Bualuang Oilfield, Gulf of Thailand: A Successful Development Using Geosteered Horizontal Wells*

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Abstract

The Bualuang field is located in Block B8/38, in the Western Basin of the Gulf of Thailand, water depth 60 meters. The field is operated by Salamander Energy (Bualuang) Ltd, which holds 100% interest.

The field was discovered in 1993 by Sun Oil (B7/32-2 well) and subsequently appraised by SOCO in 1997 with two further wells. The discovery was then known as the Pornsiri field. Although the field was initially developed using a high-density 2D seismic grid, 3D acquired in 2010 has facilitated further development drilling and exploration of surrounding satellite potential.

The development plan for the field was approved by the DMF in 2006 and was fast-tracked in 2007. A single well-head platform was installed and production connected via pipeline to an FPSO. Phase I/II of development drilling consisted of five sub-vertical producers and one water injector/disposal well. The wells were completed in June 2008 with gravel packs and electrical submersible pumps. The field came on stream in August 2008 and a month later had reached production of 17,000 bpd.

The Bualuang oil has a gravity of 27°API, viscosity of 8.5 cp and GOR of only 4 scf/stb. The primary T4 reservoir of middle Miocene age consists of amalgamated fluvial channel sandstone exceeding 50 meters in thickness. Reservoir net-to-gross is in excess of 90%; porosity approaches 30%, with permeability averaging 1.8 darcys . The top T4 sand is at 1100 meters subsea and the oil column is a maximum of 32 meters in height.

Post-Phase II log analysis and routine core analysis in relation to PVT properties indicated that water coning would be a key concern. Indeed the reservoir net-to-gross in the development wells is higher than expected, resulting in an even higher Kv/Kh ratio than initially observed. In response, future drilling phases have utilized horizontal drilling technology, combined with geosteering, to locate production wells as close as possible to the roof of the reservoir to maximize standoff from the OWC and minimize water coning.

At year-end 2011, 16 development and 2 water disposal wells had been drilled. All produced water is re-injected. EUR stands at 27 MMBO, almost double pre-development figures. Cumulative oil production is 10MMBO. Further appraisal drilling has identified oil in shallower and

deeper horizons, and in a separate fault block to the east. A second production platform was to be installed in mid-2012, with subsequent drilling of 16 development wells into 2013.

Bualuang Oilfield, Gulf of Thailand: A Successful Development Using Geosteered Horizontal Wells

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Acknowledgments
Steve Ross

SALAMANDER ENERGY
PURE ASIAN ENERGY

Presenter's notes: This presentation is about a successful development of what initially was a small field but is now more than 50 MMBBLS recoverable producing field.

The authors would like to acknowledge Salamander to allow this presentation.
In addition to the authors, there are others in the team, as well; also we thank Steve Ross for providing some plots on production.

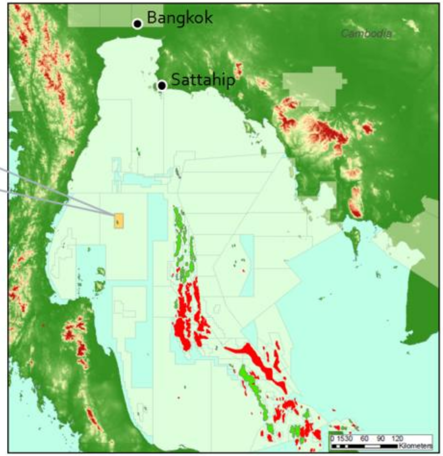
Talk Outline

- Challenges in the field
  - Thin oil Column – viscous oil
  - Active aquifer – water production
  - Reservoir Management - Managing Decline in production
- Achievements
  - Reserves Upgrade
  - Successful implementation of Technology
    - Data acquisition – Seismic & well
    - Drilling Horizontal wells
    - Completion designs
    - Reservoir Modeling

Presenter's notes: Visocus oil, 27 API and 8.5 CP low-wax oil. Harmonic decline of 40%.

B8/38 Block Location

- Bualuang Production License is part of Block B8/38
- 380 sq km
- 220km SW of Sattahip (shore base)
- Water depth 60m
- Facilities – a single WHP and production connected via pipeline to FPSO



Presenter's notes: The current existing facilities on the field consist of a single well head platform and the production is connected via pipeline to the Rubicon Offshore International's FPSO Vantage.

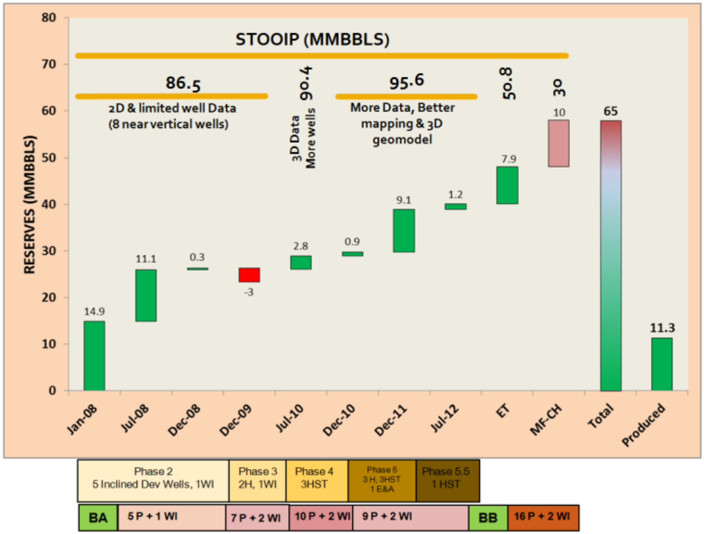
Bualuang Development

Discovery

- Discovered by Sun Oil in 1993
- 40 m of Oil Column with no Gas Cap
- Strong Aquifer support
- Viscous Oil (8.5 Cp, 28.5 API)

SBL Success Story

- 2P Reserves increase by ~400%
- Drilled 10 producers
- Production from horizontal wells
- New Facility installation
- Better Reservoir Management to control water movement
- Good Data control
- High Resolution Geomodel



Presenter's notes: This illustration is the essence of this presentation and story of Bualuang.
Discovered by Sun Oil co in 1993; Salamander entered the block in 2008, and at that time the 2P reserves were around 15 MMBBLS. These have now grown to around 70 MMBBLS due to effective field development and reservoir management, as well as continued appraisal drilling and addition of neighboring prospects, such as ET.
Several producers have been drilled to maintain production, and the challenge is to keep the water away from wells and continue drilling horizontal wells.
Currently, we have 10 oil producers and 2 water injectors on the existing platform. A second platform with 16 well slots is being installed in a few weeks (from September 18, 2012).

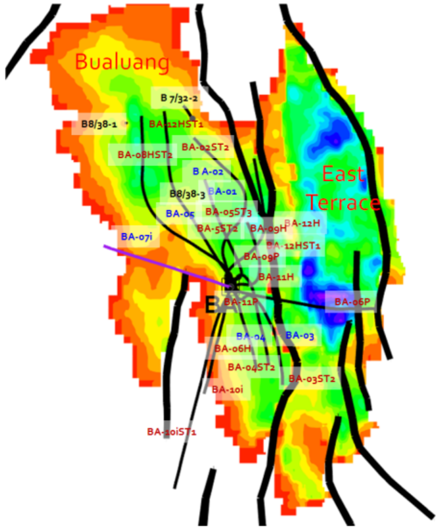
Bualuang Field Summary

Field

- Produced: 11.3 MMBBLS (31/7/2012)
- Tilted fault block, 3-way dip and fault closure
- Primary reservoir: Miocene Fluvial sands (T4)
- Depth to crest : 1092m (SS)
- OWC: 1130m TVDSS
- Reservoir thickness exceeds column height with underlying active aquifer

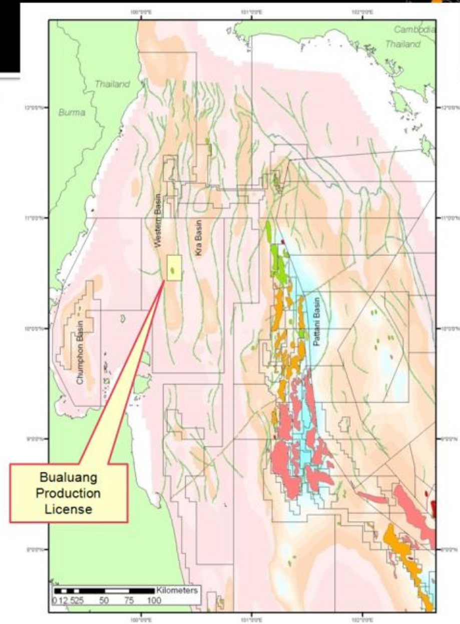
Drilling

- Total of 26 wells drilled on the field to-date
- 3 exploration/appraisal wells (by Sun Oil and Soco in 1993/97)
- 5 deviated development wells, and 1 water disposal well drilled by GFI
- Phase 3: 5 wells (1 pilot, 2 horizontal and 1 injector) between March-April 2009/Dec 2009
- Phase 4: 3 horizontal sidetracks of GFI wells
- Phase 5
  - 3 new horizontal producers, 3 sidetracks of existing wells (1 W.I.)
  - One exploration well to East Terrace
- Phase 5.5
  - 1 horizontal sidetrack

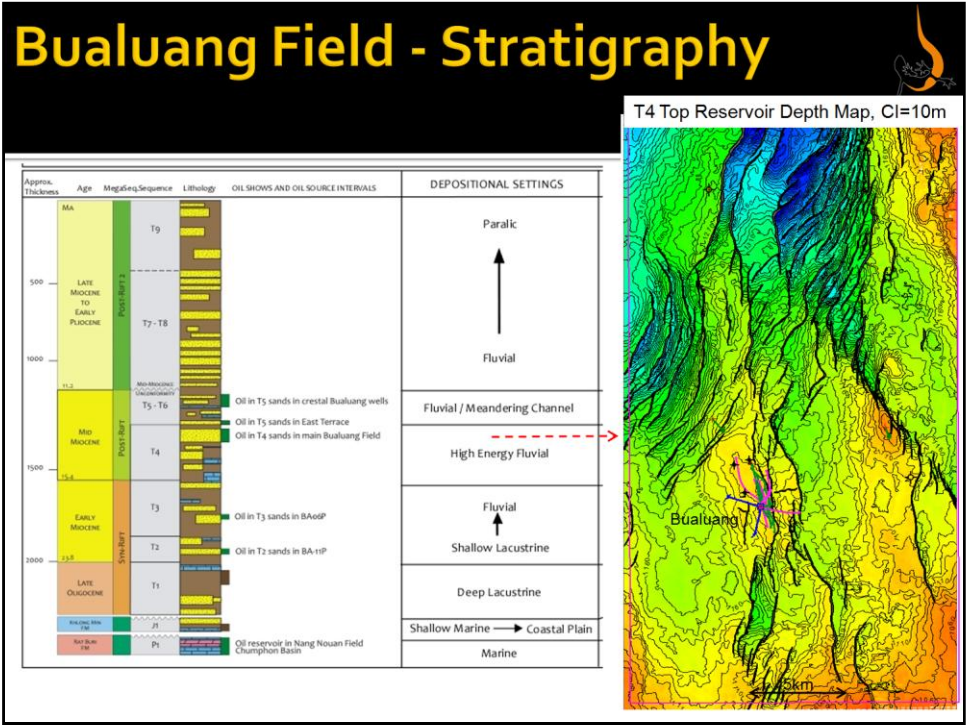


Geological Overview: Regional Structural Elements

- GOT consists of 4 main Tertiary basins
  - Chumphon
  - Western
  - Kra
  - Pattani
- Basin inception is Oligocene
- N-S oriented extensional grabens and half-grabens
- Bualuang is located in the Western Basin, essentially a half-graben
- Area was affected by regional trans-tension in the late Miocene
- The underlying pre-Tertiary rocks consist of Permian Ratburi Group carbonates and Mesozoic intrusives



Presenter's notes: The earliest date of basin inception is Oligocene. Movement along the major faults essentially resulted in N-S oriented grabens and half-grabens. Regionally the area was affected by trans-tension movements during late Miocene. The underlying pre-Tertiary rocks (the basement consists of Permian Ratburi Group (carbonates) and intrusives of Mesozoic age).



Presenter's notes: For ease in understanding the stratigraphy, it has been divided into megasequences.

1.Pre-Tertiary megasequence consists of Permian Ratburi Group carbonates. These are productive at Nang Nuan field (located some 80km SW), which has produced approximately 4.7 MMBO from the Permian Ratburi Formation. This formation is a secondary target in the area.

2. Syn-rift megasequence consists of upper Oligocene to lower-middle Miocene shales and fluvio-deltaic sandstones deposited in lacustrine environment.

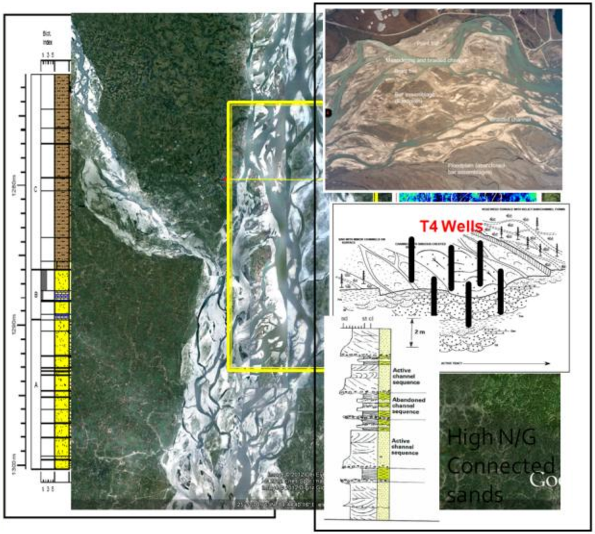
3.Post-rift megasequence 1: Upper-middle Miocene to upper Miocene predominantly fluvial clastics with occasional marginal marine mudstone and sandstone. Primary producing reservoir is middle Miocene T4 sand, deposited in a fluvial environment. These sands have been correlated with a high degree of confidence between wells and suggest that individual sands of the reservoir zone are laterally continuous. T5 sands were found to be oil-bearing in some of the crestal wells in BL. T3/T2 oil-bearing sands were logged in BA-11P well during recent drilling campaign.

4.The regional mid-Miocene Unconformity is poorly expressed in the Bualuang area and is of little or no practical significance in the Bualuang Field.

5.Post-rift megasequence 2: Upper Miocene to Recent fluvial deposits with significant marine incursions – considered overburden in B8/38.

Depositional Model for the field area

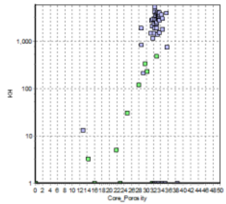
- Believe T4 mainly braided channel system due to high net:gross (over 90%)
- Abandonment phase near top – introduction of shale plugged channels
- Shale plugs may be present throughout sand
- Local carbonate concretions
- Sand body geometry from observed data and analogues is input in Petrel Geomodel and subsequently forms the basis for reservoir simulation runs.
- Model is periodically refined to match existing oil and water production history.



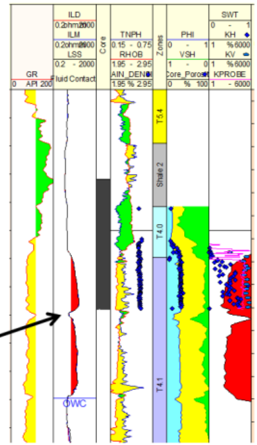
Field Properties / Log Type

Reservoir

- Deposited as an amalgamated fluvial channel sand with very high NTG (93%)
- Large active aquifer present
- Excellent poro-perm characteristics, porosity of up to 30% and permeability exceeding 1000 mD
- Good regional seal (shale 2) evident both on well logs and seismic
- A field-wide OWC at 1130m TVDSS
- Reservoir Temp ~161ºF and pressure 1600 psia



Gross : 25.13 m
Net pay : 22.7 m



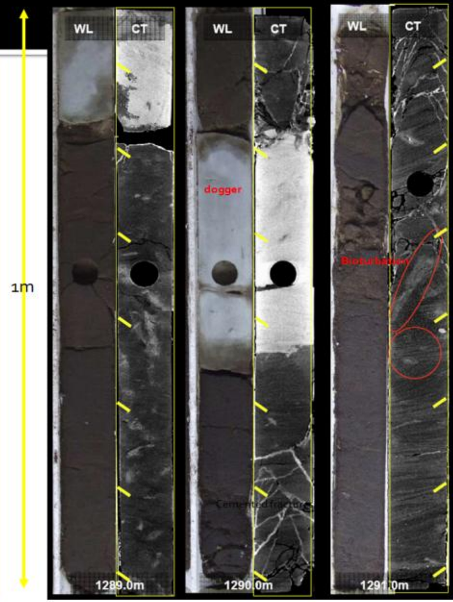
Fluid properties

- Low GOR – 4 scf/stb
- Moderate gravity of 27º API
- Low wax -18%
- Relatively high viscosity: 8.5 cp

Presenter's notes: THE ROCK has excellent poroperm properties. Presence of a large aquifer is evident from initial reservoir pressure. High NTG is seen in most wells – as shown on the log. A key feature is the baffles as high-density streaks, which can be attributed to abandonment phase, like this modern one from Brahmaputra; it act as baffles.

Core

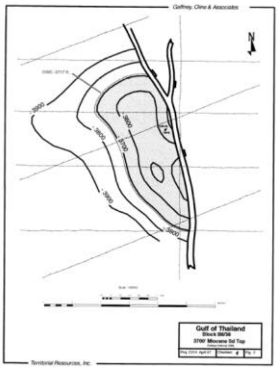
- Two wells with conventional cores
- Some interesting sedimentary features observed on core:
  - Carbonate layers, interpreted as doggers
  - Calcite-cemented fractures
  - Some bioturbation and rootlets
  - Extensive palaeosol horizons above the main sand
  - Cross-bedded and ripple-laminated sandstones
  - Generally only moderate grain sorting
  - Claystone rip-up clasts
  - Subtle bed boundaries interpreted as channel amalgamation surfaces.
  - Kv/Kh values approaching 1, <u>though earlier well data indicated a more laminated reservoir</u>



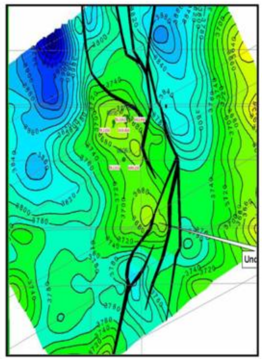
Presenter's notes: This image shows BA-05 core under white light and CT scan. It is a very homogenous rock – sedimentary structures are very well preserved. In BA-05 RCA analysis showed up to 6D of kh. Previous exploration wells had poor log quality and very poor hole conditions (to support Kv/Kh=1).

Bualuang Field Mapping Evolution (1)

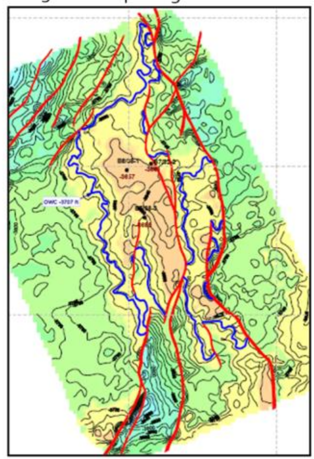
2D : SOCO Post 32/2



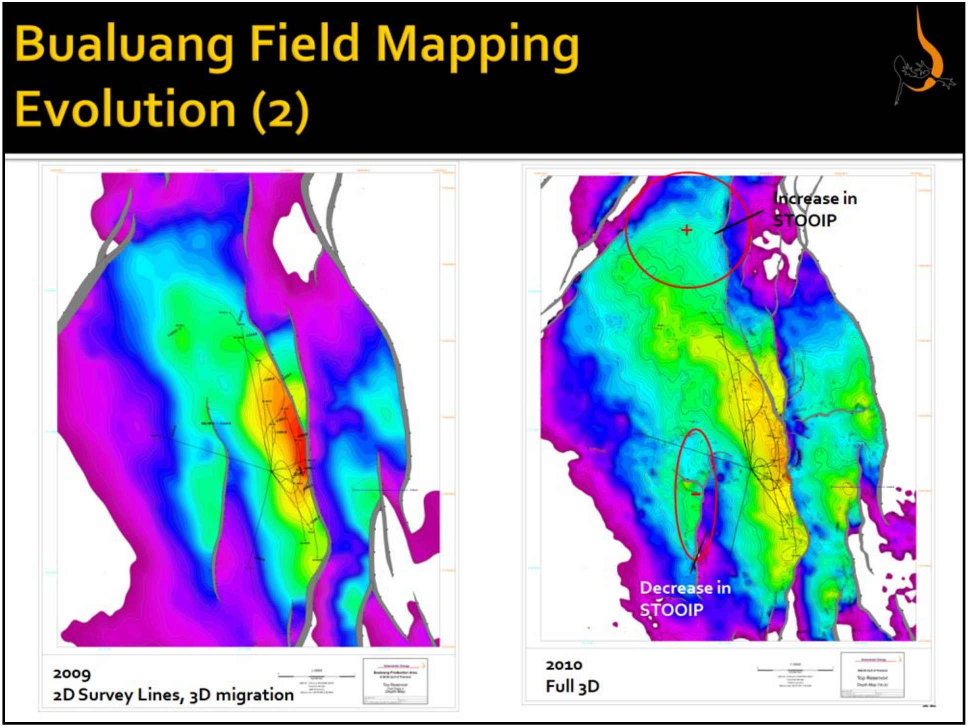
2D : GFI
Post B8/38-3



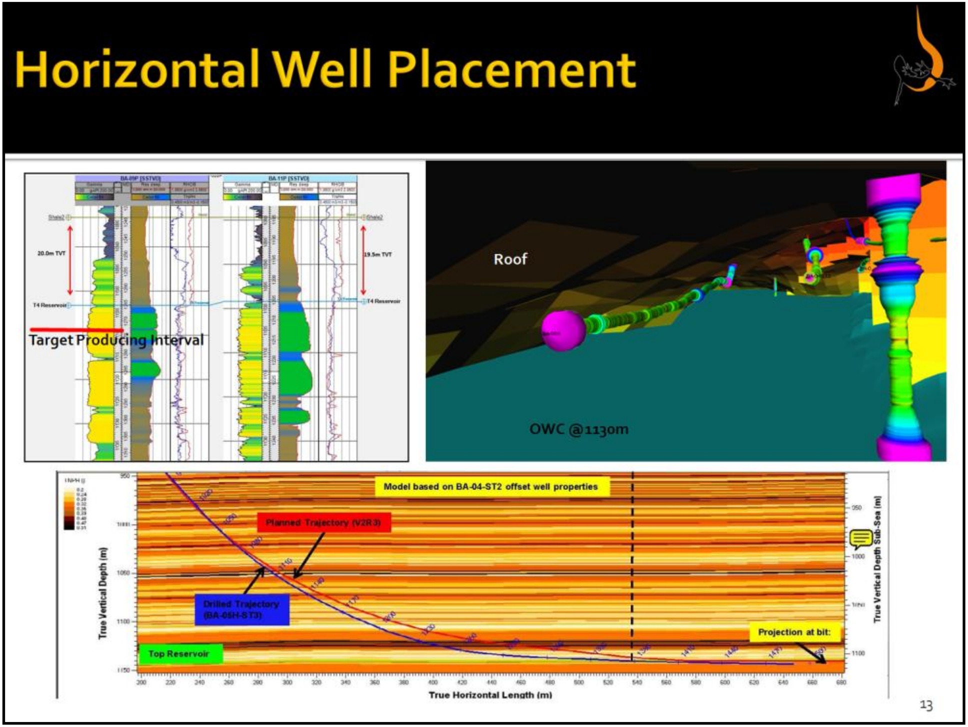
GFI Pre Development
100m spaced 2D survey lines
6.25m CDP spacing



Presenter's notes: This sequence of illustrations shows the evolution of the field mapping--how the structure mapped changed with each vintage of seismic and post-drilling. The trap area, described by the oil-water contact at -1130m tvdss, is approximately 2145 acres (8.7 square km). There is a possibility that the field may be extended into the undrilled fault block to the east (the "eastern terrace" prospect). SEL is scheduled to drill step-out well in the near future.

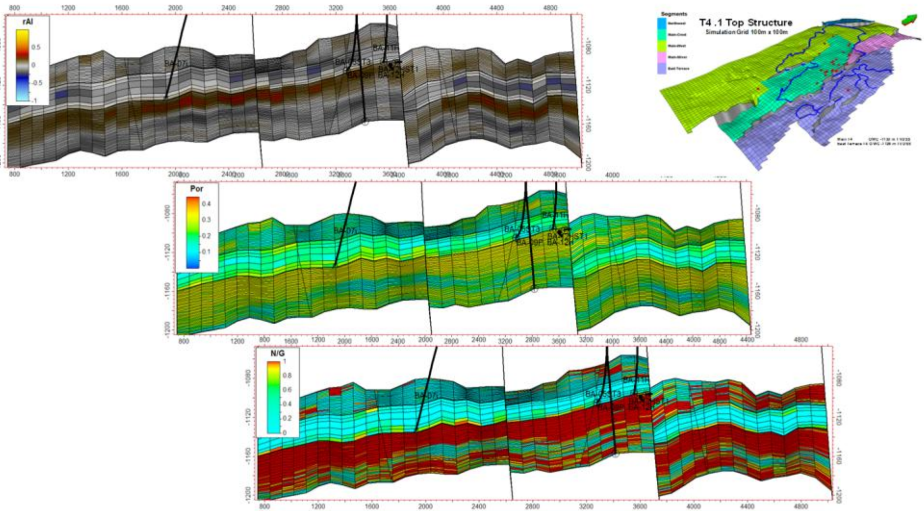


Presenter's notes: In new 3D seismic, there is more volume at the north but less at the south.



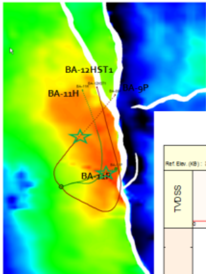
Presenter's notes: **PREDRILL PLANNING**--T4 Reservoir Landing Point; Well Path; Landing and Geosteering Strategy- by well.
•Selection of LWD Tools (Salamander); Log Response Modeling (Service Co. "Schlumberger"). **DRILLING**--GeoSteering Team in Bangkok Office; Salamander Team Geologist, Geophysicist, Operations Geologist; Service Company - 2 x Well Placement Engineers; Land the 8-1/2" Section; GeoSteer the 6-1/8" Section.

Bualuang Field Geomodel 2011- Property Modeling



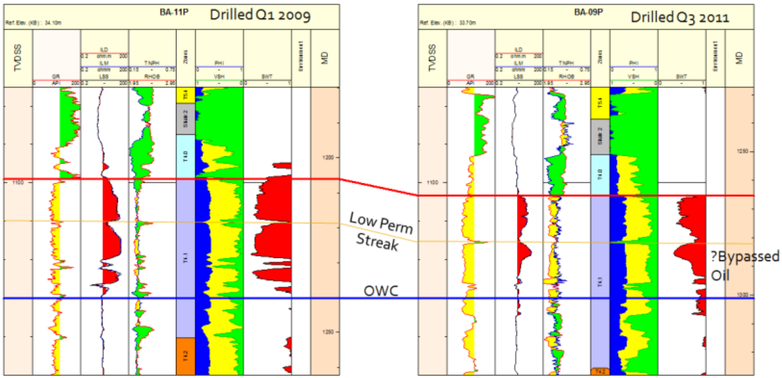
Water Movement

- comparison of pilot wells BA-11P (Q2 2009) and -9P (Q2 2011)

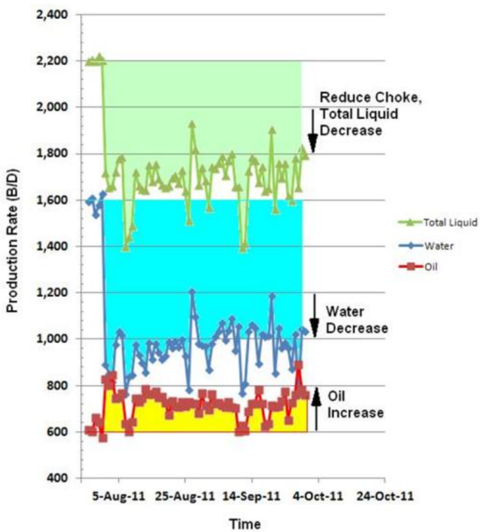


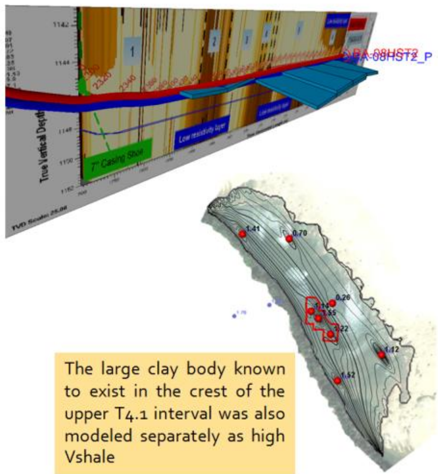
BA-11H currently producing 1500bopd, 70% water cut, 3500 bwpd

BA-9P suggests water may be moving horizontally above tight zone



Bualuang Field Geomodel 2011- Property Modeling

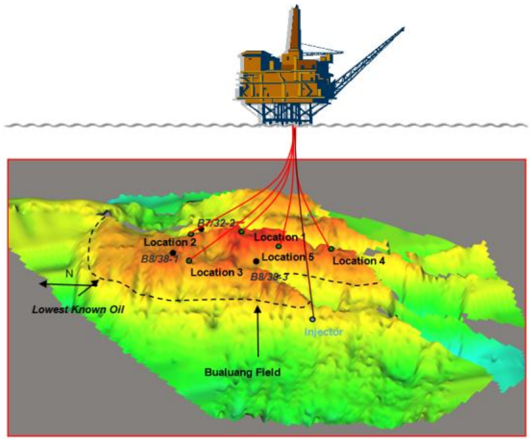




Presenter's notes: Property modeling also included the placement of clay plugs which were near the wellbore but not identifiable in the well logs. In the four wells that had azimuthal resistivity (Periscope©), certain sections with clay plugs could be interpreted and included in the property distributions. This was achieved by creating pseudo-wells two meters below the existing wells and picking clay intervals consistent with the low resistivity on the Periscope© sections. These pseudo-wells and interpreted clay-plug logs were upscaled and added to the Vshale distribution, using the calculator function.

Original Plan of Development (GFI) – Phase I/II

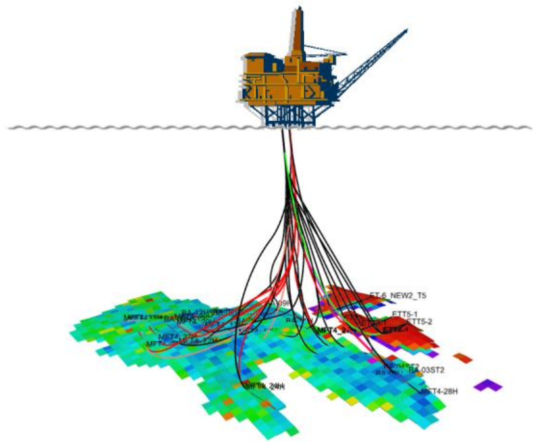
- Uncertainties for GFI
  - Sand continuity and connectivity. Net pay continuous or multiple stacked sands.
  - Presence of an aquifer
  - Structural compartmentalization
  - Oil column, GOR, viscosity
  - Velocity issues for seismic mapping
- Proposed Plan of Development
  - A single WHP (12-slots) with production connected via pipeline to an offshore FPSO
  - Six deviated wells - five producers (BA-01 to -05) and one water injector/disposal (BA-07i)
- Well Operations/Completions
  - Used OBM. For all six wells, drilled a pilot hole to identify TOR and OWC, then sidetracked and completed with gravel pack
  - Completed with artificial ESP lift (Electric submersible pump)



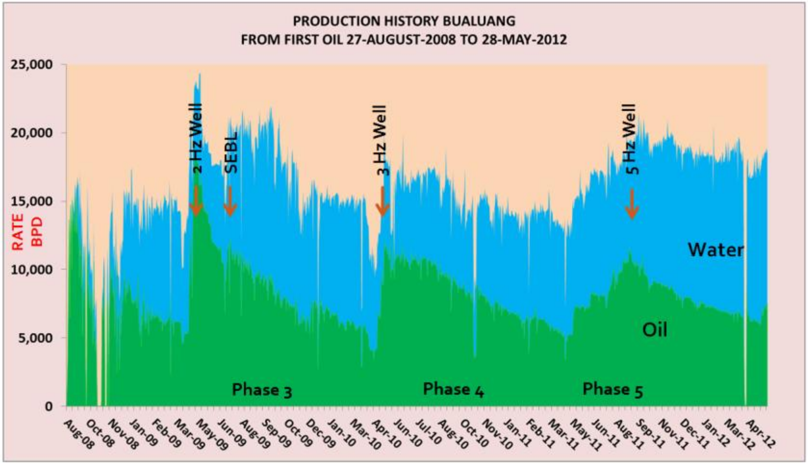
Presenter's notes: This illustration shows the Geocellular model from Petrel. GFI had a few uncertainties when the field POD was compiled. Deviated well designs were proposed, with the thought that it would encounter stacked reservoir. All six wells were drilled from Bualuang wellhead platform (BLWPA) using Jack- up rig (Ensco 51). Phase I/II wells were drilled using OBM by Schlumberger. All six wells drilled a pilot hole to identify TOR and OWC and then sidetracked and completed with gravel pack. All the producer wells were completed with artificial ESP lift. Good hole conditions and good well data were acquired, both LWD and wireline logs. A core was cut in BA-05, as shown previously. MDT tests were run in BA-04 for pressure and fluid data. Production connected via subsea pipeline to Rubicon's FPSO unit. Wellhead Platform – Major Design Features--The Bualuang Wellhead Platform (BLWPA) is a minimal facility installation. The BLWPA is designed for 4 leg jacket, remote and automatically controlled: unmanned, with 12 single well slots.

Revised POD – Phase III & Beyond

- Side tracking inclined wells using Horizontal well technology
- Long producing sections with ESS completions
- Down-hole ESPs for lifting of fluids
- Water disposal in down-flank injectors
- Far step-out of development drilling
- Installation of second platform
- Installation of water handling module



Production profile since first oil



Conclusions

- Bualuang Field can be characterized as having:
  - a relatively high viscosity oil with low GOR
  - an excellent reservoir with limited horizontal flow barriers
  - baffles aid production
  - reservoir linked with an infinite aquifer
- Reservoir Modeling suggests distributed drainage network to maximize recovery and reduce water coning
- This will require the drilling of additional horizontal wells:
  - Continuing to use geosteering technology
  - Drilling long-reach wellbores consisting of 500m to1000m+ in length
  - Consider use of inflow control devices to distribute pressure drawdown along the wellbore, and to minimize spot coning
- These wells are being continually drilled

Striving for Continued success..........