

Basin Analysis and Petroleum Systems Modeling of the Lokichar Basin (Kenya)*

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Search and Discovery Article #10676 (2014)**

Posted December 8, 2014

*Adapted from oral presentation given at AAPG International Conference & Exhibition, Istanbul, Turkey, September 14-17, 2014

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Abstract

A first wave of exploration of the Cenozoic half graben basins of the East African Rift System in the early 1990's resulted in the acquisition of 2D seismic in the Turkana area (northern Kenya) and the drilling of well Loperot-1 in the eastern part of the Lokichar Basin. The well turned out to be a commercial failure, and a second dry hole further north marked the end of the exploration activities. Recently, exploration has been revived in East Africa and revealed major discoveries near the Loperot-1 and in particular along the western bounding fault of the Lokichar Basin. This play is currently drilled out, and the first appraisal wells will reveal the commerciality of the discoveries. We will present a regional synthesis, seismic interpretation and derived isopach maps, and a series of structural restoration sequences and petroleum systems models. Using this information, we first review the failure of Loperot-1. This wildcat well encountered the organic-rich and oil-mature Lokhone and Loperot shale members and good reservoir facies in the Auwerwer and Lokhone sandstones, with oil shows. However, late tectonic activity of the trap-bounding fault is interpreted to have a destructive impact on the modeled preexisting oil accumulation. Based on a series of 2D and 3D petroleum systems models, we will then discuss the elements (source, reservoir, and seal rocks) and dynamic processes (trap formation, charge, and preservation) of the petroleum systems to discuss the success of the recent drilling activities in the Lokichar Basin. Finally, we will point out potential areas for future exploration. The analysis of the unconformities and the orientation of spatial trends in the isopach maps suggest three distinct periods of tectonic activity, from which only the most recent can be accurately dated (starting approximately Late Oligocene). The directional trend of the deepest identifiable basin fill is interpreted to be aligned with the extensional direction of the Cretaceous Central African Rift System

(NW to SE). This suggests that the Lokichar Basin might have been formed already during the Cretaceous as part of the Central African Rift System, which hosts major oil reserves in the neighboring Sudan. Sandstones of Cretaceous age are observed in the Lapur Range in the northern Turkana area, and similar sediments might be present below the Cenozoic basin.

References Cited

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Morley, C.K., F.M. Karanja, W.A. Wescott, D.M. Stone, R.M. Harper, S.T. Wigger, and R.A. Day, 1999, Geology and Geophysics of the Western Turkana Basins, Kenya, *in* C.K. Morley (ed.), *Geoscience of rift systems-evolution of East Africa: AAPG Studies in Geology*, v. 44, p. 19-54.

Tiercelin, J.-J., J.-L. Potdevin, C.K. Morley, M.R. Talbot, H. Bellon, A. Rio, B. Le Galla, and W. Vetel, 2004, Hydrocarbon potential of the Meso-Cenozoic Turkana Depression, northern Kenya. I. Reservoirs: depositional environments, diagenetic characteristics, and source rock–reservoir relationships: *Marine and Petroleum Geology*, v. 21, p. 41–62.

Tiercelin, J.-J., P. Thuo, T. Nalpas, and J.-L. Potdevin, 2009, Hydrocarbon Prospectivity in Mesozoic and Early Cenozoic Rift Basins in Central/Northern Kenya: Search and Discovery Article #10188, Web Accessed November 28, 2014.
http://www.searchanddiscovery.com/pdfz/documents/2009/10188tiercelin/images/tiercelin_ppt.pdf.html.

Tiercelin, J.-J., P. Thuo, J.-L. Potdevin, and T. Nalpas, 2012, Hydrocarbon Prospectivity in Mesozoic and Early–Middle Cenozoic Rift Basins of Central and Northern Kenya, Eastern Africa: *in* D. Gao, ed., *Tectonics and sedimentation: Implications for Petroleum Systems*, AAPG Memoir 100, p. 179–207.

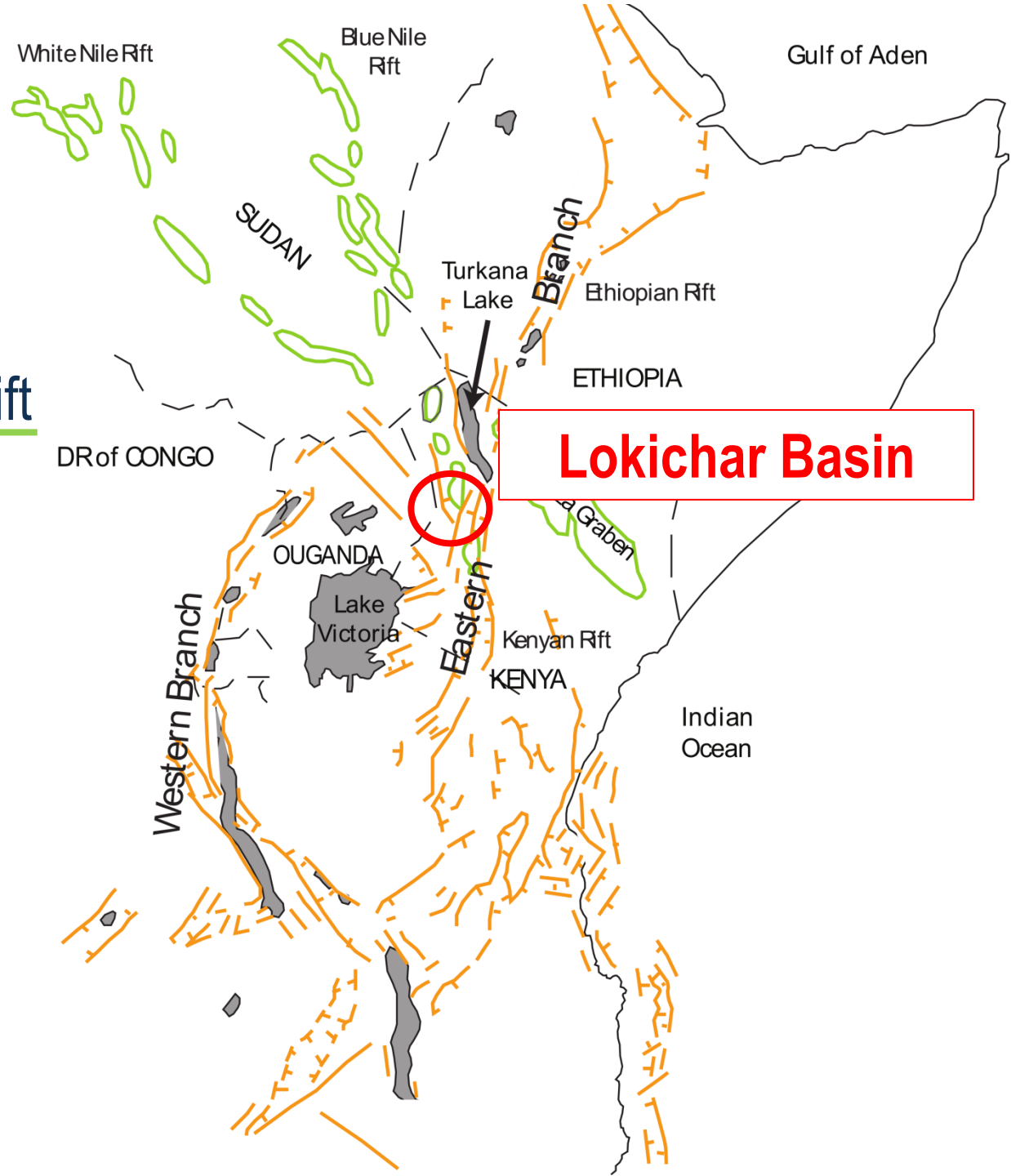
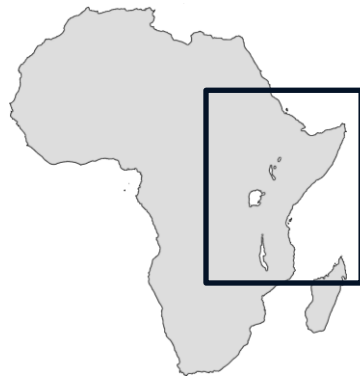
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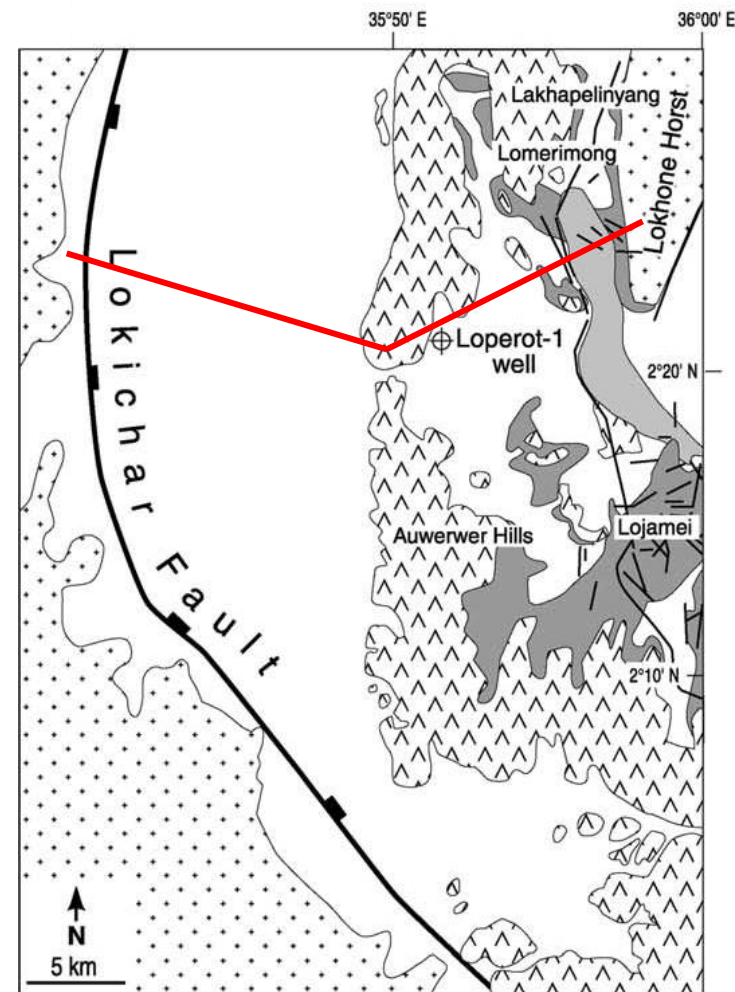
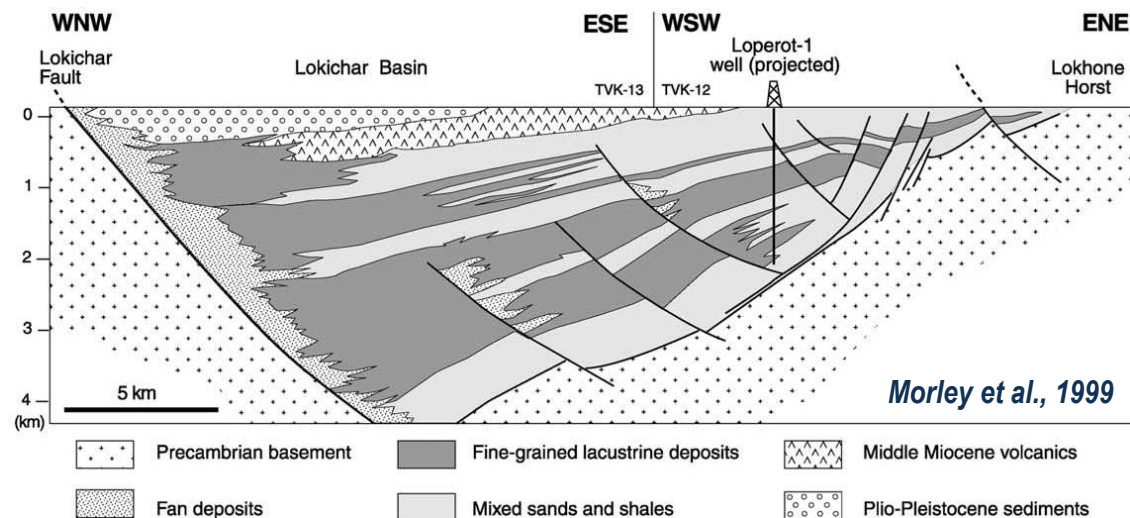
Introduction

- East African Rift System
- Central African Rift System



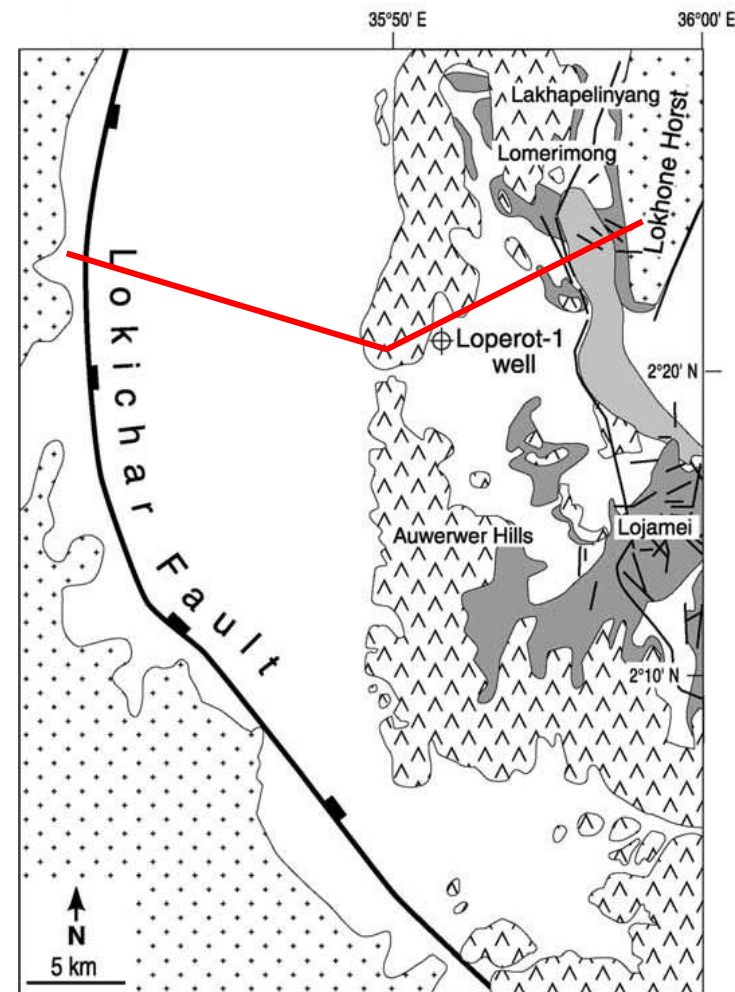
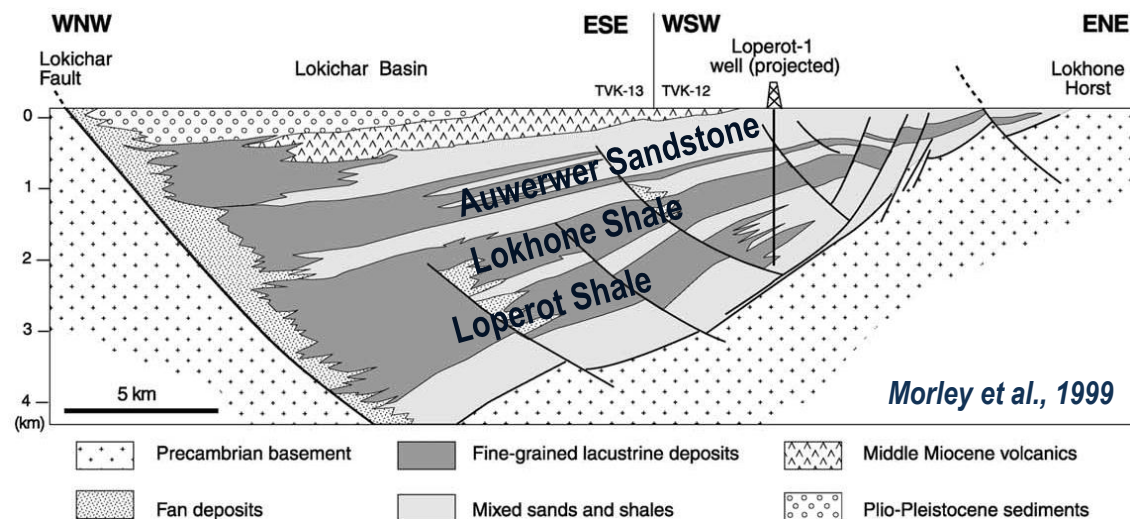
Introduction

- Cenozoic half graben
- Eocene (?) to Miocene lacustrine and fluvial sediments
- Capped by Middle Miocene basalts



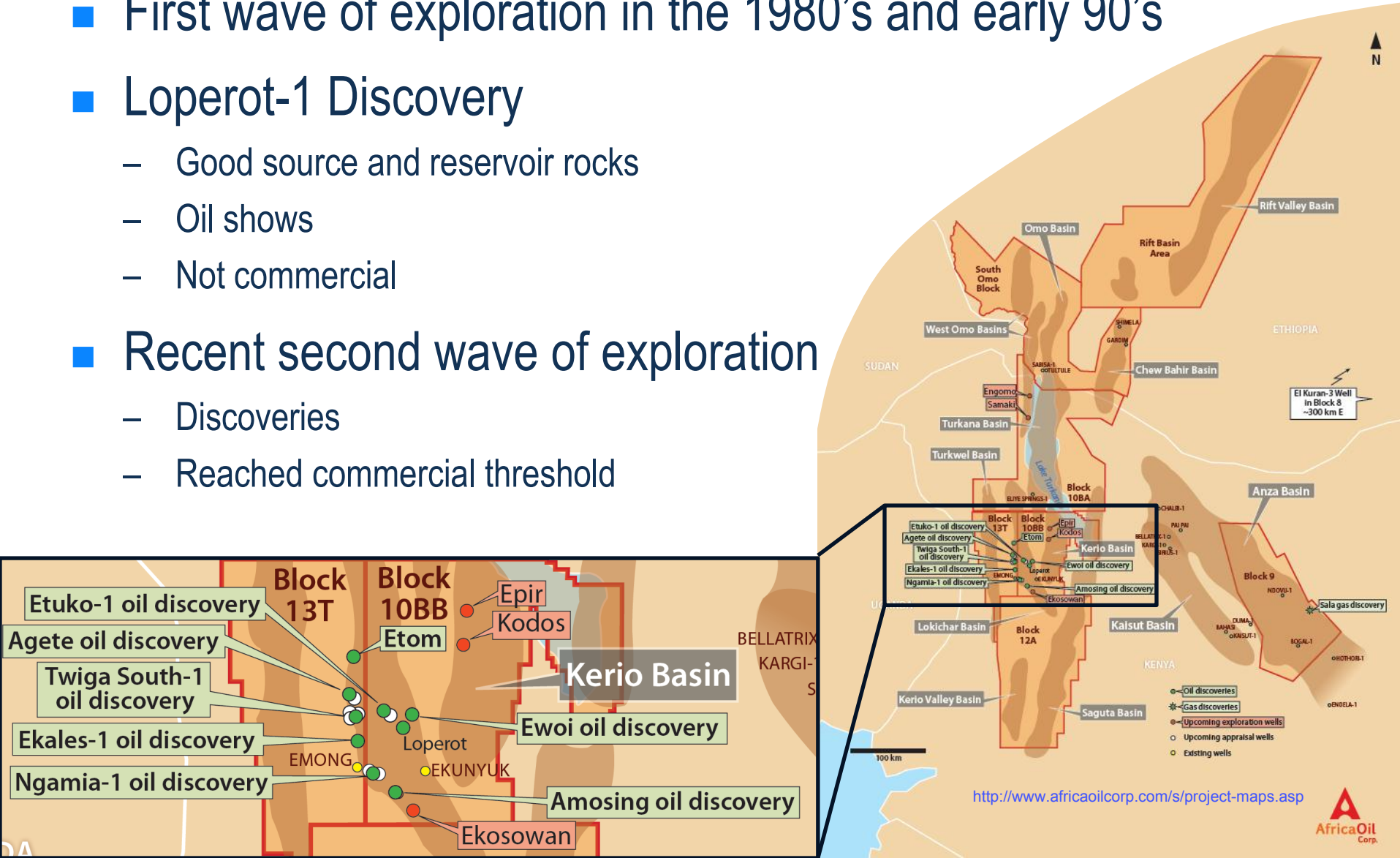
Introduction

- First wave of exploration in the 1980's and early 90's
- Loperot-1 Discovery
 - Good source and reservoir rocks
 - Oil shows
 - Not commercial



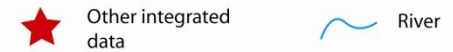
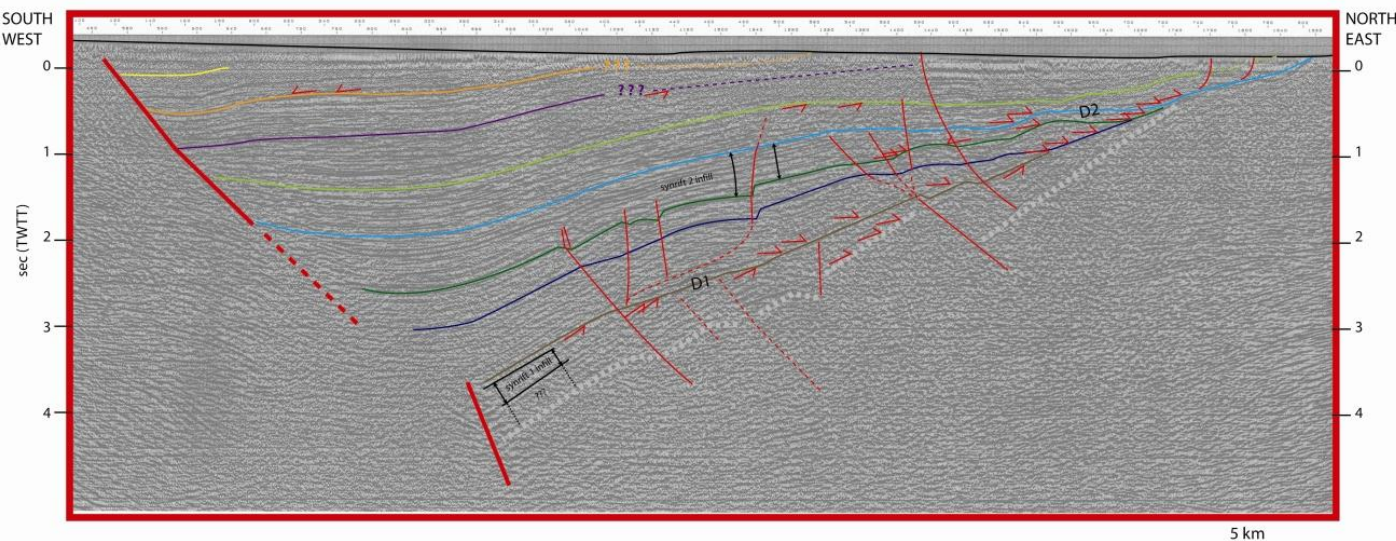
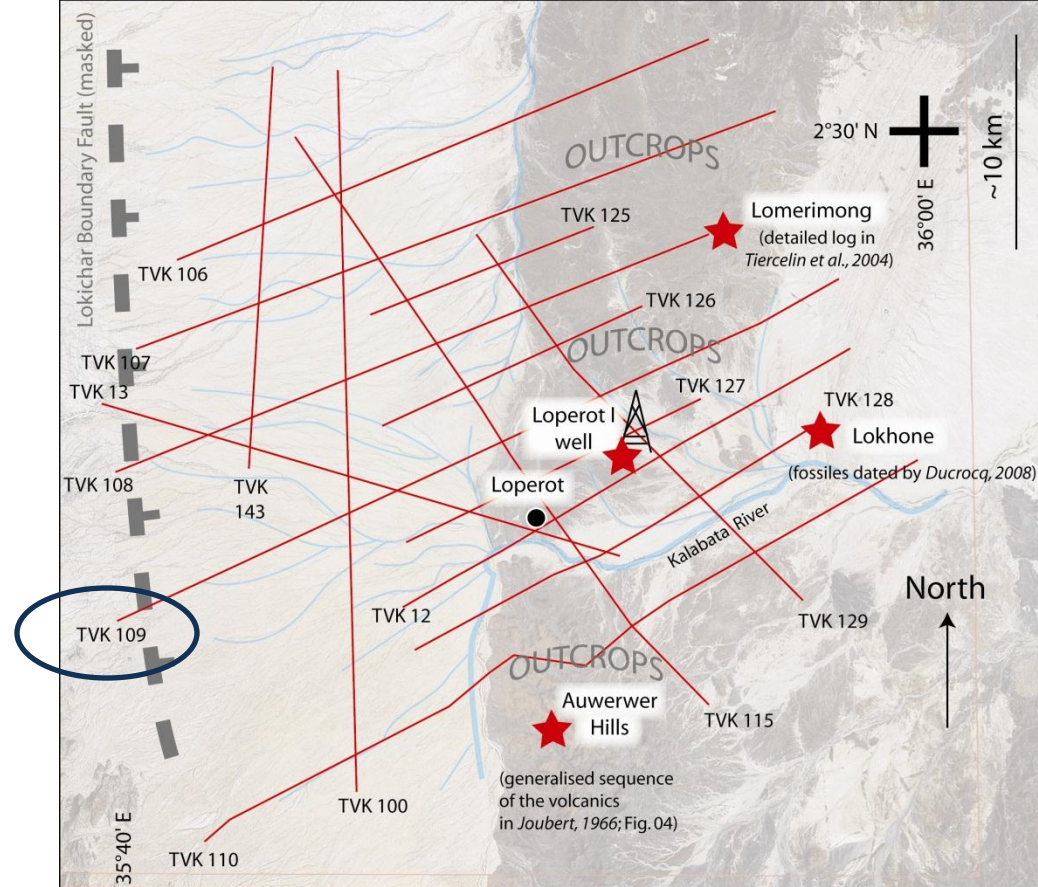
Introduction

- First wave of exploration in the 1980's and early 90's
- Loperot-1 Discovery
 - Good source and reservoir rocks
 - Oil shows
 - Not commercial
- Recent second wave of exploration
 - Discoveries
 - Reached commercial threshold



Data

- 2D seismic data
- Loperot-1 well
- Outcrops

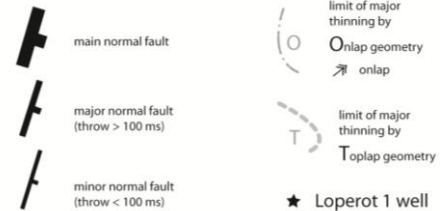
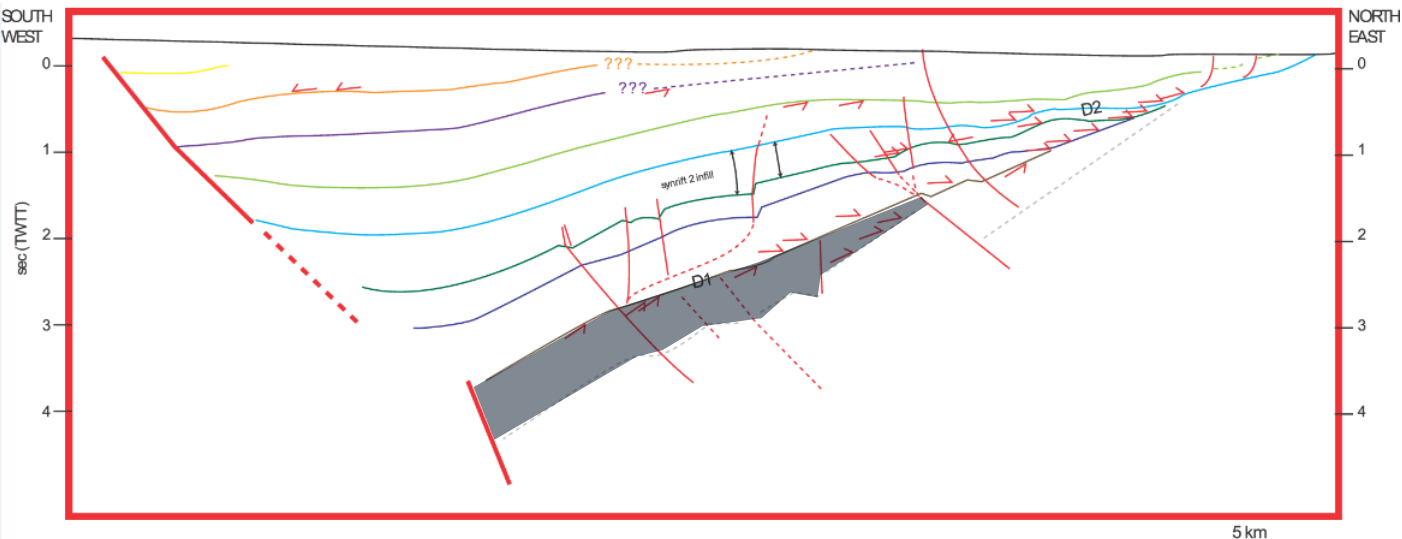
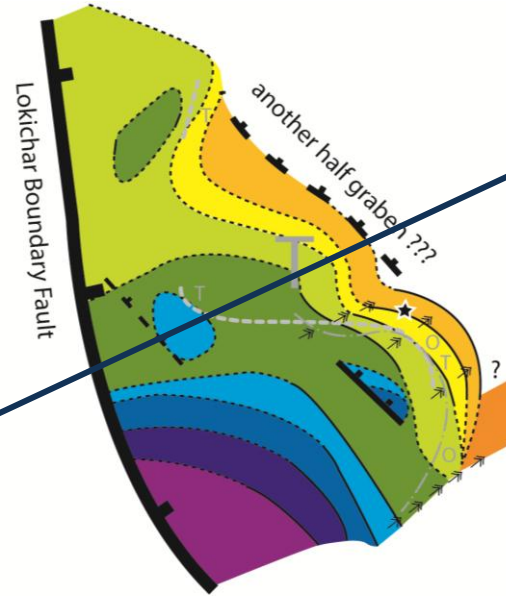


Seismic Interpretation

Sequence A

----- D1

TVK 109



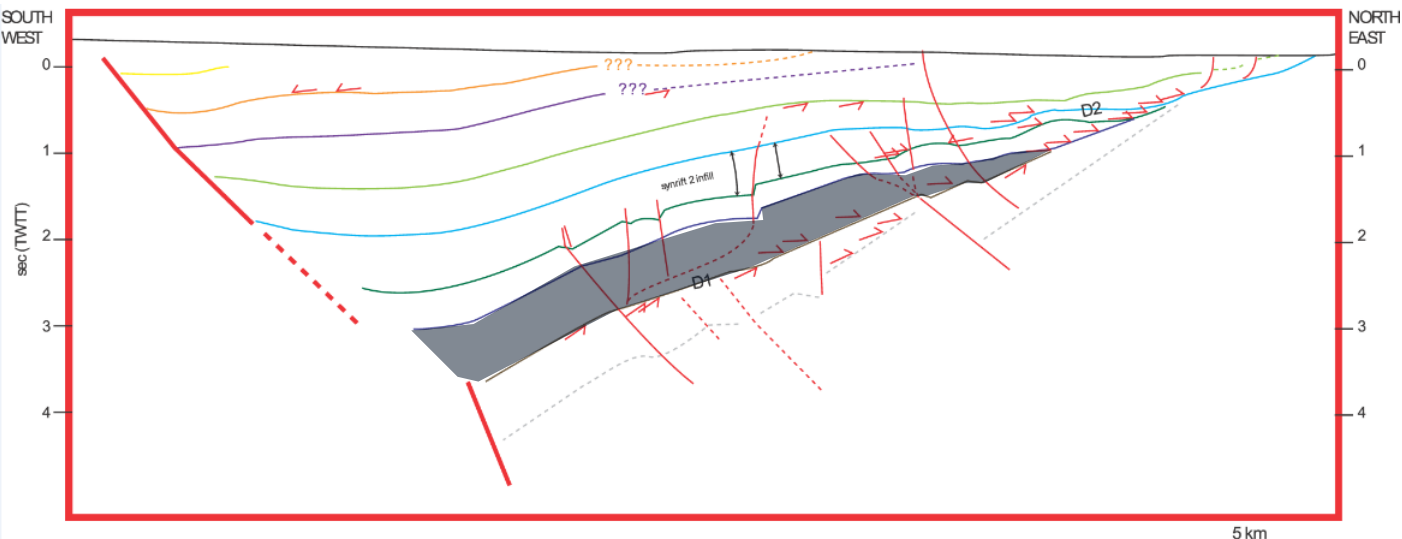
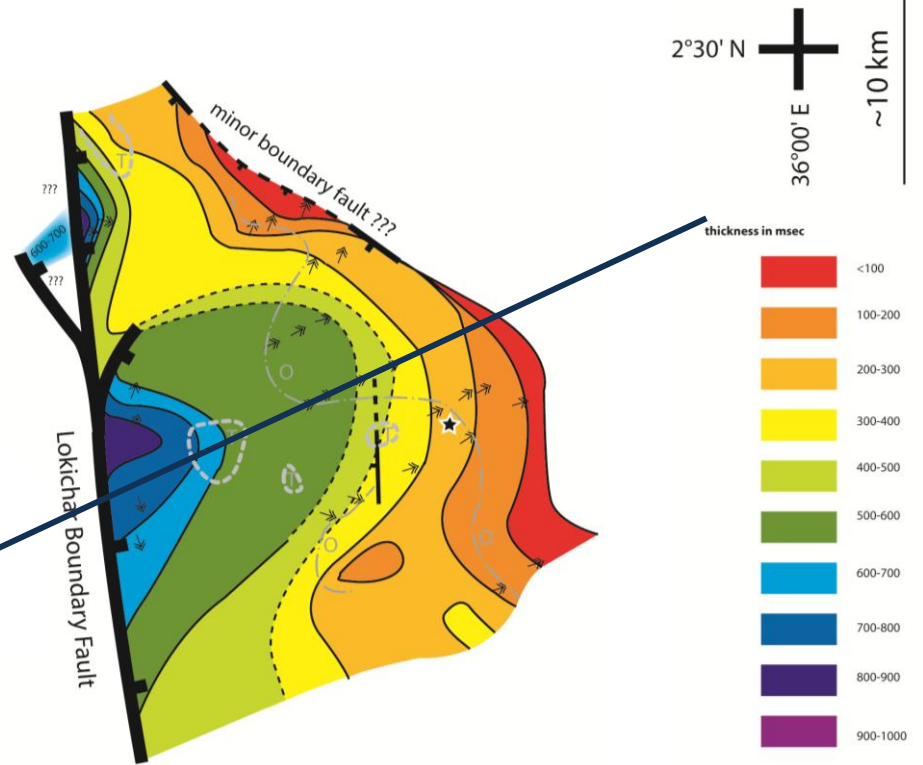
Seismic Interpretation

Sequence A

----- D1

Sequence B

TVK 109

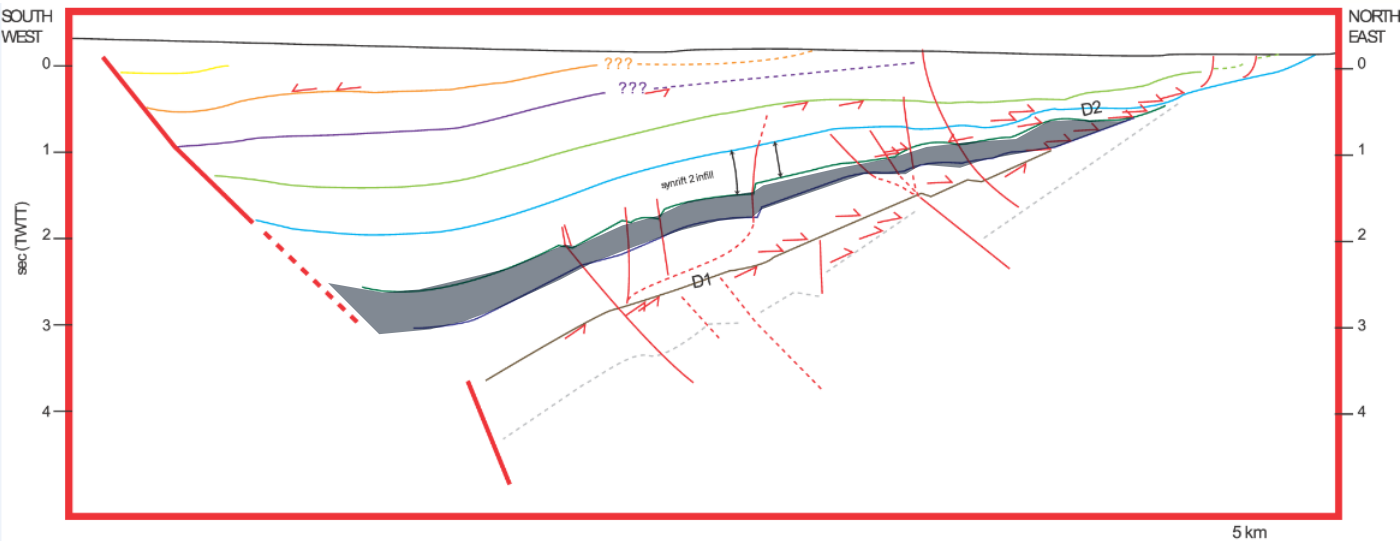


Seismic Interpretation

■ Sequence A

----- D1

■ Sequence B

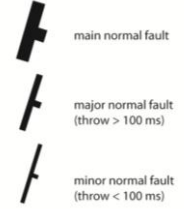
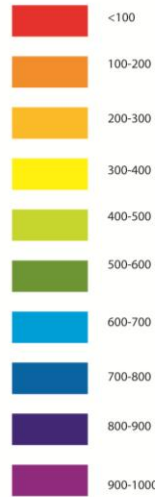


TVK 109

Okchar Boundary Fault

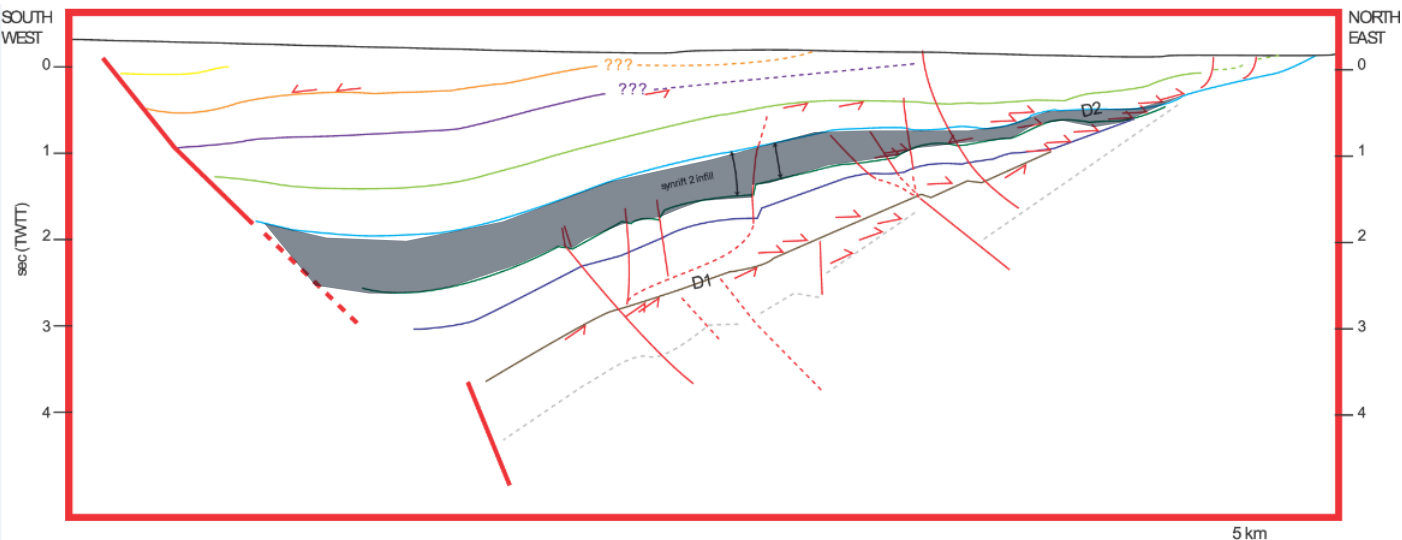
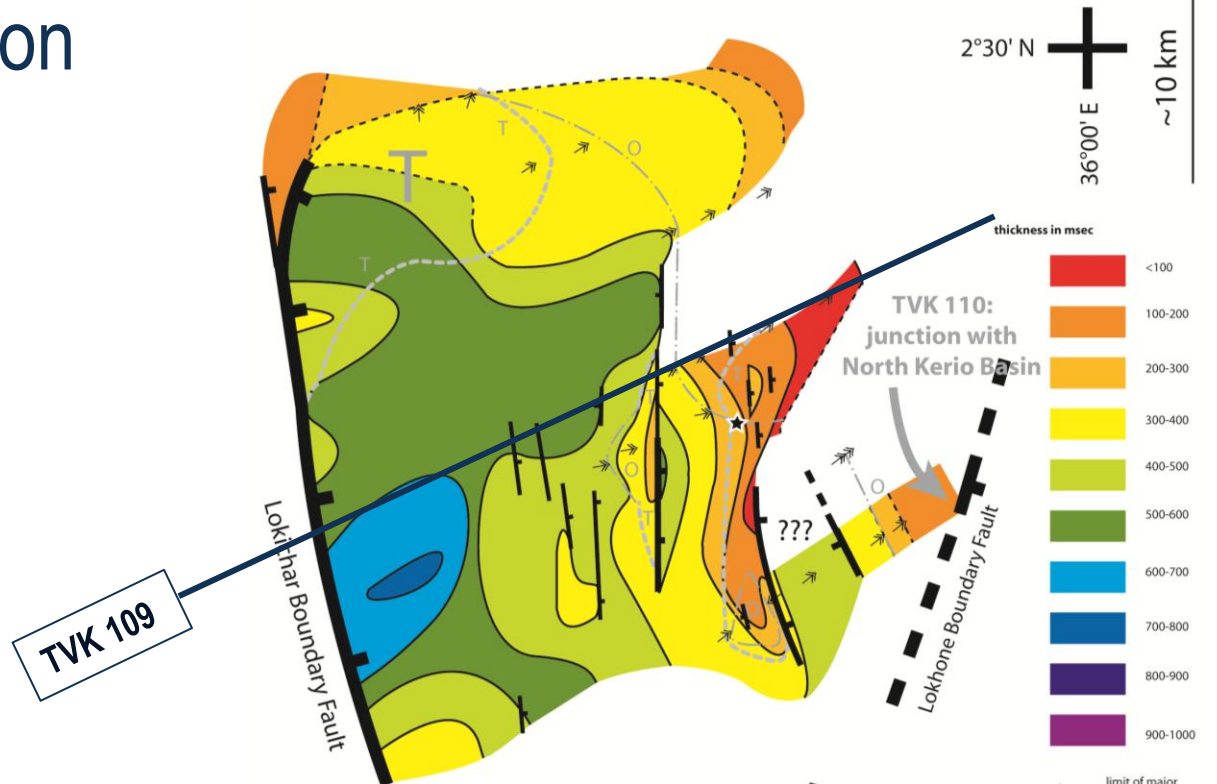
2°30' N
36°00' E
~10 km

thickness in msec



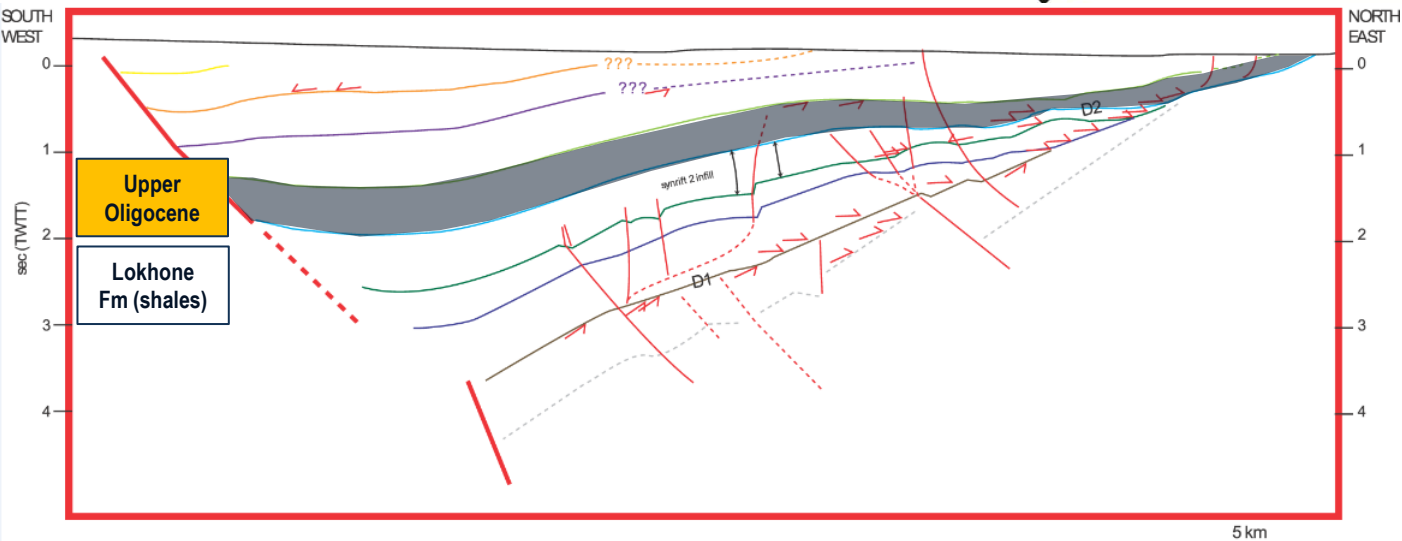
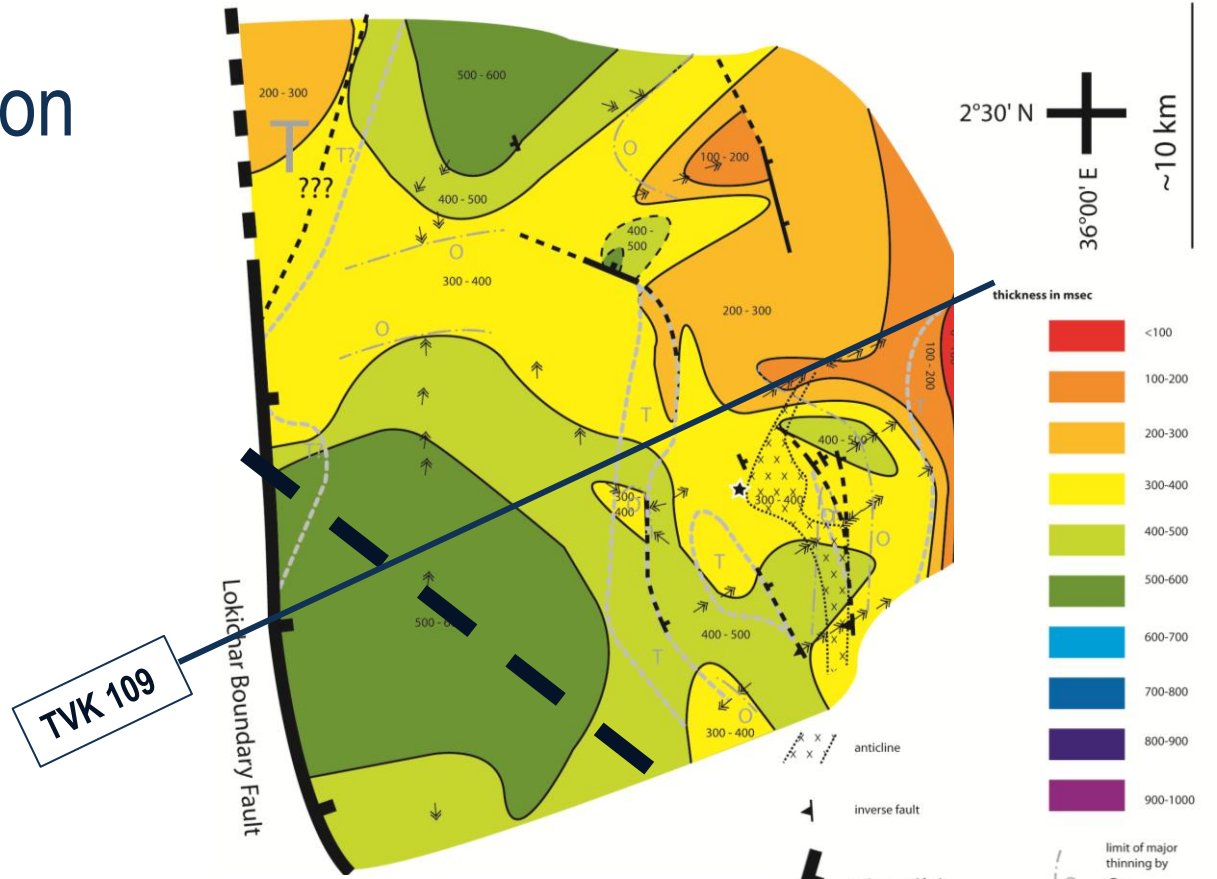
Seismic Interpretation

- Sequence A - - - - - D1
- Sequence B - - - - - D2



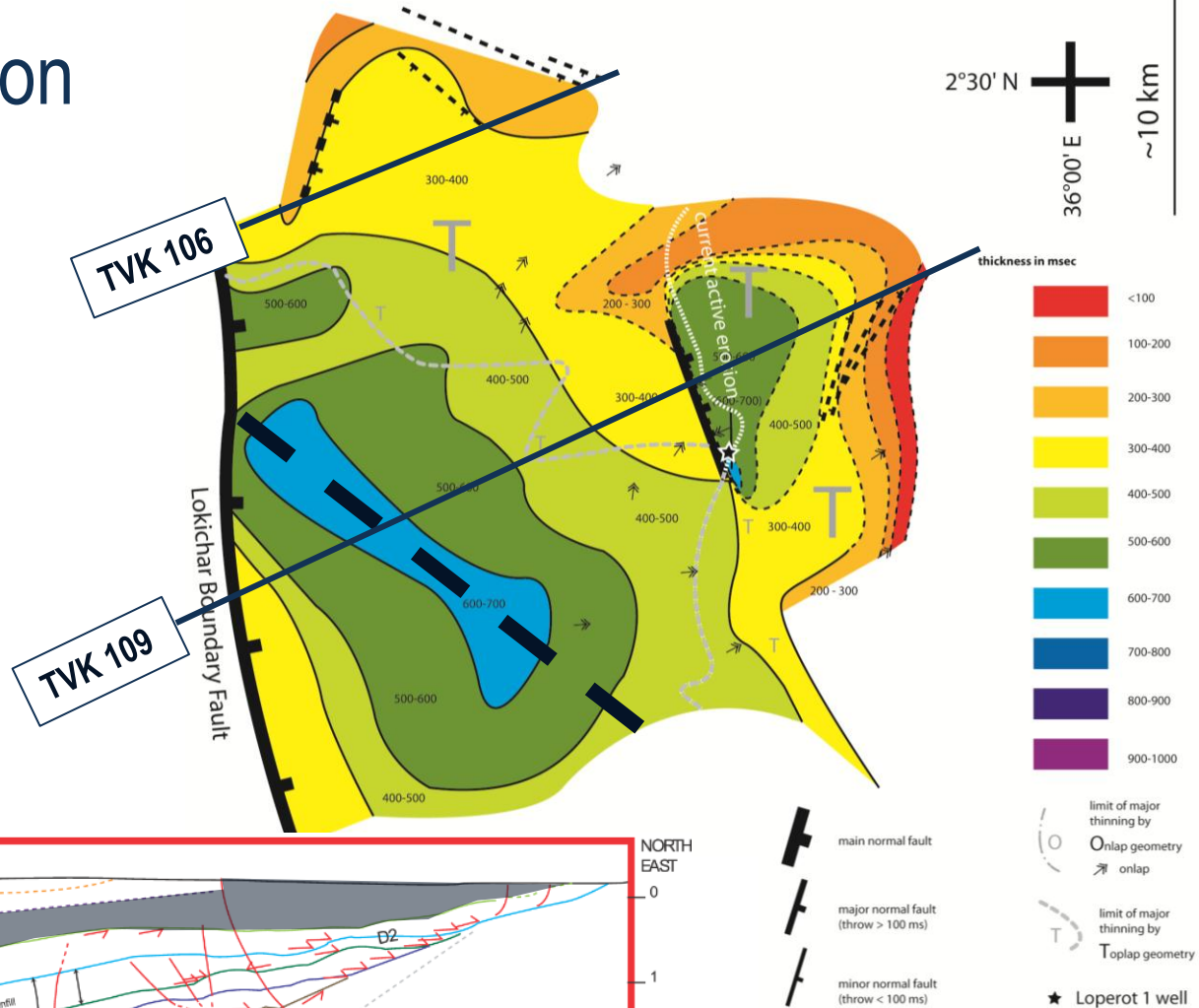
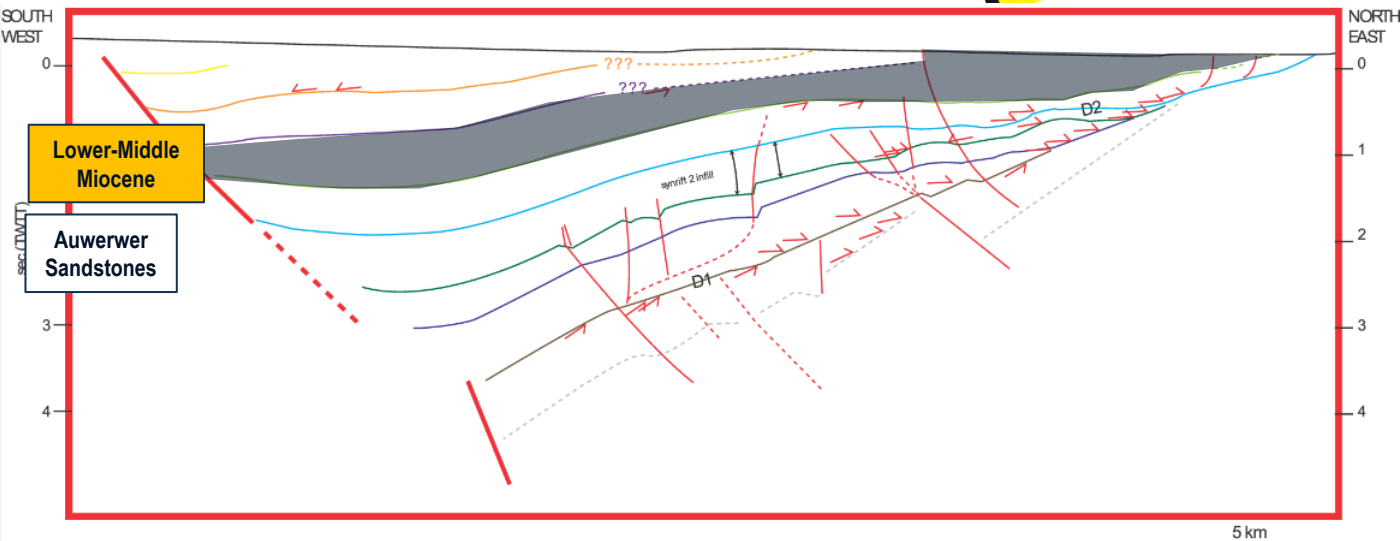
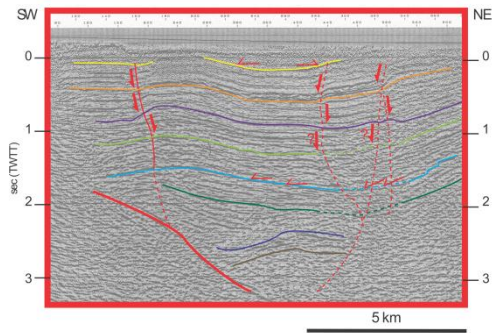
Seismic Interpretation

- Sequence A ----- D1
- Sequence B ----- D2
- Sequence C



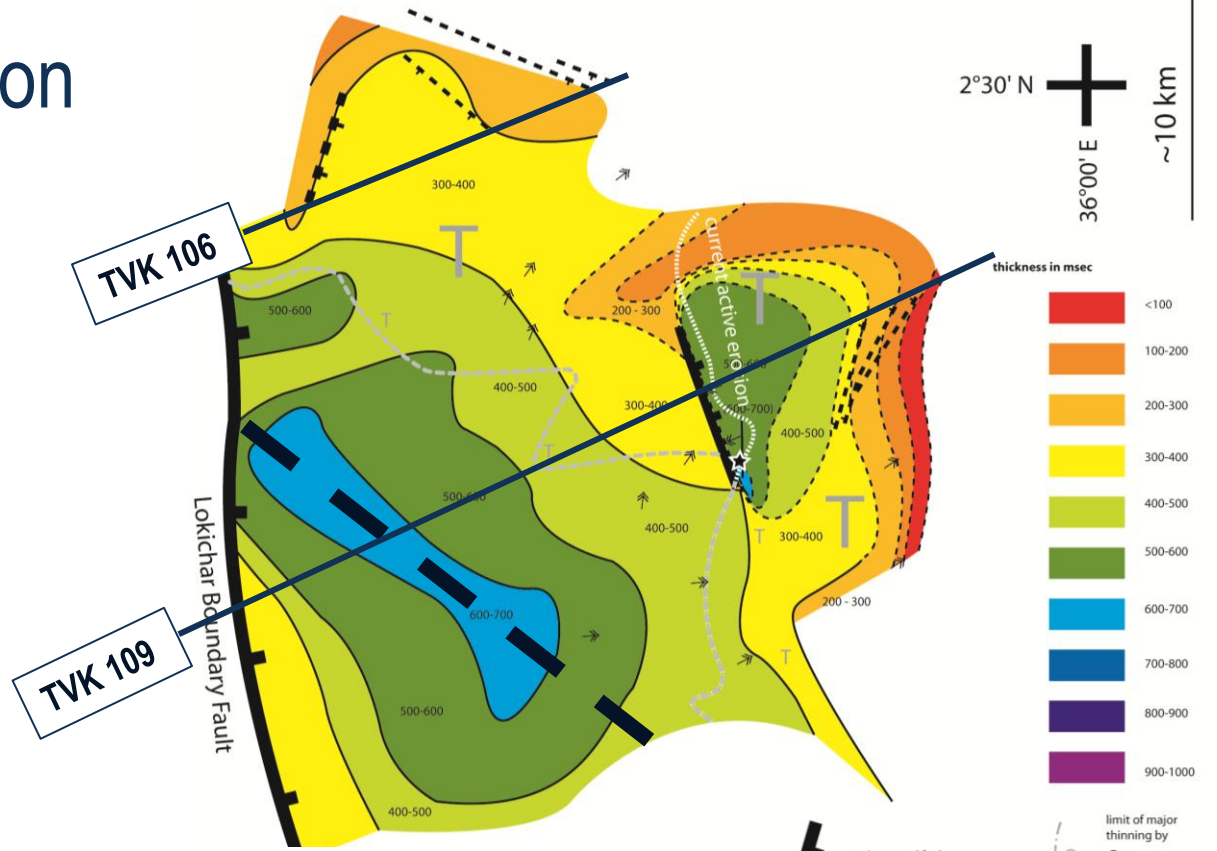
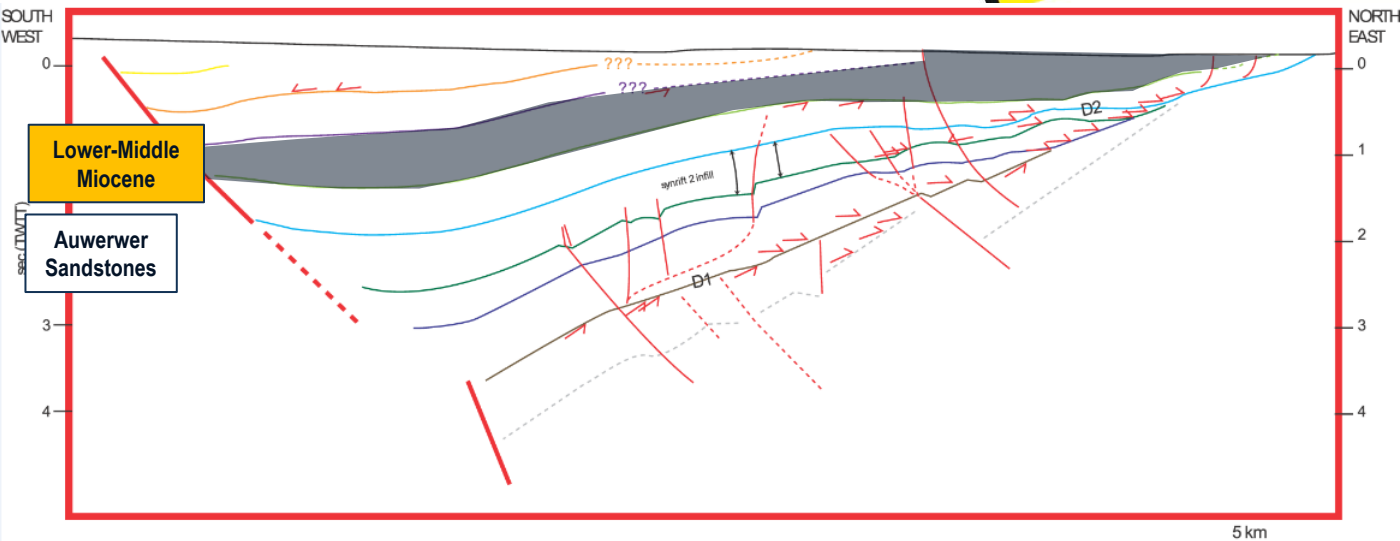
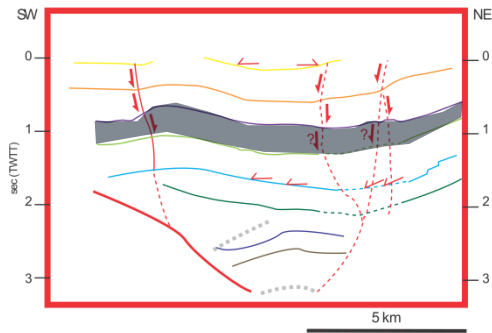
Seismic Interpretation

- Sequence A ----- D1
- Sequence B ----- D2
- Sequence C



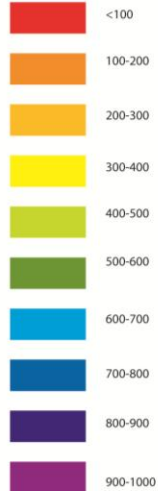
Seismic Interpretation

- Sequence A ----- D1
- Sequence B ----- D2
- Sequence C



2°30' N
36°00' E
~ 10 km

thickness in msec

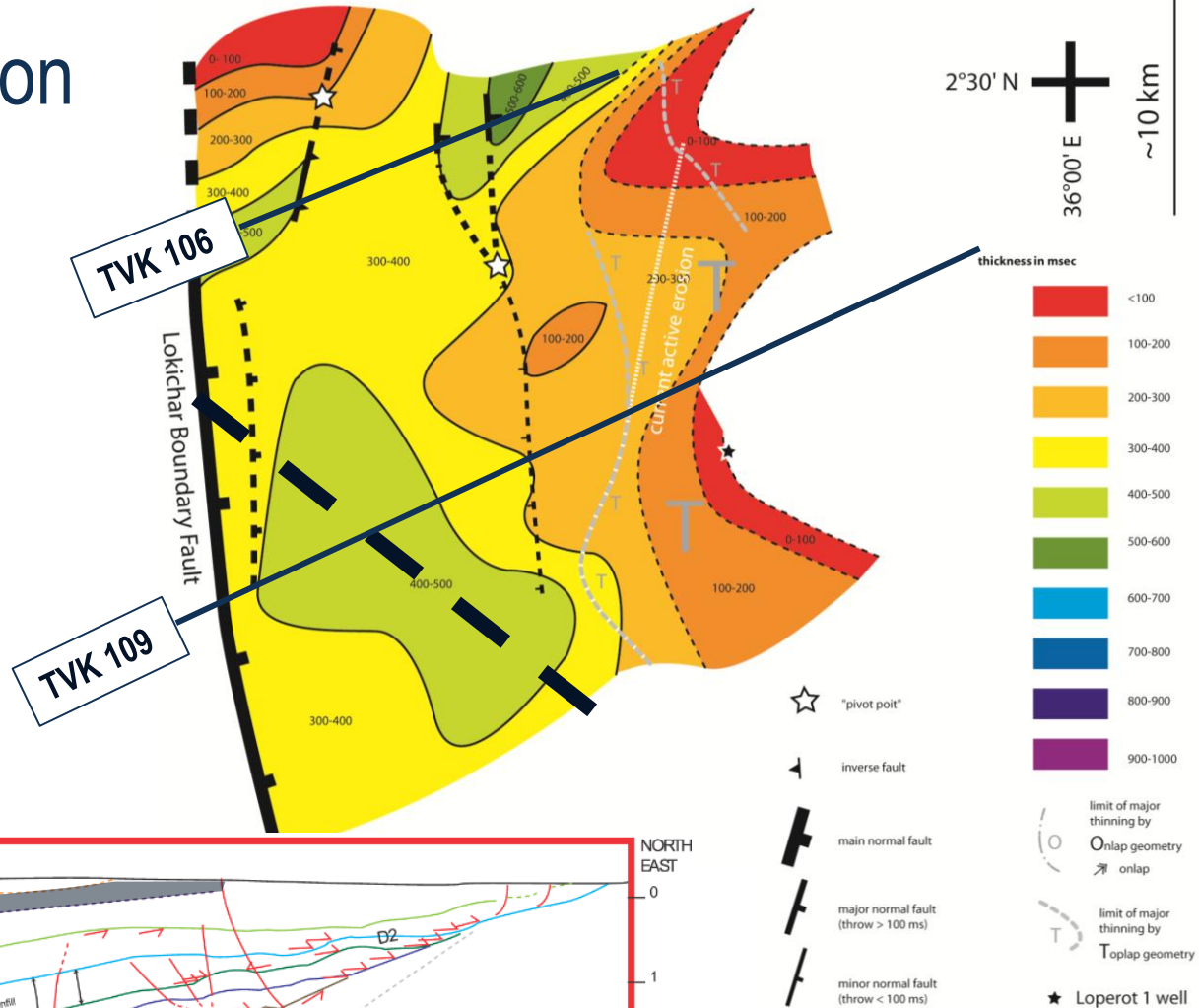
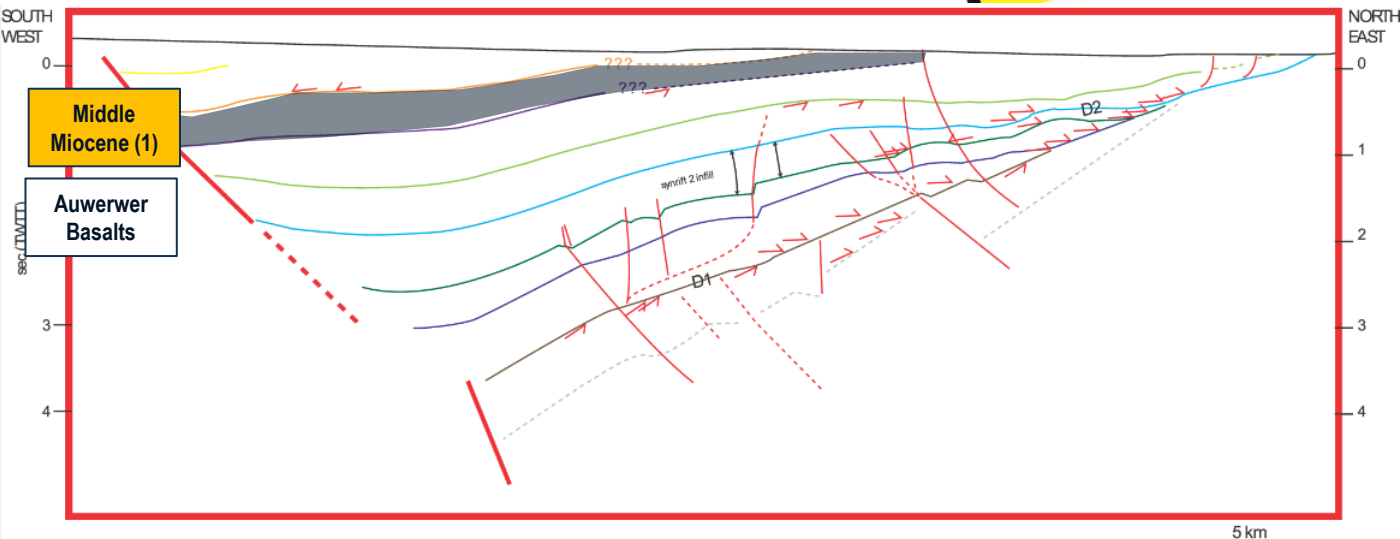
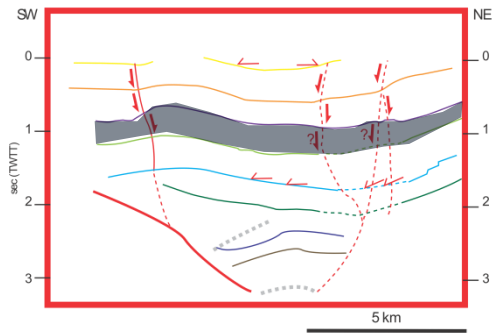


- main normal fault
- major normal fault (throw > 100 ms)
- minor normal fault (throw < 100 ms)

- limit of major thinning by onlap geometry
- limit of major thinning by toplap geometry
- ★ Loperot 1 well

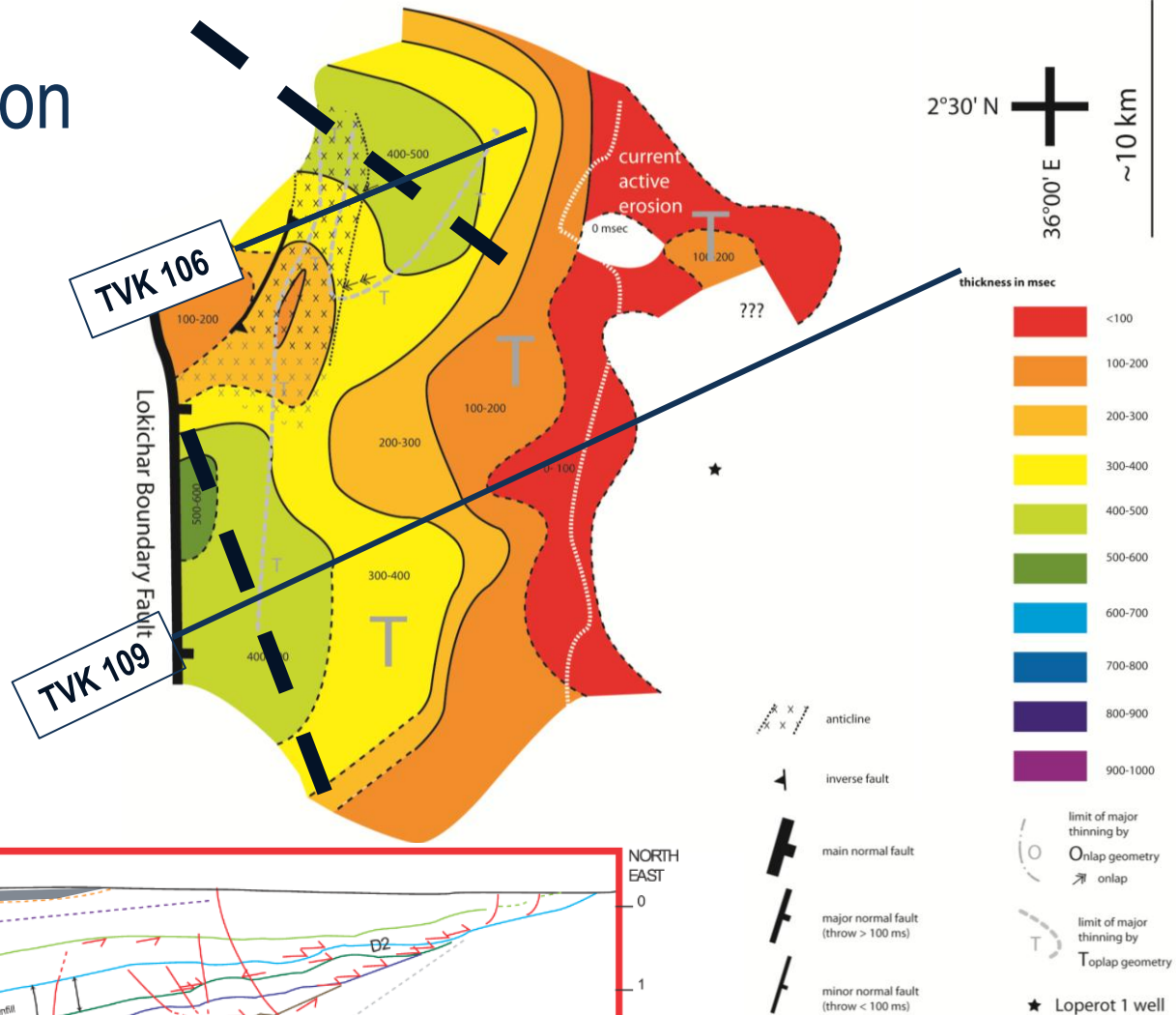
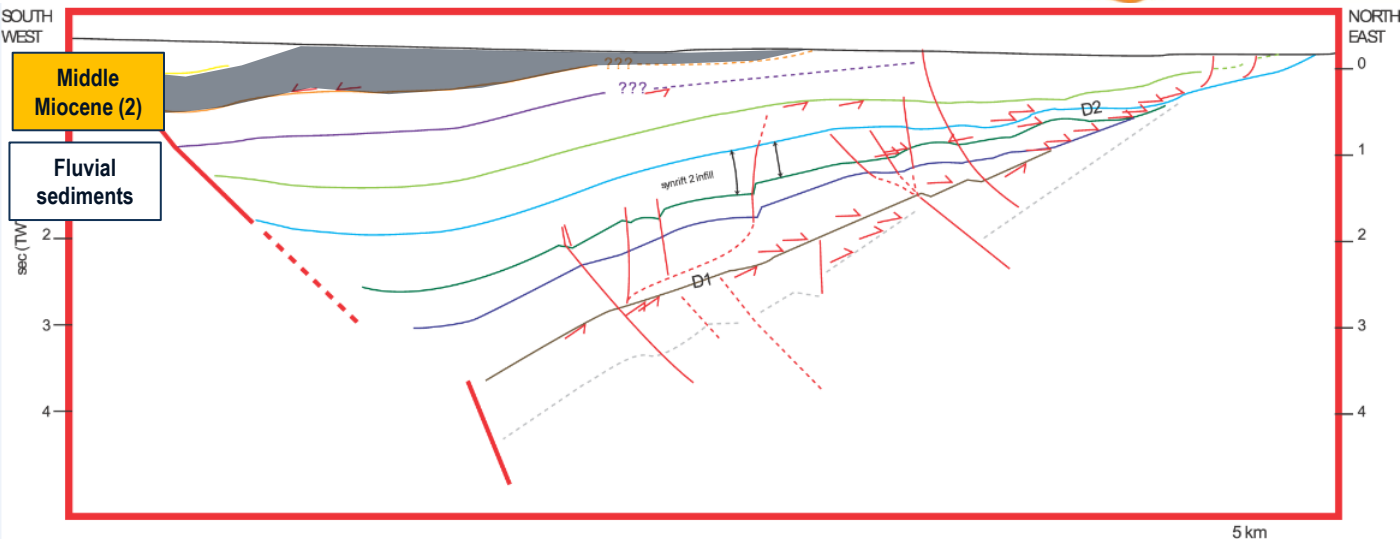
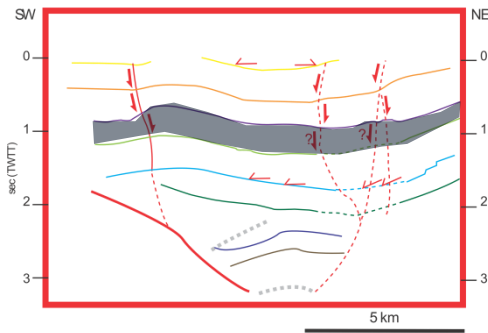
Seismic Interpretation

- Sequence A - - - - - D1
- Sequence B - - - - - D2
- Sequence C

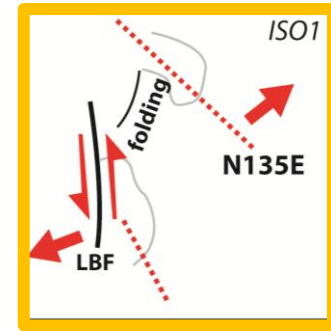


Seismic Interpretation

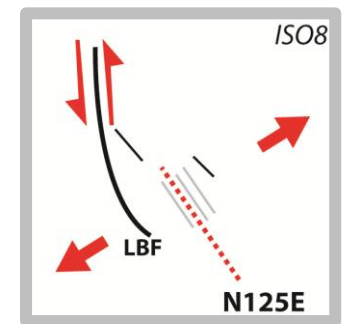
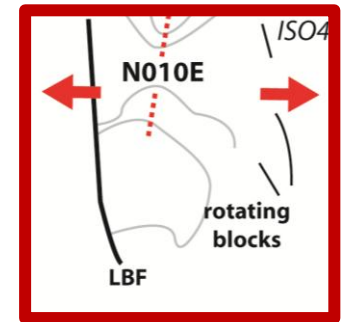
- Sequence A ----- D1
- Sequence B ----- D2
- Sequence C



- 2 major unconformities
- 3 sequences
- Tectonic inversion (Late Miocene)



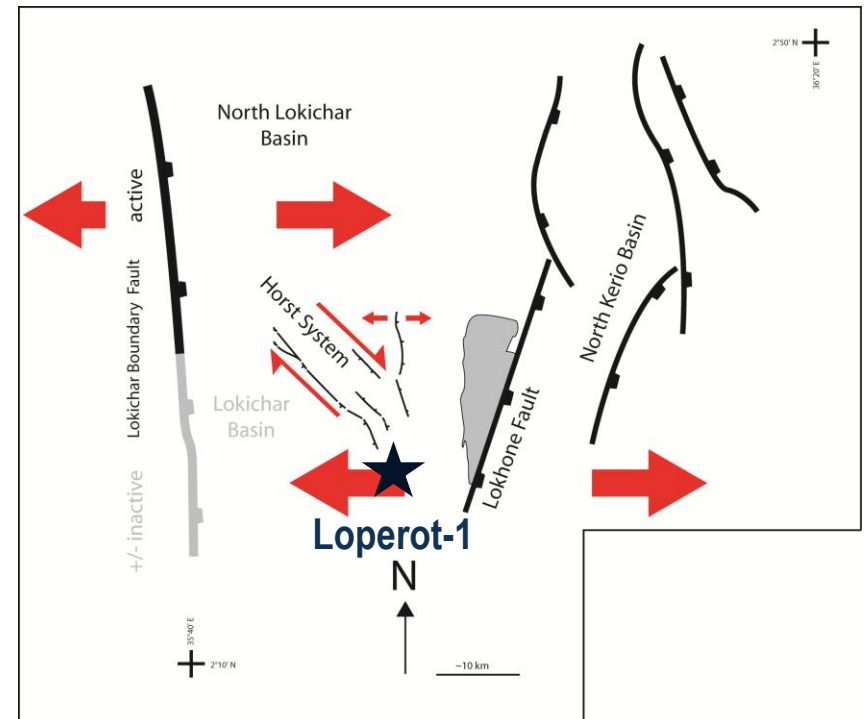
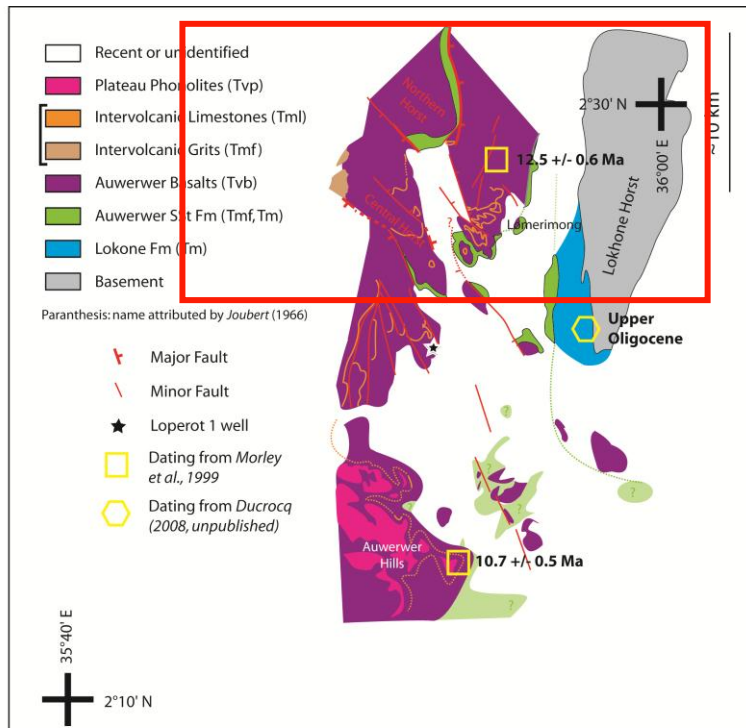
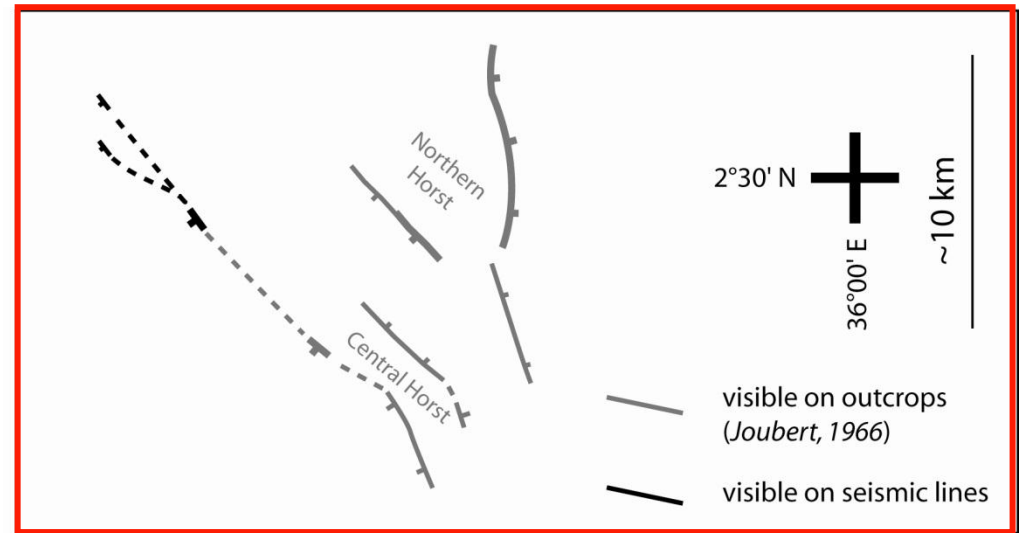
10 km



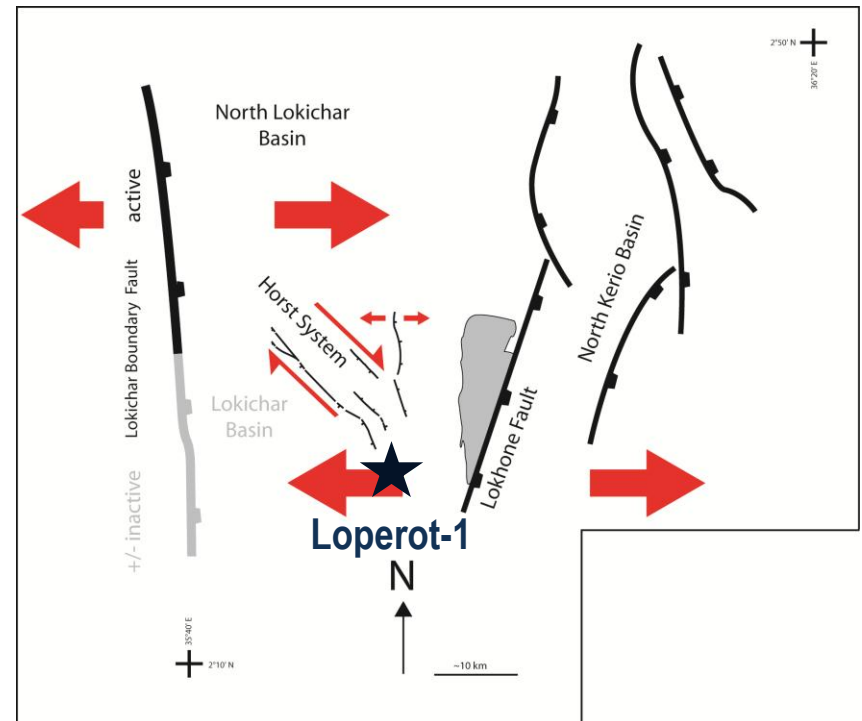
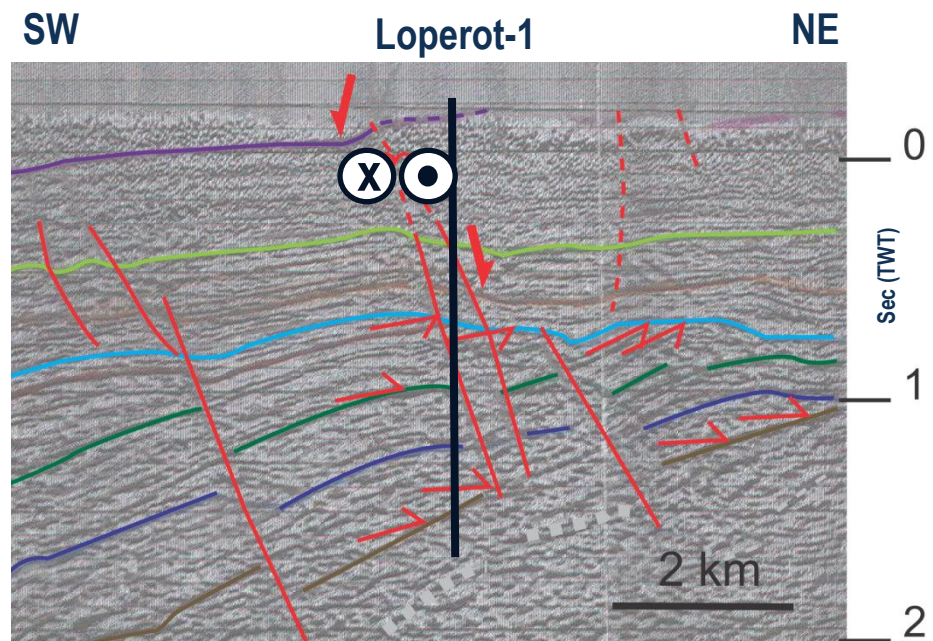
σ_H σ_h Bulk stress orientation
N135E
LBF Lokichar Boundary Fault

Structural Synthesis

- 2 major unconformities
- 3 sequences
- Tectonic inversion
(Late Miocene)

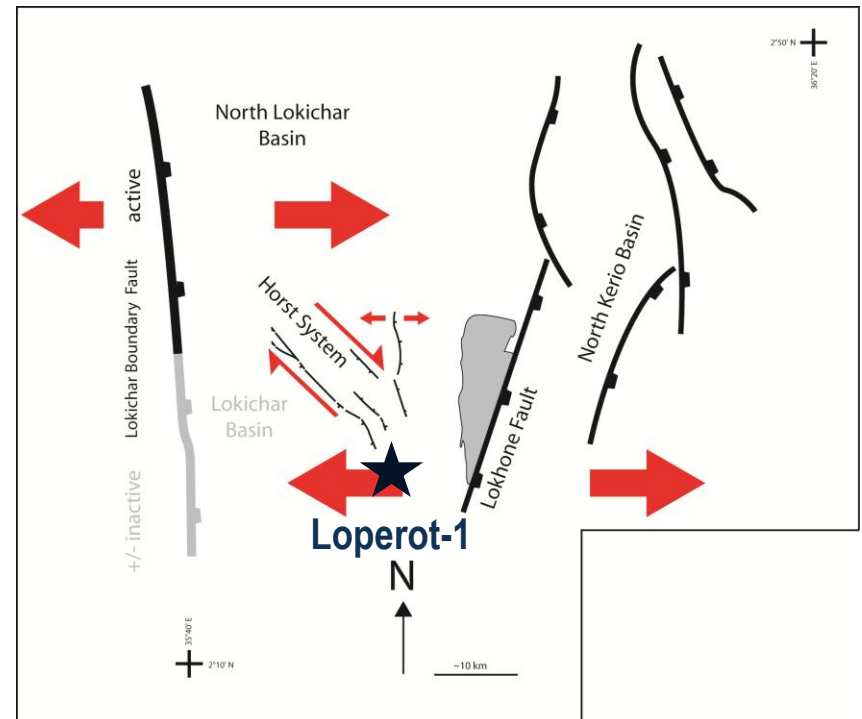
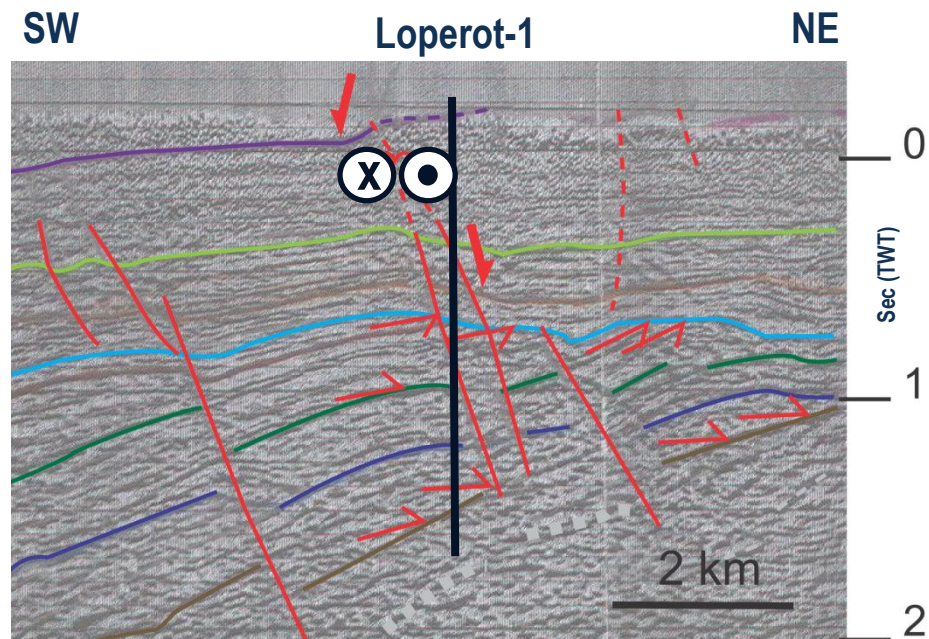
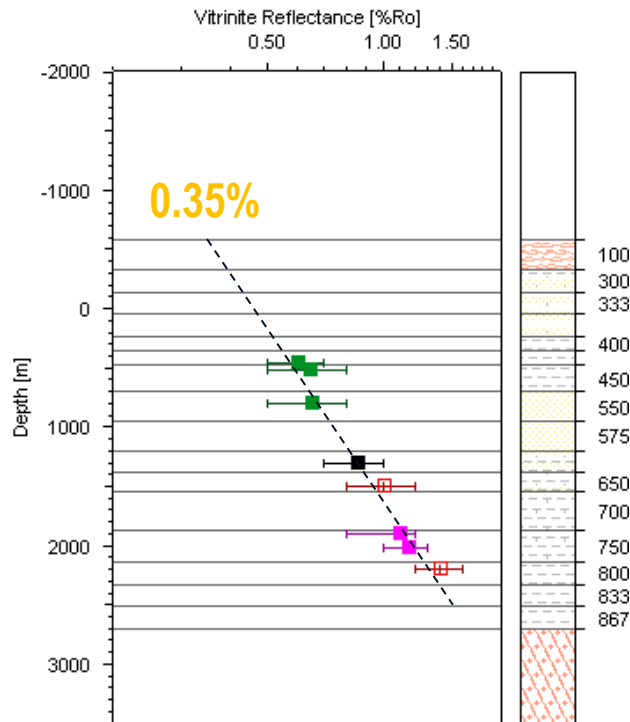


Loperot-1



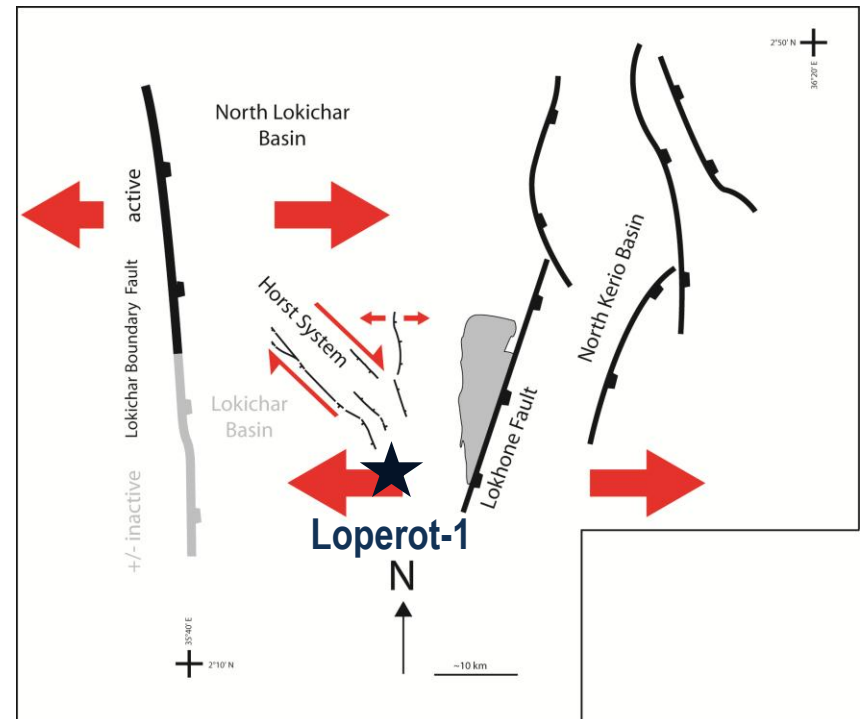
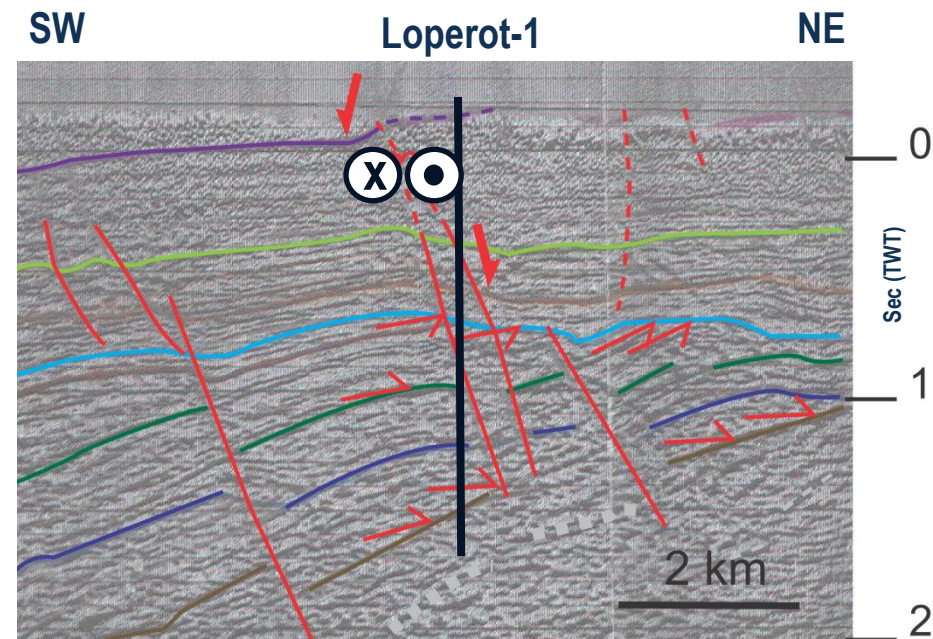
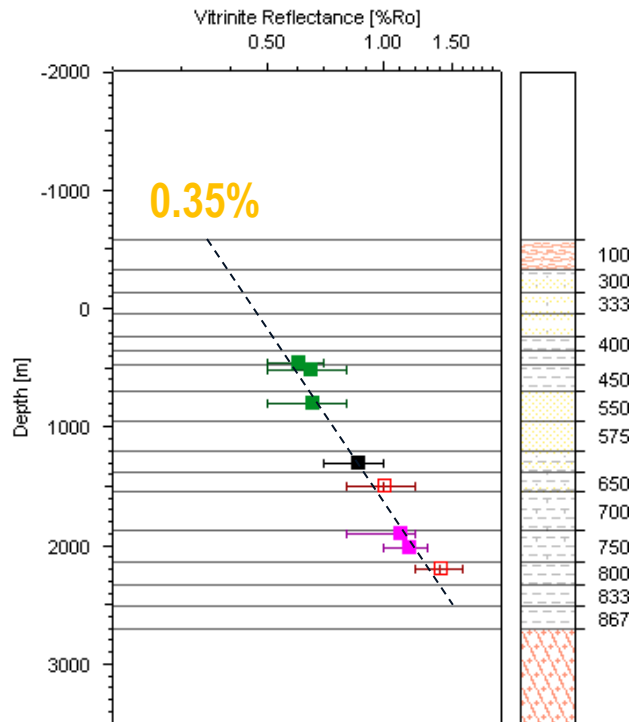
Loperot-1

■ Recent erosion



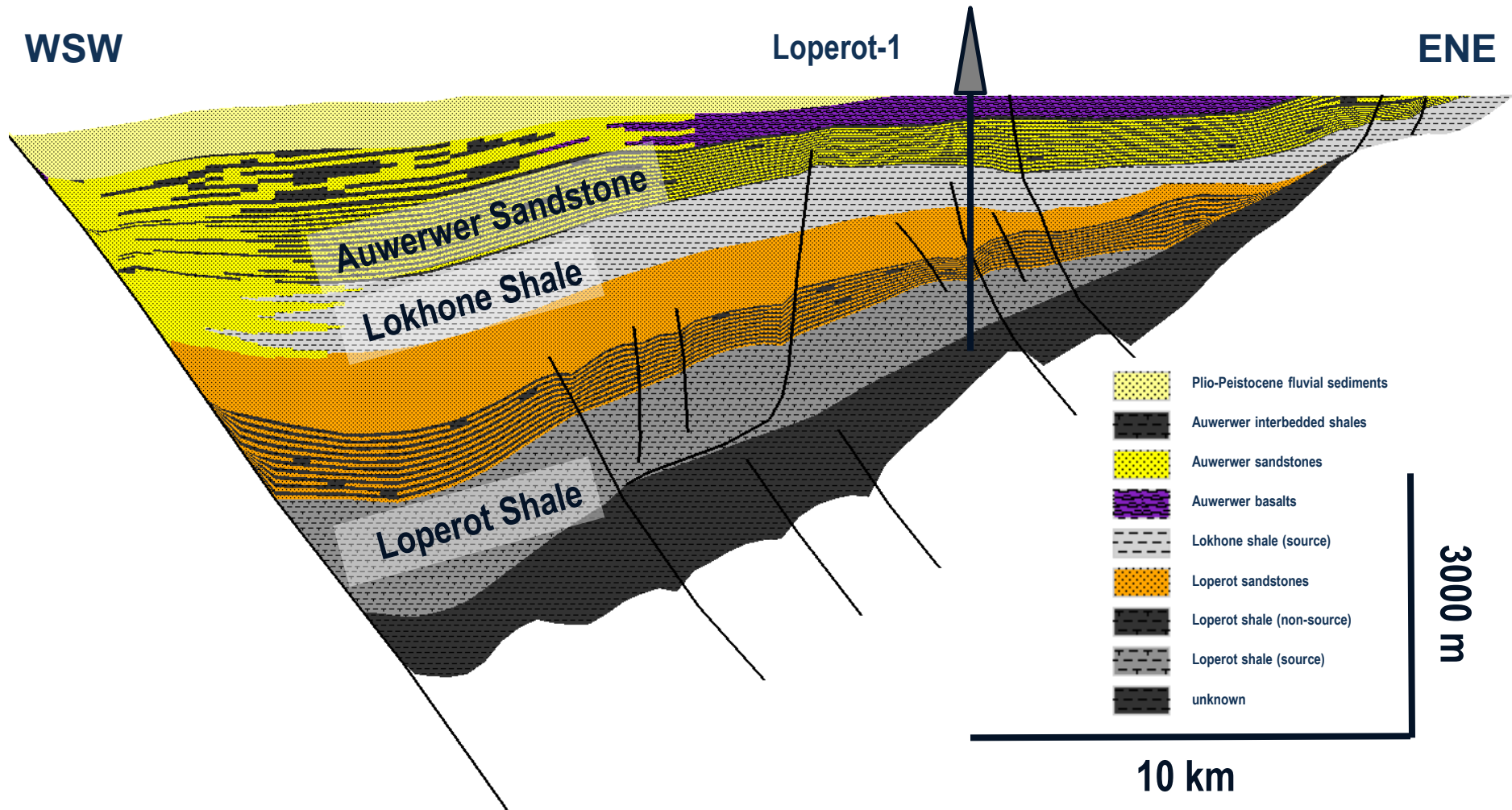
Loperot-1

- Recent erosion
- Tectonic inversion responsible for trap/seal failure?



Basin Modeling

■ Lithologies



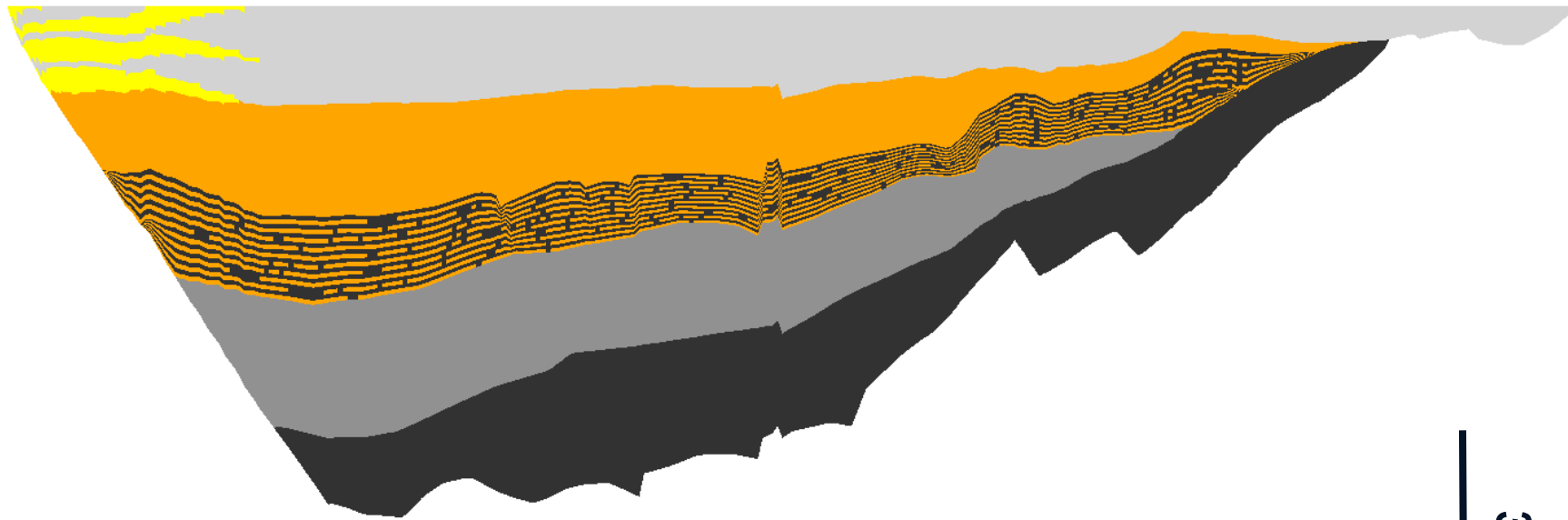
Basin Modeling

■ Lokhone Shales (Oligocene to Early Miocene)

■ Structural history

WSW

ENE



3000 m

10 km

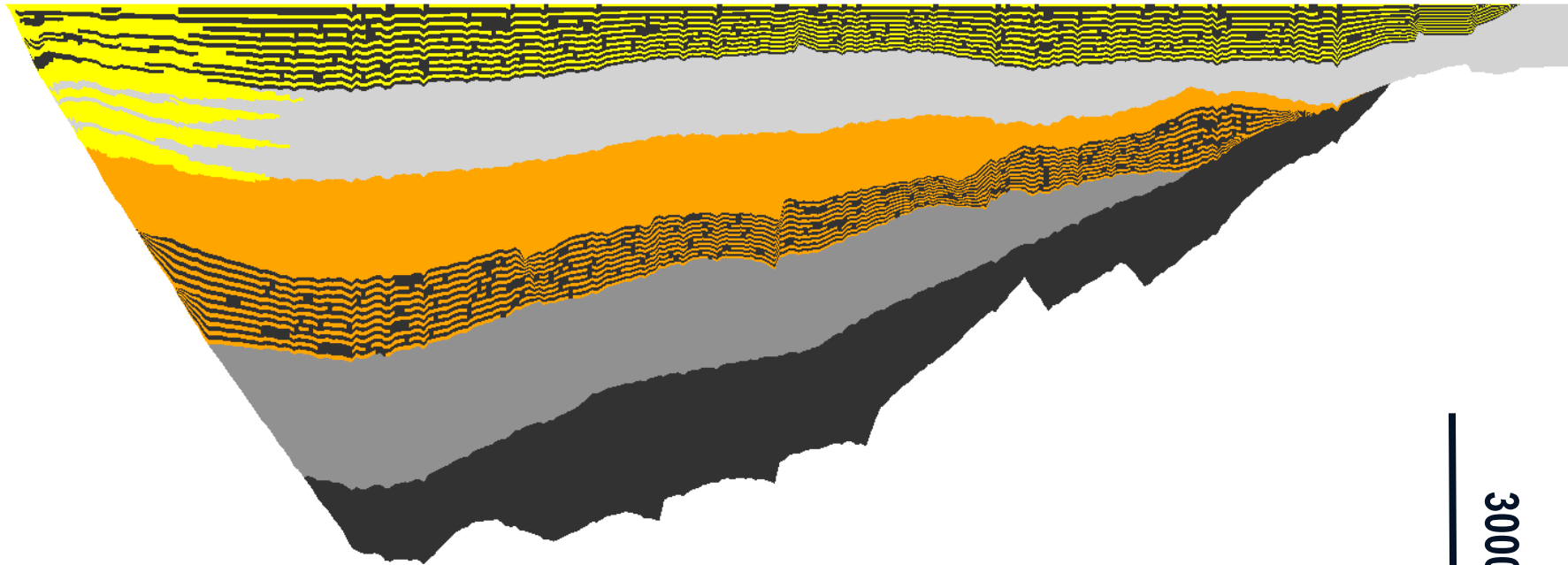
Basin Modeling

- Lokhone Shales (Oligocene to Early Miocene)
- Auwerwer Sandstones (Middle Miocene)

■ Structural history

WSW

ENE



3000 m

10 km

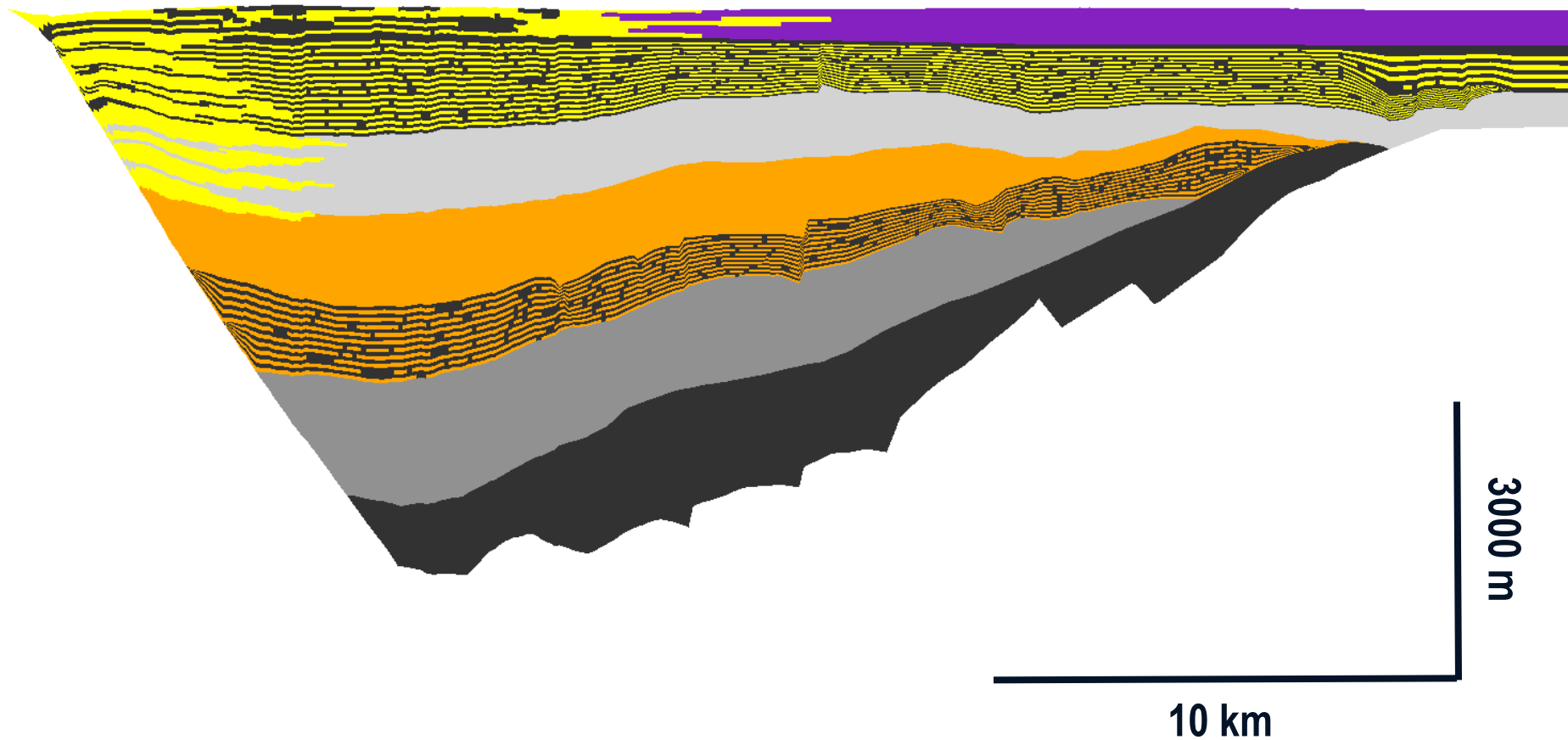
Basin Modeling

■ Structural history

- Lokhone Shales (Oligocene to Early Miocene)
- Auwerwer Sandstones (Middle Miocene)
- Auwerwer Basalts (12.5 to 10.7 Ma)

WSW

ENE



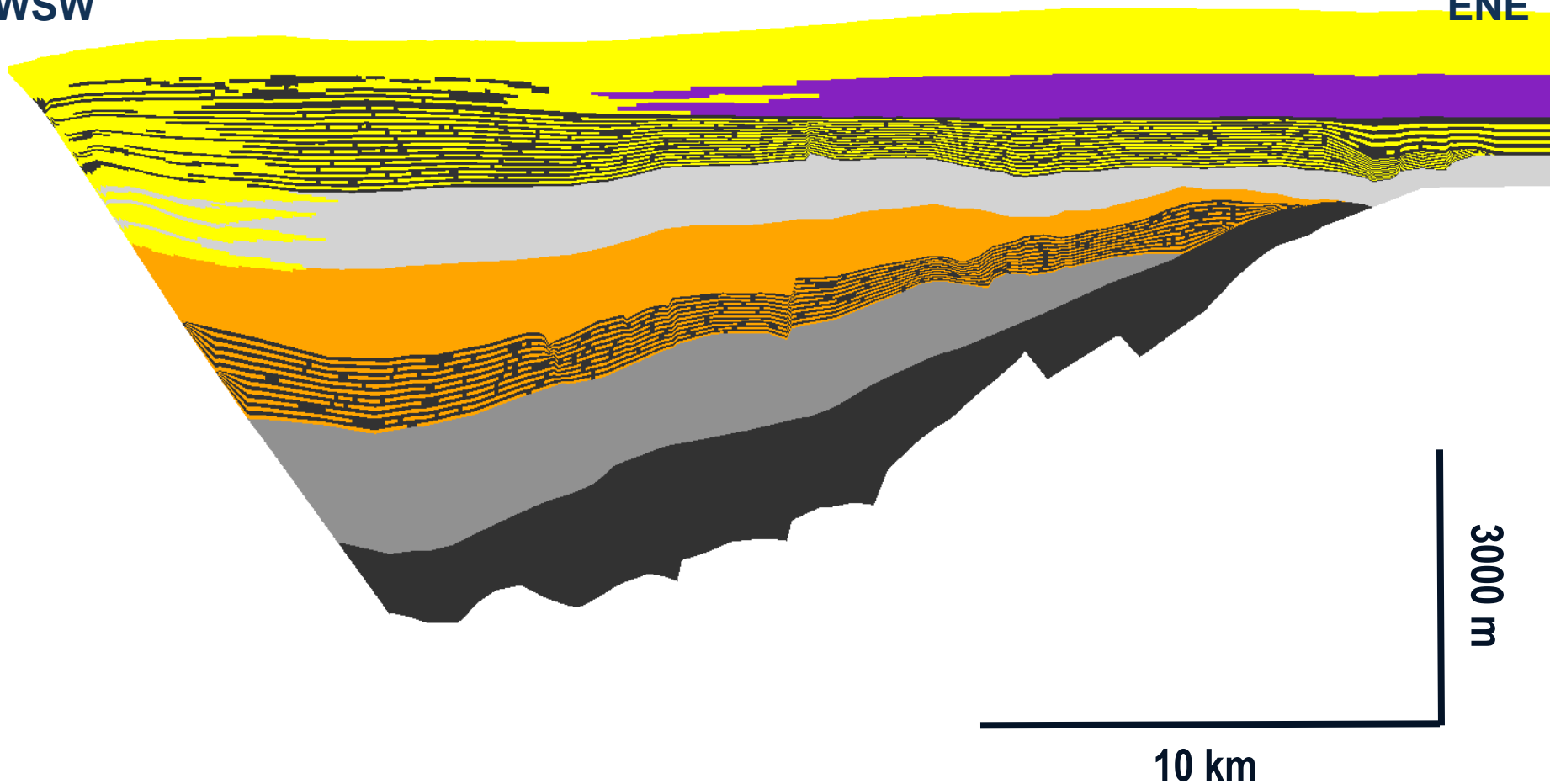
Basin Modeling

■ Structural history

- Lokhone Shales (Oligocene to Early Miocene)
- Auwerwer Sandstones (Middle Miocene)
- Auwerwer Basalts (12.5 to 10.7 Ma)
- Fluvial sediments (?) (Late Miocene)

WSW

ENE



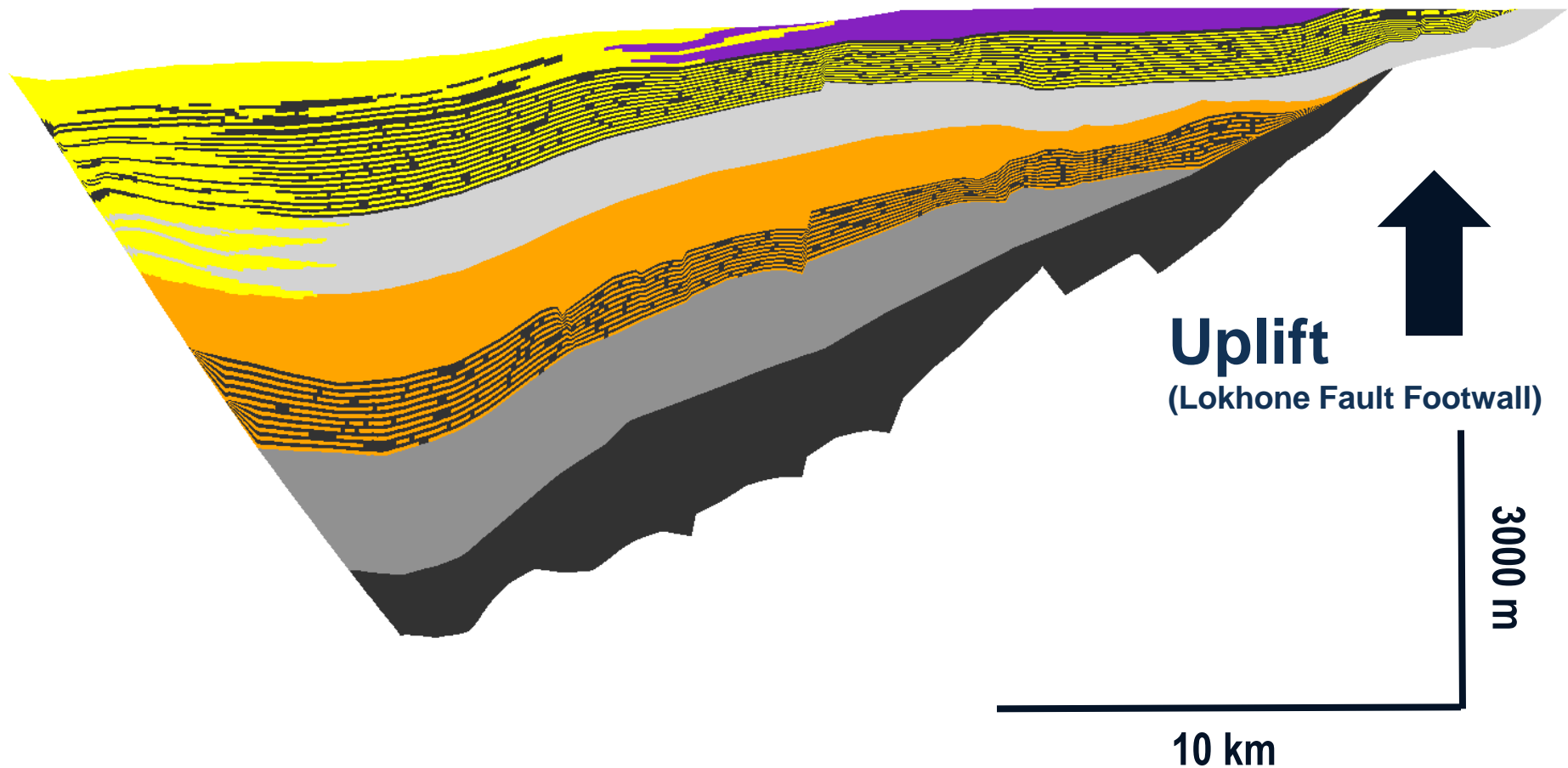
Basin Modeling

■ Structural history

- Lokhone Shales (Oligocene to Early Miocene)
- Auwerwer Sandstones (Middle Miocene)
- Auwerwer Basalts (12.5 to 10.7 Ma)
- Fluvial sediments (?) (Late Miocene)

WSW

ENE



Basin Modeling

■ Structural history

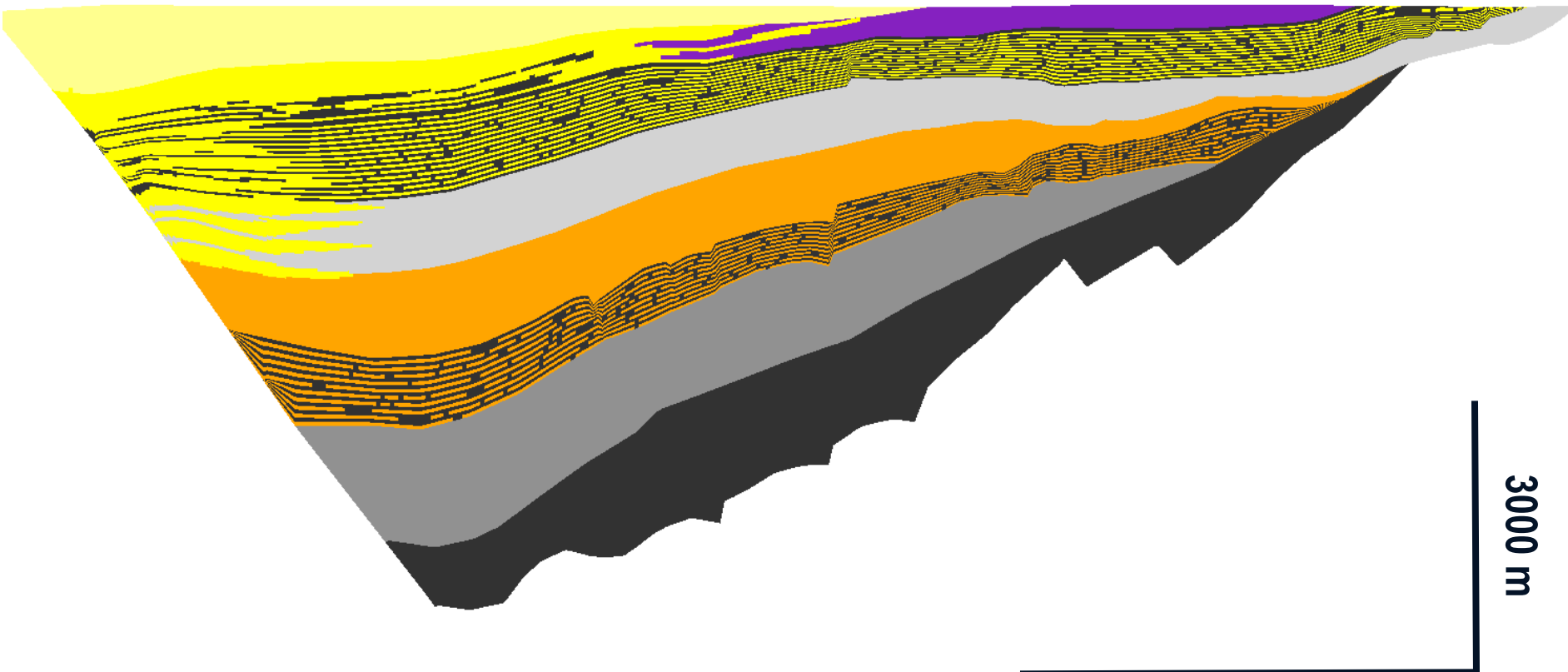
- Lokhone Shales (Oligocene to Early Miocene)
- Auwerwer Sandstones (Middle Miocene)
- Auwerwer Basalts (12.5 to 10.7 Ma)
- Fluvial sediments (?) (Late Miocene)
- Fluvial sediments (Pliocene - Pleistocene)

WSW

ENE

3000 m

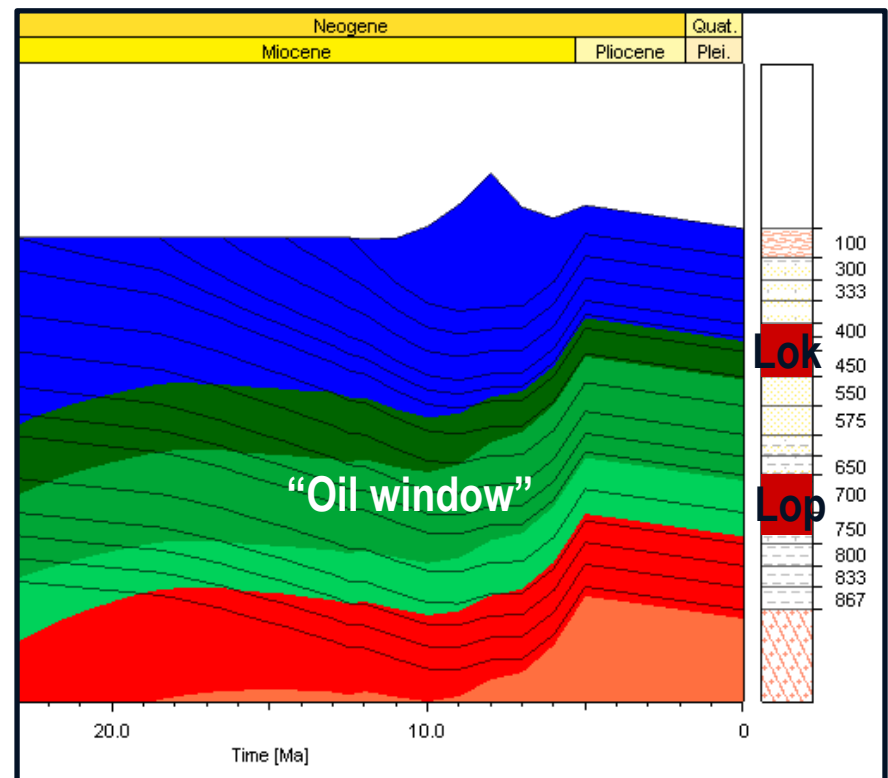
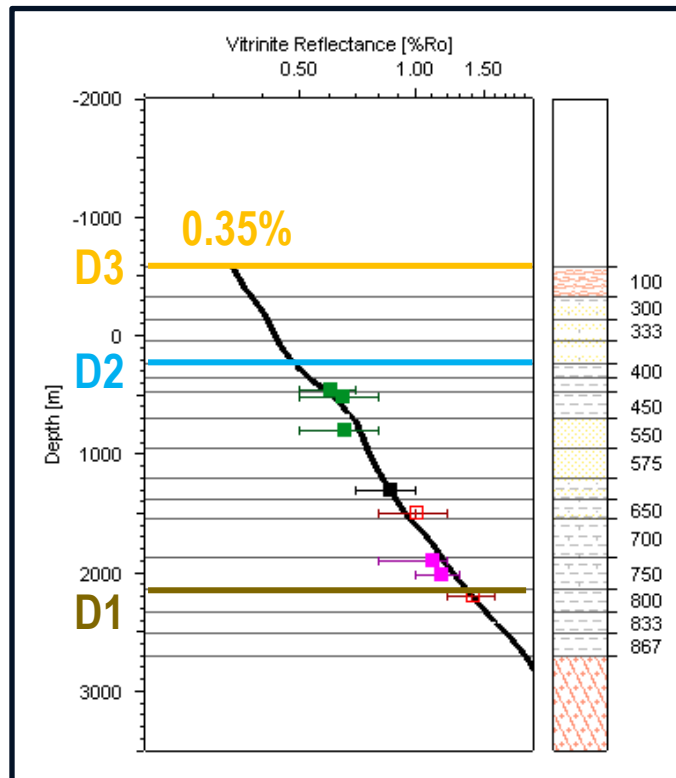
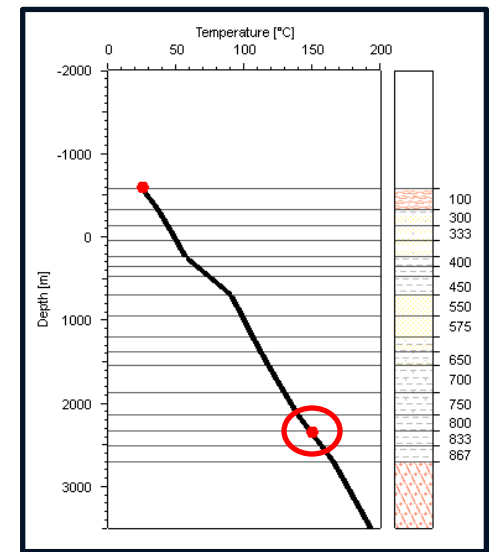
10 km



Basin Modeling

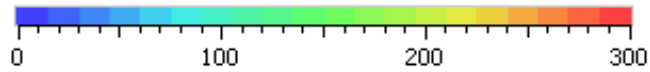
- Loperot-1
- Erosion of ca. 900m
- Lokhone Shale marginally mature
- Loperot Shale in oil window

- Corrected BHT 150 °C



Basin Modeling

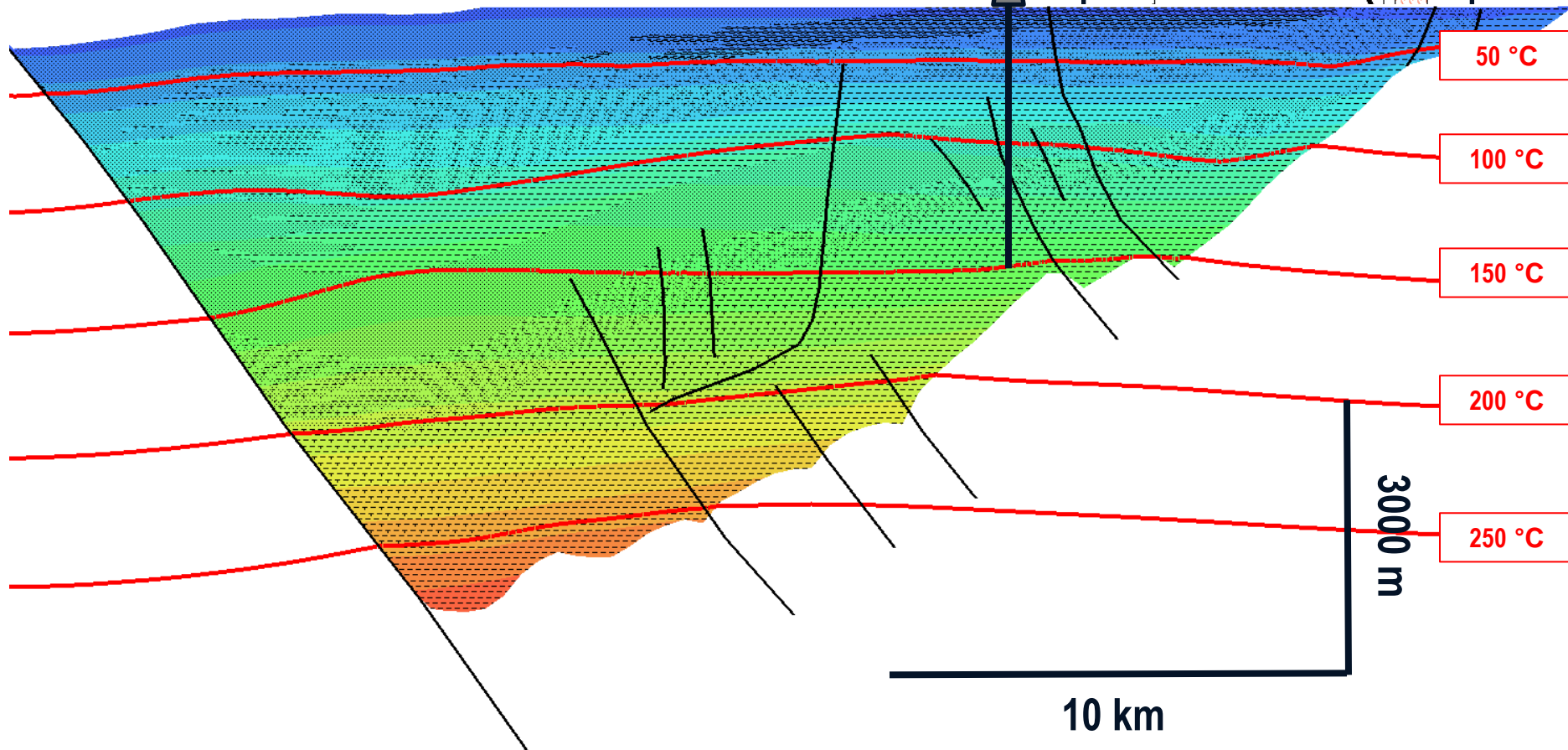
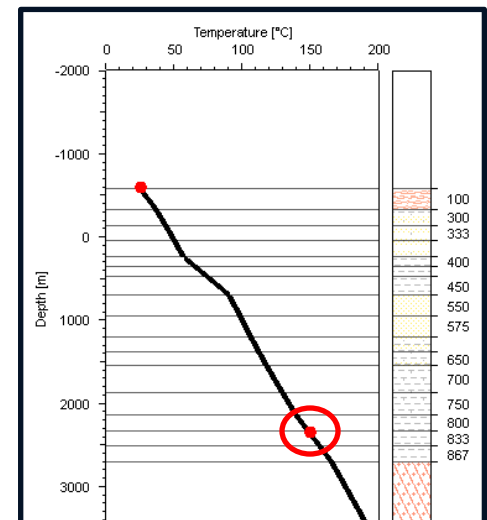
■ Temperature (°C)



WSW

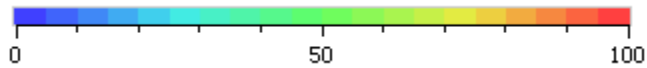
- Corrected BHT 150 °C
- Local variations due to lithology

Loperot-1

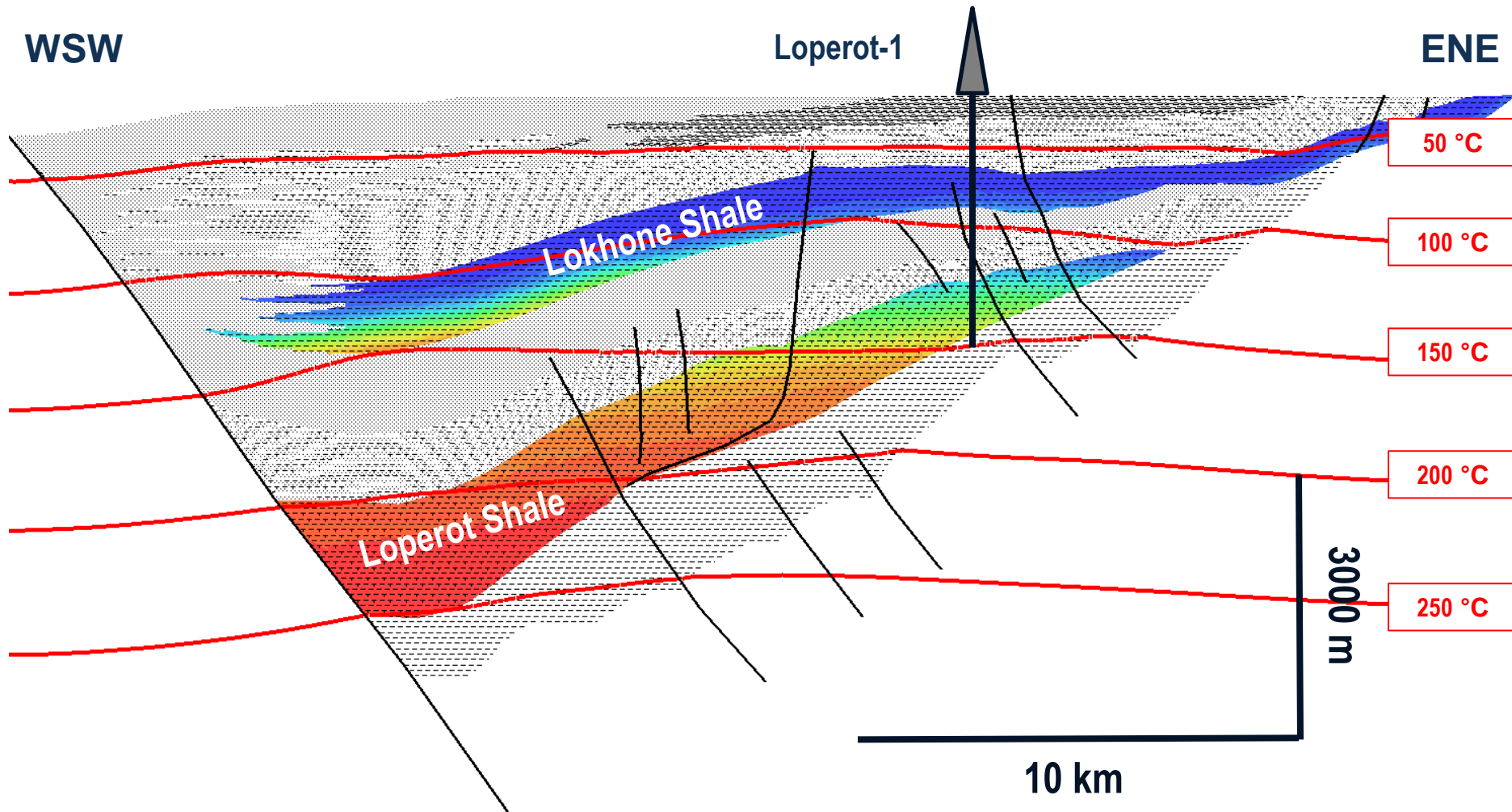


Basin Modeling

■ Transformation ratio

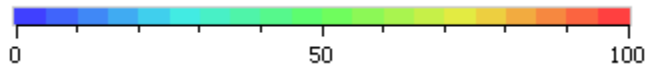


- Lokhone Shale only marginally mature at Loperot-1
- Effective kitchen of Lokhone Shale towards bounding fault
- Loperot Shale mature

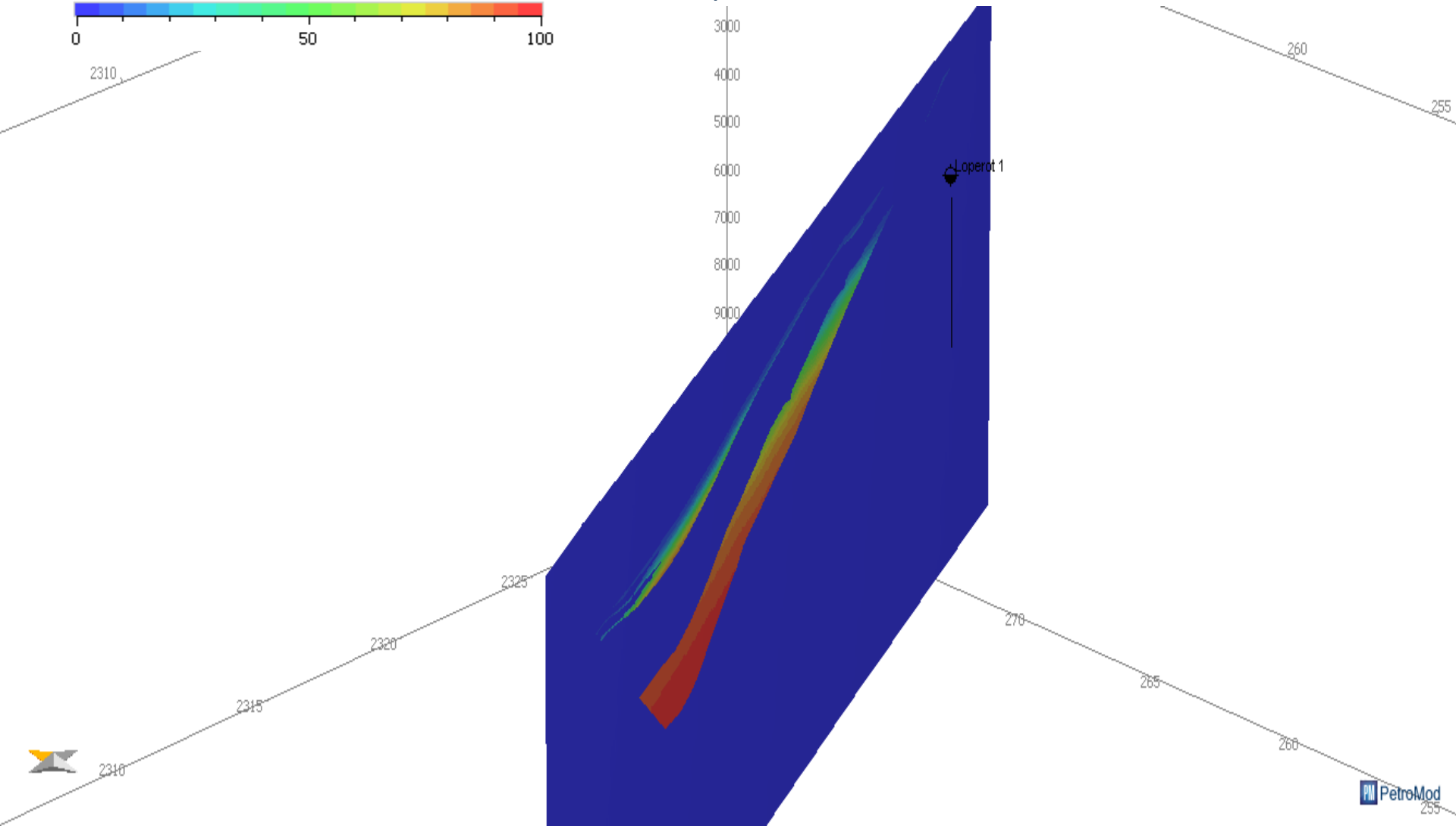


Basin Modeling

■ Transformation ratio



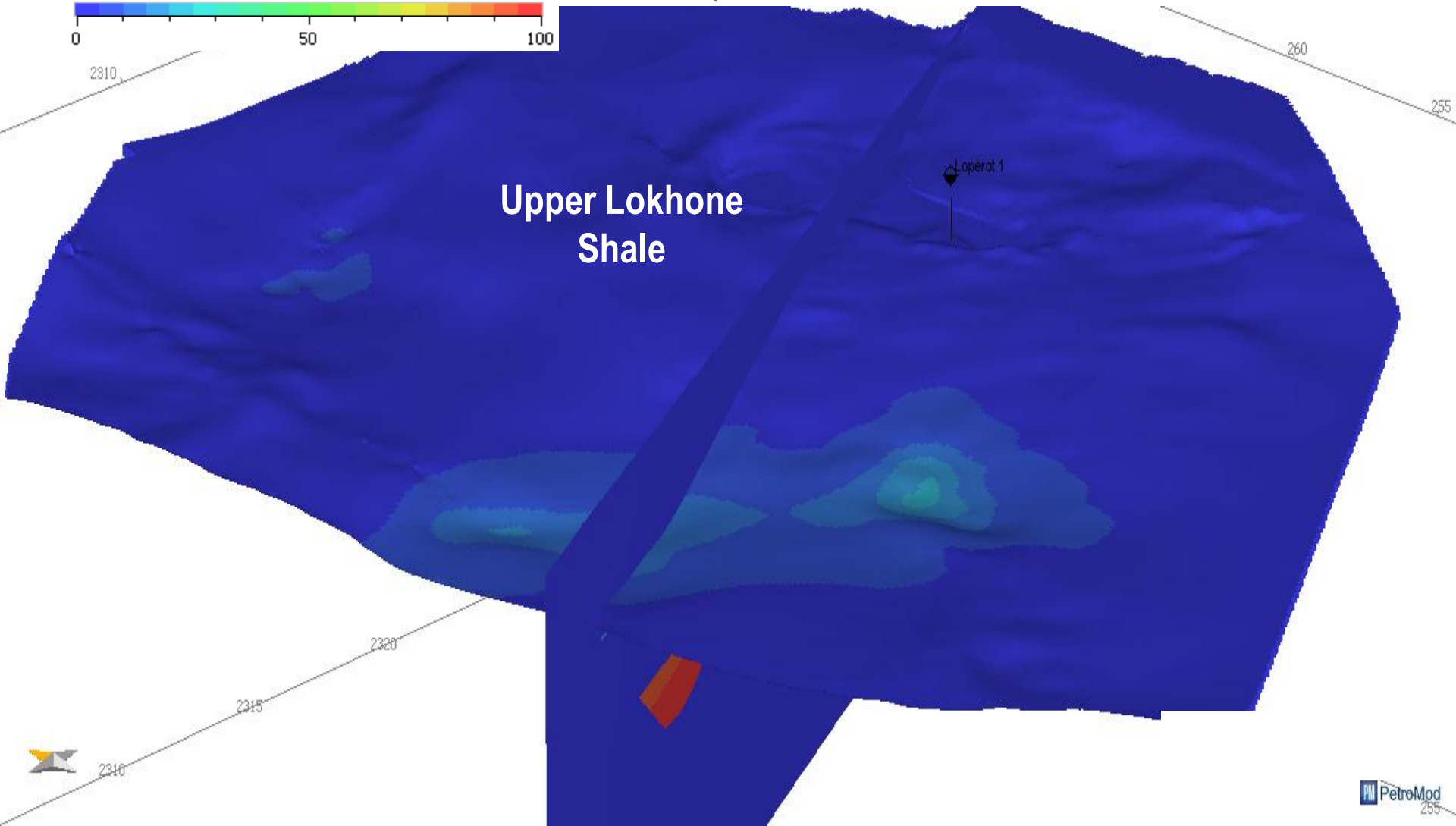
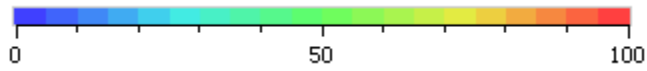
- Lokhone Shale only marginally mature at Loperot-1
- Effective kitchen of Lokhone Shale towards bounding fault
- Loperot Shale mature



Basin Modeling

■ Transformation ratio

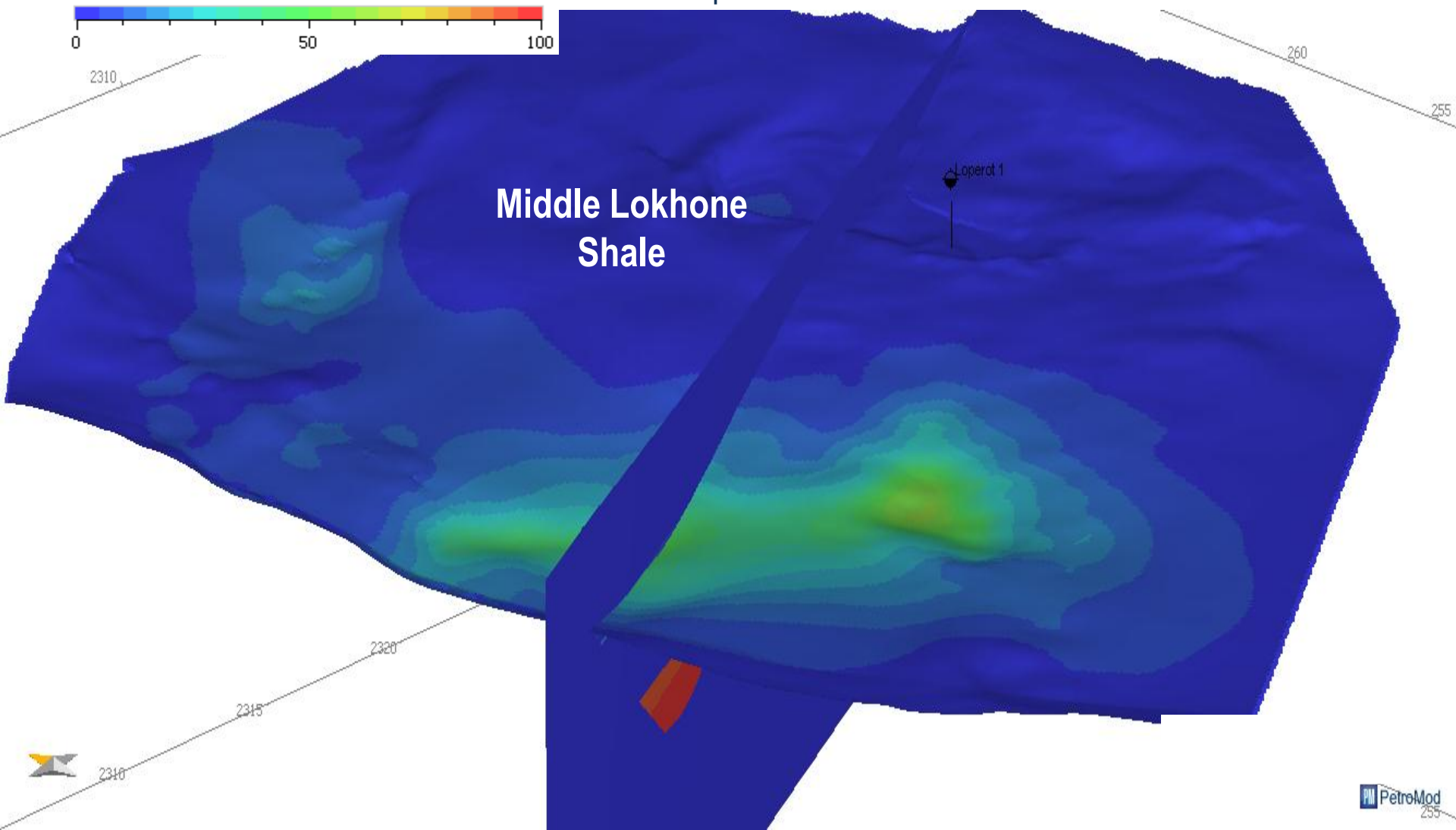
- Lokhone Shale only marginally mature at Loperot-1
- Effective kitchen of Lokhone Shale towards bounding fault
- Loperot Shale mature



Basin Modeling

■ Transformation ratio

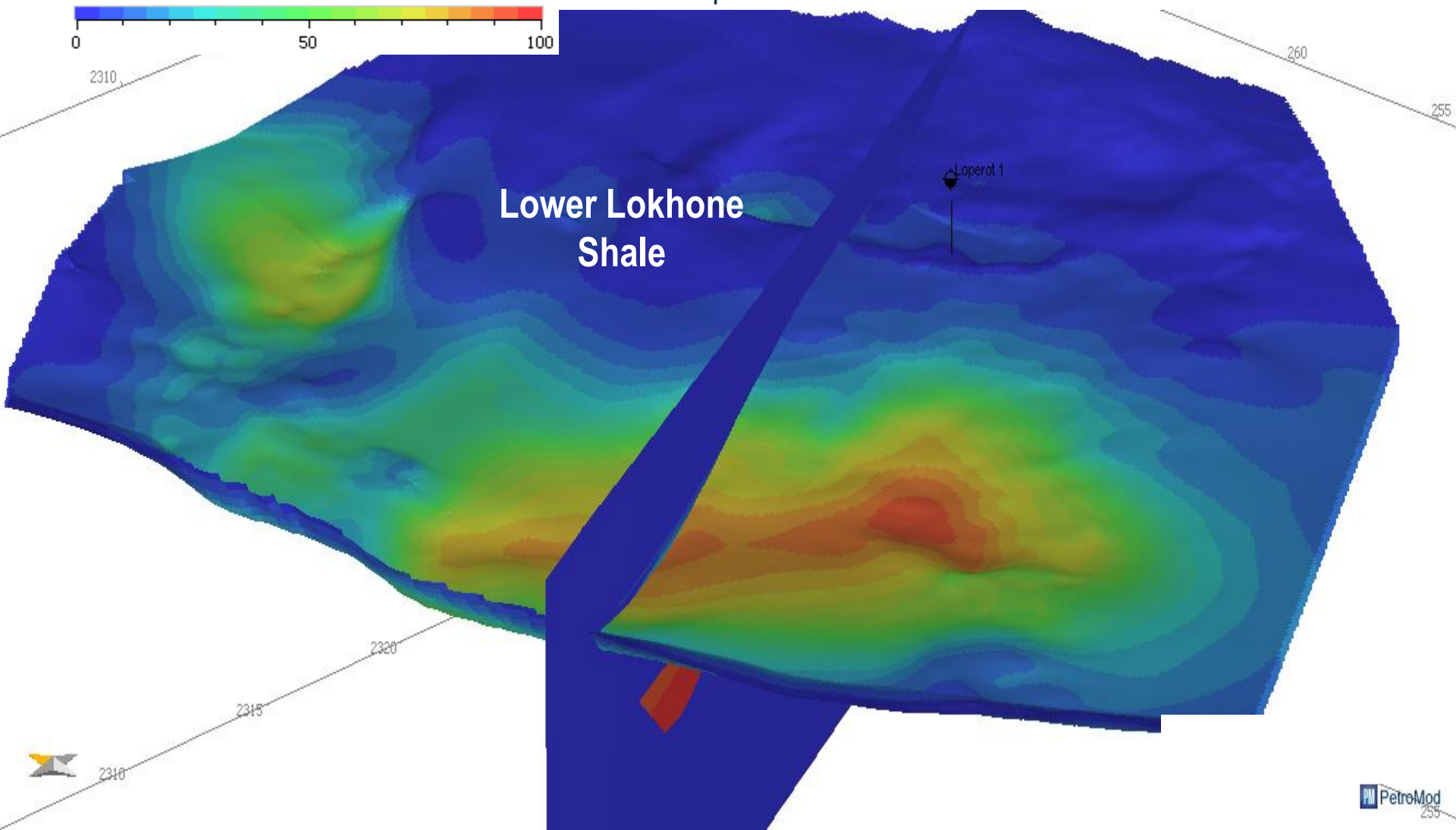
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Basin Modeling

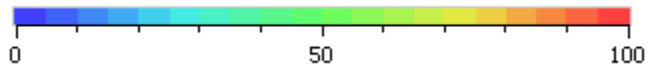
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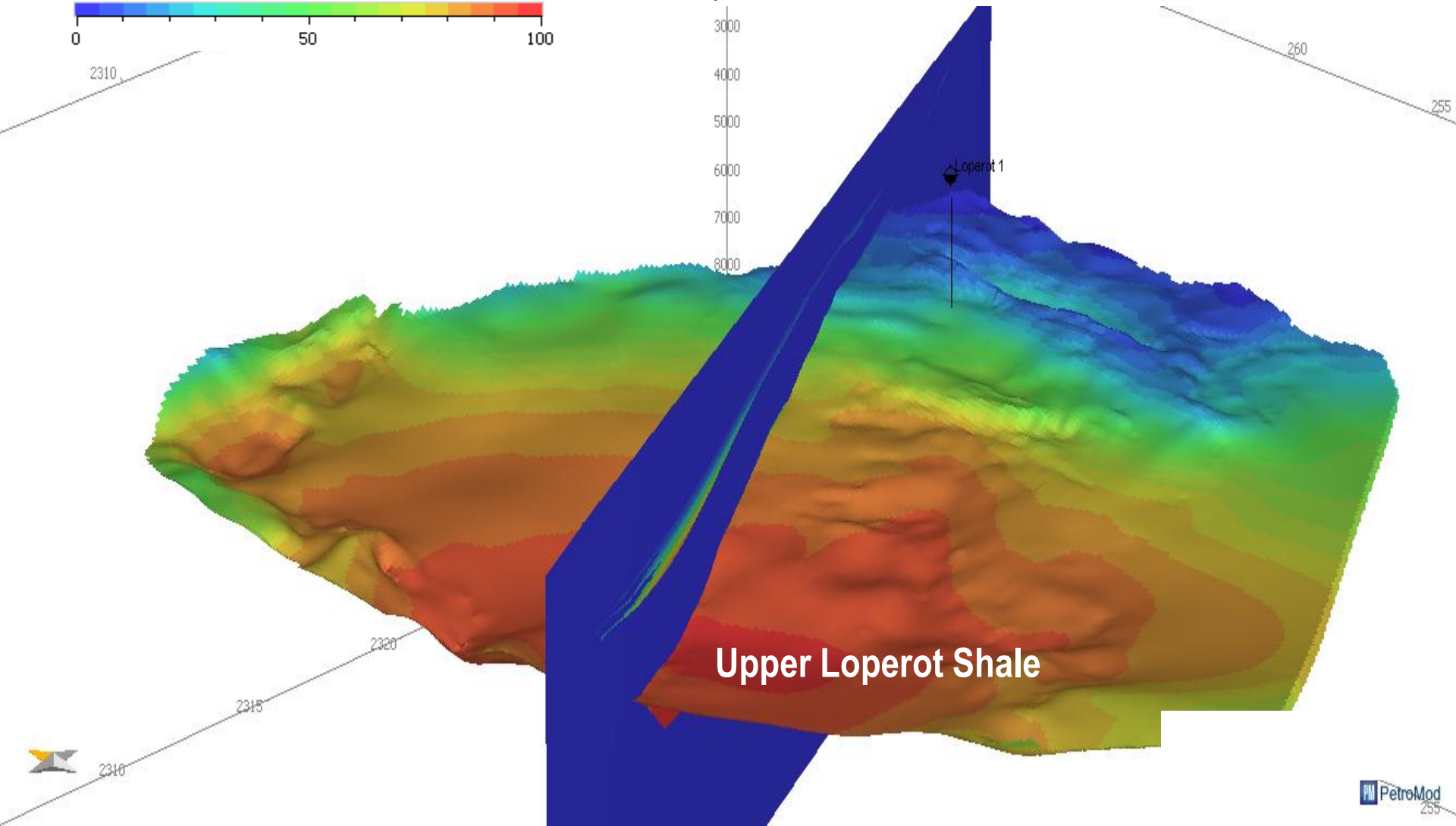


Basin Modeling

■ Transformation ratio

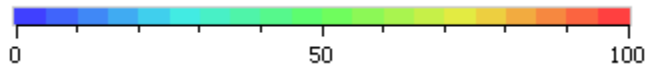


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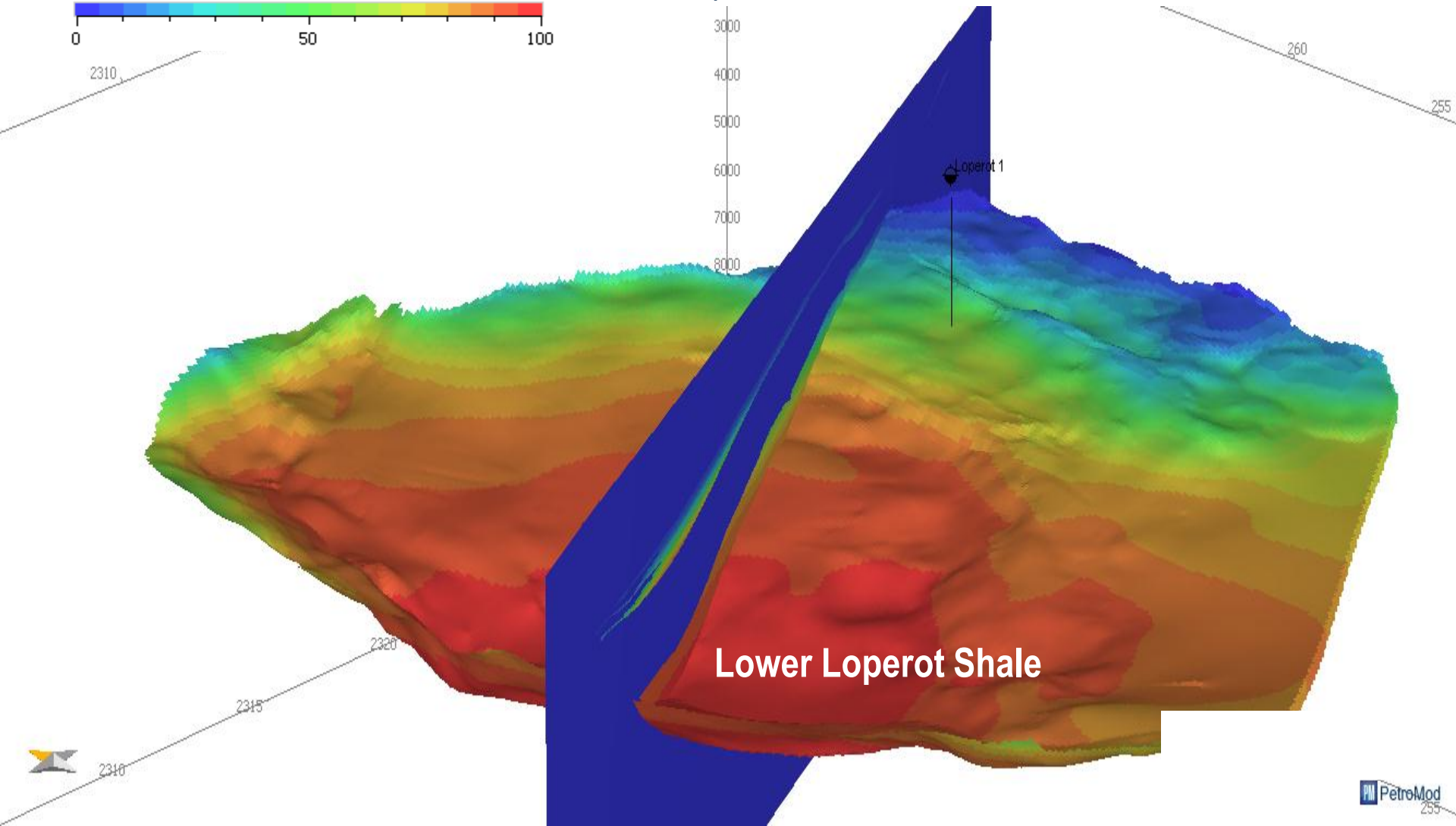


Basin Modeling

■ Transformation ratio

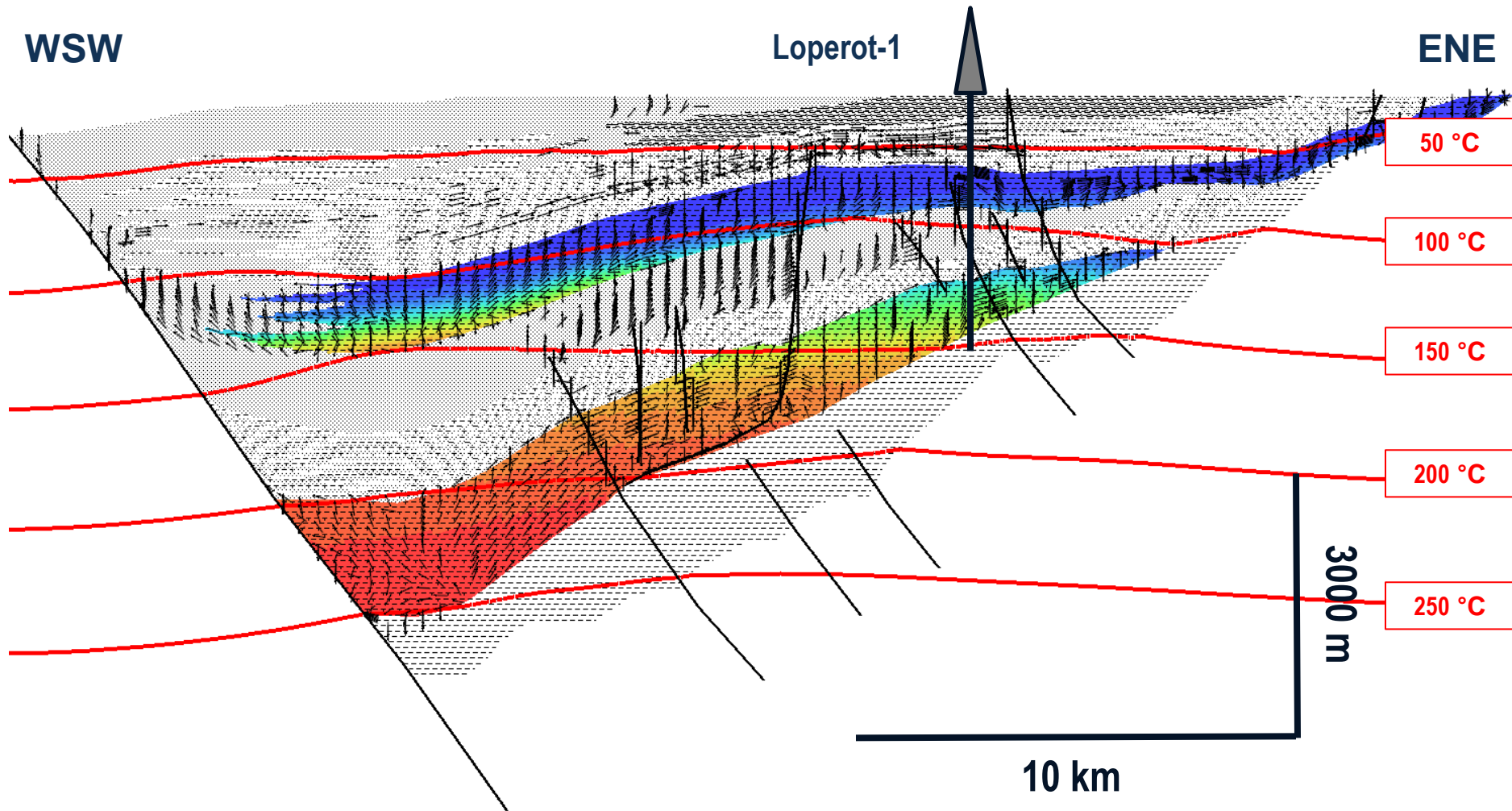


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Basin Modeling

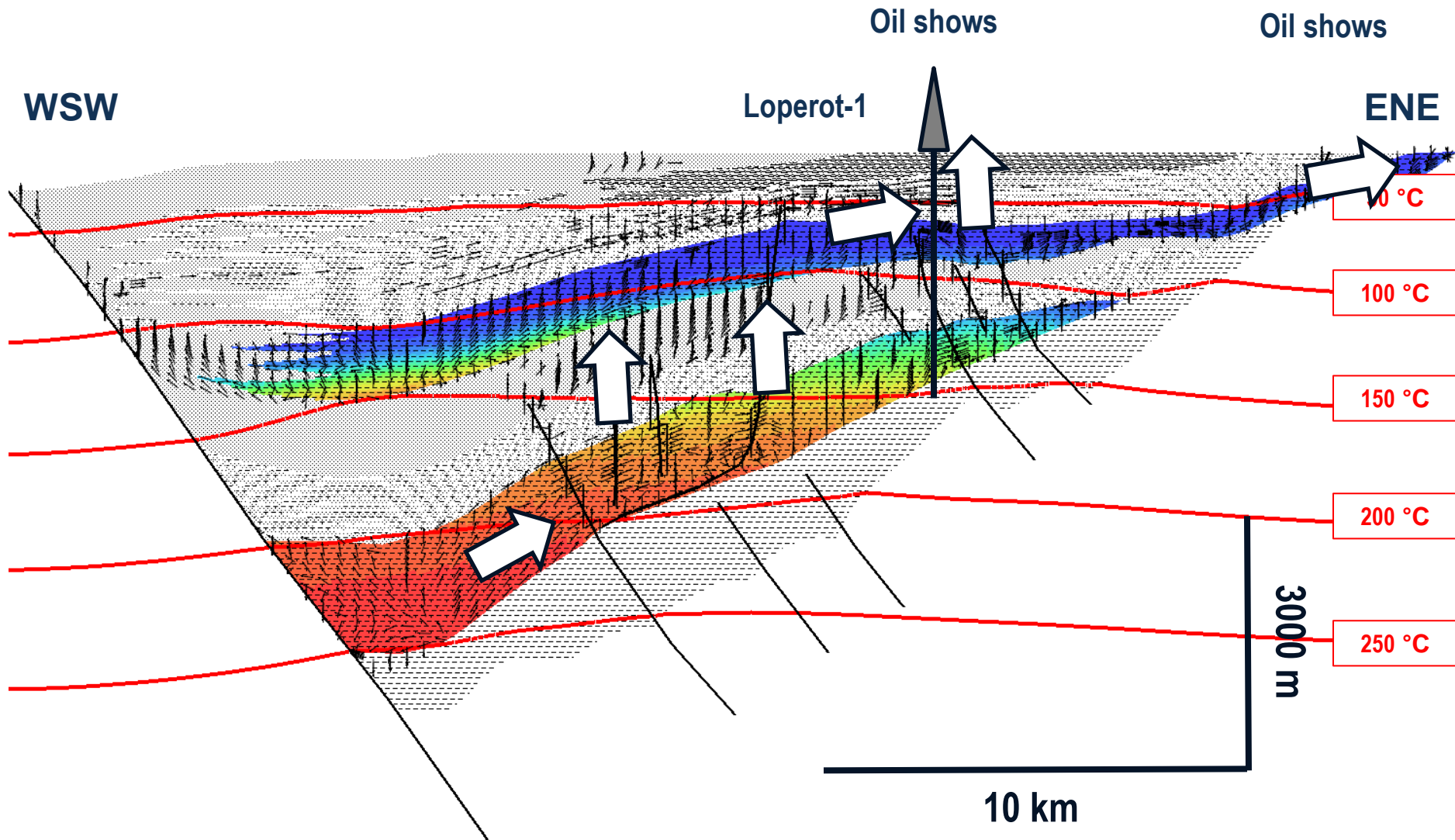
■ Hydrocarbon migration



Basin Modeling

- HC expelled from Loperot Shale (and some from Lokhone Shale) mostly migrate through fault zones towards rift flank (East)

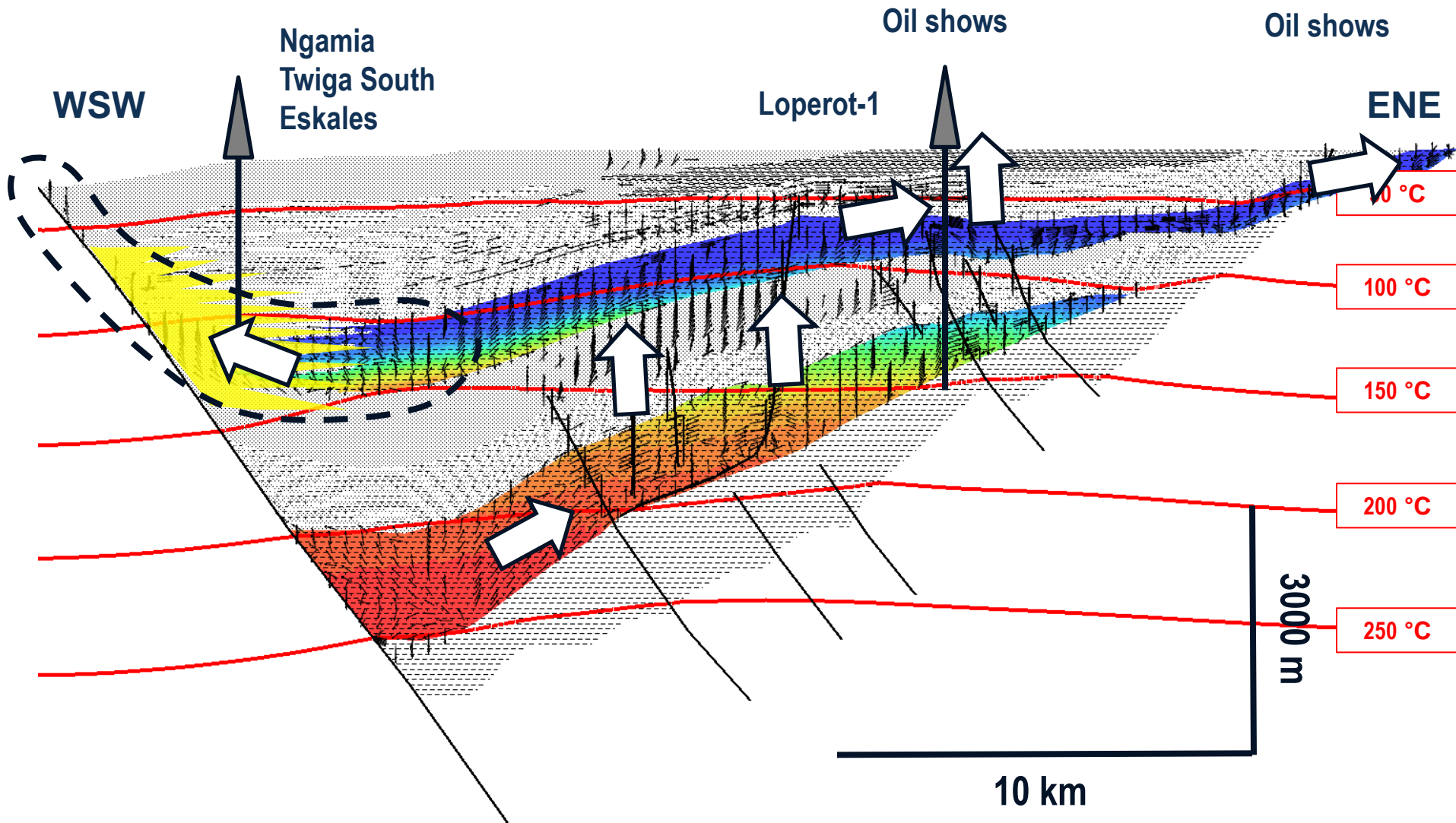
■ Hydrocarbon migration



Basin Modeling

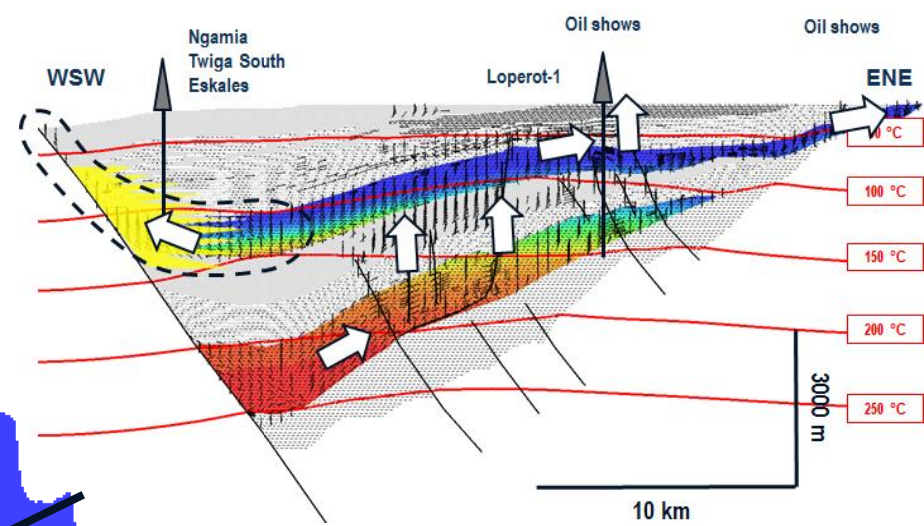
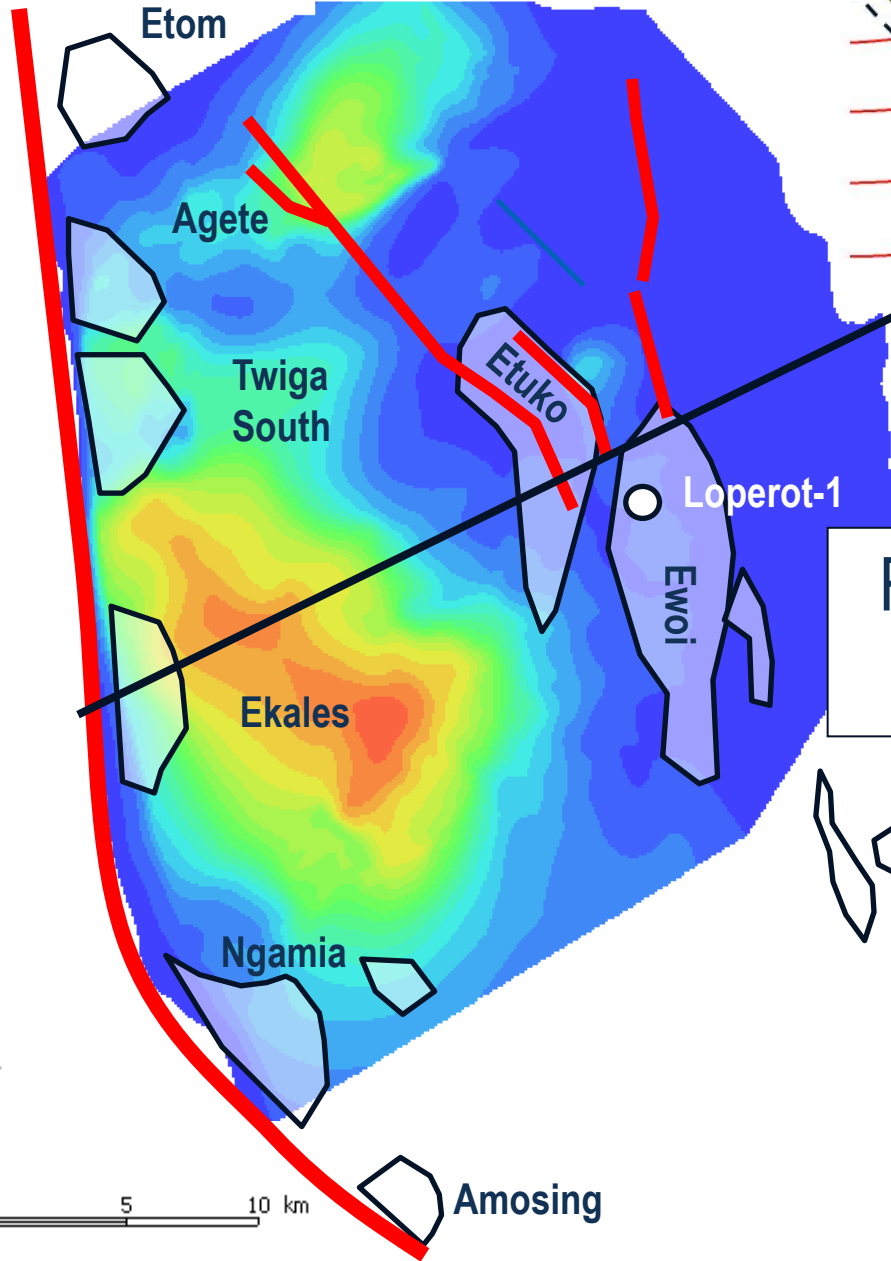
■ Hydrocarbon migration

- HC expelled from Loperot Shale (and some from Lokhone Shale) mostly migrate through fault zones towards rift flank (East)
- Charge from Lokhone Shale towards bounding fault



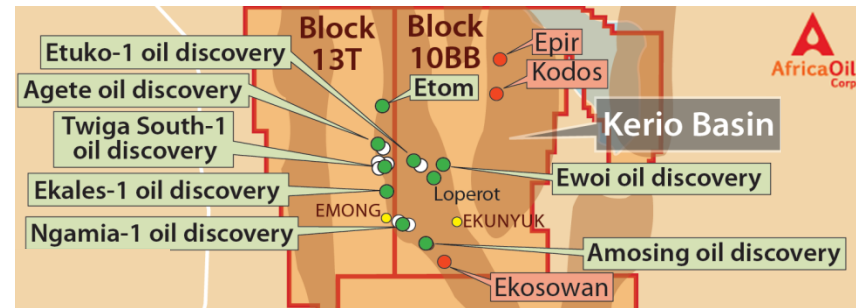
Lokichar Basin Revisited

“String of Pearls” Play



Rift Flank Play
(Loperot-1)

Ekunyuk



Where else?

■ Cenozoic Play

- Deposition of lacustrine source rocks are tied to tectonics
- Getting replaced by volcanics towards the north
- Lokichar Basin limited analogue only for neighboring North Kerio Basin

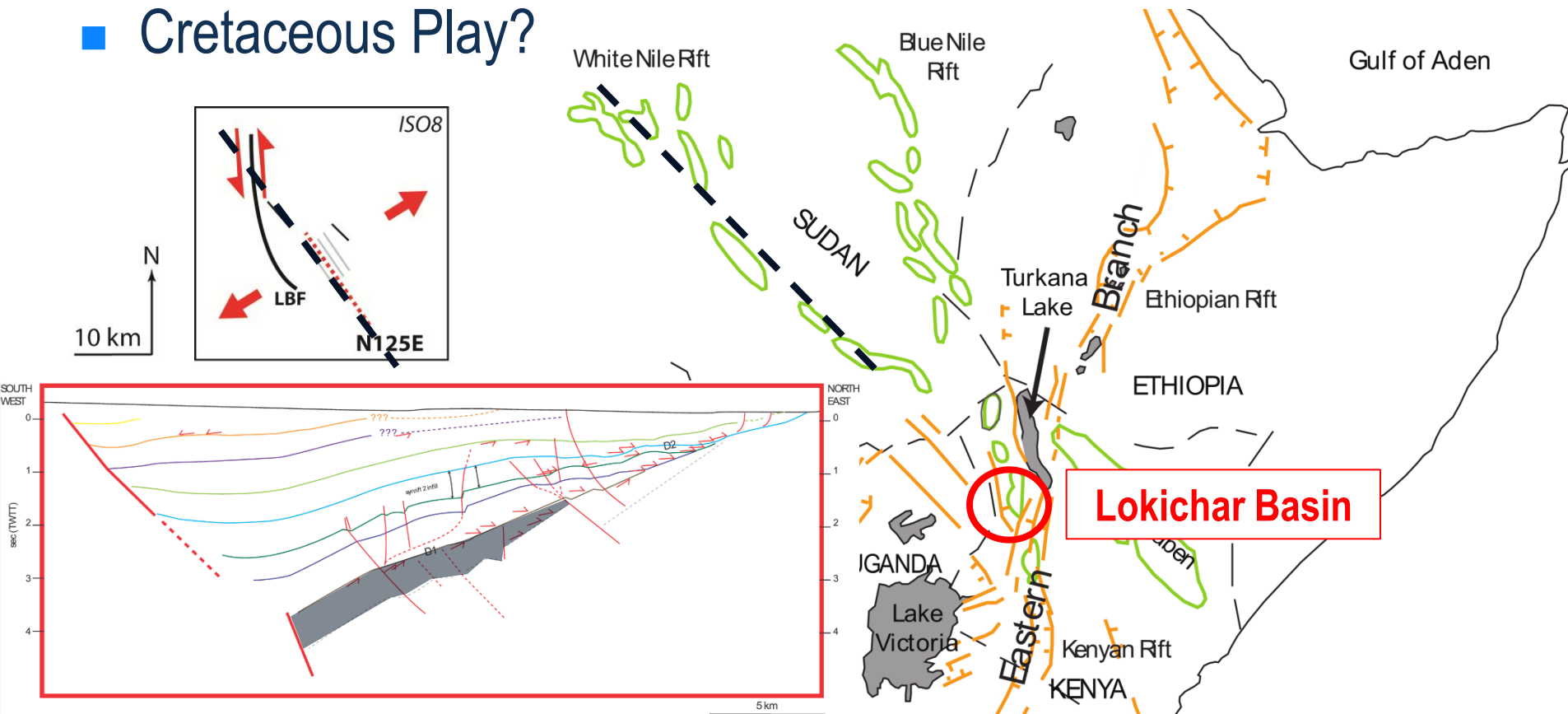


Where else?

■ Cenozoic Play

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■ Cretaceous Play?



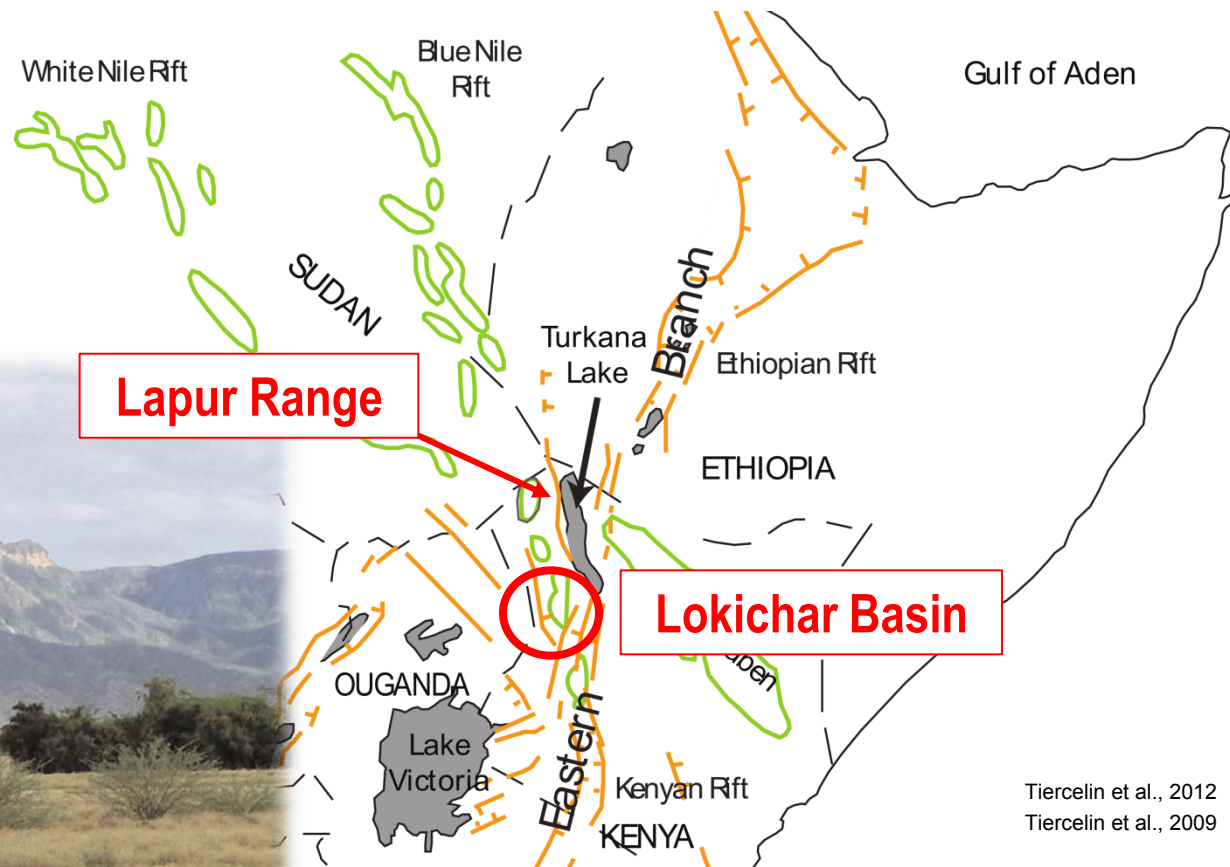
Where else?

■ Cenozoic Play

- Deposition of lacustrine source rocks are tied to tectonics
- Getting replaced by volcanics towards the north
- Lokichar Basin limited analogue only for neighboring North Kerio Basin

■ Cretaceous Play?

- Lapur Sandstones
- Reservoir quality?
- Gas?



Summary

- Two proven plays in the Cenozoic Lokichar Basin
- Shale resource potential?
- Analogue for other Cenozoic Basins?
- Deep Cretaceous Play in Lokichar Basin?

