Changes in Structural Style Along the Frontal Papuan Fold Belt From Seismic Imaging*

Marcus Parish[1]

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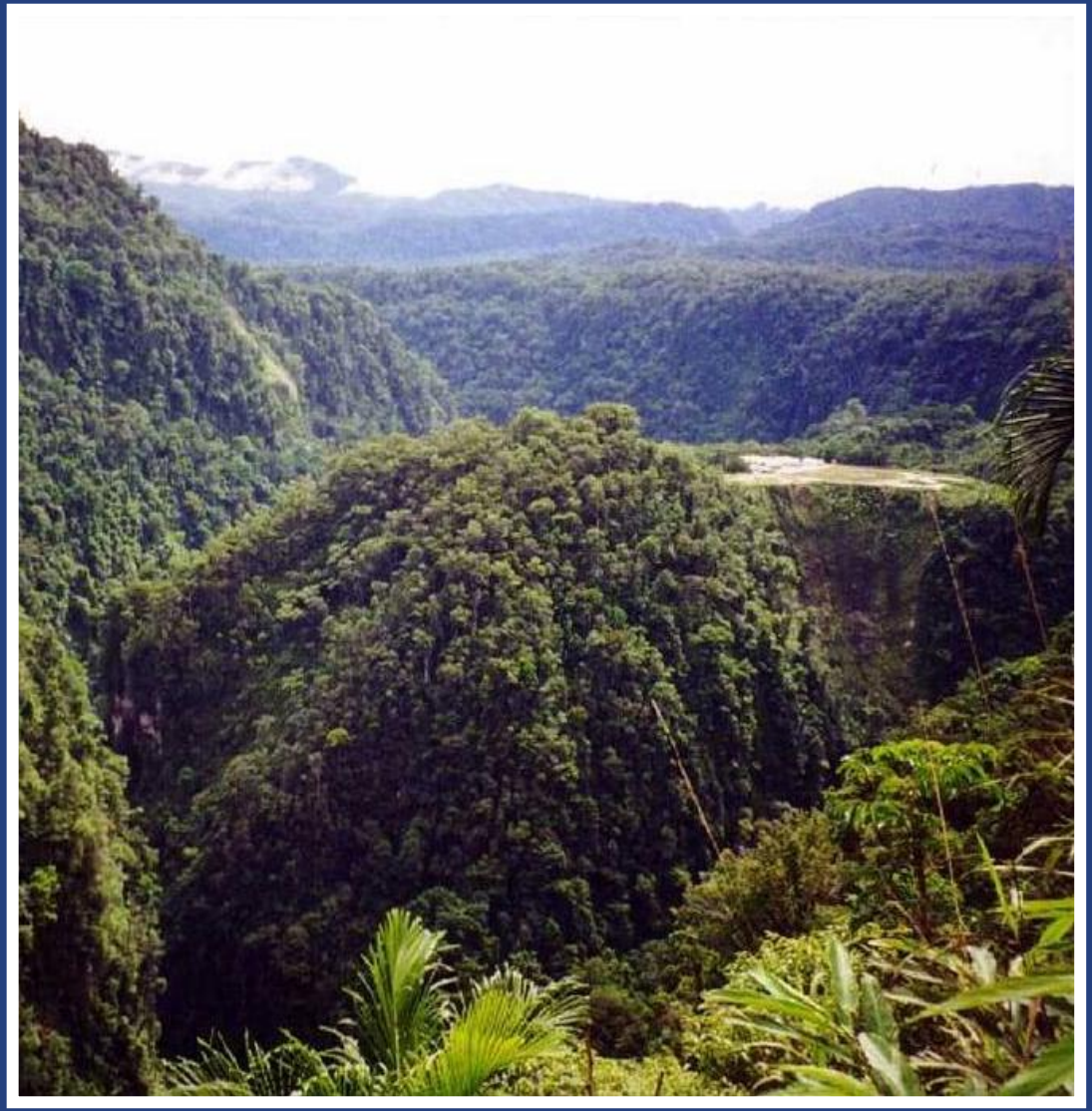
[1]Oil Search Ltd, Sydney, NSW, Australia (Marcus.Parish@oilsearch.com)

Abstract

The Papuan fold and thrust belt developed from ongoing late Miocene compression and has been the focus of hydrocarbon exploration and production since the mid 1980's with well data and seismic imaging establishing the basic structural architecture and stratigraphic framework across the Papuan thrust belt and foreland. This study examines the structural style and lateral changes across the Frontal Papuan fold belt using recent seismic imaging and associated well data. In the southeast the structural geometry of the frontal Papuan fold belt is dominated by thin skinned southwest directed emergent thrust faults and ramp anticlines that are associated with the main Kutubu producing fields. The geometry of the Papuan thrust front changes along strike to the northwest in the Muller range where the dominant structure forms an eroded frontal monocline with basement involvement and associated northeast directed fold and thrust structures. Selected seismic profiles across the Papuan fold belt and associated well bores show how these large scale structural changes and associated structural complexities reflect the importance of precursor structural controls on the deformation of the Papuan fold belt. These controls also influence both the trapping style and distribution of hydrocarbons within the Papuan fold belt with a gas dominated system developed in the northwest with oil and associated gas caps developed in the southeast Papuan fold belt.



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Marcus Parish

Oil Search Limited
ARBN 055 079 868

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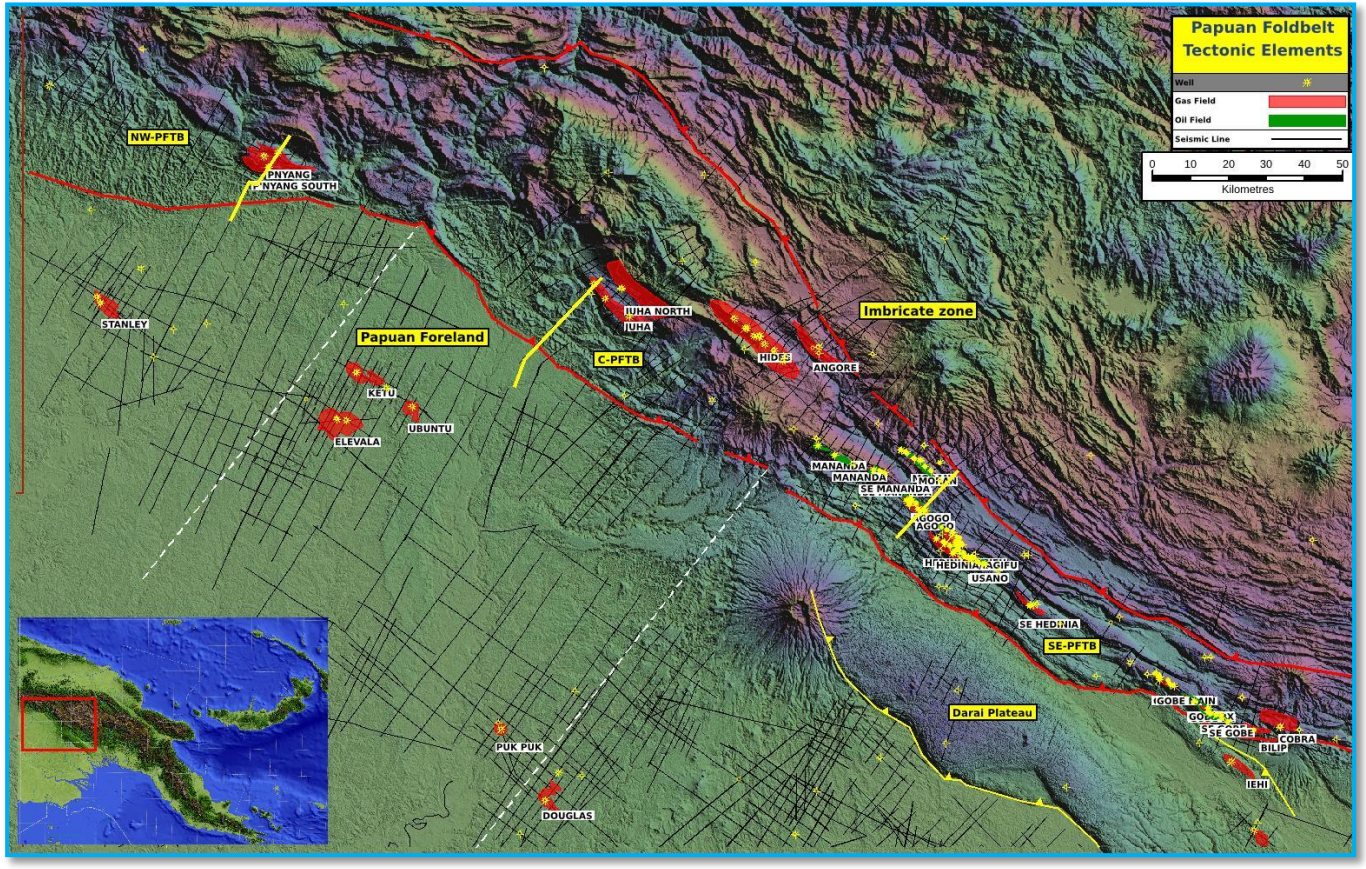
Scope of Presentation

Introduction: **Papuan Fold and Thrust Belt (PFTB):**
Tectonic elements and stratigraphy
Exploration history

Examples: **SE Papuan fold belt - Agogo**
Central Papuan fold belt - Juha
NW Papuan fold belt - P'nyang

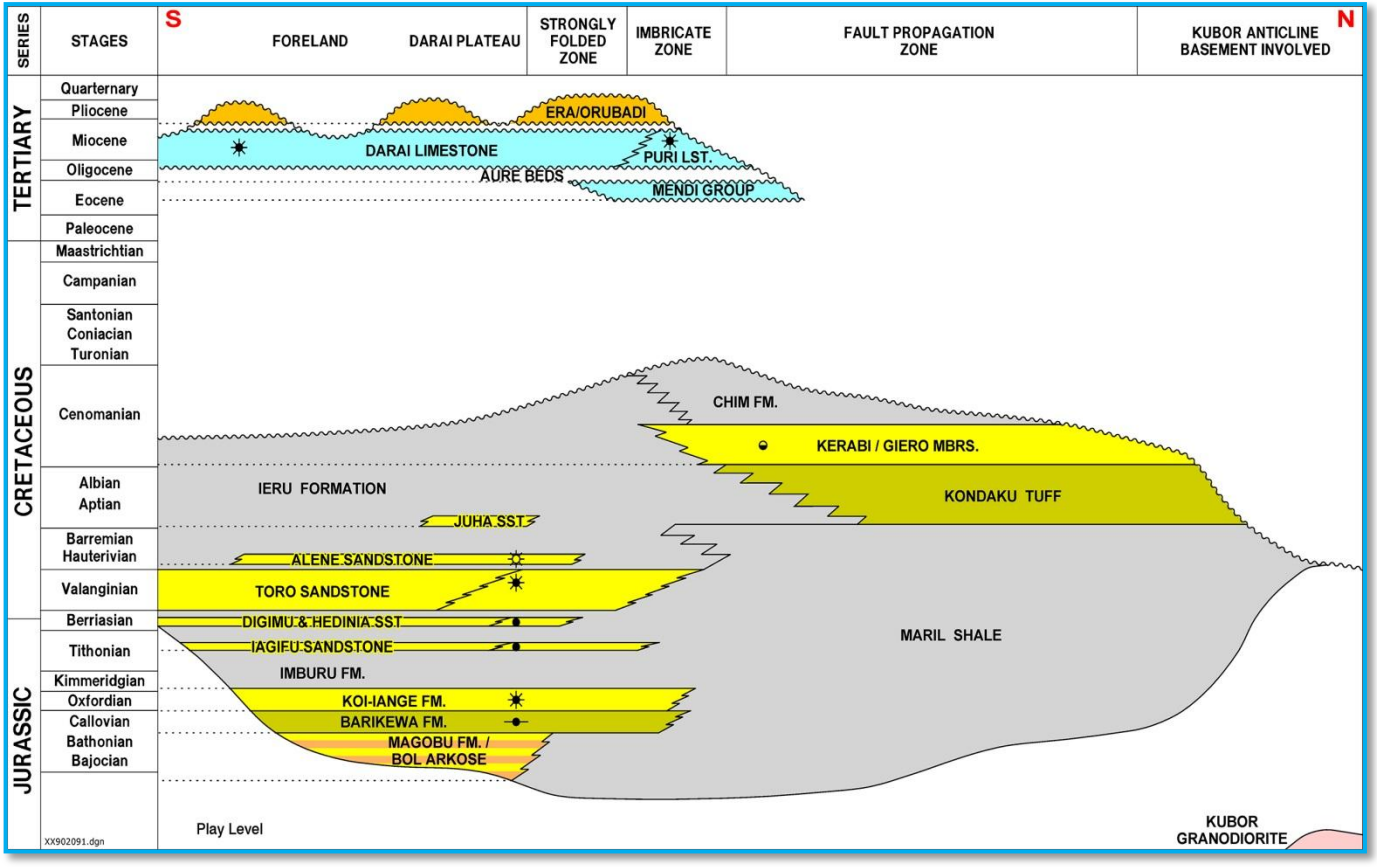
Conclusions: **Changes in tectonic style across the frontal PFTB and implications for hydrocarbon charge**

PFTB with SRTM setting and location



- Mio-Pliocene fold thrust belt
- Foreland region
- Frontal fold belt:
  - Emergent SE & Central
  - NW frontal monocline.
- Distal FTB high level shallow imbricate zone
- Numerous oil & gas seeps
- Thrust front seismic examples:
  - Agogo (SE PFTB)
  - Juha (Central PFTB)
  - P'nyang (NW PFTB).

PFTB Chronostratigraphy



» Petroleum System

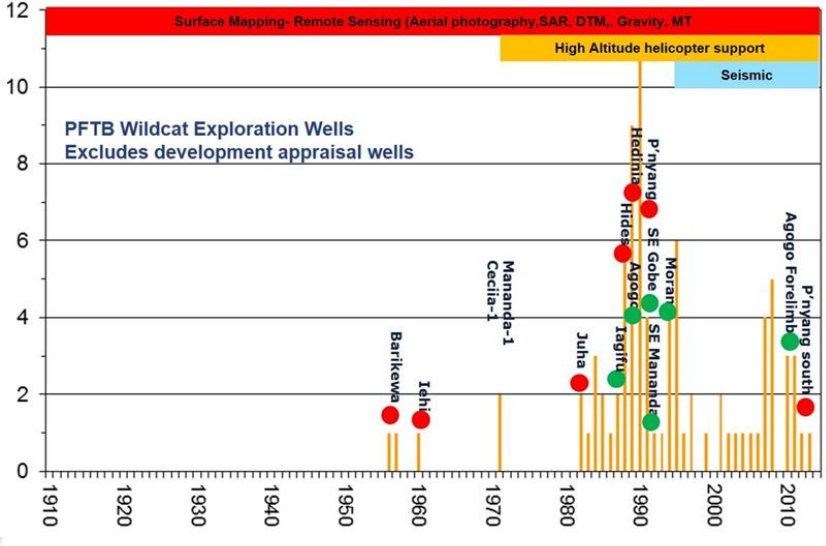
- Late Jurassic Imburu Fm marine source.
- Reservoir. Late Jurassic-Early Cretaceous shelf clastics (Toro-Iagifu Sst).
- Top Seal Ieru Fm.

» Key tectonic events

- Triassic-E Jurassic rift.
- M Jurassic- L Cretaceous passive margin.
- Late Cretaceous Coral sea rift
- Oligo-Miocene carbonate platform.
- Mio-Pliocene fold belt and inversion.

PFTB Exploration History

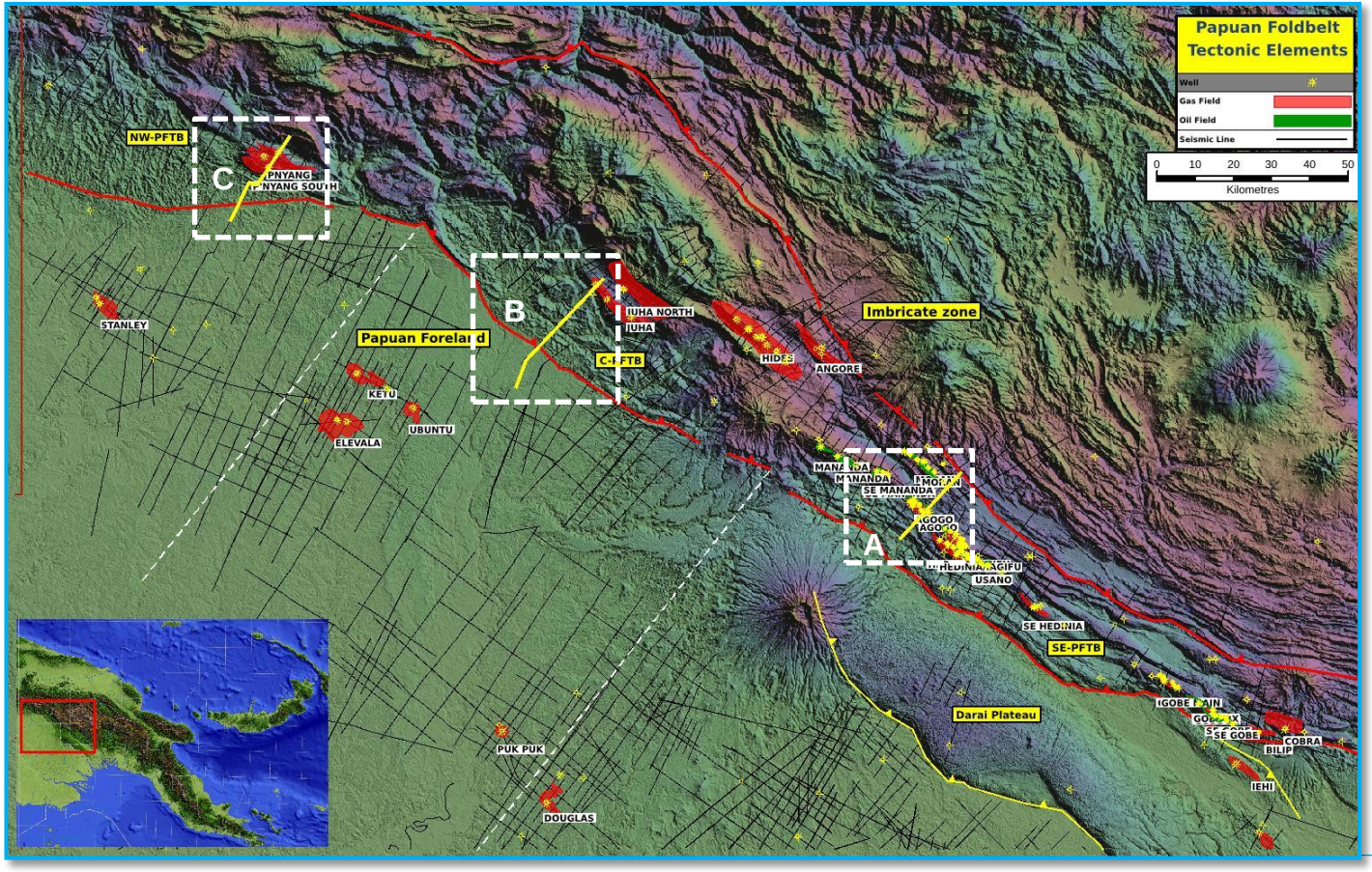
- Remote rugged mountainous terrain.
- Dense rainforest dominant karst limestone outcrop (Darai).
- Mid 1990's: Acquisition of useable seismic data (with local exceptions)
- Challenging environment-helicopter supported operations.



PFTB Seismic Operations

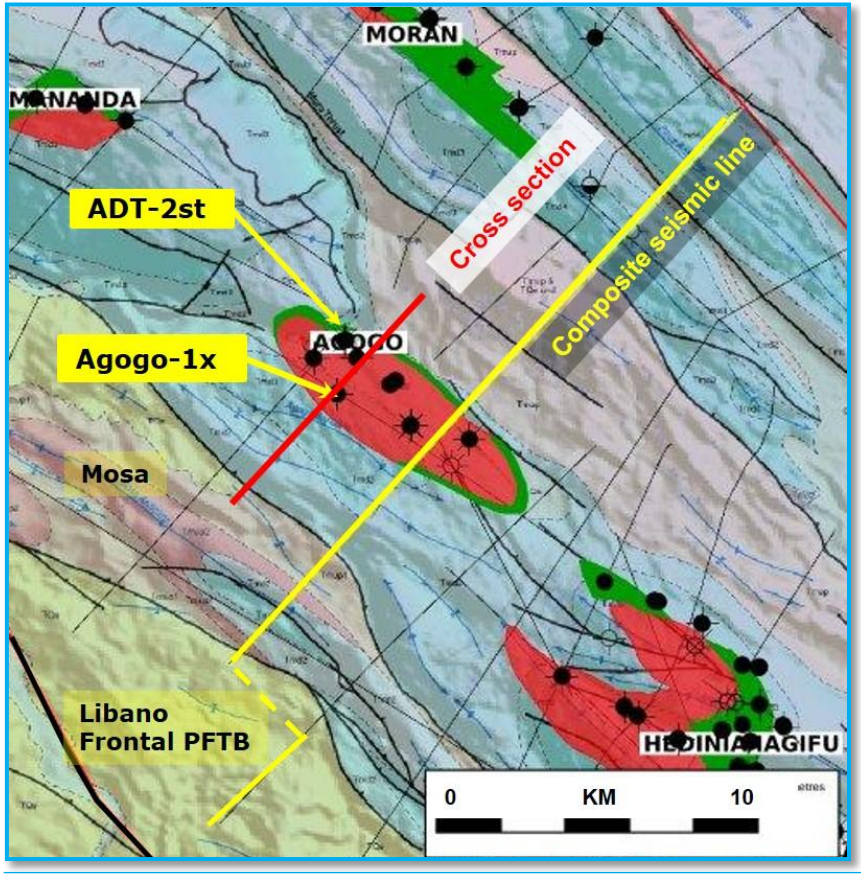
- Seismic requires line cutting, helicopter support, drilling.
- Avg. cost 2015 $300,000 /km
- Total fold belt coverage 3026 km

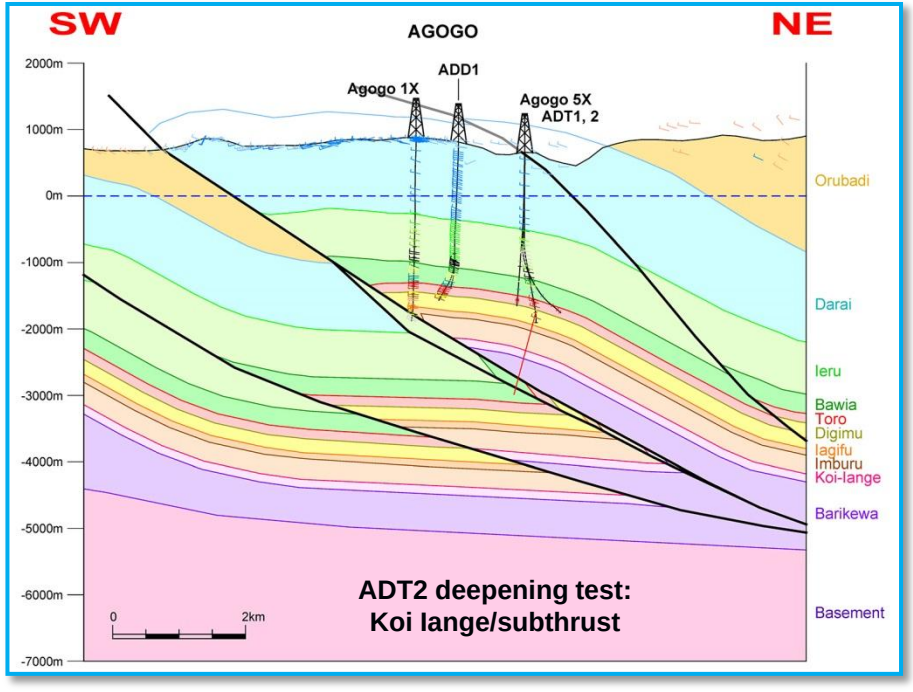
Frontal PFTB seismic images: case studies



- **A: Agogo, South-East PFTB**
- **B: Juha, Central PFTB**
- **C: P'nyang, North-West PFTB**

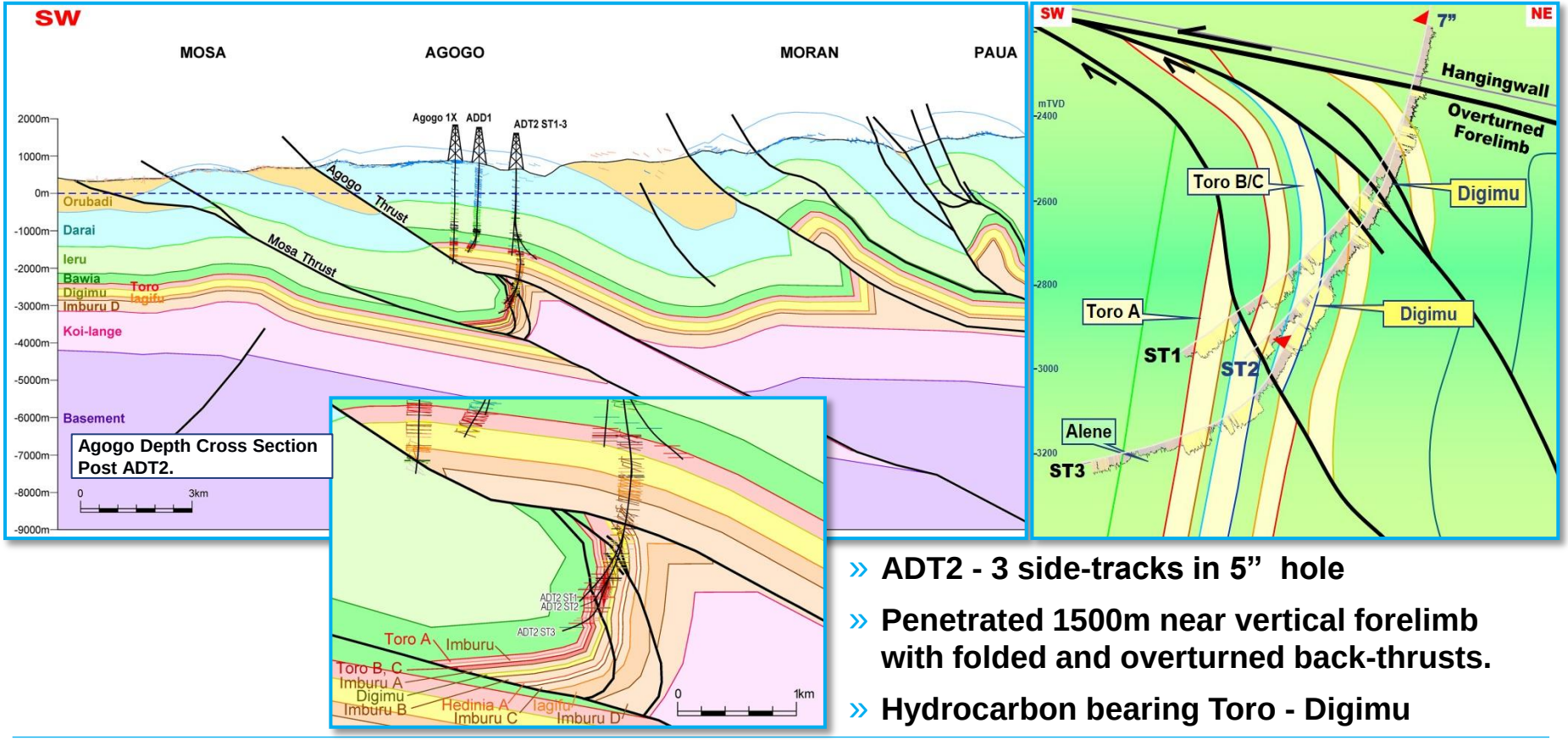
Case study A: Agogo area SE PFTB





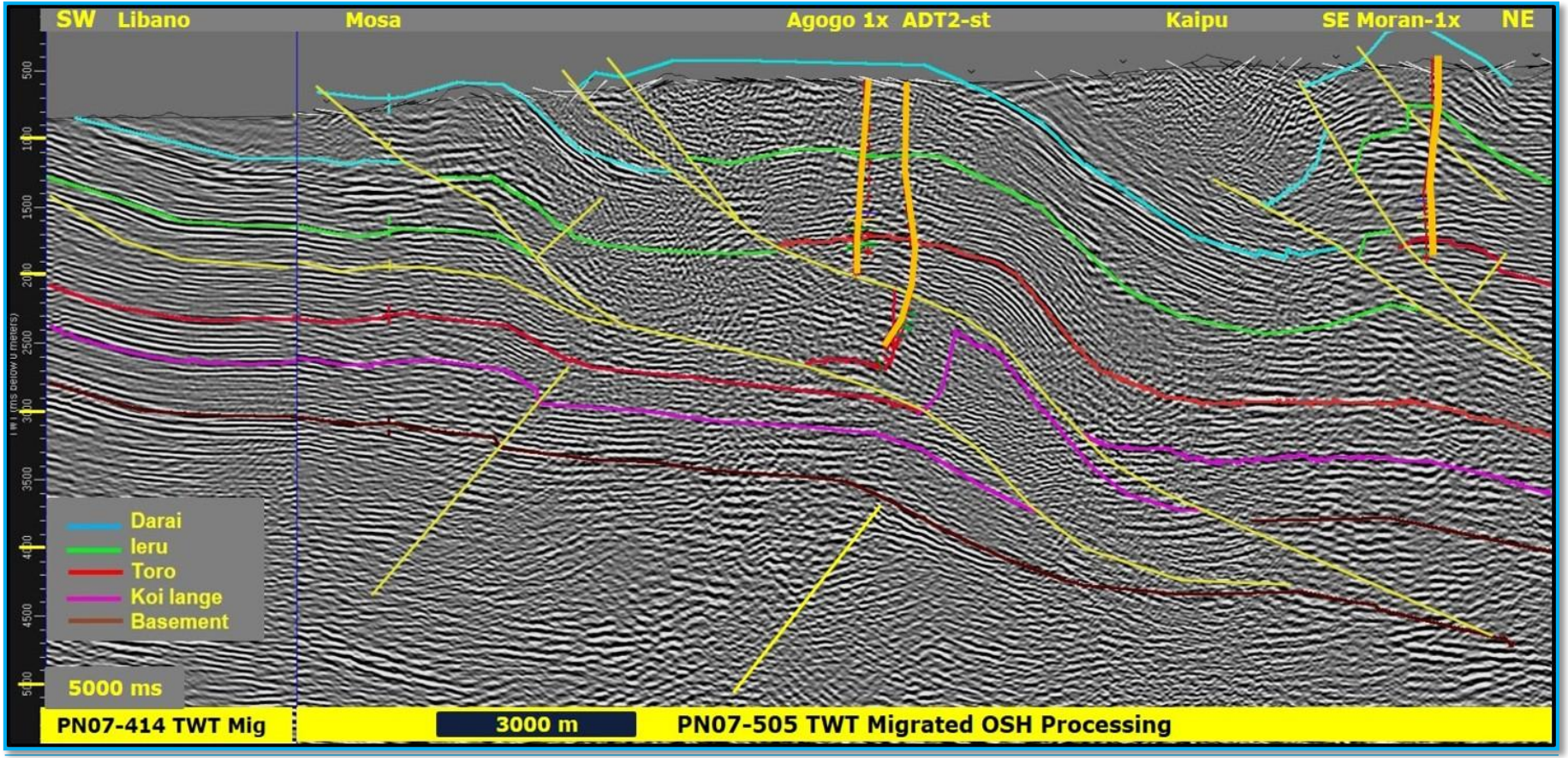
- Agogo-1x discovered 1989: oil leg & gas cap hanging-wall Agogo fault.
- Seismic acquired 2007, OSH processing migrated TWT sections.
- ADT2-ST 2010, test deeper hanging wall Koi-lange target and/or sub thrust structure

Case study A: Agogo footwall forelimb post drill-cross section

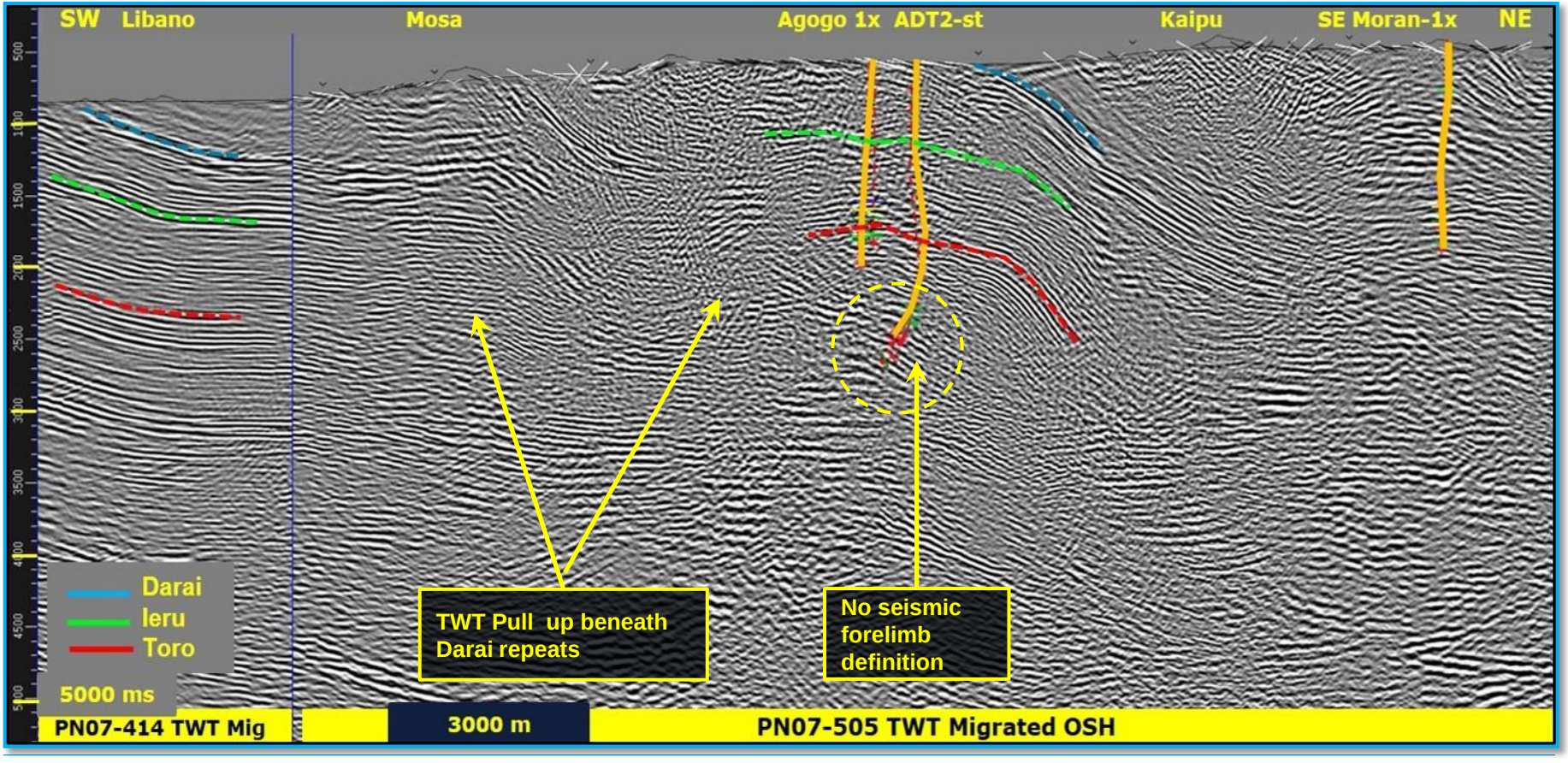


- ADT2 - 3 side-tracks in 5” hole
- Penetrated 1500m near vertical forelimb with folded and overturned back-thrusts.
- Hydrocarbon bearing Toro - Digimu

Case study A: SE PFTB Agogo area
Composite seismic line interpreted



Case study A: SE PFTB Agogo area composite seismic line un-interpreted



Case study A: Agogo area SE PFTB tectonic style

SE PFTB :

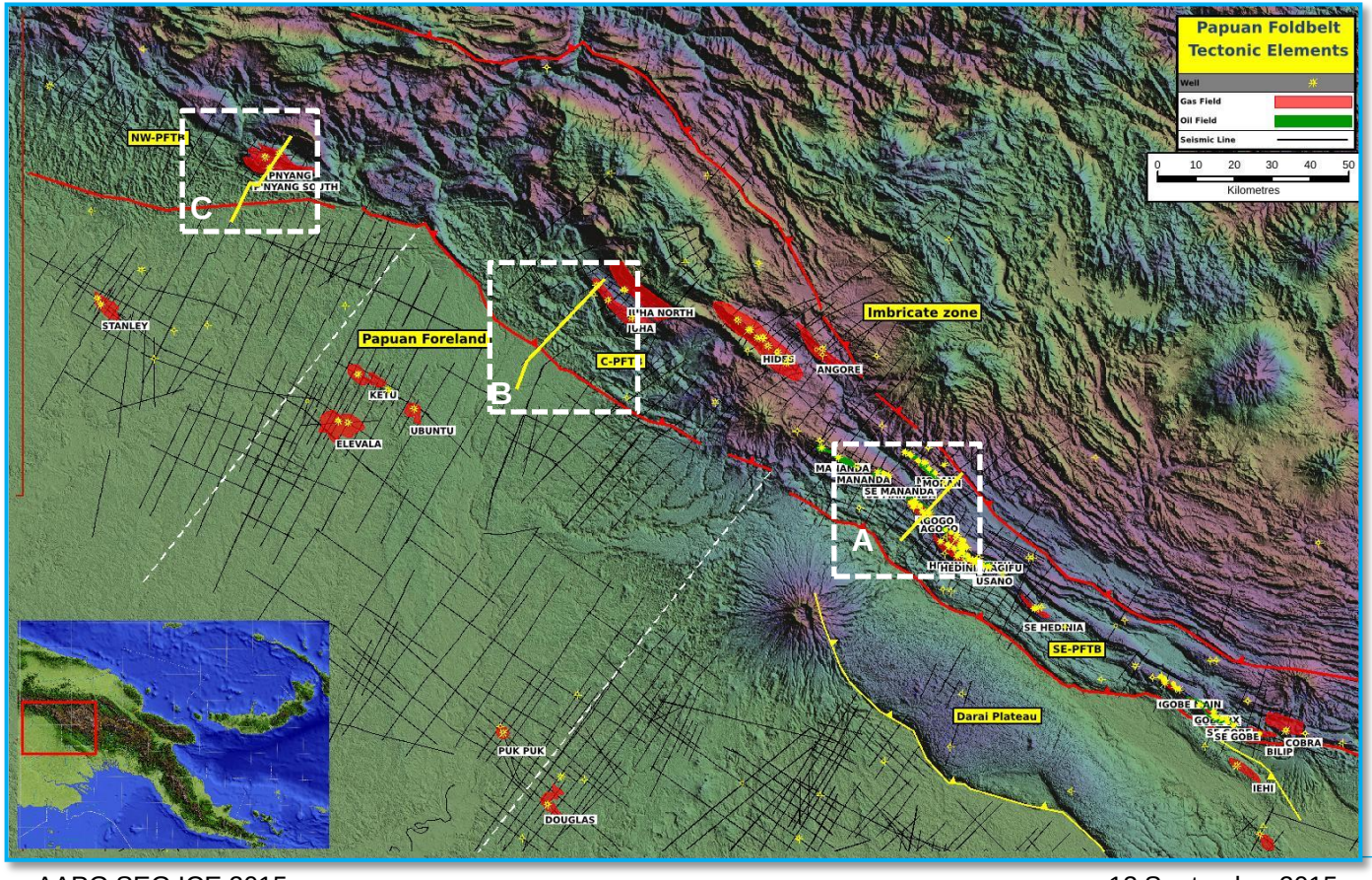
- SW-directed emergent thrust front at Libano with frontal fault progressively deepening to hinterland.

- Darai Plateau early uplift-foreland Imburu source present depth <3500 mSS marginal present day maturity.

- Frontal thrust structures along the Libano and Mosa trends are underlain by deeper NE-directed inversion faults.
  - Closure dependent on velocity modelling “time pull up and push down”.
  - Relative timing of thrusting and inversion implications for deformation sequence and charge history (thrust belt: pre-, synchronous- or post-inversion?).

- Toro involvement in the SE frontal thrust system demonstrated by the penetration of a footwall syncline with 1500m of vertical relief underlying the Mananda-Agogo-Hedinia fault system .
  - Hydrocarbon charge to the footwall syncline is proven.
  - Forelimb geometry cannot be imaged through seismic resolution.
  - Exploration currently active along the footwall forelimb trend with success at Agogo-6x, Hedinia (ADT-4).

Frontal PFTB Seismic images – case studies



- **A: Agogo, South-East PFTB**
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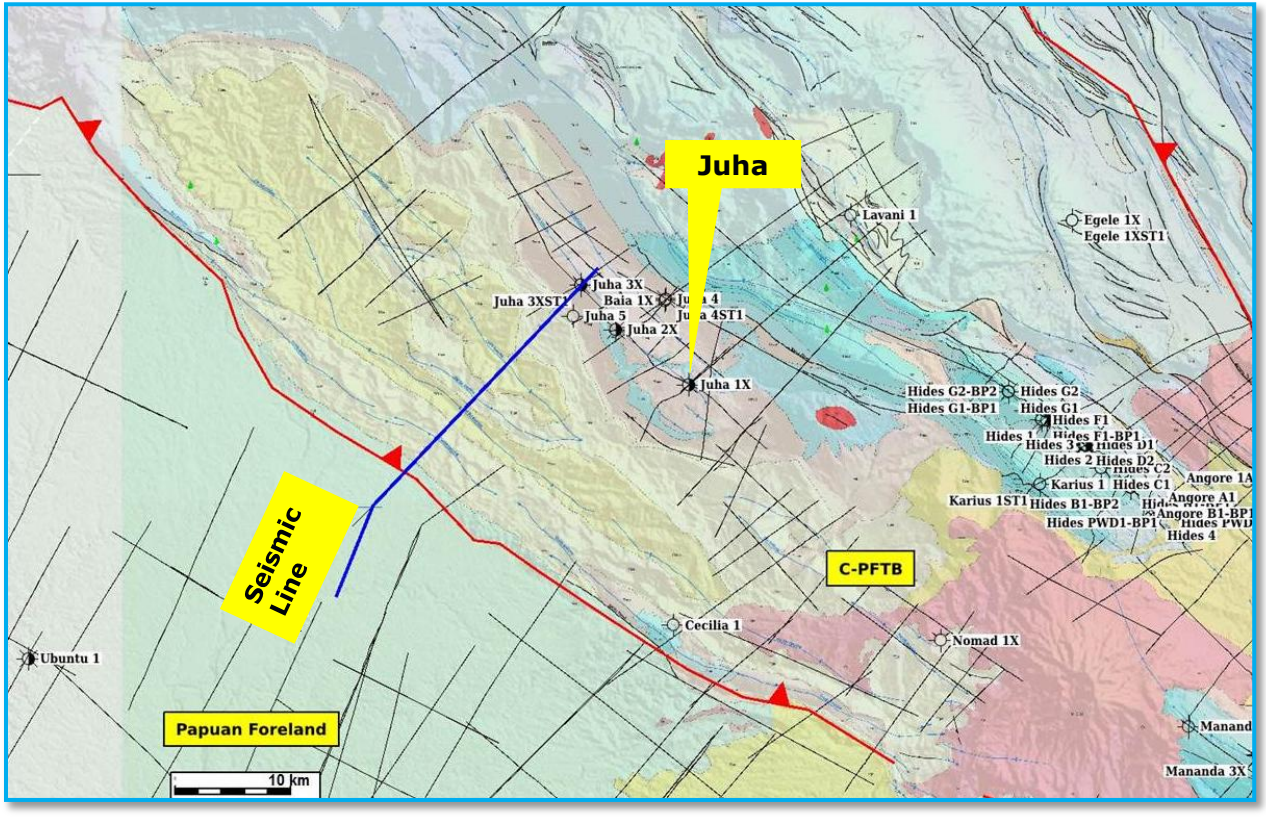
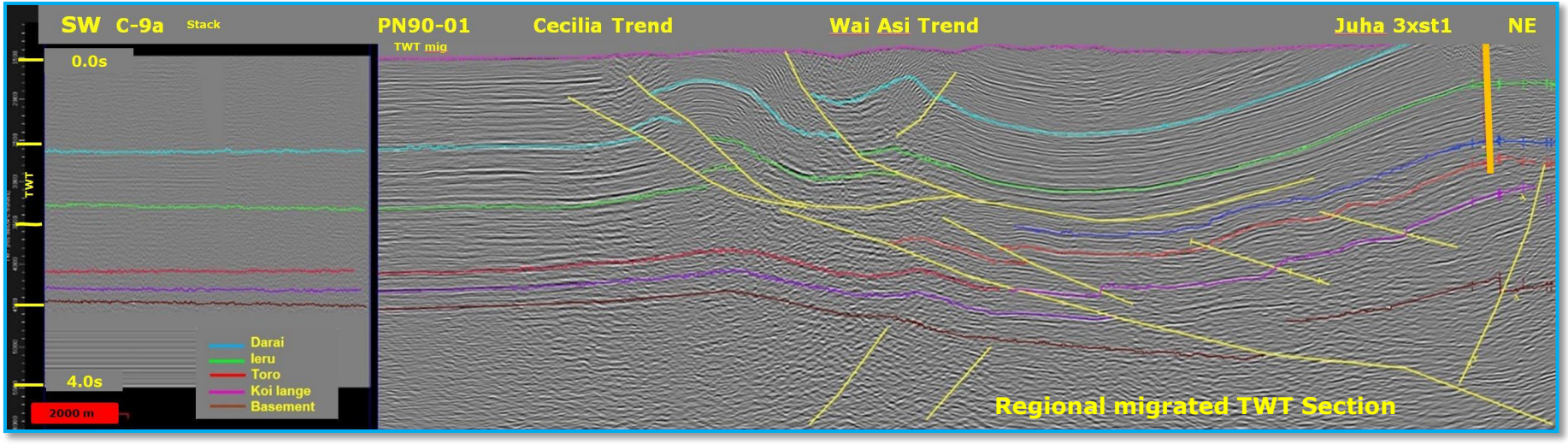
Case study B: Juha area Central PFTB



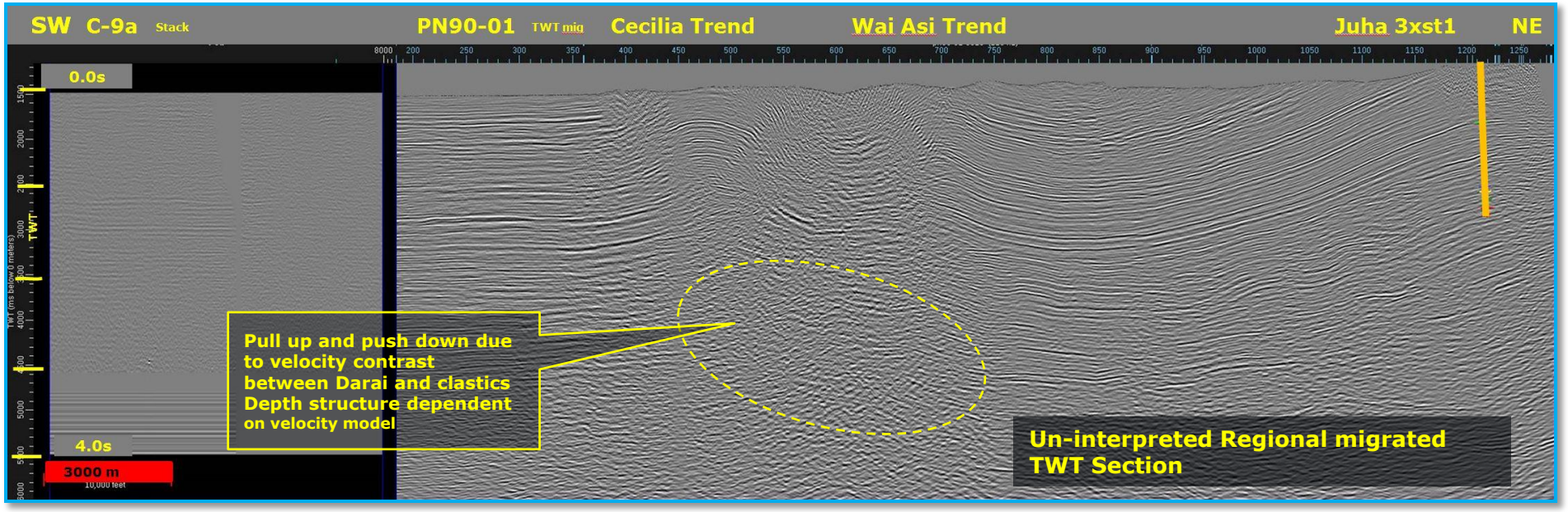
- First Foreland seismic acquired in 1970
- Cecilia-1 (1971) drilled frontal trend penetrated repeat Darai, TD above Toro target.
- Limited outcrop of Darai limestone, Juha seismic first acquired in 1981.
- Juha discovery 1982, appraisal Juha-5 2007.
- Semi-regional seismic grid acquired by Chevron in early 1990's (area of buried Darai).
- Seismic operations NE of Juha from 2013.
- Seismic lines PN90-01 and Cecilia-9a shows tectonic style over central PFTB thrust front.

Case study B: Juha area Central PFTB



- Sub horizontal undeformed foreland Imburu source depth >5000 mSS gas mature.
- Cecilia SW emergent thrust front with shallow level Ieru-Darai imbricates underlying Toro involved duplex; leading edge thrust cuts back into basement inversion underlying the elevated Juha trend
- Shallow level frontal folds are not Toro involved due to Intra Ieru detachment
- Possible Toro involvement underlying the Wai Asi trend within leading edge Toro duplex
- Deep SW dipping inversion trends underlying the FPTB along the Cecilia-Wai Asi trend, timing of Inversion and thrusting?

Case study B: Juha area Central PFTB



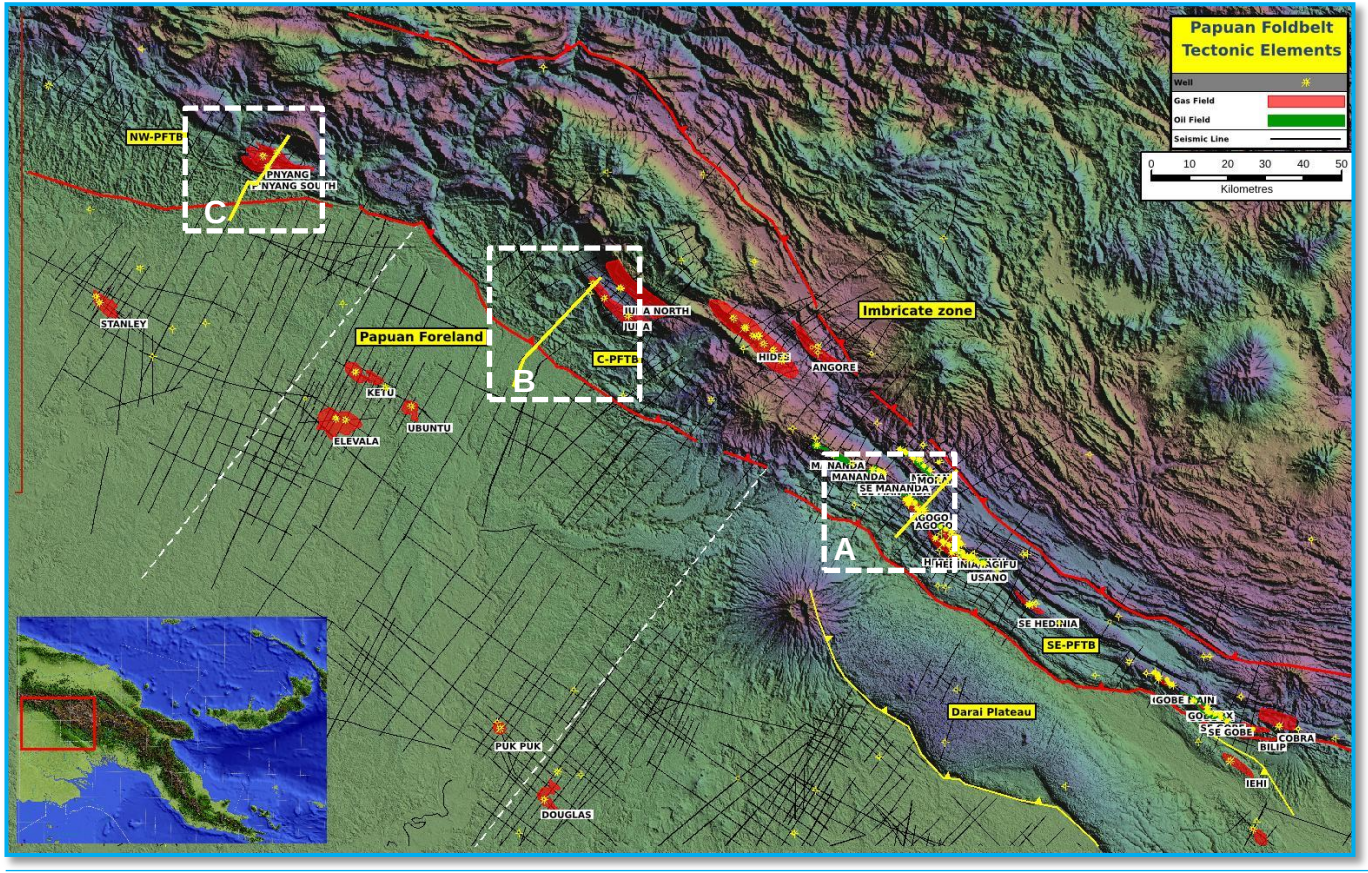
- Good quality seismic definition - absence of surface Darai and low surface dips (10-15 degrees).
- Time pull up/push down underlying the Cecilia and Wai Asi surface trend.

Case study B: Juha area Central PFTB tectonic style

Central PFTB:

- **SW-directed emergent thrust front at Cecilia.**
- **Foreland Imburu source burial depth >5000 mSS (Gas mature).**
- **Frontal thrust structures comprise a shallow level imbricate thrust system with intra Ieru detachment overlying a deeper Toro involved duplex; leading edge of the duplex has possible Toro involvement beneath the Wai-Asi trend and involves basement inversion underlying Juha.**
- **Deep-seated inversion structures facing to the NE may underlie the frontal thrust system along the Cecilia and Wai Asi trends; depth conversion and structure dependent on velocity modelling.**
- **Implications for structural timing of inversion versus fold belt development and charge history.**

Frontal PFTB Seismic images: case studies



- **A: Agogo, South-East PFTB**
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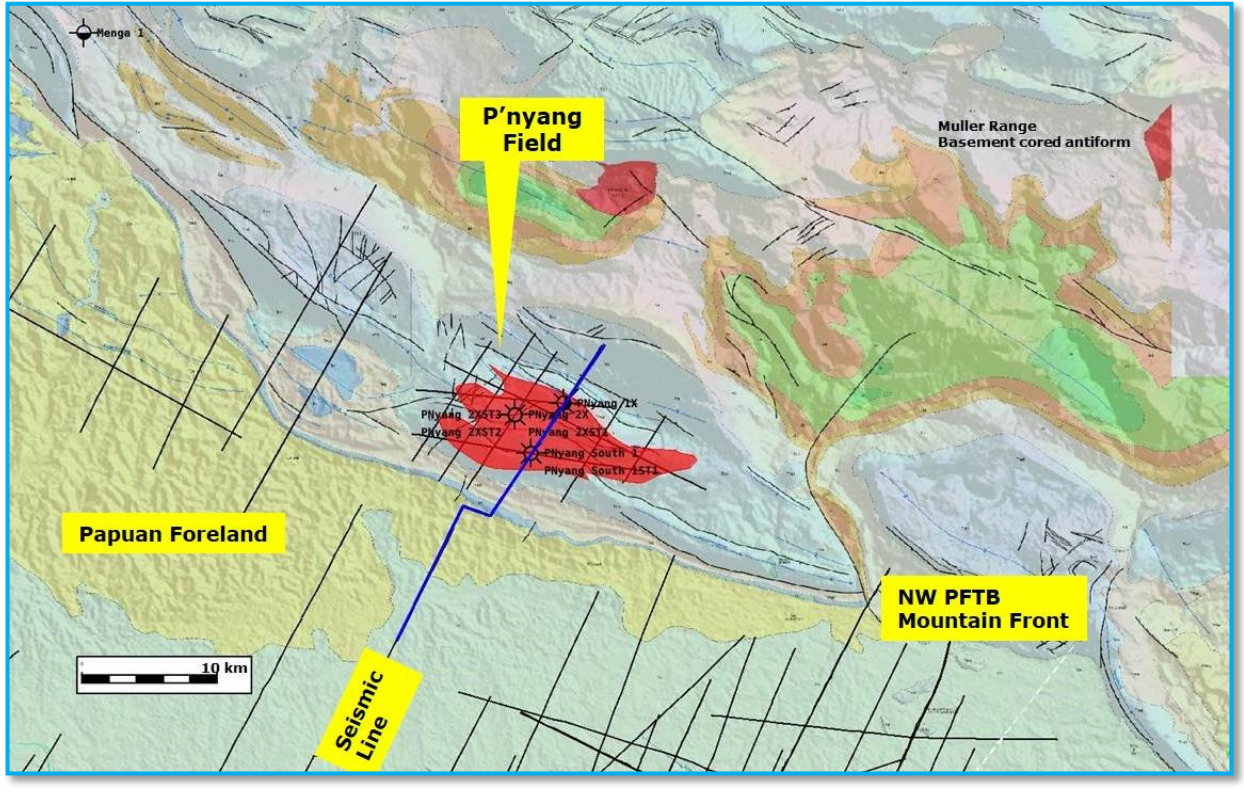
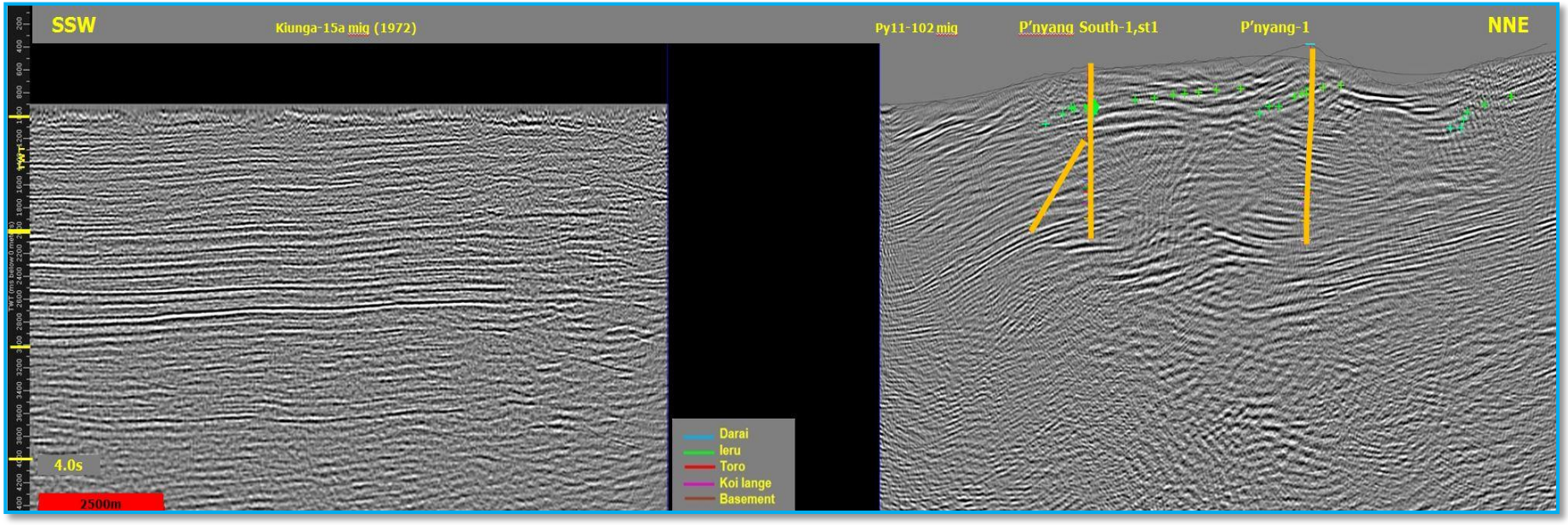
Case study C: P'nyang NW PFTB



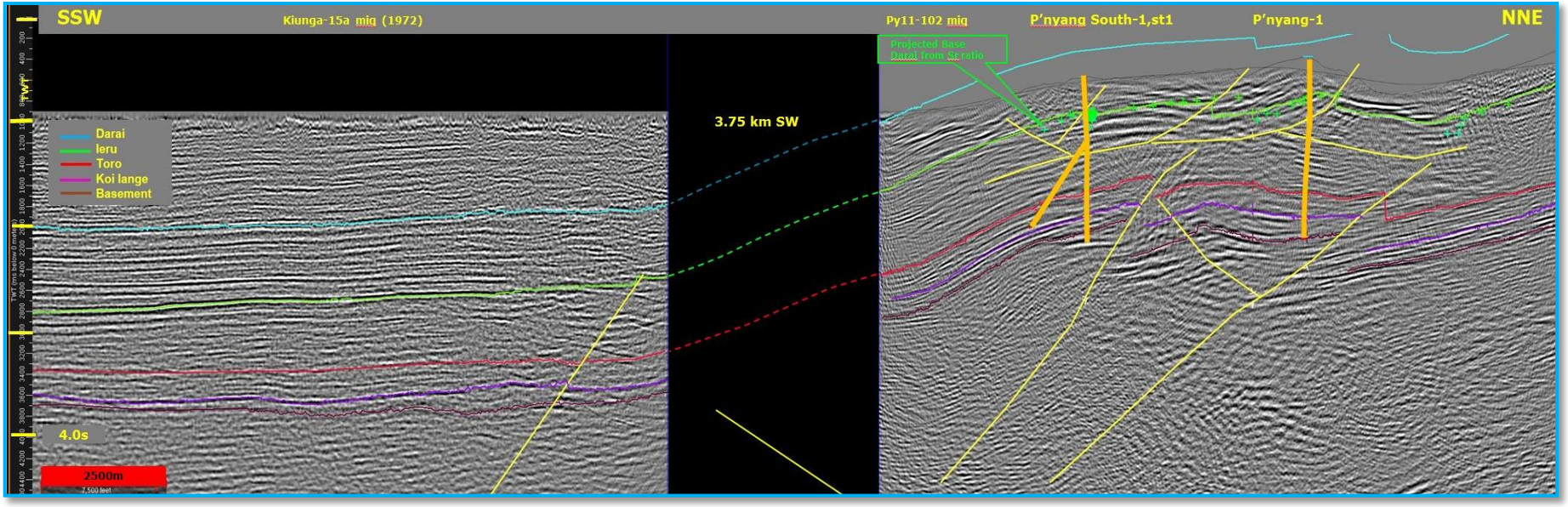
- P'nyang 1x gas discovery (1990) from field mapping delineating NW-SE trending P'nyang anticline.
- P'nyang-2x, and 2xst3 confirmed GDT and WUT (1991).
- Seismic delineation of P'nyang field first undertaken in 2011.
- Successful drilling and field delineation at P'nyang South 1 &St 1 in 2012
- Seismic lines PN11-02 (2011) & Kiunga 15a (1972) shows structural style over the NW PFTB.

Un-interpreted composite seismic line Kiunga 15A & PY11-102



- **Foreland seismic Kiunga 15a acquired 1972.**
- **Py11-102 (2011) good quality seismic definition due to low surface Darai dips (10-15 degrees).**

Interpreted composite seismic line Kiunga 15A and PY11-102



- NW PFTB dominated by mountain front monocline with little emergent shortening.
- Tectonic style SW dipping basement back thrusts with intra Ieru detachment separating Darai and deeper Toro-involved structures; P'nyang South 1 and ST1 confirmed seismic interpretation in 2012.
- Foreland Imburu source burial depth >4000 mSS gas mature-displacement of early oil charge?

Summary and Conclusions

Lateral changes in structural style across the Frontal PFTB and foreland basin are controlled by NE-SW trending lineaments forming the Bosavi and Strickland transfer zones. This has important implications to the dynamics of hydrocarbon charge, phase and structural timing.

- **NW PFTB (P'nyang area)**
  - **Mountain front monocline with minimal shortening <3km. Tectonic-style SW-dipping basement involved back thrusts with intra Ieru detachment separating shallow surface and deeper (Toro) level structures.**
  - **Foreland basin Imburu source burial depth >4000 mSS presently mature for gas with probable flushing of earlier oil charge.**

- **Central PFTB (Juha area)**
  - **SW directed emergent thrust front with duplexing, intra Ieru detachment and basement involvement (Juha).**
  - **Shortening ca. 5km.**
  - **Deep foreland burial >5000 mSS mature for gas generation in advance of the encroaching Fold belt. Leading edge of the PFTB overlies possible array of deeper inversion faults- timing implications to charge and migration history.**

Summary and Conclusions

- **SE PFTB (Agogo area)**
  - **Early uplift Darai plateau- shallower foreland burial-oil/gas.**
  - **SW-directed emergent thrust front at Libano with frontal fault progressive hinterland deepening, overall shortening 6km.**
  - **Toro involvement along the frontal fault system proven in footwall syncline with 1500m of vertical relief underlying the Mananda-Agogo-Hedinia fault system. Currently, undefined by seismic imaging. Proven footwall charge with active exploration along trend.**
  - **Frontal thrust structures along the Libano and Mosa trends are underlain by deeper NE-directed inversion faults. Relative timing of maximum foreland burial, inversion and thrust belt propagation has important implications for migration and charge history (interplay between maximum foreland burial, inversion and thrust belt propagation).**

Any Questions ?