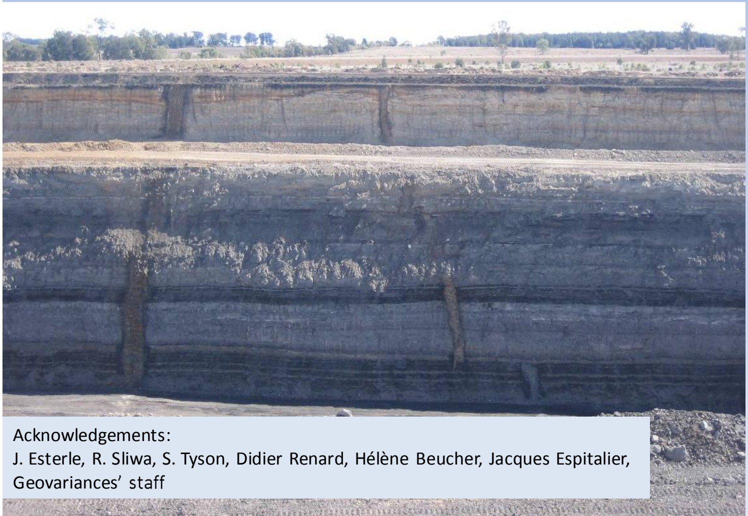
Geological interpretation of lithofacies border effects curves for the Walloon Subgroup, northeastern Surat Basin, Queensland, Australia



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Geostats Rendezvous
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Context of the study

- **Geological heterogeneity**, or vertical and lateral continuity and associations of sedimentary lithofacies in the Walloon Subgroup, will influence the connectivity of coal reservoirs, aquitards and aquifers, and the way that water and gas flow through the sequence.

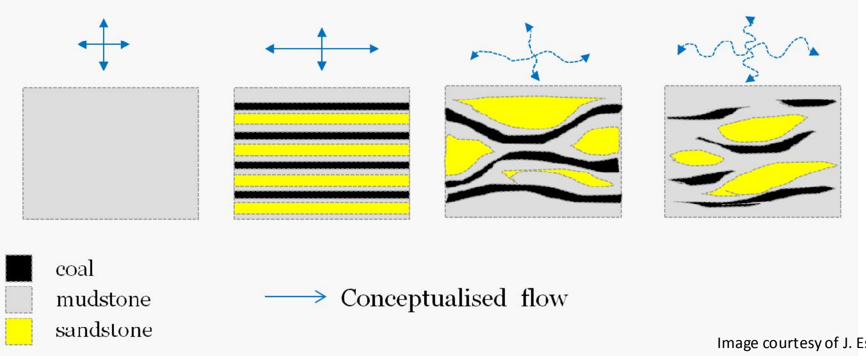
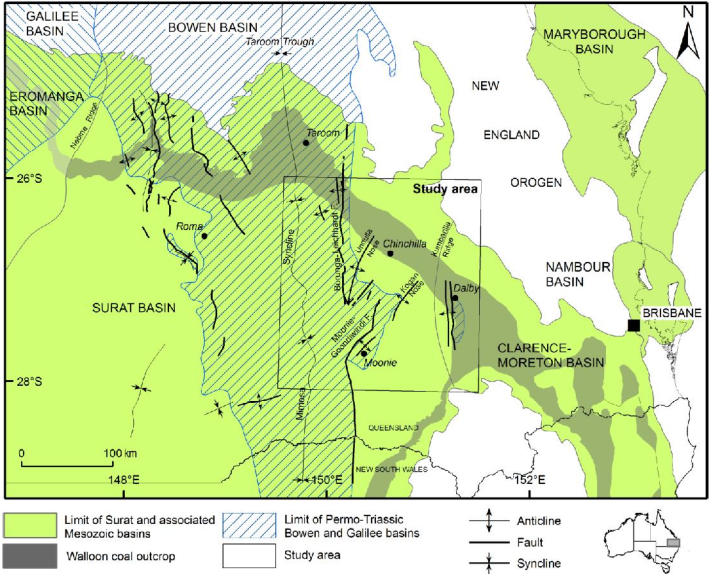
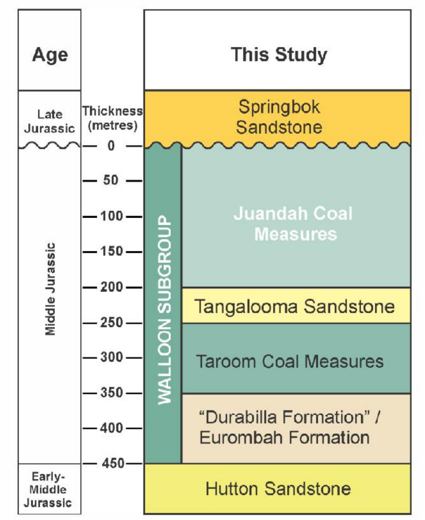


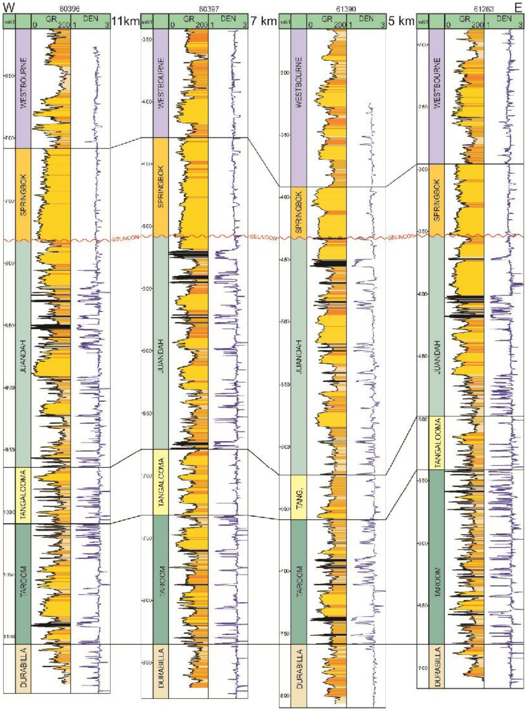
Image courtesy of J. Esterle

Study area – northeastern Surat Basin



Stratigraphy





Lithofacies interpretation

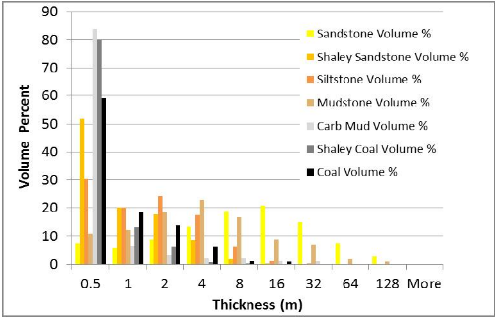
Lithofacies	Density Value	Gamma Value
Coal	<1.5 g/cc	n/a
Shaley coal	≥1.5 g/cc & < 1.8 g/cc	n/a
Carbonaceous mudstone	≥1.8g/cc & <2.0 g/cc	n/a
Mudstone	≥2.0 g/cc	≥140 API
Siltstone	≥2.0 g/cc	≥110 API & <140 API
Silty Sandstone	≥2.0 g/cc	≥90 API & < 110 API
Sandstone	≥2.0 g/cc	< 90 API

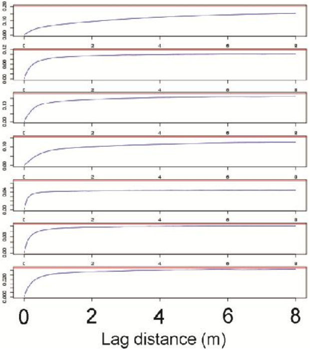
- Simple approach - cut off values
- Preference given to density log
- Created a script
    - Ran the script on the well logs

Open file company data – simple hierarchy of log types
GR logs normalised to common sand-shale line

- **7 lithofacies assigned down each well**

Diagnostics: lithofacies thickness distributions, proportions and univariate variograms





N=350 wells and n=190299 counts of different facies in the well logs; 30cm window.

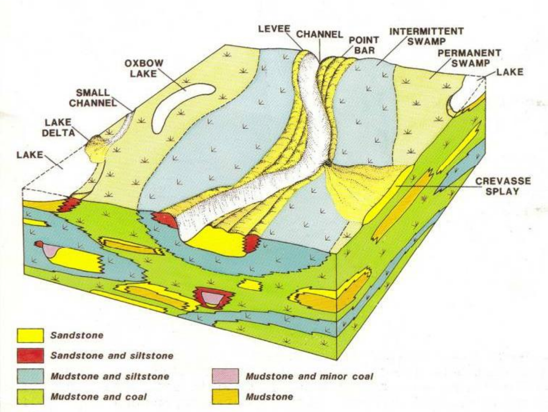
- **Coals seams <1 m**
- Mudstones and siltstones 4-8 m
- Silty Sandstones <2 m
- Sandstones 8-32 m

Majority of coal plies thin, discontinuous and difficult to correlate over large distances

Ongoing research aims to stochastically model the spatial geological heterogeneity within the Walloon Subgroup coal seam gas reservoir.

Commonly sedimentary facies follow a cycle..

- Walther's Law….conformable vertical succession of facies reflects the lateral distribution of environments, assuming no unconformity

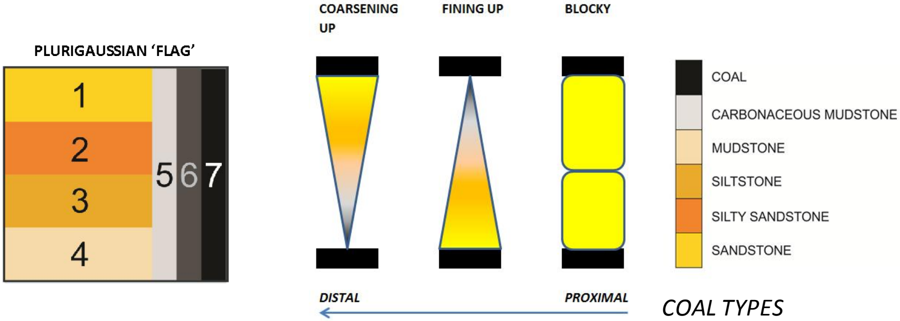


Block diagram of a meandering river system, showing similar depositional environments to those proposed for the Walloon Subgroup (from Draper in Beeston & Gray 1993)

- Lateral lithology transition probabilities reflect vertical transition probabilities
- Coals can occupy abandoned channels, or occur in interfluves, similar to modern analogues

Aim

- Investigate the **vertical stacking characteristics** (vertical facies transitions) of the Walloon Subgroup as part of a plurigaussian truncated (PGS) modelling exercise
  - Quantify cyclicity
  - Interpret structural characteristics of input data relative to **depositional models**



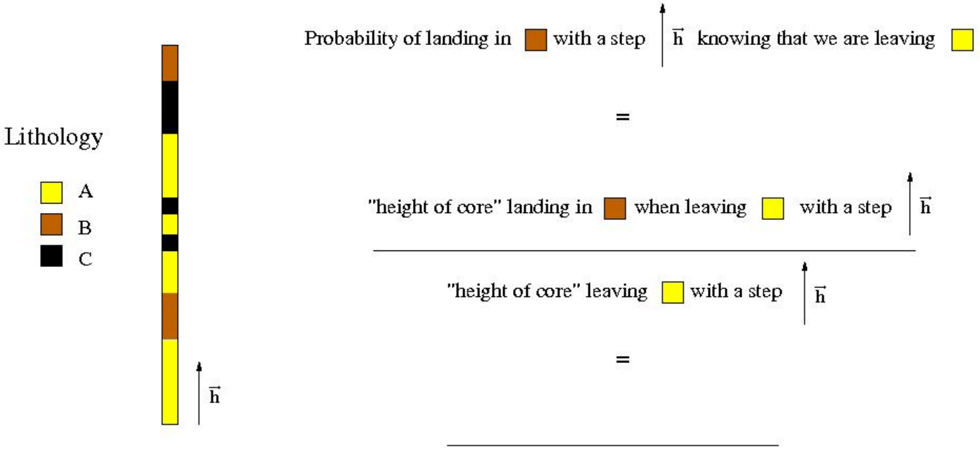
Method: Lithofacies contacts analysed by formation using border effects curves

- Border effects curves represent the combination of two geostatistical structural tools (the negative ratio between the indicator non-centred covariance, and the indicator variogram of the lithofacies we are leaving).

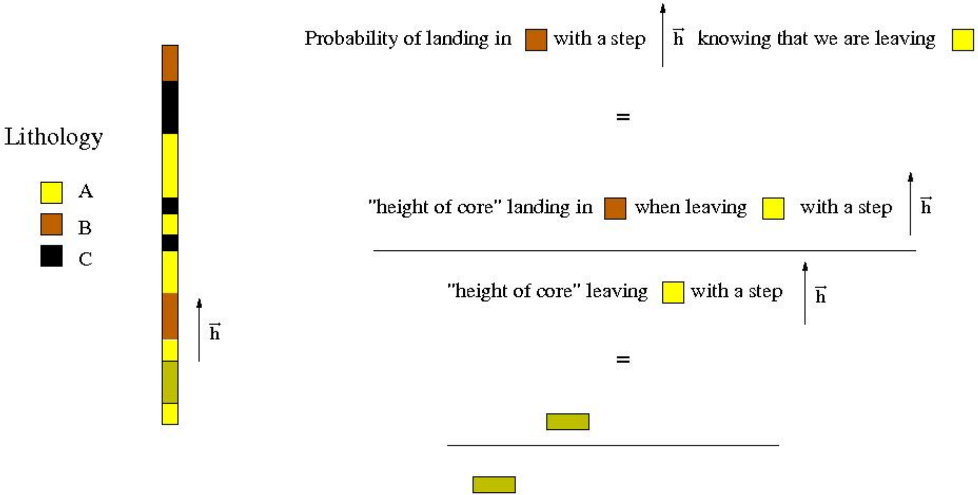
- A sliding scale of various lag lengths was applied to each down-hole lithofacies log, and used to calculate transition probabilities according to the example formula below:

Probability of landing in Siltstone with a step $\uparrow \vec{h}$ knowing that we are leaving Sandstone

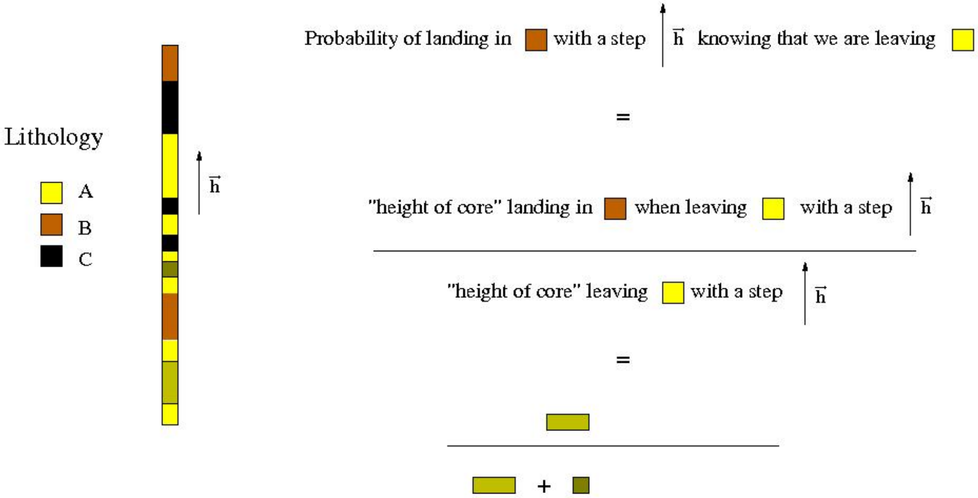
$$= \frac{\text{“height of core” landing in Siltstone when leaving Sandstone with a step } \uparrow \vec{h}}{\text{“height of core” leaving Sandstone with a step } \uparrow \vec{h}}$$

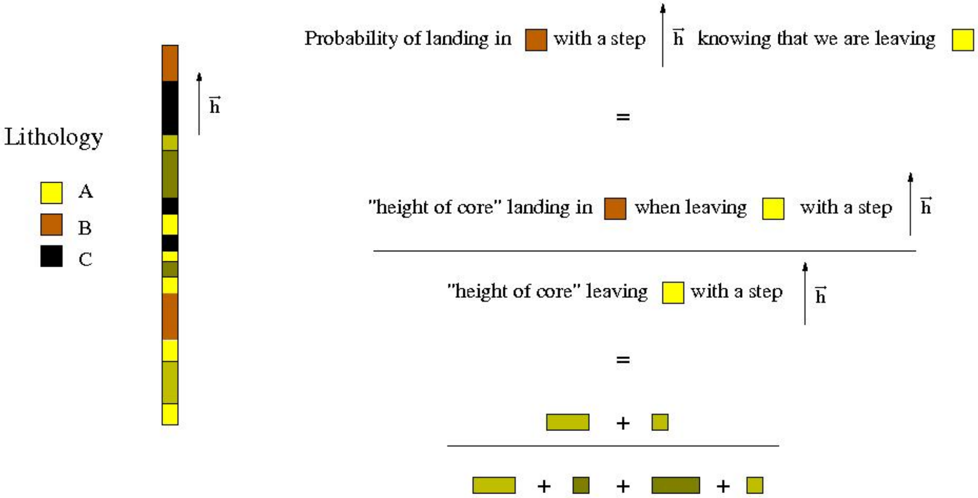


Lithology
A
B
C
h
Probability of landing in with a step h knowing that we are leaving
=
"height of core" landing in when leaving with a step h
"height of core" leaving with a step h
=



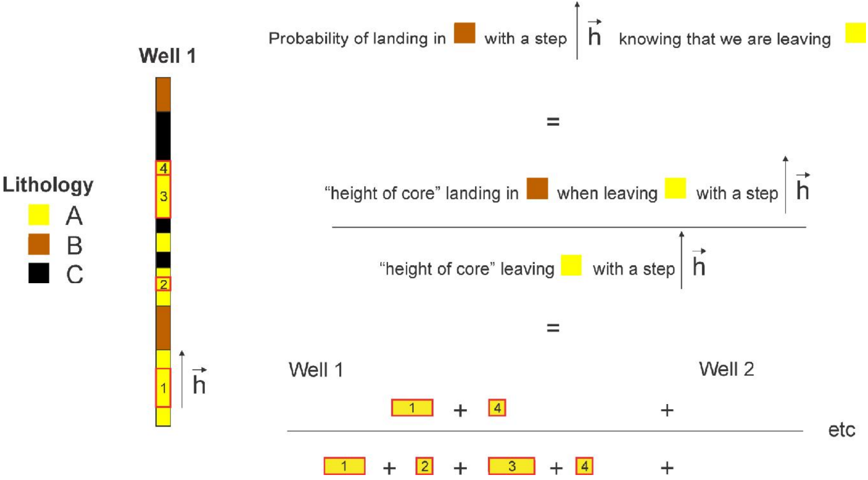
Lithology
A
B
C
h
Probability of landing in with a step h knowing that we are leaving
=
"height of core" landing in when leaving with a step h
"height of core" leaving with a step h
=


Lithology
A
B
C
h
Probability of landing in with a step h knowing that we are leaving
=
"height of core" landing in when leaving with a step h
"height of core" leaving with a step h
=
+


Lithology
A
B
C
h
Probability of landing in with a step h knowing that we are leaving
=
"height of core" landing in when leaving with a step h
"height of core" leaving with a step h
=
+
+ + +

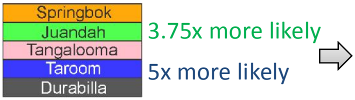
Border effects calculation

- Determination of lithofacies transition probabilities in both the up- and down-hole directions

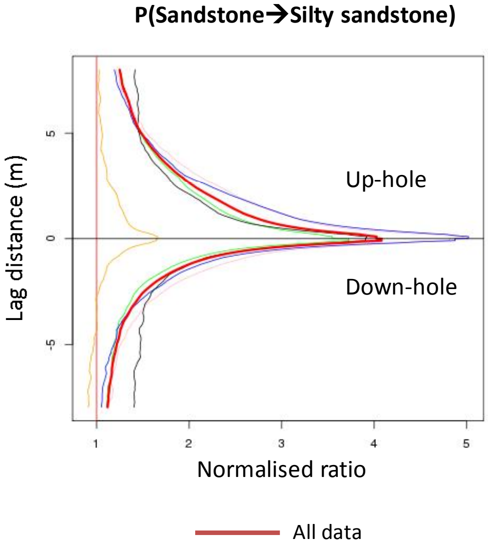


Border effects curves

- All possible combinations
- Each formation treated separately

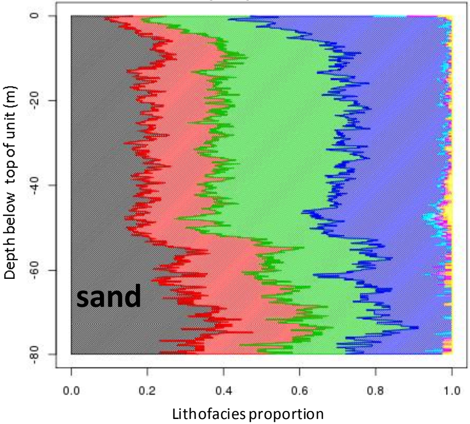


- Un-normalised or normalised for proportions
- Symmetrical or asymmetrical curves



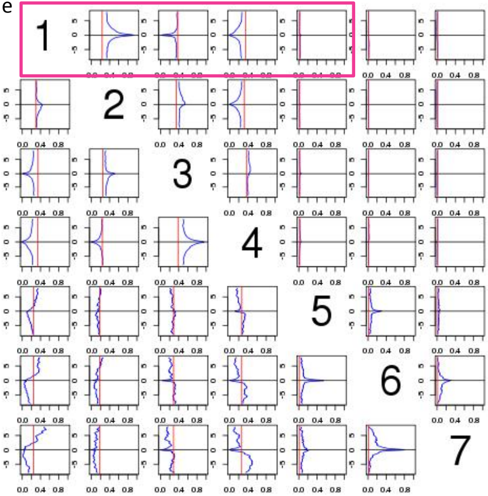
Example: Durabilla Formation

Vertical proportion curve



***Border effects matrix** (un-normalised)*

Next slide



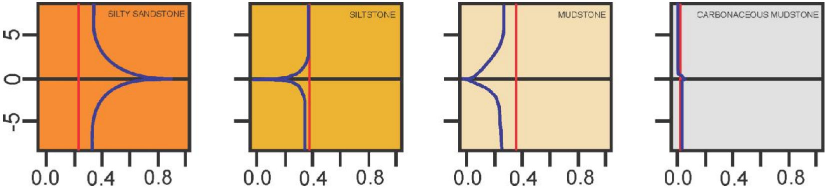
VPC displays overall fining upward trend

Border effects matrices initially interpreted against VPC's (1st order trends)

- **Red line =** probability of being in given lithofacies, knowing we are not in diagonal facies, irrespective of lag distance
- **N.B. Low proportion of coal**
- Symmetrical and asymmetrical curves

Example Durabilla interpretation key
"Leaving sandstone"

1



Initial probability of leaving sandstone for silty sandstone = 0.9. Decreases with increasing lag distance.

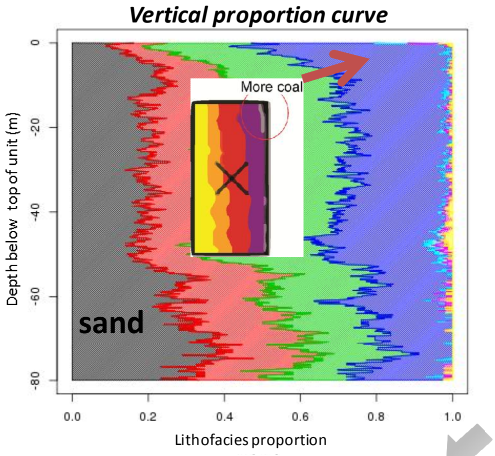
Initial probability of leaving sandstone for siltstone = 0. Must pass through silty sandstone. → Separation (c.f. plurigaussian flag)

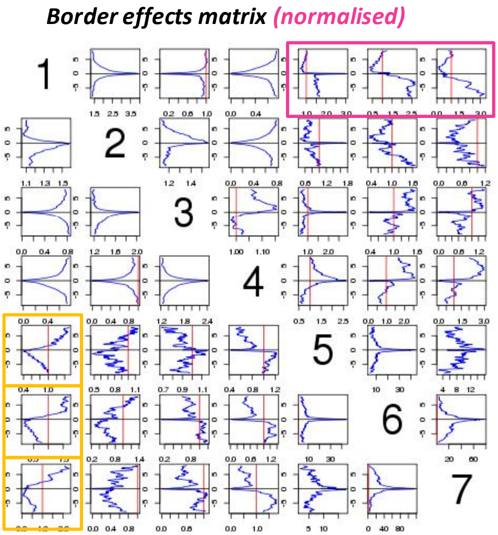
Initial probability of leaving sandstone for mudstone= 0. Must pass through 2 and 3.

No separation. Initial probability of leaving sandstone for carb. mud low (~0.05).

Inverted border effects curve = separation. Initial probabilities → function of thresholds.

Example: Durabilla Formation





VPC displays overall fining upward trend

Some transitions show obvious asymmetry. Why?
What can be reproduced statistically?

- **Mire facies (5,6,7): obvious asymmetry**
- Can P(Mire→1) asymmetry be explained by VPC?
- What about 2nd order trends?

Asymmetry – leaving mire facies for sandstone

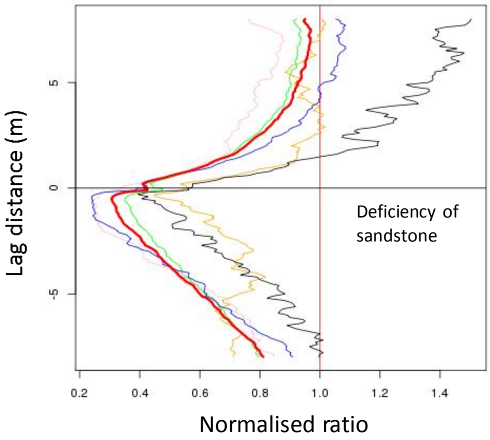
- Compare up- and down-hole ranges
- Sill reached quicker in up-hole direction →

RANGE, up ⇨

Springbok	Different dep. system
Juandah	>8 m, may not reach
Tangalooma	
Taroom	Low
Durabilla	Lowest

- Tendency for **carb. mdst** to be overlain by sandstone → autocompaction of peats and channel attraction, or channel incision
- Tang/Juandah asymmetry less obvious, suggesting upward decrease in channel switching/fining up cycles

P(Carb. mdst→Sandstone)



All data

Asymmetry – leaving mire facies for sandstone

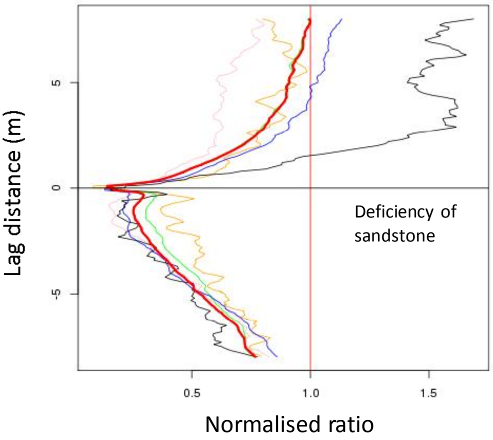
- Compare up- and down-hole ranges
- Sill reached quicker in up-hole direction →

RANGE, up ⇨

Springbok	Different dep. system
Juandah	~8 m
Tangalooma	>8 m
Taroom	Low
Durabilla	Lowest

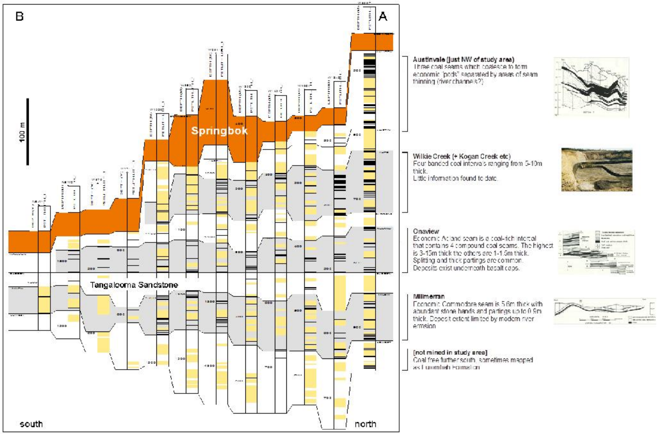
- Tendency for **coals** to be overlain by sandstone → channel attraction or incision
- Tang/Juandah asymmetry less obvious, suggesting upward decrease in channel switching/fining up cycles

P(Shaley coal→Sandstone)

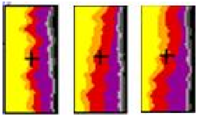


All data

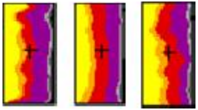
Hypothesis: progradation



Isatis VPC's



Upper Walloon streams more stable
→ Less avulsion, thicker coaly units



NORTH *SOUTH*

Distribution of coal-rich and coal-poor intervals from north to south. **Hypothesis - prograding sequence with thicker coals and thicker sandstones up-section and to the north** (from Sliwa & Esterle 2008).

Upsection – progressively more upstream depositional environments

Asymmetry – leaving silty sandstone for siltstone

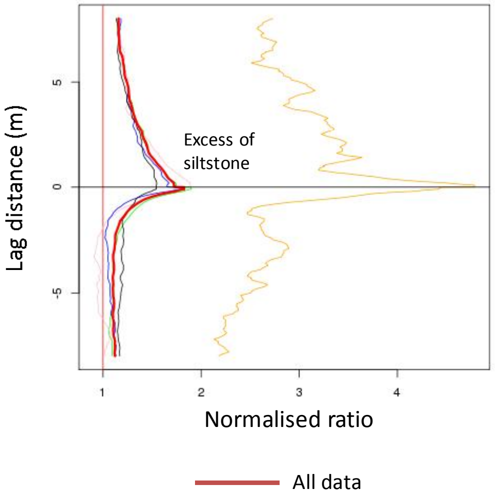
- Compare up- and down-hole ranges
- Sill reached quicker in down-hole direction →

RANGE, up ⇨

Springbok	Different dep. system
Juandah	>8 m in up-hole
Tangalooma	direction for all
Taroom	WSG formations
Durabilla	

- Further support for strong fining upward cycles
- Minor differences between WSG formations

P(Silty sdst.→Siltstone)

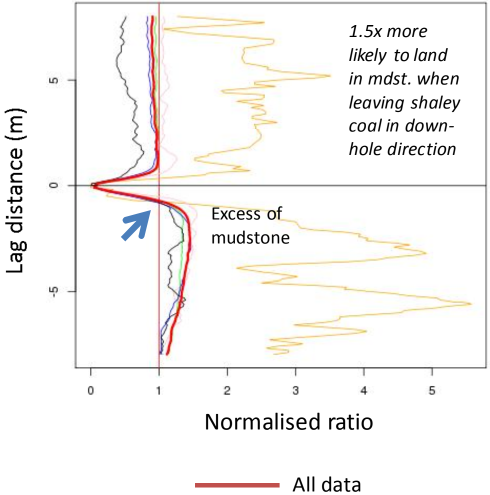


Asymmetry – leaving mire facies for mudstone or siltstone

- Similar up and down ranges
- Excess of mudstone down-hole

- Further support for strong fining upward cycles
- Minor differences between WSG formations
- Mire facies underlain by mudstone or siltstone consistent with lake/abandoned channel fill

P(Shaley coal→Mudstone)

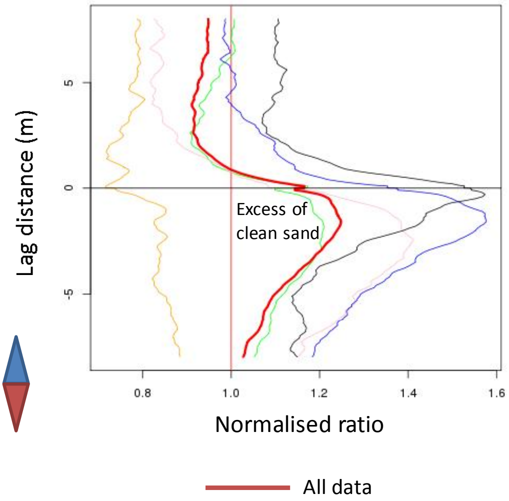


Asymmetry – leaving silty sandstone for ‘clean’ sandstone

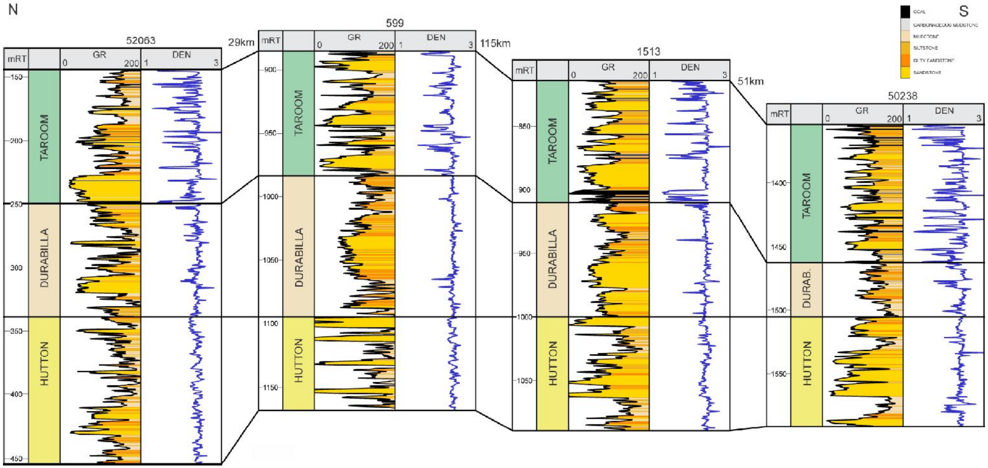
- Excess of clean sand down-hole

- Further support for strong fining up cycles in Taroom and Tangalooma, n.b. Juandah has blocky sands
- Durabilla Fm. is ~ symmetrical
- **Durabilla hypothesis:** combination coarsening and fining up sequences consistent with distributary channel behaviour

P(Silty sdst.→ ‘Clean sdst.’)



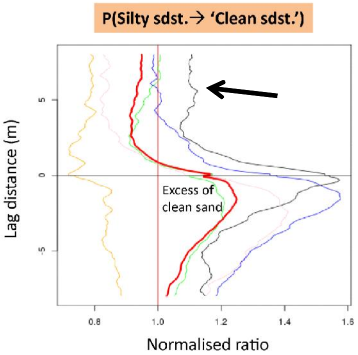
Durabilla Formation – transitional reorganisation/platform development?

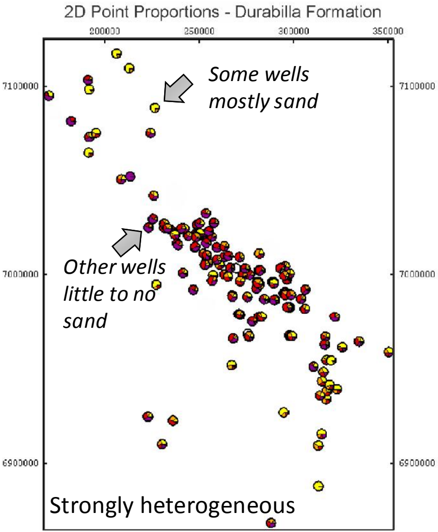


Curves that don't reach the sill..

Possible causes:

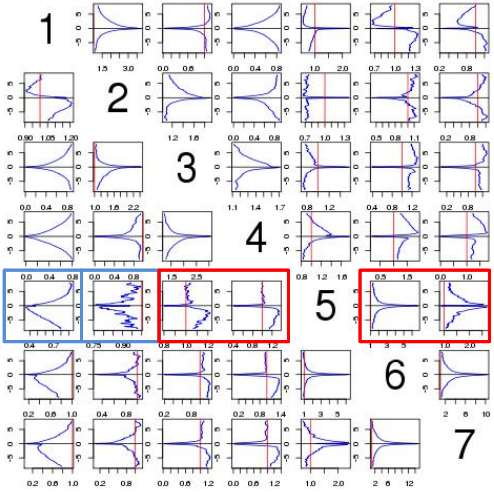
- Lateral non-stationarity, or
- The 2 facies rarely occur together in a drillhole





Border effects curves consistent with prior geological knowledge..

- e.g. from open-cut mines, core logging
  - Good test of cut-off values and lumping
- Intuitive presentation
- "Excesses and deficits" variably compensated >>>
- Generally speaking, asymmetry may be explained by 1st order (Fm-scale VPC's) trends and/or 2nd order trends
  - ✓ VPC's can be reproduced by PGS
- In our case VPC's do not explain the observed asymmetry
  - Border effects curves show ~similar patterns for all the WSG formations, which have contrasting VPC's
  - Asymmetry more easily explained by autogenic (local intrabasinal) sedimentary processes



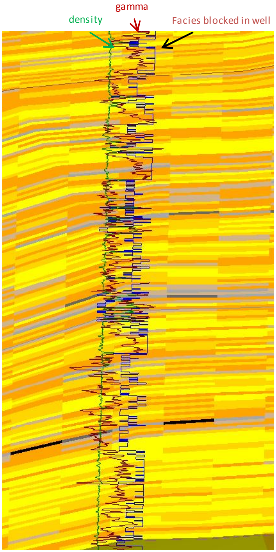
Normalised Juandah matrix

Conclusions

- **Border effects curves** represent a useful tool for quantifying geological heterogeneity, testing depositional models, and interpreting the structural characteristics of the input data to geostatistical models.
- Determination of **lithofacies transition probabilities**, in both the up- and down-hole directions, revealed that vertical stacking patterns in the Walloon Subgroup are non-random and show trends that can be used to guide realistic stochastic simulations.
- Many lithofacies transitions are **symmetrical**, i.e., there is an equal probability of leaving, say, sandstone for siltstone in both the up- and down-hole directions over short distances.
- Some transitions are **asymmetrical** and likely reflect autogenic sedimentary processes.
- Differences between formations consistent with a **prograding fluvio-lacustrine system**
  - Asymmetrical border effects curves suggest strong fining up sequences that get abandoned and capped by mudstones then coals
  - Coals overlain or cut by sandstones (autocompaction of peats and channel attraction, or channel incision)

Conclusions

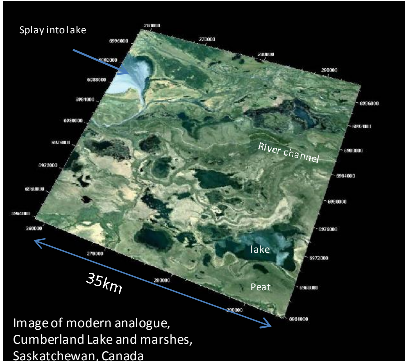
- Not all asymmetry can be reproduced by PGS methods; however, its geological interpretation enhances understanding of the depositional system and assists in its conceptualisation.



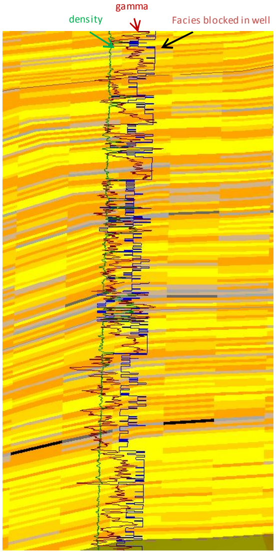
500x500x2m; vertical exaggeration 25%

Thank you

- BEESTON J.W. & GRAY A. 1993. The ancient rocks of Carnarvon Gorge. Department of Minerals and Energy, Brisbane, 48 pp.
- RYAN D. J., HALL A., ERRIAH L. & WILSON P.B. 2012. The Walloon coal seam gas play, Surat Basin, Queensland. *APPEA Journal* **52**, 273-289.
- SLIWA R. & ESTERLE J. 2008. Re-evaluation of structure and sedimentary packages in the eastern Surat Basin. *In:* Blevin J. E., Bradshaw B. E. & Uruski C. eds. *Eastern Australasian Basins Symposium III* p. 527. Petroleum Exploration Society of Australia, Special Publication.



from Ryan et al. (2012)



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