The role of mobile shales in the formation of anticlines and hydrocarbon accumulations in the NW Sabah Fold Belt, offshore Malaysia

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What's Next?
SIS Global Forum 2017
September 13–15
Le Palais des Congrès de Paris

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Outline

I. Introduction

1. Background and Objectives
2. Approach

II. Modelling Results

1. Basin Modelling
2. Modelling Outcomes

III. Conclusions

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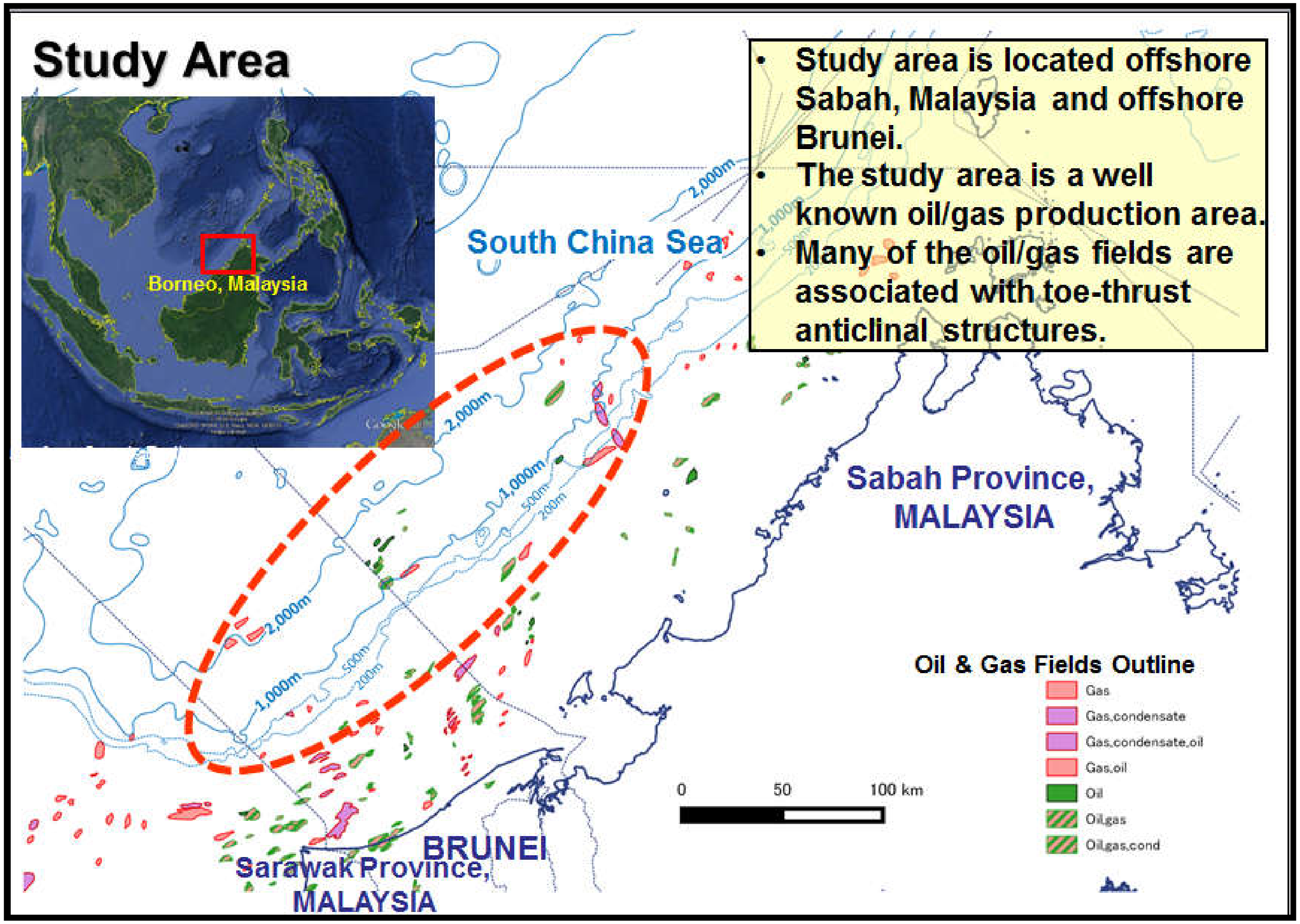
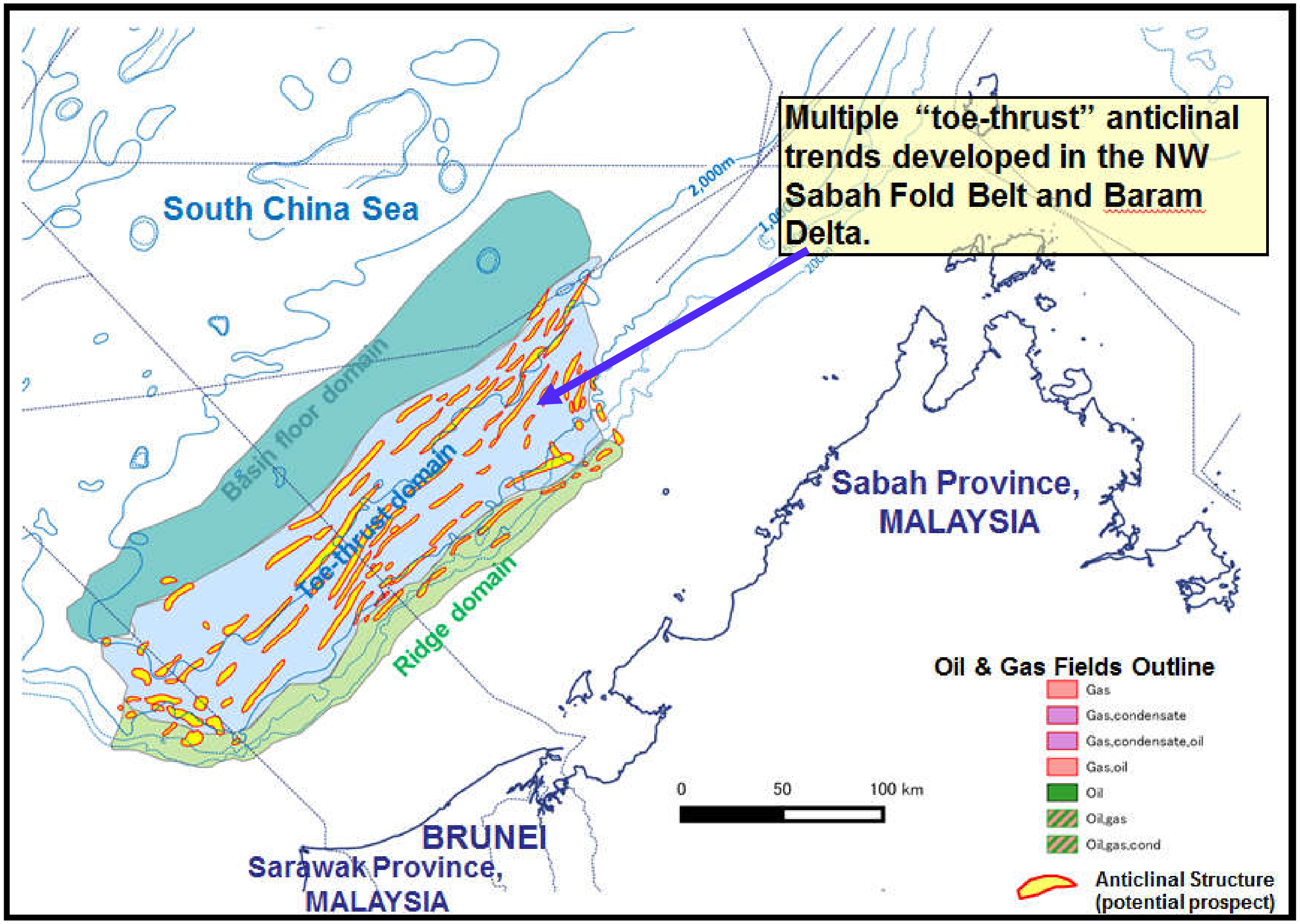
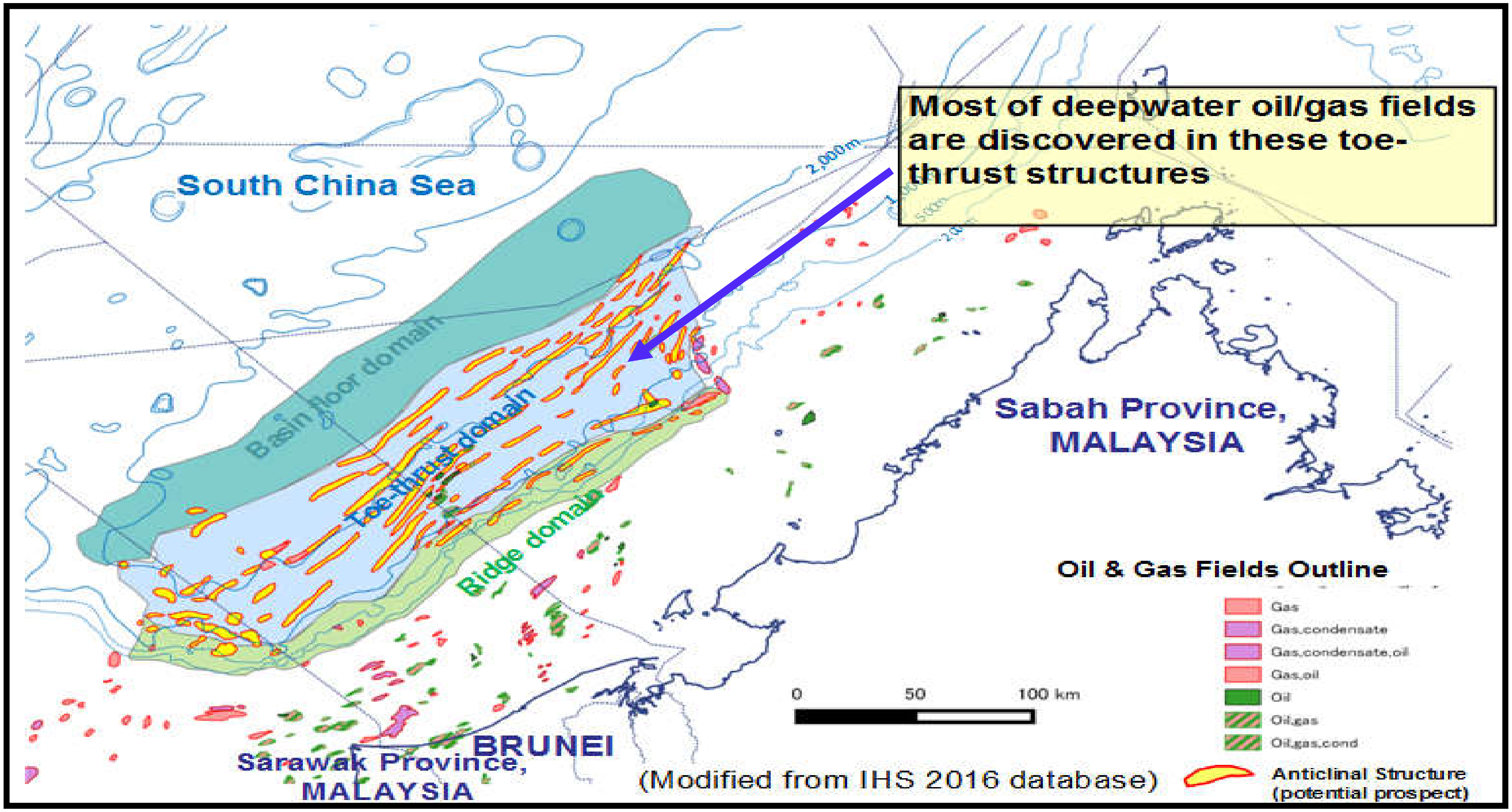
Study Area


Study Area
Borneo, Malaysia
South China Sea
• Study area is located offshore Sabah, Malaysia and offshore Brunei.
• The study area is a well known oil/gas production area.
• Many of the oil/gas fields are associated with toe-thrust anticlinal structures.
2,000m
1,000m
500m
200m
Sabah Province, MALAYSIA
BRUNEI
Sarawak Province, MALAYSIA
0
50
100 km
Oil & Gas Fields Outline
Gas
Gas,condensate
Gas,condensate,oil
Gas,oil
Oil
Oil,gas
Oil,gas,cond

Area Potentially Impacted by Mobile Shales



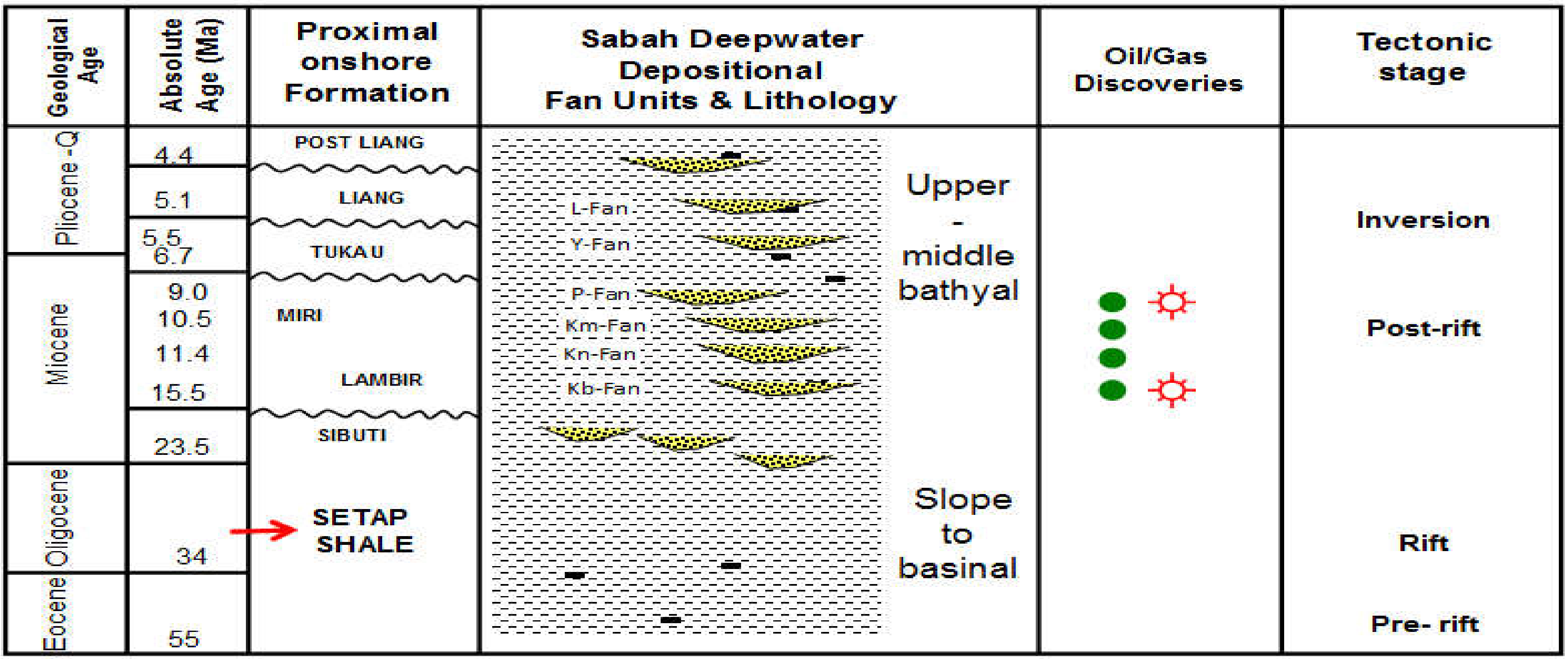
Area Potentially Impacted by Mobile Shales



Background and Objectives

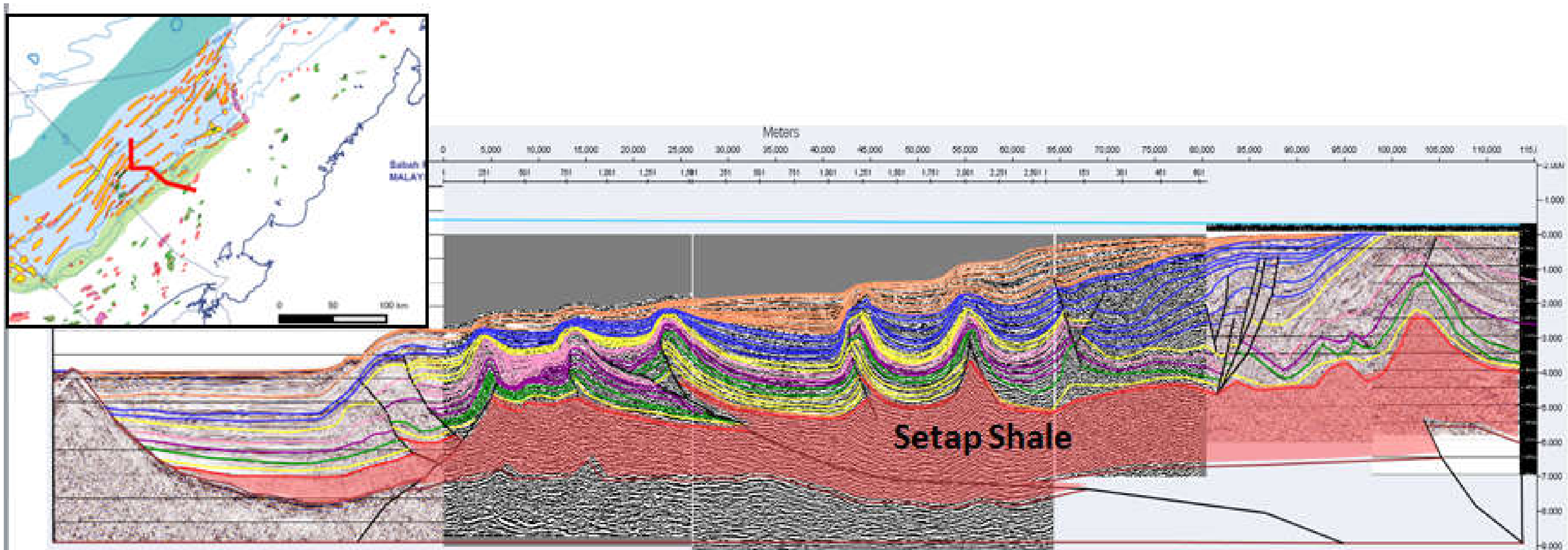
- **Significant oil and gas fields have been discovered in anticlinal traps in the Sabah Fold Belt.**
- **However, petroleum systems are not fully understood in this fold belt area.**
  - ➢ Effective source rock intervals and mature kitchens are not well defined
  - ➢ Hydrocarbon migration & charge mechanisms remain uncertain
- **It is inferred from seismic observations that the presence of "mobile shales" play an important role in hydrocarbon migration and charge mechanisms.**
- **The objectives of this study are to incorporate the concept of mobile shales into hydrocarbon migration and charge systems in the fold belt area, and build a new hydrocarbon migration and charge model using basin modelling technique.**

Generalized stratigraphy of the study area (Offshore Sabah & NW Sarawak)



(Modified after Van Hattum et al., 2006 ; Cullen, 2010 ; Kessler and John, 2015)

Regional Seismic Cross Section

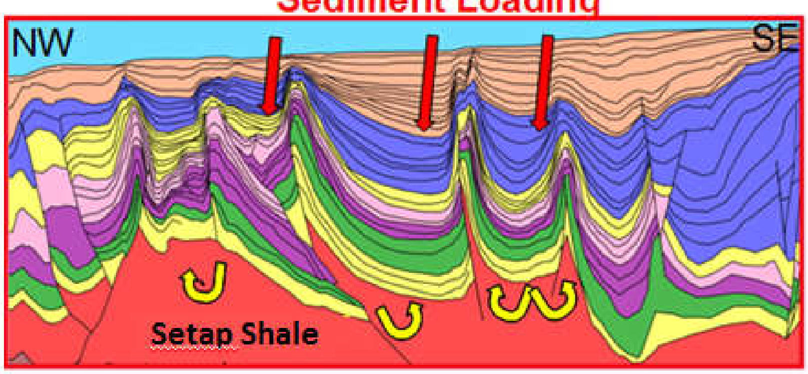


NW

Jong et al., (2015)

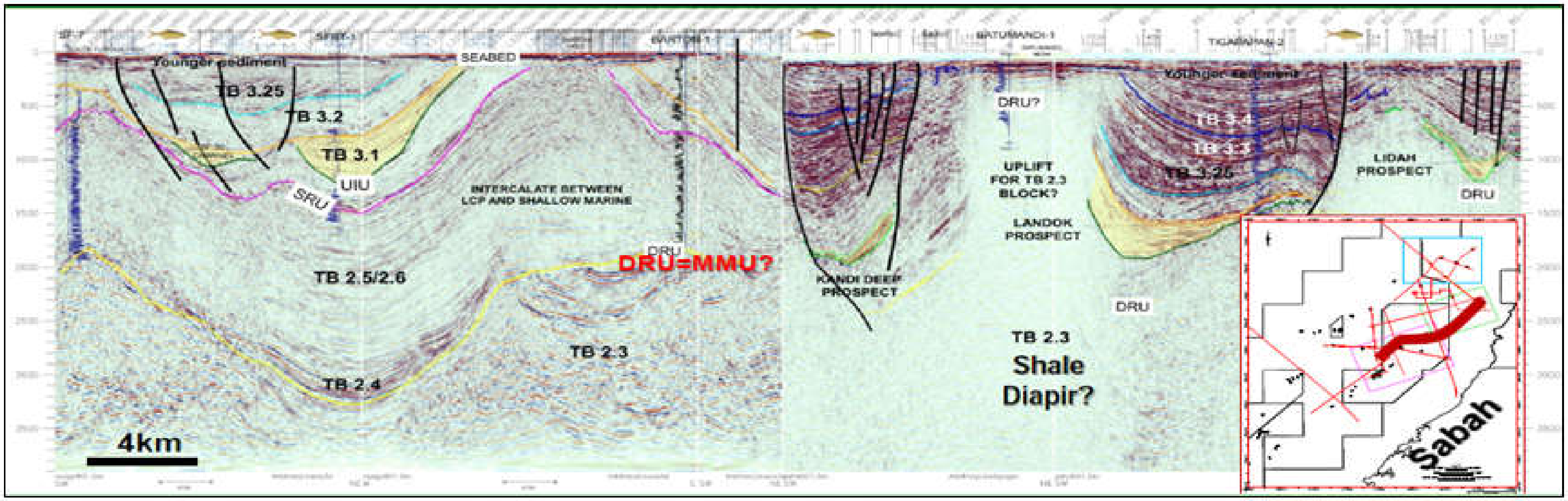
SE

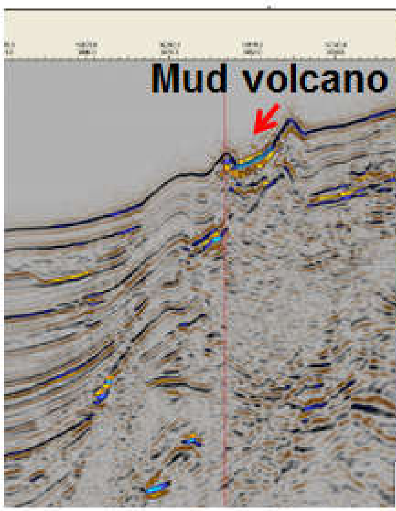
Sediment Loading

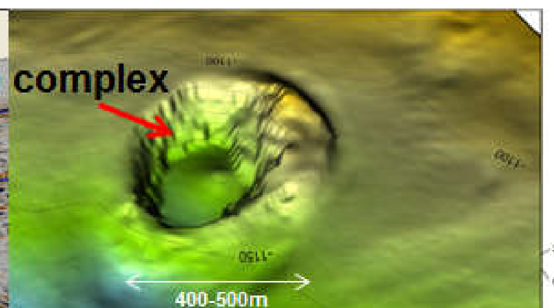


- The regional NW-SE dip section across the NW Sabah province, offshore Malaysia suggests a compressional fold and thrust belt driven by sediment loading with diapirism of mobile shales (the "Setap Shale") in anticlinal cores.
- Sedimentation is ongoing while folds develop.

Mobile Shale







Top: Potential shale diapir interpreted in the regional seismic data (Kessler and Jong, 2016)

Left: Mud volcano observed in the study area (courtesy of JX Nippon)

Mobile shales are highly overpressured mud or shale substrates involving grain-to-grain plastic flow. The shales behave overall in a weak, ductile manner rather than as a fluid. They may move by shearing at critical state deformation (Van Rensbergen & Morley, 2003).

Approach

- ***Approach:***
  Basin modelling technique (using PetroMod software by Schlumberger)
- ***Integrated Data:***

- Seismic Interpretation
- Well Data:
  - Rock physical properties
  - Geochemical data
  - Logging data

- ***Conceptual model for shale mobility:***
  Overpressured and under-compacted shales overlain by a thick and denser sediment layer can become mobile under critical conditions.

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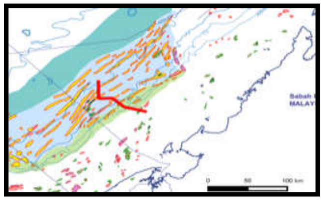
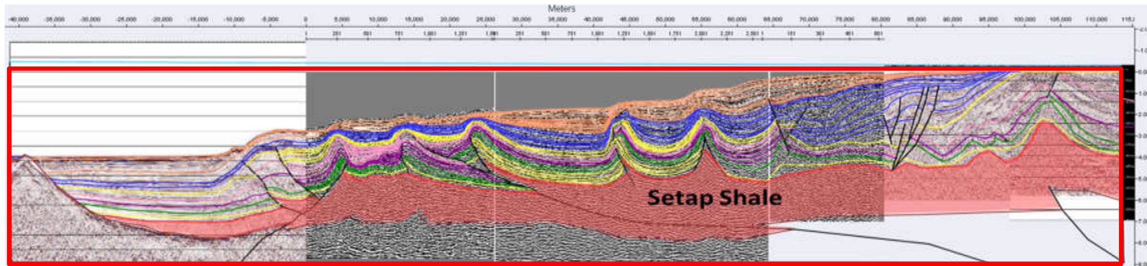
Regional Seismic Cross Section





Regional interpreted 2D seismic section

NW

Depth converted & modeled

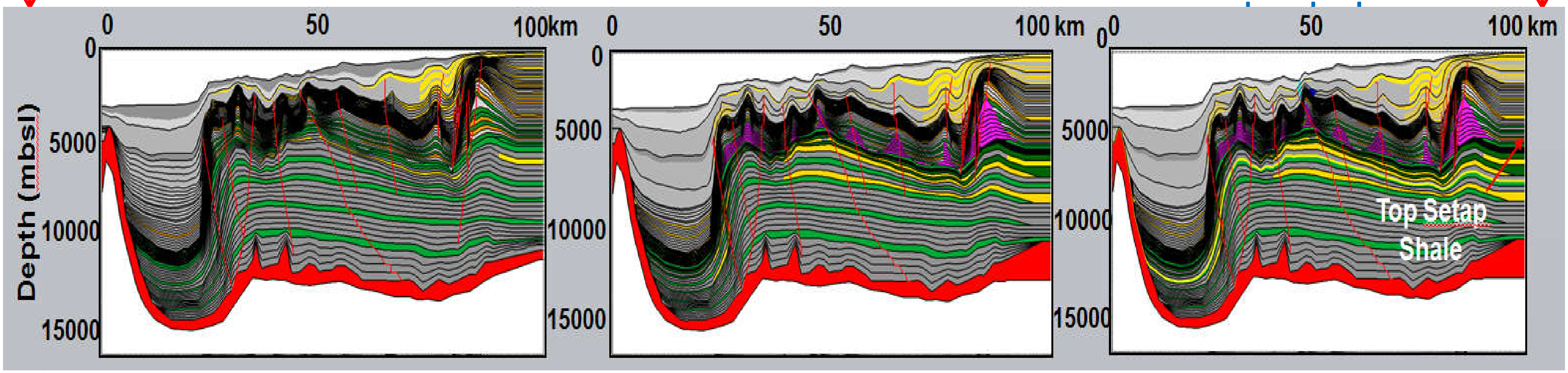
Jong et al., (2015)

SE

Model 1 without shale mobilization

Model 2 with shale mobilization

Model 3 with shale mobilization



Distance : 110 Km
Number of layers: 68
Grid model : 34000 cells

Organic shale
Mobile shale
Lean shale
Sandstone
Basement
Mud volcano
Fault
Paleo mud volcano

Boundary Conditions

1. Paleo- water depths:

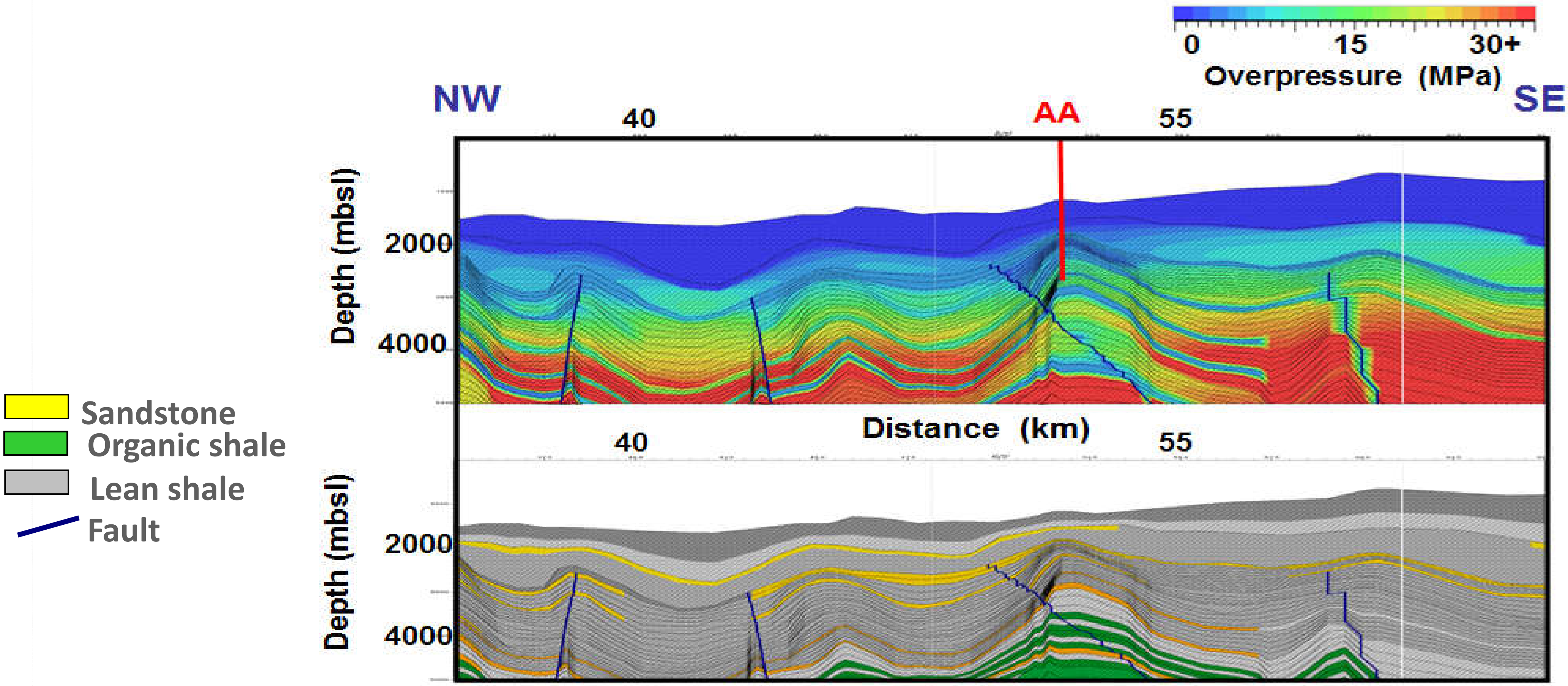
- has been the same as present depth since 10.8 Ma
- were shallower than present day depth before 10.8 Ma

2. Paleo-temperature at the sediment-water interface depend on paleo-water depths.

3. Paleo-heat flow maps have been created from frifting heat flow models with beta values of 1.5 - 1.7.

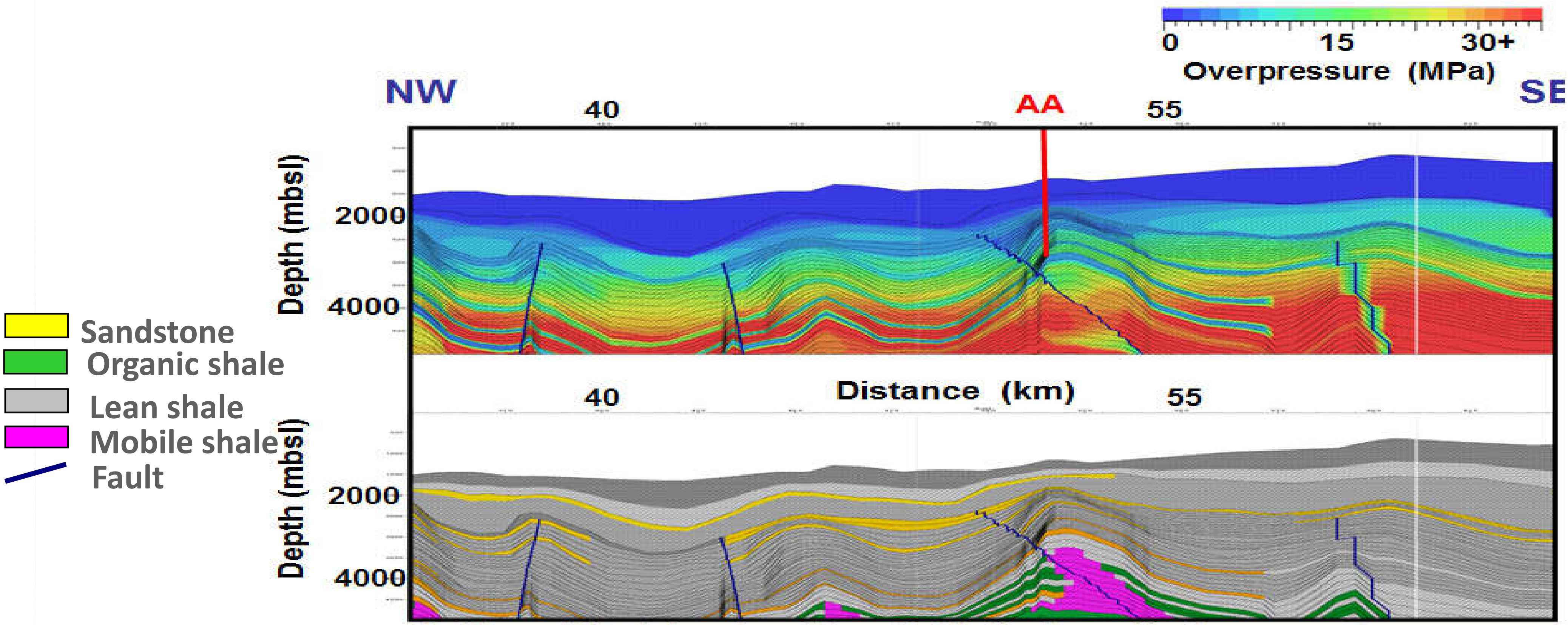
Temperature, vitrinite reflectance, Tmax, LOP and pore pressure data derived from 4 key wells have been used for modelling calibration.

Overpressure Distribution - Model 1



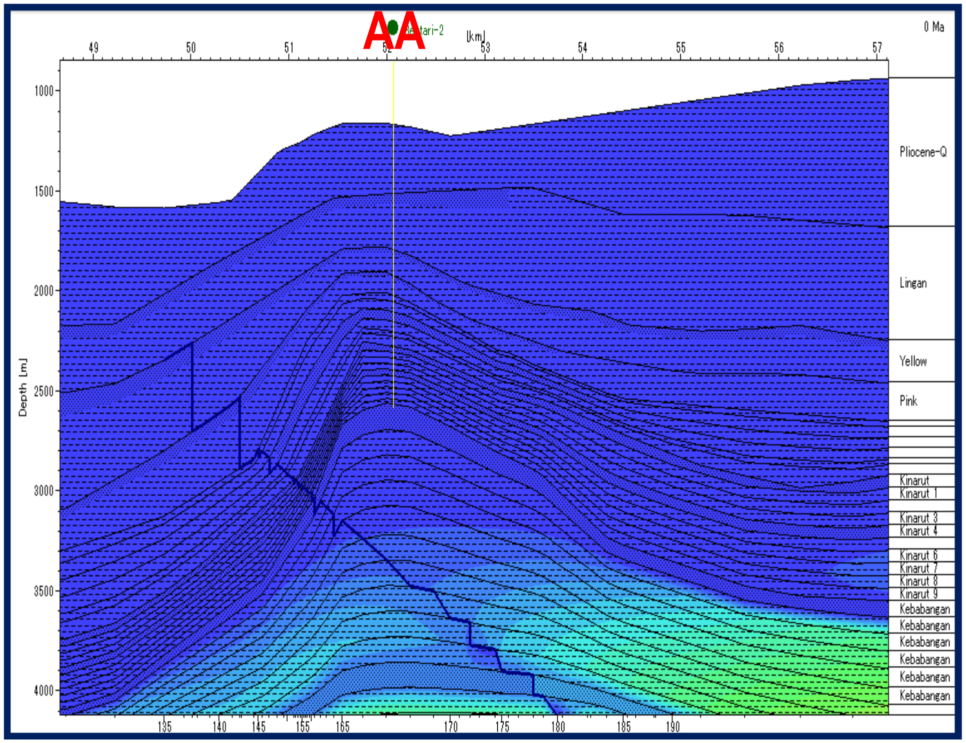
Faulting and sandstone distribution in combination can create overpressure compartments.

Overpressure Distribution - Model 2

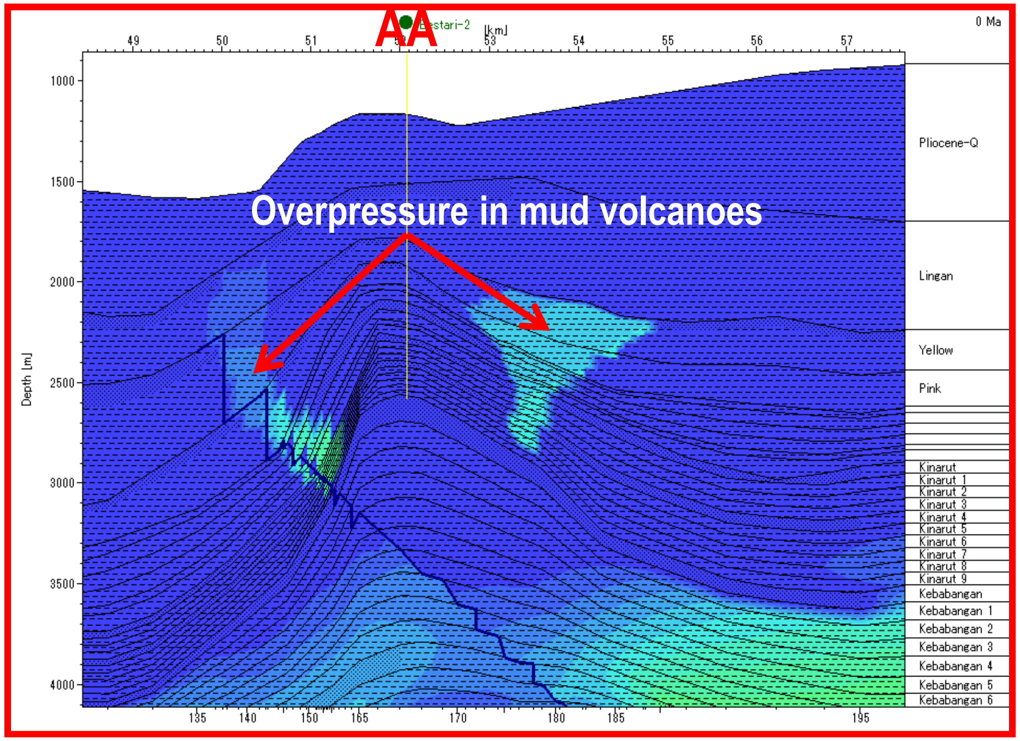


Faulting, mobile shale and sandstone distribution in combination can create overpressure compartments

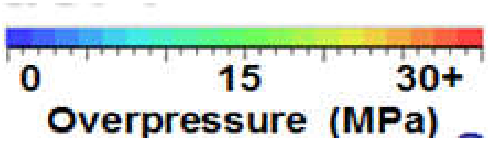
Impact of mud volcanoes in overpressure distribution



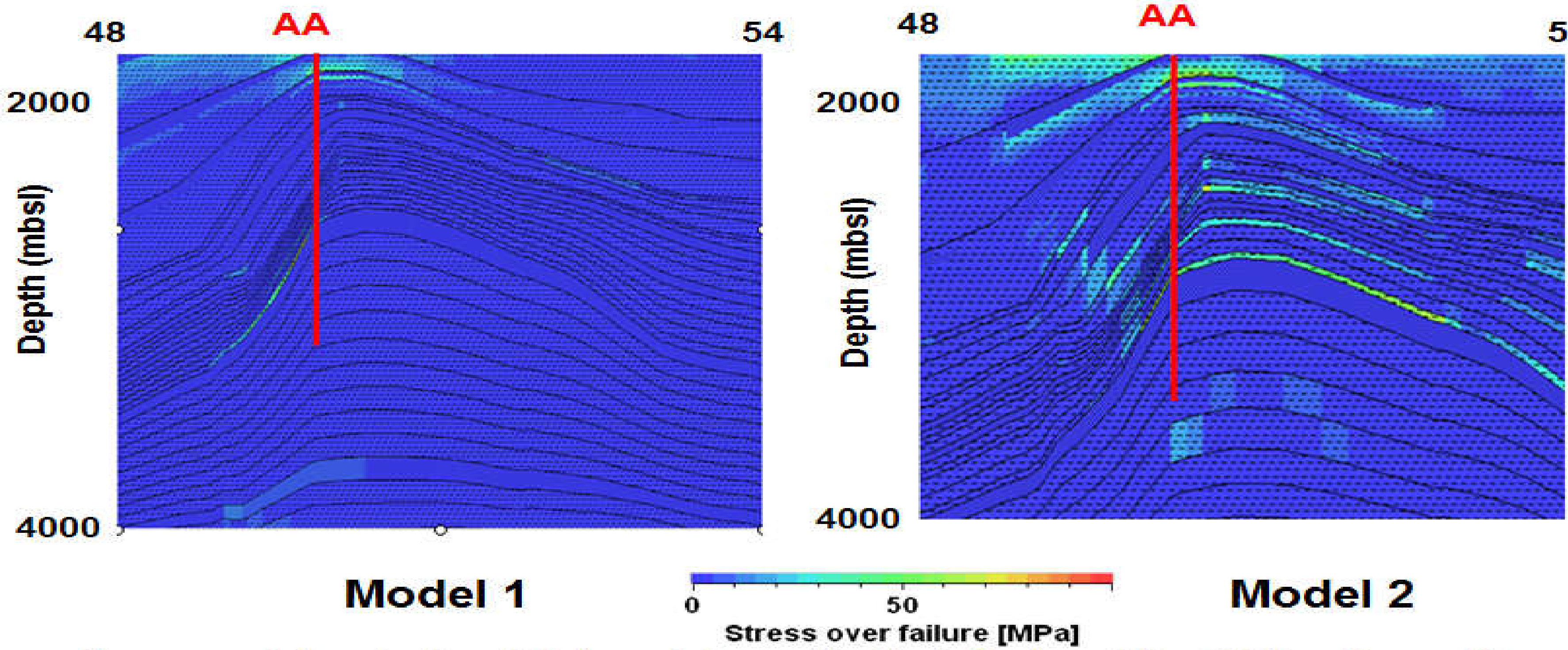
Model 2



Model 3

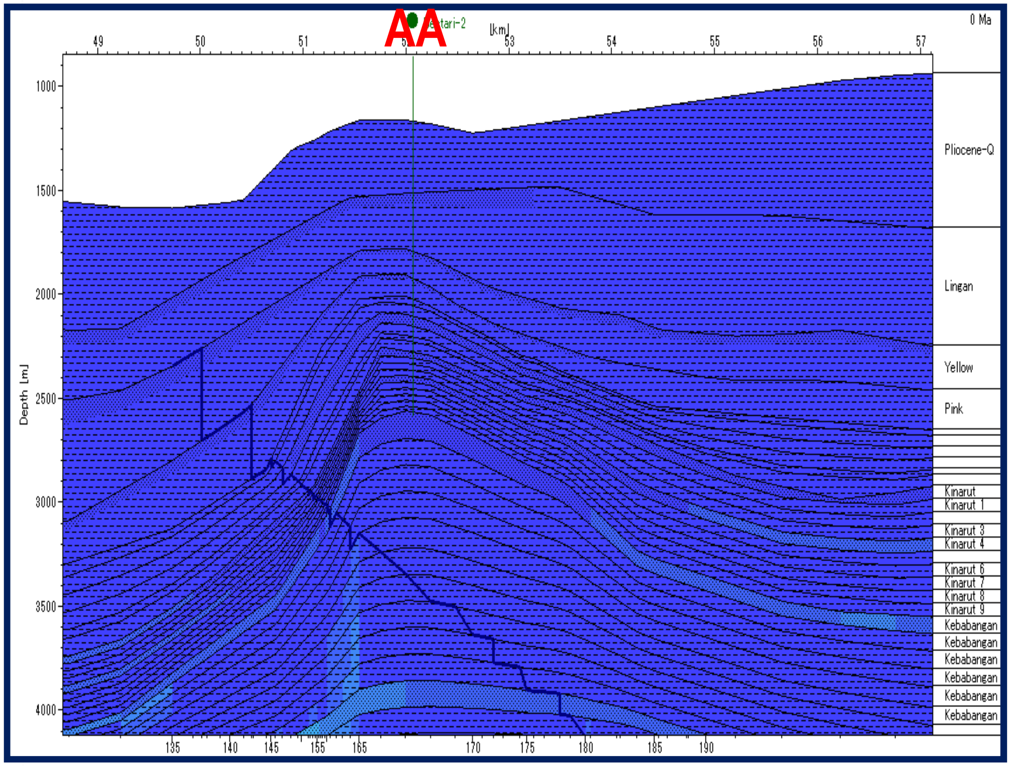


Stress over failure distribution above mobile shales

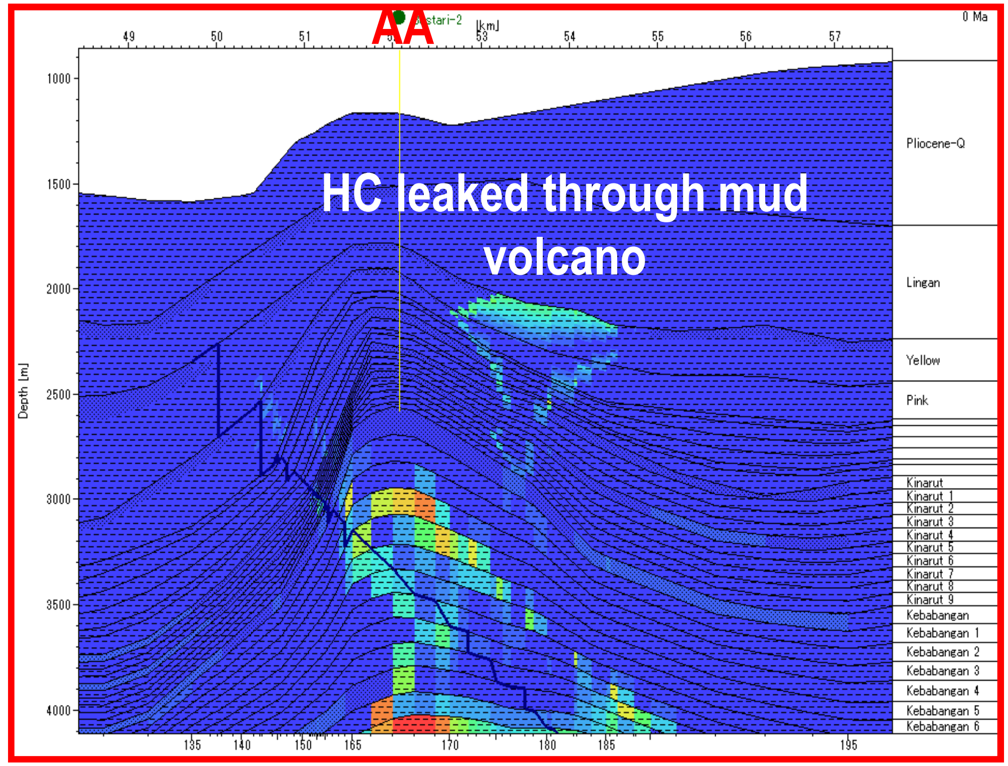


Stress over failure is closed distance between the Morh Circle and the yieldline. For positive values the Morhr circle exceeds the yieldline which indicate fracturing.

Stress over failure distribution around mud volcanoes



Model 2

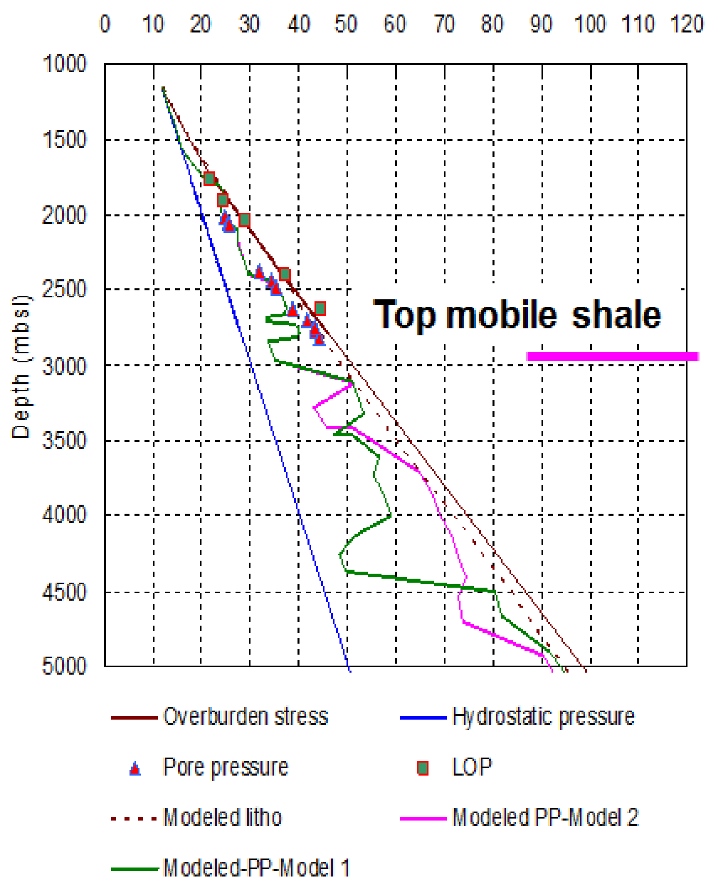


Model 3

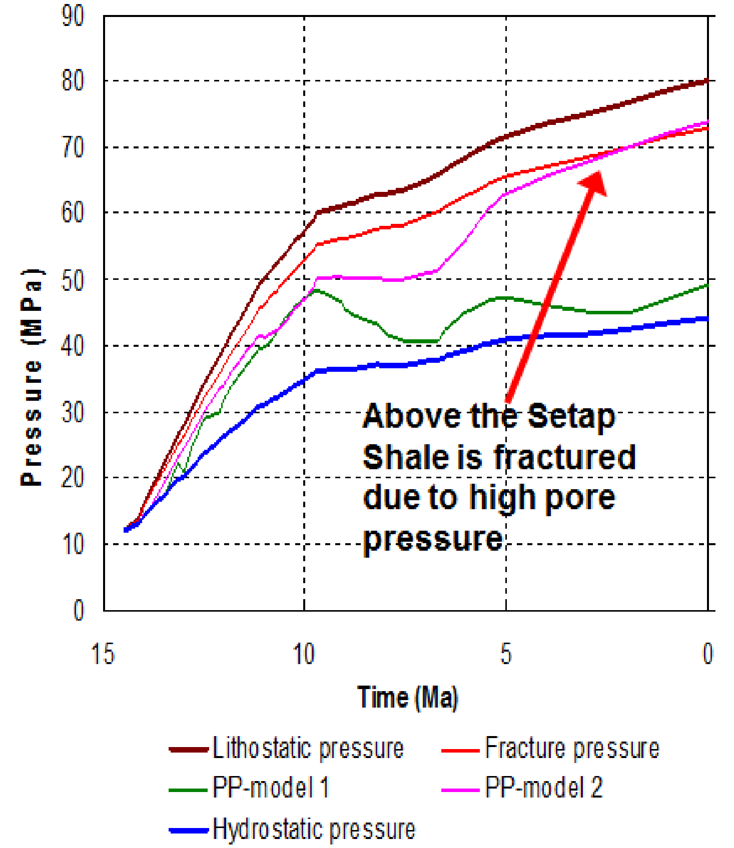
Impact of Shale Mobility in pore pressure in Structure AA

High pore pressure → sediments less compacted
→ Higher porosity/permeability

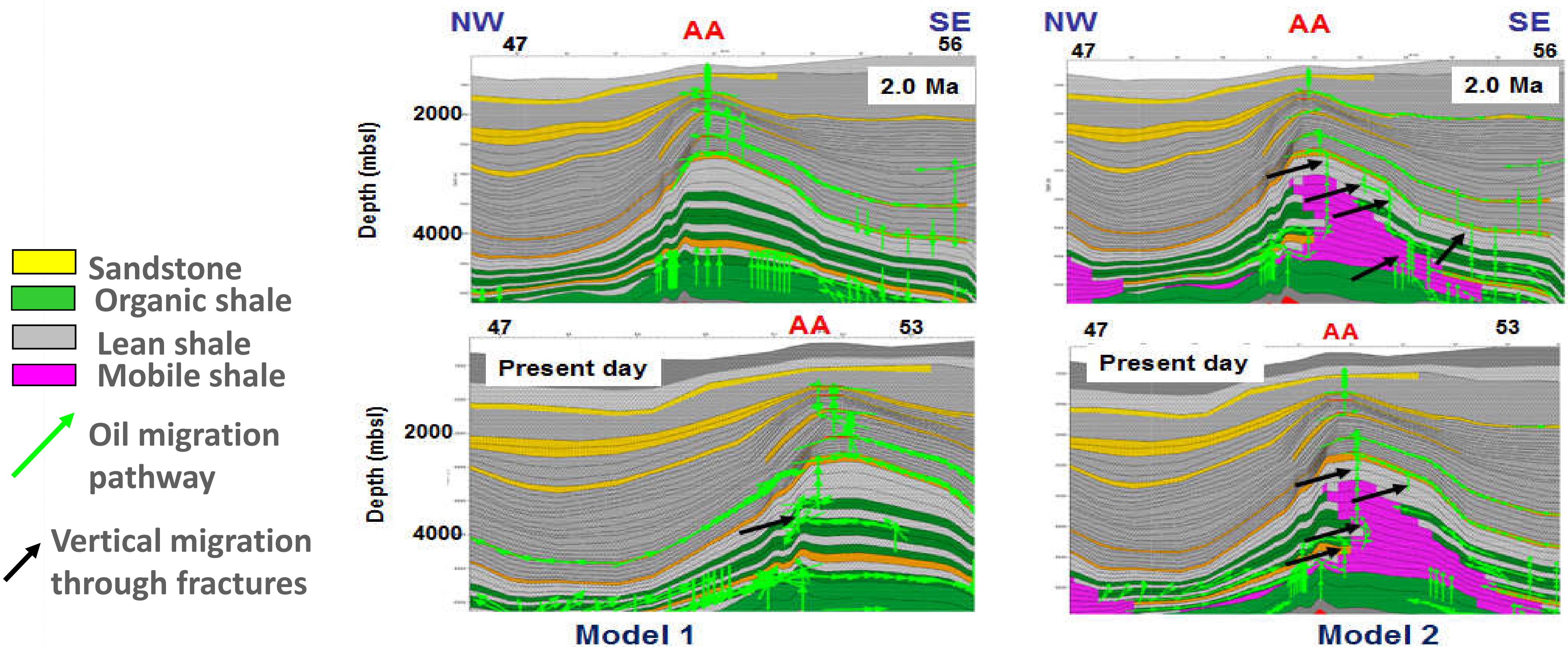
Pore pressure-depth profile



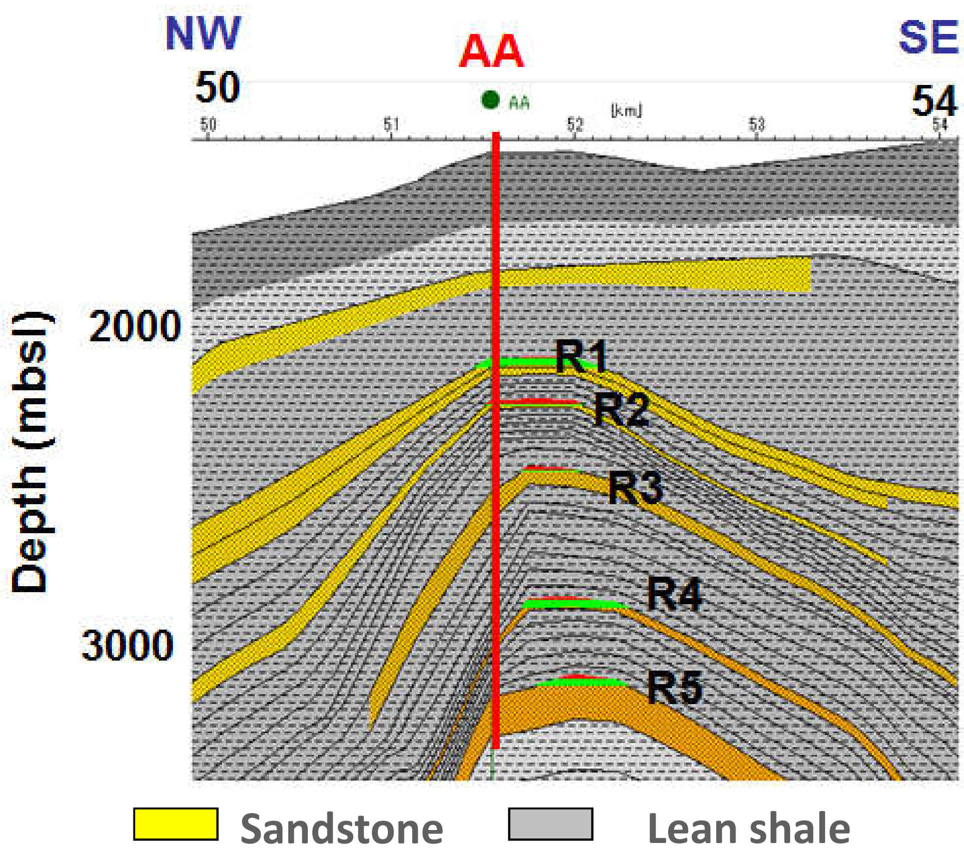
Pore pressure evolution of a layer above mobile shale at Well AA



Oil Migration and Charging



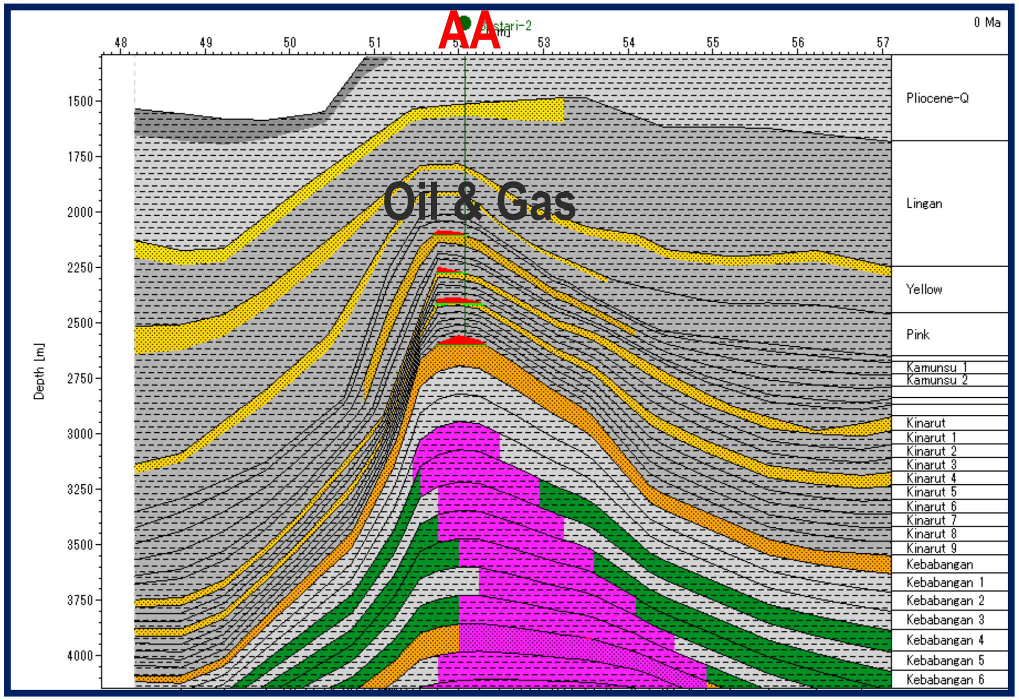
Hydrocarbon Types and Amount of HC Accumulated by Models 1 & 2



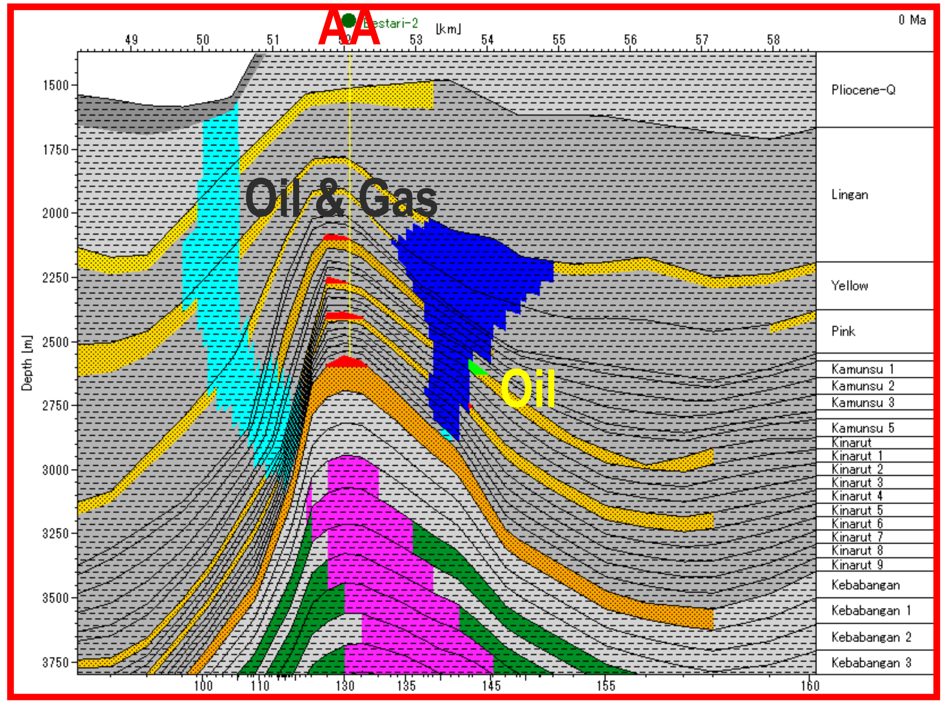
- Both models charged oil with minor gas in the multiple reservoirs in Structure AA. It is consistent with the well results.

- Model 2 charged much bigger amount of hydrocarbon than Model 1 (especially oil) because HC migration has been facilitated due to fractures and higher permeability.

Impact of mud volcanoes in HC accumulation



Model 2



Model 3

- Sandstone
- Organic shale
- Lean shale
- Mobile shale
- Recent mud volcano
- Paleo mud volcano

Volume of HC (oil) accumulations in Model 2 is larger than that in Model 3

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Conclusions

- Toe-thrust anticlines have resulted from compressional folding driven by sediment loading in the NW Sabah Fold Belt. The modeled mobile shale may facilitate the creation of shale-cored structures in this area.

- Shale mobilization and mud volcanoes can contribute locally to high pore pressure gradients and fractures.

- The resulting fractures may facilitate fluid flows including hydrocarbon migration (especially oil).

- Mud volcanoes generated from highly overpressured shale may affect the amount of oil and gas accumulations in the nearby traps.

Acknowledgements

This work was presented as an oral presentation in 2016 International Geological Congress, and updated for this forum with an additional model to study the impact of mud volcanism associated with highly overpressured shale on oil and gas accumulations in nearby traps. We thank the Management of JX Nippon Oil & Gas Corporation for providing the supporting data and permission to publish and share this presentation.

Our utmost appreciation goes to our exploration colleagues in KL and Miri Offices (Malaysia) for their insightful discussions and suggestions that enhanced the quality of this study.