A Review of Thin Bedded Pay Determination and Produceability

Benjamin Panting[1], Dr Nicola Scarcelli[1], Dr Domenico Chiarella[1]

[1]*Earth Sciences Dept., Royal Holloway University of London, United Kingdom*
MDFB036@live.rhul.ac.uk

Abstract

This study has focussed on late Cretaceous aged reservoir targets located at the head of a large type 1 canyon system which is 3.5 km wide and 1.5 km deep. The canyon fill is complex and is dominantly characterised by a randomly filled modified embedded stack.

This study has employed an integrated approach to transcend from the scale of the canyon down to the bed scale through utilising a rich suite of subsurface data including 3D PSDM seismic data, RMS amplitude maps, bayesian inversion products, conventional wireline, core data, special core analysis and production data.

Integrated route mean squared amplitude and facies mapping has characterised the inter-canyon system as a channel levee complex for which the average thickness of the reservoir interval is 290 metres within which thin bedded sands have been proven as attractive secondary reservoir targets and succeed in providing an effective means of communication between discrete bodies of massive sands.

A prospective target within the channel levee complex has been identified in the Campanian turbidite sands where the production potential from thin bed sands is likely to be greatest. Within this zone, the dominant style of thin bed inheriting from the proximal levee is the thick-thin beds classified as lithofacies 2 for which thicknesses range between 2 cm and 20 cm, porosities range between 10 % and 16 % and permeability is 680 mD.

Although thin beds are unlikely to contribute significant increases to the effective stock tank oil in place (STOOIP, while in production), thin bedded zones of the reservoir should not be overlooked as evidently there is resource in place that can offer opportunities to increase production value by perforating behind pipe prospects at relatively low cost and may offer opportunities for infill or step out drilling.

The key findings of this study are important in the context of declining production from a field currently deemed as a late life asset and so provide insightful value toward potentially extending the commerciality of this field through informing future business decisions involved with maturing research, well-tests and production strategies.

Ultimately, thin beds are considered an important resource for increasing value late into the natural life of the field.

Introduction

The scope of this project surrounds the determination and function of thin bedded pay within a mixed mid to deep-water development asset consisting of turbidite plays which are hosted within a type 1 canyon system which incises into the West African continental slope.

The producing Campanian (Senonian Epoch, 89.3 +/- 1 to 65.5 +/- 0.3 Ma) reservoirs were deposited during the early drift stages of the African continental margin where the base Campanian marks a major unconformity due to the onset of major incisions developing on the continental slope.

The field studied is located within the channel head region of the canyon and is characterised as a confined system dominated by channelised submarine turbidity processes and associated channel levee deposits. The channel levee complex is characterised by high degrees of sinuosity, cross-cutting, amalgamation, erosion and overprinting.

Aims

I) Derive a methodology utilising wireline data to consistently determine thin bedded intervals and identify lithofacies to be discerned such that Net Reservoir, Net Thin Beds and Non-Reservoir may be distinguished to identify trends within the channel complex.

II) Review 3D seismic data for the prospect of determining lateral continuity of thin beds away from well control.

III) Review core to determine the continuity characteristics of thin beds and establish what types of depositional environments manifest as having the best continuity.

IV) Investigate the production potential and STOOIP contribution from thin beds.

V) Identify a prospective target zone in the reservoir where the potential of thin bedded pay is greatest.

Datasets

To achieve the aims this study has utilised a rich suite of subsurface data including 3D PSDM seismic data, bayesian inversion products, conventional wireline, core data, special core analysis and production data.

Key Limitations

- The geophysics dataset is unable to resolve any geological feature below the vertical resolution of 16 metres and so beds, bed sets, and potentially smaller turbiditic deposits may not be imaged.
- Wireline tools are not technically equipped for resolving individual thin beds and consequently it is not possible to take true measures of reservoir properties for thin beds.
- Although not a data limitation, reservoir characterisation of the turbidite geo-bodies is made particularly challenging due to the depositional nature of the channel levee complex within the canyon system leading to complex seismic reflection profiles.
- Core data is unlikely to represent the complexity and distribution of the reservoir in any location or at any depth except for within the well and interval the core was extracted from, but to some degree may act as a proxy for wells in other areas.
- Core data is extremely limited in spatial extent and is unable to quantifiably solve the question of how laterally continuous the thin beds are within the reservoir.

Analysis

Channel-Levee Cross Section

A high level summary would reveal that the large majority of depositional elements are present that one would expect within a confined submarine channel complex as summarised in the below figure.

Observations from cores taken across the reservoir interval reveal a complex fill within the canyon that largely resembles a randomly filled modified embedded stack as per the canyon fill schema defined by Kendall and Haughton (2008). Evidently though, some zones resemble a semi-organised pattern with embedded stacking and a mild degree of aggradation. Within this system the juxtaposition of channel elements and stacking patterns are likely to be controlled by the frequent migration of the channel thalweg or the nature of the turbidite depositional processes leading to significant erosion, overprinting and amalgamation.

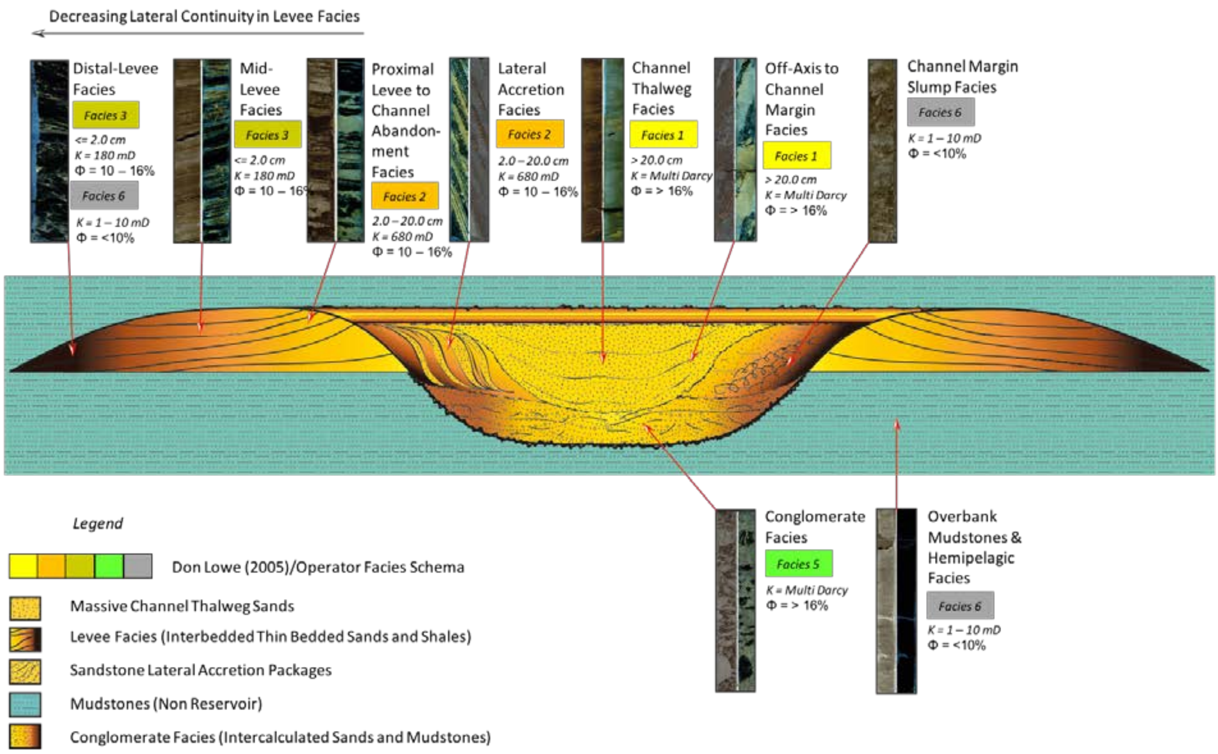

Figure 1: Inter-canyon channel Lithofacies summary. Note NTG inherently decreases with decreasing lateral continuity

The complexity of stacking patterns within the reservoir introduces stratigraphic barriers and baffles that are not favourable to the production of hydrocarbons. This key issue highlights the importance of better understanding the distribution of thin beds within the reservoir and how effectively the thin beds act in providing a means of communication between high quality discrete turbidite sand bodies located within the channel thalweg.

As expected, NTG, lateral and vertical continuity appears best within proximal range of the levee, with these parameters rapidly decreasing away from the source of sediment supply. The dominant mode of deposition for thin beds is within the levee and so the prospect of communication being provided by thin beds is good assuming the proximity of discrete high quality sand bodies fall within the range of the proximal levee.

Seismic Profile

At the broad scale, the seismic reflection profile is characterised by a single major incised canyon feature which has an approximate width of 2.5 km. At the inter-canyon scale, nested within the main canyon are 4 orders of smaller incised canyons with widths approximately ranging between 200 and 750 metres. A key observation in defining each inter-canyon incision is the steep sided geometry of dipping reflectors which truncate nearby reflection events with the base of each incision having an erosional surface often located above a shaly reflective event. This shaly package is interpreted to represent a depositional hiatus of the sand fairway.

At the canyon fill scale, the seismic expression of the canyon fill is best described as chaotic. The seismic profile indicates that the brightest and strongest events are located over the axis of each canyon thalweg highlighting high quality reservoir sands hosting hydrocarbon fluids. Distally away from the canyon thalwegs the reflection profile becomes progressively more chaotic and appearing less bright before eventually manifesting as translucent to hollow events. This motif is interpreted to represent the shale content of the canyon fill increasing distally away from the thalweg.

Based on the observations from the seismic data, the author concludes that the seismic expression and core data complement each other to support the interpretation that the canyon fill largely resembles a randomly filled modified embedded stack.

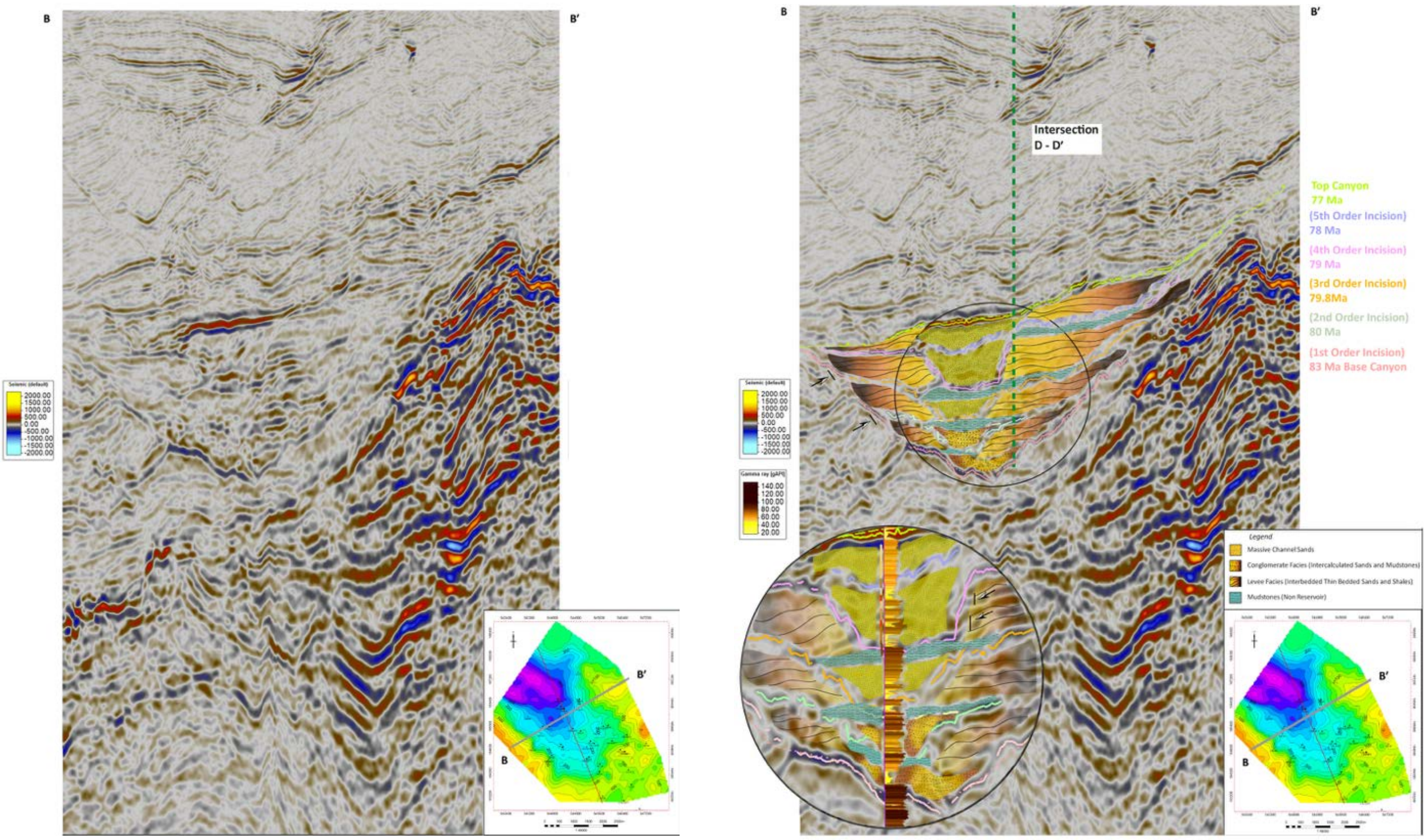

Figure 2: Mid-Canyon seismic reflection cross section B - B'

(Striking SSW to NNE adjacent to major incision (L: Un-interpreted, R: Interpreted))

Canyon Morphology

Utilising a 3D visualisation of the canyon enables consideration to be given toward the shape, morphological features and bathymetry of the base canyon and how features control and influence the propagation of turbidity currents through the canyon.

Key findings are summarised as the canyons entry point locating to the South East with steep canyon sides aiding to laterally confine the energy focussing the flow of turbidity currents basinward such that the main sand fairway follows a South East to North West trend. The steep zones of the stepped bathymetry would aid turbidity currents to increase in energy enabling the current to propagate further through the canyon and that the currents would interact with zones of depressions where deposition will focus ponded turbidite sediments. Potential sources of sediment supply include sub-marine flows entering the canyon, initiation of turbidity currents inheriting from seismically induced slope failure in the sheer walls of the canyon, or from gravitational slope failure induced turbidity currents.

Holistically accounting for the considerations from the core and seismic expression of the canyon, the author has deduced that this system may be classified as a Type I canyon as defined by Jobe et al (2010). According to Jobe et al, Type 1 canyons indent the shelf edge and are linked to areas of high coarse-grained sediment supply, generating erosive canyon morphologies, sand-rich fill, and large downslope submarine fans/ aprons where the canyon becomes less confined toward the abyssal plain. Type I canyons are dominated by erosive, sandy turbidity currents and mass-wasting depositional processes which sculpt the canyons.

In terms of the wider project aims, perhaps the most significant finding from the analysis of the canyon morphology is the identification of a narrow zone (highlighted in figure below) whereby the bathymetry of the canyon is likely to focus currents promoting sinuosity and cross-cutting.

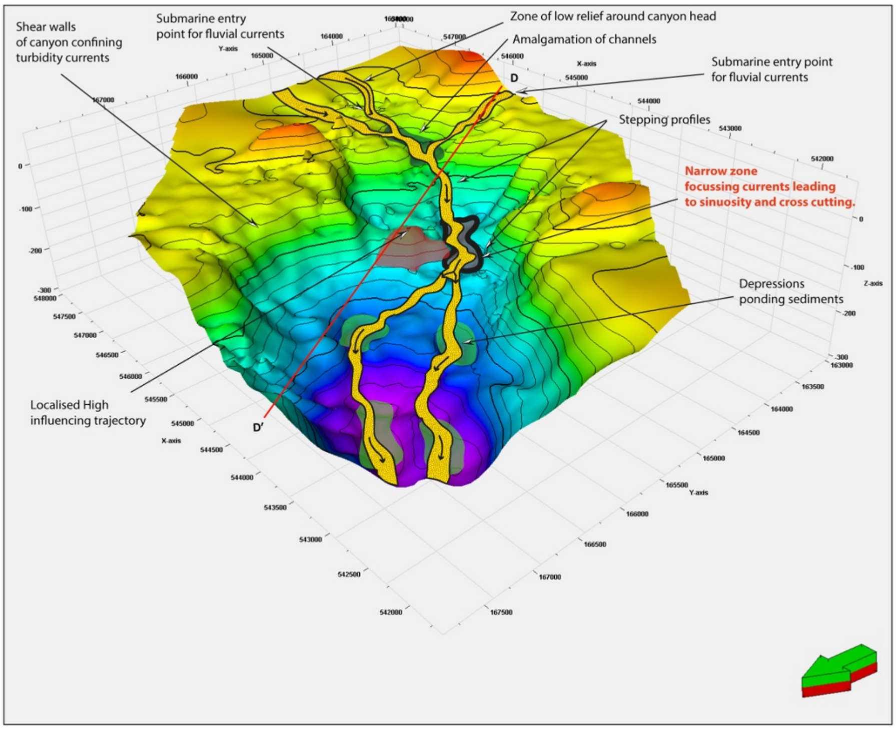

Figure 3: Viewing up canyon in a SSE direction with Geological interpretation of turbidity channel within the base canyon

Integrated Studies

Recognising that at the reservoir scale a geophysical approach is inadequate in resolving individual elements of the channel system such as the levee's and that at the bed scale the wireline tooling is limited in identifying individual thin beds, it is necessary to employ an integrated approach to qualitatively describe the architecture of the reservoir within a spatial and stratigraphic framework. This approach enables the distribution of the channel lithofacies (thin beds, massive channel sands and non-reservoir facies) to be mapped out before observing the degree to which cross-cutting occurs within the channel system.

Wireline

Noting individual thin beds are below the resolution of the wireline tooling and that assigning petrophysical properties to categorise thin beds from other lithotypes appears controversial, the reality is that regardless of individual bed thickness (massive sands vs thin beds), the effective porosity property depends on measurements being resolved across a global window of investigation by a combination of the gamma density (GR) tool and the compensated neutron (CNL) tool.

Qualitatively, the gamma density and compensated neutron tool can resolve features at a gross scale of 50 - 100 cm and 60 - 200 cm respectively. From a quantitative perspective, the vertical spacing between the source and the receiver of the GR and CNL tools is such that reliable measurements can be recorded from a minimum bed resolution of 60 cm each.

Therefore, it can be acknowledged that the wireline tooling can resolve packages of thin beds at gross scale and thus using porosity cut-offs can be differentiated from other lithofacies.

From the raw data, effective porosity is generated using the Newton-Raphson iterative technique which progressively accounts for corrections such as variability within the invaded zone, in hydrocarbon density, in the matrix density and clay volume to arrive at an output for effective porosity from an optimised neutron density cross plot. Effective porosity cut-offs are then used to determine lithotypes.

RMS Maps

This methodology concentrated on utilising pie chart data for effective porosity from a given stratigraphic interval combined with the trend of bright amplitudes from the RMS maps to guide the interpretation of the channel levee complex toward identifying the channel plan of the main sand fairway and zones where thin beds are known to have been penetrated by the wells. Observations from core data could then be integrated to interpret the depositional style (levee, lateral accretion package, crevasse splay).

Furthermore, the resulting maps enable the identification of areas where cross-cutting occurs and consideration for the prospective communication between massive sand geo-bodies and thin beds. The cross-cutting relationship between differing channels is an important consideration. This is because the channel planform, trajectory and degree to which cross-cutting occurs ultimately controls the degree to which lithofacies inheriting from the levee (thin beds) component of a more recent channel will be located within proximal (vertical and lateral) distance to discrete reservoir zones inheriting from the channel thalweg component of an older, pre-existing channel.

With this rationale in mind one can capitalise on the strength of this method to identify a prospective target zone in the Campanian turbidite sands where the production potential from thin bed sands is likely to be greatest.

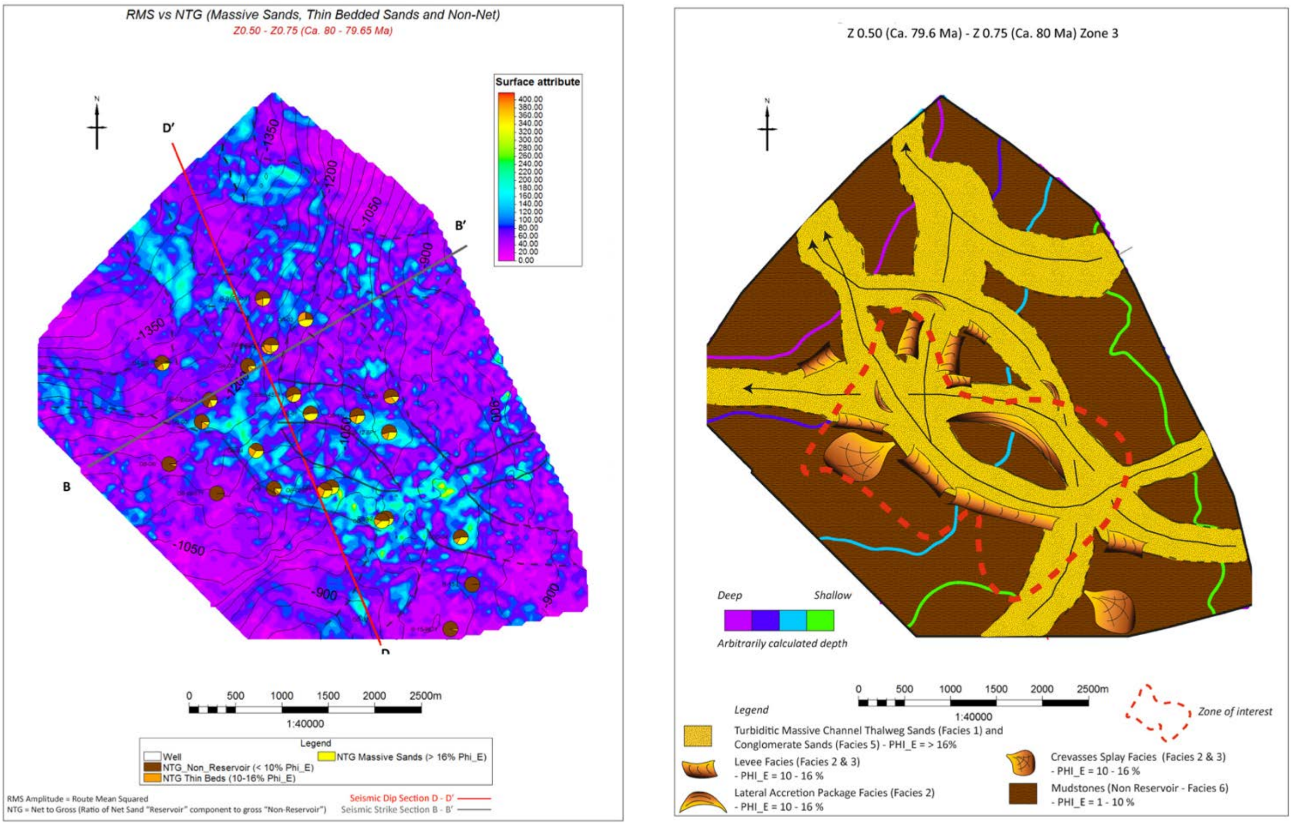

Figure 4: Campanian channel levee complex interpreted from RMS amplitude and effective porosity data for lithofacies

Reservoir summary

This summary model below details the cross-cutting channels and juxtapositioning of the levee components with discrete massive channel thalweg sand geobodies between which thin beds are speculated to provide a means of communication.

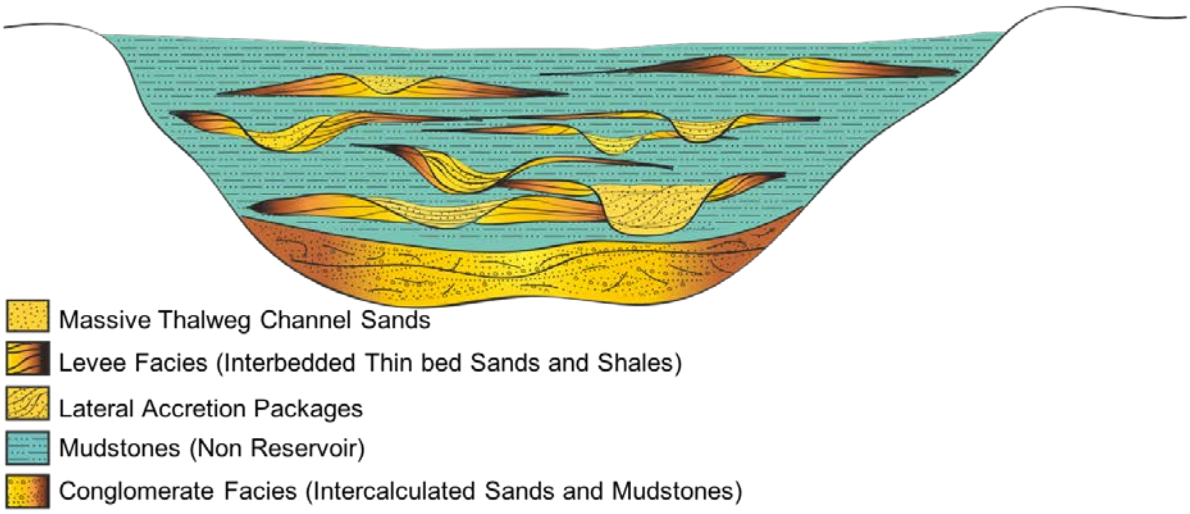

Figure 5: Reservoir summary model

Production Data

Considering the profile for the thin bed production well, it is perhaps expected that production from the thin bed intervals (Ca. 150 BOPD) is an order of magnitude lower than from the massive sands (Ca. 2500 BOPD). Thus, it can be concluded that thin bedded packages are unlikely to contribute significant increases to the effective stock tank oil in place (STOOIP, while in production), but are not worth overlooking as evidently there is resource with production value in place.

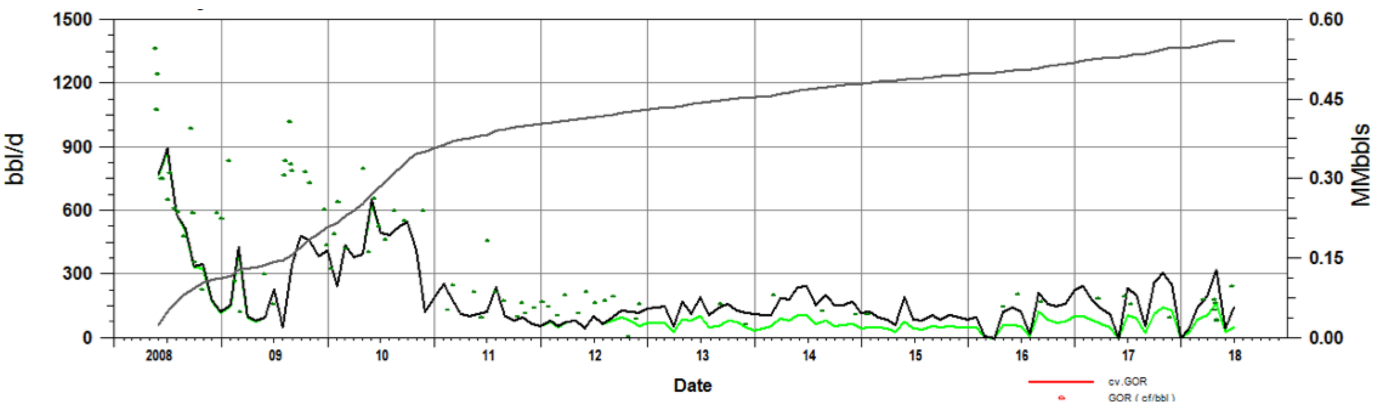

Figure 6: Thin bed production profile

Green Curve: Oil rate per day (Q = Rate), Black Curve: Total Liquids (MMbbls), Grey Curve: Net Production (MMbbls)

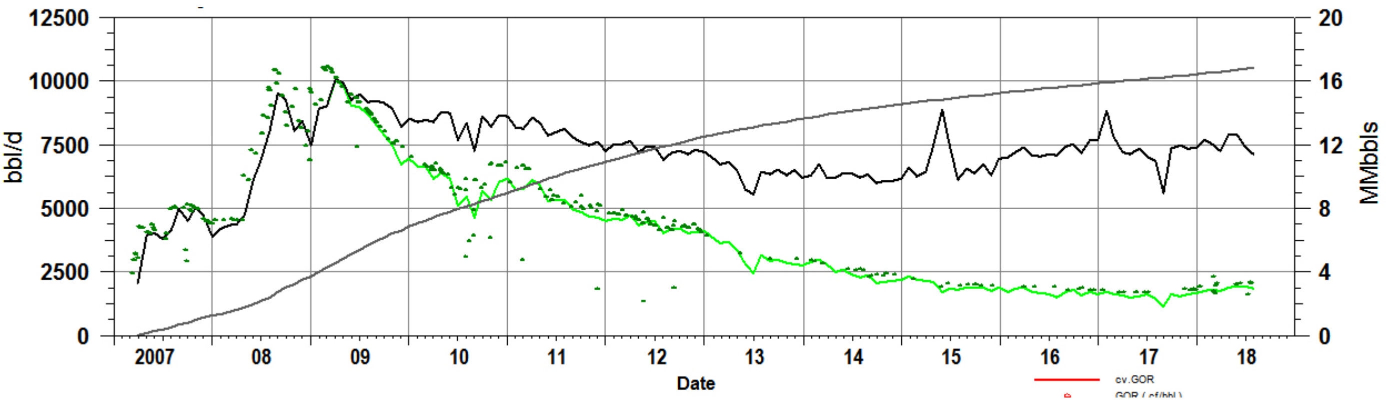

Figure 7: Massive channel thalweg sand production profile

Green Curve: Oil rate per day (Q = Rate), Black Curve: Total Liquids (MMbbls), Grey Curve: Net Production (MMbbls)

Conclusions

This study has focussed on a canyon system identified as a large type 1 canyon system. At the gross canyon scale, the fill is identified as dominantly having random organisation, especially in areas proximal to the head of the canyon and proximal to rapid drop-offs in canyon topography. In the terraced zones of the canyon, a semi-organised pattern with embedded stacking and a mild degree of aggradation has been identified.

Route Mean Squared Amplitude and facies mapping have characterised the inter-canyon system as a channel levee complex. A detailed analysis has established a zone of interest within the terraced zone where high sinuosity and cross-cutting has promoted the concentration and juxtapositioning of thin beds within proximal distance to massive sands inheriting from channel thalwegs. From a production standpoint, the cross-cutting relationship has been established as an important means for providing communication to discrete massive sand areas of the reservoir.

A prospective target within the channel levee complex has been identified from RMS amplitude and facies mapping in the Campanian turbidite sands where the production potential from thin bed sands is likely to be greatest. Within this zone, the dominant style of thin bed inheriting from the proximal levee is the thick-thin beds classified as lithofacies 2 for which thicknesses range between 2 cm and 20 cm, lateral continuity is most consistent, porosities range between 10 and 16 % and permeability is 680 mD.

The author concludes that thin bedded packages are unlikely to contribute significant increases to the effective stock tank oil in place (STOOIP, while in production), but should not be overlooked as evidently there is resource in place that can offer opportunities to increase production value by perforating behind pipe prospects at relatively low cost.

Ultimately thin beds are considered an important resource for increasing value late into the natural life of the field.

References

Jobe, Z., Lowe, D. and Uchytil, S. (2010). Two fundamentally different types of submarine canyons along the continental margin of Equatorial Guinea. Marine and Petroleum Geology, 28(3), pp.843-860.

Kendall, C. and Haughton, P. (2008) [online] Sepmstrata.org. Available at:
http://www.sepmstrata.org/CMS_Images/Organized-versus-disorganiz.jpg [Accessed 1 Aug. 2018].