PS Depositional Environment, Thin Bed Potential, Evaluation Strategy at Offshore Fields, Bay of Bengal, Bangladesh*

Marin Matesic[1]

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[1]South Asia Exploration Department, Adelaide, South Australia (marin.matesic@santos.com)

Abstract

The Sangu Field in the Bay of Bengal, Bangladesh produces gas from tens to hundreds of millidarcy sandstones of Pliocene-age. Santos is planning a drilling programme in the Bay of Bengal area in 4Q 2013.

The depositional environment of the reservoir rocks is very similar to the modern depositional setting in the Bay of Bengal. Two distinctively different reservoir rock “packages” are observed: heterolithics (interbedded sands and shales) and massive clean sandstone beds.

Integrated sedimentological and ichnological analysis of seven cored wells Sangu 1, 2, 3, 3Z , 4, 5 and Semutang 5 by Gowland and Taylor 1998, has defined 10 facies associations based on lithofacies and ichnofabrics. Most of the facies association represent sediments developed in a typical siliciclastic tidal flat and comprise intertidal mixed flat, subtidal mud flat, subtidal mixed flat, subtidal sand flat, tidal channel, tidal sand shoal (two types), offshore transition zone, shelfal muds. They were deposited as heterolithic units and are thinly bedded.

The massive fine-grained sandstone in the section is interpreted as having been deposited by high-density turbidity currents. A deep-water origin would not be consistent with the associated tidal deposits, raising the possibility that the turbidites occupy a shelfal setting and were sourced directly from major distributaries during peak discharge. Such an event could be attributed to the monsoon season, when massive volumes of suspended sand load can evolve into concentrated sediment flows dispersed across the shelf. After such flows terminated, the newly formed sediment substrate was available for reworking by tidal currents. Thus, the concept of suspended load dominated flows is proposed (hyperpycnal flow by Bates 1953).

The massive fine-grained sandstones, deposited from high-density currents have proven to be a good gas producer. Individual sands with

relatively small area and thickness are capable of producing significant amount of gas. However, the heterolithic, thinly bedded sands are the main producers in Sangu field. The minimum limit of producing sand thickness is poorly understood. Besides bed geometry, the high clay mineral content affects the conventional log interpretation.

Two significant issues have to be addressed in the future drilling campaign. Firstly, better understanding of massive sand distribution and calibration of sand geometries interpreted on seismic is required. Secondly, any potentially bypassed thinly bedded pay in the tidal-dominated delta sands should be appropriately characterized. For that reason, use of Image Logs, Nuclear Magnetic Resonance, Wireline Pressure Tester and Rotary Sidewall Coring has been proposed.

Depositional environment, thin bed potential, evaluation strategy at offshore fields, Bay of Bengal, Bangladesh

Author: Marin Matesic, South Asia Exploration Department, 60 Flinders Street, Adelaide, South Australia 5000, marin.matesic@santos.com

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Objectives

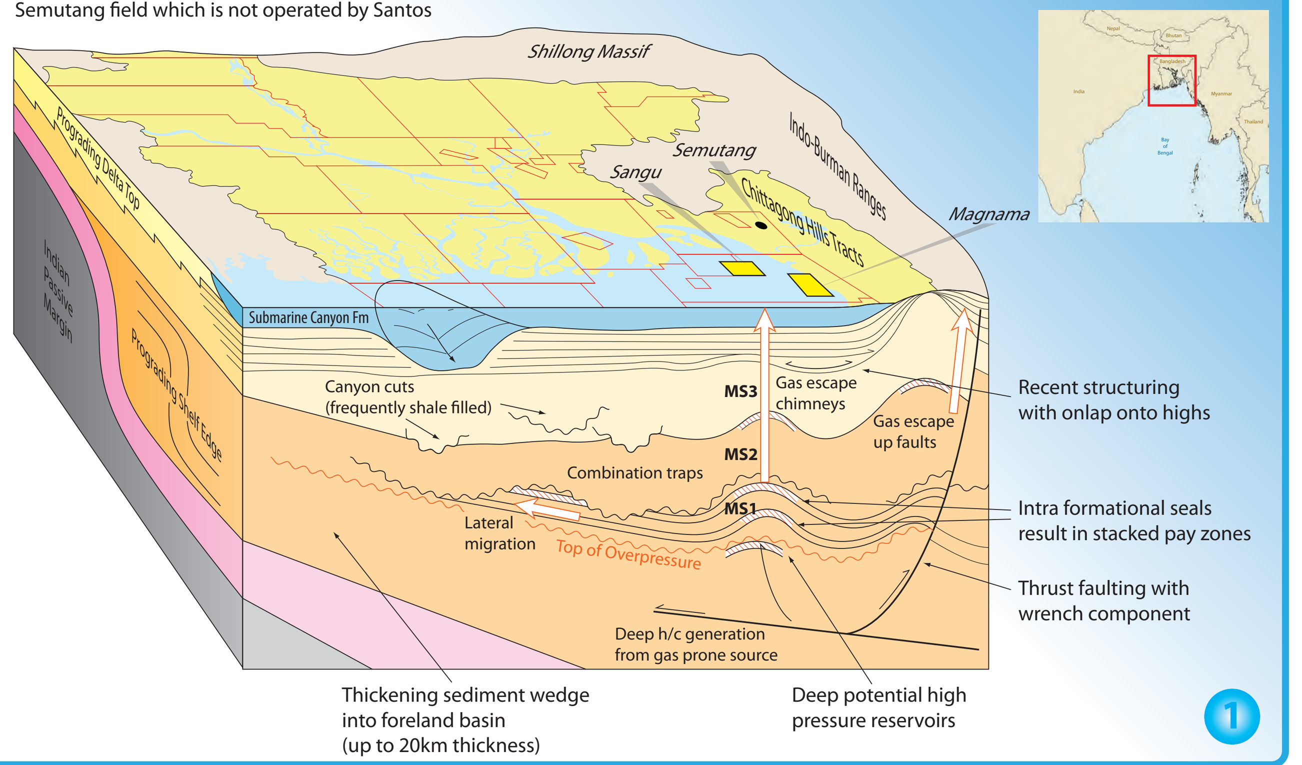
- Present stratigraphy, lithology and petrography of shallow marine part of the Bay of Bengal
- Provide a depositional mechanism to explain the observed facies and the implications on hydrocarbon exploration and development
- Explain hyperpycnal facies model and its application to interpreted core descriptions
- Show thin bed problem in Sangu field and question the minimum thickness capable of producing gas
- Present planned evaluation program

Acknowledgments

This project would not have been possible without the cooperation of Petrobangla. A special note of thanks goes to them and the people of Bangladesh, the true owners of the resources. I gratefully thank my managers John Chambers, Paul Strong, Mike Starcher for their encouragement to submit this work to AAPG Singapore 2012 conference. I also acknowledge their help with editing, appropriate suggestions and generous contribution of time. I am indebted to Ron McNab for drafting and help with poster formatting. A special note of thanks goes to my colleagues and friends at Santos for their valuable comments. Santos are thanked for sponsoring the author's attendance at this conference.

Study Area and Dataset

Santos is planning a drilling programme in the Bay of Bengal area in 4Q 2013. Currently, Santos holds Sangu producing field and Magnama exploration license.
A well drilled in the Sangu area typically consists of sediments deposited into a series of seismostratigraphic units called Megasequences (MS1, MS2, MS3). 3D and 2D seismic datasets are available for Sangu and Magnama fields.
Cored intervals examined in this study are primarily from the MS1 and some from MS2. Some core mentioned in this study comes from Semutang field which is not operated by Santos



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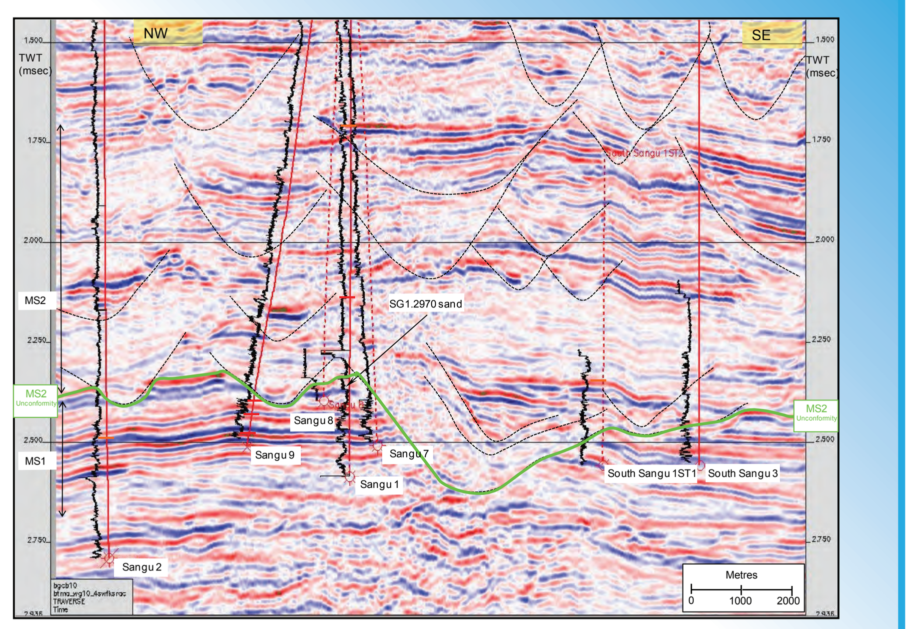
Seismic Line



MS1 is the main gas producing interval in Sangu Field. Note the MS1 continuous amplitudes relative to MS2, which in contrast has an abundance of channel features

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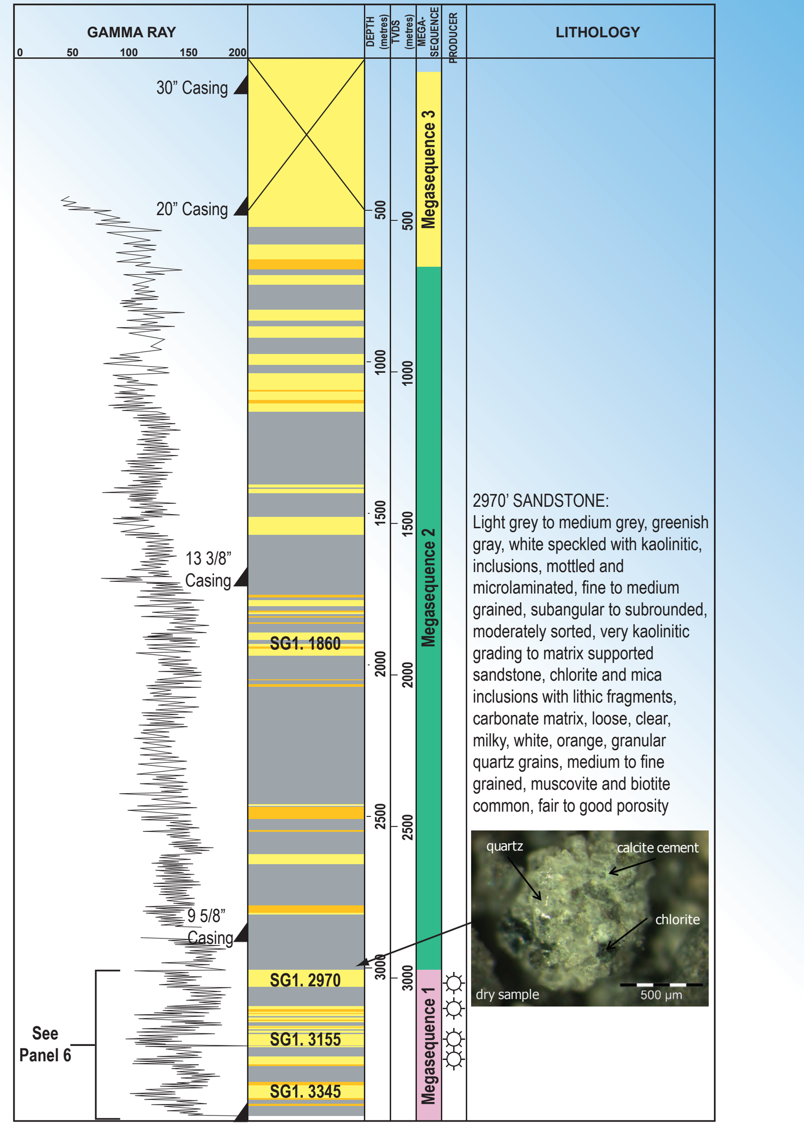
Sangu 1 well and Stratigraphy

The sedimentary sequence comprises a thick series of fine to very fine sand/sandstone, siltstone and claystone. Sandstones have relatively high amounts of clay which has a significant impact on the response of conventional logging tools.

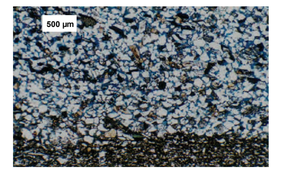
Sangu 1, (Megasequence 1)



Sand Petrography

Petrographic examination suggests that the dominant controls on reservoir quality are variations in grain size and detrital clay content, with only minor effects from diagenesis, mainly quartz overgrowths and authigenic chlorite). The high clay mineral content affects the conventional log response and interpretation.

WELL:	Sangu 1 (core A)
DEPTH:	3017.05m
LITHOLOGY:	Lithic arenite
GRAIN SIZE:	Mean: Fine sand
COMPACTION:	Low to moderate
SORTING:	Poor to moderate
GRAIN SHAPE:	Subangular to subrounded
HELIUM POROSITY:	12.8%
MODAL POROSITY:	16.5%
HORIZONTAL PERMEABILITY:	26.1 mD



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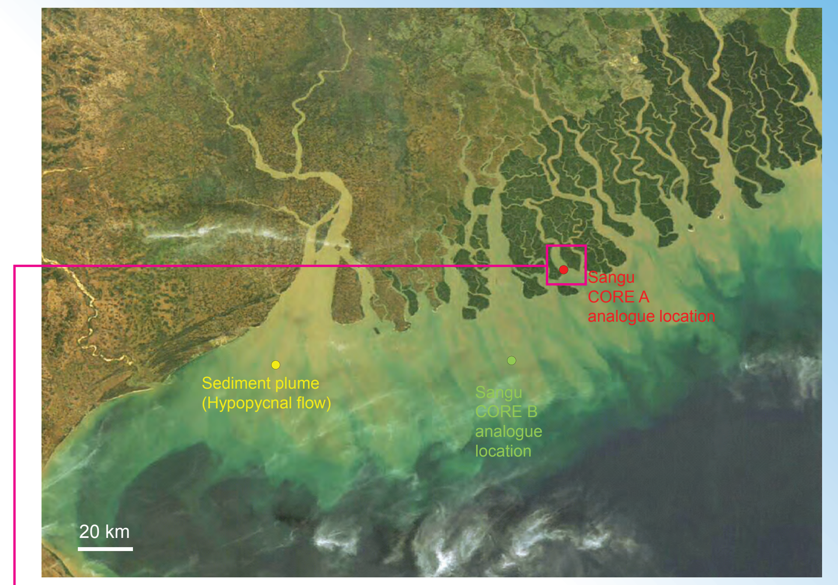
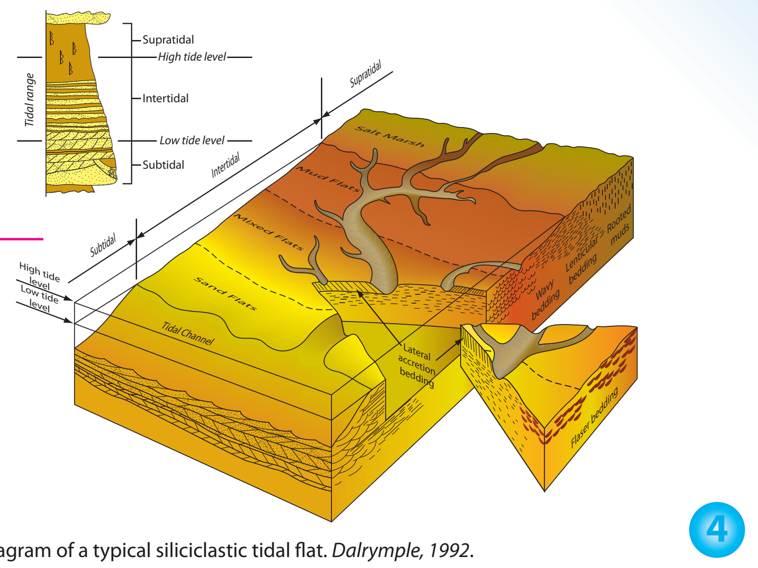
Depositional Setting

- Cored intervals represent similar setting as the modern day environment
- Rivers of Bengal delta system have characteristic of long lived and highly dynamic (fluctuating) flow which has peak discharge during monsoon season
- Most of the cored section belongs to typical facies associations of siliciclastic tidal flat (example core A, heterolithS) and are occasionally interbedded with thick sandstones (core B, massive sandstones)



Tidal dominated Ganges-Brahmaputra delta. Sediments flow through the channels of the delta releasing sediment plume into the Bay of Bengal. Satellite image taken 29th March 2011, www.eosnap.com



Block diagram of a typical siliciclastic tidal flat. *Dalrymple, 1992.*

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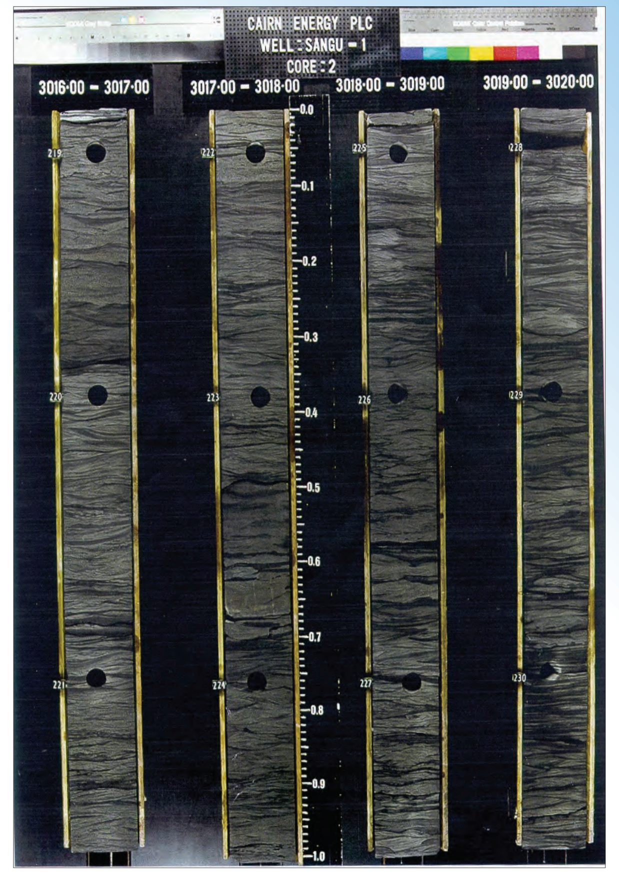
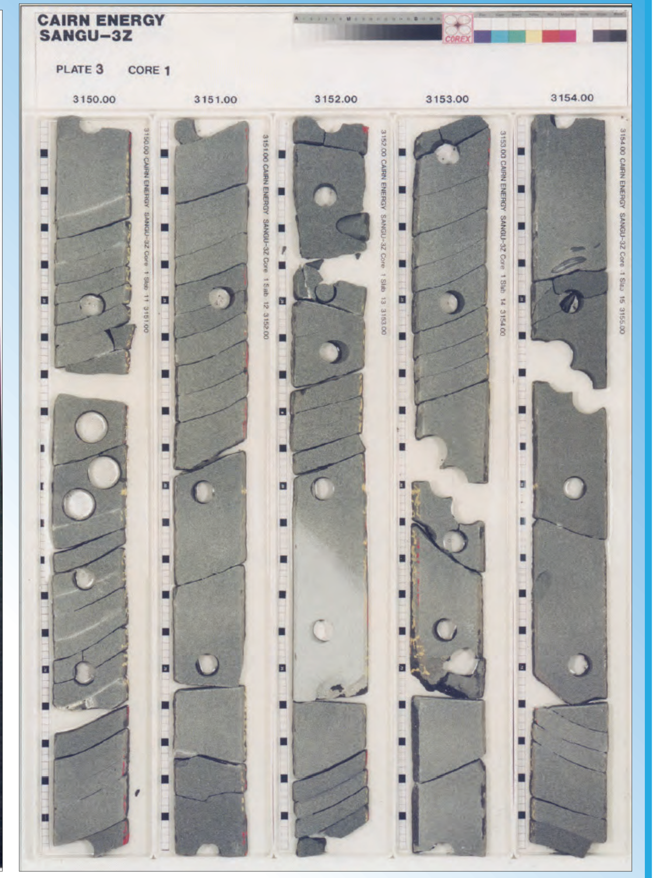
Two Contrasting Facies

Core A



Core B



Sangu thin beds in core photos SG1. 2970
2970 gas producing sand in Sangu 1 well.

- Laminated muds and very fine sandstones
- Sharp bases, Mud drapes, Hummocky Cross Stratification & herring bone cross stratification, starved current ripples
- Bioturbated
- Deposited by tidal activity and storm events
- Main producer in Sangu field, Sand 3155, has the same environment of deposition.

Sangu massive beds in core photos SG3Z.2635
2635 gas producing sand in Sangu 3Z well. Excellent producer with relatively small area (1sq. km) and thickness (40m).

- Very fine to fine grained massive sandstones
- General lack of sedimentary textures
- Not bioturbated
- Occasional mud intraclasts
- Sandstones attributed to deposition from turbidity currents

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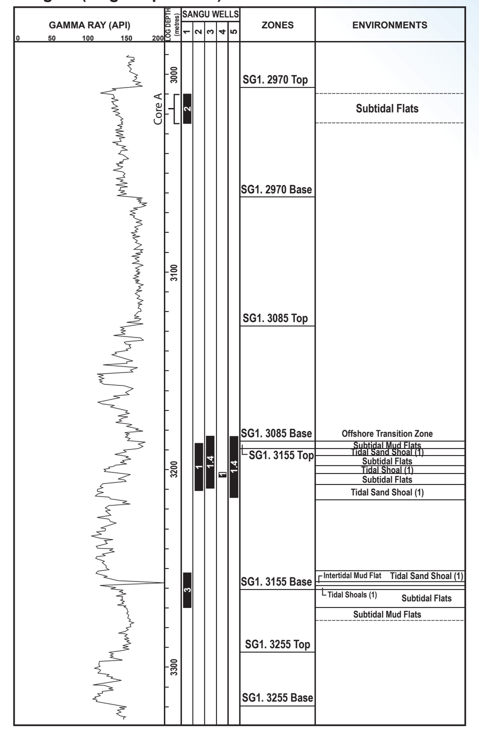
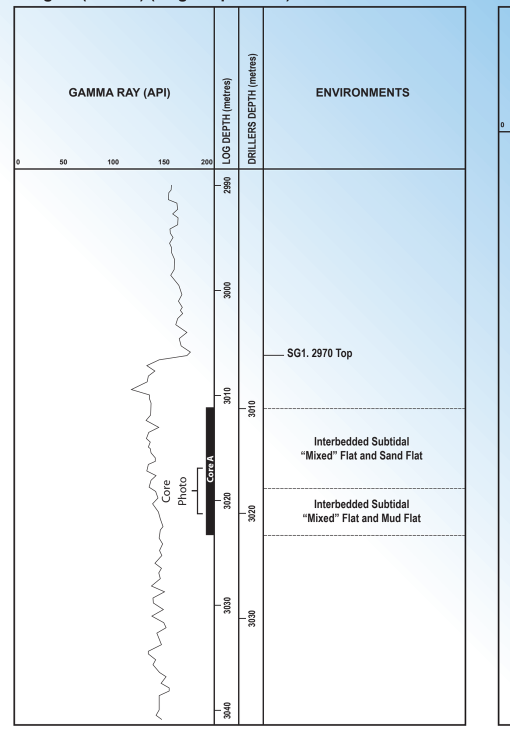
Cored Intervals

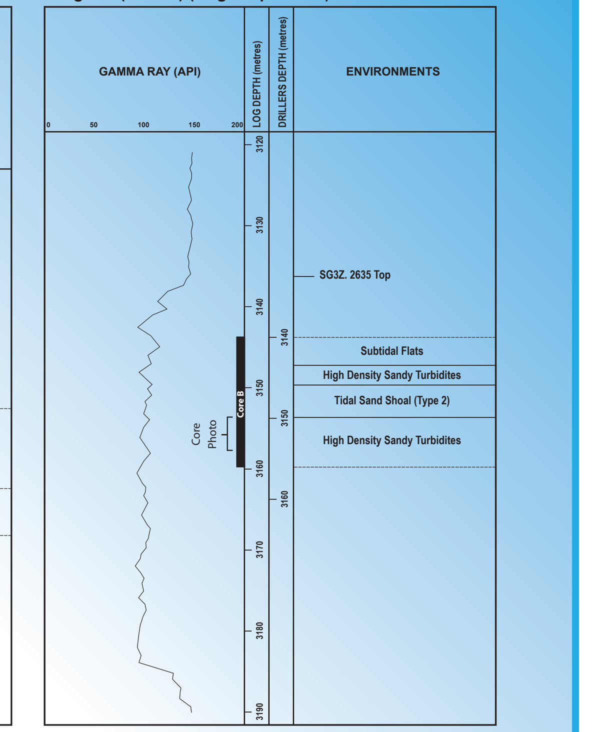
Sangu 1 (Megasequence 1)



Sangu 1 (Core A) (Megasequence 2)



Sangu 3z (Core B) (Megasequence 1)



- Integrated sedimentological and ichnological analysis of seven cored wells Sangu 1, 2, 3, 3Z, 4, 5 and Semutang 5 by *Gowland and Taylor, 1998* has defined 10 facies associations based on lithofacies and ichnofabrics:
  - Intertidal mixed flat, subtidal mud flat, subtidal mixed flat, subtidal sand flat, tidal channel, tidal sand shoal (two types), offshore transition zone, shelfal muds and "sandy turbidites".

- Heterolithic thinly bedded sands within section
- The minimum limit of producing sand thickness is poorly understood - thin bed contribution

- Maximum individual thickness of "sandy turbidite" interval in offset well, Semutang 5 (not shown) is 13m. The interval is incompletely cored, so may be thicker
- Problematic association between deep water components (sandy turbidites) with shallow water facies of tidal sand shoal

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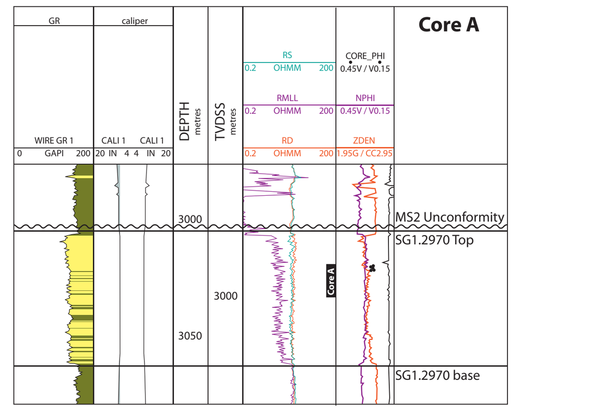
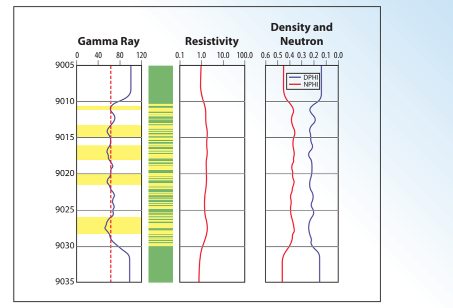
Thin Bed Problem

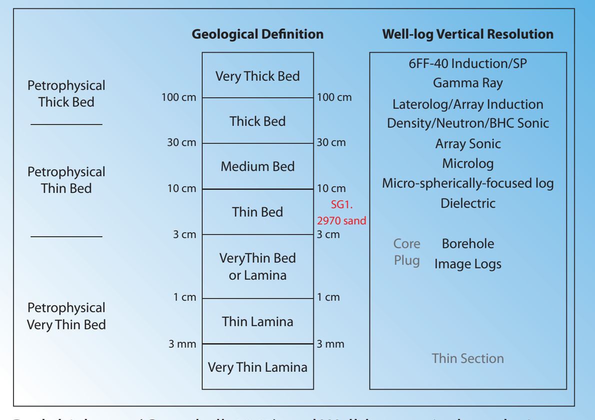
The heterolithic, thinly bedded sands are the main producers in Sangu Field. The minimum limit of producing sand thickness is poorly understood.
Besides bed geometry, the high clay mineral content affects the conventional log interpretation.



Sangu 1 2970 producing sand where Neutron-Density crossover and resistivity have been suppressed. Core photo to left.



Typical response of conventional logs due to thin bed effect (*Passey et al., 2004*).
This is very similar to the 2970 sand response.



Bed thickness (*Campbell, 1967*) and Well-log vertical resolution.
Note tool resolution for Core plug and Image log data.

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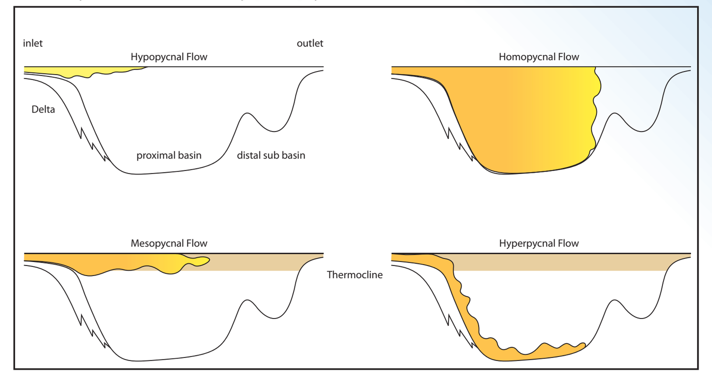
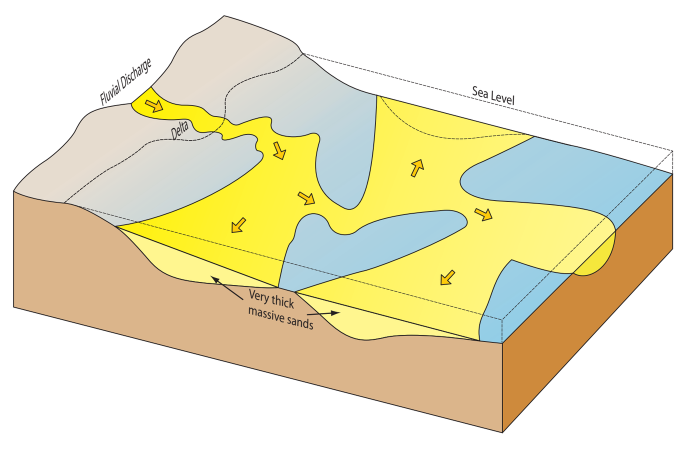
Sandy turbidite (hyperpycnite) on Shelf



Basic conceptual diagram of flood deposit types according to density differences between the effluent and the receiving basin: Hypopycnal, Homopycnal, Mesopycnal, Hyperpycnal flow. Inspired by *Bates, 1953*.



The increase in the overall density of the fluvial discharge forces the flow to plunge (hyperpycnal flow) and to fill deepest part of submarine landscape. Modified after *Zavala et al, 2011*. The newly formed sediment is then reworked by tidal activity.

The massive fine grained sandstone in the section (Core B) is interpreted as having been deposited by high density turbidity currents (Gowland and Taylor 1998). However a deep water origin would not be consistent with the associated tidal deposits, raising the possibility that the turbidites occupy a shelfal setting and were sourced directly from major distributaries during peak discharge. Such an event could be attributed to the monsoon season, when massive volumes of suspended sand load can evolve into concentrated sediment flows dispersed across the shelf. A mechanism based on suspended load-dominated flows (*Bates 1953*) is proposed:

- During discharge events, the form of a flow is determined by sediment concentration, salinity and temperature differences which result in density contrast between inlet and outlet water. The sediment plume takes the form of one of the four basic types of flow (upper left figure)
- Sediment concentration is low at the beginning of an idealized conceptual single sustained discharge event. Initially hypopycnal, homopycnal and mesopycnal flow types dominate as most of the sediment is buoyant. As a monsoon event progresses, sediment density reaches the critical concentration and inlet suspended sediment becomes denser than the receiving body of water. From that point onward, hyperpycnal flow dominates
- A turbidity current is triggered and sediments (massive sandstones in our example) begin filling the deepest parts of the available submarine topography
- Towards the end of event, the density of the inlet flow decreases and the system reverts to the initial more buoyant forms. After such flows terminated, the newly formed sediment substrate was available for reworking by tidal currents and biological activity

The sediments deposited by such mechanism are called hyperpycnites (*Mulder et al., 2003*) or sandy turbidites.
A hyperpycnite is a particular type of turbidite having poorly known and intensely debated facies characteristic (*Zavala et al., 2011*).
The major difference from the deep water classical turbidite is the origin of sediment from long lived and highly dynamic fluvial inflow, compared with surge-like flow caused by slope instability (*Mutti et al., 1999*) in deep water environment.
Not surprisingly, core sampling is a major issue in fully diagnosing the long-lived hyperpycnal sedimentation where not all genetic facies proposed by *Zavala, 2011* have been encountered. Nevertheless, the massive sands encountered in Sangu and Semutang core record could belong to the very common S1 facies described by *Zavala et al., 2011*.

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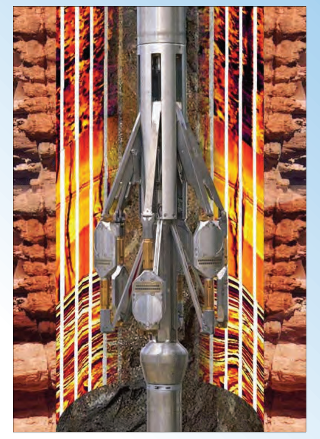
Summary

- The Sangu Field in the Bay of Bengal, Bangladesh produces gas from tens to hundreds of millidarcy sandstones of Pliocene-age. Santos is planning a drilling programme in the Bay of Bengal area in 4Q 2013.
- The depositional environment of the reservoir rocks is very similar to the modern depositional setting in the Bay of Bengal
- Two distinctively different reservoir rock "packages" are observed: heterolithics (interbedded sands and shales) and massive clean sandstone beds.
- Most of the facies association represent sediments developed in a typical siliciclastic tidal flat and comprise: intertidal mixed flat, subtidal mud flat, subtidal mixed flat, subtidal sand flat, tidal channel, tidal sand shoal (two types), offshore transition zone, shelfal muds. They were primarily deposited as heterolithic units and are thinly bedded
- The heterolithic, thinly bedded sands are the main producers in Sangu field. The minimum limit of producing sand thickness is poorly understood. Besides bed geometry, the high clay mineral content affects the conventional log interpretation
- The massive fine grained sandstones, deposited from high density currents have proven to be a good gas producer. Individual sands with relatively small area and thickness are capable of producing significant amount of gas
- The massive fine grained sandstone in the section is interpreted as having been deposited by high density turbidity currents. A deep water origin would not be consistent with the associated tidal deposits. This work proposes the turbidites occupy a shelfal setting sourced directly from major distributaries during peak discharge, probably in the monsoon season, when massive volumes of suspended sand load can evolve into concentrated sediment flows dispersed across the shelf. After such flows terminated, the newly formed sediment substrate was available for reworking by tidal currents. Thus, the concept of suspended load dominated flows is proposed (hyperpycnal flow by *Bates, 1953*)
- Two significant issues have to be addressed in the future drilling campaign. Firstly, better understanding of massive sand distribution and calibration of sand geometries interpreted on seismic is required. Secondly, any potentially bypassed thinly bedded pay in the tidal-dominated delta sands should be appropriately characterized
- For that reason, use of Image Logs, Nuclear Magnetic Resonance, Wireline Pressure Tester and Rotary Sidewall Coring has been proposed

Evaluation Program



Two significant issues have to be addressed in future drilling campaign:

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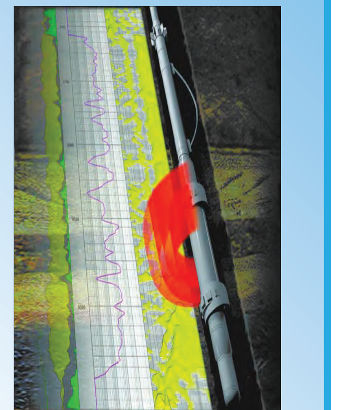
For that reason the use of Image Logs, Nuclear Magnetic Resonance, Wireline Pressure Tester and Rotary Sidewall Coring has been proposed.

IMAGE LOG

The acquisition of image logs will provide highly detailed, core-like images of the formations encountered by the borehole. These images are produced by measuring and mapping formation micro-resistivity with each of the 150 pad-mounted button electrodes on six independent arms. The tool will potentially allow the delineation of thin beds down to centimetre scale, distinguish clearly between the two contrasting environments of deposition. By incorporating image data and following thin-bed petrophysical analysis workflows it is hoped to improve net pay estimations.

NUCLEAR MAGNETIC RESONANCE (NMR)

The NMR tool utilizes the very same principles as medical MRI by directly measuring the magnetic resonance of hydrogen atoms in fluids. Amplitude of the measured signals gives porosity, whereas the actual signature carries information on rock properties and fluid characteristics. NMR will assist with the quantification of pay zones in tidally dominated heterolithic beds and identify zones of water-free production. This is particularly important in units where shale occurs in relatively high amounts, leading to significant bound water.

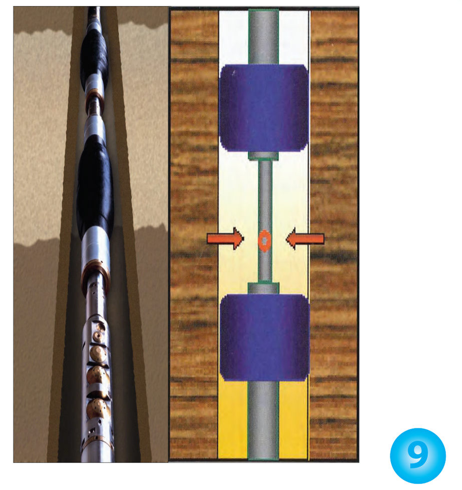


ROTARY SIDEWALL CORING (RSC)

The RSC tool can be used to provide physical samples of the thinly bedded reservoir by acquiring cores perpendicular to the borehole wall. The core is recovered as a cylindrical shaped plug of the formation. The core samples will allow important lithological calibration of the NMR and image log data and will provide accurate readings of porosity and permeability. These data will reduce reservoir analysis uncertainty in thinly bedded formations.

WIRELINE PRESSURE TESTER

Key information regarding producibility of heterolithic beds can be provided by wireline pressure testing.
By using dual-packer techniques, a faster version of drill stem testing can be achieved. The module uses two inflatable packers, set against the borehole wall, to isolate 1 to 4 metres of formation. This allows testing of a zone with greater net-to-gross uncertainty and permeability distribution, typically associated with thin bed packages. Additionally, it allows fluids to be withdrawn at a higher rate without dropping below the bubble point. A permeability estimate with a radius of investigation in the range of a few metres is provided. Fluid samples can be taken if required for compositional analysis.



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