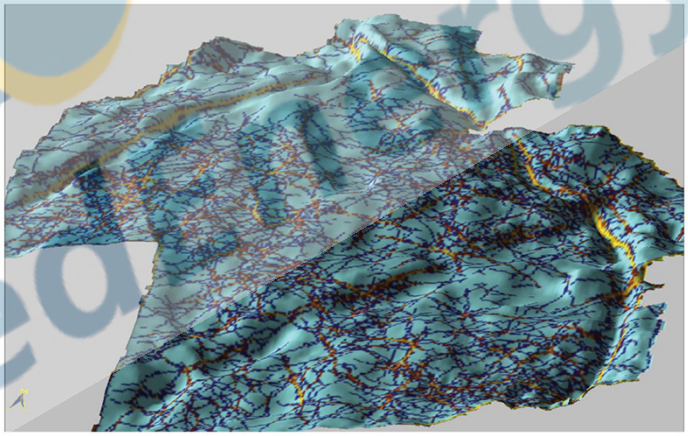
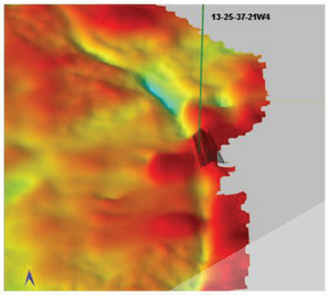


Figure 8: Base Mannville coal fault/fracture pattern from "Ant Tracking". Higher confidence discontinuities are shown in brighter colors.

(from Hyland et al, 2010)

Localised flexure …



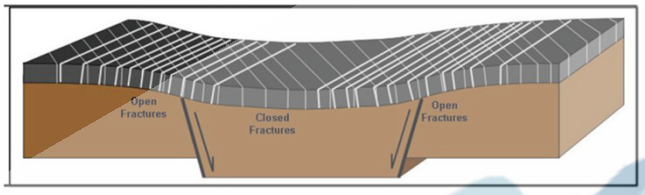
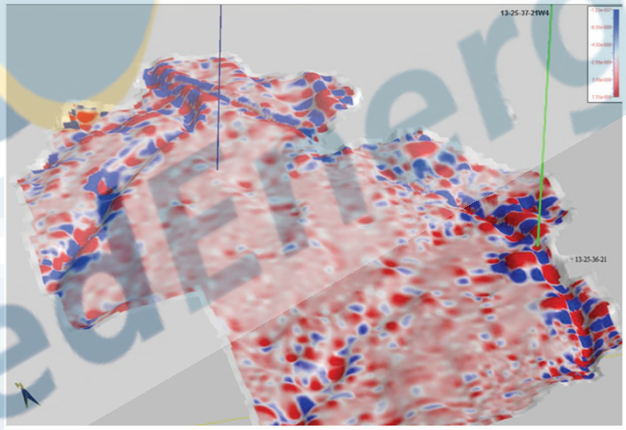
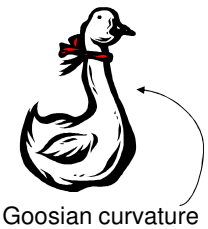


Figure 9: Mechanism of secondary fracturing near 13-25-36-21w4 wellbore. The coal seam is locally deformed by normal faulting of the underlying sediments; on the flanks, open secondary fractures will appear due to the local extensional stress; in the lower block the fractures will be closed due to the local compressional stress.

(from Hyland et al, 2010)

Gaussian curvature – enhanced permeability?





Goosian curvature

Figure 10: Top Mannville coal Gaussian curvature. Note the location of 13-25-36-21W4 in a highly anomalous area.

Fracture logs & Gaussian curvature

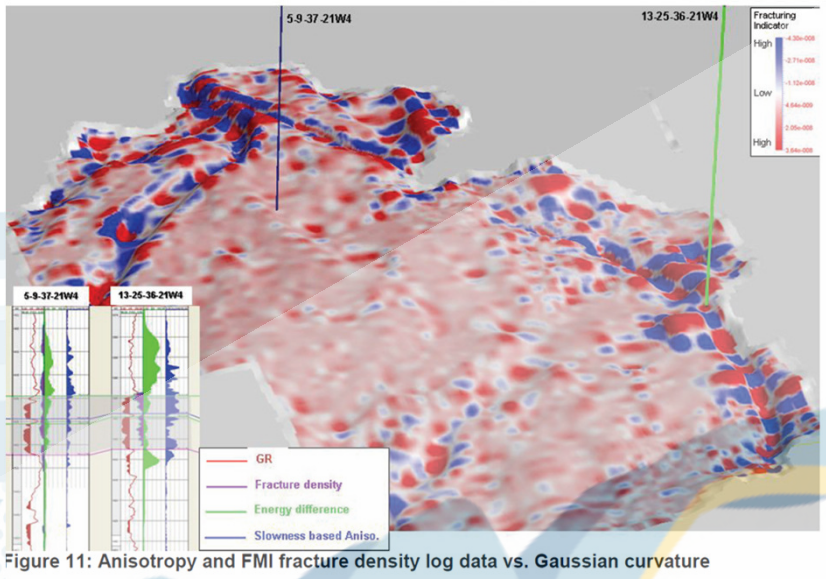
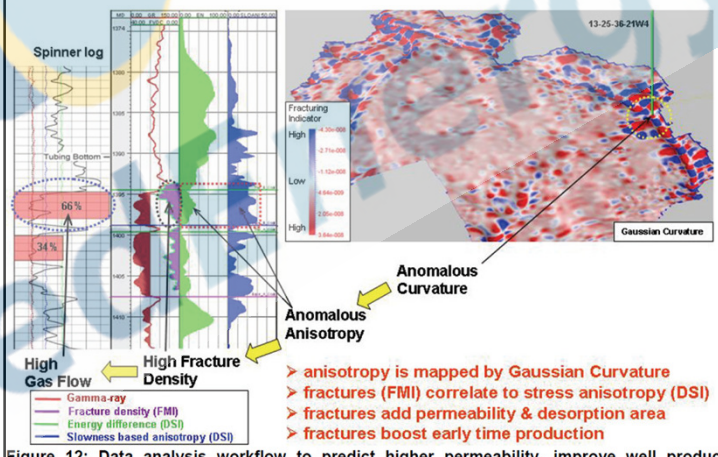


Figure 11: Anisotropy and FMI fracture density log data vs. Gaussian curvature

Bringing it all together …



- anisotropy is mapped by Gaussian Curvature
- fractures (FMI) correlate to stress anisotropy (DSI)
- fractures add permeability & desorption area
- fractures boost early time production

Figure 12: Data analysis workflow to predict higher permeability, improve well productivity, reserve recovery and ultimately capital efficiency

Stress and the state of aperture 'openness'

CoalBedEnergyConsultants

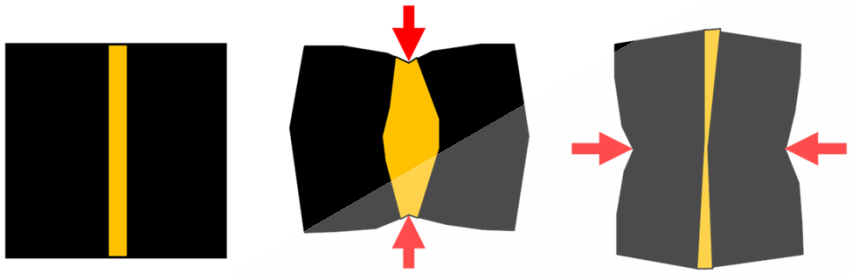


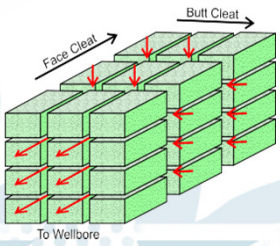
Figure 5: Aperture change of coal discontinuities resulting from change in main stress direction; main stress direction shown with red arrows; no main stress direction (left), main stress direction parallel to discontinuity (center) and perpendicular to discontinuity (right)

(from Ryba et al, 2011)

CoalBedEnergyConsultants

Definition of 'face' and 'butt' cleats

- Face cleats are dominant and form "parallel to the principal stress direction".
- Butt cleats form orthogonal to face cleats but do not cut across them.



May be several superimposed phases of cleat formation …

Maceral content also plays a part …

- More cleats in vitrinite.
- Less cleats in inertinite.

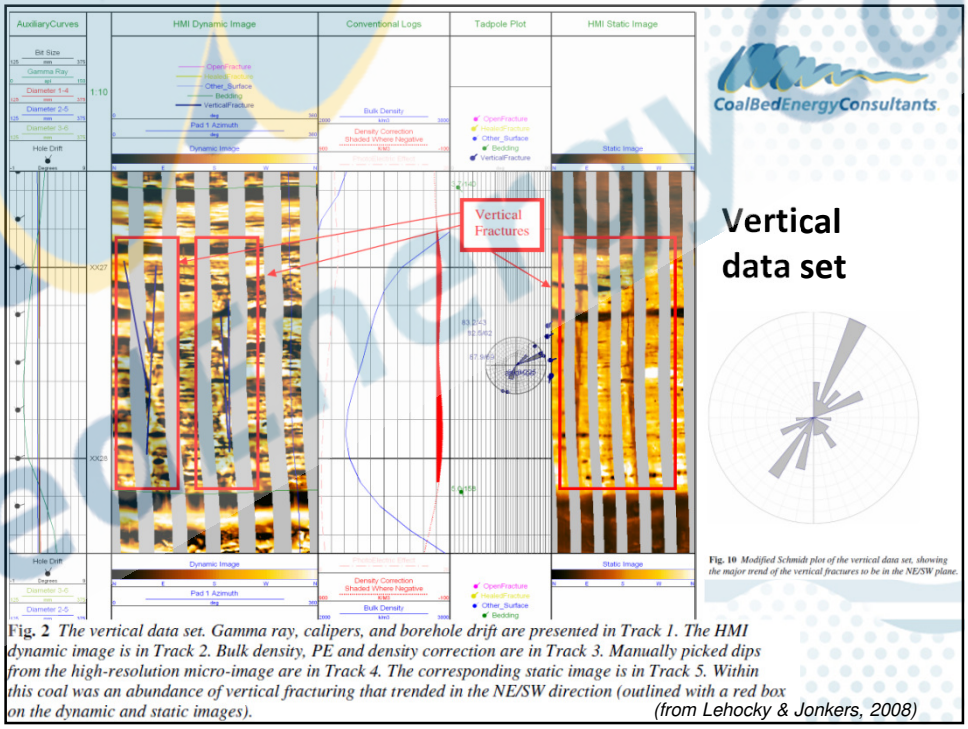
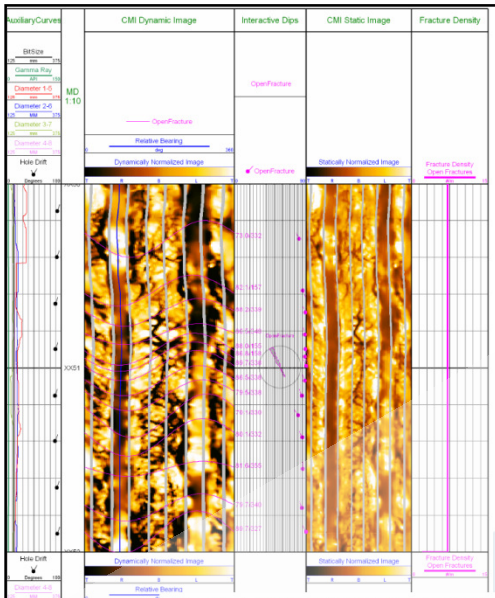


Fig. 2 *The vertical data set. Gamma ray, calipers, and borehole drift are presented in Track 1. The HMI dynamic image is in Track 2. Bulk density, PE and density correction are in Track 3. Manually picked dips from the high-resolution micro-image are in Track 4. The corresponding static image is in Track 5. Within this coal was an abundance of vertical fracturing that trended in the NE/SW direction (outlined with a red box on the dynamic and static images).*

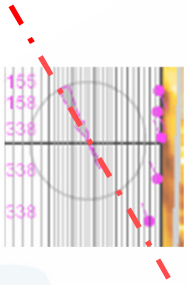
Fig. 10 *Modified Schmidt plot of the vertical data set, showing the major trend of the vertical fractures to be in the NE/SW plane.*

(from Lehocky & Jonkers, 2008)



CoalBedEnergyConsultants

CMI horizontal example



Major cleat direction

Fig. 13 *A CMI shuttle example horizontal data set. Gamma ray, calipers, and borehole drift are presented in Track 1. The CMI dynamic image is in Track 2. Manually picked dips from the compact micro-image are in Track 3. The corresponding static image is in Track 4. The calculated fracture density is presented in Track 5. Within this image was the presence of fracturing trending in the NW/SE plane.*

(from Lehocky & Jonkers, 2008)

CoalBedEnergyConsultants

Stress direction and open fractures

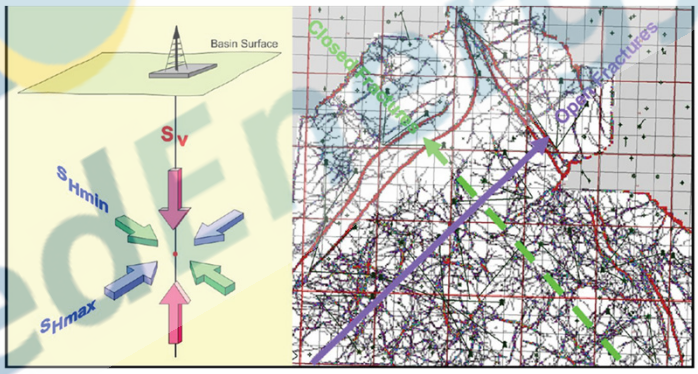
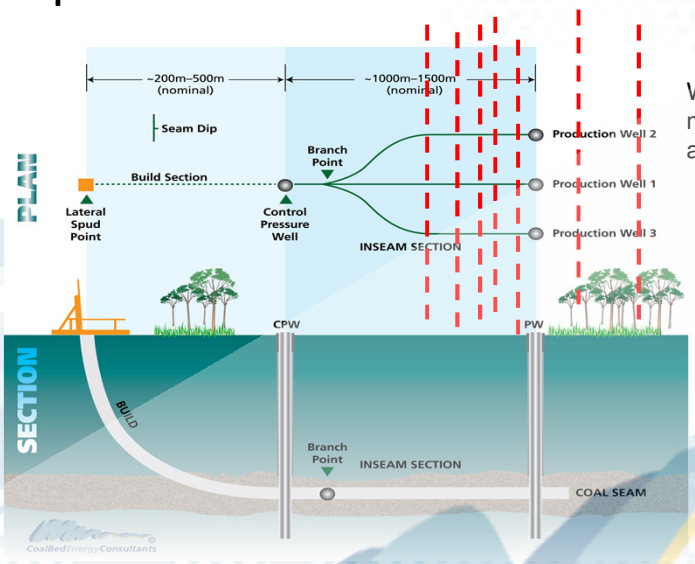


Figure 3: Preferred fluid flow directions in fractured/unfractured reservoirs that aligned with the axis of the larger horizontal principal stress (SHmax); In a fractured reservoir, open fractures will be parallel to SHmax and closed fractures will be perpendicular to SHmax.

(from Hyland et al, 2010)

Implications for laterals



Want to hit as many of these as possible!

More work on image logs …

- Can help with assessing borehole breakout … important for determining stress direction.
- Full waveform sonic can:
  - Identify stress profile
  - Help with fracture characterisation – cleat intensity!

"Acoustic log signatures vary from one seam to another based on density of cleat development "… *(Ali et al, 2008)*

What is your experience with image logs?

Steeply dipping cleats from image log

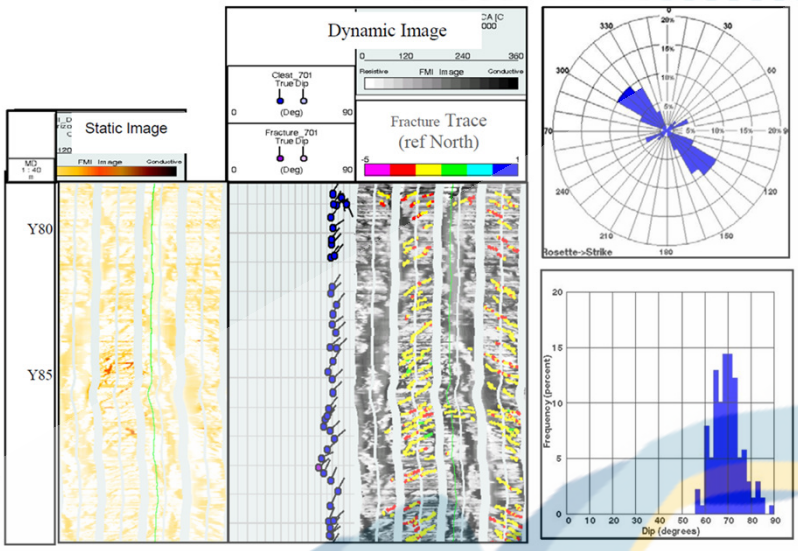


Figure 5. Intensely fractured coal seam (seam number 7) with most of the cleats dipping above 65°. The strike azimuth of the dominant cleat set is towards NW-SE.

(from Ali et al, 2008)

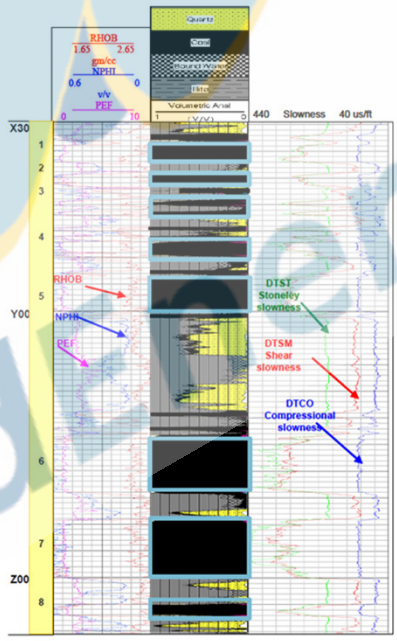


Figure 2: Composite plot of bulk density, neutron porosity, PEF measurement, compressional, shear and Stoneley slowness along with identified coal beds. Compressional slowness in most of coal beds are in range of 122-130us/ft and density is in range of 1.45-1.55 gm/cc.

(from Ali et al, 2008)

- Relationship between max horizontal stress and face cleat is such that if parallel to cleat = face cleats remain open. If not …
- Stoneley waveform transmissivity analysis provide new approach for understanding cleating in coals.
- Resistivity and sonic image assist with identification of cleat density.

CoalBedEnergyConsultants

Perm is king, and most perms are low!

- This technology will be very important in years to come. Need to characterise **perm directionality** as a priority in many low perm terrains.
- Image vertical wells.
- Use CMI technology in laterals.
- It will not help with micro cleats but will help with big picture.
- Can use CMI to help with production logging & interpretation.

CoalBedEnergyConsultants

Hydraulic fracture analysis

Bound to be very important in time …

- How far?
- Which direction?
- Was it effective?

- **Microseismic?**
- **Multifractured horizontal SIS wells …**

Microseismic for frac monitoring …

CoalBedEnergyConsultants

"The essential problem with a hydraulic fracture is that typically the engineer has no method of imaging where the stimulation fluid went once it enters the borehole" … *(Maxwell, 2007)*

- **Concept:** passive seismic monitoring of micro earthquakes to image the fracture network created during hydraulic fracturing stimulation.
- **Goal:** improved reservoir engineering.
- Microseismic a niche technology? ***What do you think? Who has experience of it in this room?***
- **How deployed:** an array of triaxial geophones in a single monitoring well, used to record seismic waves associated with the frac.
- **Tricks for young players:** recording sensitivity and resolution are critical aspects to interpret any microseismic image.

Horizontal wells & hydraulic fracturing

CoalBedEnergyConsultants

- **Red:** frac only really effective around heel.
- **Blue:** Much more effective frac, worked over entire length of hole.

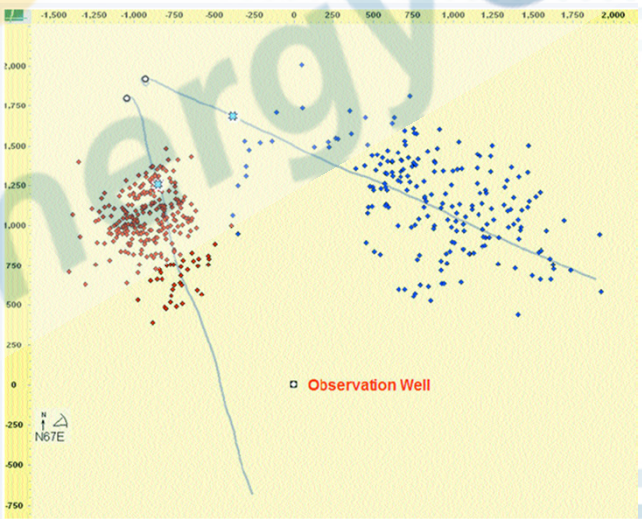


Figure 2. Map view of images of two hydraulic fracture images. The SW well with red microseisms was fraced first, followed by the NE well with blue microseisms that fraced second. *(from Maxwell, 2007)*

Face & butt stimulation!

- Clear preferred orientation that reflects fracture network.

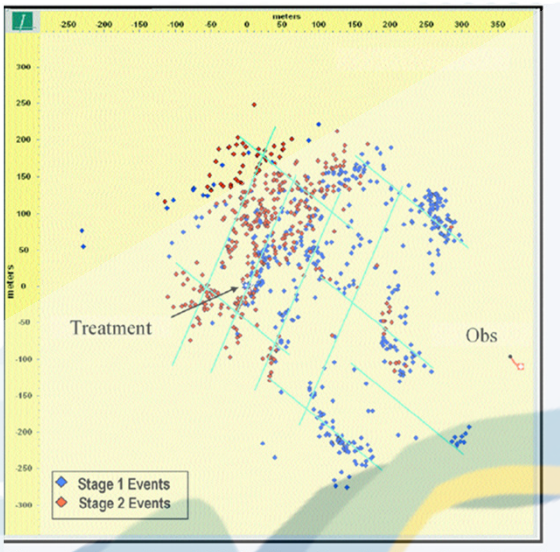
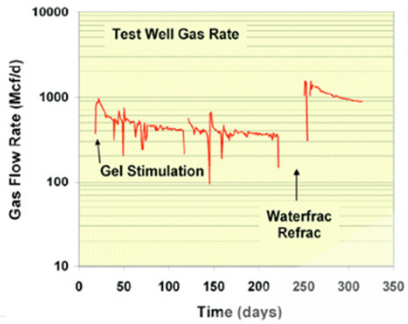


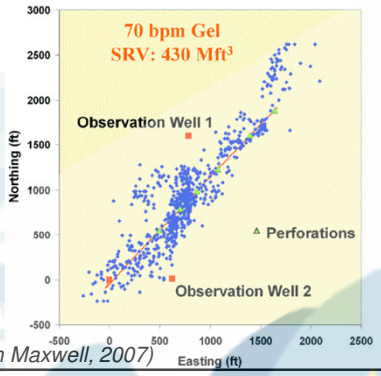
Figure 3. Map view of CBM stimulation showing stimulation of multiple fracture sets. (from Maxwell, 2007)

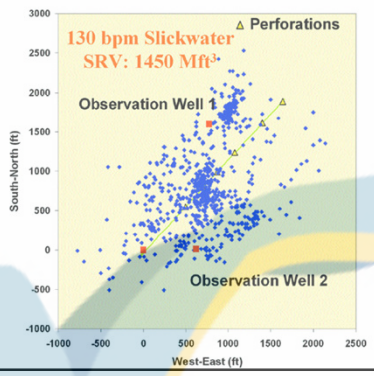
Holy grail of microseismic …

- Optimizing the fracture job for the desired fracture length and height,
- Determining the fracture orientation to better locate in-fill drilling locations,
- Better design and fracture staging to effectively cover all of the pay zones.

Clear improvement in production after 2nd frac!

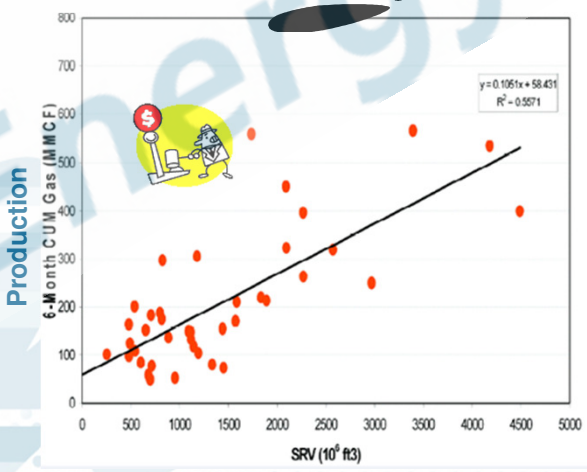






(from Maxwell, 2007)

Big fracs seem to work!



Size of frac ("stimulated reserve volume")

Pressure depletion analysis …

- Infill drilling target identification? Low frequency EM?
- Passive EM 30-300 Hz (Qin, 2008). Adsorption of gas impacts EM radiation.

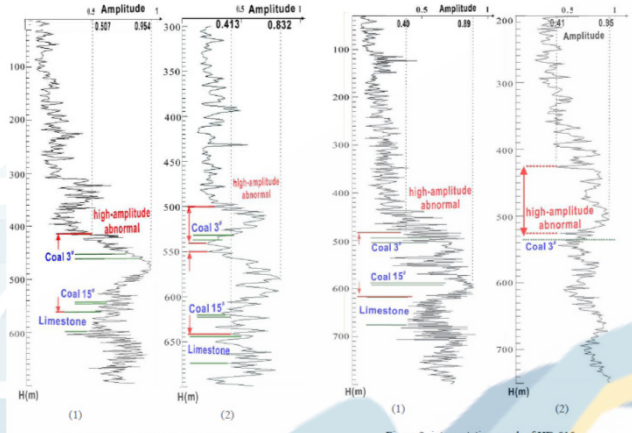


Figure 1: interpretation graph of HD-010 and HD-011 measuring point about ultra-low frequency electromagnetic curve in hudi test area

Figure 2: interpretation graph of HD-015 and P1-3 measuring point about ultra-low frequency electromagnetic curve in hudi test area

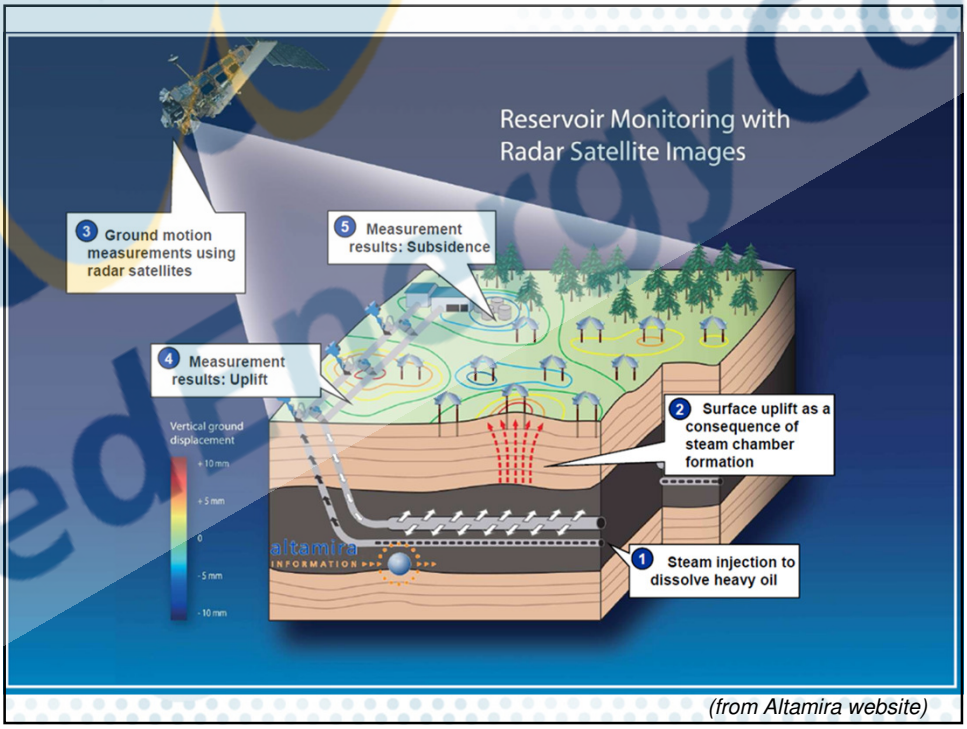
Let's talk about this …

- What are these researchers trying to achieve, and do we think there is merit in the approach?
- Does anyone remember "LOTEM" technology … which I think is similar …

CoalBedEnergyConsultants

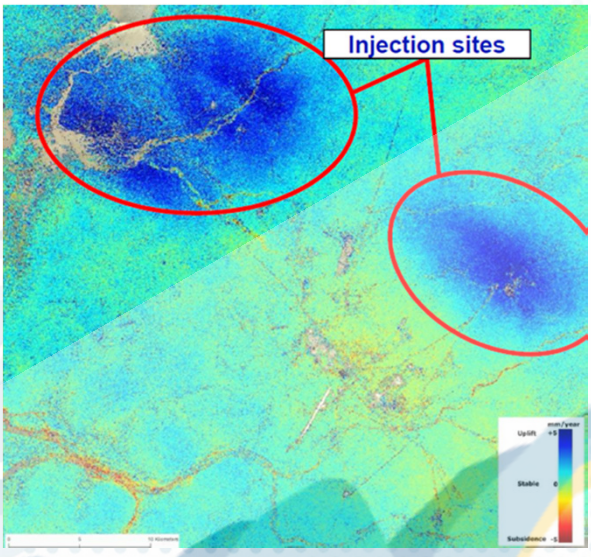
Satellite imaging technology

- Radar satellites
- Work on basis of high precision measurement of ground deformation … ***useful for regional reservoir depletion analysis?***
- Measurement frequency can be weekly, monthly, quarterly …



(from Altamira website)

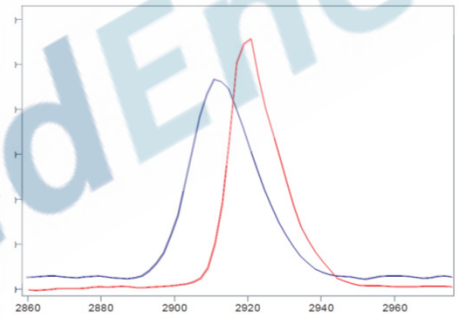
Example of InSAR monitoring of CO2 injection site



(for further information … see john bradshaw at cgss, canberra

Measuring gas content via Raman spectroscopy

- Method pioneered for CSG applications by Welldog Inc. of USA.



Raman spectra at 1,400 psi of methane production gas (red line) and methane solution gas (blue line). Solvation of the methane causes a shift to lower energy for the solution gas peak.

Some general observations

- As the locations of coal basins are well known the emphasis for exploration is **not finding new reserves** … it is in fact, more about getting more bang for the buck from production & completion techniques.
- The trend is for geophysical activities to be **heading downstream** …

This is where the action is!

End of 'what is going on' module …

"More sharks here than in your average CSG junior board …"