Modern Seismic Imaging and Basin Modeling Reveals Sub-Basalt Hydrocarbon Potential of Offshore India*

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Abstract

Mesozoic sediments on the western flank of India are covered by flood basalts that were prevalent around the time of the Tertiary-Cretaceous boundary and impact petroleum exploration in offshore western India. Deccan Basalt blankets Kutch, Saurashtra, Bombay, and Kerala-Konkan basins along the western flank of the Indian peninsula. The Kerala-Konkan Basin has neither undergone extensive structural deformation nor has it been greatly influenced by the post-basalt fluvial sediment deposition systems. Gravity modeling studies rule out any large-scale underplating or thicker magmatic crust and indicate that the volcanism decreases to the south. Plate-reconstruction studies suggest restricted environment of deposition and favorable thermal domains during the early rift phase that were conductive for deposition and maturation of source rocks. Kerala-Konkan Basin is an ideal basin to evaluate the sub-basalt trap concept and study the thermal effect of flood basalts on the pre-existing Mesozoic sediments and potential hydrocarbon accumulations.

Analyzing sub-basalt sediments by seismic or drilling was always challenging due to the massive nature of the basalt so any additional knowledge that can be derived from existing data will have substantial value. In this study, we took an integrated approach using seismic and gravity interpretation, as well as petroleum systems modeling, to assess the sensitivity of the hydrocarbons and their properties to the thermal impact of the Deccan Basalt in Kerala-Konkan deepwater basin. Different scenarios are analyzed to account for the variation of factors, including reservoir and source rock properties and thermal effects to improve understanding of the nature of possible sub-basalt hydrocarbon leads and prospects.

The results of simulations and diverse scenarios indicate the possibility of sizable volumes of gaseous hydrocarbons that could be trapped against structural highs or stratigraphic pinch-outs against basalt.

This study analyses specific elements and geologic processes of sub-basalt petroleum system in the basin. Even with the limited available data, hypotheses can be more rigorously tested to determine the likelihood of hydrocarbon generation and preservation and the resulting prospectivity and hydrocarbon type distributions. This regional study of the Kerala-Konkan Basin provides an improved assessment of key risk factors related to the development of subbasalt potential petroleum systems through geologic time.

Selected References

Coffin, M.F., and O. Eldholm, 1994, Large igneous provinces: crustal structure, dimensions, and external consequences: Reviews of Geophysics, v. 32, p. 1-36.

Mathur, R.B., 1993, Status of hydrocarbon exploration in western offshore basins, India: Journal of the Geological Society of India, v. 41/4, p. 291-298.

Srinvasan, S., and B.M. Khar, 1995, Frontier basin exploration in India – Perspectives and challenges: Proceedings of Petrotech 95, New Delhi, Technology Trends in Petroleum Industry, v. 1, p. 3-19.

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WesternGeco International Limited (India)

Indian Institute Technology (IIT – India)

Schlumberger Information Solutions (SIS)

Sub-Basalt Strata Geophysical Imaging Introduction

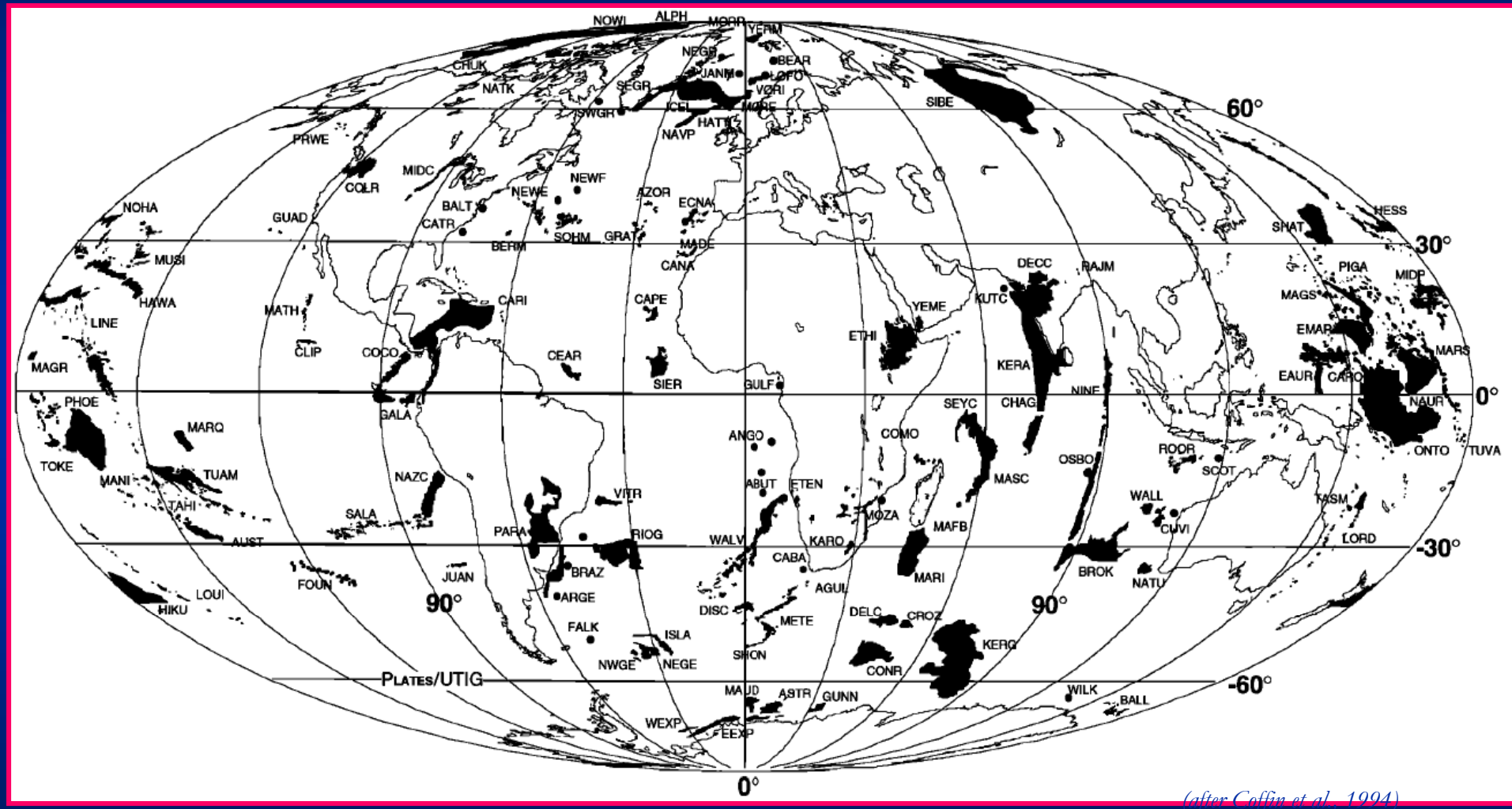
- Is the present state of modern technology able to generate adequate images for uncovering the potential reservoir systems below basalt through integrated interpretation of multi-measurements and basin simulation?
- The focus however is not only on imaging, as it is the understanding of sub-basalt geology and of pertinent petroleum systems that are key in regions with inadequate or no well information

Sub-Basalt Strata Geophysical Imaging
Thermal Regime

- Noteworthy worldwide are the large number of reservoirs in areas affected by igneous activity, fields with significant recoverable gas reserves.
- The associated features of igneous rocks provide exploration opportunities for sub-basalt, fractured basalt and intra-basalt reservoirs.
- Modeling of thermal effects over geological time is important.
- Possibility that hydrocarbons are destroyed when basalts are too thick and/or deposited too rapidly.

Worldwide Distribution of Volcanic Basins

Worldwide Magmatic Basins



(after Coffin et al., 1994)

Comparative Analysis

- Hydrocarbon potential
- Reserve, production and exploratory wells
- Basin analysis - source, reservoir, seal
- Rock properties
- Drilling

Challenges

- Exploration
  - Generate adequate images for de-risking the potential reservoir systems below basalt through integrated interpretation and basin simulation

    → Focus on imaging as well as understanding of geology and petroleum systems with reduced (or none) well information → Conceptual, Basin-scale Thinking → Geological Models

- Drilling and Production
  - Well-bore stability and penetration while drilling through basalt
  - Are the reservoirs beneath capable of delivering economic production?

Technology Integration

- Combining advanced seismic and non-seismic acquisition; processing and imaging; inversion; modeling; and interpretation

  → Negate the weakness of one method with the corresponding strength of the other by combining seismic and non-seismic with log measurements and interpretation

- Basin modeling / simulation for volcanic petroleum systems

  → Looking at source / reservoir / seal scenarios in connection with mapped structures through thermal modeling and maturation studies at basin scale under consideration of magmatism. Are the sediments "over-cooked" by volcanic activity?

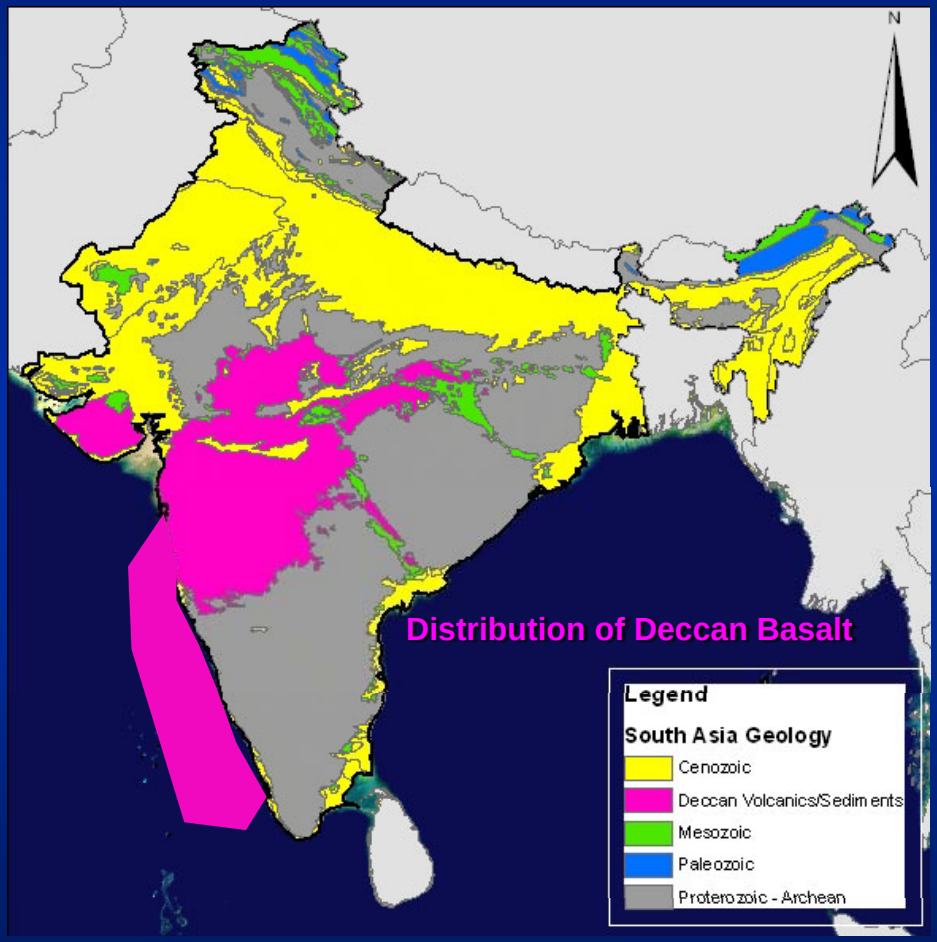
- Utilization of effective drilling and production technologies

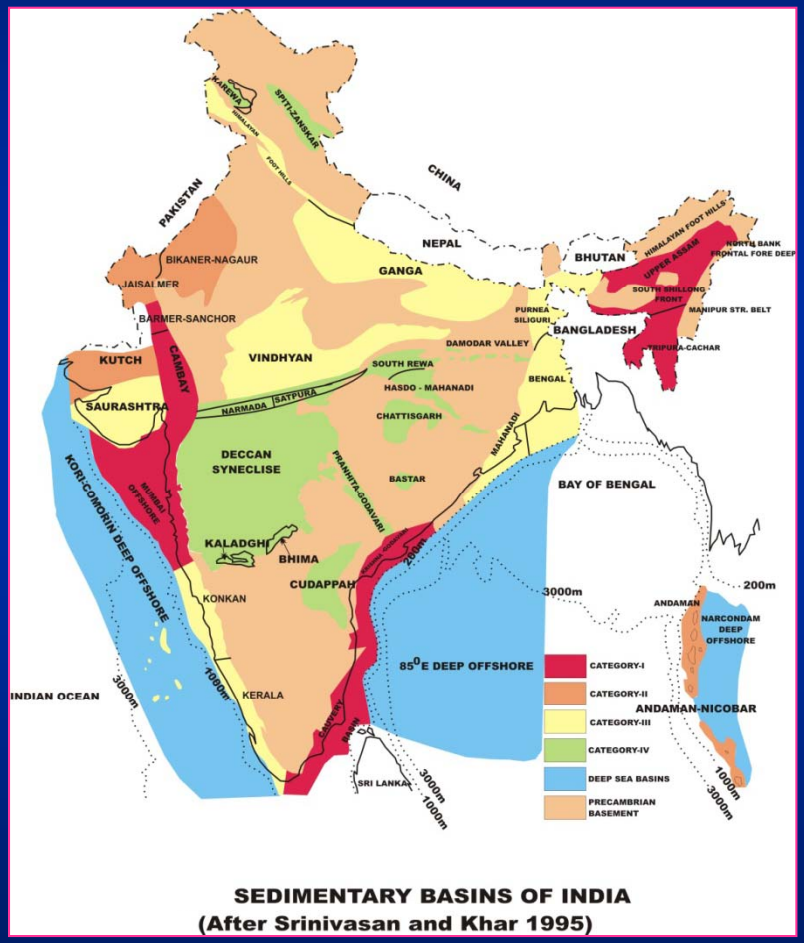
Seismic Imaging Problems

- Transmission losses due to near vertical rays penetrating the high velocity basalt as predicted by Snell's law
- Wave propagation through basalt lowers wavelet frequency
- Many sub-basalt reflections are multiples masking weak sediment interface reflections
- Interference (tuning) effects in basalt can make it difficult to estimate base basalt

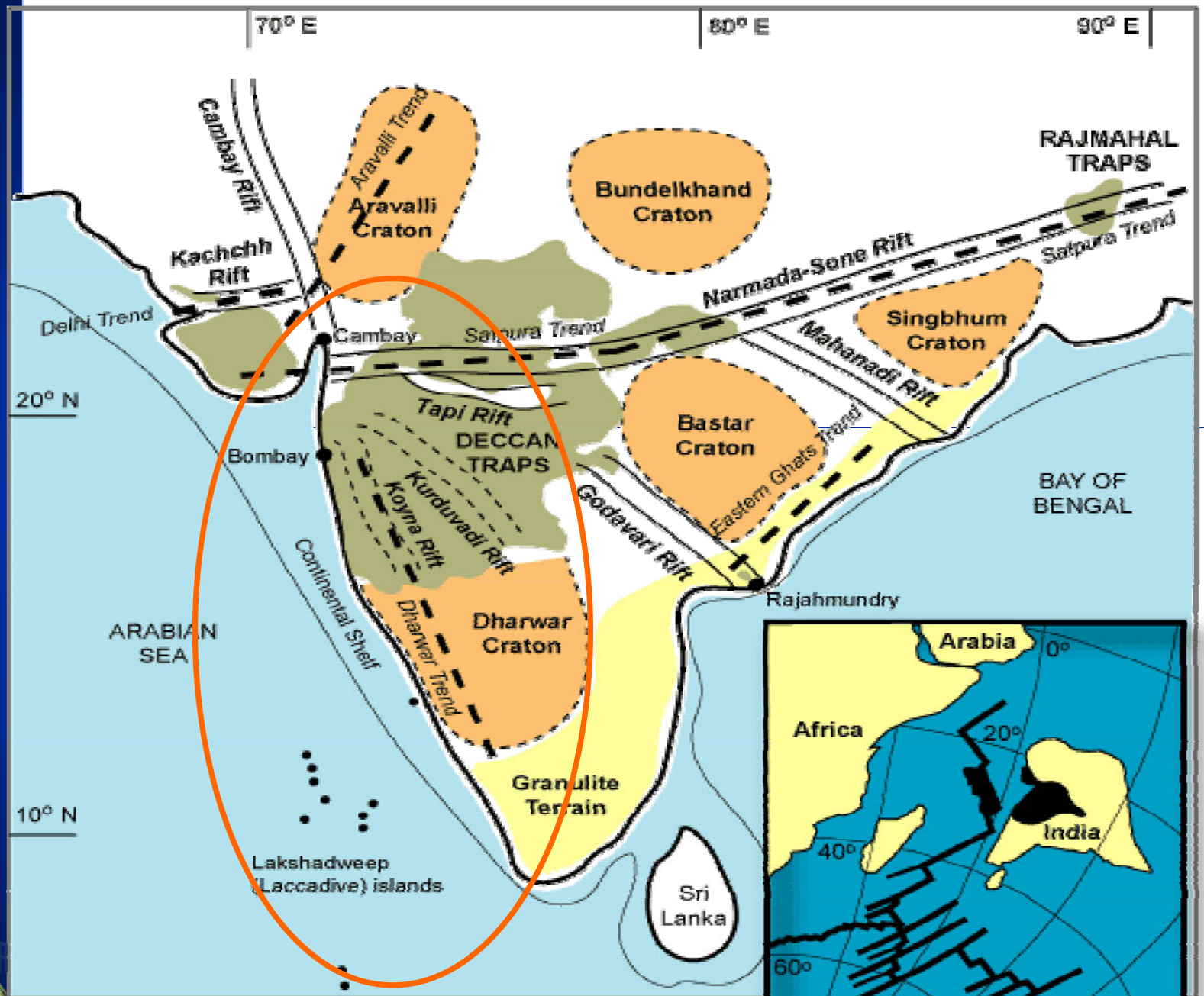
Deccan Traps

Indian Scenario



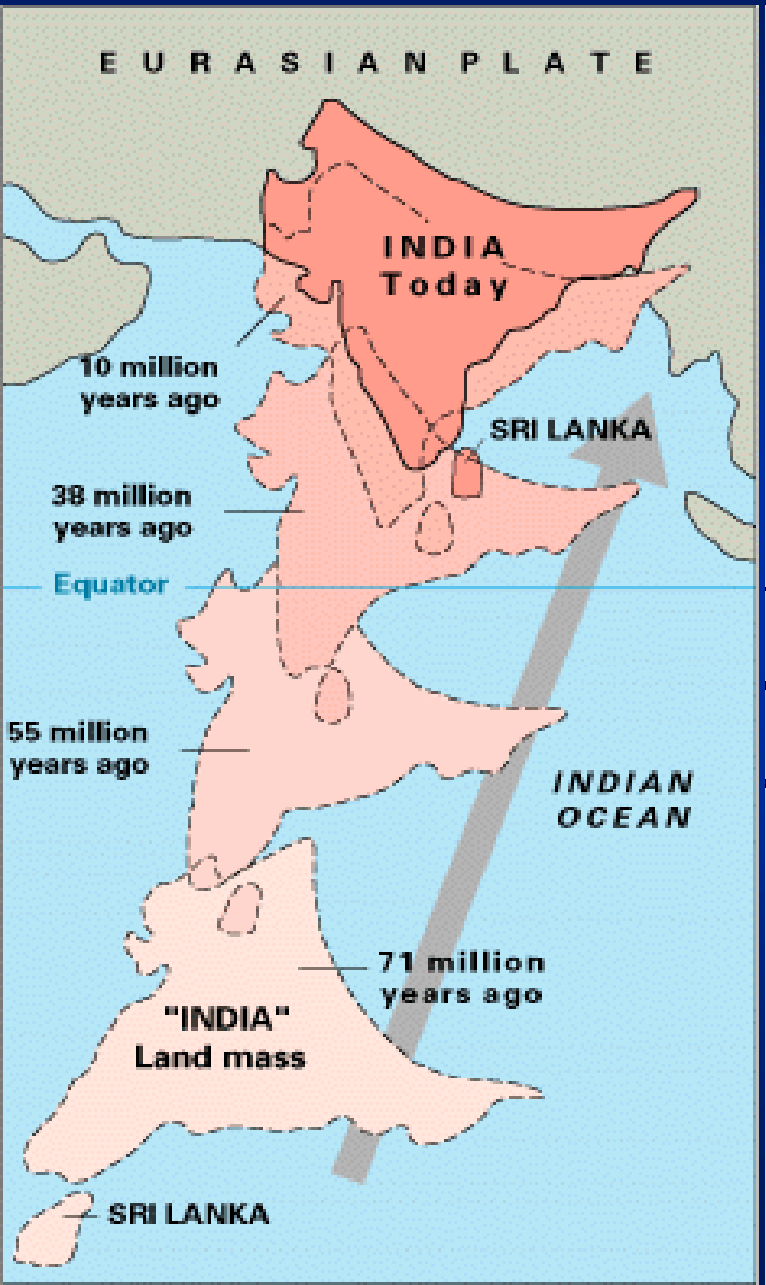


http://en.wikipedia.org/wiki/Geology_of_India

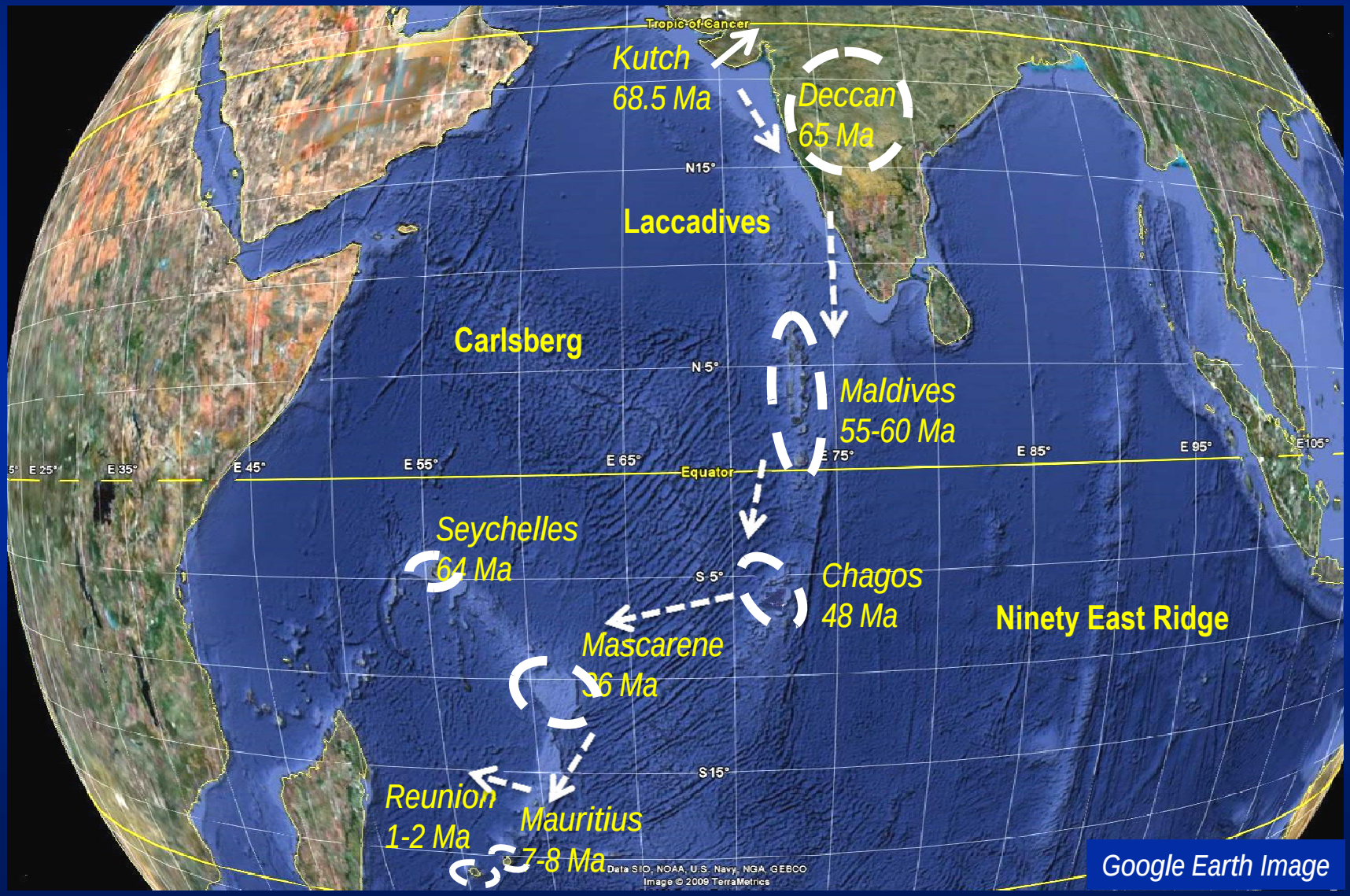

70° E
80° E
90° E
Cambay Rift
Aravalli Trend
Aravalli Craton
Bundelkhand Craton
RAJMAHAL TRAPS
Kachchh Rift
Narmada-Sone Rift
Satpura Trend
Delhi Trend
Cambay
Satpura Trend
Mahanadi Rift
Singbhum Craton
20° N
Tapi Rift
DECCAN TRAPS
Bastar Craton
Bombay
Kurduvadi Rift
Koyna Rift
Eastern Ghats Trend
BAY OF BENGAL
Godavari Rift
Continental Shelf
Rajahmundry
ARABIAN SEA
Dharwar Craton
Dharwar Trend
Granulite Terrain
10° N
Lakshadweep (Laccadive) islands
Sri Lanka
Arabia
0°
Africa
20°
India
40°
60°

Migration Path of India During Cretaceous
Reunion Hot-Spot
Collision with Asia – Formation of Deccan Traps

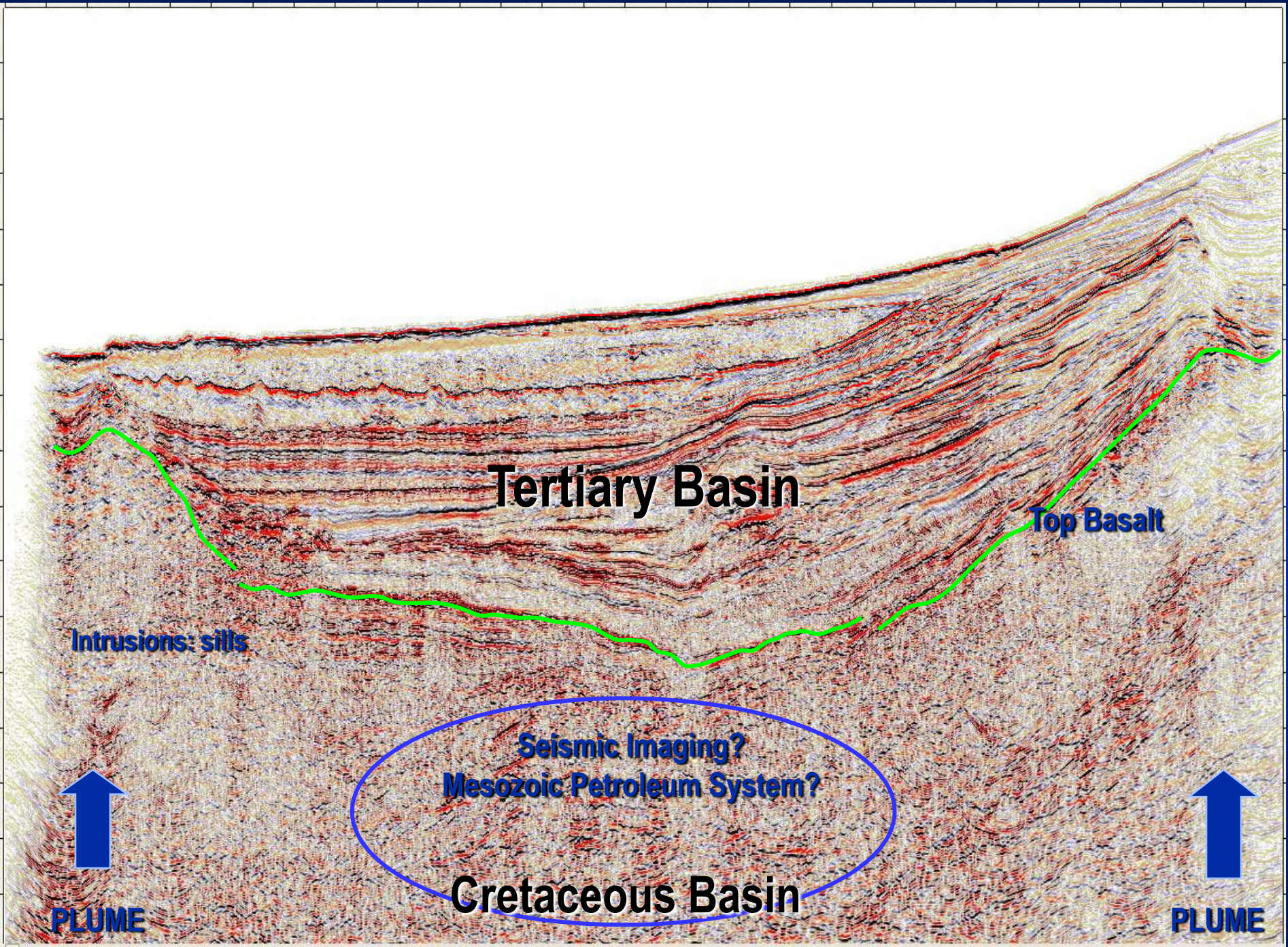
Flood Basalts and Plate Tectonics



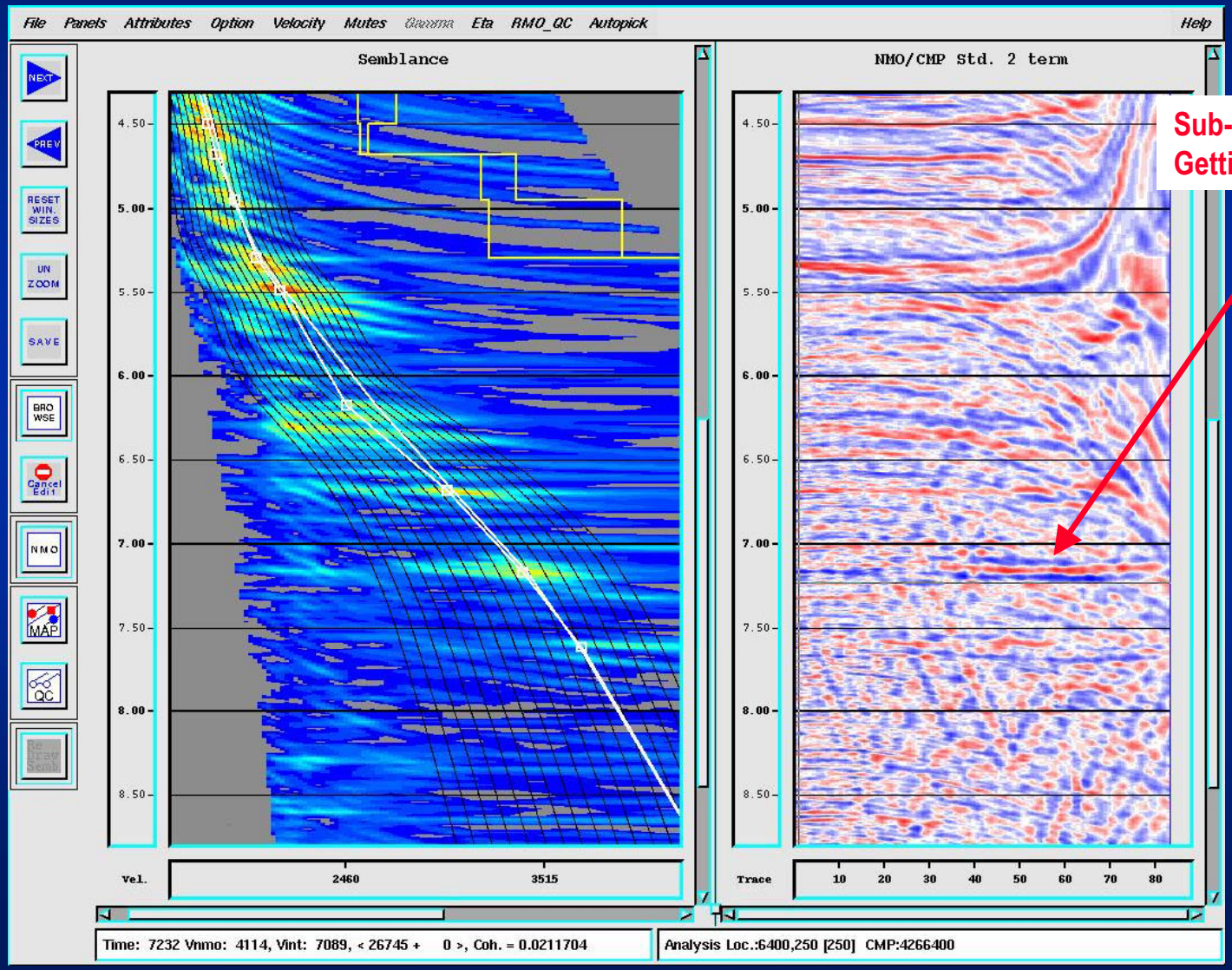
Basalt younging towards South



Modern Seismic Petroleum Systems Models


Tertiary Basin
Top Basalt
Intrusions: sills
Seismic Imaging?
Mesozoic Petroleum System?
Cretaceous Basin
PLUME
PLUME

Emphasis on Longer Offsets



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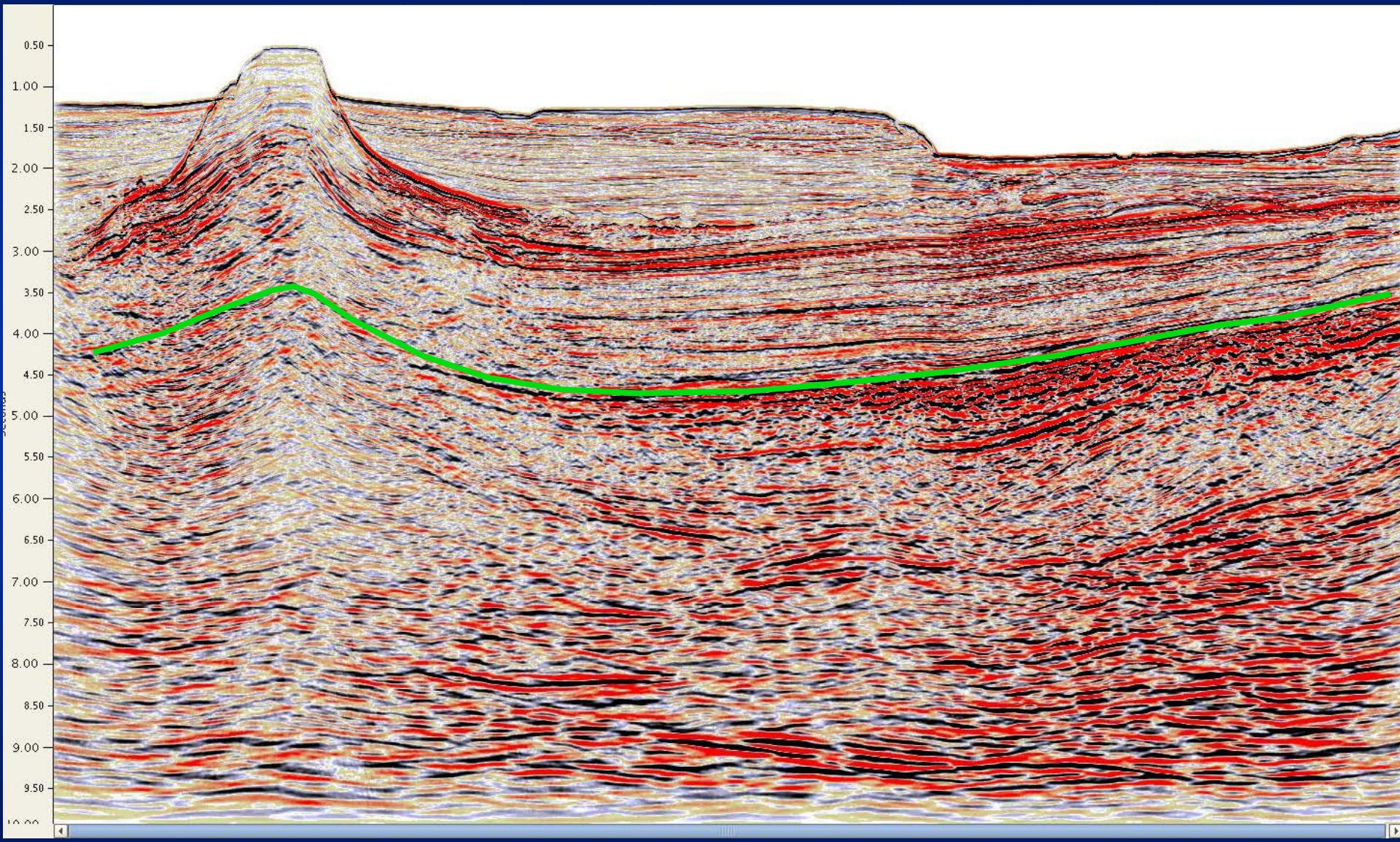
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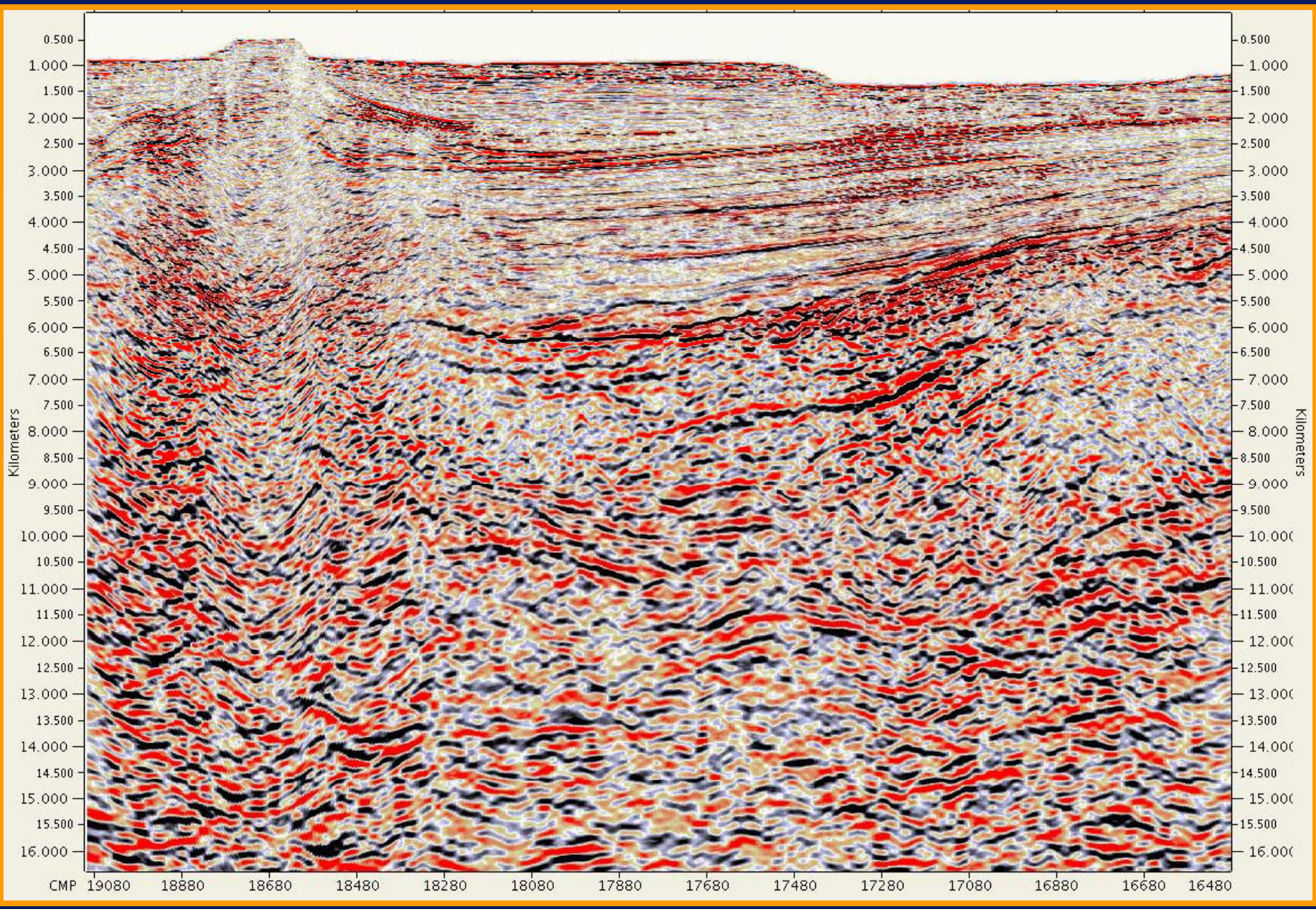
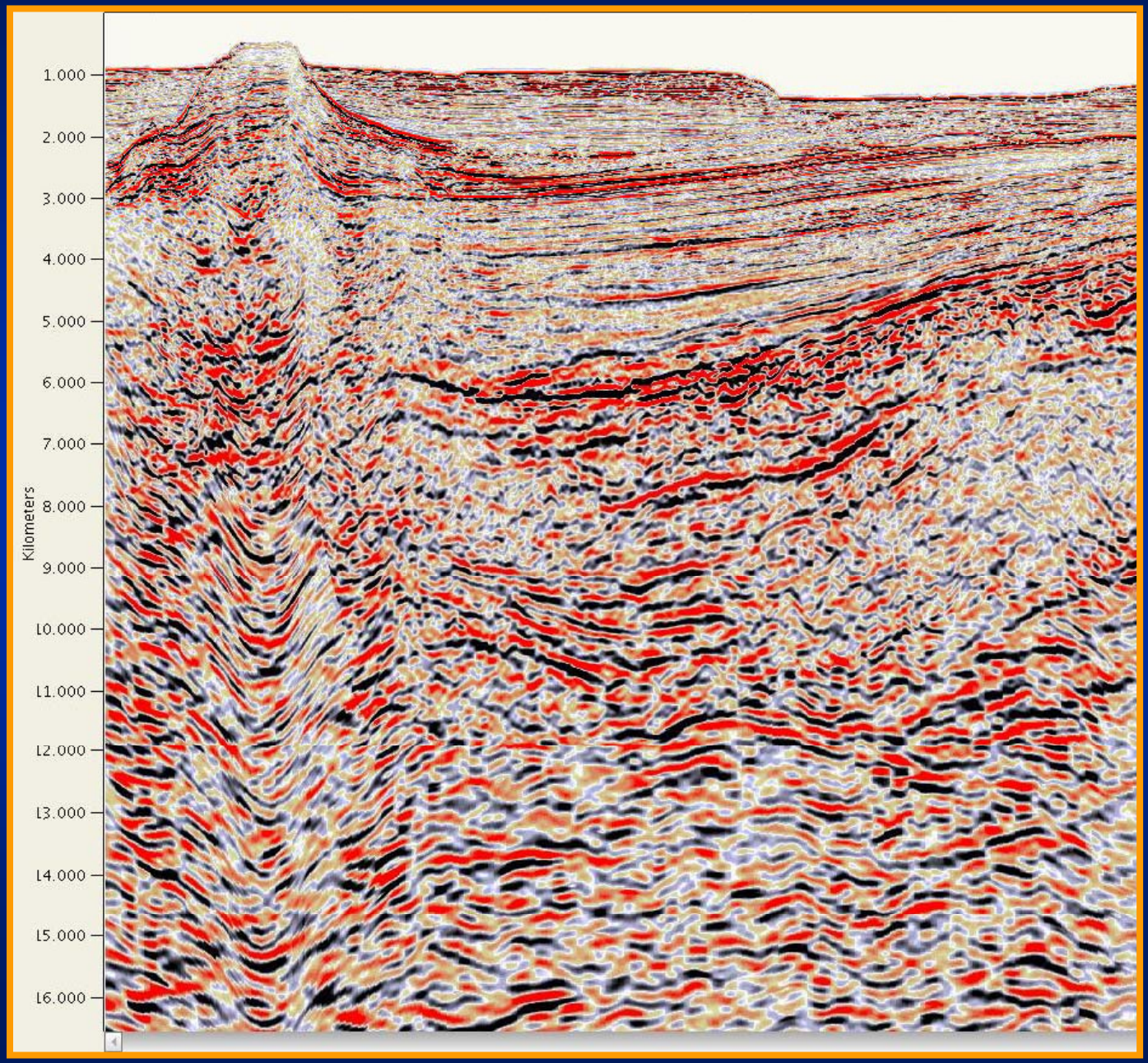
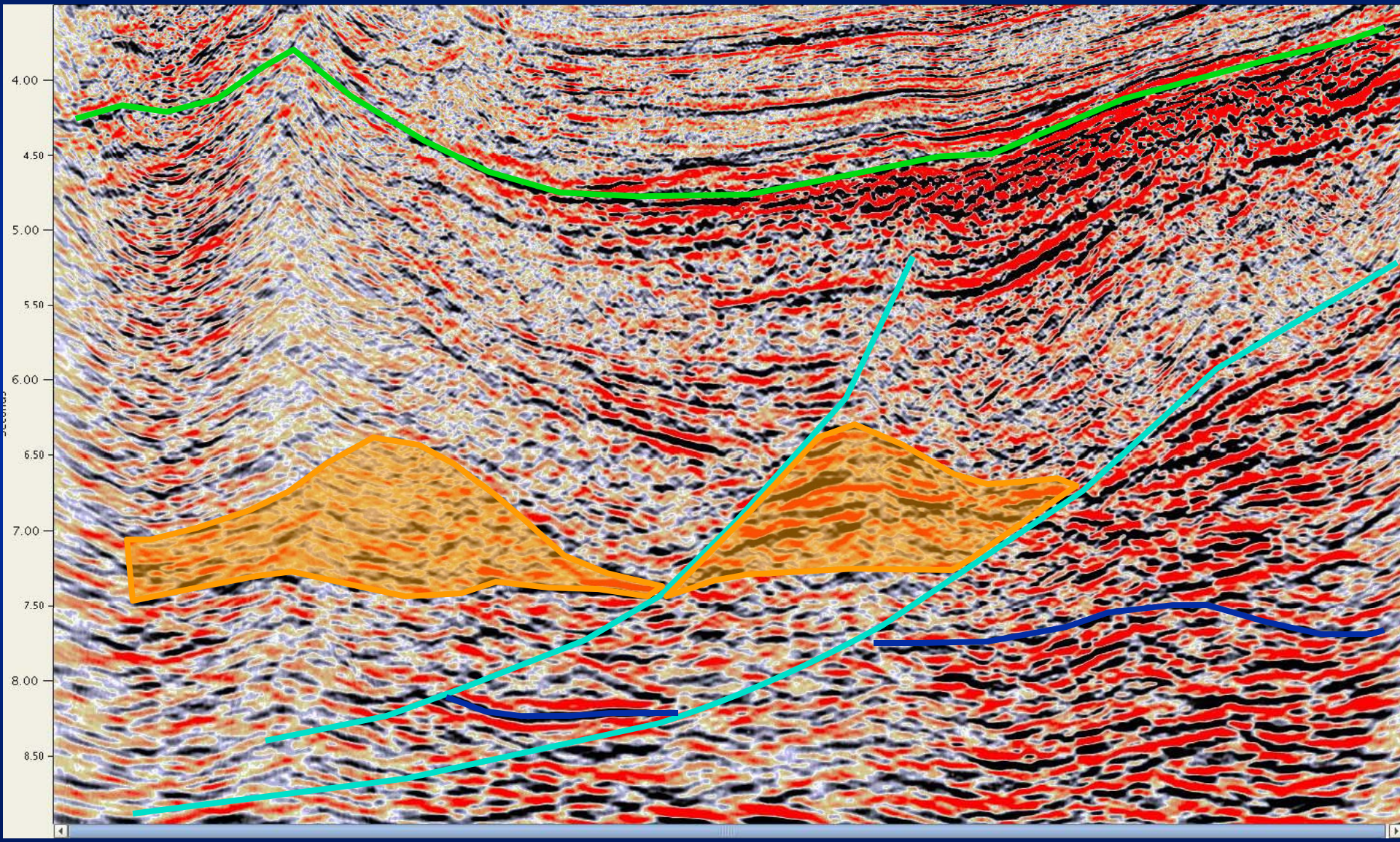
Over-Under PSDM

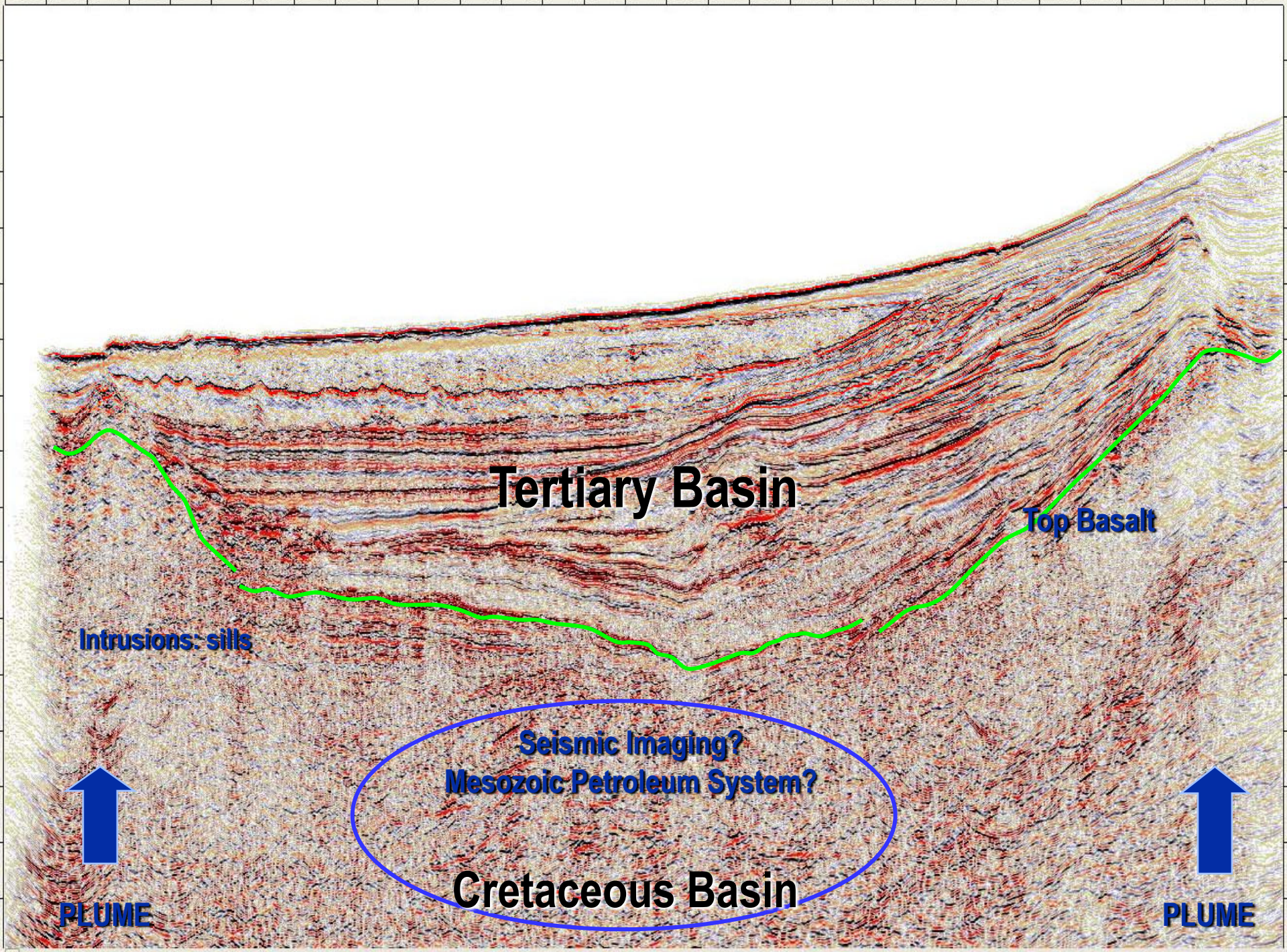


Kirchhoff PSDM

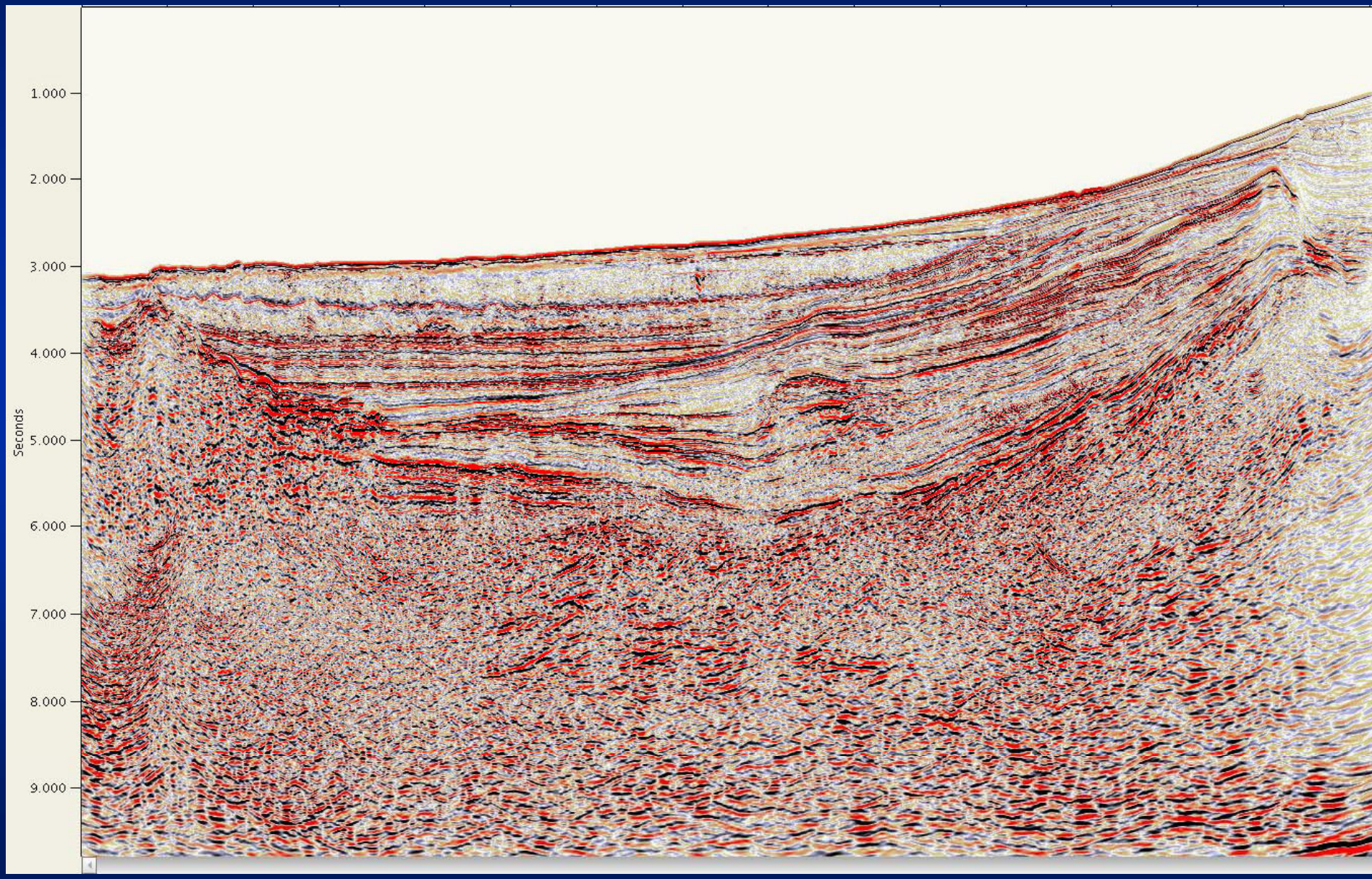


Focus on Top Basalt and Sub-Basalt

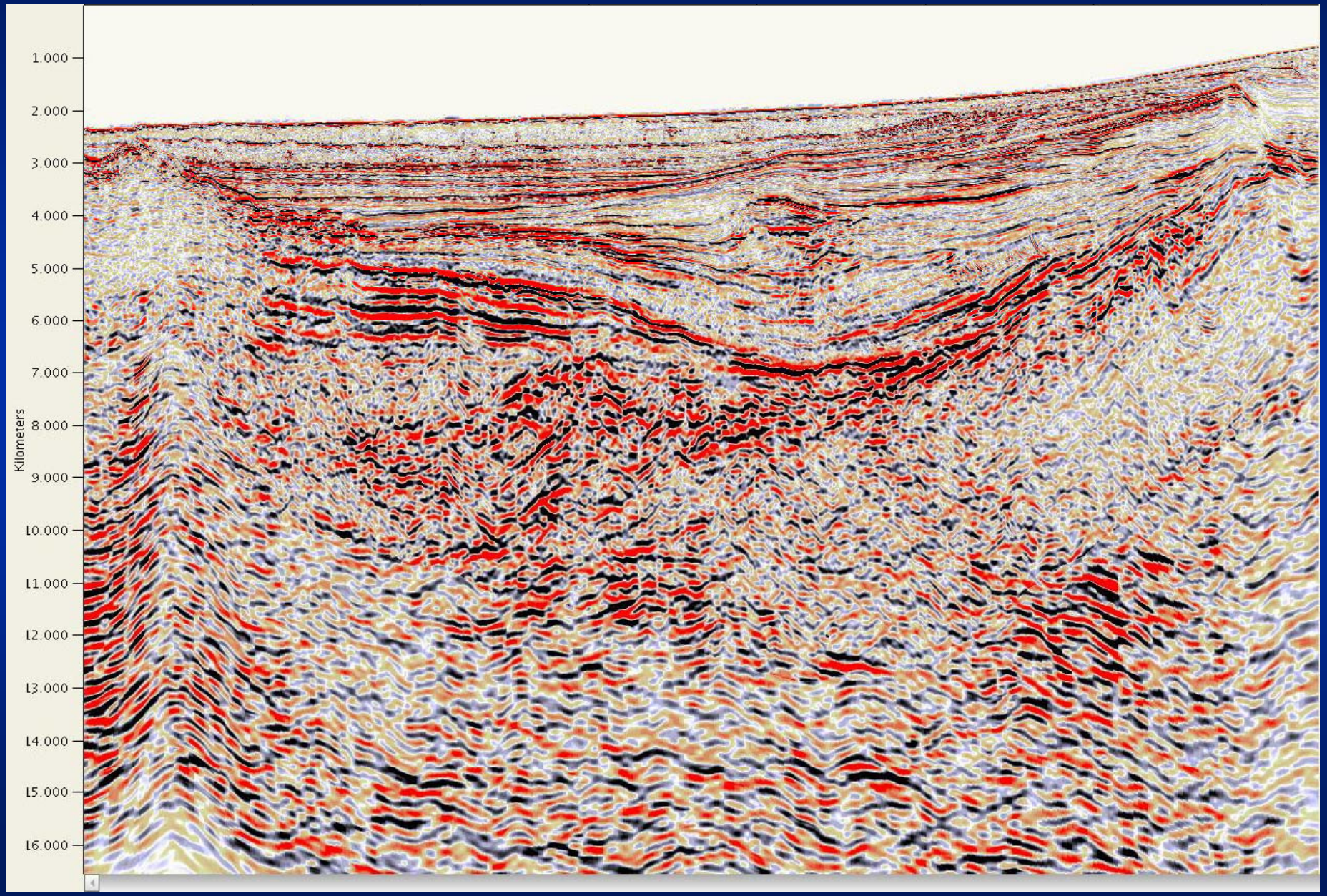



Tertiary Basin
Top Basalt
Intrusions: sills
Seismic Imaging?
Mesozoic Petroleum System?
Cretaceous Basin
PLUME
PLUME

Line A – Kirchhoff PSTM

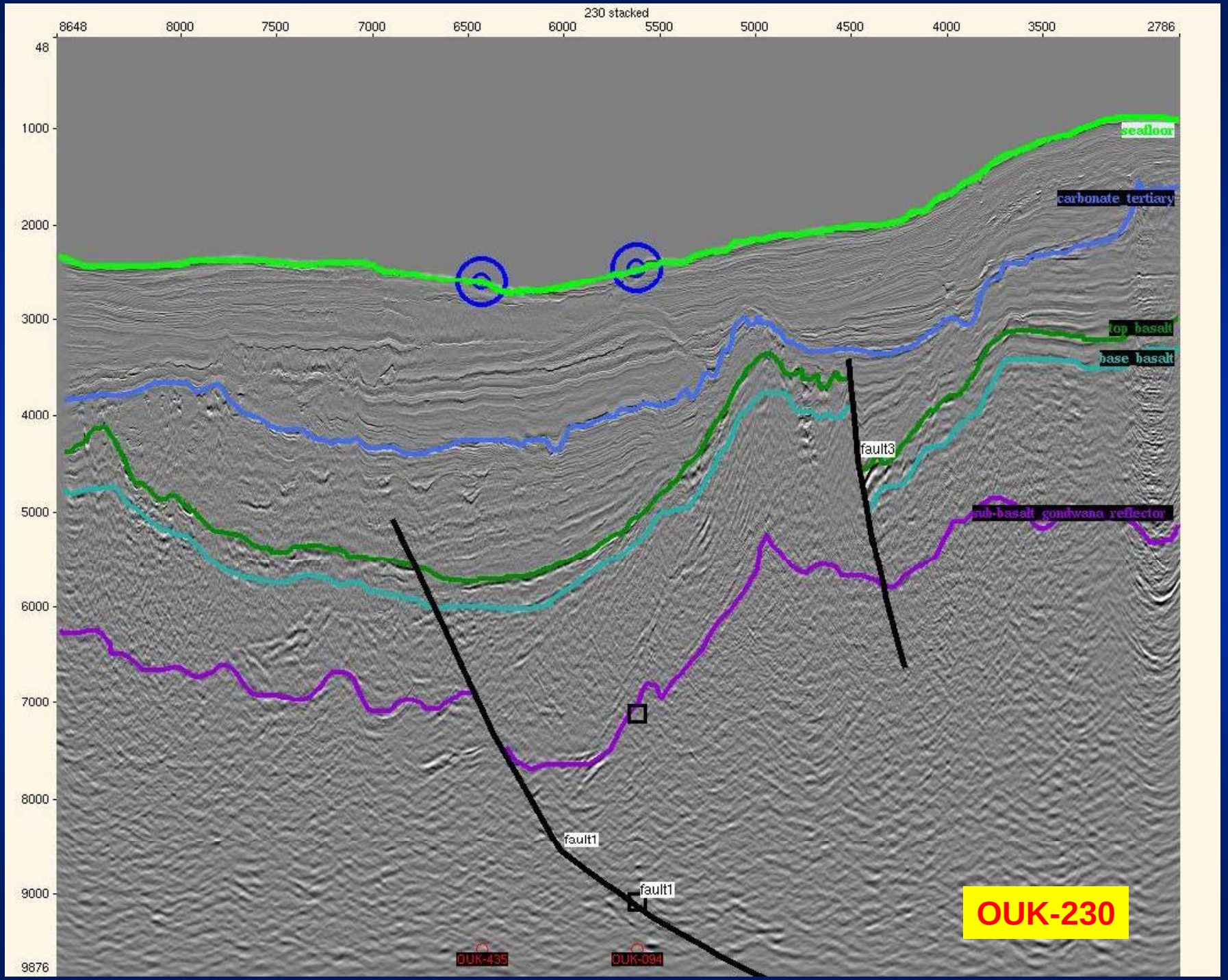


Line A (Dip) – Kirchhoff PSDM



Advanced Seismic Imaging – KK Over/Under Survey

- Main geophysical objective is improve overall structural imaging, with emphasis on sub-basalt imaging by enhancement of low-frequency energy
- The higher frequency content and improved bandwidth also improves seismic resolution
- Sub-Basalt events clearly identifiable, however spatial continuity still limited


230 stacked
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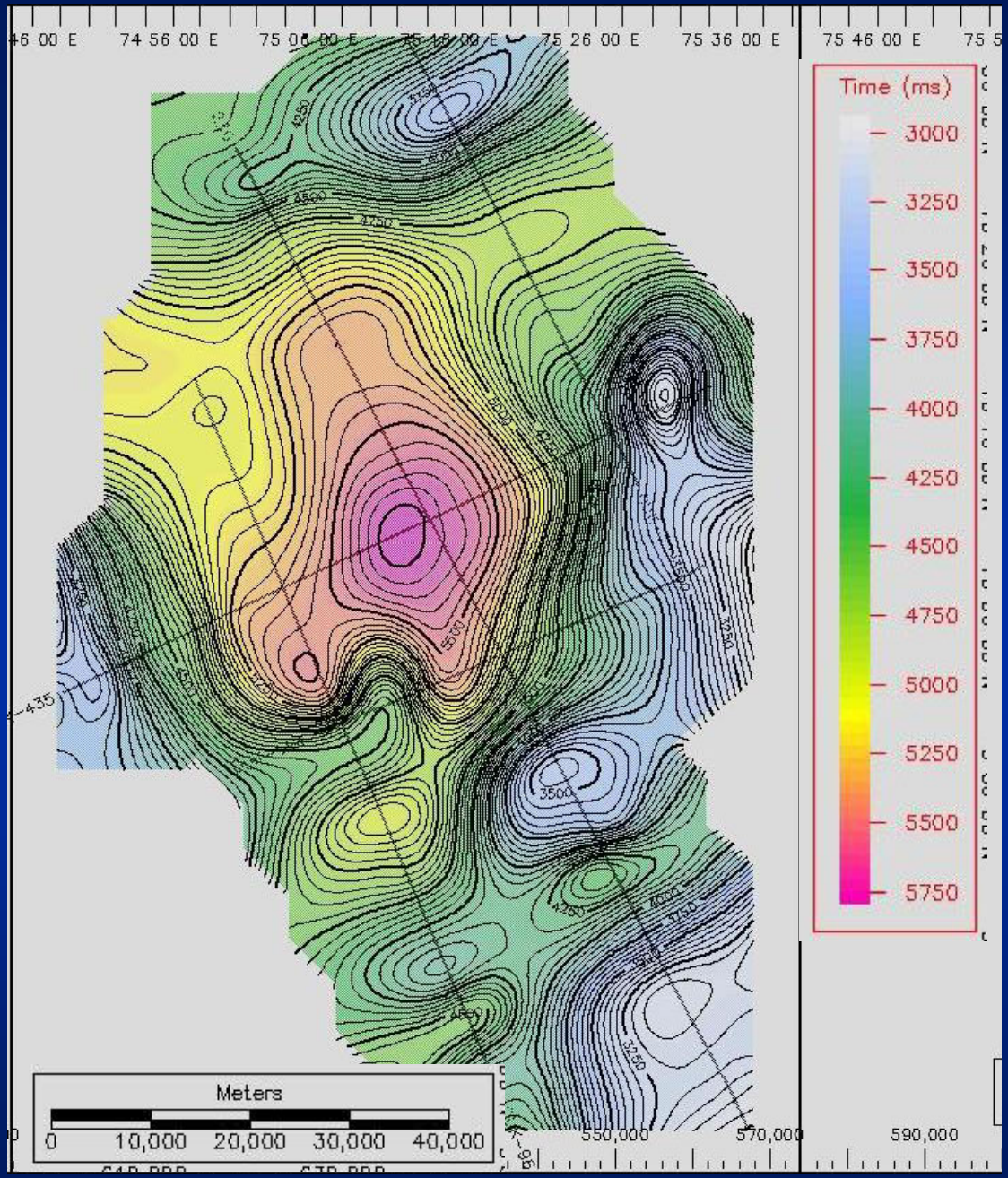
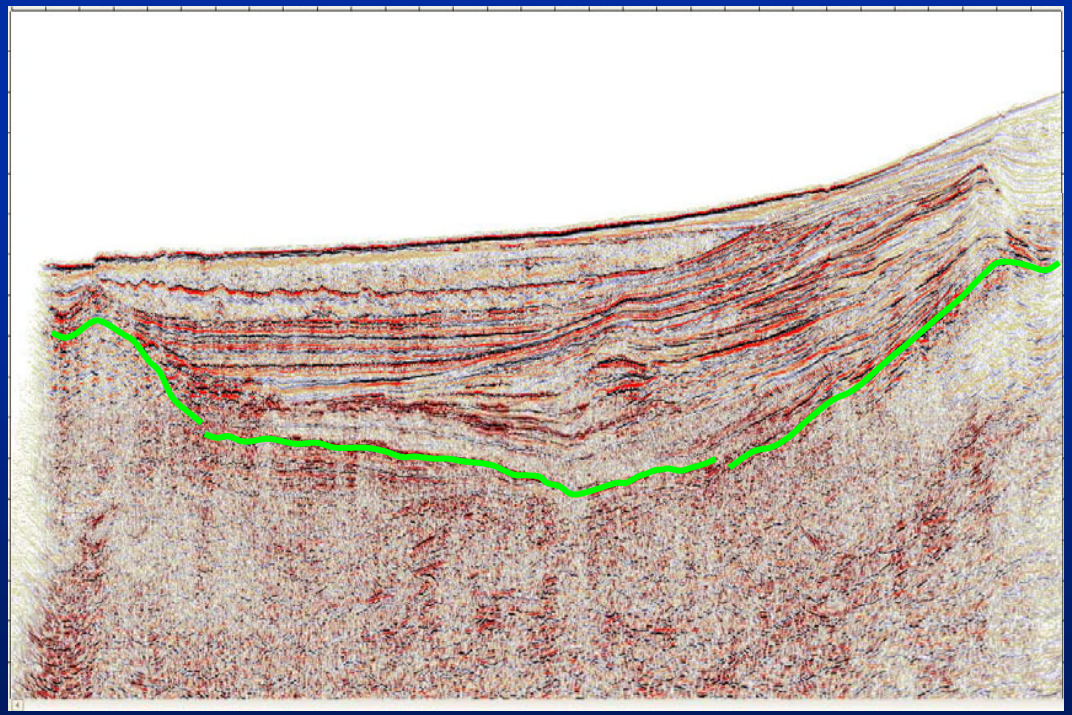
4000
5000
6000
7000
8000
9000
9876
seafloor
carbonate tertiary
top basalt
base basalt
sub-basalt gondwana reflector
fault3
fault1
fault1
OUK-435
OUK-094
OUK-230

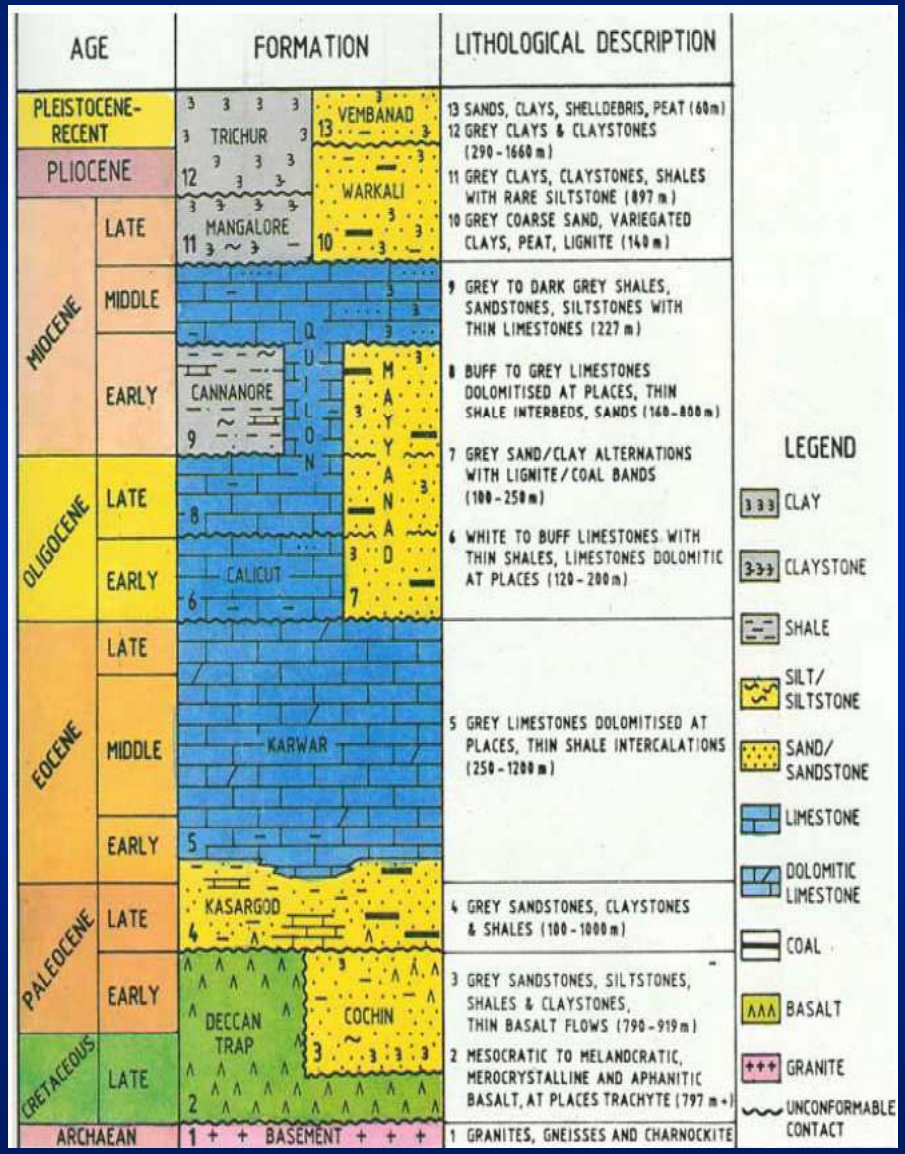


Top Basalt West India (TWT-PSTM)

Petroleum Systems Modeling

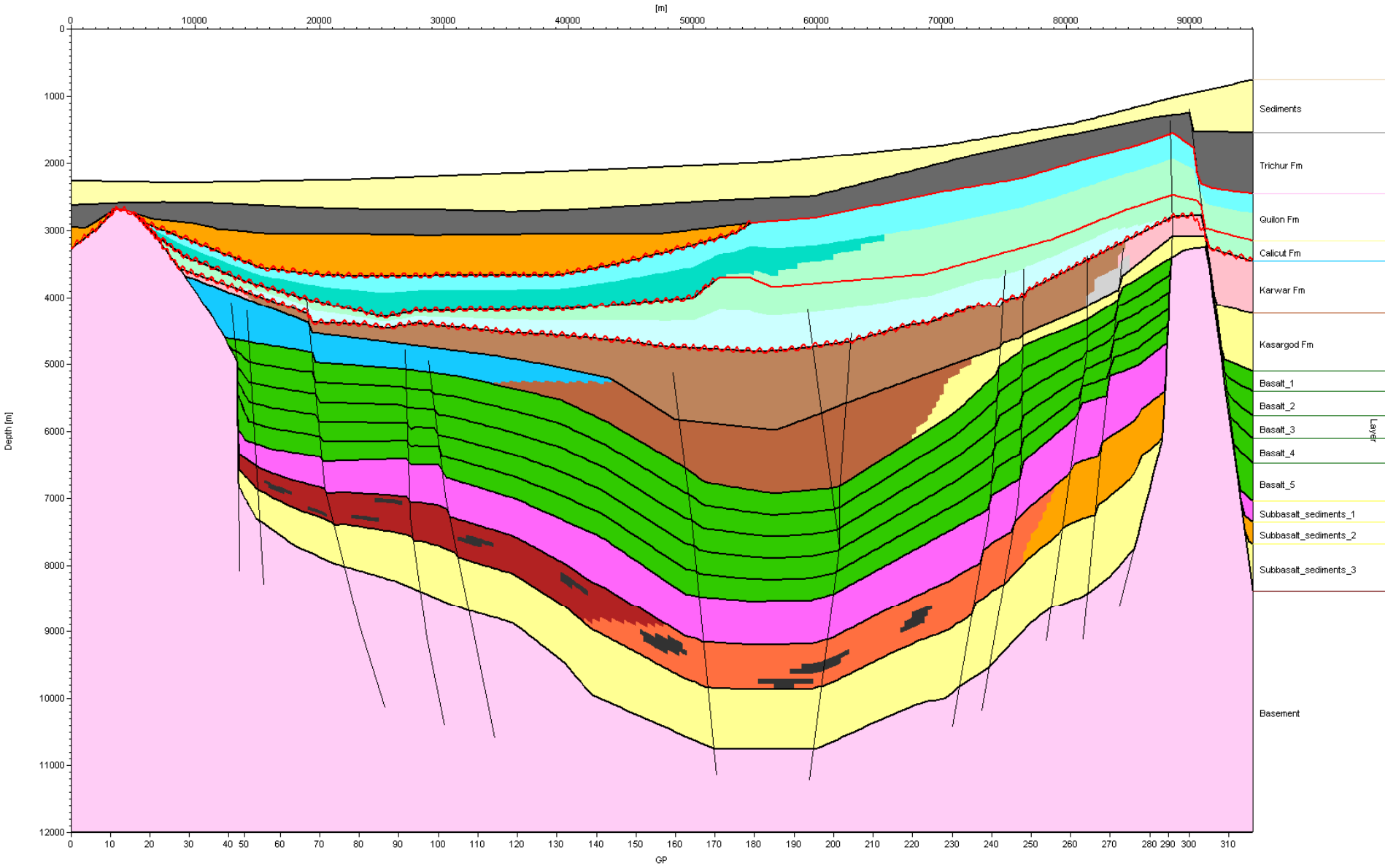


Lithostratigraphy and Facies definition of Kerala-Konkan Basin model

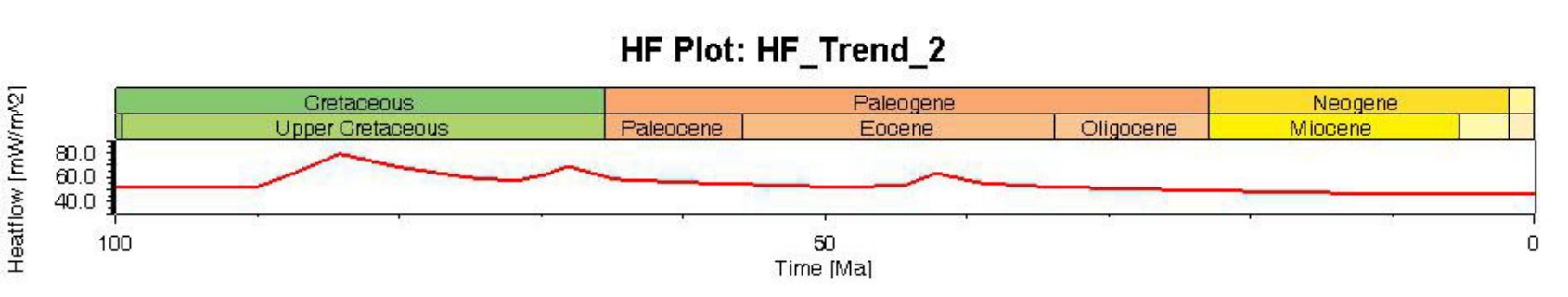


Mathur (1993)

Deep-Water Kerala- Konkan Basin
Petroleum Systems Two-Dimension Interpretive Model



Thermal History of the region

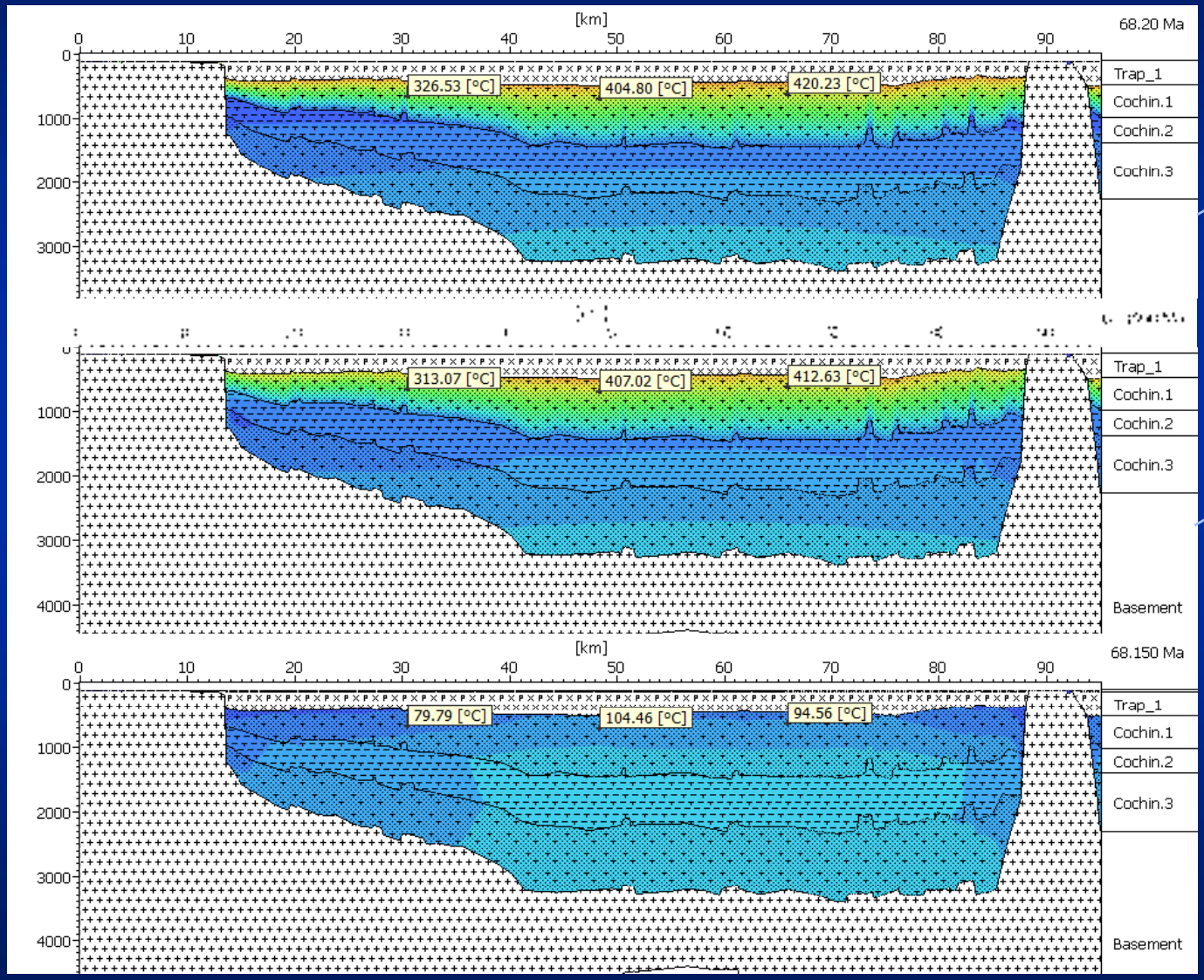


1. The first peak describes the breakup between India/Madagascar and Gondwana (Africa) in the Turonian (~89 Ma) and has the biggest thermal impact.

2. Second peak at ~65 Ma (Early Paleocene) is related to the separation of Seychelles and India.

3. Third peak at ~35 Ma, having the lowest temperature effect, is the collision of India and Asia in Priabonian time

Temperature effect of first Eruptive Phase

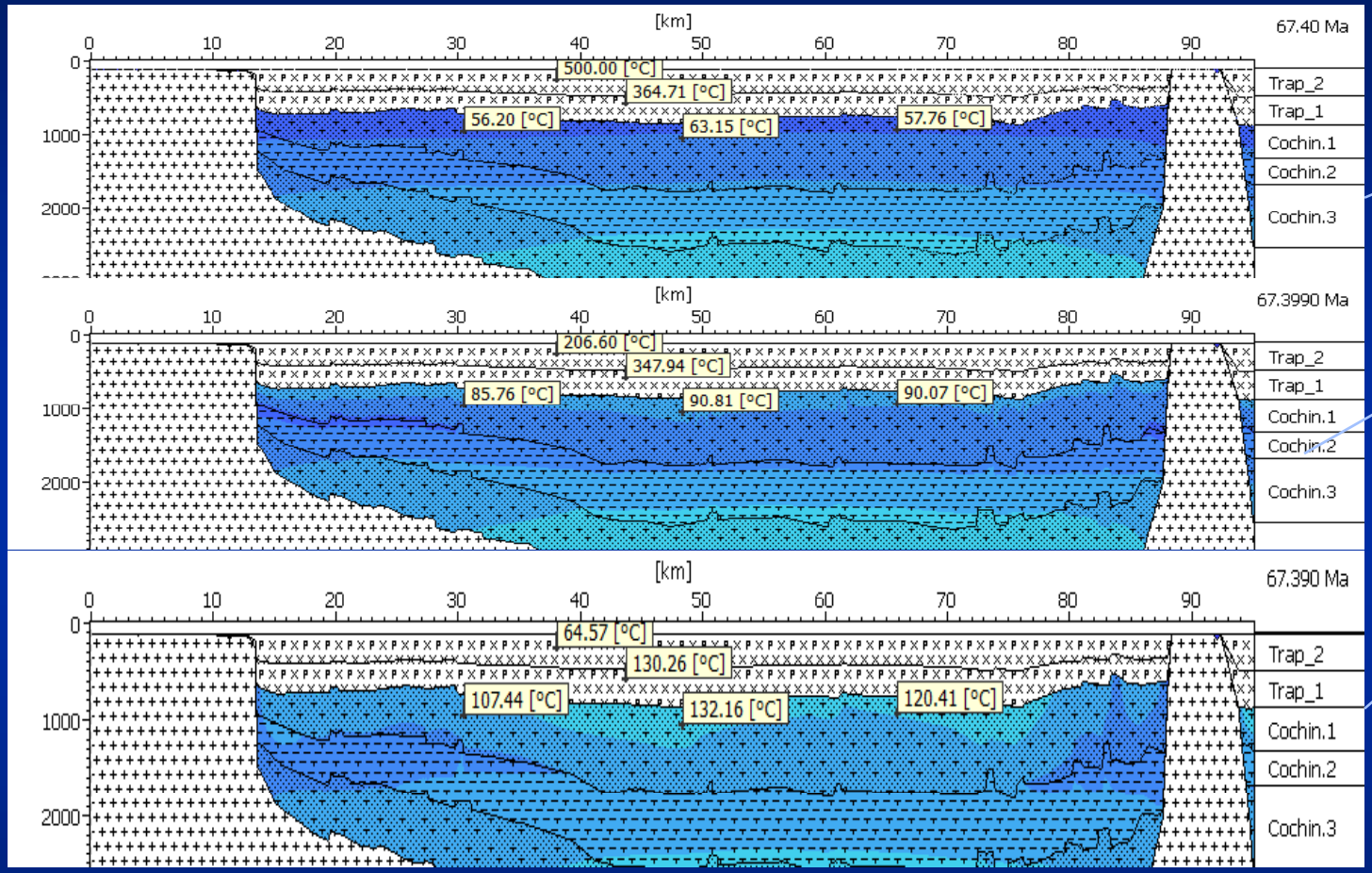


First Eruption

After 1000 years
Temp. decreased
But still elevated

After 50,000 Yrs
Temp. equilibrated

Temperature effect of Second Eruptive Phase



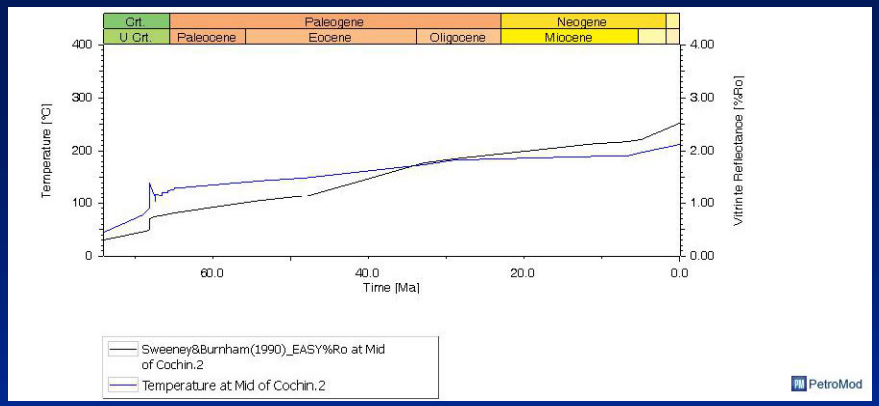
2nd Eruption:
Delayed temp. effect on underlying sediments, because of insulation of cooled first erupted bas

After 1000 years:
Sediments below are heated up

After 10,000 Yrs
Temp. decreased, going for equilibriation

Effect of volcanic eruptions on underlying sediments is very short-term and limited in spatial distribution.

The temperature effect on underlying sediments is decreasing between the first and the second eruption event.



Only the first eruptive phase has a significant impact on temperature evolution of the pre Deccan sediments. The extent of thermal effect in distance wise may be within few hundreds of meters. In this case, the possible effects on generation in potential source rock is also very negligible.

Petroleum migration is simulated with `hybrid` petroleum migration modelling which is an integration of Darcy and flow-path migration methods and enables pressure, volume and temperature controlled hydrocarbon phase calculations.

As the source rock is underlain by reservoir quality sandstone of continental origin, hydrocarbons can also be expelled downwards to be trapped.

Petroleum migration scenarios were also tested by changing parameters like the lithology and nature of faults of the reservoir rock of the sub basalt petroleum system.

(i) homogeneous lithology and
(ii) layered lithology,
(iii) closed faults throughout the basin evolution and
(iv) open faults during various major events of rifting.

Conclusion of PSM:

- The result of the simulations and diverse scenarios reflect the possibility of the existence of sizable volumes of gaseous hydrocarbons that could be trapped against the structural highs.

- Although volumes of the postulated hydrocarbon reserves are quite similar for all of the studied models, the very sparse hydrocarbon reserves that have been found so-far in the sediments above the basalt could be the effect of dispersion of previous gas migration through leaky faults in periods of higher tectonic activity.

- Still, we may conclude that under basalt, gaseous phase hydrocarbons are more likely to exist. Both high basal heat flow during early rifting and the Deccan igneous events could also have enabled secondary cracking of the oil into gas. The remaining major challenge therefore is to properly map Mesozoic sedimentary structures as opposed to effects caused by the profuse lava flows

Sub-basalt Geology Outlook

Geology Basis (1)

* Basalt studies: stratigraphy, composition, mineralogy, geochemistry, layering, fracturing, faulting

* High resolution characterization of reservoirs preserving detailed heterogeneities of the basalt and possible intra basalt reservoirs. Outcrop usage! Merge heterogeneities at different scales into a geological meaningful model. Deterministic basalt model rather than stochastic.

Geology Basis (2)

* Problem of absolute age dating of magmatic and source rocks offshore in the absence of wells and suitable outcrops is evident . DSDP sites
* Geochemical analysis of HCs and rocks (most important parameters are the TOC (total organic carbon), vitrinite reflectance, hydrogen index and transformation ratios):
  - revealing biomarkers and type of kerogens
  - providing link to nature of source rocks
  - insight to oil migration paths
  - correlation of source rocks among different basins

Geology Basis (3)

* Importance of Bio-stratigraphy (use of biomarkers):

- - thermal history of organic material / levels of maturity at which oil was generated (with increasing maturity the concentration of the biomarker decrease) => revealing paleo-temperatures
- - commonly used for paleo-environmental and source assessment of sedimentary organic matter
- - Analogous! Most basins are treated independently, common factors in basalt covered areas worldwide.

Main elements of sub-basalt exploration workflow

- Geology:
- Basin Analysis and Modeling: Palinspastic Reconstruction, Plate Tectonics Evolution, Maturity and Source Rock Simulation, Geochemistry, Age Dating
- Geophysics:
- Multimeasurements, Long-Offset Seismic Data, Multicomponent, Forward and Inverse Modeling: Gravity, Resistivity, Magneto-Tellurics, Seismic Refraction & Reflection, PSDM, Low Frequencies, De-multiple, Well-log Response Analogs

Geophysics Imaging

- Multi-measurements:
- Long-Offset Seismic Data
- Multi-component – Shear Waves
- Forward and Inverse Modeling: Gravity, Resistivity, Magneto-Tellurics, CSEM
- Seismic Refraction & Reflection, PSDM, Low Frequencies, De-multiple
- Well-log Response Analogs – VSP's

Workflow KK Basin

- **Understand results through modeling and interpretation:**

Seismic

- Use acoustic and elastic modeling for concept verification
- Perform illumination study
- Long-offset data modeling (diving wave tomography, converted waves)
- Modeling of absorption / attenuation compensation (Q)
- Source modeling

Non-Seismic

- Potential fields (Gravity (FT), Magnetics (HR))
- Electromagnetics (MMT (2D / 3D, anisotropy)), CSEM (feasibility, penetration, sensitivity)

Integrated interpretation of all value-adding existing data

- Volcanic basin modeling and historical basin evolution
- Definition of all paleo-lows and paleo-highs throughout seismic volumes.
- Fabric of rift and tectonic inversion
- Uncover hydrocarbon migration paths to defined traps (reservoirs/seals)

Conclusions

- Continuous development of workflows and of G & G schemes for magmatic basins from basin scale to prospect scale requires a clear understanding of the processes acting over geological time scale:
  - depositional and structural
  - thermal and geo-mechanical
- Exploration risk assessment requires not only assessment of uncertainties but iterative sub-basalt Petroleum Systems Modeling (concepts and interpretations)
- **Sub-Basalt Producing Basins are part of a growing business**