Subsurface High-Grading in CSG/CBM Provinces: Implications and Illustrations for Appraisal and Development*

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Search and Discovery Article #40927 (2012)**
Posted May 21, 2012

*Adapted from oral presentation given in Singapore at the Geoscience Technology Workshop (GTW) on Unconventional Hydrocarbons, 15-16 March 2012

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General Comments

CBM sweet-spotting through subsurface high-grading studies
- A statistical impact – distribution shift
- Understanding the scale at which the optimization can be made

Integration of information is key to success.
- Defining success correctly: a statistical impact – distribution shift
- Sweet-spotting of net coal thickness locally can positively impact appraisal and estimate of reserves, but also can potentially impact development.
- Deliverability and drainage optimization are achieved through integration and mapping of data at different scales.

Manufacturing model for coal-seam gas development still remains adequate and necessary; however, we can be a more discerning manufacturer!

References

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Subsurface High-grading in CSG/CBM provinces

implications and illustrations for appraisal and development

LEAP Energy

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Introduction

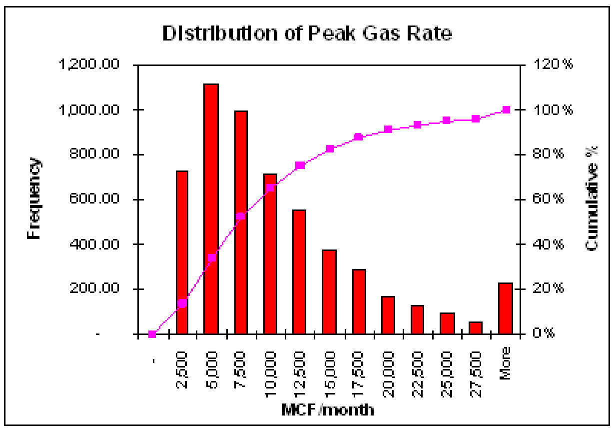
- Why this talk :
  - Often heard myth : 'Sweet-spotting is not possible' in CSG, manufacturing-like approach is only recourse
  - Demonstrate that in a non-conventional sense, significant high-grading is possible
- Optimization is possible, but not at single well scale
  - See CSG through a statistical lens
  - Sweet-spotting geared towards statistical improvement, not well by well
  - Distribution shift
- Illustration
  - Volume in-place high-grading, and guided appraisal / development through seismic
  - Deliverability and drainage optimization

Footnote: Examples from real studies, but outcomes have been significantly distorted to conserve strict confidentiality

General characteristics of CSG provinces

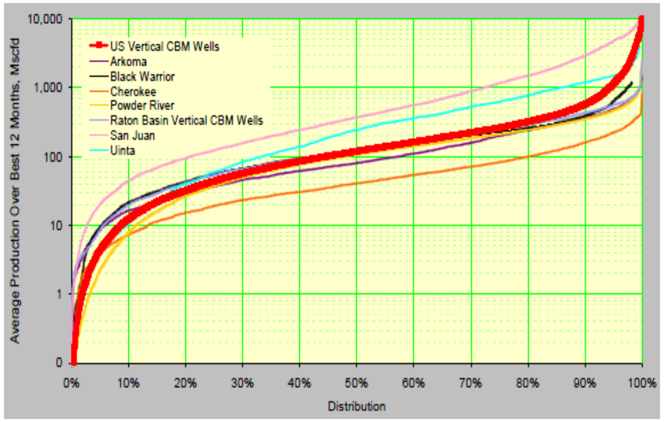
- Large areas, multiple seams, very variable reservoir characteristics within short distances

- Significant inter-well variability, deliverability (perm) and recovery follow lognormal distribution



Source : SPE 107308
G.Swindell (2007)

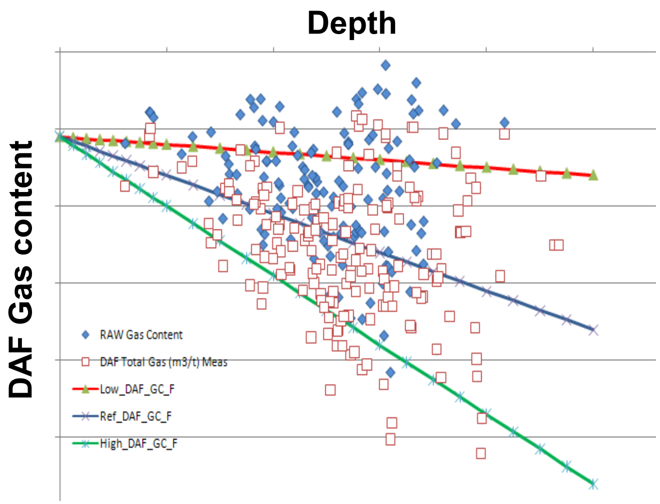
Source : AAPG 2006
C. Boyer

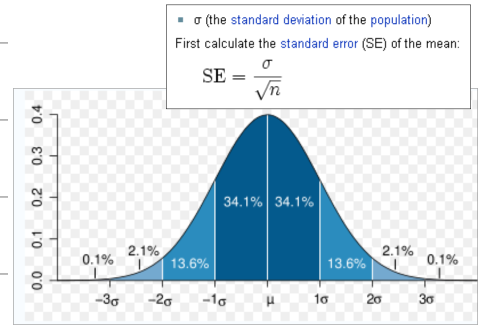


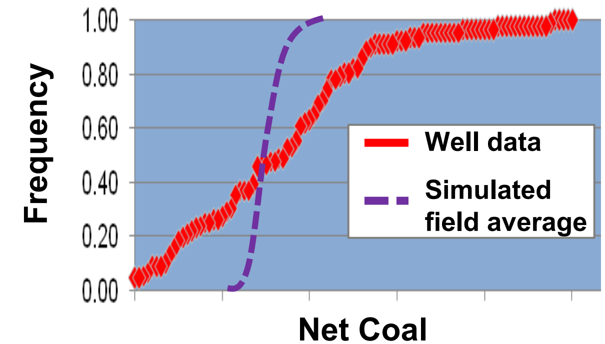
(Geo-) Statistical techniques are fundamental to :

- Understand Value Of Information – what confidence can be given to sparse data
- Concept select decisions under variability
  – distribution of the possible outcomes vs. the ‘type curve’
- Averaging (upscaling) a range of possible outcomes into a single curve

Viewing CBM provinces through a statistical lens

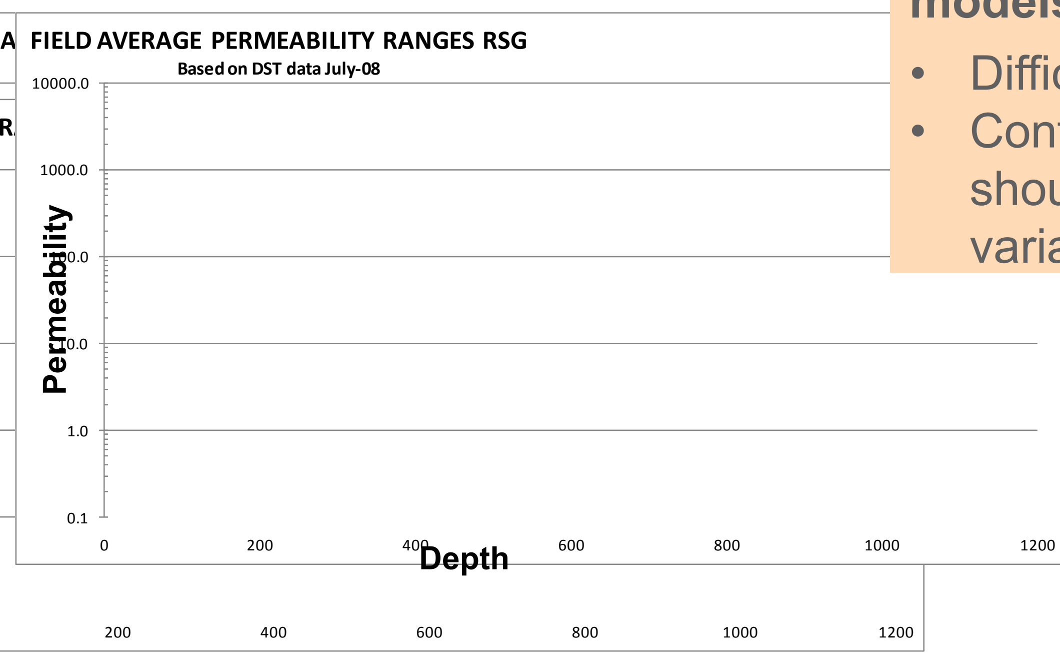




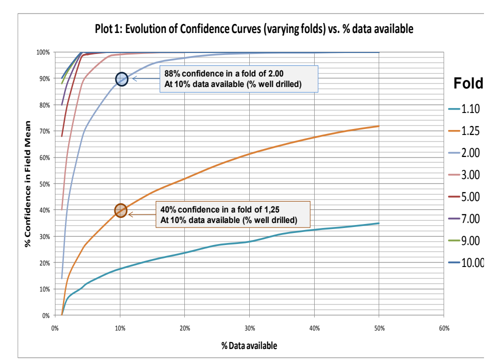


Most reservoir parameters exhibit significant variability around overall trend models :

- Difficult to predict individual well outcomes
- Confidence in field-average estimates should increase with further appraisal, variability remains



Some techniques available for
terizing uncertainty from variability and
ailable data to date



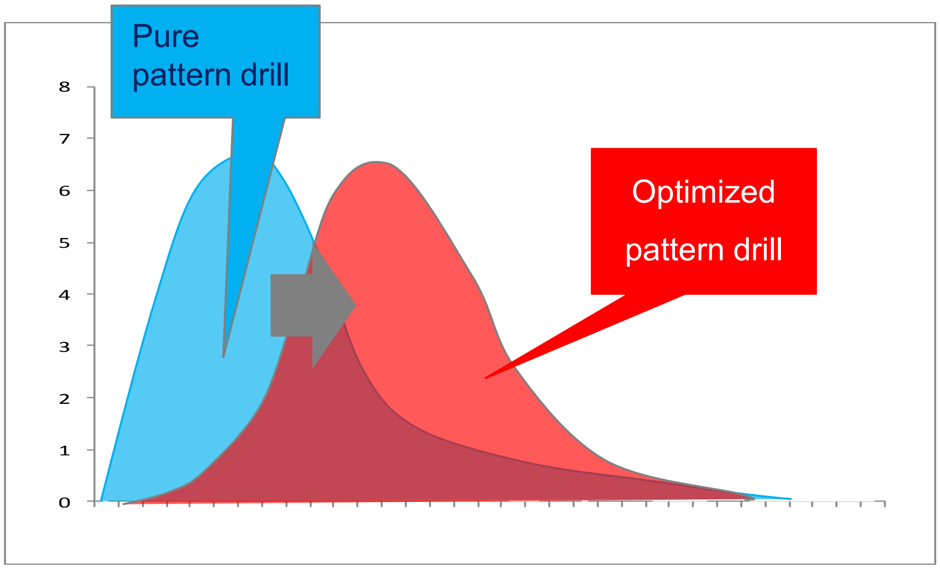
Confidence curve –SPE-133518

Subsurface High-grading studies : Integration of disciplines and reservoir data to achieve a distribution shift

Geophysical	Geological	Petrophysical	Reservoir Eng.
Structural deformation Faults Coal wash-outs High net coal mapping	Fracture interpretation from core Structural history Tectonic history	Borehole image Breakouts and fracture interpretation	DST interpretation Formation testing

Outcome improvement

UR/well or Peak Rate

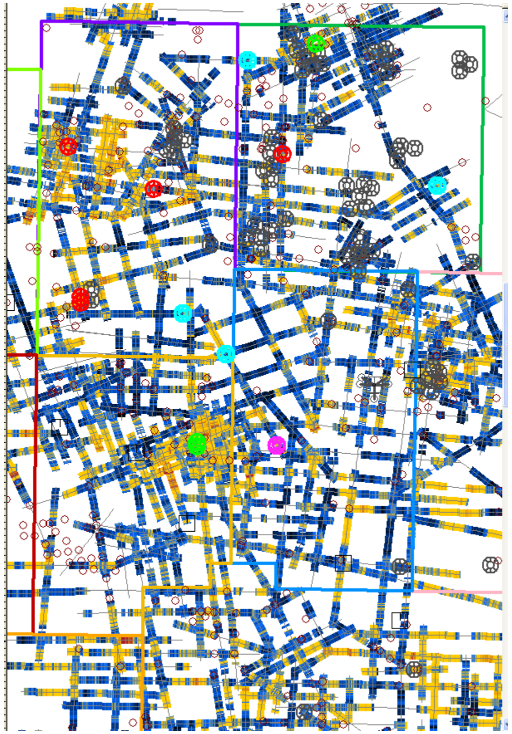


Increase the probability of drilling **higher deliverability** wells

Increase the probability of drilling **higher GIP/km2** wells

Case Study (1)
Seismic based coal prediction

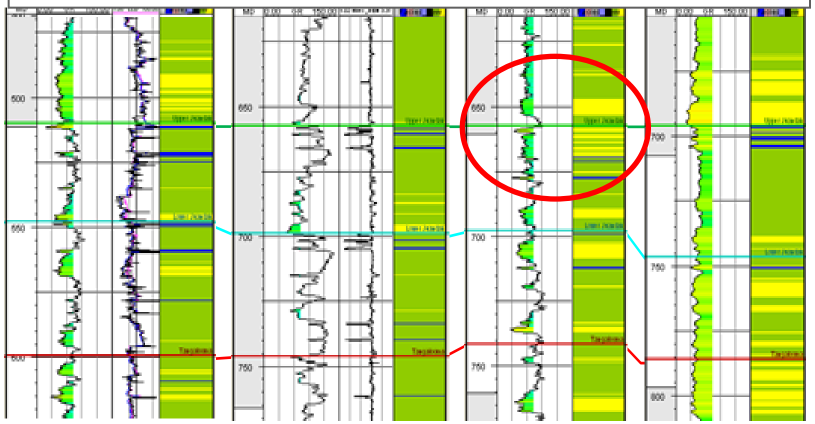
LEAP Energy

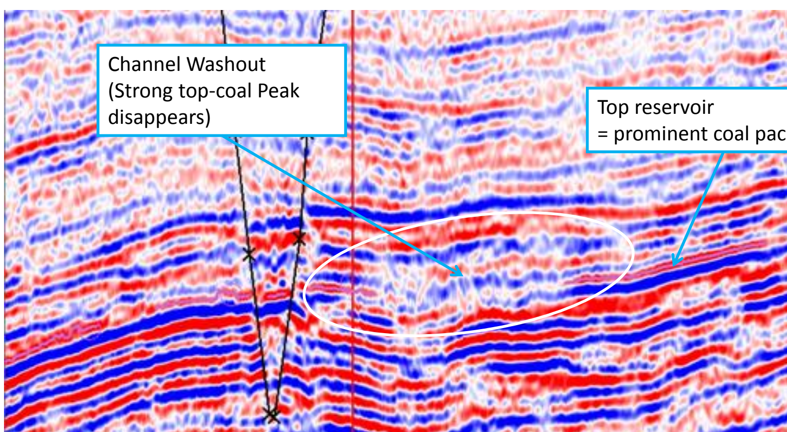


- **The opportunity :**
  - go beyond 'blind' drilling at appraisal and development phase, and target areas of suspected better coal thicknesses
  - 2D seismic data available over a very large development area
- **The challenge :**
  - multiple vintages of 2D seismic, variable quality
  - Bundles of thin coal seams, difficult to image individually
- **The workflow :**
  - Stratal slicing, attempting to image bundles of coal seams
  - A/B techniques to normalize amplitudes between surveys
  - Quality index of lines/areas computed from seismic synthetics
  - Net coal predictability tested first
  - Gridding/interpolation between seismic lines

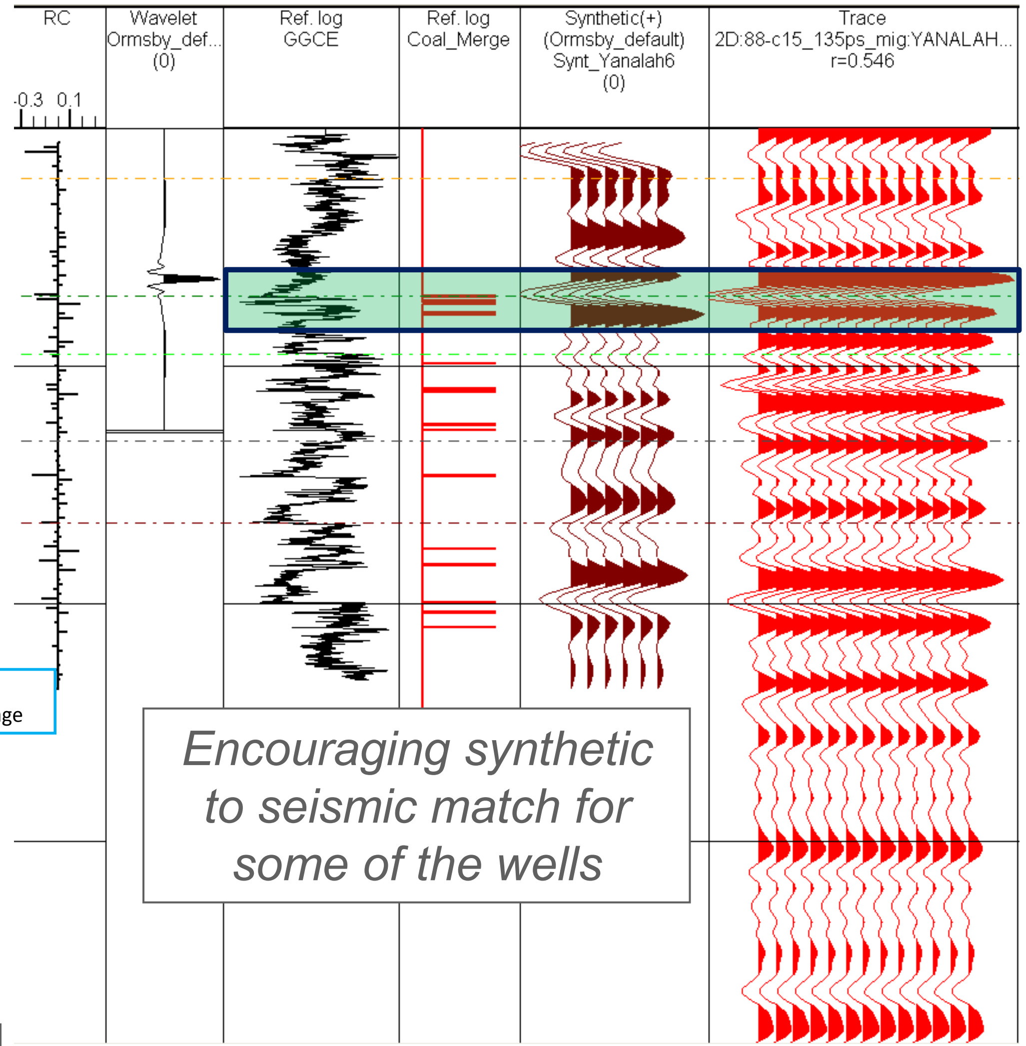
Case study (1)
Qualitative indications of high-grading potential

Indications of channel-related “coal wash-outs” in wells





Suggestion of “channel wash-outs” on selected seismic lines



Encouraging synthetic to seismic match for some of the wells

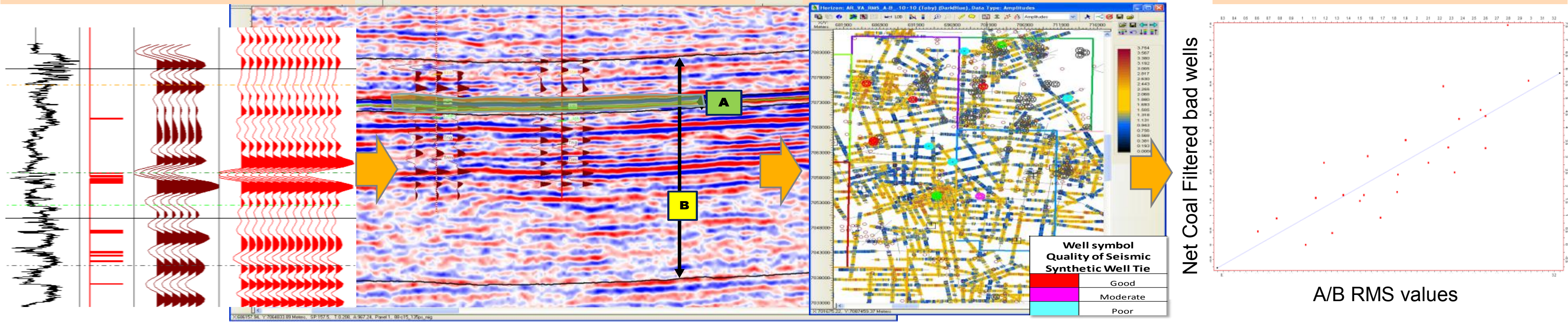
Case Study (1) workflow for Net Coal prediction from 2D seismic

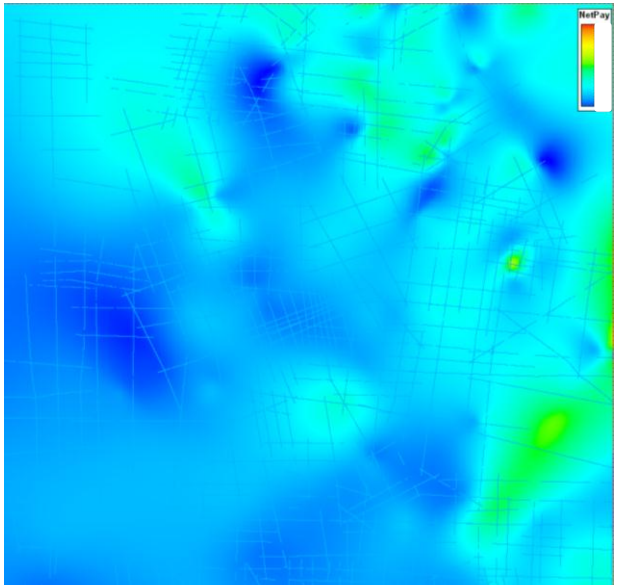
Perform synthetics and define goodness of tie

Define A/B windows and extract amplitudes

Generate maps and overlay goodness of tie

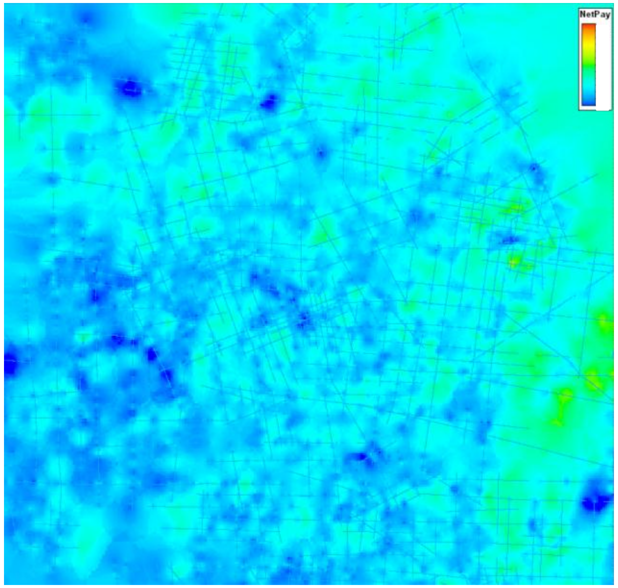
Verify statistical tie of Amplitude vs. NetCoal





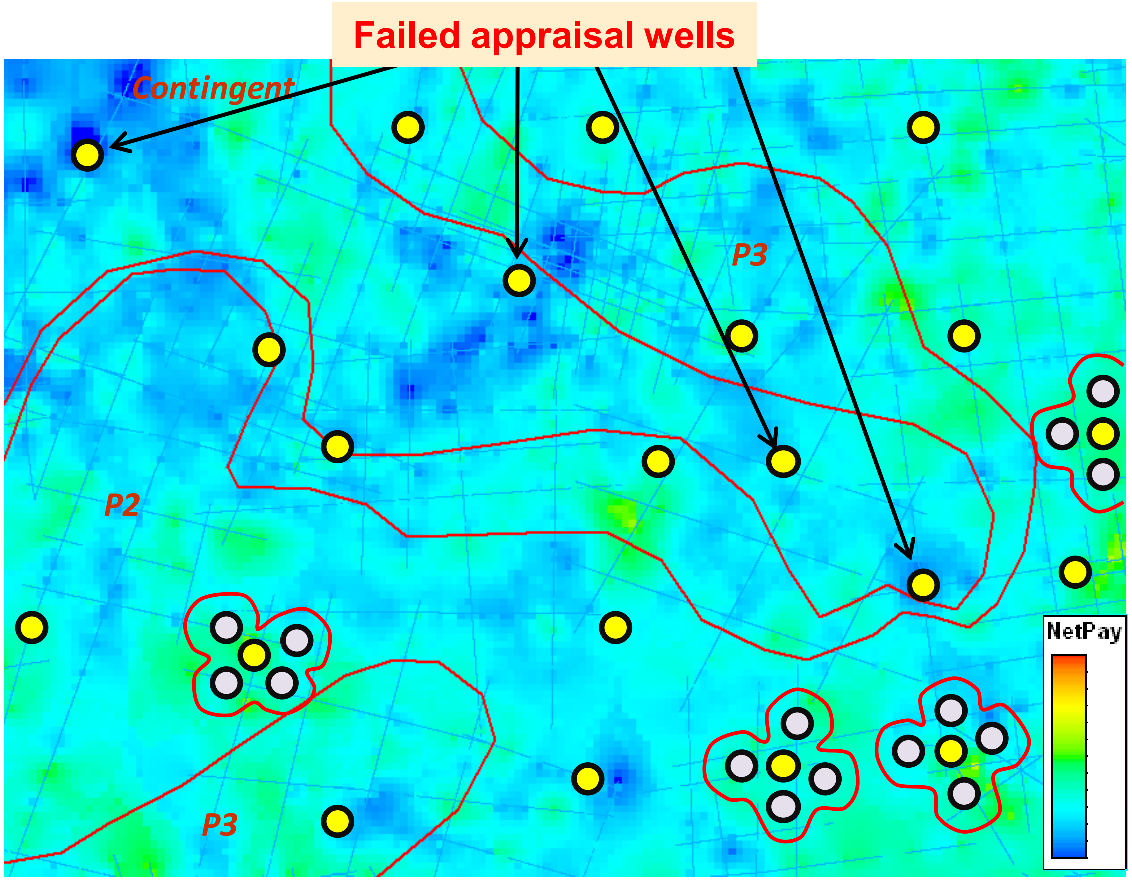
Net coal map based on well gridding only

Integration of geophysical data



Wells & seismic constrained net coal map

Impact of seismically constrained net coal mapping on appraisal and pilot location selection



Color shade shows seismically constrained net coal mapping.

Red polygons correspond to resource categorization areas which are currently based on well data gridding only

Appraisal wells are shown in yellow, pilot wells in light purple. Well planning to date was done w/o seismic.

Like in most cases, resource areas were defined by interpolation of sparse well data. Consequently, large sectors are being downgraded based on just one or two bad well results

It is obvious how the seismic may help a more optimum selection of appraisal and pilot locations and consequently a more effective resource maturation strategy.

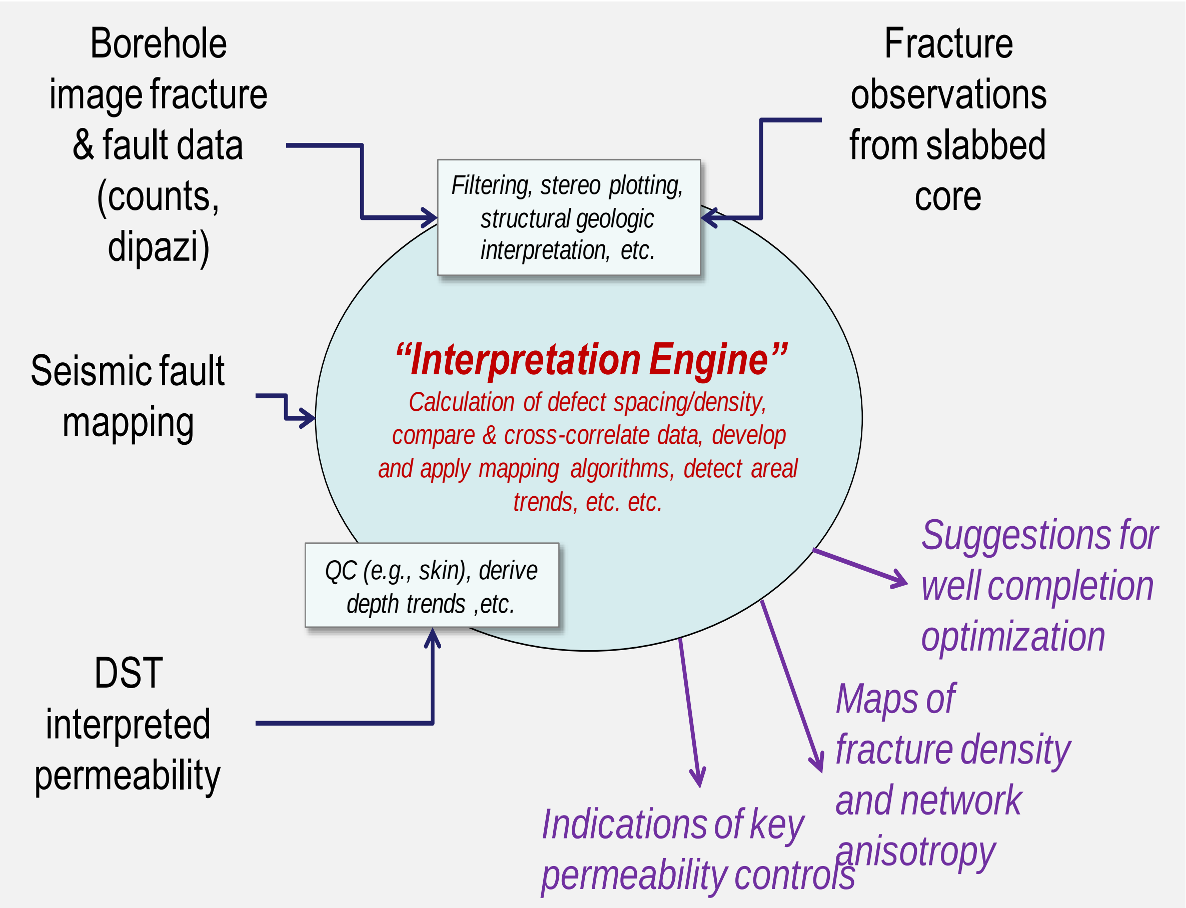
Case Study (2) Natural fracture system characteristics prediction

The opportunity :

- Utilize combination of borehole image, seismic and well test data to understand and optimize drainage pattern, and identify possible areas of increased permeability

The challenge :

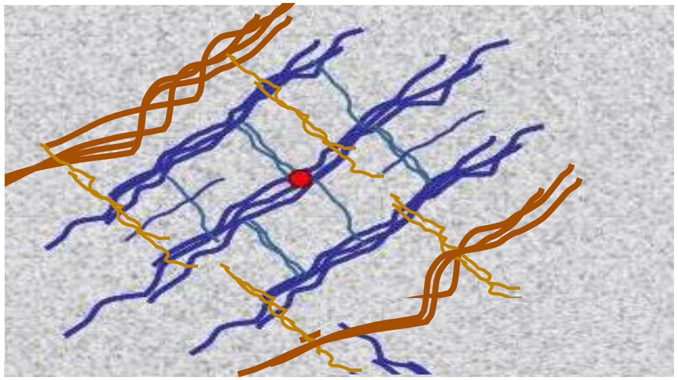
- Non-traditional workflows need to be developed to create maps of natural fracture system
- Translate various source of data into (semi-) quantitative assessment



Key elements of the fracture network characteristics and optimization opportunities

Orientation
Maximize fracture intersection through azimuthal deviated drilling

Intensity
Determine areas of increased permeability (sweet-spots) to adapt spacing and



Anisotropy
Optimize spacing in different areas of the field
Non-regular spacing orientation

Proposed workflow for drainage pattern optimization

Integration of Geophysics, Geology and Reservoir Engineering

Seismic Mapping

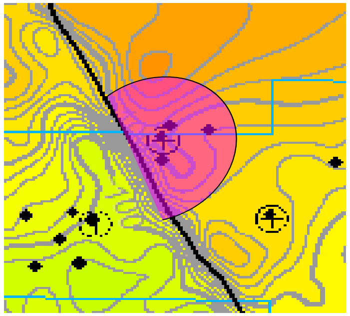
Core interpretation

Borehole images

Well testing / DST

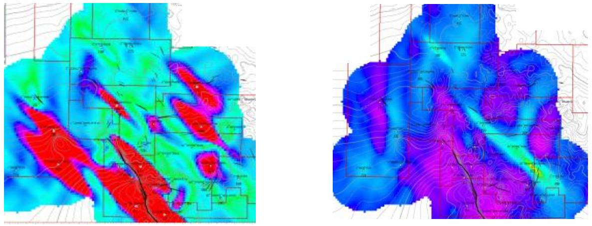
Drainage constraints mapping

Indentify key structural features and therefore possible impediments to drainage

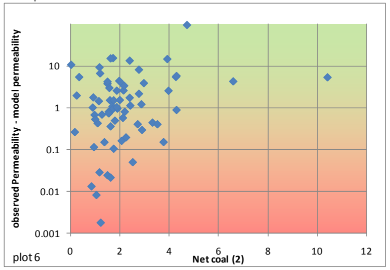


Presence of faults can be assessed and corroborated with DST interpretation (barriers)

Map permeability distribution characteristics – possible intensity and anisotropy

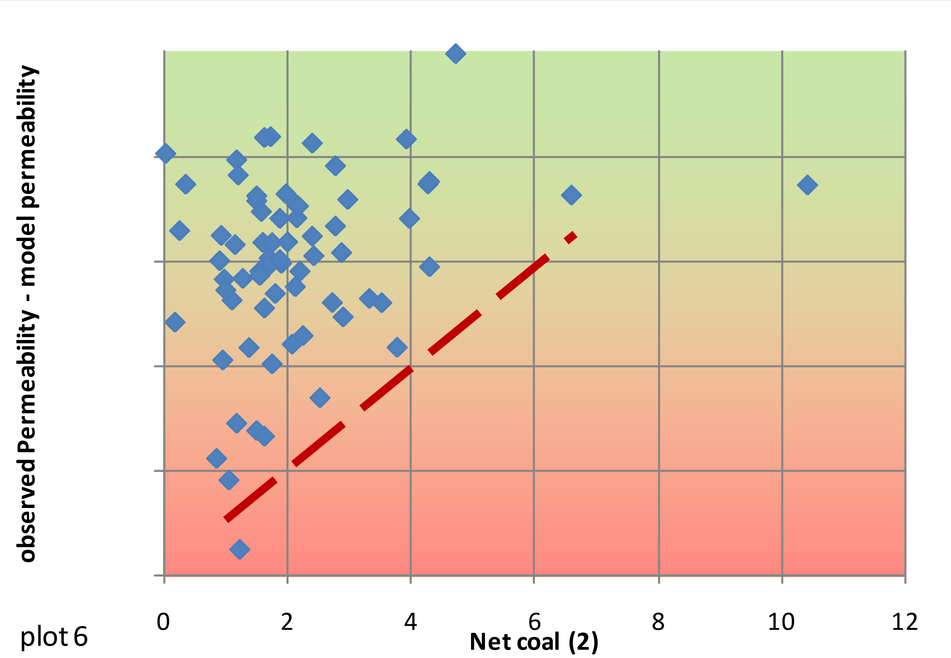


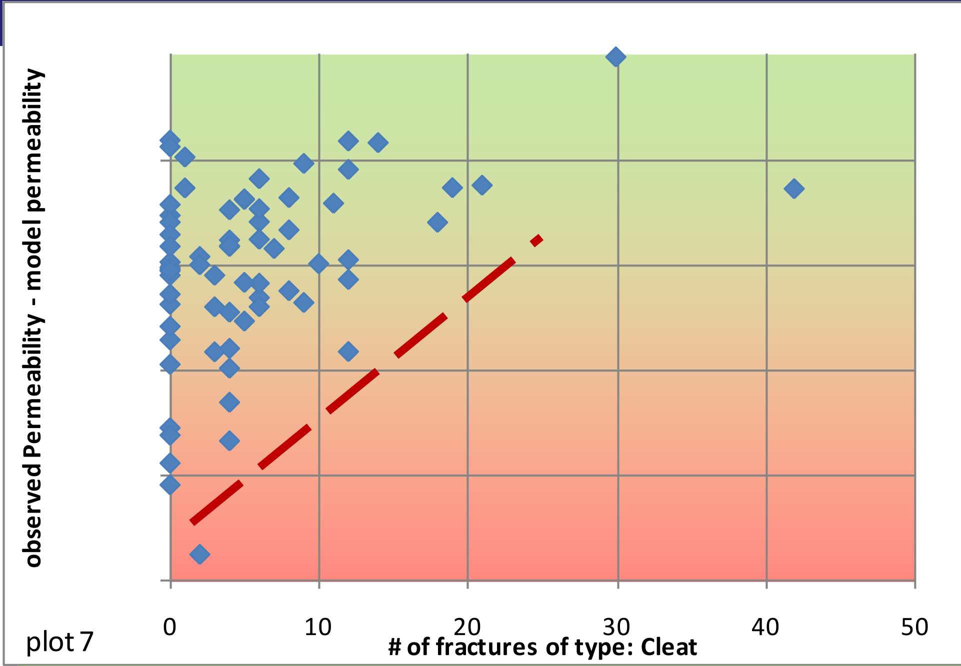
Spatial trend representation



Statistical relationships **fracture density** (and/or other parameters) vs **permeability**

Case Study (2) Natural fracture system characteristics prediction





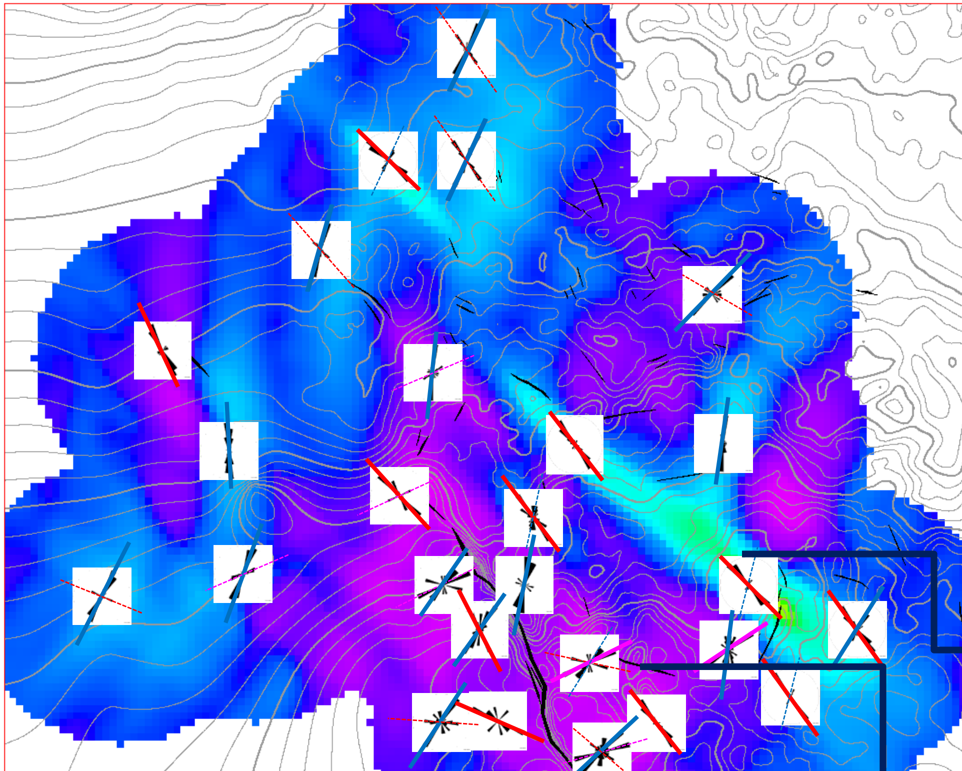
The **higher the net coal**, the higher the chance that **at least one of the coal beds** has a **cluster of fractures** with large enough aperture and continuity to provide **good permeability**

Similarly, the **higher # of joints and cleats** intersected by a well, the higher the chance that at **least one of these fractures** has enough aperture and continuity to provide **good permeability**

- [left] High-grading areas of thicker coals increases the chance of high fracture counts and therefore reduces the risk of low permeability
- [right] High-grading fracture sweetspots increases the chance of drilling into well connected networks and therefore reduces the risk of low permeability

Fracture density mapping – expected relationship to permeability

Fracture families are individually mapped and a modulus computed



Note: cleat mapping is limited to areas within 10km from well control (scanner data)

Combined cleat spacing (defects/10m) map:

- Based on kriging of well data guided by cleat orientation
- Each cleat set is gridded separately first, maps per set are then merged
- # at wells shows the well observed cleat density

High fracture density

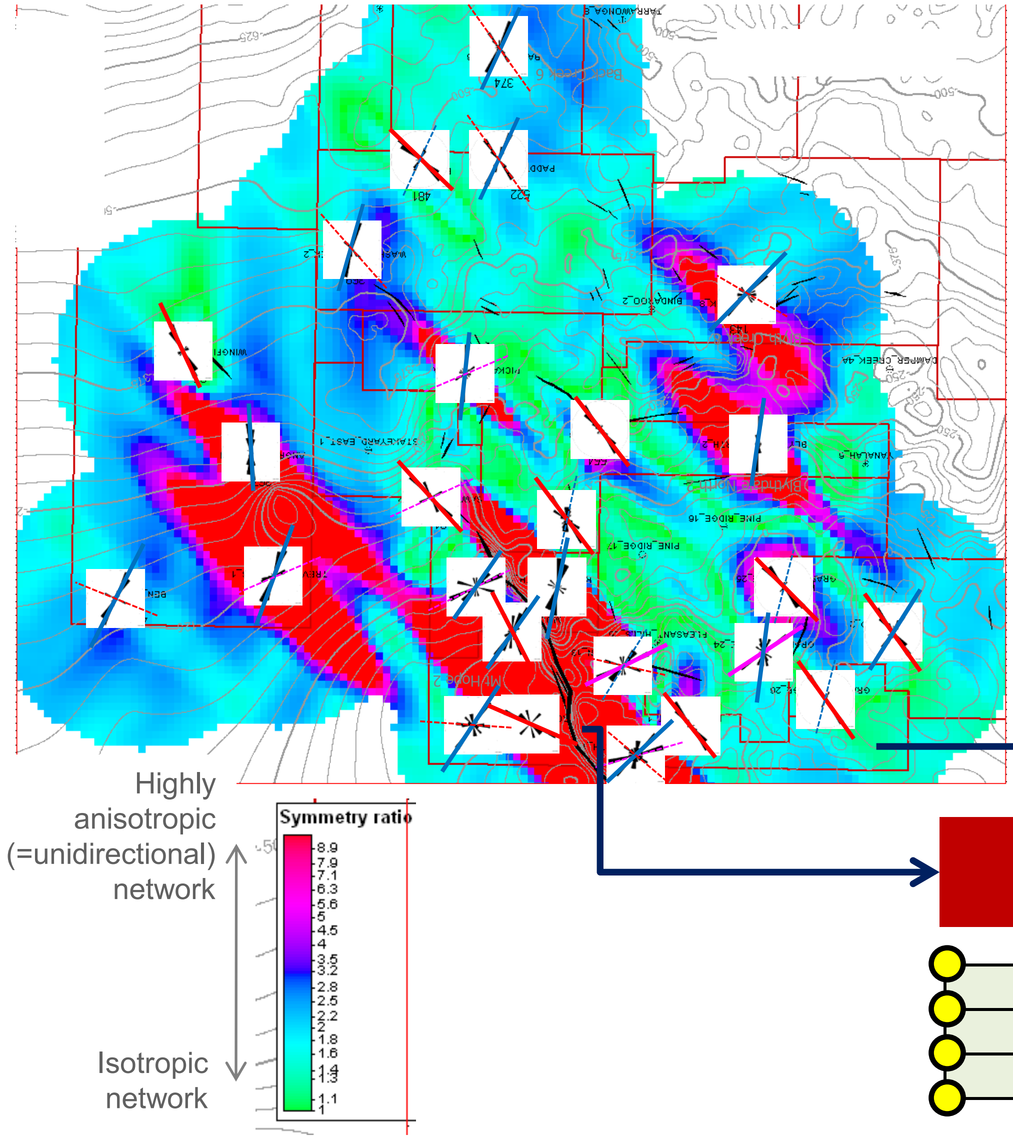
Single or multiple directions
Expected to coincide with areas of limited risk of poor permeability

Low fracture density

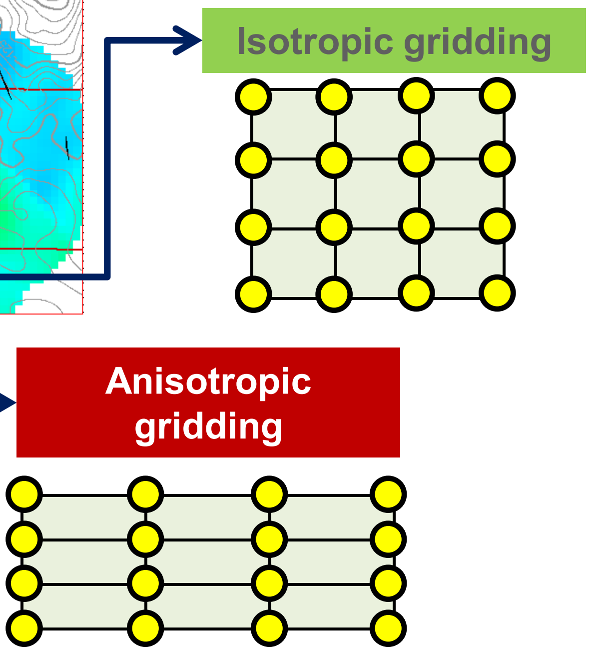
Single or multiple directions
Expected to coincide with areas of high risk of poor permeability

Mapping Anisotropy – relative density of fracture families

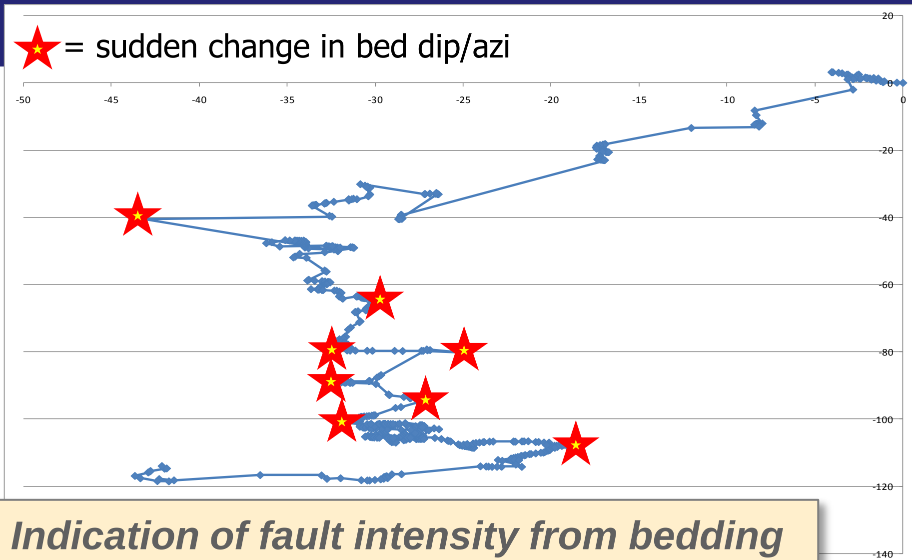
Allows the assessment of spacing – quantitative analysis is possible through reservoir simulation or analytical calculations



- Combined cleat anisotropy map (ratio of largest over smallest set spacing):
- Based on kriging of well data guided by cleat orientation
- Each cleat set is gridded separately first; maps per set are then merged

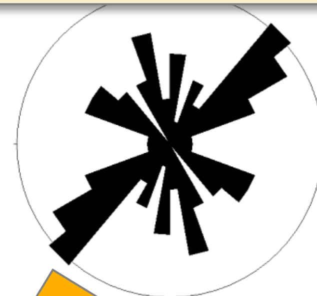


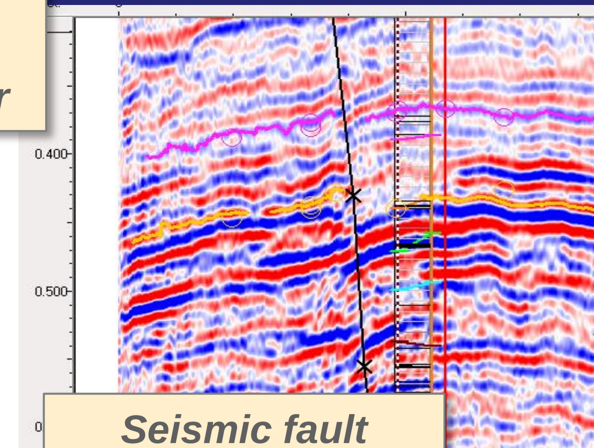
Similar workflow to map fault density data



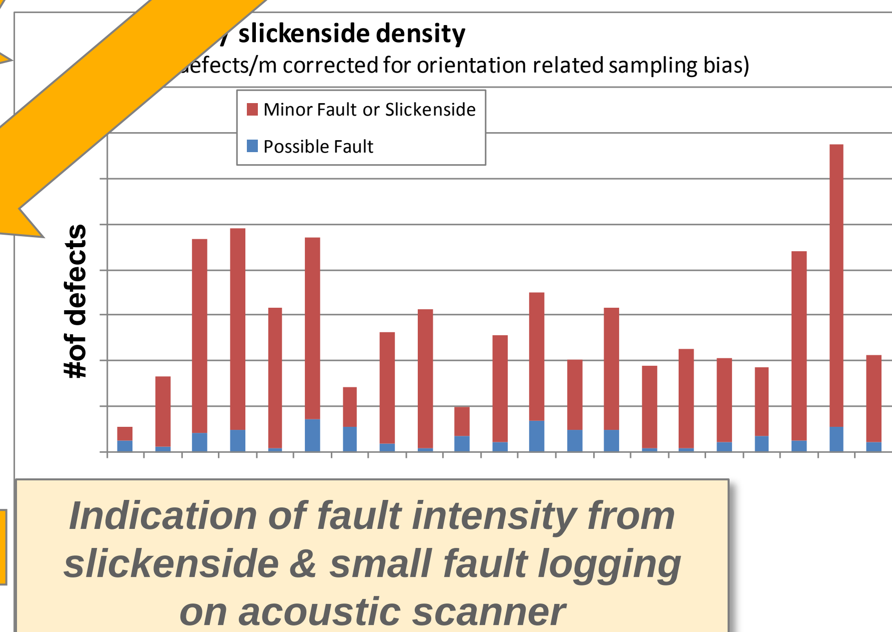
Indication of fault intensity from bedding dip/azi "walkout plots"

Shear fracture orientation from acoustic scanner





Seismic fault mapping



Indication of fault intensity from slickenside & small fault logging on acoustic scanner

Fault maps utilizing / integrating all this information to yield

- Indication of faulting intensity in different parts of the field
- Indication of relative structural compartment (= block) size
- Indication of anticipated block geometry
- Better landing of in-seam wells

Conclusions

- CBM Sweet-spotting through subsurface high-grading studies
  - A statistical impact – distribution shift
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- Integration of information is key to success
  - Defining success correctly : a statistical impact – distribution shift
  - Sweet-spotting of net coal thickness locally can positively impact appraisal and reserves build, but also potentially development
  - Deliverability and drainage optimization achieved through integration and mapping of data at different scales

- Manufacturing model for coal-seam gas development still remains adequate and necessary
  - We can however be a more discerning manufacturer !