[PS]Reservoir Characterisation of the Paradise and Hickory Discoveries, Offshore Ghana: Integration of Depositional and Diagenetic Concepts*

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Abstract

The Paradise and Hickory discoveries represent two of the seven discoveries made by Hess in the Deepwater Tano Cape Three Points Licence, Offshore Ghana between 2011 and 2013. These two discoveries have reservoirs within a Cenomanian aged turbidite sandstone interval and are comprised of a rich gas condensate fluid. Both accumulations are within four way dip closures with the reservoirs occupying the same seismically defined deep water slope canyon (the Paradise Canyon), with the Paradise discovery occupying a more axial part of the canyon system and Hickory representing more of a marginal location. The Paradise Canyon is interpreted to be a high net-to-gross confined slope canyon complex, with the fill dominated by stacked, coarse-grained high-density turbidite channel deposits and hetrolithic debris flow deposits. Following burial, these reservoirs have undergone multiple phases of diagenesis including the growth of carbonate cements and authigenic clays. This paper highlights some of the work to characterise the reservoir using a combination of seismic, Image logs, sidewall cores and conventional logs to further our understanding of the controls on reservoir quality and deliverability within these two fields. We present an integrated depositional and diagenetic model, where the architecture of the channel fill exerts a first order control on reservoir quality, yet also has a role in influencing the digenetic overprint. The rock types associated with the channel axis, while having overall the best porosity and permeability, are also prone to cementation by allowing the preferential passing of basinal pore waters, particularly above scoured zones at the channel base. The model and geological understanding has implications for the reservoir flow behaviour and possible development strategies.

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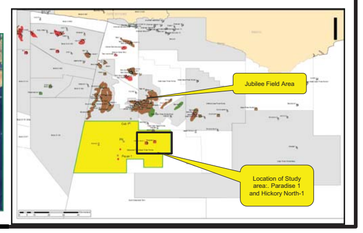
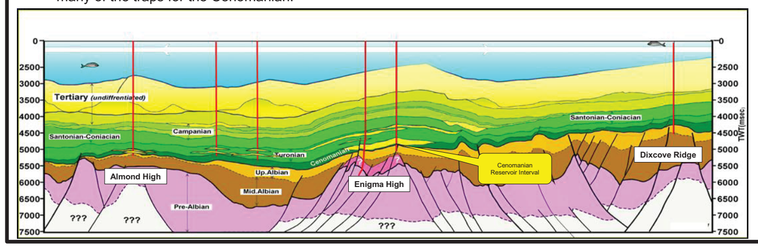
INTRODUCTION

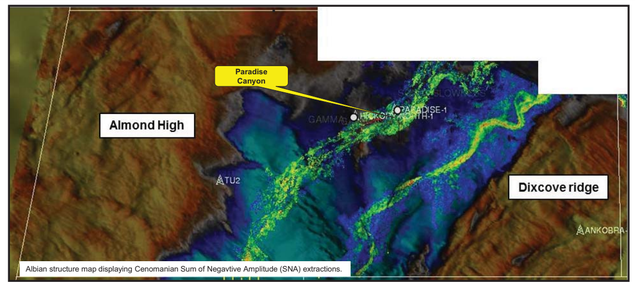
- Paradise and Hickory represent two of the seven hydrocarbon discoveries made by Hess in the Deepwater Tano Cape Three Points License in Offshore Ghana.
- These are reservoired within a Cenomanian aged turbidite sandstone deposited in a high net-to-gross slope canyon, which following burial has undergone multiple phases of diagenesis.
- This study is an investigation of the controls on diagenesis and the impact on reservoir quality in the Cenomanian reservoirs of Ghana.



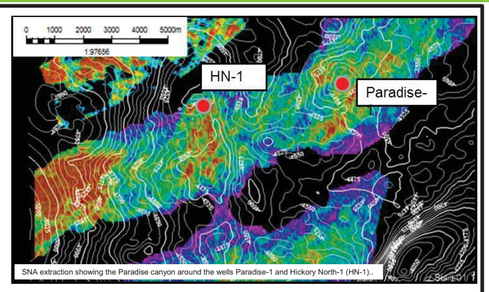
REGIONAL SETTING

- The Cenomanian/Turonian succession in the Tano Basin, Ghana represents a post rift/Sag phase following the rifting of Africa from South America along the West African Transform Margin (WATM).
- A series of transcurrent fracture zones divide the margin into a series of trans-tensional/extensional basins and major structural liniments.
- Two major structural liniments (the Dixcove ridge and Western ridge/Almond High) influenced turbidite channel and fairway development, a third liniment (the Enigma high) developed through an inversion event and set up many of the traps for the Cenomanian.





Albian structure map displaying Cenomanian Sum of Negavtive Amplitude (SNA) extractions.

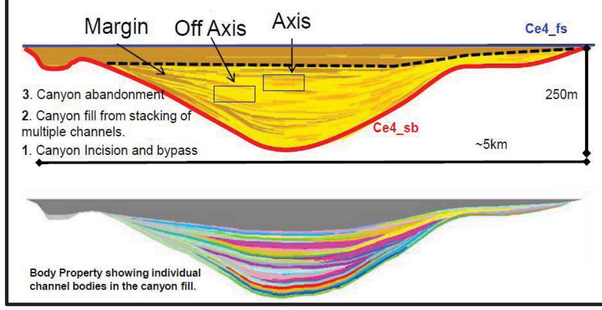


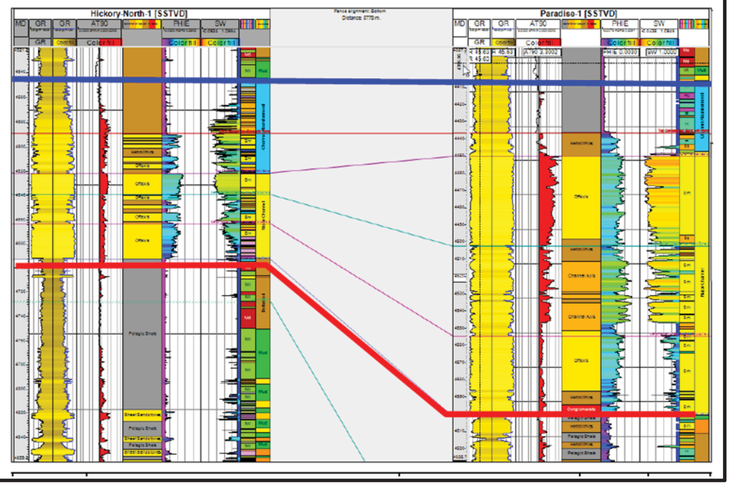
SNA extraction showing the Paradise canyon around the wells Paradise-1 and Hickory North-1 (HN-1).

- The Paradise and Hickory reservoirs both occupy the same seismically defined deepwater slope canyon fairway (The Paradise Canyon).
- The Paradise Canyon is interpreted to have a high net-to-gross, high energy fill of high density turbidite channels and heterolithic debris flow deposits.
- The Paradise-1 well represents an axial, upslope part of the canyon system while Hickory North-1 (HN-1) represents more of a marginal location and downslope.

DEPOSITIONAL ELEMENTS

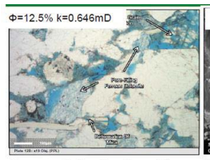
- Integration of Image log data calibrated with extensive sidewall cores allow the interpretation of depositional facies.
- The gross canyon container is interpreted to be 250m thick and 5km wide, this has a multi-phase fill of stacked 4th order channel elements. and is capped by a progressive fining upwards package, interpreted as an abandonment phase.
- Each channel element has a coarser grained axial area formed of multiple amalgamation surfaces and pebbly sandstones,, and a finer grained "off axis" area formed of finer grained, well sorted, stratified sandstones.

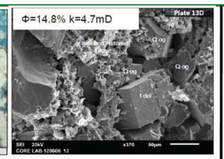




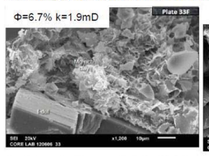
DIAGENESIS

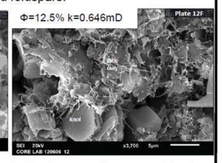
- Detailed analysis of thin section, SEM and XRD reveal multiple types of cement and detrital clay in different depofacies.
- Dominant authigenic components include pore filling ferroan dolomite and pore filling authigenic clays, ferroan dolomite is concentrated within the channel axis fill around bed boundaries/scours.



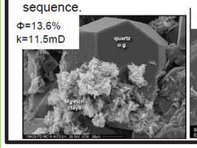


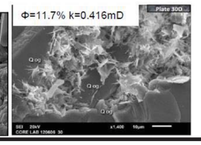
Ferroan Dolomite: Pore filling and Rhombic, commonly fills secondary porosity near dissolved feldspars.



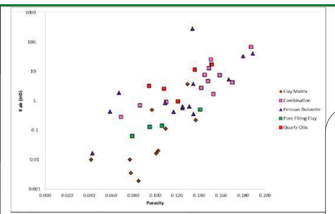


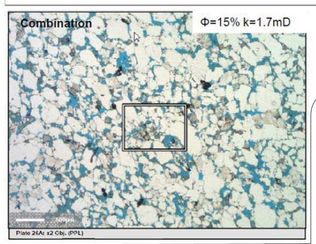
Authigenic Clays: Mainly Webbed mixed composition – mg rich clays. Some locally platy forms. Mostly wispy illite in the abandonment sequence.



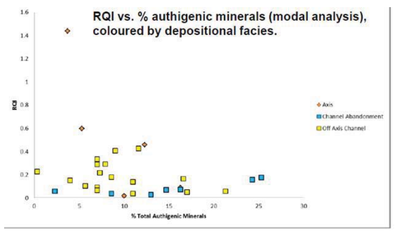


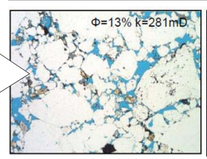
Quartz Overgrowths: discontinuous to locally well developed/interlocking. Quartz cementation at Paradise is better developed, at Hickory it mainly inhibited.

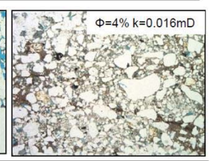




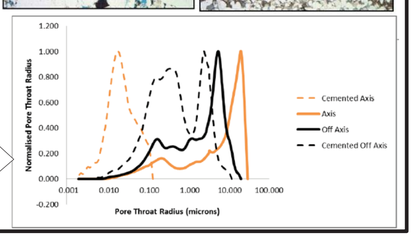
When uncemented, the channel axis sand contains the highest permeability in the reservoir. However ferroan dolomite and pore filling clays create intervals of very low permeability in this facies type.



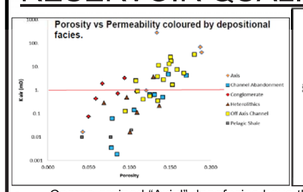


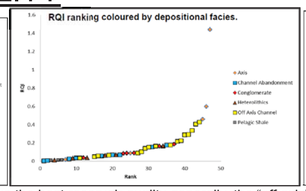


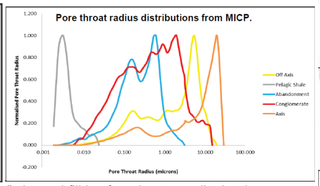
The channel axis facies has a strong diagenetic control on reservoir quality. The off axis is less prone to cementation and the overall impact on RQ is less. Sands within the abandonment sequence display constantly Low RQI due to fine grain size and illitic clays.



RESERVOIR QUALITY

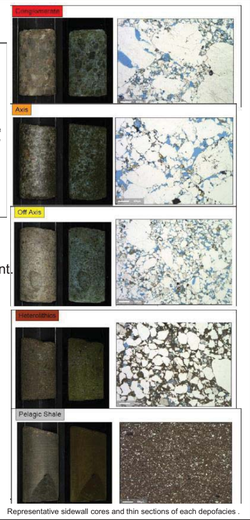






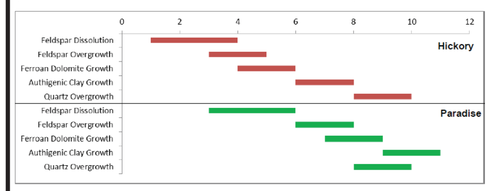
- Coarse grained "Axial" depofacies have the best reservoir quality generally, the "off axis" channel fill is of moderate quality but has a narrower Porosity and Permeability range.
- Channel abandonment hetrolithics generally display low reservoir qualities, due to both their fine grained nature and a diagenetic overprint.
- Sidewall cores within Axial sandstone and Conglomerate depofacies reveal some very low permeability intervals due to a diagenetic overprint. .

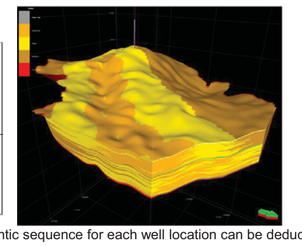
Depofacies	Environment of Deposition	Rock Types	Porosity Range	Perm Range
Axis	Turbidite sandstones associated with the centre of an individual channel body.	Coarse grained sandstones and gravel beds/ traction carpets.	4 - 20%	0.01 - 300mD
Conglomerate	Gravel beds accoiated with the Thalweg of individual channels and the bypass phase of the channel complex.	Poorly sorted clast suppoirted conglomerates	5-11%	0.05 - 5mD
Off Axis Channel	Turbidite sandstones associated with the centre of an individual channel body.	Medium - fine grained sandstones.	10-20%	0.3 - 35mD
Heterolithics	Thin bedded sandsones acciated with the "wings" of an individual channel.	Fine grained sandstones and siltstones.	5-14%	0.01 - 5mD
Channel Abandonment	Thin bedded sandstones accoaiated weith the abandonment of the channel complex beneath the FS.	Cemented fine grained sandstones and siltsones	5-14%	0.001 - 5mD
Pelagic Shale	Hemipelagic fallout.	Mud rocks.	1-5%	<0.01 mD

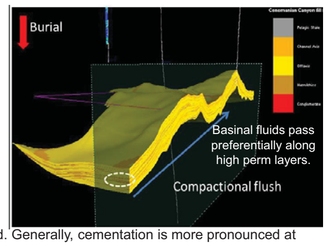


Representative sidewall cores and thin sections of each depofacies .

INTERGRATED MODEL







- By analysing the relationships between the cement types, the paragentic sequence for each well location can be deduced. Generally, cementation is more pronounced at Hickory (downslope).
- Hickory generally has a more sequential paragenic sequence, with most of the carbonate cements and clays having been precipitated out before quartz cementation. Burial histories suggest that the required temperature for quartz cementation at both Paradise and Hickory were met at the same time, suggesting a diachronhous development of carbonate cements.
- One model is that basinal fluids expelled during a compactional flush pass preferentially along high permeability streaks in the channel axis, causing feldspar and lithics dissolution and the precipitation of carbonate cements and authigenic clays in the pore spaces.

CONCLUSIONS

- Depositional architecture exerts a primary control on reservoir quality in the Cenomanian reservoirs in Ghana, higher permeabilities are encountered in a coarser grained channel axis sand, with lower permeability associated with channel margin and abandonment heterolithics.
- The reservoir quality is modified by diagenesis, with the main RQ reducing cements being Ferroan dolomite and authigenic Mg rich clay, but this has the greatest impact within former high permeability coarse grained basinal lags and at bed boundaries within the channel element axis.
- W propose a model where basinal fluids generated from downslope compactional flush pass preferentially up high perm streaks in the channel axis, dissolving feldspar and lithic fragments and re-precipitating carbonate cements and clays.
- While the overall permeability may be lower in the off axis, this may have overall more consistent and predictable permeability distribution.

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