Sub-Basalt Geology, Deepwater Offshore India*

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Abstract

This article describes the geophysics imaging of sub-basalt features, offshore India--off the west coast Kerala-Konkan Basin and the southern tip off India. Data originates from regional 2D seismic lines and modern 3D surveys; these were integrated with joint regional investigations, with gravity, magnetic, electromagnetic and MT data to form the basis for the geologic assessment of the key components of deepwater petroleum systems. These include both the Tertiary overburden above basalt and below it and involved the critical imaging of the Mesozoic lithology. The modern marine 3D surveys, conducted with long spreads and processed with state-of-art migration algorithms, brought in remarkable improvements in imaging resolution and coherence of sub-basalt structures. These were interpreted by pairing images of pre-stack time and depth migrated lines.

Kerala-Konkan Basin is a vast deepwater unexplored frontier region that lies south of the Mumbai Offshore area, the main productive oil province of India. The Mesozoic strata of Kerala-Konkan Basin is buried under the Upper Cretaceous flood basalts of the Deccan Traps that formed at the Cretaceous-Tertiary boundary. Regional lines cover outer shelf, slope, rise, and ocean basin, providing insight into the nature of continental and oceanic crust layers, including those of Mesozoic age, under basalt. To focus on risked prospect plays with upside drilling potential, coherency of sub-basalt strata needs be represented by interpretable structural prospect closures and by stratigraphic channels and pinch-outs, which are delineated by pattern recognition and seismic attribute analyses.

Interpretation mapping of the PSTM/PSDM paired images provides for correct placement of structures in depth. Furthermore, this methodology focuses on fault path displacements and rectifies horizon continuity. For the purpose of seismic interpretation the sub-basalt velocity model derived from data provides for better confidence in the structural dynamics of the seismic section.

This article presents remarkable sub-basalt imaging results from modern data sets in the deepwater realm of the Kerala-Konkan Basin. These were integrated with ancillary geophysical regional line interpretations for the purpose of understanding the nature of sub-basalt hydrocarbon prospects.

Sub-Basalt Geology
Deepwater Offshore India

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Sub-Basalt Strata Geophysical Imaging

Question:
Is the present state of modern technology able to generate images adequate to reveal the potential reservoir systems below basalt?

Modern imaging technology plays a key role in the understanding of sub-basalt geology and any associated petroleum systems, particularly in areas with inadequate or no well information.

Sub-Basalt Strata
Thermal Regime Considerations

- Worldwide, there are a large number of significant reservoirs in areas affected by igneous activity, fields with significant recoverable gas reserves
- Associated features of igneous rocks can provide exploration opportunities in sub-basalt, fractured basalt and intra-basalt reservoirs
- Important to model thermal effects over geologic time
- The possibility that hydrocarbons are destroyed when basalts are too thick and/or deposited too rapidly also needs to be considered

Sub-Basalt Hydrocarbons

- Worldwide exploration potential: ~800 Tcf gas (~12% of world total) and ~40 billion barrels oil (~3% of world total) may exist under basalt cover
- Sub-basalt geologic maturity conditions are generally gas-prone
- geologic investigations of sills and dykes are equally important as they can affect components of the petroleum system (thermal effects, migration and trap formation)

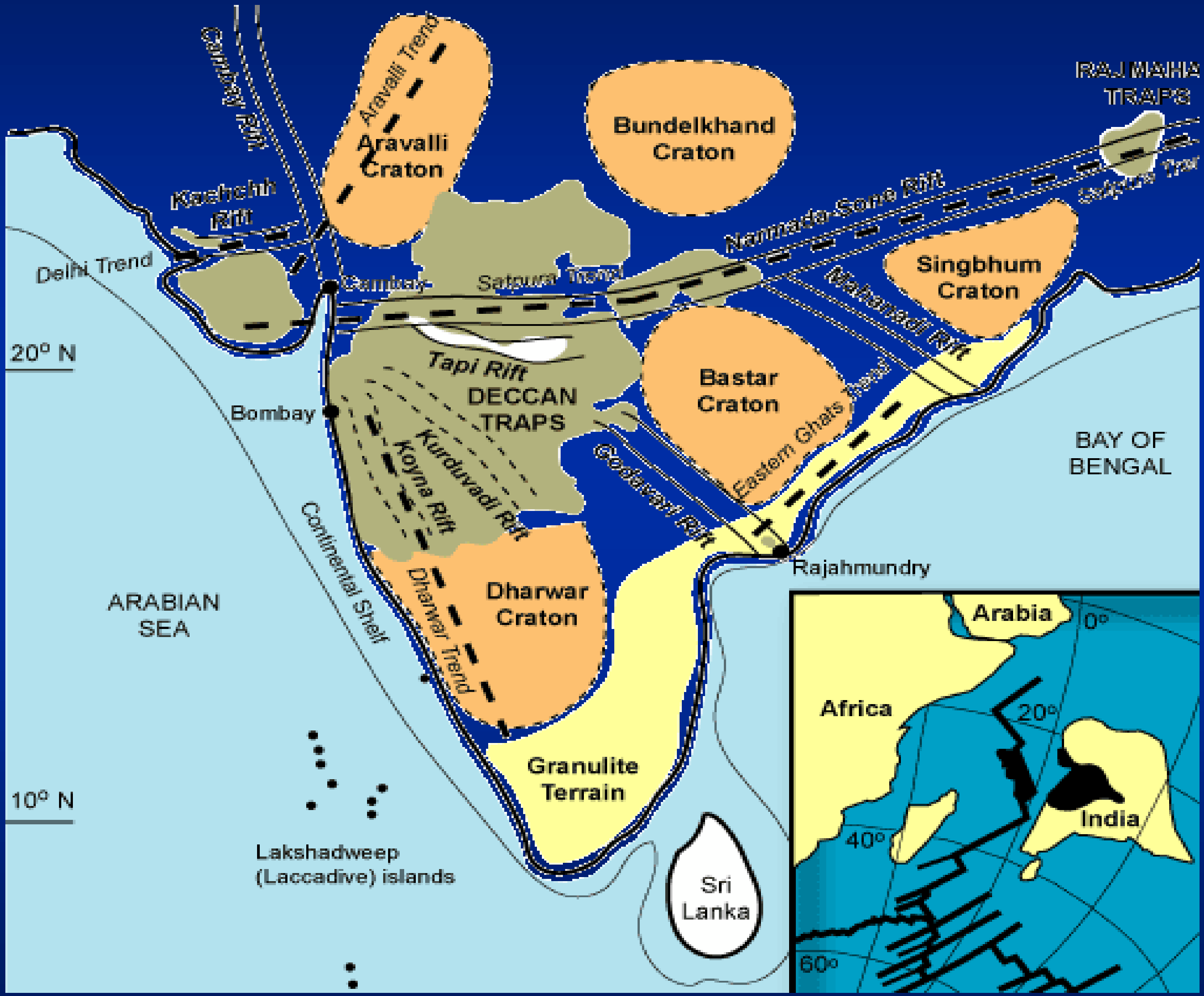
Sub-Basalt Worldwide Matrix

Geology / Basins/ Province		Volcanism age (million years)	Sub-basalt sediments	Thickness	Depositional environment	Source Rock	Vitrinite reflectance	Total organic content (%)	Thermal effect of Basalt	Reservoir lithology	Seal lithology	Types of traps	H/C
Columbia River Basalt Group		17	Cretaceous-Paleocene	~3048	Fluvial	Type-III	0.24-1.38	0.3-17.9	✓	Fluvial Sandstone	Basalt flows	Anticline Thrust	Gas (methane)
North Atlantic Volcanic Province	Faroe	62	Cretaceous-Paleocene (?)	unknown	Sedimentary layers in lava flows	Type-II	1.2*	7*	✓	Vesicular-fractured basalt Clastic tuff	Basalt flows	Intra-trappean sediments, Vesicular basalt	Gas indication
	Green-land	62	Cretaceous-Paleocene	>1000	Terrestrials Fluvial	Type-III (?)	1.2	7		Fluvial Sandstone	Shale	Structural Fold Fault	Oil seepage Gas indication
	Ireland (Corrib)	62	Carboniferous -Cretaceous	~4000	Fluvial	Type-III	2.0			Fluvial Sandstone	Evap-orites Shale	Anticline	Dry gas
Deccan Trap, India		66	Carboniferous -Cretaceous	~2500	Fluvial Deltaic	Type-III	0.5-2.0	2.75 to 6.25	✓	Fluvial Sandstone	Shale	Structural Extensional tectonics	Gas indication
Parana Basin		130	Ordovician-Paleocene	~4000	Fluvial Deltaic Marine	Type-II Type-III	>1	1.5-4.6	✓ calculated	Fluvial Sandstone	Basalt flows Shale	Structural Fold Fault	Gas Oil

* Data implied on both Greenland and Faroe

- Solimoes Paleozoic Basin (Amazon) is largest producing sub-basalt basin ~60,000 bopd
- Volcanic basins generally gas-prone with basalts acting as a regional seal

Indian Basins Affected by Basaltic Lava Offshore Deepwater Realm - Arabian Sea



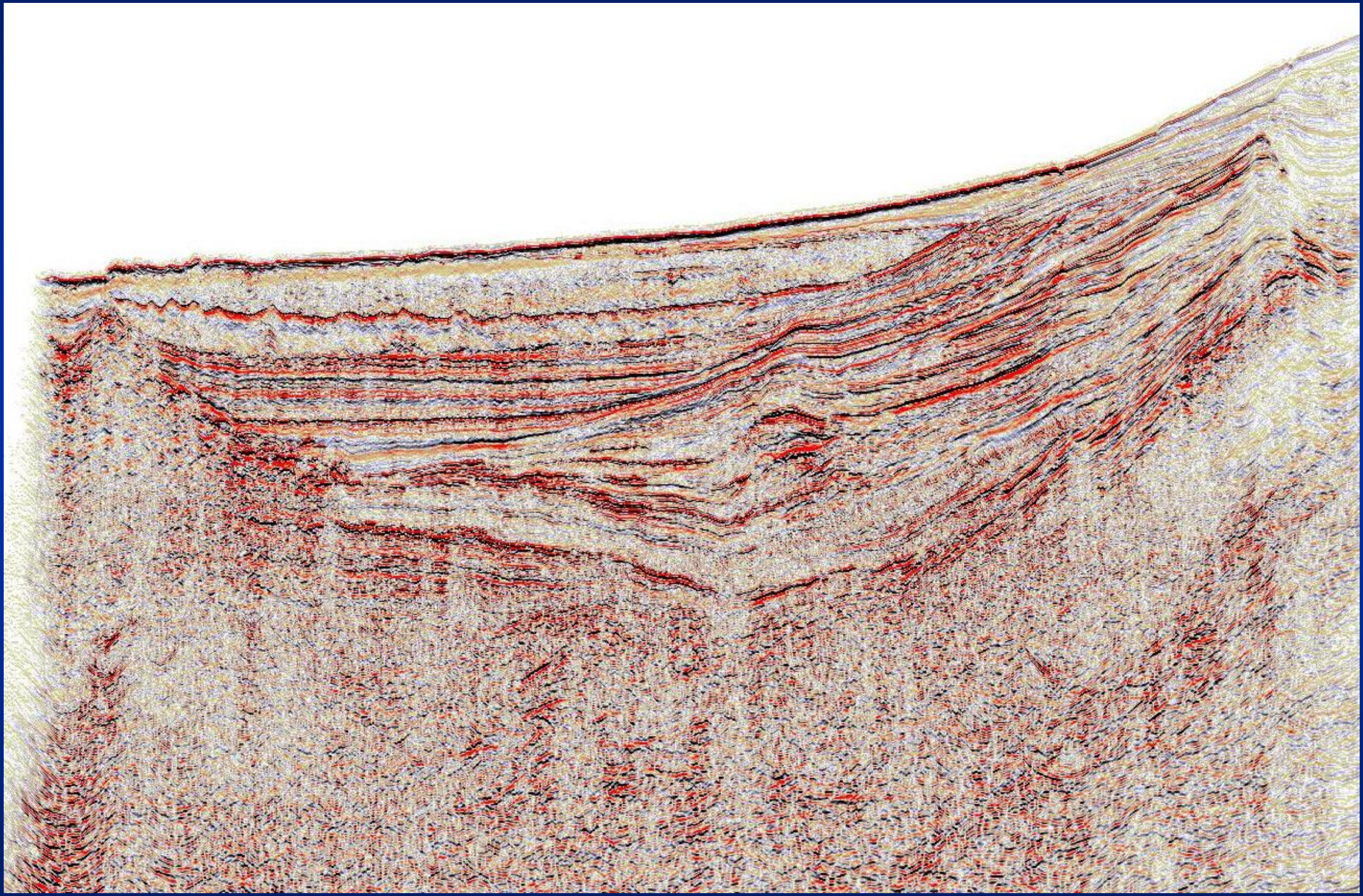
Major Tectonic events

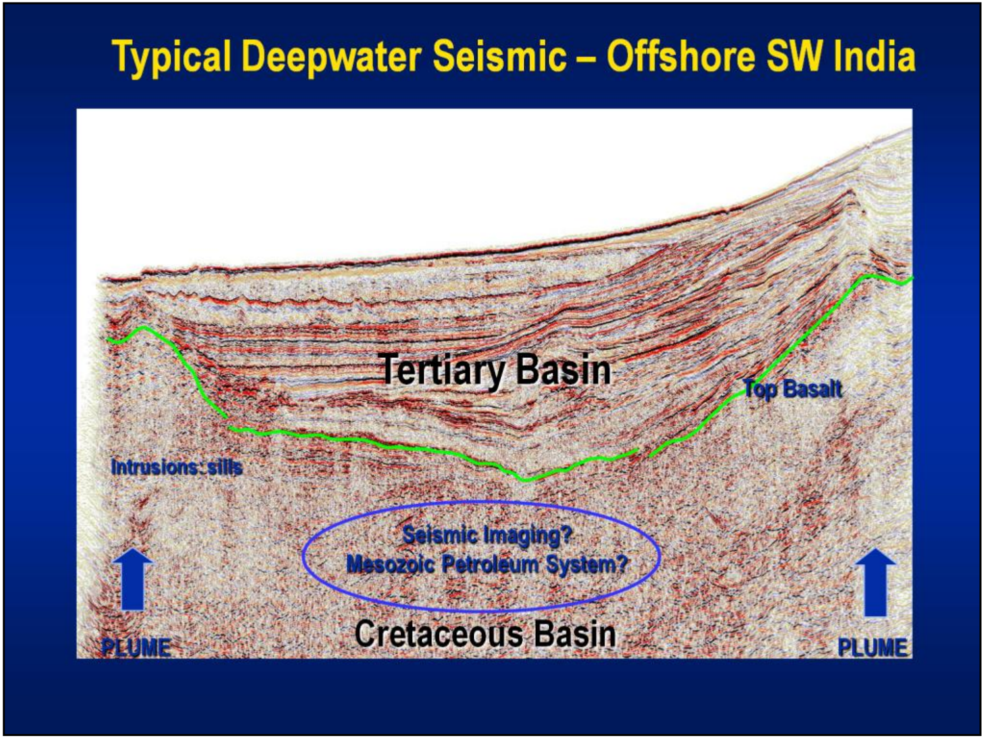
- Detachment of India from Madagascar
- Melting of western India at the K/T boundary
- Late Cretaceous plate passage over Reunion Hot Spot
- Extrusive lava flows at the K/T boundary in western India

Main Seismic Imaging Issues

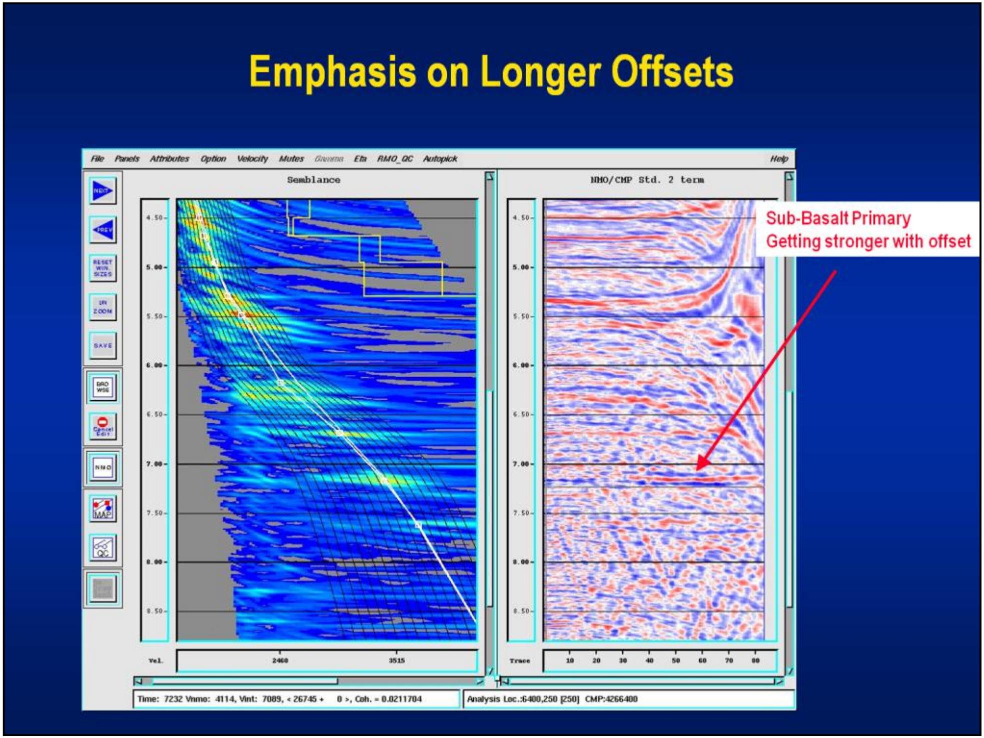
- Transmission losses due to near vertical rays penetrating the high-velocity basalt
- Wave propagation through basalt attenuates bandwidth
- Many sub-basalt reflections are multiples masking weak sediment interface reflections
- Interference (tuning) effects in basalt can make it difficult to identify the basalt base

Typical Deepwater Seismic – Offshore SW India

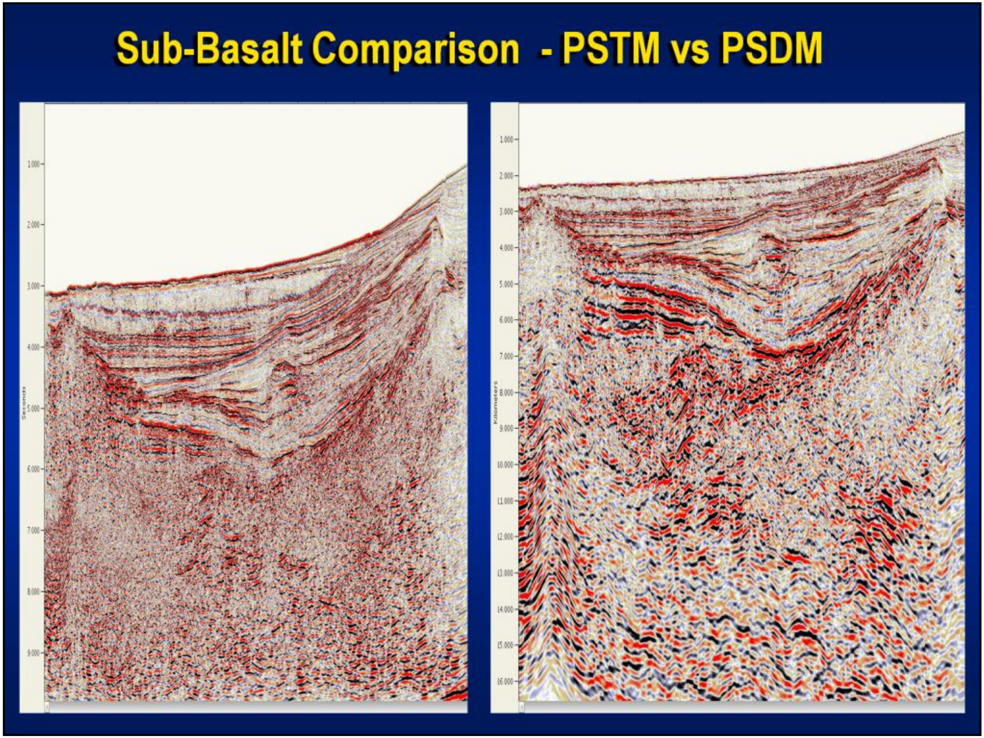




Presenter's notes: Interpreted section, of profile in previous slide, showing Tertiary inits overlying Mesozoic sub-basalt strata and also two volcanic "plumes" (east/west).



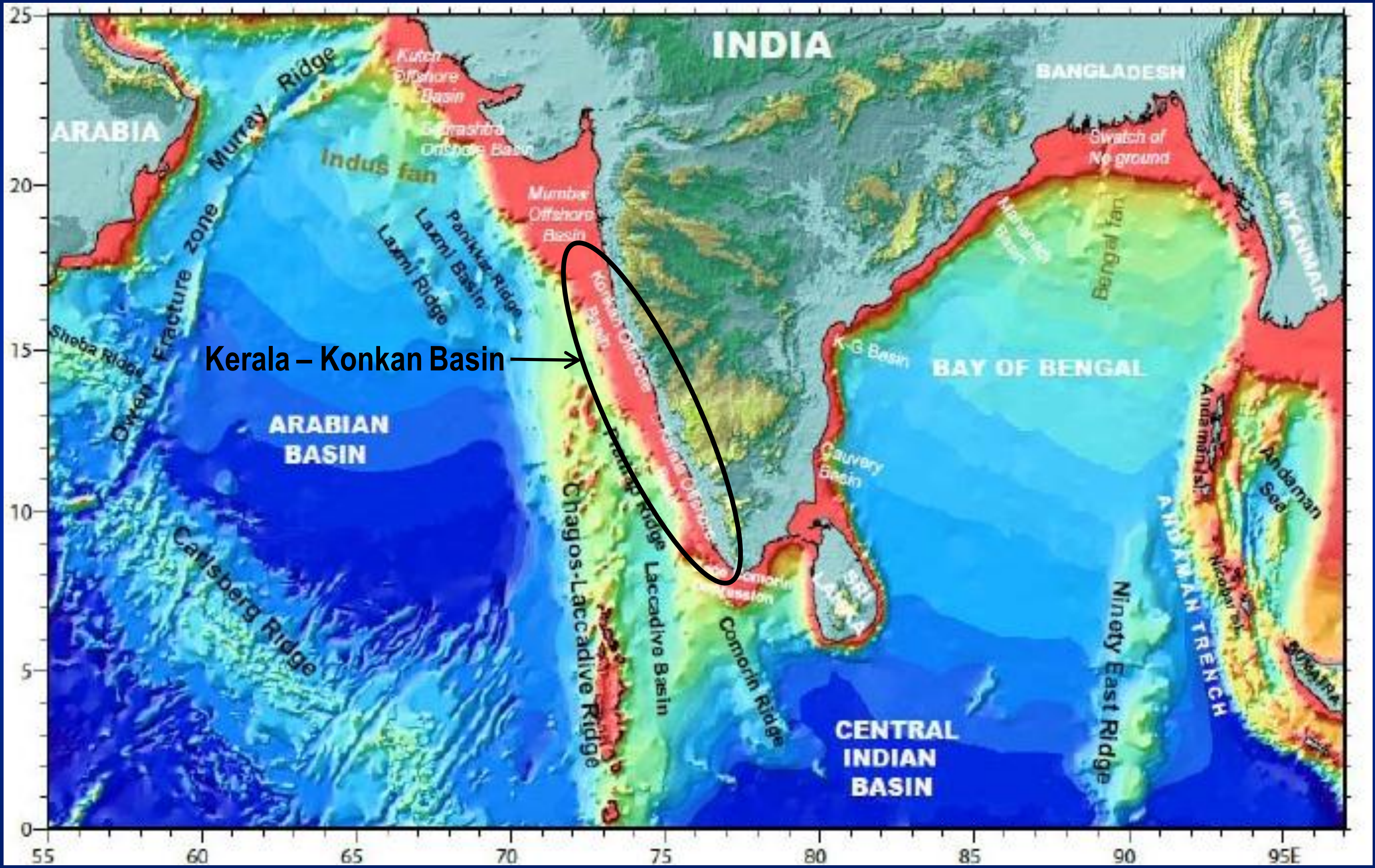
Presenter's notes: Velocity "picking" clearly emphasizes non-hyperbolic events over the longer offsets, a technique that is a <u>must</u> (long-offset data) for imaging of sub-basalt. Energy scattered--to end up on far traces.



Presenter's notes: Good comparison: PSTM/PSDM (circa 2008) shows that there are additional sub-basalt lava flows in the Cretaceous (PSDM) sedimentary sequences.

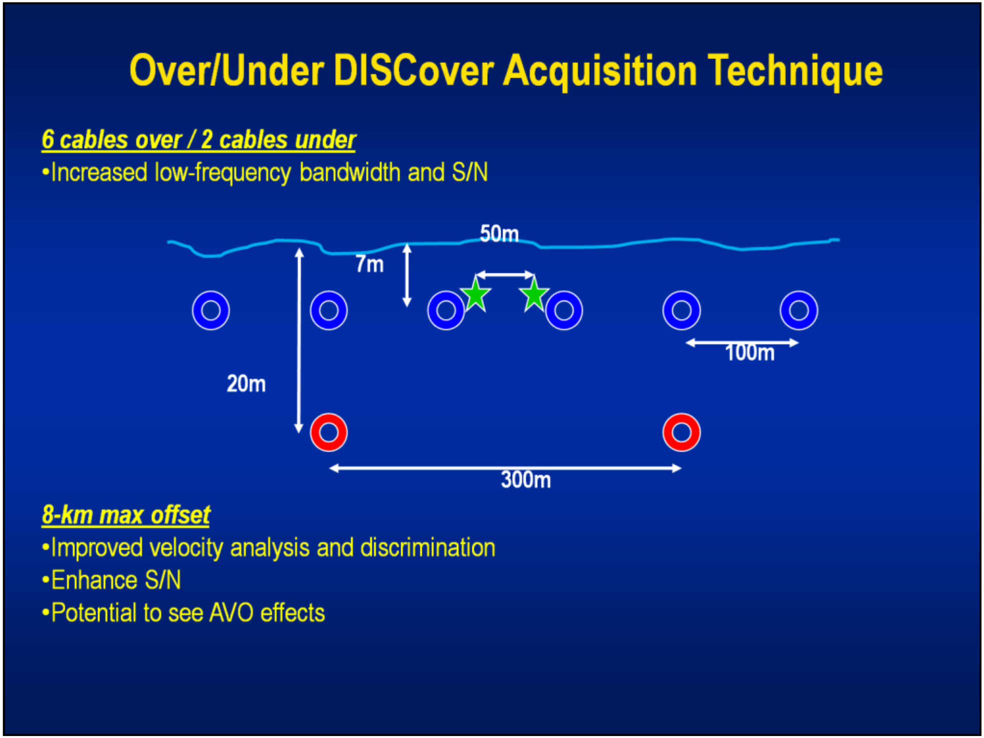
Over-Under DISCover Technique

Morphology Offshore India



Kerala-Konkan Project Location

Presenter's notes: Location of the project, lines inside this 3D acquired in 2010, processed in 2010/2011.

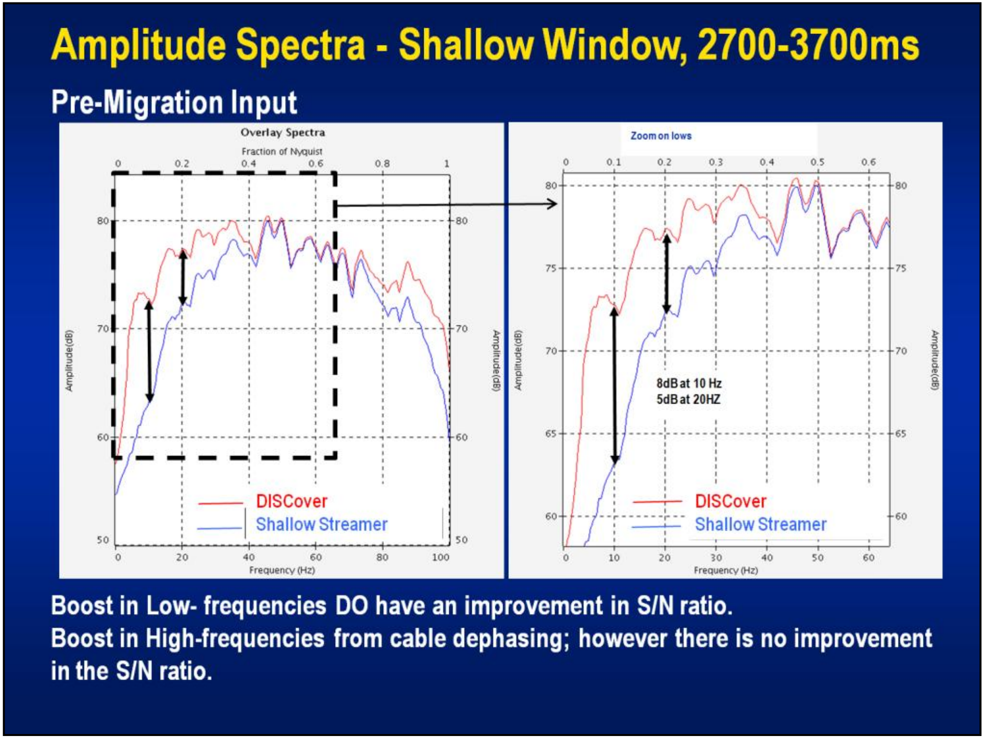


Presenter’s notes: Description of main elements of the DISCover Technique: 6 cables over at 7m depth, 100m separation, 8000m offset; 2 cables under at 20m depth, 300m separation; V-frame source array, flip/flop, 50m source interval.

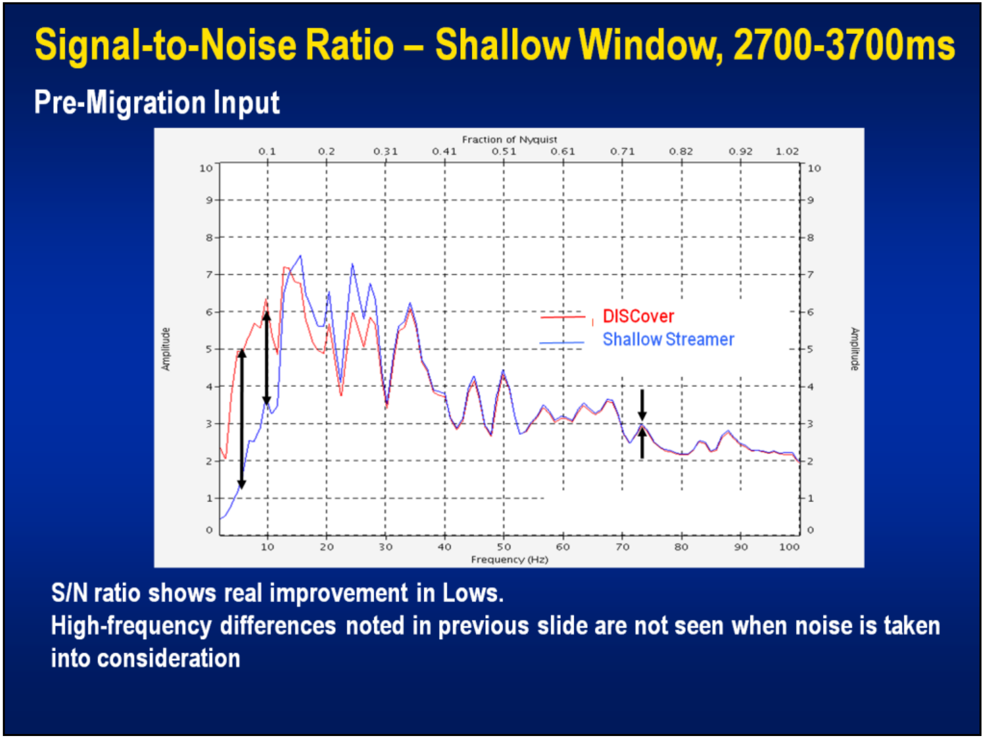
Measuring upcoming wavefield (signal), but also reflected downgoing wavefield (opposite polarity) and interfere – sometimes constructive at certain frequencies.

2 difference measurements – shallow and deep; solve for upgoing and downgoing wavefield; then downgoing discarded.

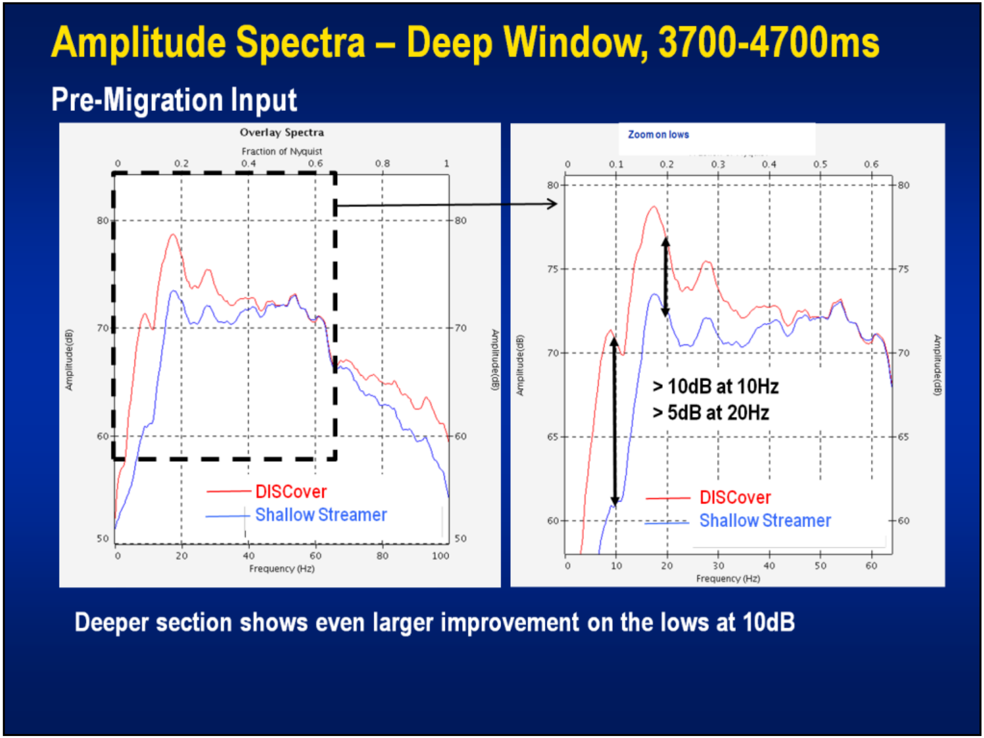
Interference worst with low frequencies (measuring pressure). For deeper cables – low frequencies easier to interpolate, with fewer required; deeper water richer in low frequencies.



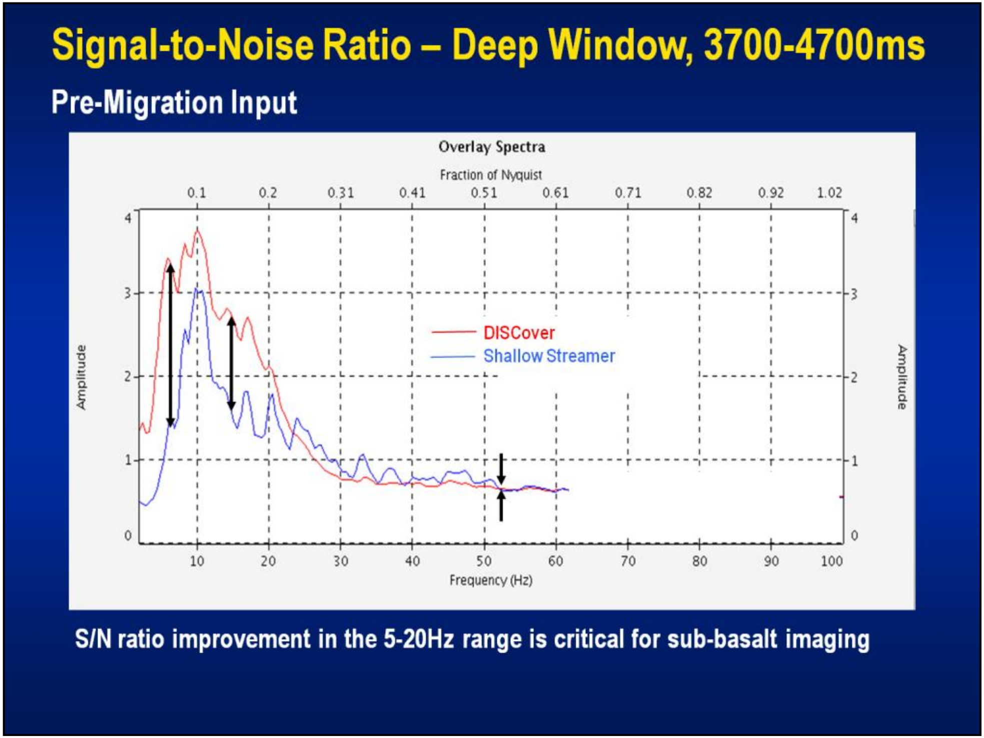
Presenter's notes: Frequency bandwidth gains produced with the DISCover technique. The combined dataset has significance in signal levels up to and in excess of 0-15Hz.



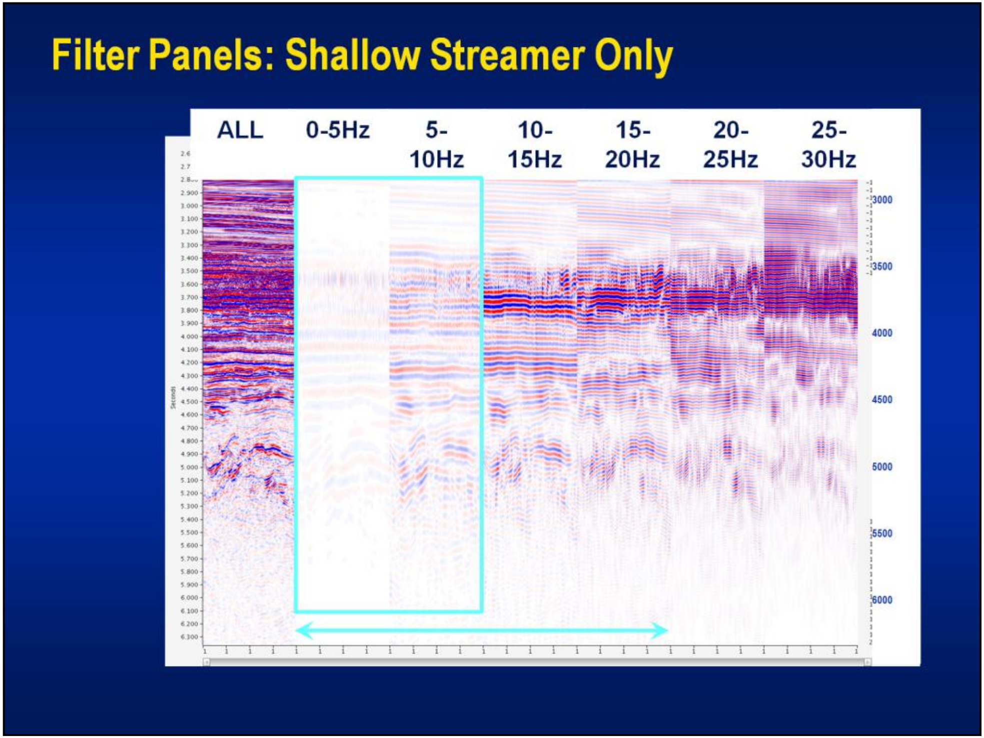
Presenter's notes: Signal/noise ratio improvement (pre-migration).



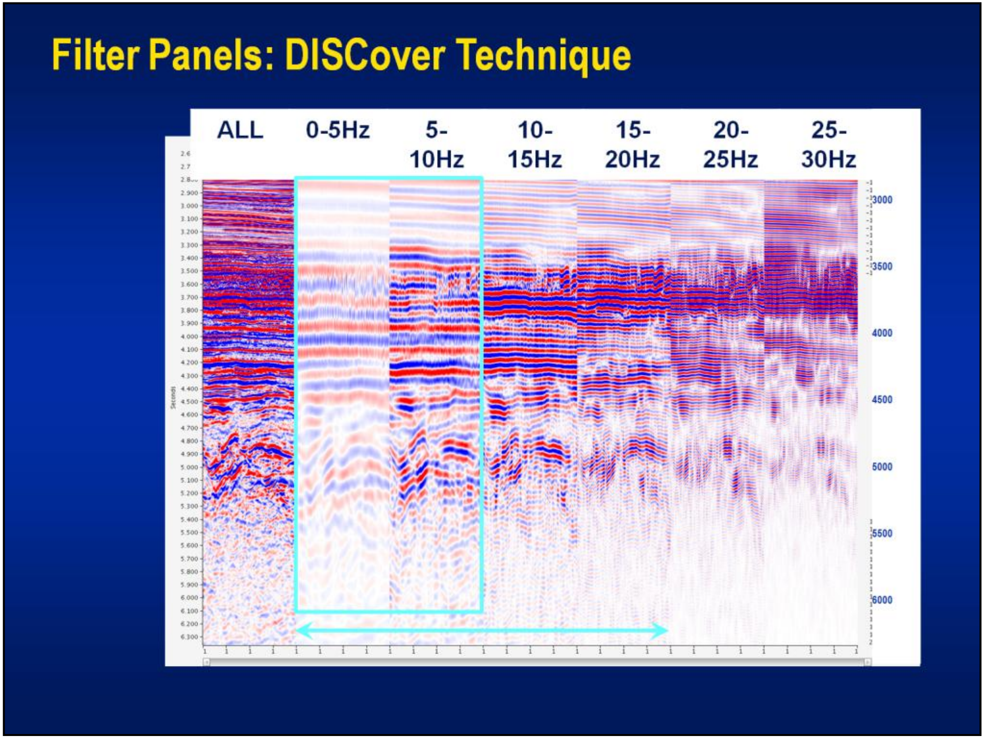
Presenter's notes: Amplitude spectra (deep window) – pre-migration.



Presenter's notes: Signal/noise ratio (input to migration). The combined dataset has significance in signal levels up to and in excess of 15Hz.



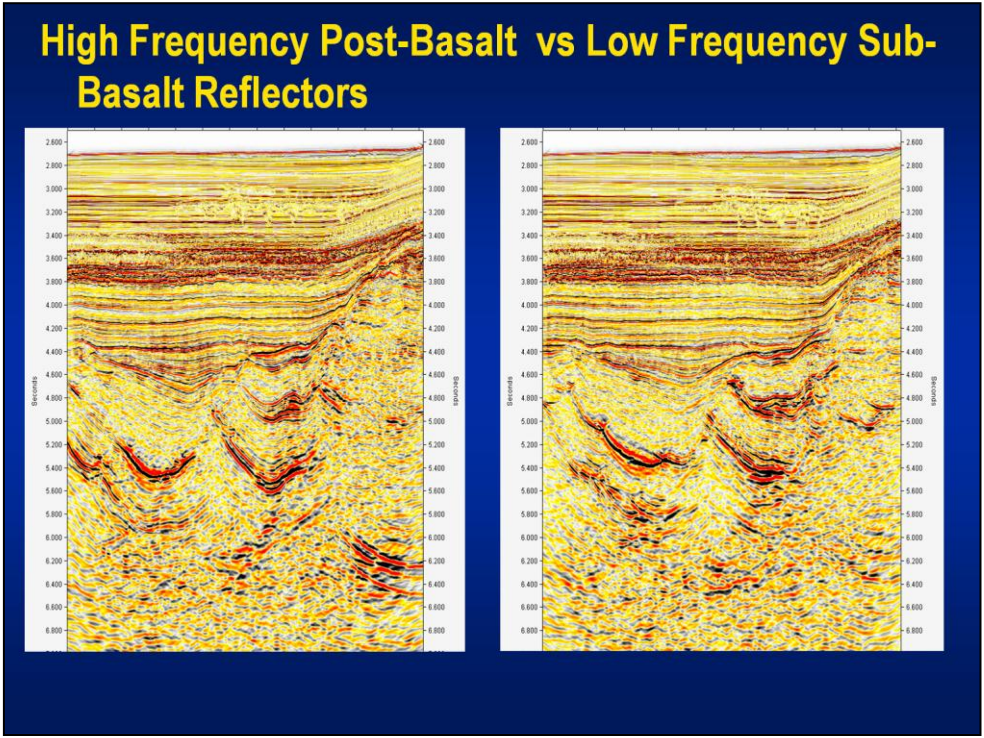
Presenter's notes: Filter panel: shallow streamer only with selective contributions to overall response.



Presenter's notes: The DISCover filter panel with the spectacular gain on lower frequency contribution to overall response.

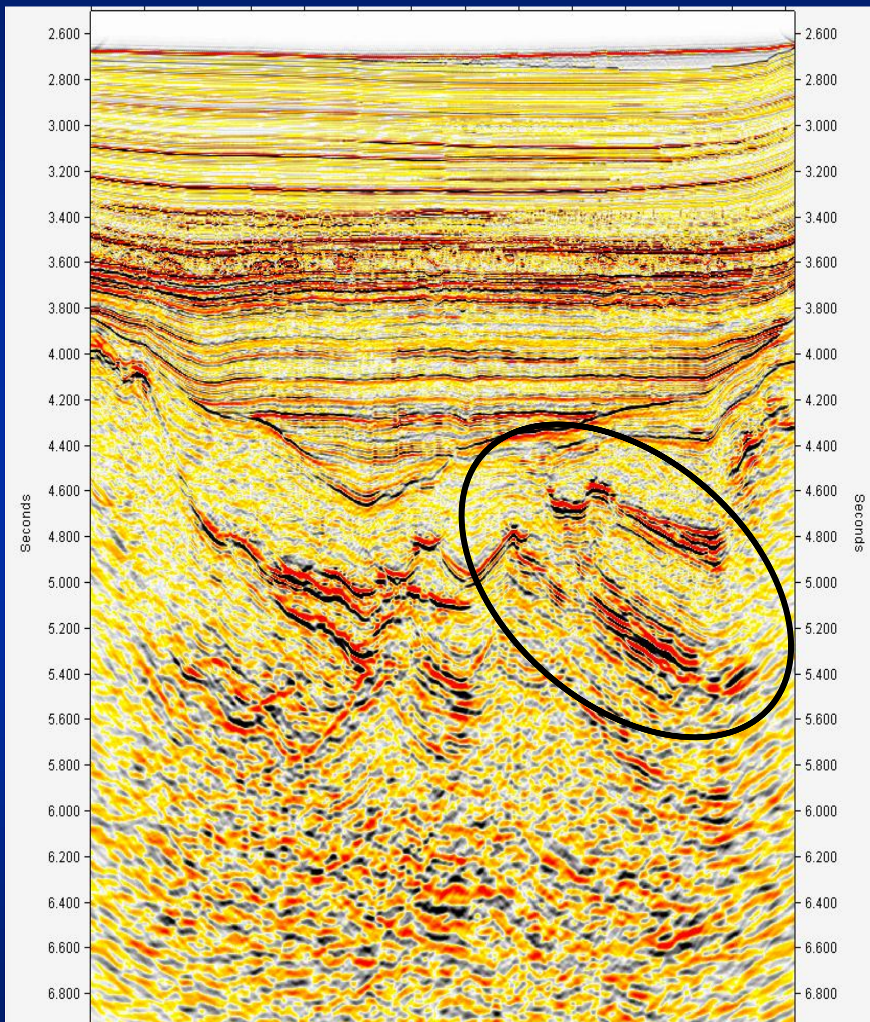
Modern Technology
Sub-Basalt Imagery

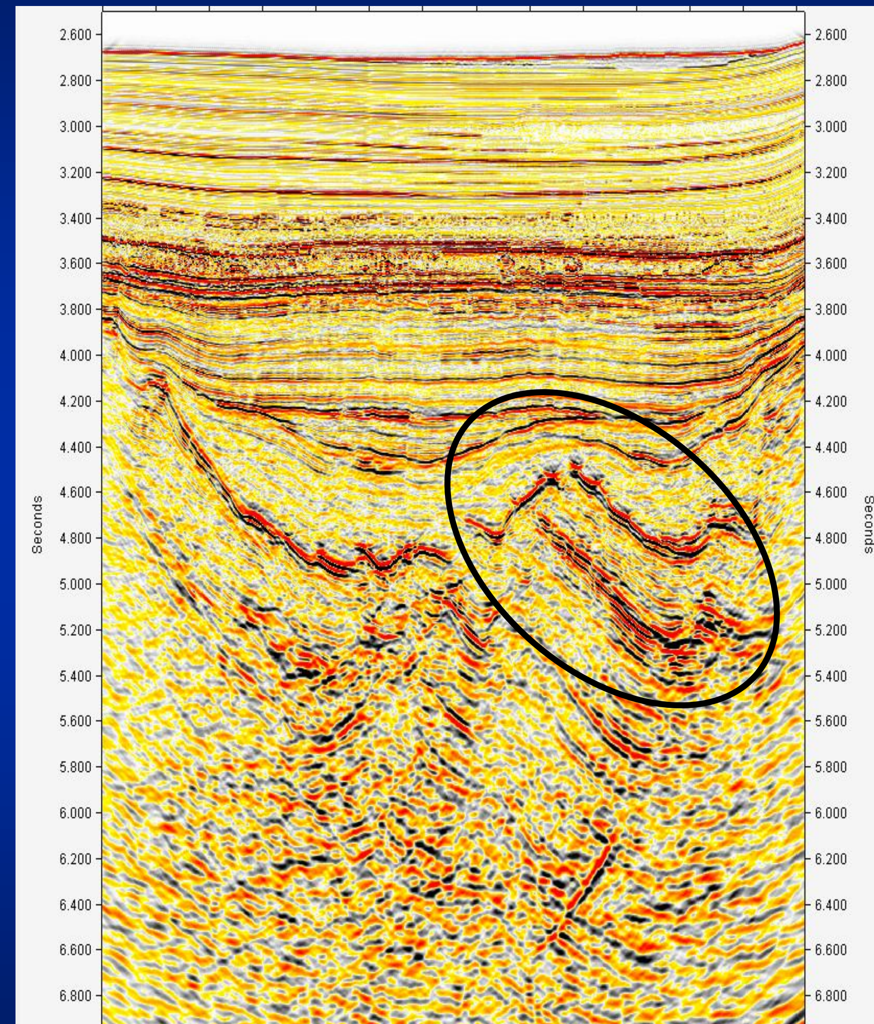
Extraordinary Results



Presenter's notes: First of six slides showing several examples of min-basin imaging within the Mesozoic under basalt, with description of features and exploration potential of sedimentary wedges and mapped closures. These slides show a clarity of reflections under basalt that has never been produced before and that enhance the exploratory potential of the deepwater Mesozoic offshore West India.

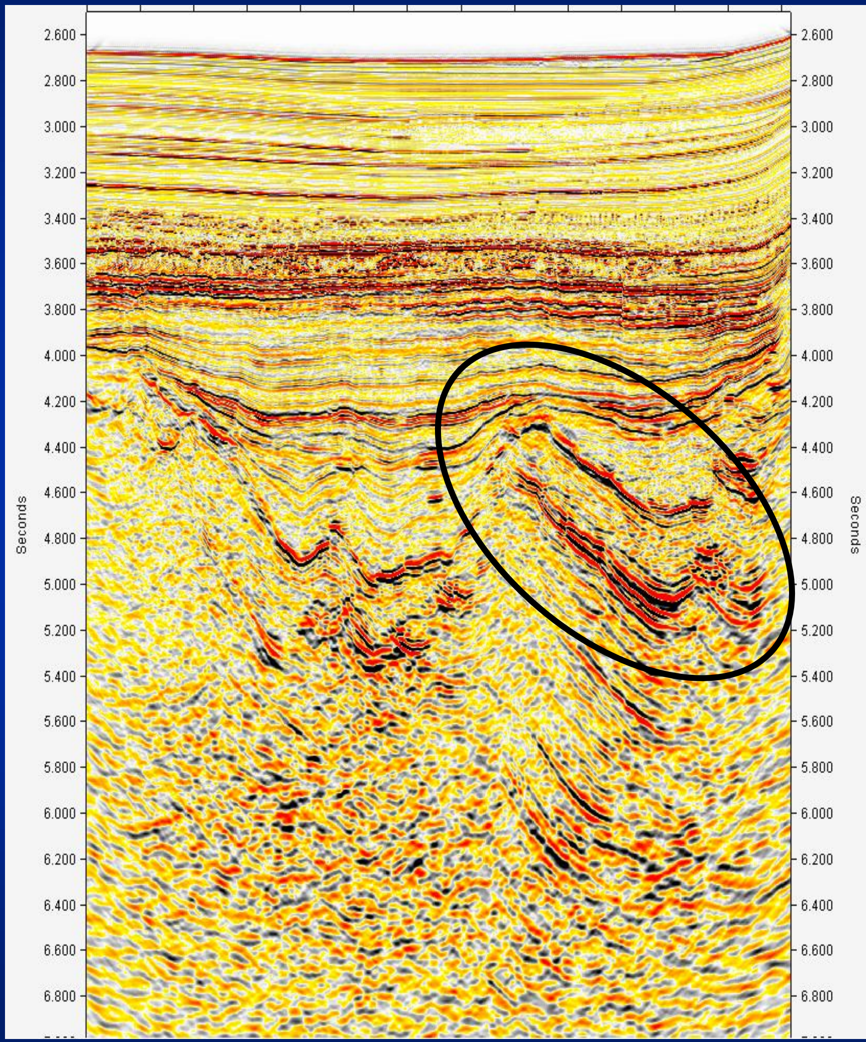
High Frequency Post-Basalt vs Low Frequency Sub-Basalt Reflectors

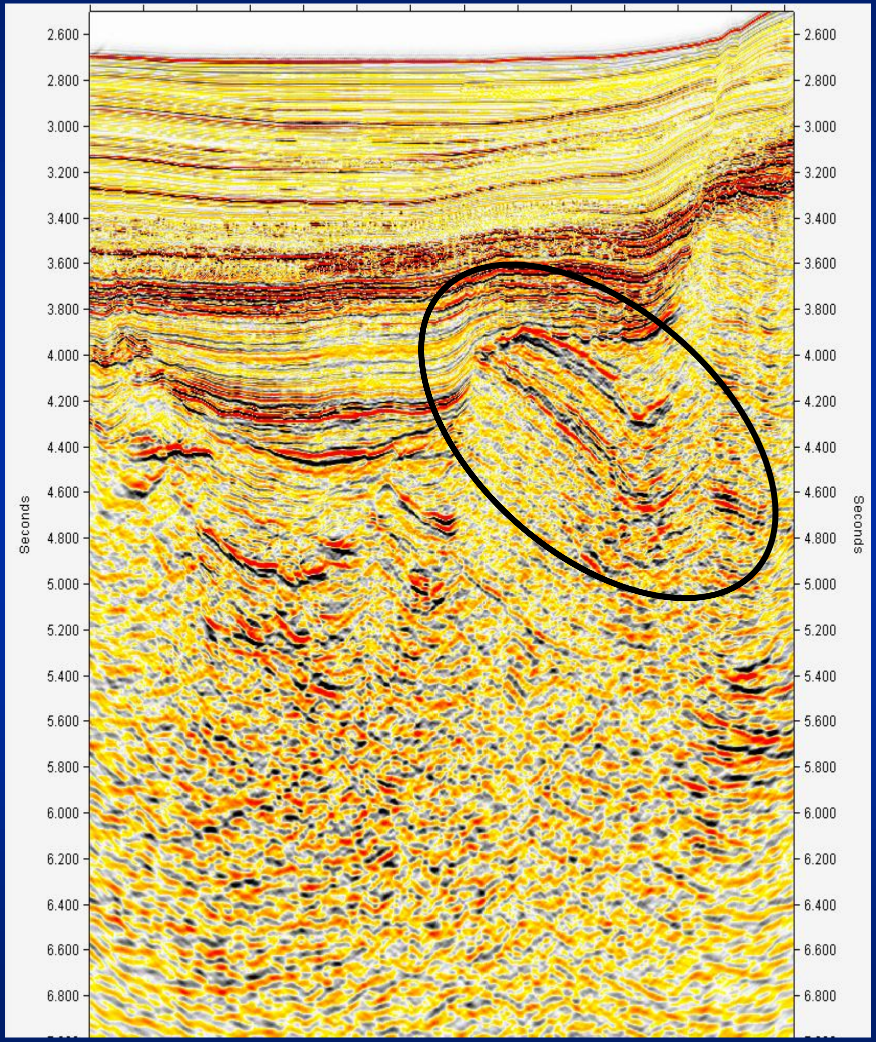




Mesozoic mini-basins surrounded by basalt lava intrusives

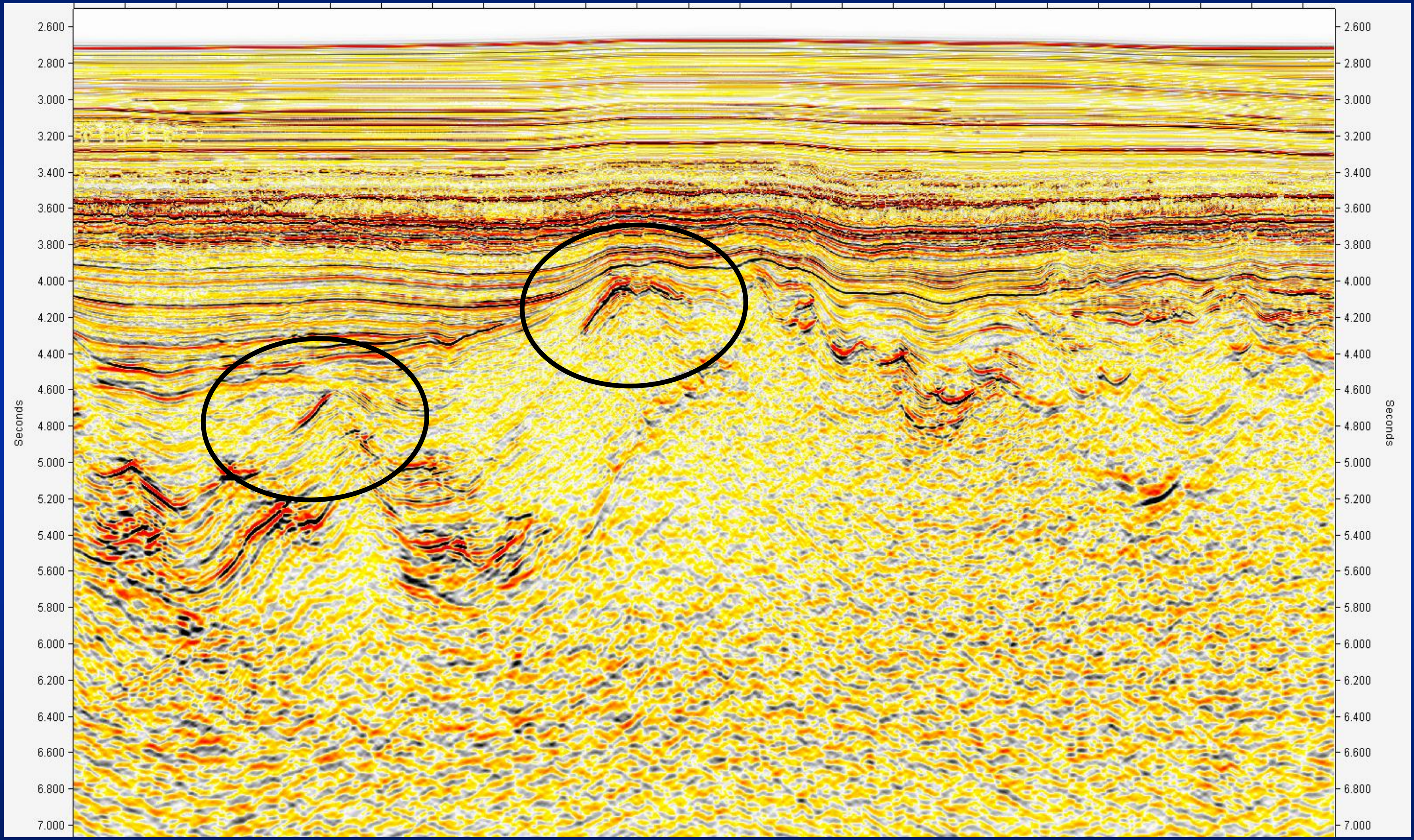
Mesozoic Mini-Basins - Seismic Character



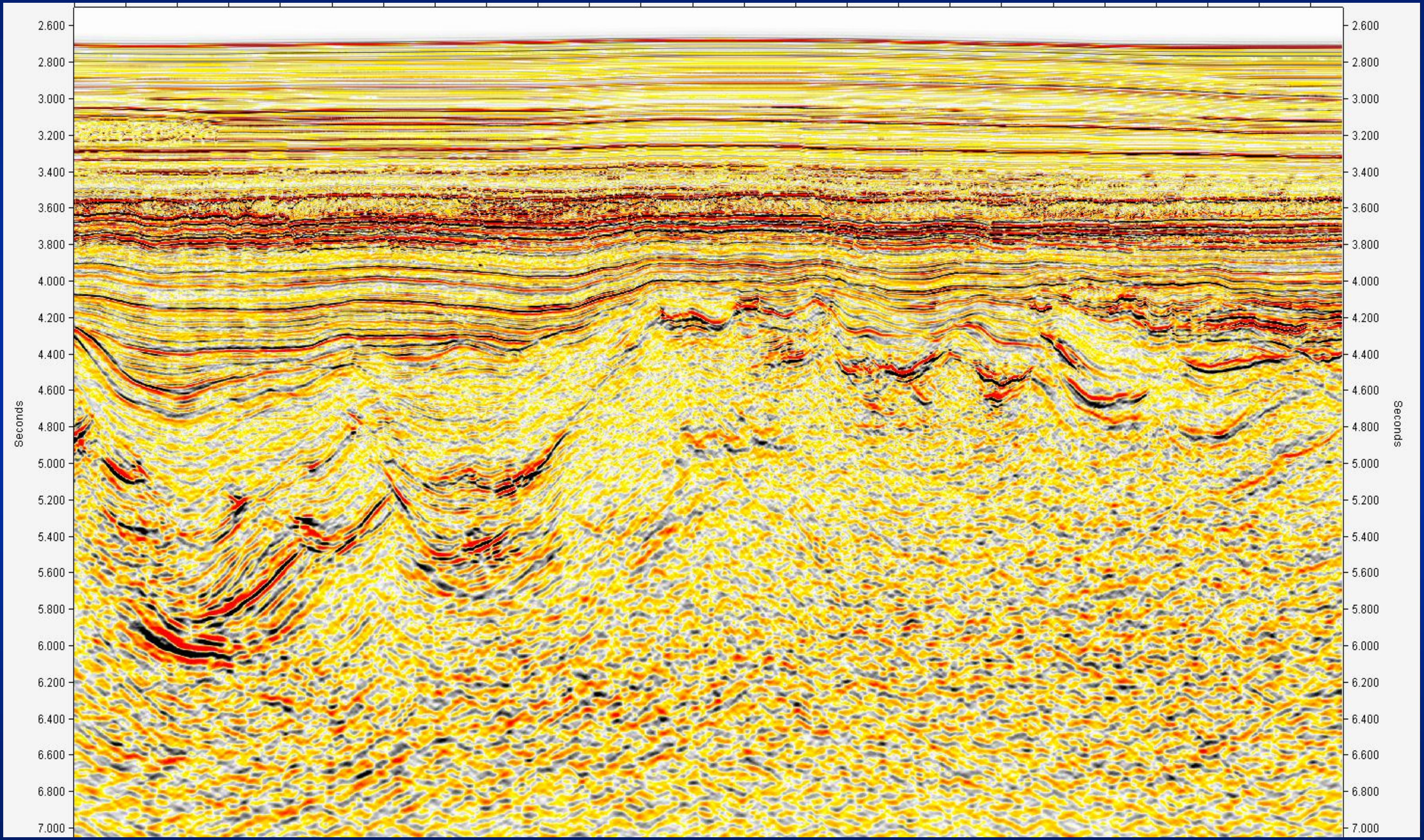


Mesozoic mini-basins surrounded by basalt lava intrusives

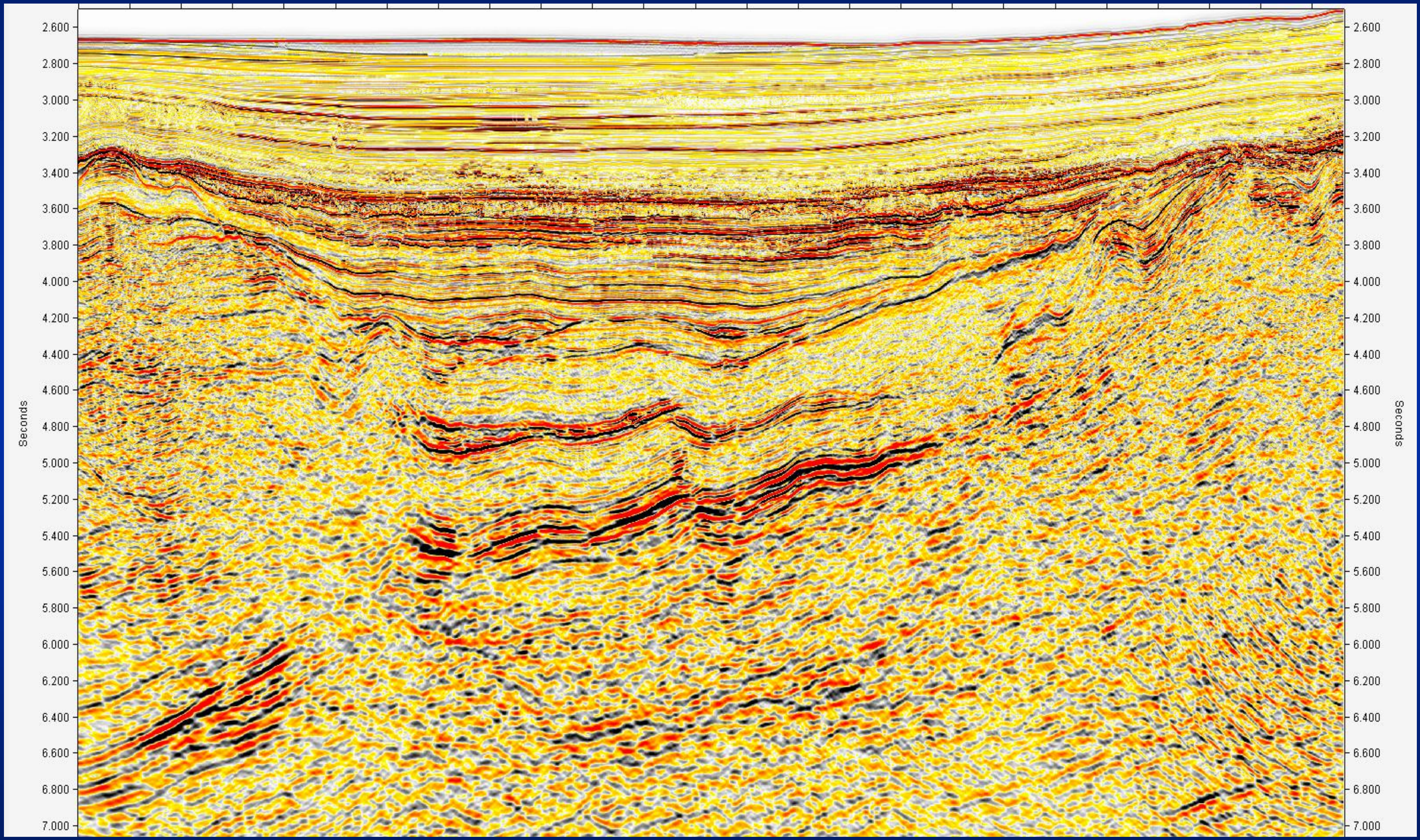
Basalt High Bordering Mesozoic Basin Margin



Basalt High Bordering Mesozoic Basin Margin



Geologic High Feature near K-T Boundary



Summary & Conclusions

- The offshore Kerala-Konkan Basin off southwest India contains a largely unexplored deepwater sub-basalt section

- Development of G & G workflows for magmatic basins from basin to prospect scale requires a clear understanding of the processes acting over geologic time scale:

  - depositional and structural
  - thermal and geomechanical

- Modern seismic reflection techniques can make extraordinary improvements in sub-basalt imaging to significantly improve this geologic understanding through:

  - Acquisition technology to enhance bandwidth in the lower frequencies
  - Longer offsets for better velocity analysis and discrimination

Acknowledgement

Data courtesy of ONGC and WesternGeco