Carboniferous exploration & development in the UK Southern North Sea

Successes and failures - a 30 year retrospective

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https://t2m.io/44QfSBo7

Avant propos

Introductory comments and apologies

5 founding myths

Winding up comments

Carboniferous petroleum systems around the Mid North Sea High, UK

A.A. Monaghan [a,*], S. Arsenikos [a], M.F. Quinn [a], K.R. Johnson [a], C.J. Vincent [b], C.H. Vane [b], A.W. Kim [b], C.N. Uguna [b], S.D. Hannis [a], C.M.A. Gent [b], D. Millward [a], T.I. Kearsey [a], J.P. Williamson [b]

Marine & Petroleum Geology 2017

Exploration and development in the Carboniferous of the Southern North Sea: a 30-year retrospective

BERNARD BESLY

Special Publication, Geological Society London, 2018

Hydrocarbon potential of the Visean and Namurian in the northern Dutch offshore

M. M. TER BORGH*, W. EIKELENBOOM & B. JAARSMA

ACKNOWLEDGEMENTS

The following companies and individuals are thanked for discussion and material assistance over a period of many years.

British Geological Survey, Conoco Phillips, Cuadrilla Resources, Engie (Gaz de France), Esso UK, Shell UK, Third Energy, Tullow Oil,

Pat Barnard , John Collinson, Steve Corfield, Colin Jones, Julian Moore, Andy Mortimer, Peter Turner

UK activity since 1984

± 143 exploration wells with Carboniferous targets

± 37 discoveries

27 named fields placed on production

3.6 TCF recoverable gas

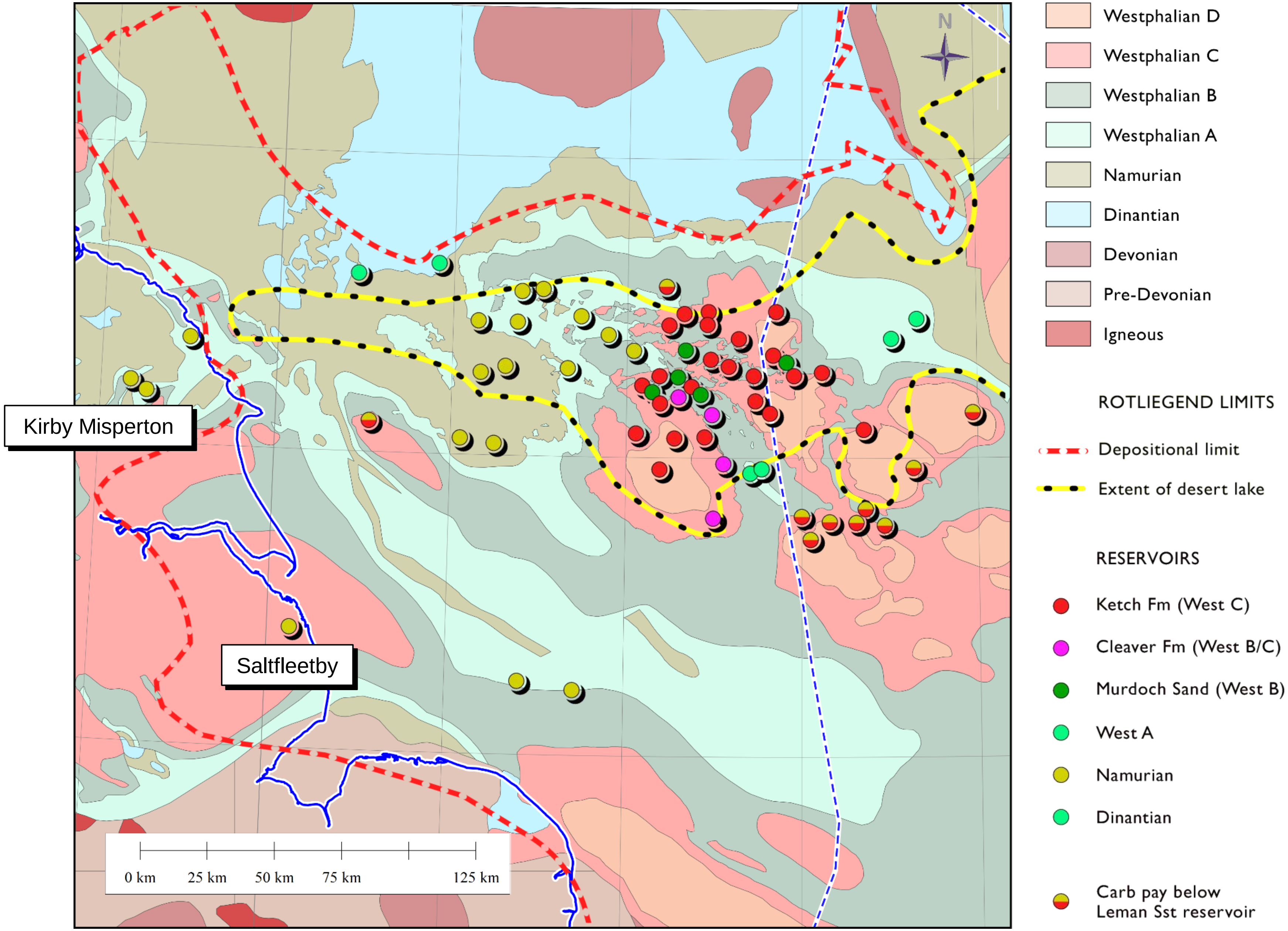
Gas generally contains high N_2 and in some cases high CO_2

Development slow

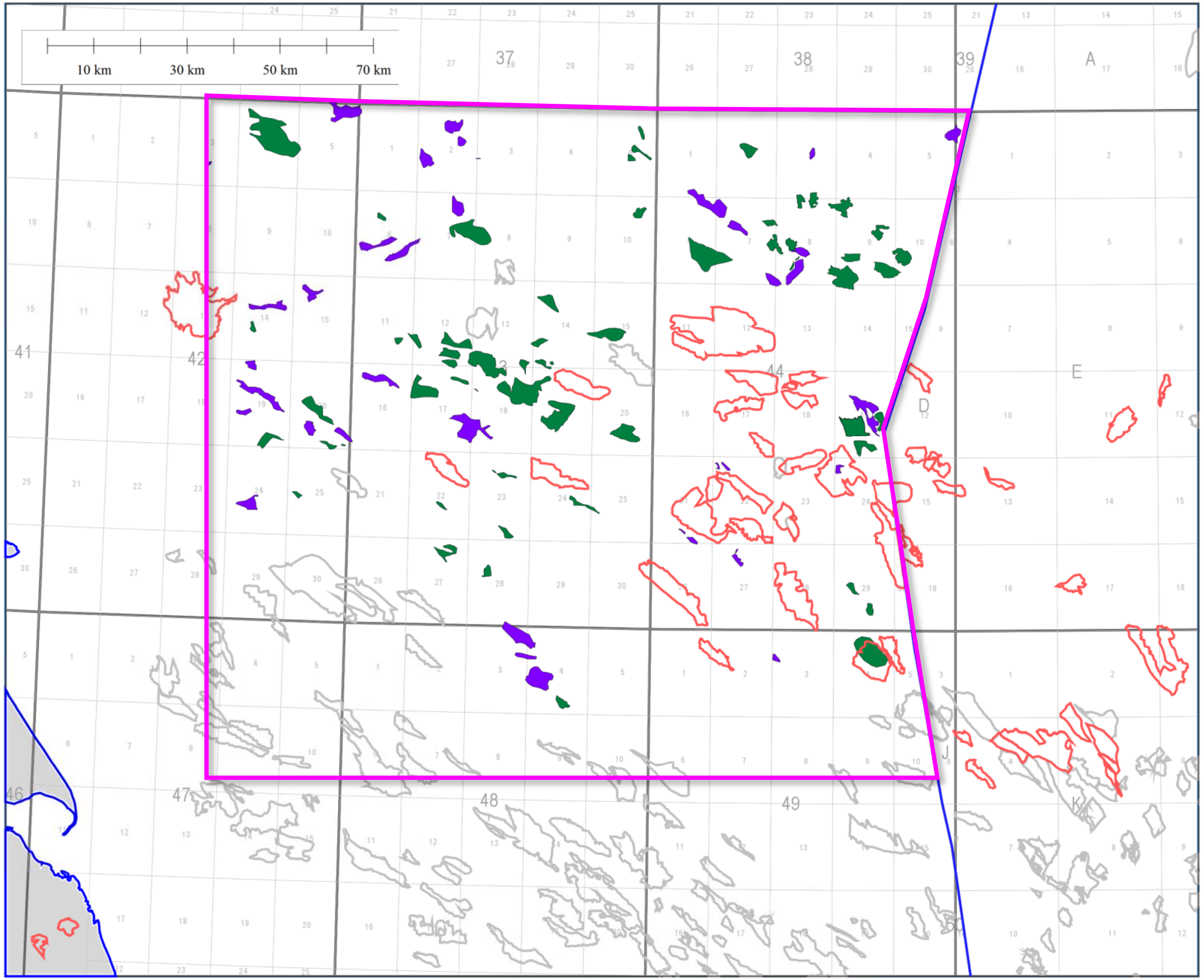
Some field performances disappointing

After c. 10 years perception that Carboniferous "difficult" and risky

In same period two significant gas discoveries in UK onshore



UK Southern North Sea; known unknowns



Published BGS analysis 2001

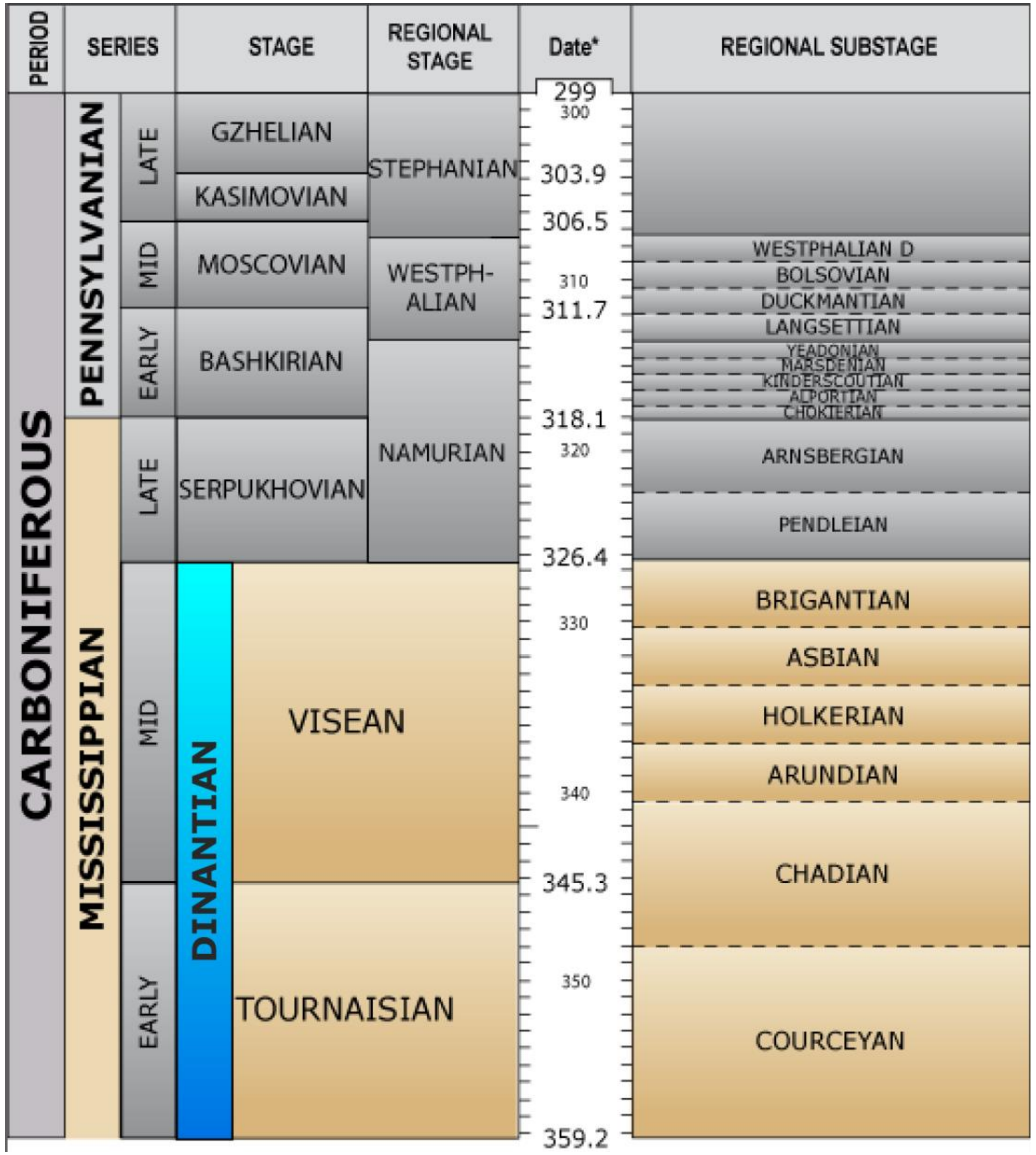
- 285 prospects > 500 acres
- 148 with P50 > 50BCF
- 127 in open acreage

Total unrisked P50 volume c. 17.5 TCF (7.8 TCF in open acreage)

- 72 base Permian closures
- 213 intra-Carboniferous traps

- 7 of the prospects in open acreage have since been drilled
- 4 discoveries

Carboniferous play elements



HYDROCARBONS

Export to younger reservoirs

S **Westphalian coal**

S Namurian basinal shale + minor coal

S Dinantian basinal shale + minor coal

RESERVOIRS

R **Westphalian red beds**

R **Fluvial / deltaic sandstones in Late Namurian to Westphalian**

R Fluvial / deltaic sandstones in Early Namurian and Late Visean

SEALS

Lacustrine Permian

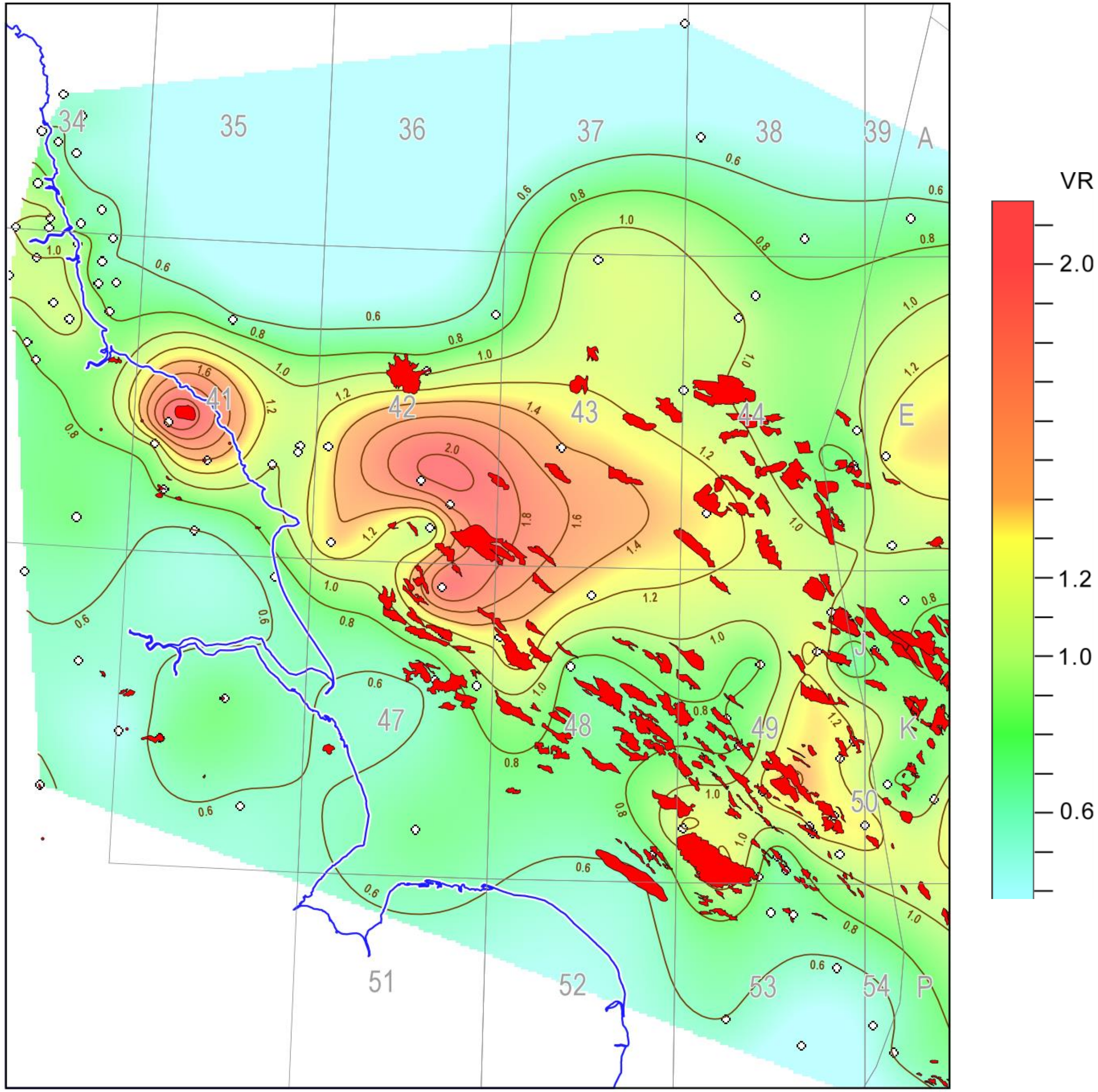
Sub-regional

Multiple potential marine & lacustrine shale seals within Carboniferous

- Extremely thick succession (? > 6.5 km)
- Complex stratigraphy
- Nature of “Carboniferous play” different in different areas depending on subcrop

Founding myth 1

“The gas comes from Westphalian coals”

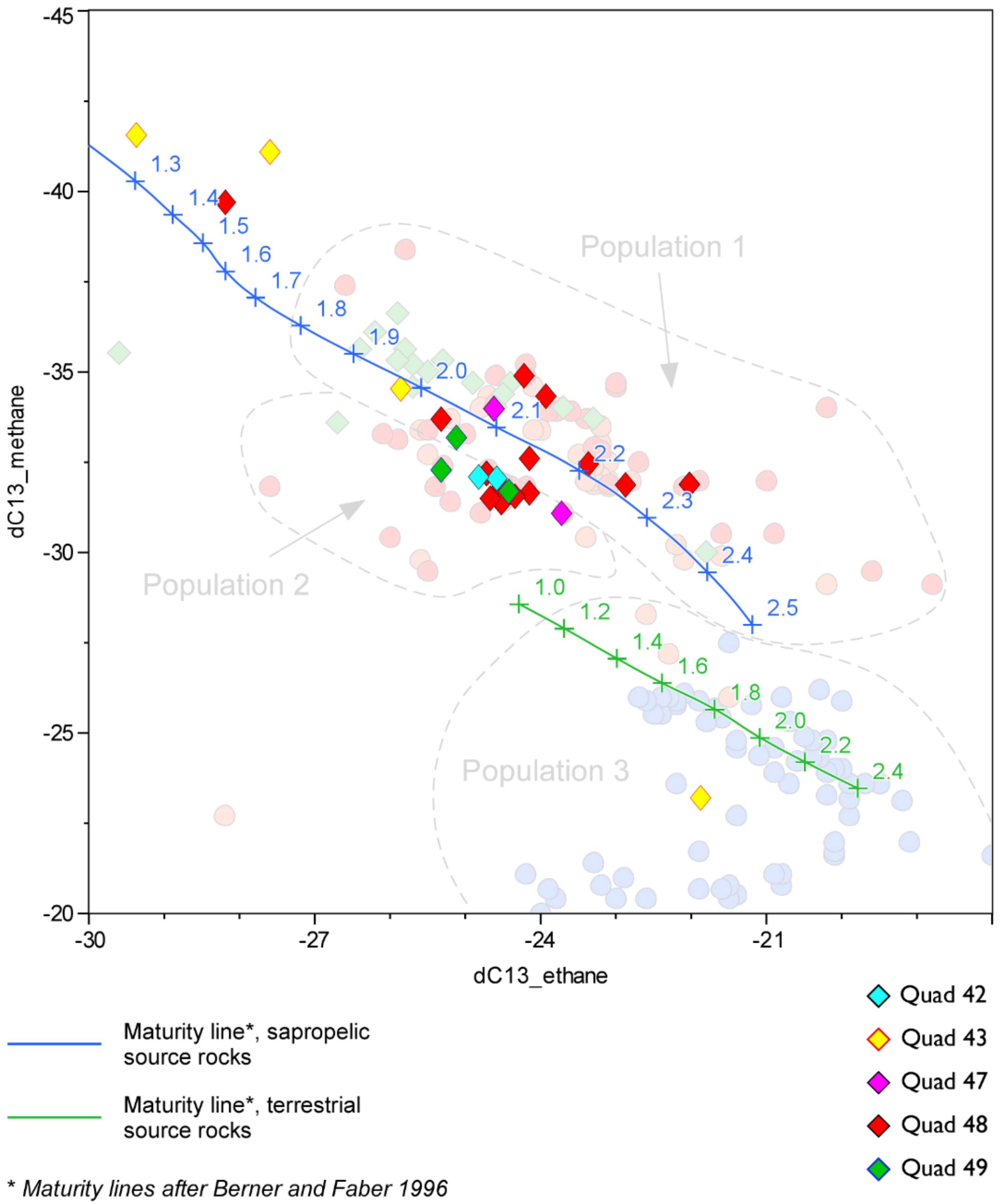


Maturity pattern dominated by effects of Mesozoic and Tertiary inversion

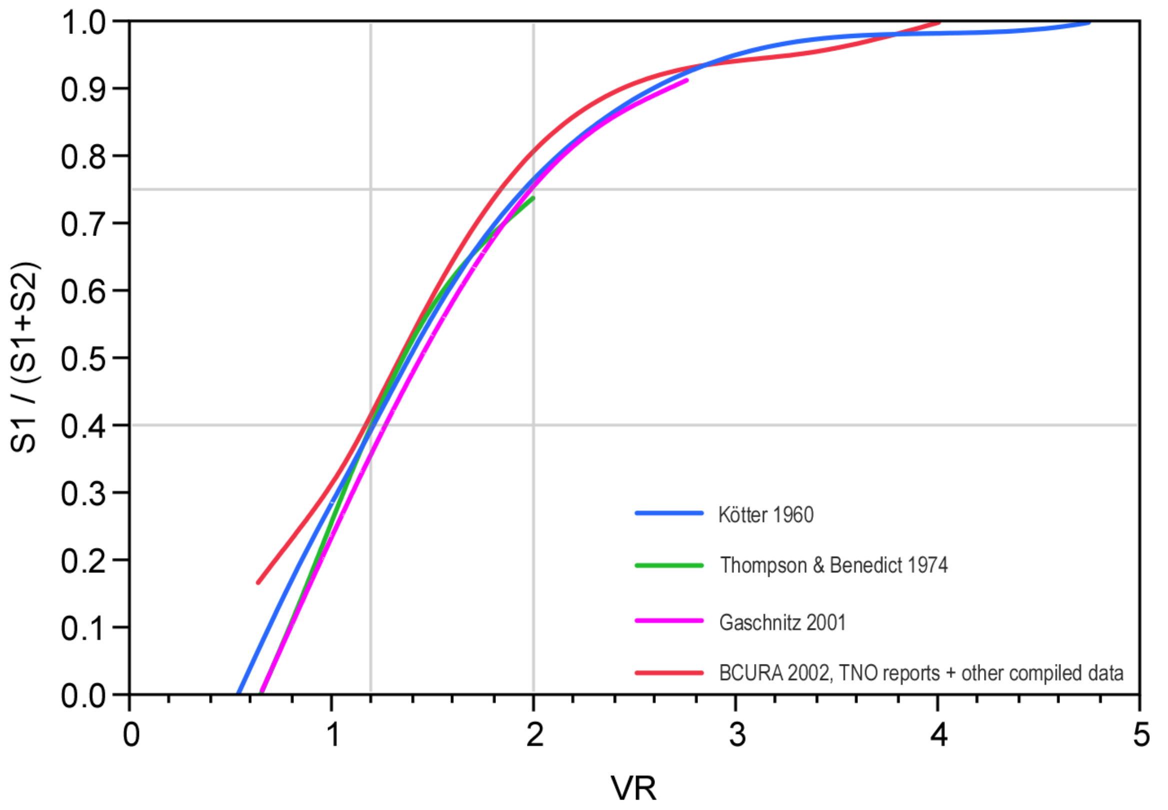
Many fields are remote from mature source in Carboniferous immediately beneath u/c

Some fields are remote from Westphalian subcrop

What source rocks? What maturities?

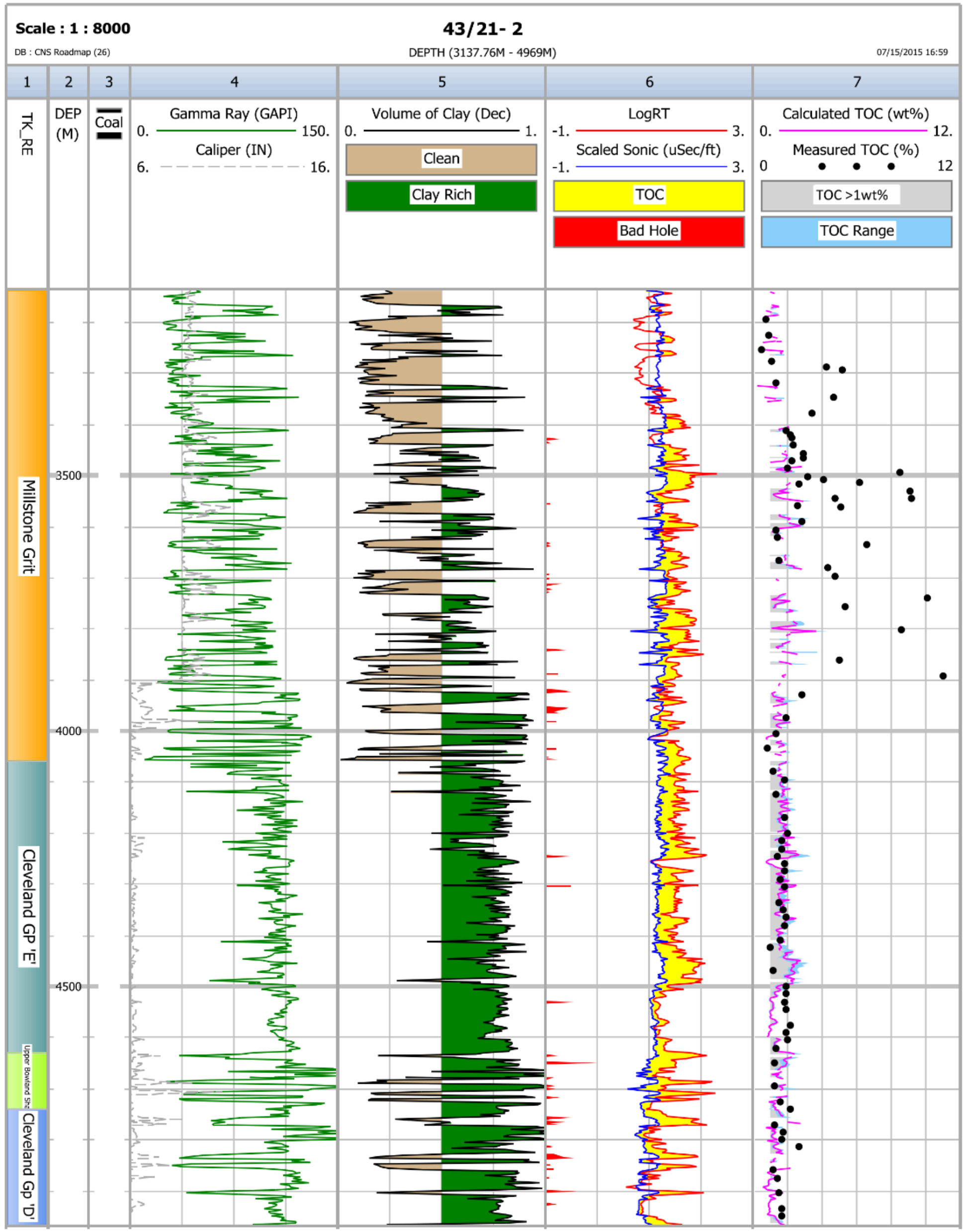


Carbon isotope data imply much of the gas is sourced from sapropelic source rocks at maturities of VR 2.0 – 2.5



Maturity / volatile matter relationships in coals show significant expulsion of gas in maturity range VR range 1.4 – 3.0

Coals not needed for working charge system



Results of North Yorkshire drilling campaign show that working gas charge does not depend on presence of coals

Abundant type III kerogen present as disseminated plant material throughout non-coal lithologies

TOC in thick shale units generally not > 3% (even in Lancashire 'shale gas' objectives)

Low TOC compensated by very large thickness

TOC and petrophysically-derived TOC from offshore well 43/21-2, Gent 2015

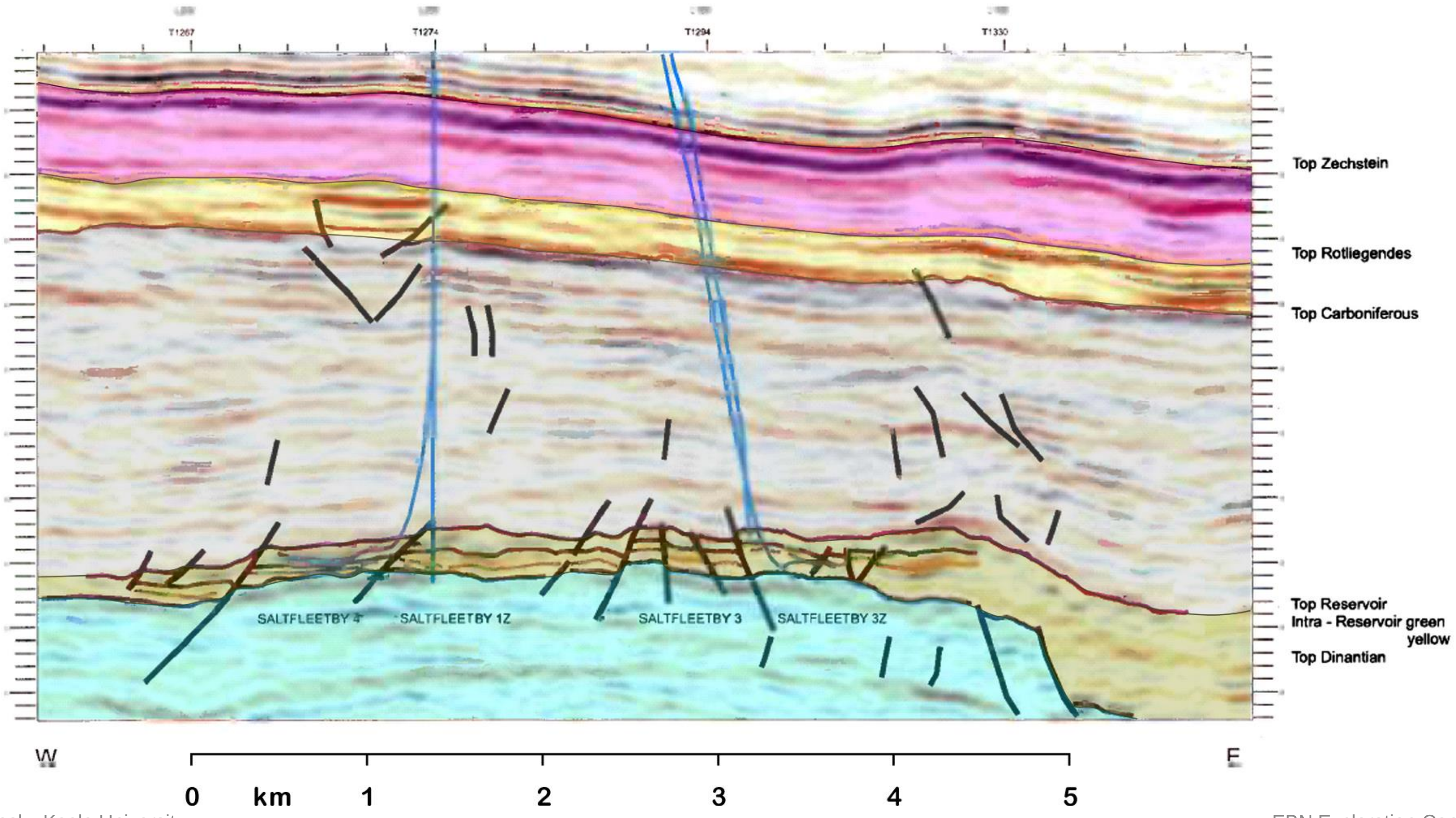
"Intra-Carboniferous seals are risky"

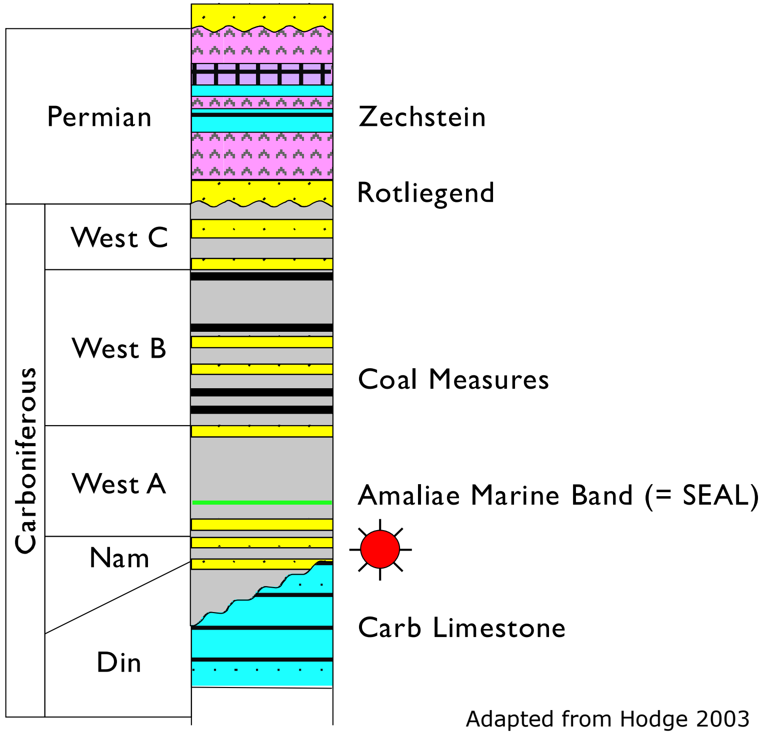
Potential seals within Carboniferous: thin marine shales or silty slope or delta top muds

- generally perceived to have high integrity risk
- silt content / vulnerability to minor faulting

Saltfleetby Field demonstrates that intra-Carboniferous seals can be effective

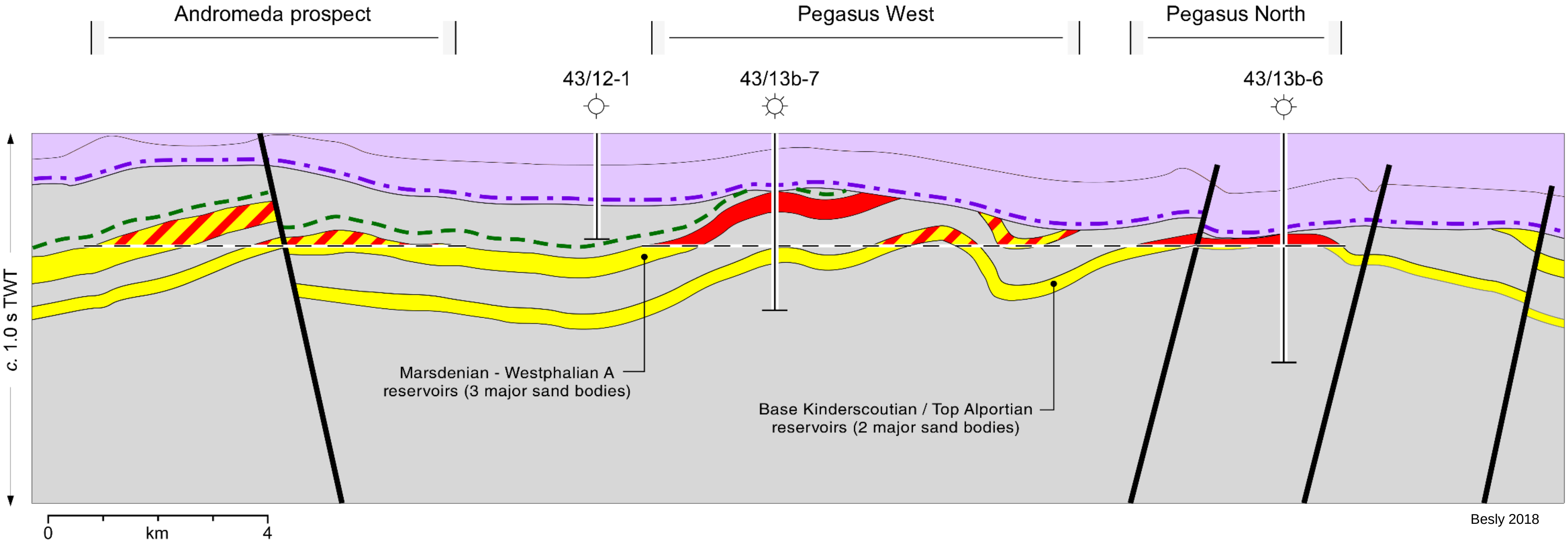
Intra Carboniferous traps are viable even where overlying Rotliegend is in non-seal facies





Adapted from Hodge 2003

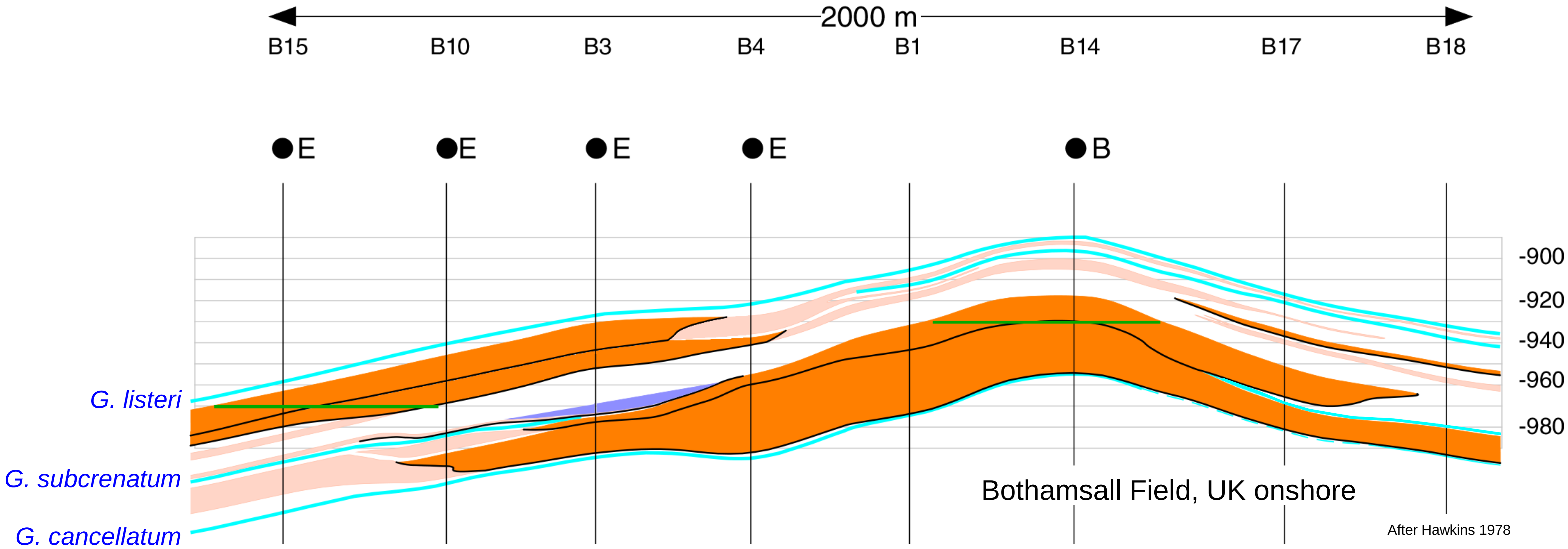
Intra-Carboniferous seals in combination traps



PEGASUS FIELD – 43/12 & 43/13

- Composite anticlinal trap requiring on both Silverpit and intra-Carboniferous seals; no closure at base Permian
- Multiple contacts and possibility of stacked pay
- Multiple reservoir/seal combinations can lead to unexpected trap geometries with stratigraphic component

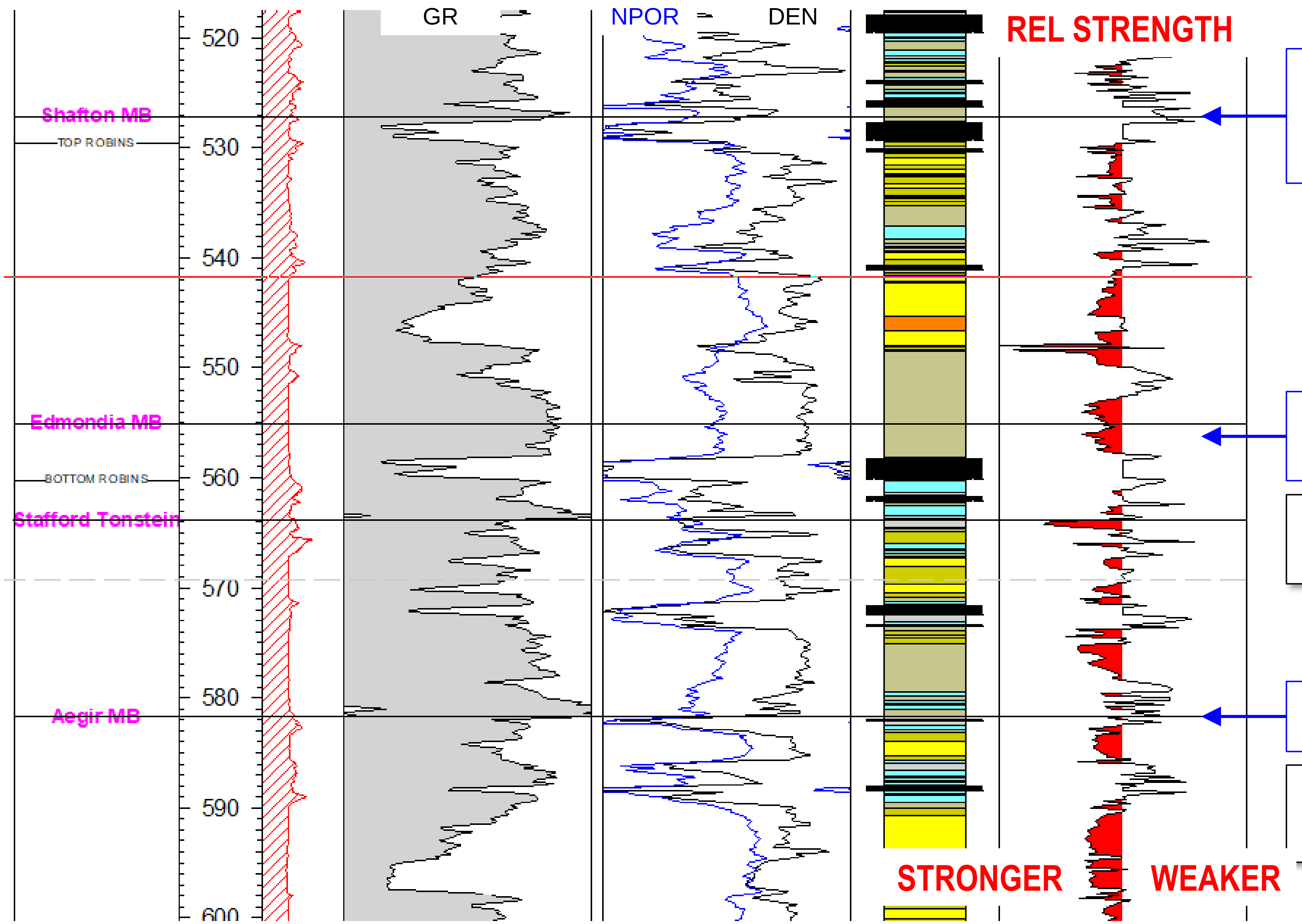
Intra-Carboniferous seal capacity



Potential seals formed by Marine Bands, interdistributary bay fills, lacustrine shales

- Retention capacities up to 500 metres, more usually ± 300 metres
- Capacity may be impaired by presence of silt
- Not usually more than 15 metres thick - all potential seal facies vulnerable to erosion

Intra-Carboniferous seal integrity



Marine horizon affected by soil formation – poor seal potential

Thick marine horizon – no soil modification **– 4 metres good seal potential**

Best seal:

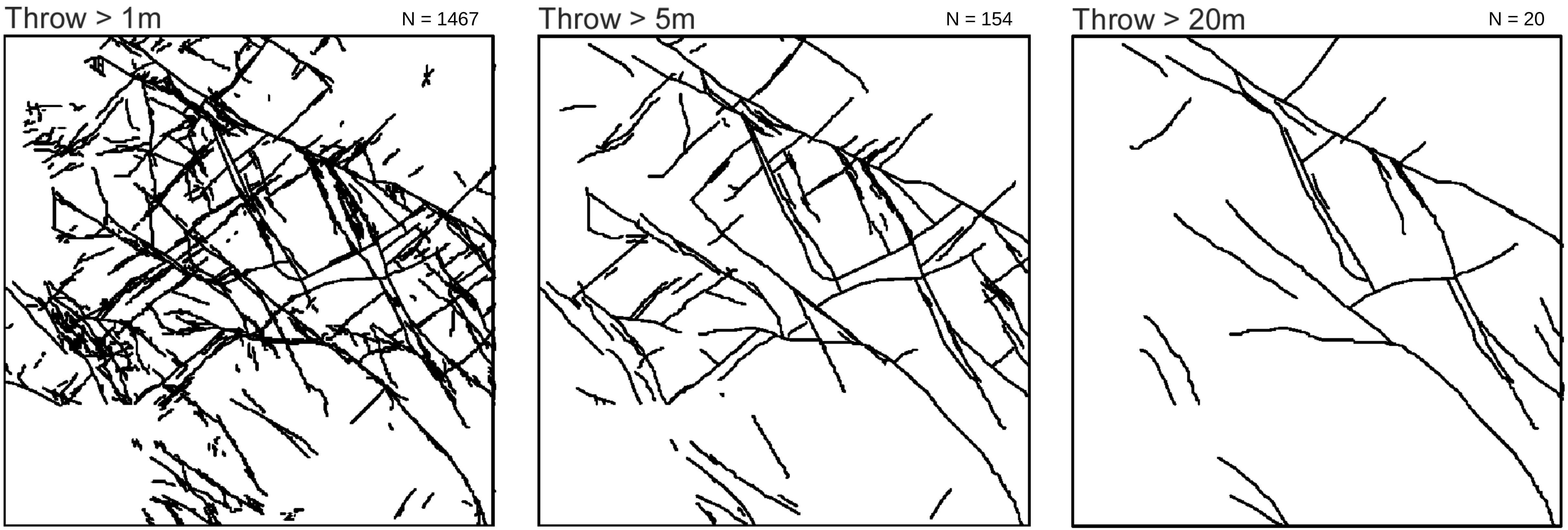
– high GR, high RHOB, mod NPOR

Thin heterolithic marine horizon – poor seal potential

Poor seal:

– high GR, mod RHOB, high NPOR

Sub-seismic faulting and seal integrity - 1



Faults in 20 km^2 area proved by coal mining, Yorkshire Coalfield, filtered by maximum throw

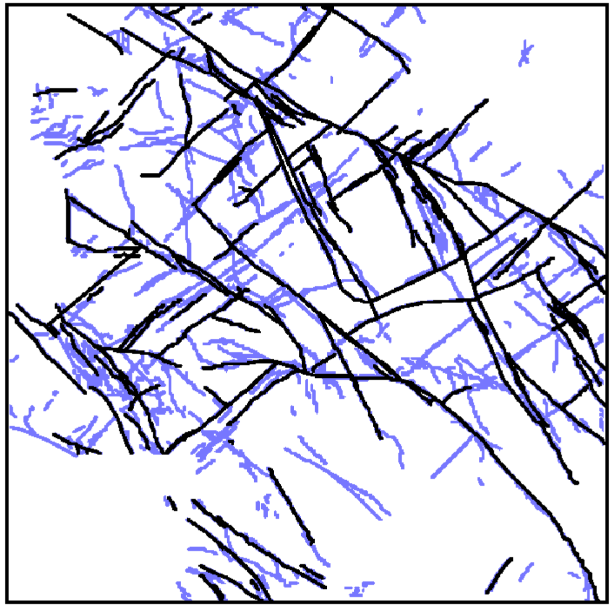
Bailey *et al.* 2002

- Mining records show fractal distribution of faulting with large number of faults below seismic resolution
- 3D reservoir modelling of Yorkshire dataset implies fault juxtaposition significantly enhances sand body connectivity even in very low net:gross succession
- Sub-seismic faulting is major risk in intra-Carboniferous seal breach
- To reduce risk associated with intra-Carboniferous seals it would be desirable to demonstrate seals of suitable lithology having thicknesses of > 5 metres

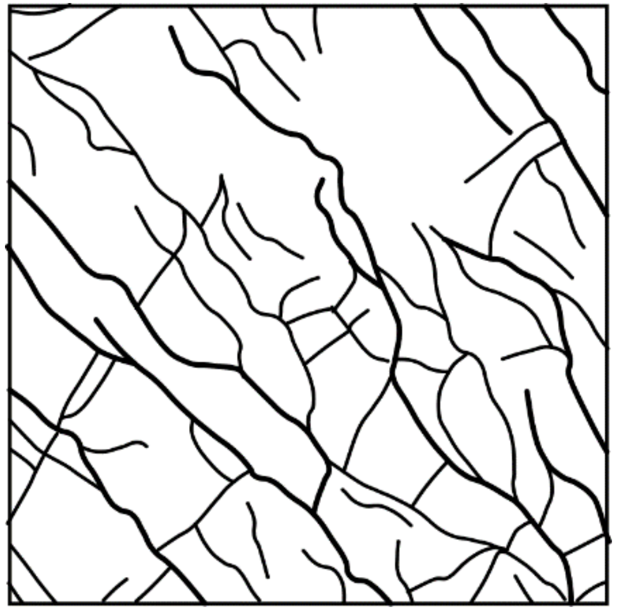
Sub-seismic faulting and seal integrity - 2

Comparison of mining and offshore seismic datasets suggests lower limit of fault throw resolved by seismic is between 5 and 10 metres

Yorkshire dataset, throw > 5 m

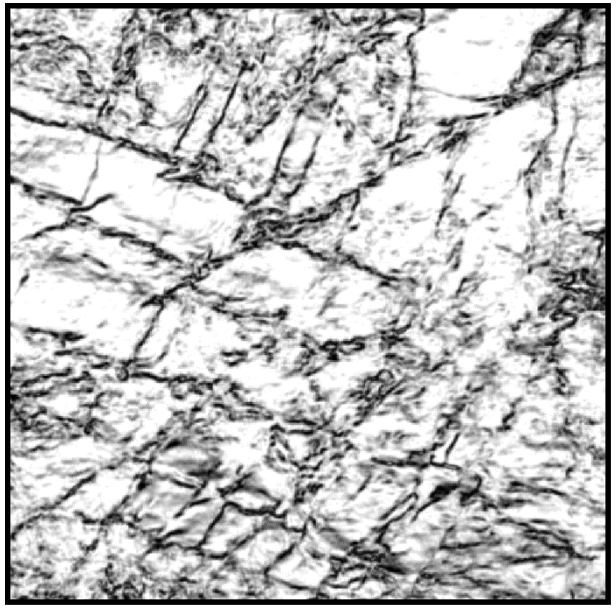


Yorkshire dataset, throw > 5 m (black) + throw > 1 m (blue)



Faults in 20 km2 area, SE Quad 44, mapped from 3D seismic

After Cameron *et al* 2005

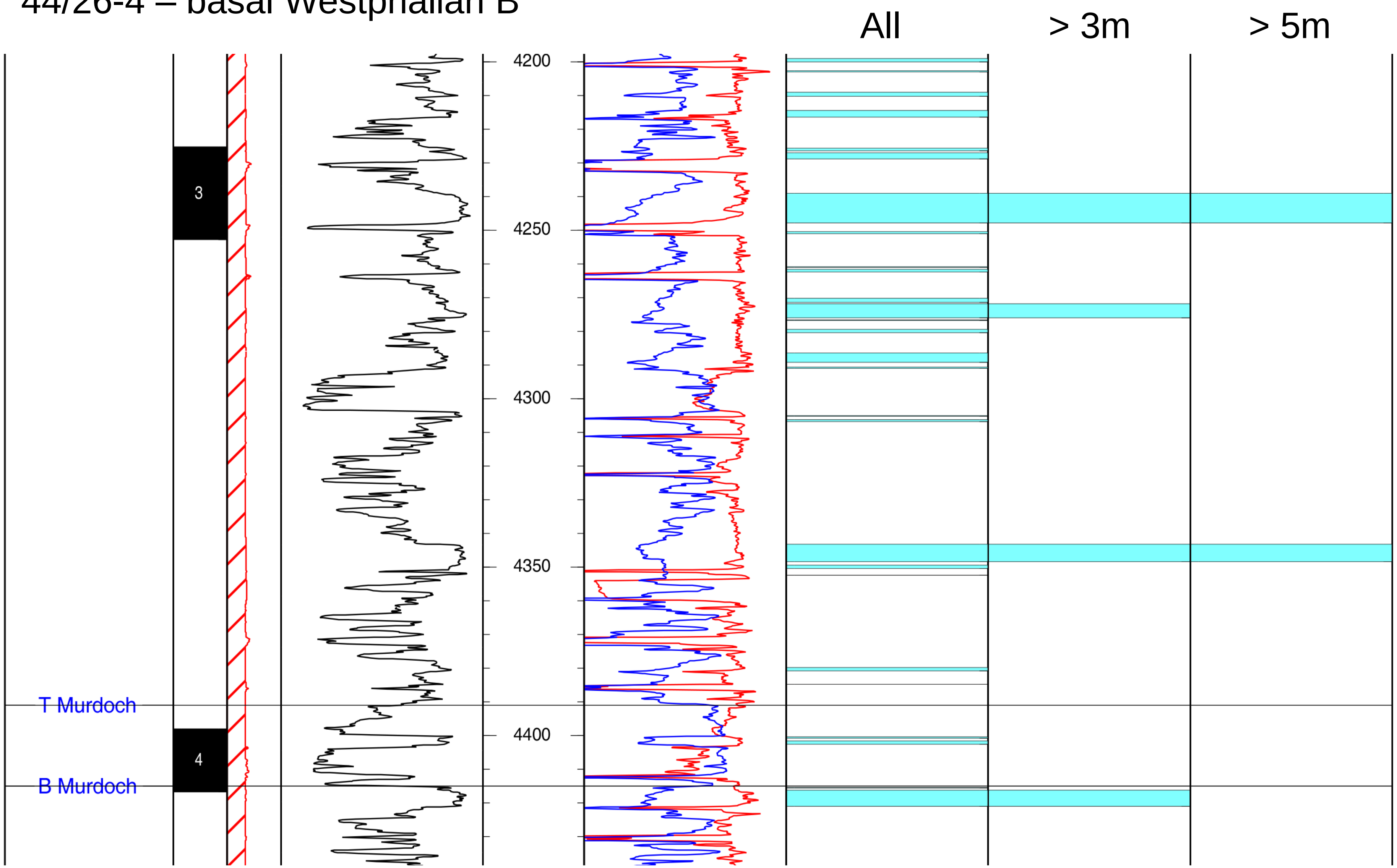


Faults imaged by coherency extraction, 20 km2 area, NL Quad E

Ter Borgh *et al* 2018

Intra-Carboniferous seal thickness

44/26-4 – basal Westphalian B



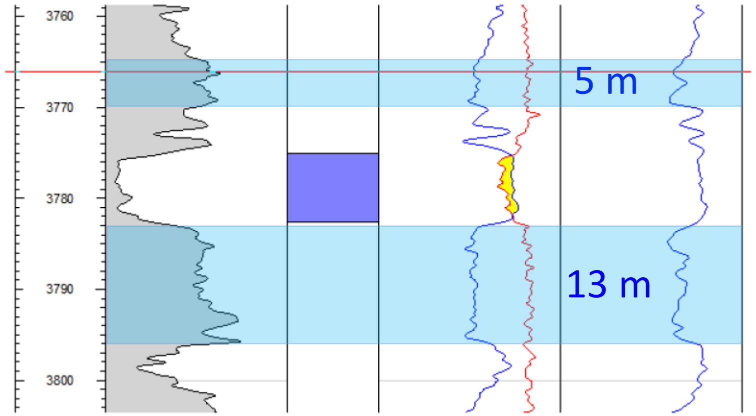
Potential sealing lithologies abundant at all levels in Westphalian Coal Measures and upper part of Namurian

Almost all are extremely thin and vulnerable to minor faulting and / or incision

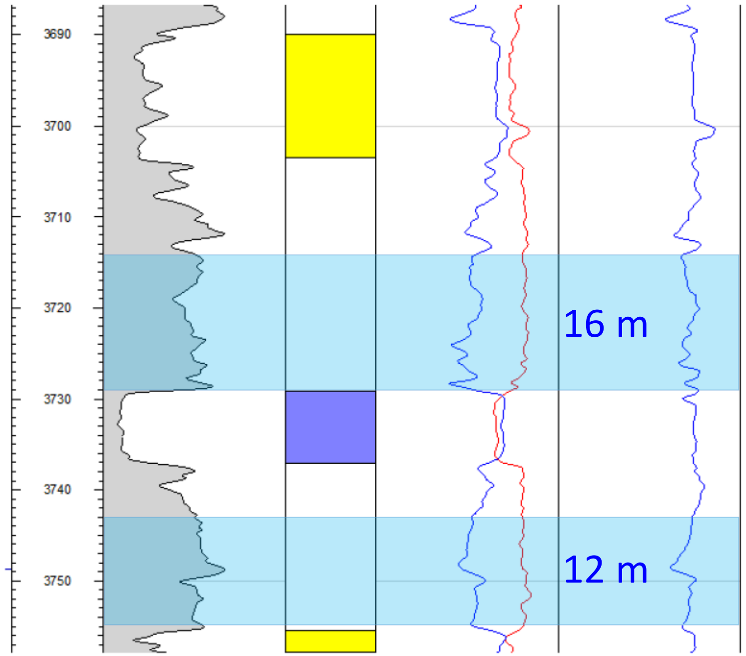
Potential seal horizons are present even in sections without marine flooding events

Intra-Carboniferous seal examples – Cavendish & Trent Fields

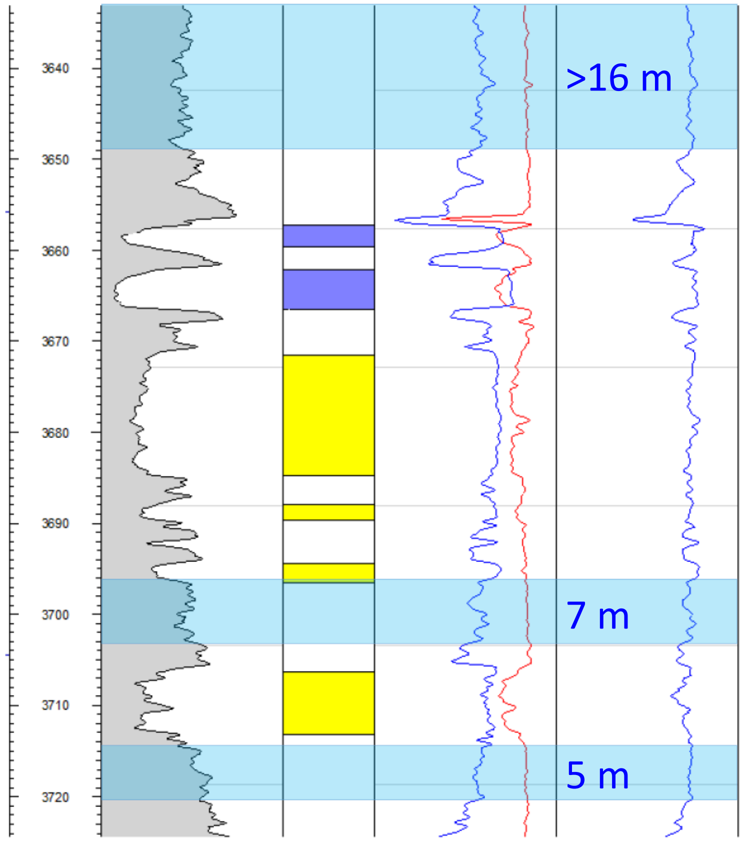
TRENT FIELD   43/25-1 Mid Westphalian A reservoir



CAVENDISH FIELD   43/19a-2 Base Westphalian A reservoir



CAVENDISH FIELD   43/19-1 Top Marsdenian reservoir

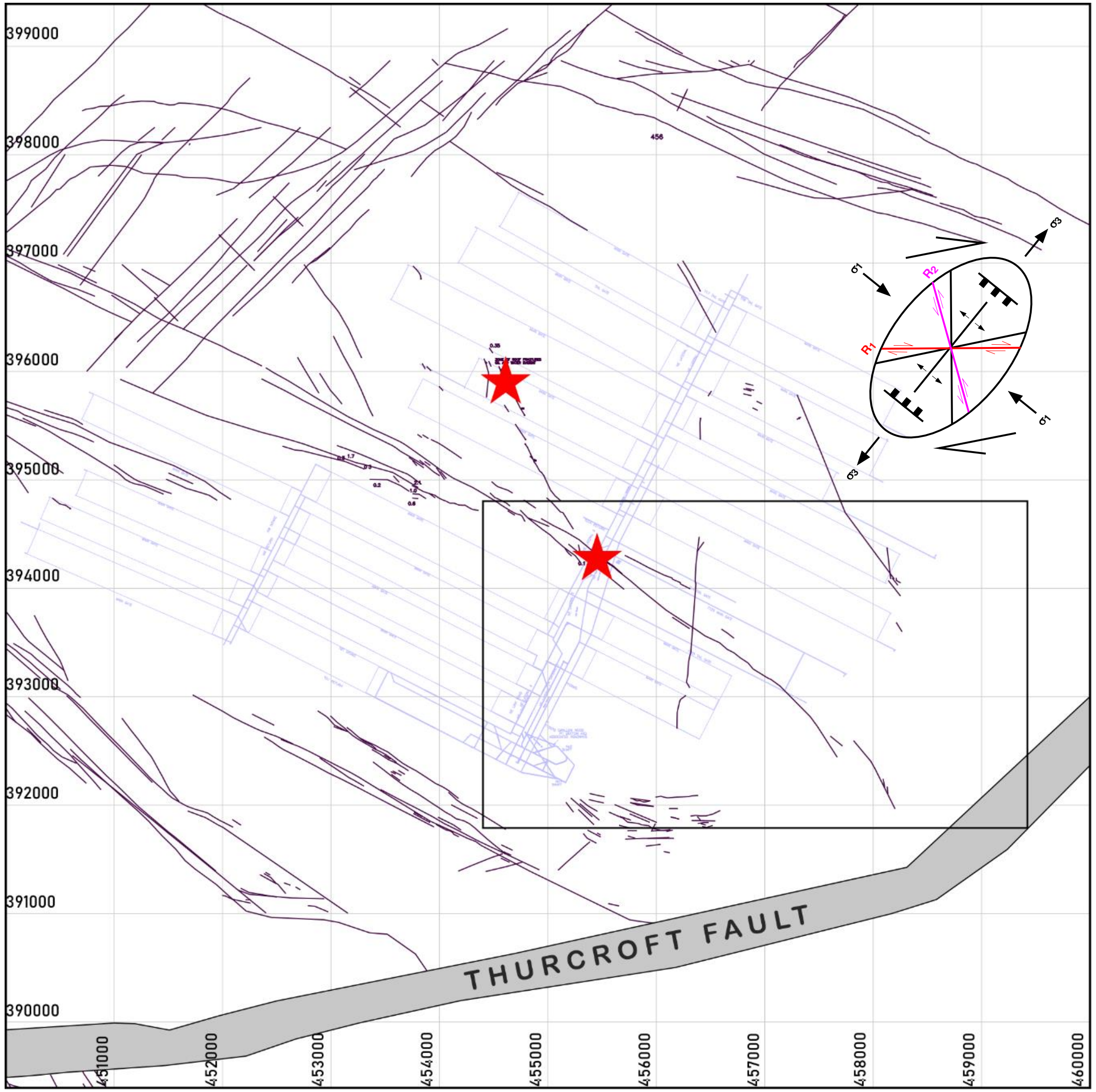


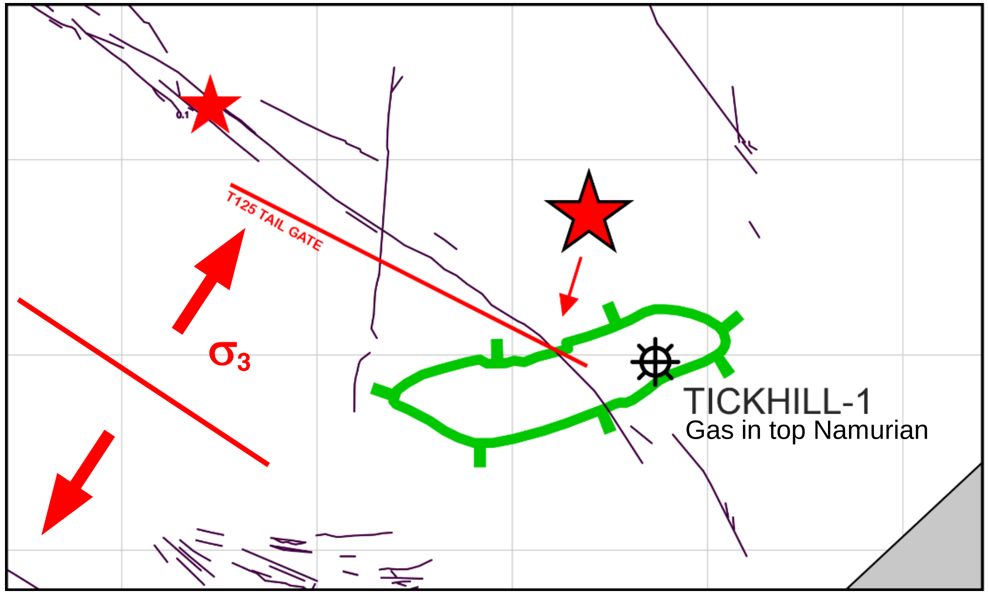
Thick shale units are preferentially developed in lower part of Westphalian A and in upper part of Namurian

Already known to be effective seals in Pegasus, Cavendish, Kepler

Define a fairway involving Carboniferous sealing in this part of Carboniferous succession

Breached seal – example and implications





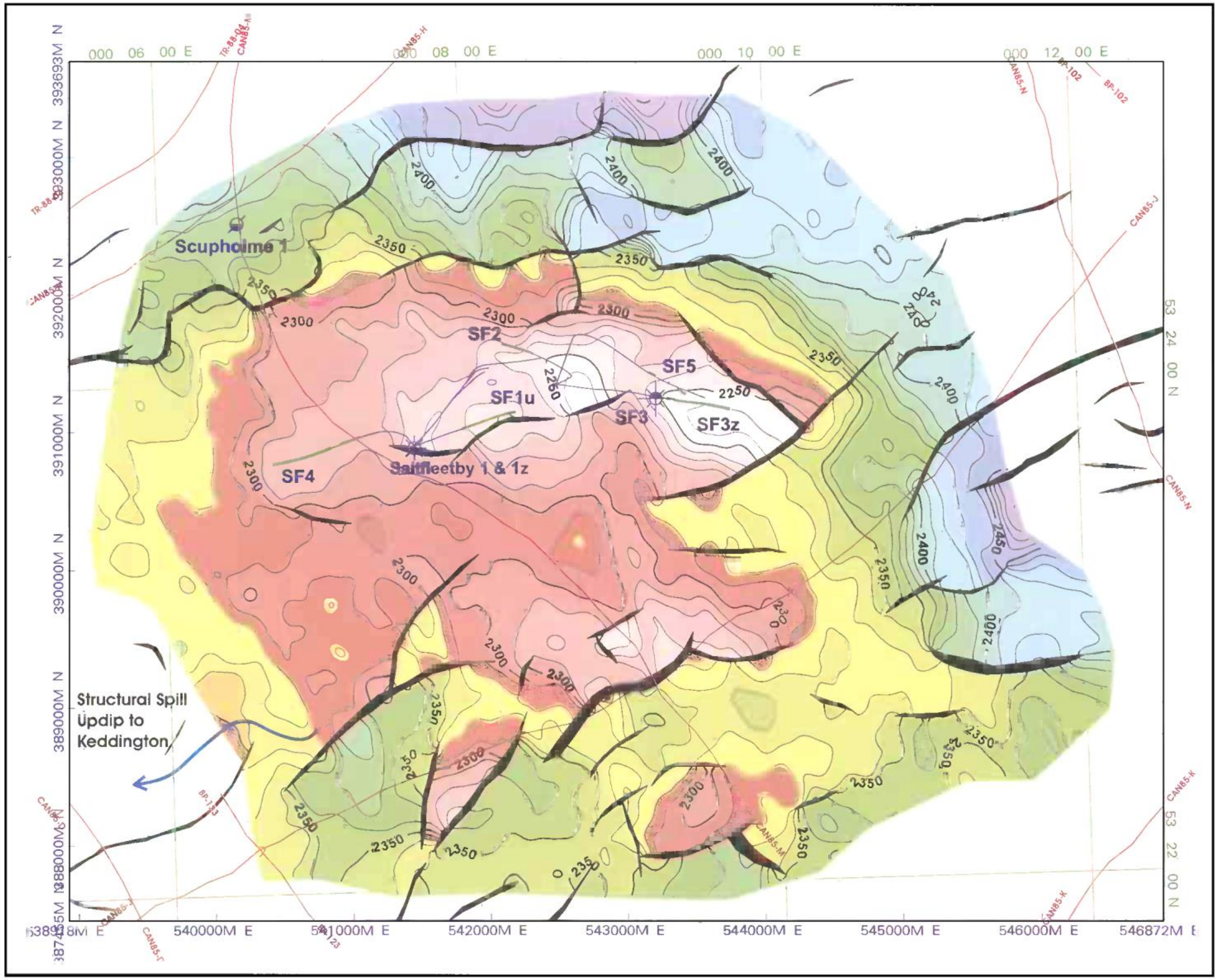
Maltby Colliery, Yorkshire, Westphalian A coal seam

- VRe c. 0.65 – 0.8
- in footwall of Gainsborough Trough bounding fault
- known minor gas influxes associated with NW – SE trending fractures

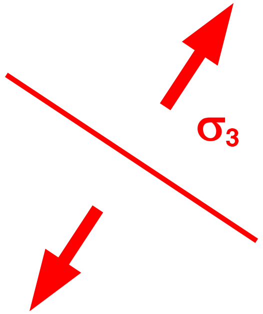
Major 2012 gas influx where tunnel intersected gas-bearing fracture system within closure

Sub-regional in-situ stress data implies NW – SE fractures currently in extensional regime

Saltfleetby Field – a working intra-Carboniferous top seal



Hodge 2003



Base Westphalian A reservoir

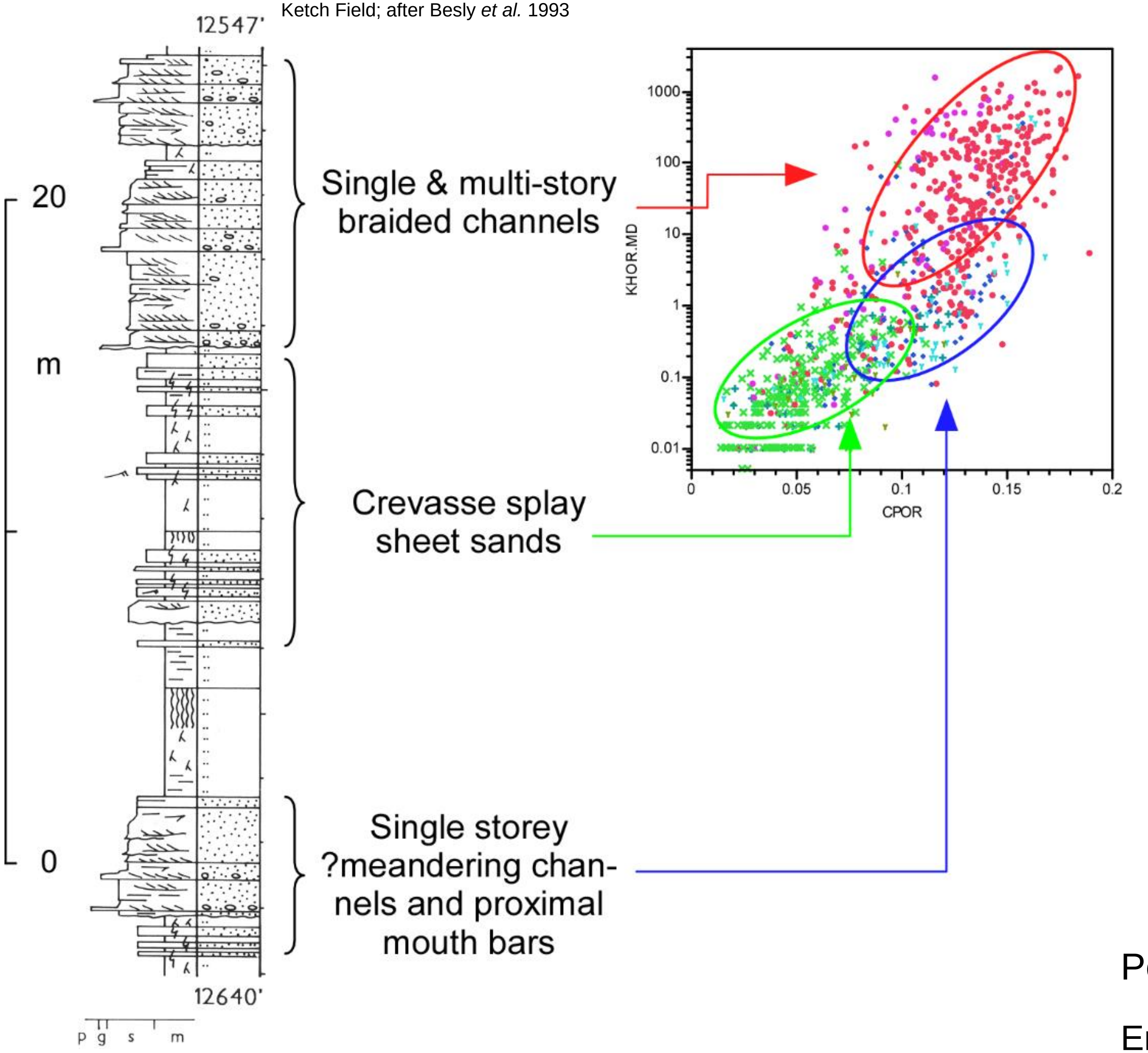
Variscan structure, no Mesozoic modification, tilted during Tertiary

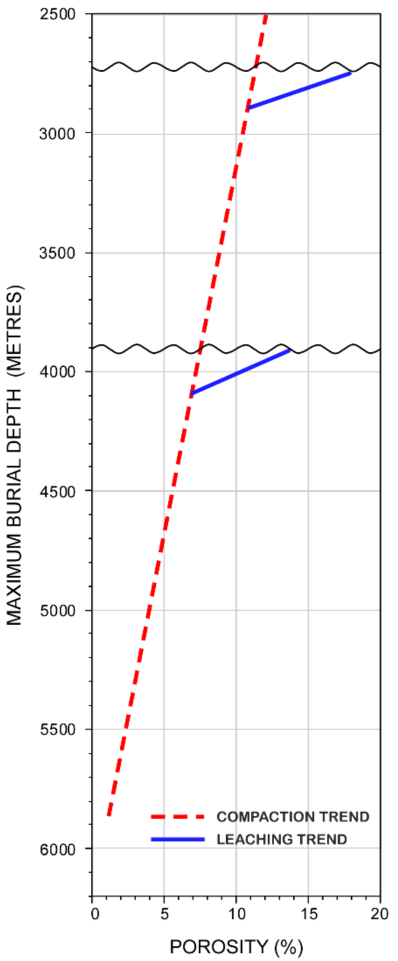
Seal formed by *G. amaliae* Marine Band – c. 8 metres thick

Most faulting parallel to present σ_1

Founding myth 3 “Carboniferous production is from fluvial reservoirs”

Ketch Field; after Besly *et al.* 1993





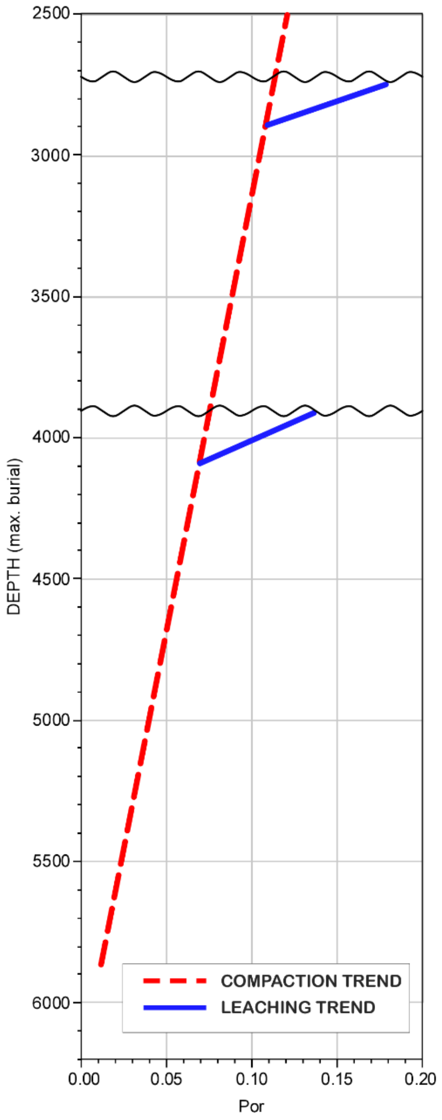
After Bailey *et al.* 1993

Porosity trend related to burial before Variscan inversion

Enhancement due to leaching at Variscan unconformity surface

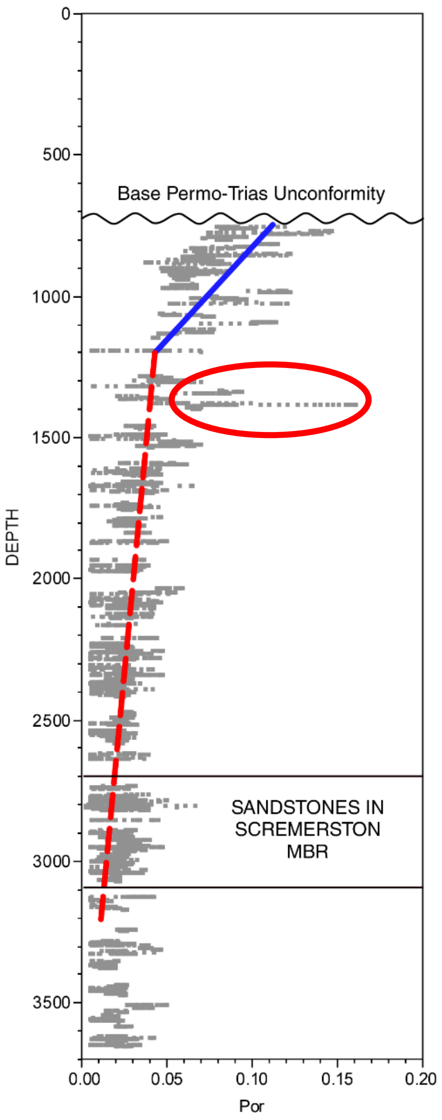
Reservoir quality trends – older reservoirs

REGIONAL TREND, SOUTHERN NORTH SEA (QUADS 43 & 44 - Bailey et al. 1993)



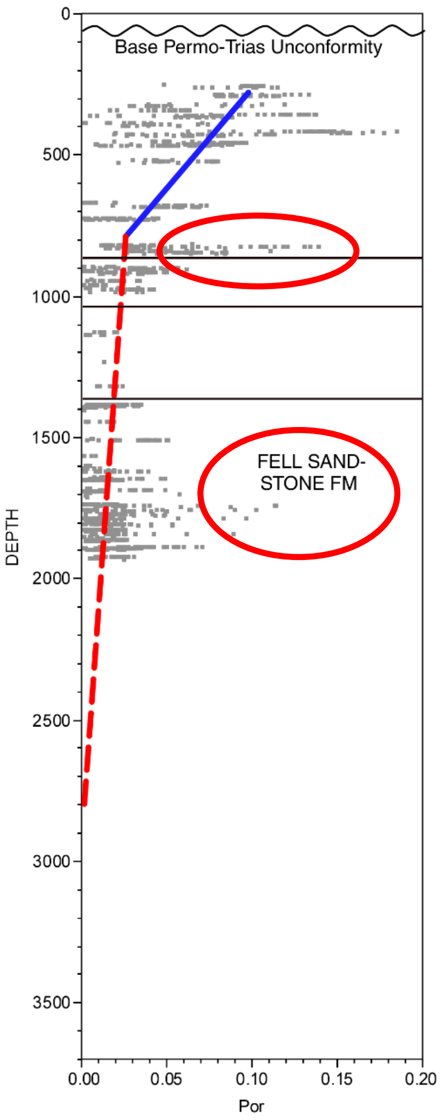
LOG POROSITY vs. DEPTH

SEAL SANDS-1

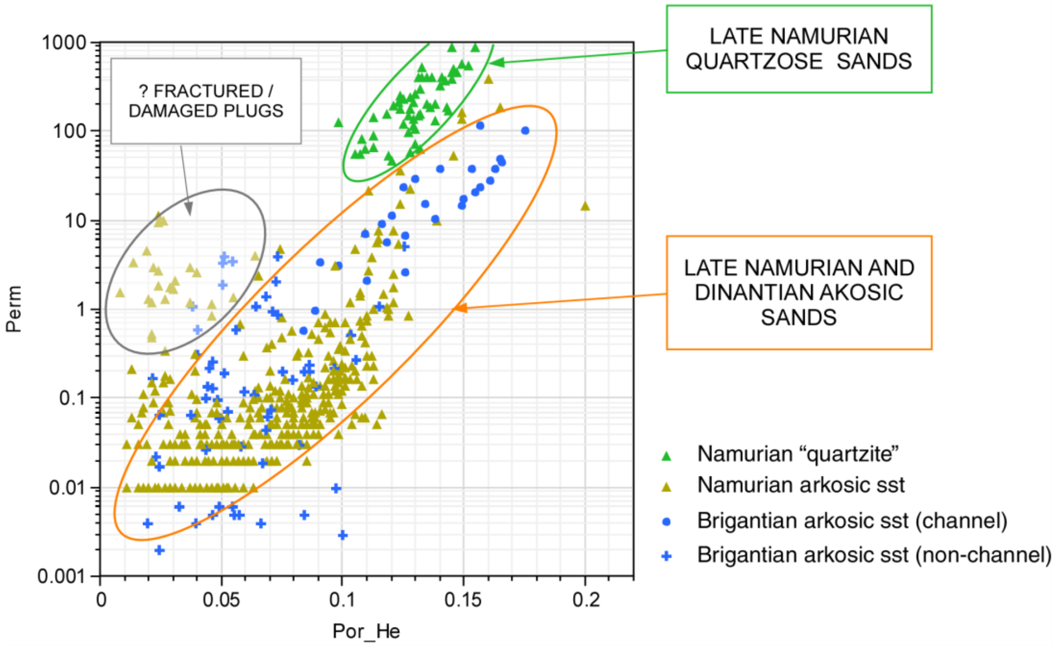


LOG POROSITY vs. DEPTH

BRAFFERTON-1

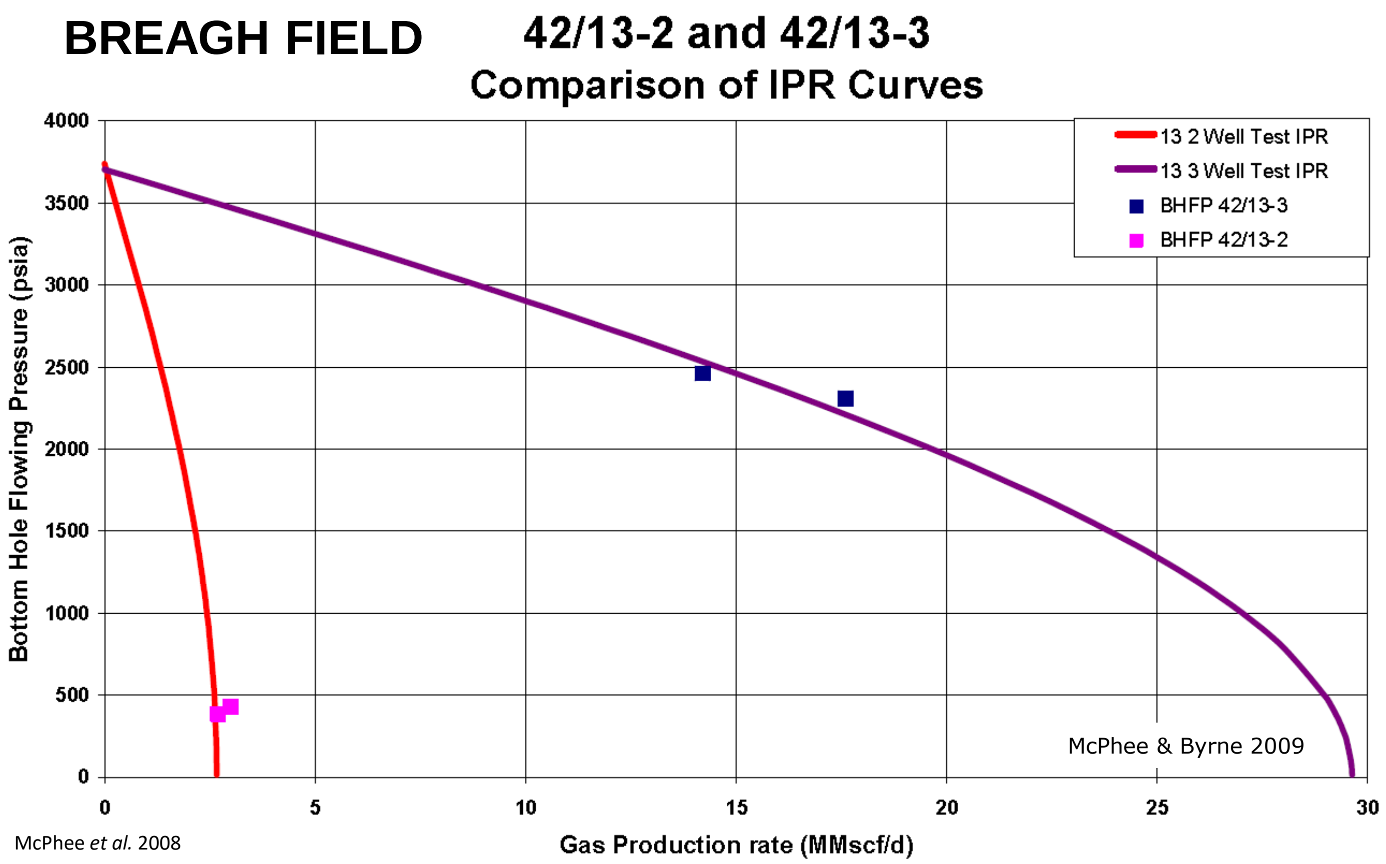


PLUG POROPERM, TRENT AND BREAGH FIELDS - E&A WELLS



- Log analysis of two UK landwells supports Bailey *et al.* porosity model
- Although sandstones in deeper parts of basin fill are generally very tight there are exceptions
- Cut-off for 1 mD permeability at 10% porosity

Formation damage skews perception of reservoir quality



McPhee *et al.* 2008

Formation damage during drilling reduced by careful attention to mud system

Excess overbalance + imbibition of WBM filtrate in clay-prone reservoir creates excessive skin

Use of OBM leads to 10 x productivity increase

42/13-2 - 1997

Heavy salt brine mud
400psi overbalance

155 ft perf (5 intervals)
Max flow 3.0 MMscfd

Skin +47 (+24 - +175)
WBM filtrate invasion up 60 inches

42/13-3 - 2007

Oil-based mud
Minimal overbalance

110 ft perf
Max flow 17.6 MMscfd

Skin 0 - +2
Negligible invasion

Founding myths 2 & 3 – impact on field performance

Field	Production start	Reservoir	Status (April 2017)	Published volumes (BCF)			Production to April 2017	% of published recoverable
				Recoverable	GIIP	RF (%)		
Murdoch	1993	Murdoch Sst	Producing	348	478	73	378	109%
Boulton B	1997	Ketch Fm	Producing	142	206	69	279	196%
Schooner	1996	Ketch Fm	Producing	612	1059	58	308	50%
Trent	1996	Millstone Grit Fm / Caister Fm	Ceased	92	111	83	113	123%

Long-term performance of UK Carboniferous reservoirs has shown very wide departures from what was expected

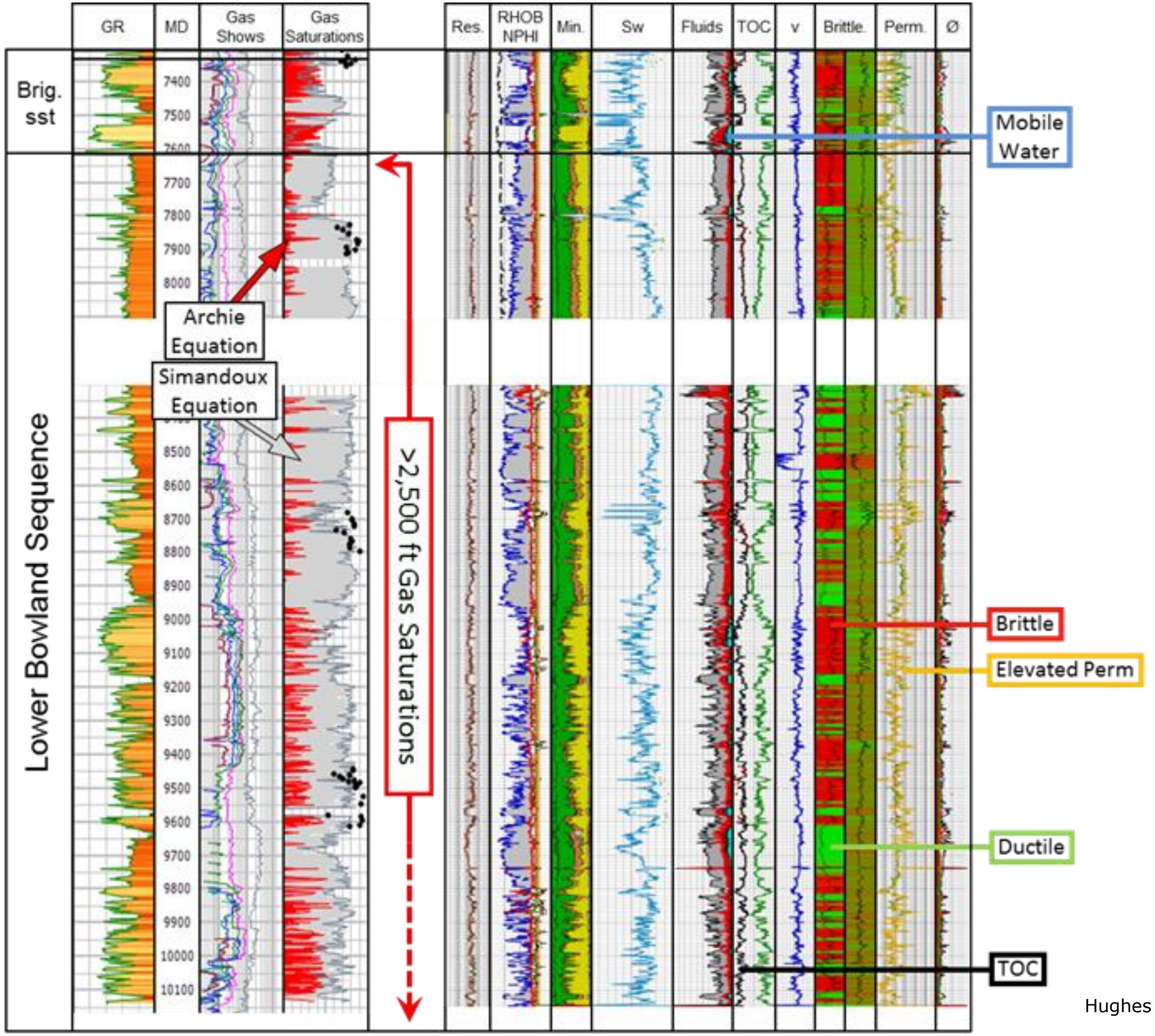
Boulton B and Schooner: faulting has increased connectivity

- improved reservoir performance in Boulton B; deleterious in Schooner

Trent: reservoir thought to be petrophysically poor may have contributed to production + faulting may have increased connectivity

Founding myth 3

“Carboniferous production is from fluvial reservoirs”



Hughes et al. 2018

What constitutes a Carboniferous reservoir objective?

Implications of unconventional gas exploration in UK onshore

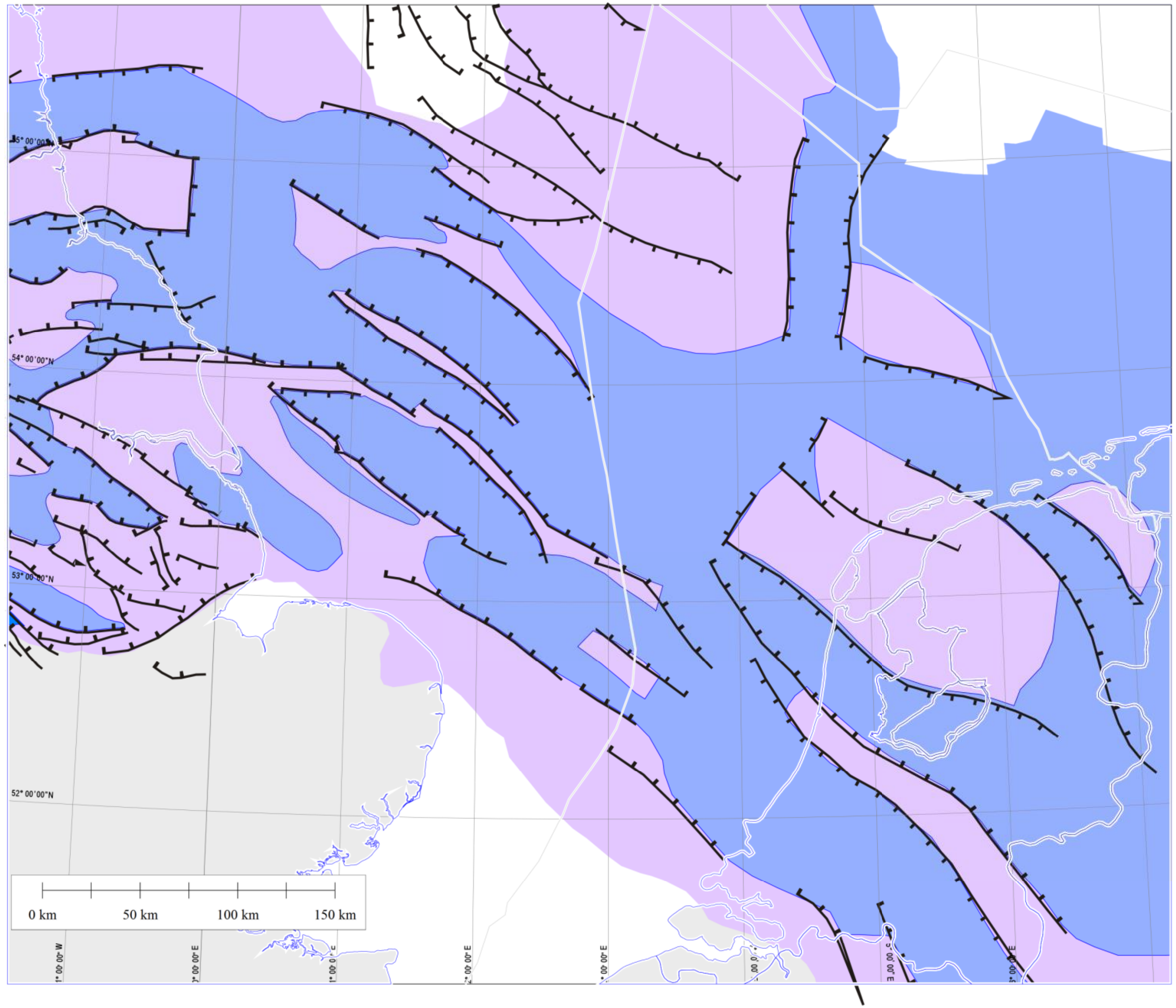
Kirby Misperton Deep:

- unconventional resource contained within a ‘hybrid play’
- thin bedded heterolithics and tight turbidite sands
- naturally fractured silica-rich sandstones interbedded with organic-rich shales
- brittle lithologies suitable for fracture stimulation

Pay not recognised in conventional log analysis

Founding myth 4

"Basin geometries are known"



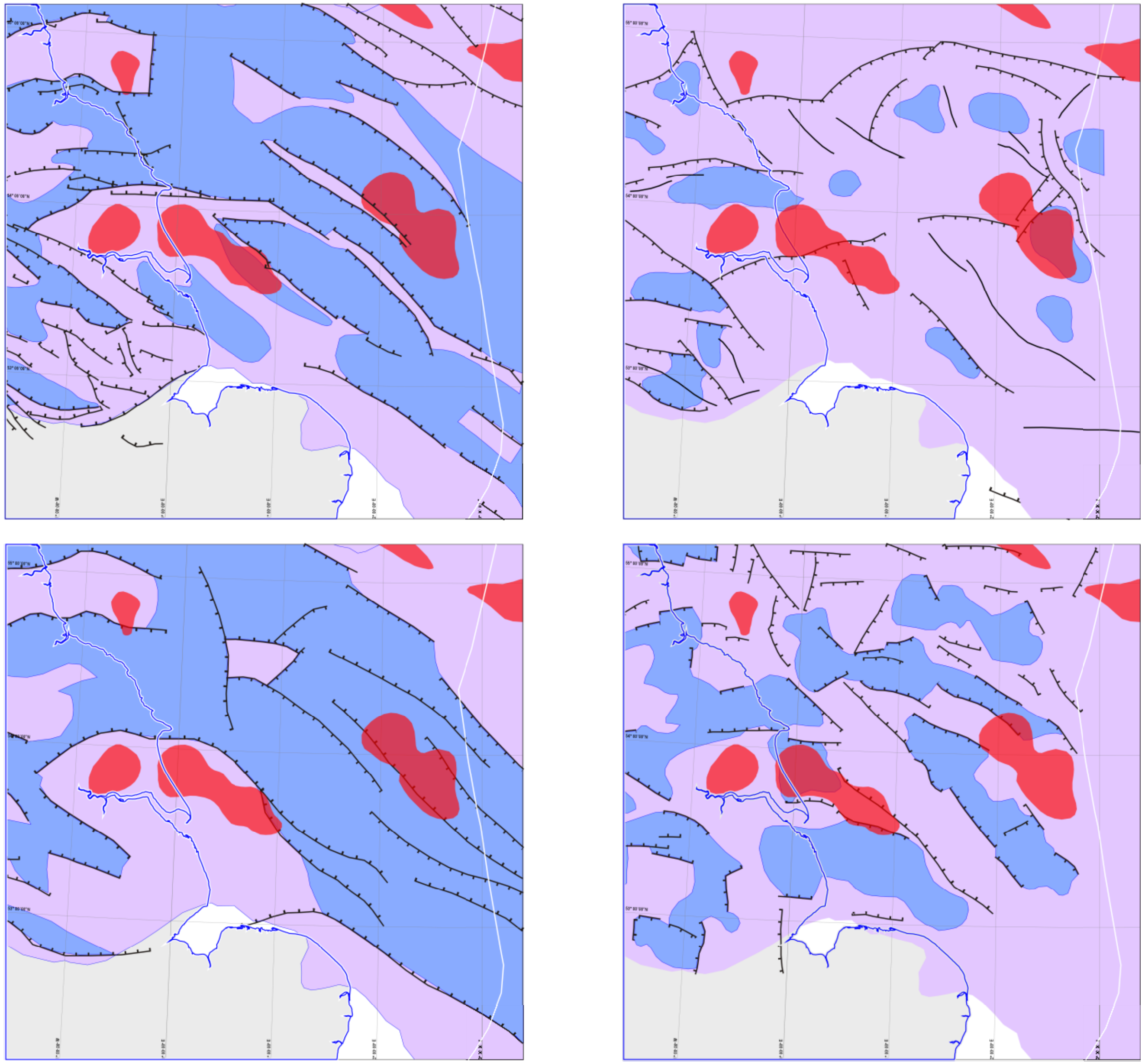
Map of depocentres and highs in Carboniferous basin complex compiled from combination of seismic interpretation and gravity modelling

Most commonly presented map based on 3 sources:

Fraser & Gawthorpe 2003	UK onshore
Corfield et al. 1995	UK offshore
Kombrink et al. 2010	Netherlands

Note that, away from well penetrations, base Carboniferous is poorly imaged in basinal areas

Founding myth 4 “Basin geometries are known”



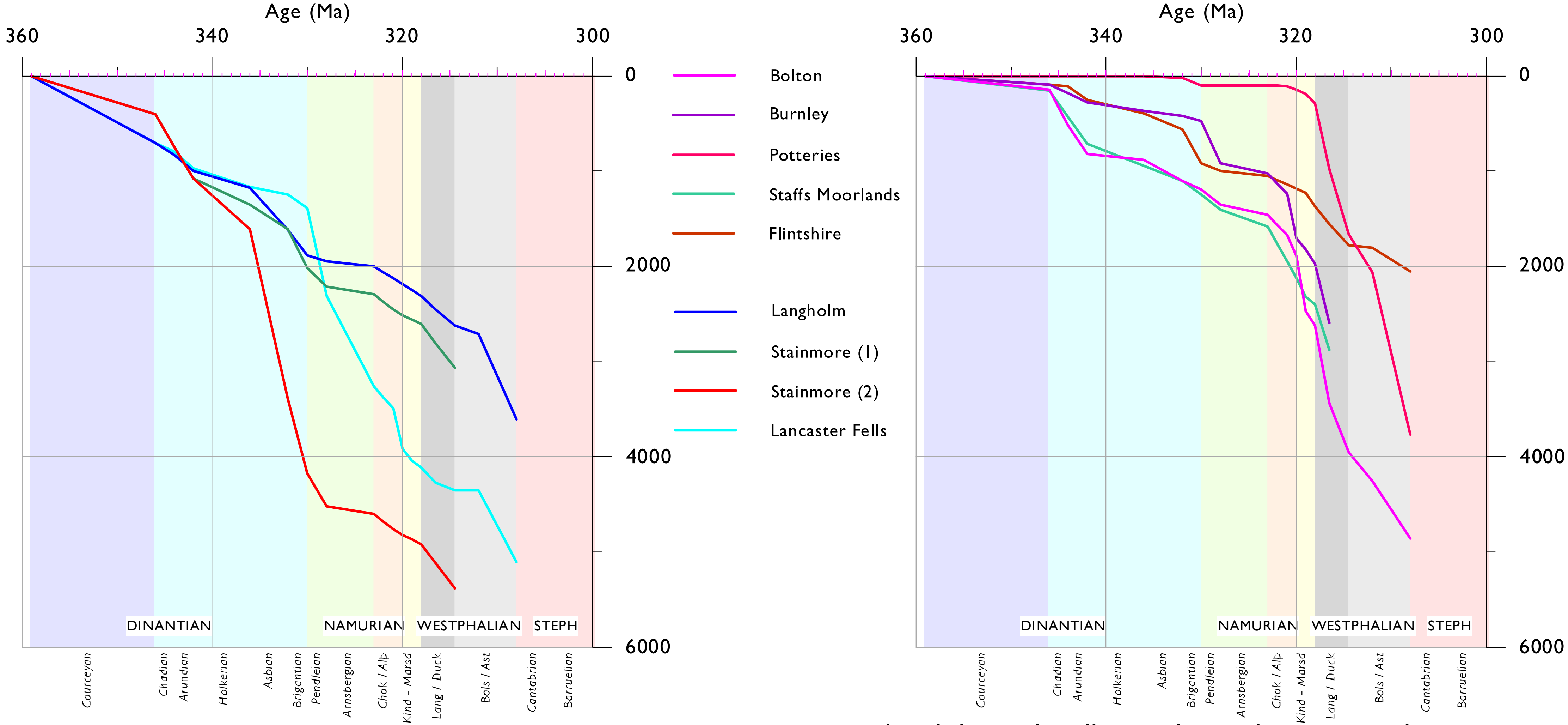
Alternative interpretations put basinal depocentres in very different places

No consensus even on position of southern edge of “Mid North Sea High”

Features interpreted as granites from gravity data locally interpreted as basinal depocentres

Founding myth 5

“Basins formed in rift and sag episode(s)”

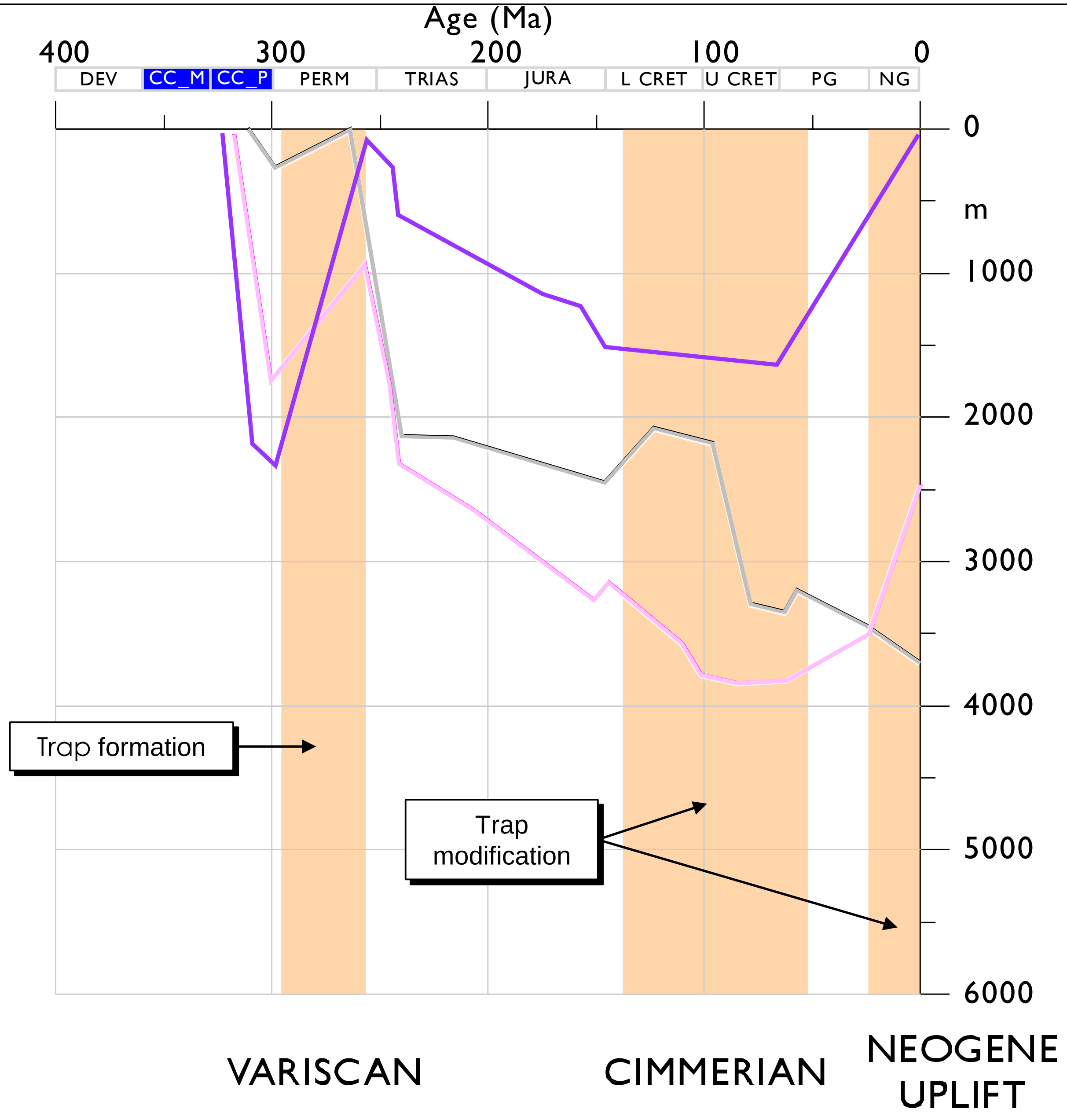


Leeder 1982, 1988; Fraser & Gawthorpe 2003

Foreland thrust loading + dynamic topography
(Kombrink et al. 2008)

Partitioned strain in long-lived regional transtensional regime
(de Paola et al. 2006)

Plays – timing



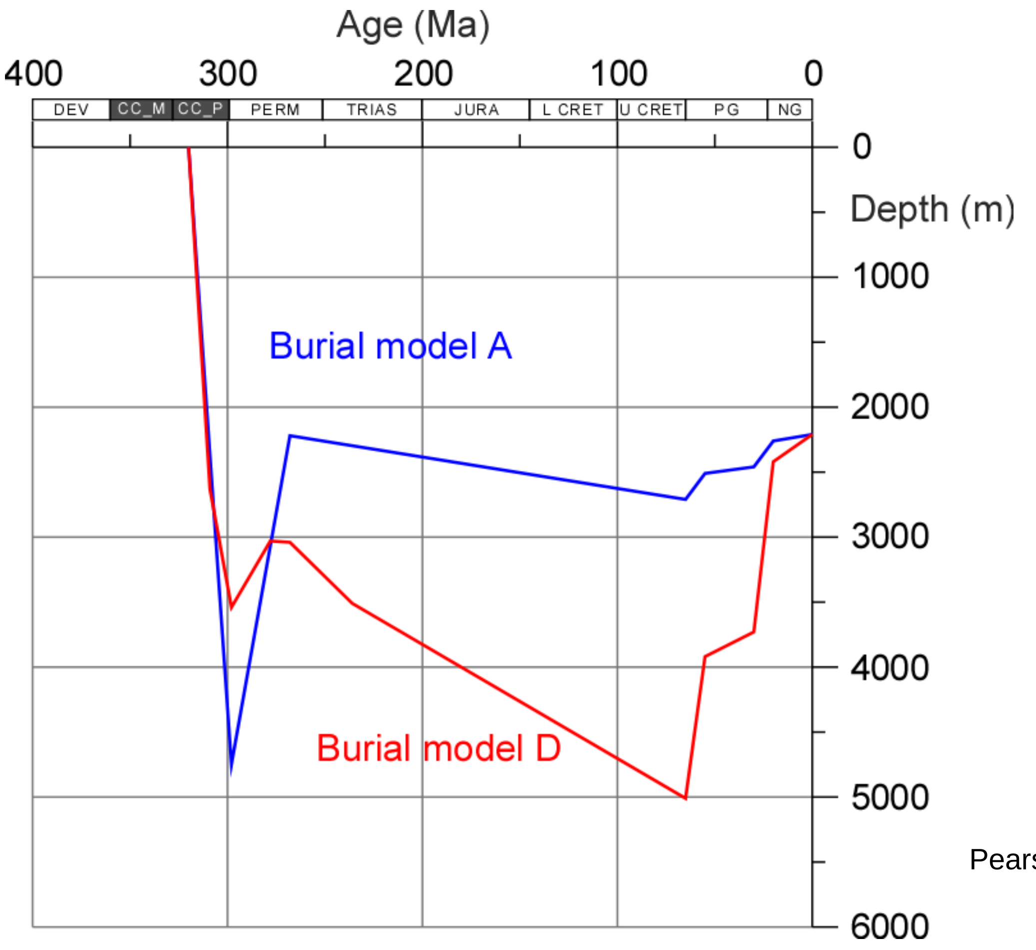
Leeds Basin (UK onshore)	Base Namurian
Variscan structure	max burial in Variscan cycle
Neogene modification	Major Cret – Neogene uplift

Cleveland Basin (UK Q42)	Base Namurian
Variscan structure	max burial in Cret
Modified in Cimm / Neogene	major uplift in Neogene

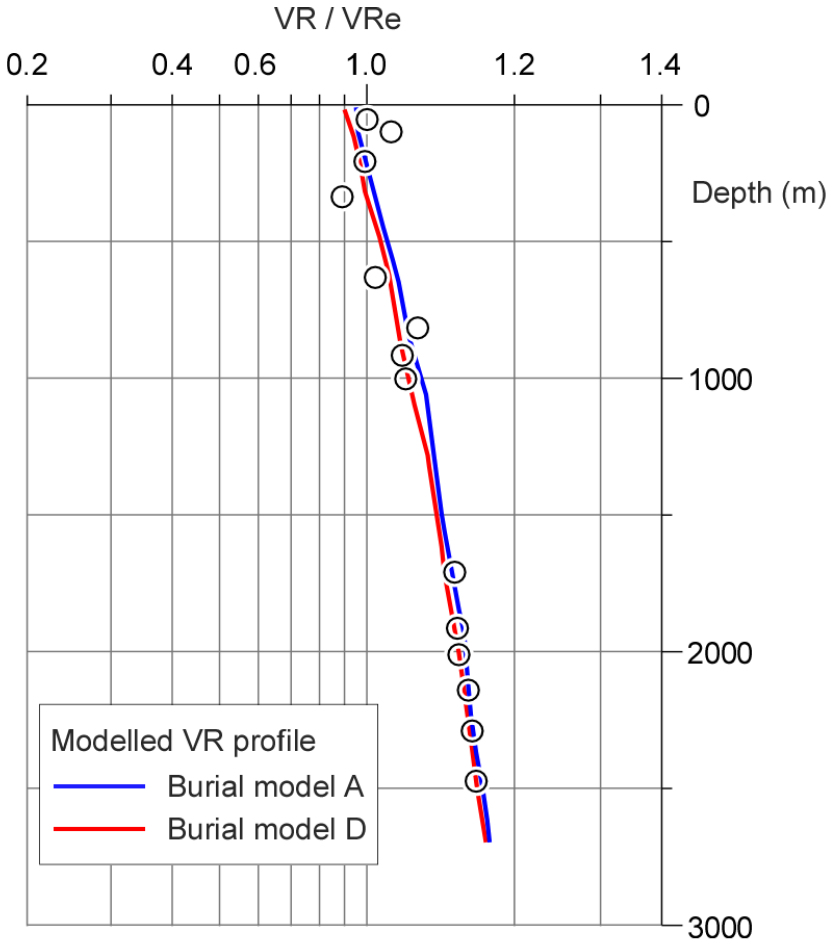
Silverpit Basin (UK Q44)	Top Westph Coal Measures
Variscan structure	currently at max burial
Cimmerian modification	

Importance of quantifying pre-Permian exhumation

Alternative burial histories – Upholland-1 (UK onshore)



VR profile + modelled maturity profiles



Pearson & Russell 2000

Alternative burial histories – Upholland-1 (UK onshore)

Final comments

The Carboniferous is a complex system that needs to be unravelled

- hugely thick succession
- stratigraphic and palaeogeographic evolution mean that succession is very different in different parts of the basin complex
- multiple sub-basins
- complex histories of subsidence, fill and burial
- multiple source rocks – full of hydrocarbons

Nature of petroleum systems

- not a single play
- different fairways
- need for fine-tuned approach – more focussed recognition of specific play segments

Learning from past experience

- better drilling practices
- greater appreciation of the value of technical studies
- need to conserve knowledge and pass it on to new generations