Unraveling Reservoir Architecture of Complex Low Net: Gross Red-Bed Fluvial Sequence Using Palaeosoils and Chemostratigraphy*

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Abstract

The lack of stratigraphical markers and microfossils in continental, fluvial, low net-to-gross red-bed sequences, make conventional e-log based interwell correlations particularly challenging. Effective reservoir modeling and development of such reservoirs therefore rely on application of sedimentological concepts that set the basis for a robust correlation framework. This paper presents a case study located offshore UK, where the sedimentary characteristics and reservoir architecture of a fluvial reservoir were re-evaluated by applying a multidisciplinary approach including pedofacies analysis and chemostratigraphy. This study developed an independent chronostratigraphic framework based on chemostratigraphy related primarily to a careful description and interpretation of “non-reservoir” facies. The innovative use of shear sonic to detect palaeosols in uncored sections was also used for modeling channel distribution. This approach ultimately allowed the identification of meaningful stratigraphic units characterised by changes in the sequence of vertical stacking of pedofacies types. The latter were interpreted as the result of different depositional environments, hence reservoir architecture and connectivity.

The application of the pedofacies concept, the use of shear logs, associated with heavy-mineral analysis, allowed an independent validation of the chemostratigraphic correlation scheme, and provided a framework for more sophisticated reservoir modeling. In particular, the recognition of the overall style of fluvial behaviour that may influence the style of channel sand-body stacking provided a predictive model to assess reservoir lateral and vertical connectivity. Also, indication of proximity to channel belts enabled identification of stratigraphical which are likely to be laterally connected to channels not penetrated in the wellbore.
Unraveling reservoir architecture of complex low net: gross red-bed fluvial sequence using palaeosoils and chemostratigraphy.

Andrea Moscariello

AAPG Cape Town, October 2008
Outline

- Introduction

- The Barren Red Measures Group:
  - Palaeogeography, Stratigraphy, Climate and Tectonic

- The case study: Schooner and Ketch Fields SNS, UK
  - Sedimentology
  - First Lithostrat. Correlation & Conceptual geological model
  - Field Performance
  - Second Chemostrat. Correlation and Paleosols
  - Impact of new integrated approach and results

- Conclusions & Learnings
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Challenges of distal fluvial systems

- Distal fluvial sandstone associated with red-beds/barren sedimentary successions are common HC-bearing reservoirs worldwide (e.g. Unaizah Fm, Gharif Fm, TAGI, Bunter Sst FM, Silverpit Fm, etc.)

- Understanding reservoir architecture and sand connectivity is key to establish effective predictive models

- Correlation is challenging because of the difficulty to apply common chronostratigraphic methods (e.g. biostrat)

- Even more complicated in endoreic basins where the fluvial system is located away from sea/lacustrine flooding.
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Palaeogeography – Westphalian C

- Upper Carboniferous continental fluvial system
- Variscan foreland basin
- Southern Margin of the foreland bulge (Mid North Sea High)
Stratigraphy, Climate and Tectonic

<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>SUB SYSTEM</th>
<th>SERIES</th>
<th>STAGES</th>
<th>Age Ma</th>
<th>Formation</th>
<th>Depositional environment</th>
<th>Climate</th>
<th>Tectonic</th>
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<td>PERMIAN</td>
<td>UPPER</td>
<td>AUTUNIAN</td>
<td>SAKMARIEN</td>
<td>295</td>
<td>Rotliegend Group Silver Pit Claystone</td>
<td>desert playa lake</td>
<td>arid wetting upwards</td>
<td>subsiding basin</td>
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<td></td>
<td></td>
<td></td>
<td>ASSELIEN</td>
<td>305</td>
<td></td>
<td></td>
<td></td>
<td>Variscan deformation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>STEPHANIAN</td>
<td>308</td>
<td></td>
<td>low gradient fluvial plain dominated by low sinuosity braided rivers</td>
<td>warm and humid; drying upwards</td>
<td>subsiding southern flank of the Mid North Sea High</td>
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<tr>
<td>CARBONIFEROUS</td>
<td>SILESIAN</td>
<td>WESTPHALIAN</td>
<td>WESTPHALIAN D</td>
<td>311</td>
<td>Ketch Fm</td>
<td>coastal delta plain dominated by low sinuosity meandering rivers</td>
<td>warm and humid</td>
<td>early Variscan deformation</td>
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<td>WESTPHALIAN B</td>
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<td>Foreland of Variscan thrust zone</td>
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<td>WESTPHALIAN A</td>
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</table>

(Moscariello, 2003)
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- Conclusions
Study area Location

Distance from Mid North Sea High: ca. 120 km
The Ketch Formation

Correlation Methods for a Subsurface Formation

- Seismic: very deep and below salt
- Biostratigraphy: barren
- Magneto-stratigraphy: too short time of deposition
- Tuff layers (tephra): no volcanic activity
- Vertebrate taphonomy: no too many around
- Coals: absent
- Litho-stratigraphy: vertical packages based on wireline logs and extrapolated laterally (distinct N:G intervals)

- Sequence stratigraphy?
- Palaeosoils?
- Chemo-stratigraphy?
Reservoir Sedimentology - Facies

Based on sedimentological core analysis and wireline log.

<table>
<thead>
<tr>
<th>Facies</th>
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<tr>
<td>Composite channels</td>
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<td>Single channels</td>
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<tr>
<td>Proximal crevasse splay</td>
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<tr>
<td>Fine-grained lacustrine and overbank deposits</td>
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<td>Sols</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Grain-size</th>
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<tbody>
<tr>
<td>Gravel</td>
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<tr>
<td>10-15%</td>
</tr>
<tr>
<td>Coarse to medium sand</td>
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<tr>
<td>35-40%</td>
</tr>
<tr>
<td>Fine sand</td>
</tr>
<tr>
<td>20-30%</td>
</tr>
<tr>
<td>Silt</td>
</tr>
<tr>
<td>30-40%</td>
</tr>
<tr>
<td>Clay</td>
</tr>
<tr>
<td>5 -10%</td>
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</table>

<table>
<thead>
<tr>
<th>N:G</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 %</td>
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</tbody>
</table>
Reservoir facies

1 - Fluvial channel

Stacked/amalgamated channel fills with fining upward trend.

Planar and trough cross bedding

Pebble conglomerate/lag

Cross bedded sets typically developed at the base of sand body

Low sinuosity braided channel bar complex deposited during high stage flood conditions

Pebble conglomerate dominated by Qz clasts. Abrupt changes to finer grained Sandstone

Vertically aggraded and laterally coalesced low sinuosity braided channel complex
Non-Reservoir facies

2 - Flood Plain

Bedded very fine grained sandstone with interbedded silt-claystone

Fining upward trend

Ripple-cross and planar lamination

Massive very fine sandstone with soft sedimentary deformation

Haematitic reddish/brown silt/claystone with rootlet/plant remains and pedogenic fabric

Pedogenic/mottled/churned clay/peds rich/siltstone with calcretes

Proximal overbank deposits.
Sheetfloods, crevasse splays with interbedded floodplain deposits

Interfluvial/flood plain deposits relatively well drained

Palaesois
Conceptual Geological model

Depositional environment of the Barren Red Measures - Upper Carboniferous SNS

- Large interfluvies with well layered mud, siltstone and ephemeral lacustrine deposits.
- Low sinuosity, sandy, braided river belts.
- Inland source area
- 80 km
- 60-90 km
Model 1: Litho-stratigraphic correlation across the Schooner Field (flattened at Ketch Formation base)
Model 1: Sequence stratigraphy approach

Unit A: Aggradation at early base level rise and valley infill caused by backstepping

Unit B: Non reservoir

Unit C: Finer sediments indicating increased rates of BL rise. Great floodplain storage of accommodation

1996 model: Width range: 250-4000 m; T:W range: 1:9 - 1:500
Field Production Performance

e.g. Well 4 actual vs. planned
Model 2: Chemo-stratigraphic correlation across Schooner Field (flattened at Ketch Formation base)
Challenge

- Reservoir performance, connected HC, doesn’t seem to honour the 1st correlation and related geological conceptual model.

- The new, 2nd correlation and associated reservoir connectivity, might be right but is largely inconsistent with 1st geological model.

- How can we ensure the new correlation is right?

- No alternatives: Back to the rocks and give a better look also at the non-reservoir intervals.
Pedofacies types

**Type 1**
Primary sedimentary structures (bedding, soft sed. deformation, etc..) preserved, no (or very rare) occurrence of bioturbation and/or rootlets. Some hematite nodules occur.

**Interpretation:** high sedimentation rate and high aggradation; channel or frequently feed alluvial plain

**Type 2**
Primary sedimentary structures are preserved but can be locally disturbed by bioturbation or rootlets which make up 10-20 % of the fabric.

**Interpretation:** moderate aggradation sediments
Pedofacies types

Type 3
Rare preservation of primary sedimentary structure up to 30-50% of fabric disturbed by bioturbation and rootlets.
**Interpretation:** low aggradation sediments

Type 4
No primary structure preserved, original fabric completely churned up, heavy bioturbation, ferruginous features (pisolites) and siderite nodules, salt (barite ?), pedorelicts.
**Interpretation:** mature paleosol, (ultisol, tropical podzol, calcrete) intense redox and illuviation processes, wet/dry cycles very low or absent aggradation rate (long sub-aerial exposure).
Pedofacies at the microscope

**Pedofacies 1**: Undisturbed lamination picked out by aligned mica and hematite-rich clay.

**Pedofacies 2-3**: Anisotropic, parallel alignment of clay minerals, also with a parallel extinction pattern; grain coatings present (arrowed).

**Pedofacies 3**: Cluster of opaque nodules showing separation from the groundmass (outlines around grains); stress cutans also present.

**Pedofacies 4**: Multiple-stress cutans and opaque clay filled fine brecciation cracking, developing through soil fabric from larger cracks.

 Increased evidence of clay movement, the presence of better developed soil fabrics and an intimation of the existence of a soil structure in pedofacies 4.
Pedofacies distribution on the Upper Carboniferous alluvial plain: Ketch Formation

Pedofacies models: M. Kraus et al…
Pedofacies cyclicity
Pedofacies stratigraphy

Pedofacies stratigraphy

pedofacies type

stratigraphic log

GR (API)

Pedofacies

Thickness (ft)
Recognition of Pedofacies in uncored wells

Correlation between shear sonic log and pedofacies from core data.

Pedofacies 1 (i.e. non-pedogenised facies) to 4 (strongly pedogenised facies) indicate high and low sedimentary aggradation, respectively.
Reservoir anatomy based on pedofacies vertical and lateral distribution

Example of lateral correlation and pedofacies distribution for 2 wells in the Silver Pit Basin (Barren Red Measures, Westphalian C)

(Moscariello, 2003)
Impact on Reservoir Prediction - Sequence Stratigraphy

*old model*
Fluvial architecture

Relative change in base level, wetness and available accommodation space

Unit A
Unit B
Unit C
Sequence stratigraphy

old model
Fluvial architecture

Relative change in base level, wetness and available accommodation space

new model
Fluvial architecture

Units 1,2,3

Units 4,5

Lithostratigraphy
Chemostratigraphy & Pedofacies
Impact on Reservoir Modeling and Field Performance Prediction

New Geological Conceptual Model

Alternative Reservoir Analogue (Keighley et al, 1998)

Revised aspect ratio

Reliable prediction capabilities

Update geo-cellular model
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Conclusions

- Flood plain composition and vertical evolution in low N:G systems are intimately linked to channel sand distribution and reservoir architecture.

- Use of multiple and independent approaches (N:G distribution, pedofacies, chemostratigraphy) allowed us to:
  
  - define an alternative evolutionary model of the sedimentary basin which resulted to be more consistent with the regional tectonic evolution of the basin (sequence stratigraphy approach helps but is correlation driven !!)
  
  - better constrain the static and dynamic model by using appropriate analogue data (i.e. reservoir performance prediction).
Learnings

1. Limitation of using lithostratigraphic subdivision based on wireline log in isolation.

2. Shear sonic together with GR can be successfully utilised to identify pedofacies vertical patterns in uncored wells.

3. Chemostratigraphy can be efficiently used as a tool to assist definition of a reliable correlation framework, hence connectivity.

4. Importance of palaeosoils/pedofacies in characterising internal reservoir architecture in low N:G, barren fluvial reservoirs also in the subsurface.
THANK YOU
References


http://search.datapages.com/data/sepm/journals/v66-67/data/068/068005/0901.HTM


