The Crustal Architecture and Continental Break Up of East India Passive Margin: An Integrated Study of Deep Reflection Seismic Interpretation and Gravity Modeling*

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Abstract

The East Indian passive margin was developed after the disintegration of eastern Gondwanaland by the break up from Antarctica in the Early Cretaceous. In accordance with other passive margins, the break-up involved stretching, thinning and a probable process of mantle exhumation prior to the sea floor spreading. To understand the continental break up and margin evolution; a combined study of gravity, magnetic and seismic data focuses on determining the crustal architecture and different crustal types, such as continental, proto-oceanic and oceanic crusts, and their boundaries. The data set comprises the latest India-Span deep reflection seismic profiles acquired by GX Technology along with gravity and magnetic data, and 2D seismic data from Reliance Industries Ltd.

Six major tectonic segments composing the East Indian margin played a pivotal role in the continental break up and passive margin development. The proto-oceanic crust corridor located oceanward of these segments indicates the role of different rifting processes and breakup mechanisms and can be kinematically linked to above-mentioned tectonic segments. The orthogonally rifted segments, e.g. the Krishna-Godavari and Cauvery rift zones, developed a hard linkage through a major dextral transfer fault called the Coromondal fault zone. The proto-oceanic corridor is narrow along the Coromondal segment and wide in segments, which were initiated by orthogonal rifting. The continental crust terminates abruptly along the Coromondal segment and thins considerably before it terminates in orthogonal-rifting segments. Outboard of proto-oceanic crust lies the oceanic crust. Outboard of proto-oceanic crust, the oceanic crust is present, where anomalies produced by geomagnetic isochrons are not yet identified due to the Late Cretaceous mantle plume activity that produced the 85E Ridge. This activity modified the thicknesses of all three crustal types in its influence zone.

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The crustal architecture and continental break up of East India Passive margin: an integrated study of deep reflection seismic interpretation and gravity modeling

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AAPG Annual Convention & Exhibition

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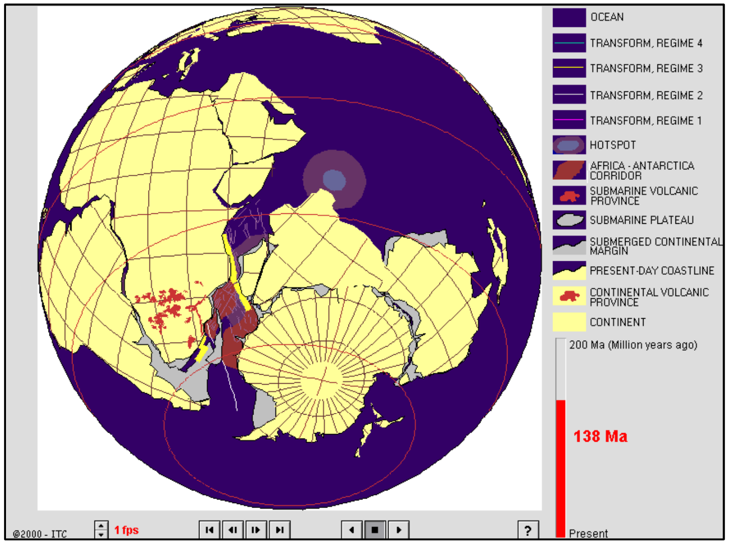
Key Questions

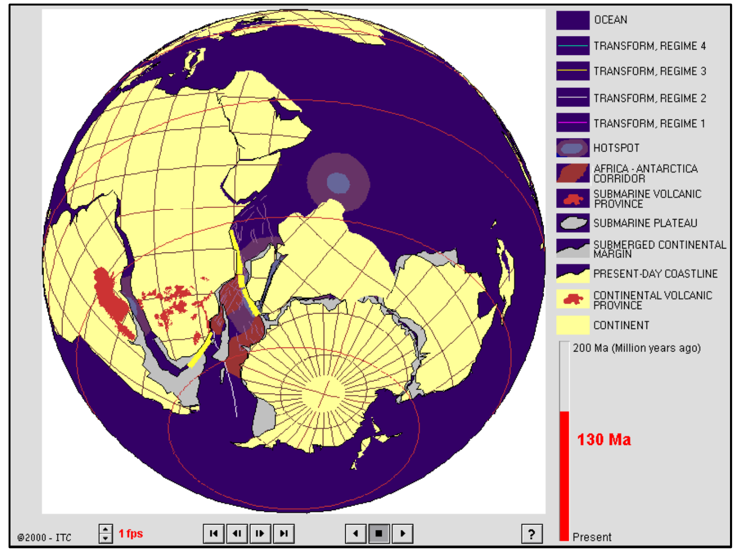
- What is the extent of continental crust in deepwater offshore East India?
- Is it possible to interpret mantle exhumation phenomenon in East India?
- Is it possible to identify kinematic linkage between rift zones and strike slip zones?

Break up History and Passive Margin Development of India

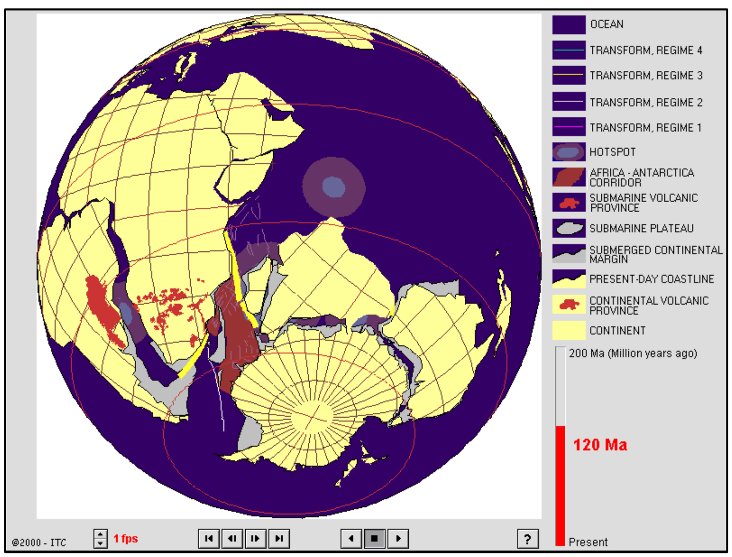
(from Reeves et.al. 2000)



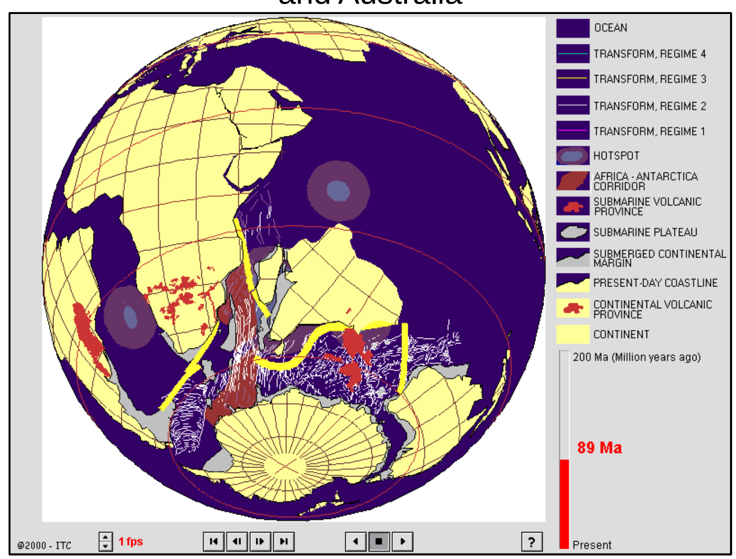
138 MA: Gondwana is an assembly of India-Antarctica and Australia



130 MA: Break up between India- Antarctica and Australia

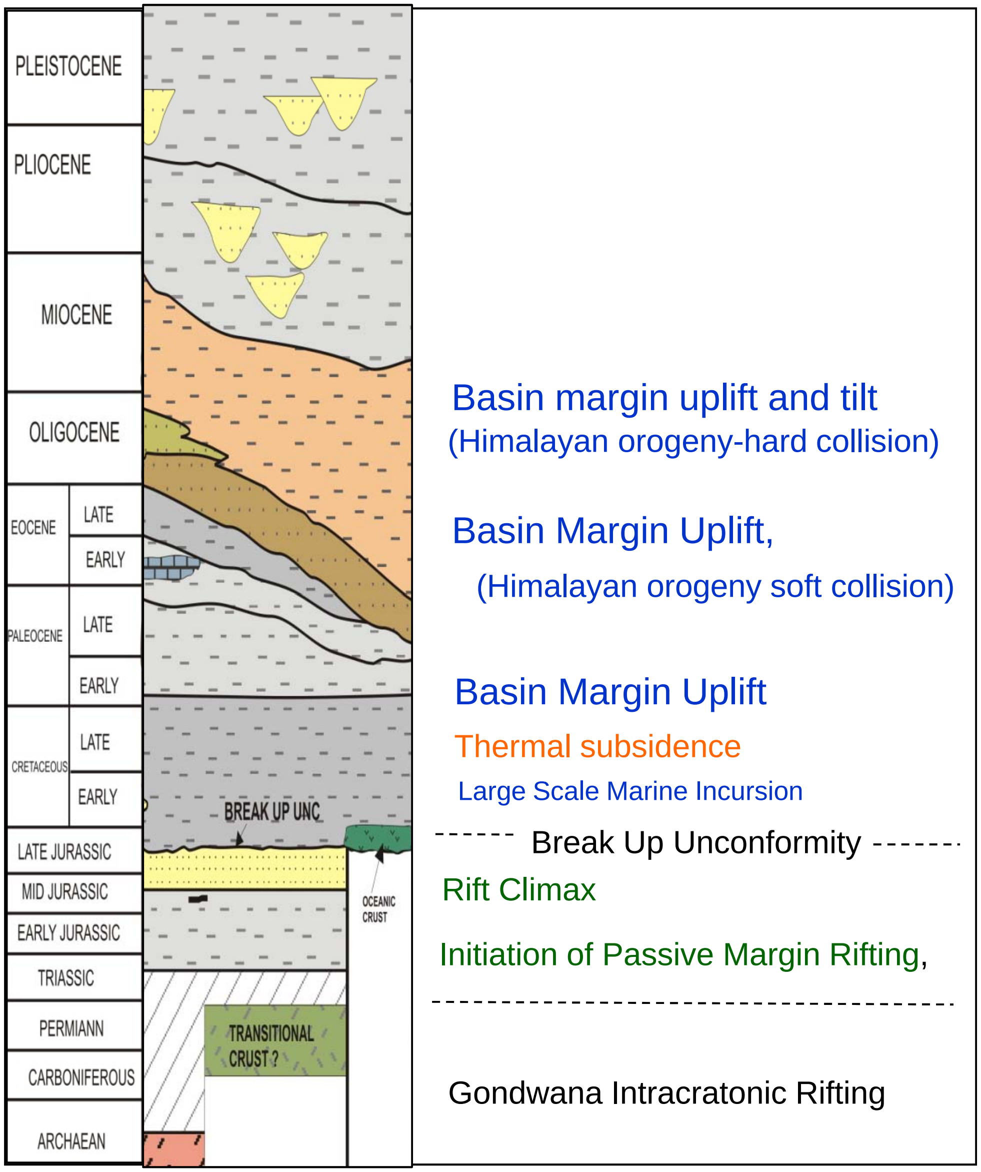


120 MA: Nascent Oceans are developing between India- Antarctica and Australia



90 MA: India's rapid northward drift initiated

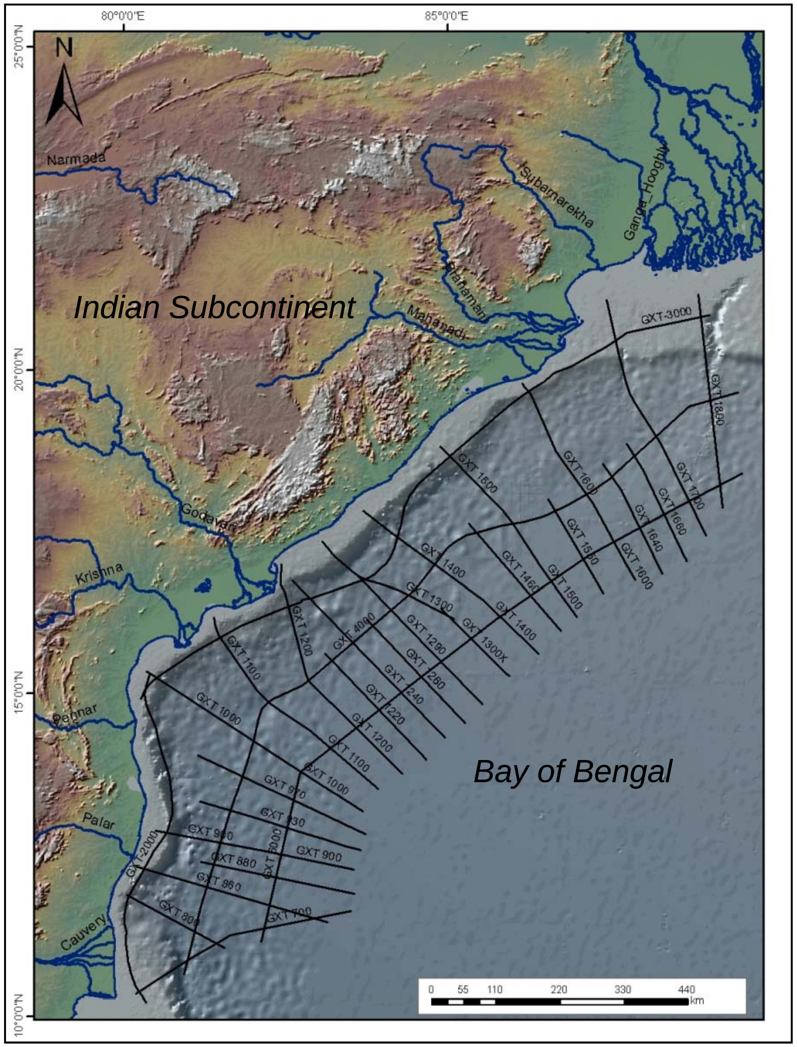
The Salient features of East India Passive Margins



modified after Rao, G.N., 2001

- ✓ The passive margin of East India developed after India - Antarctica break up @136-132 Ma
- ✓ The Basement rock consists of Archean and Proterozoic mobile belts (Eastern Ghats)
- ✓ A interplay of orthogonal, oblique and strike slip segments are present all along passive margin
- ✓ Crustal architecture shows both non-volcanic and volcanic rifted margin
- ✓ Sedimentation history from Jurassic to Present

Study Area and Data Coverage



Map of the study area, offshore East India, showing

- IndiaSpan reflection seismic profiles (GX Technology)
- Onshore topography of Indian Subcontinent (Smith and Sandwell, 1997)
- Drainage system
- Offshore bathymetry of Bay of Bengal (Smith and Sandwell, 1997)

Additionally few key seismic profiles from Reliance Industries Ltd is also available for study

Note the narrow present day shelf all along passive margin

Sedimentary Basins along East Coast India

Source: Directorate General of Hydrocarbon in India, web: www.dgh.india.org

Proterozoic Basins

- Onshore Cuddapah Basin
- Onshore Vindhyan Basin

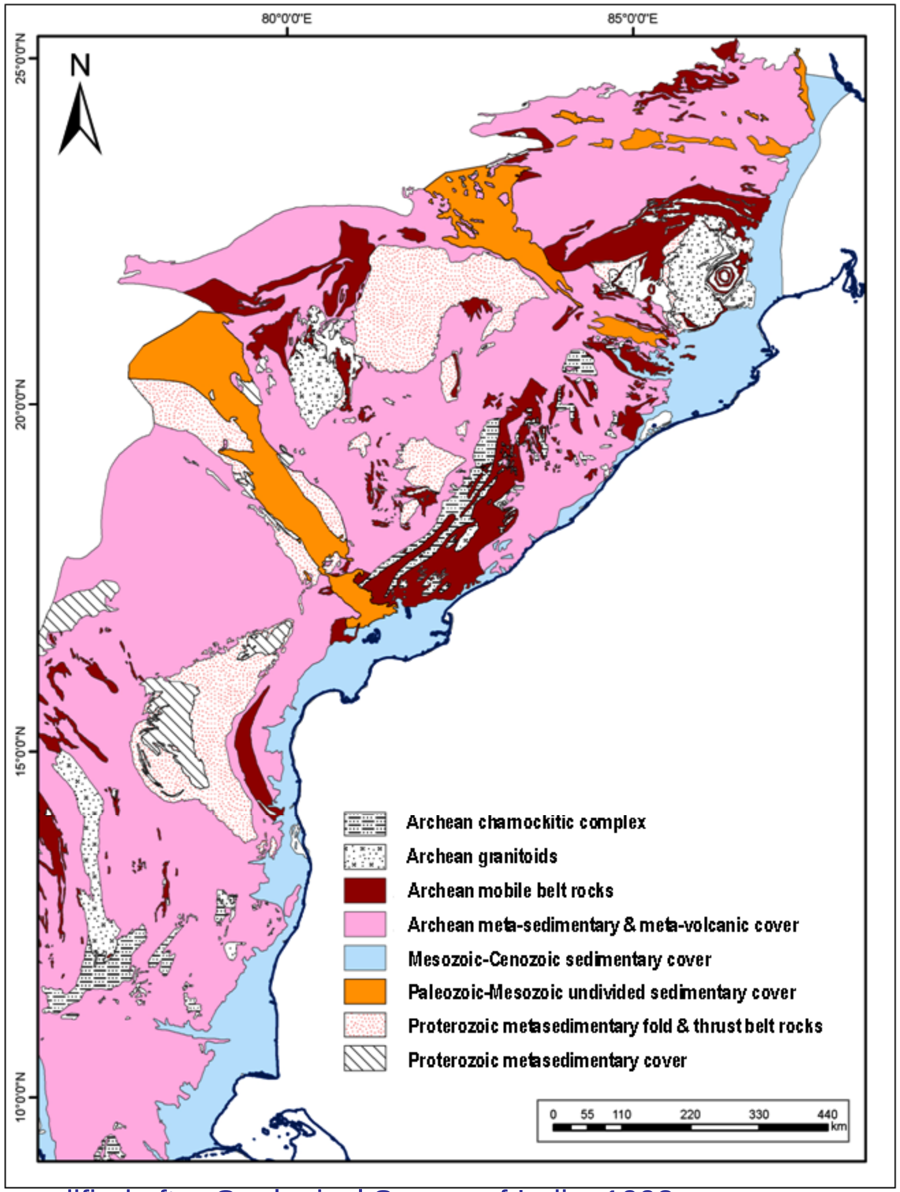
Permo-Triassic (Gondwana) Basins

- Onshore Pranhita-Godavari Basin
- Onshore Mahanadi Basin
- Onshore Damodar Valley Basins

Passive Margin Basins

- Onshore and offshore Cauvery basin
- Offshore Palar-Pennar Basin
- Onshore and Offshore Krishna- Godavari Basin
- Offshore Mahanadi Basin
- Onshore and offshore Bengal Basin

Geologic Setting and Basement Configuration



modified after Geological Survey of India, 1993

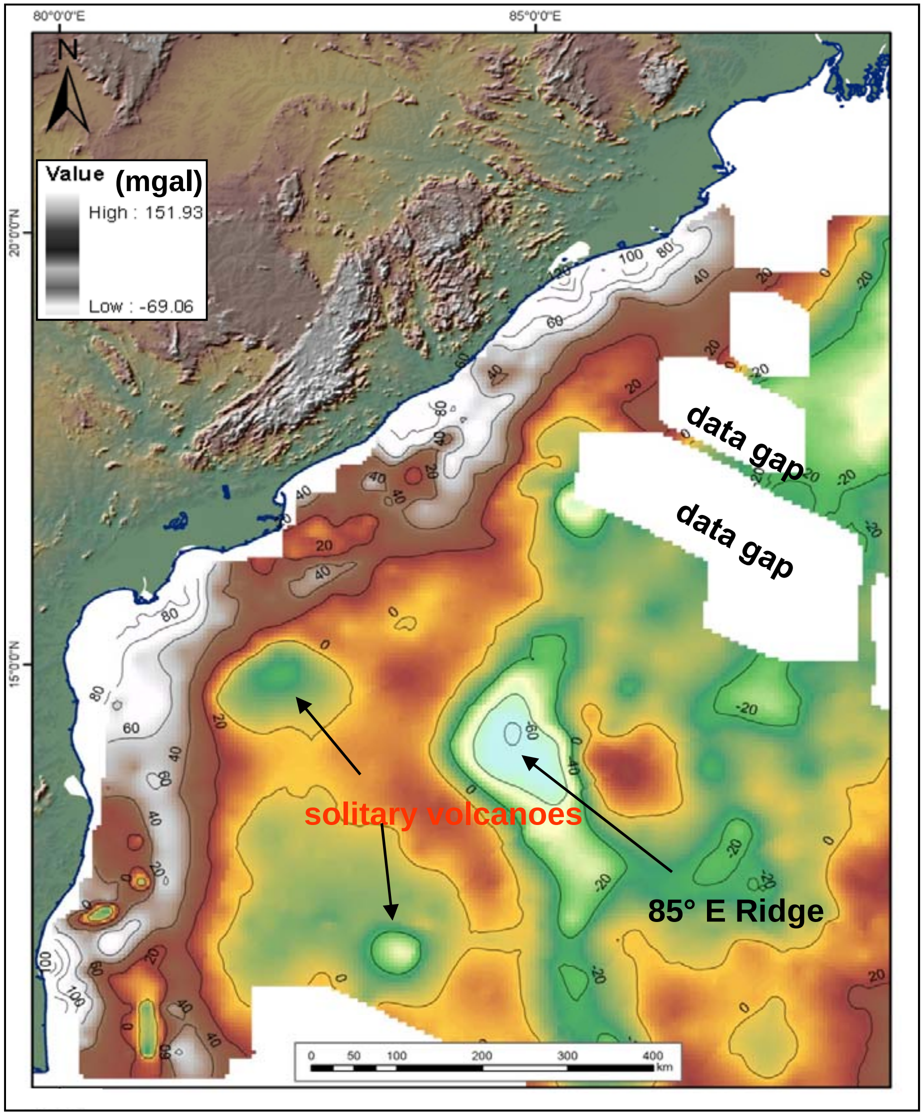
Primarlity dominated by Proterozoic mobile belts superimposed on top system of Achaean cratons. i.e. Southern Granulitic Terrain and the Eastern Ghat Mobile Belt.

The external onshore portion of the passive margin contains following basement rocks.

- Remobilized basement with granitic gneisses adjacent to the Cauvery basin
- mobile belt rocks with khondalite adjacent to the Krishna-Godavari basin
- Remobilized basement with granitic gneisses adjacent to the rest of the Krishna-Godavari basin
- Charnockite between Krishna-Godavari and Mahanadi basins
- Singhbhum batholitic granites and some granodiorites adjacent to the Mahanadi basin

The Eastern Ghat mobile belt of India is supposedly the counter part of the Napier Complex in Enderby land in East Antarctica.

Isostatic Residual Anomaly Map



Courtesy: Reliance Industries Ltd, Fugro Robertson Inc., 2006

Isostatic residual anomaly map with 3*3 km resolution derived from interpolated ship-track gravity data (Fugro Robertson Inc., 2006).

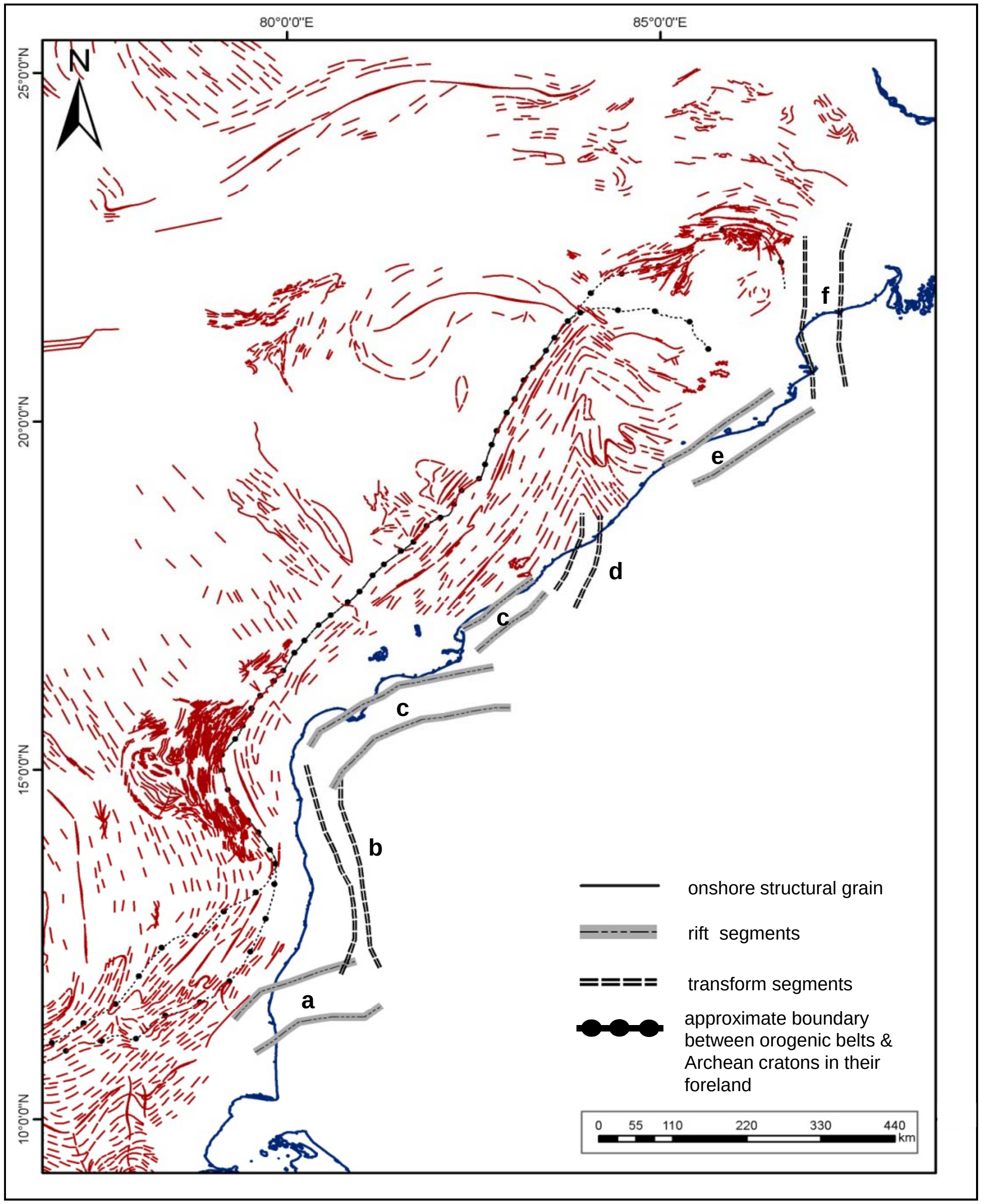
The positive anomaly on continental side coupled with negative anomaly on oceanic side represents a good candidate for crustal boundary.

The 85º E Ridge is a prominent gravity low representing crustal roots underneath a chain of volcanic loads.

Two isolated anomalies of similar origin to the W of the ridge in Krishna-Godavari and Cauvery basis are associated with hot-spot-related solitary volcanoes.

It is important to note that the Kerguelen hotspot activity closely after break up makes it difficult to indentify magnetic anomalies produced by geomagnetic isochrones in Bay of Bengal.

Tectonic Segments of Offshore India



Map of major tectonic segments of the study area and structural features of the adjacent onshore

There are six major segments:

(a) The NE-SW trending Cauvery rift zone

(b) NNW-SSE trending dextral Coromondal transfer zone (Pennar-Palar Basin)

(c) NE-SW to ENE-WSW trending rift units of the Krishna-Godavari rift zone

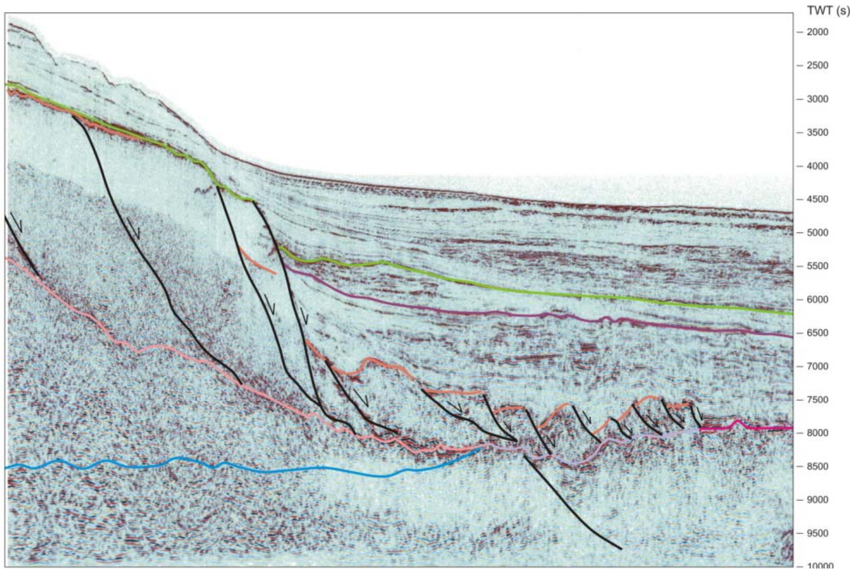
(d) NNW-SSE trending North Vizag transfer zone between Krishna-Godavari and Mahanadi rift zones

(e) NE-SW trending Mahanadi rift zone

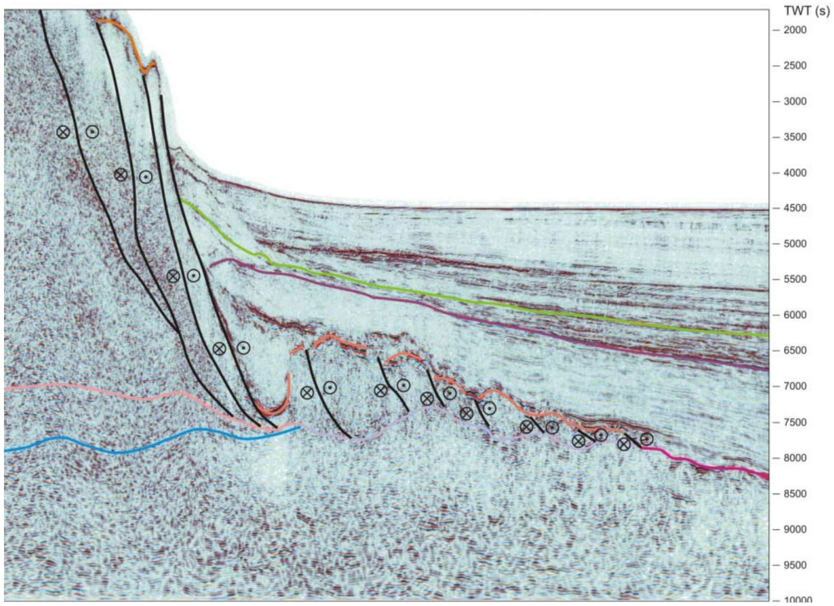
(f) NNW-SSE trending dextral Konark transfer zone.

modified from Ray, 1963; Geological Survey of India, 1993

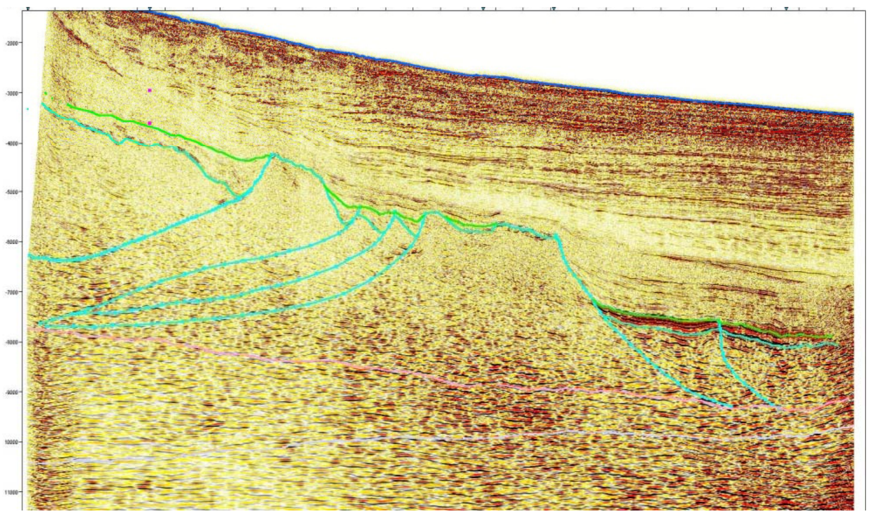
Seismic Interpretation showing Break control along East India



Break-up controlled by normal faulting (Easterly dipping) in the Cauvery basin region along dip oriented reflection seismic profile

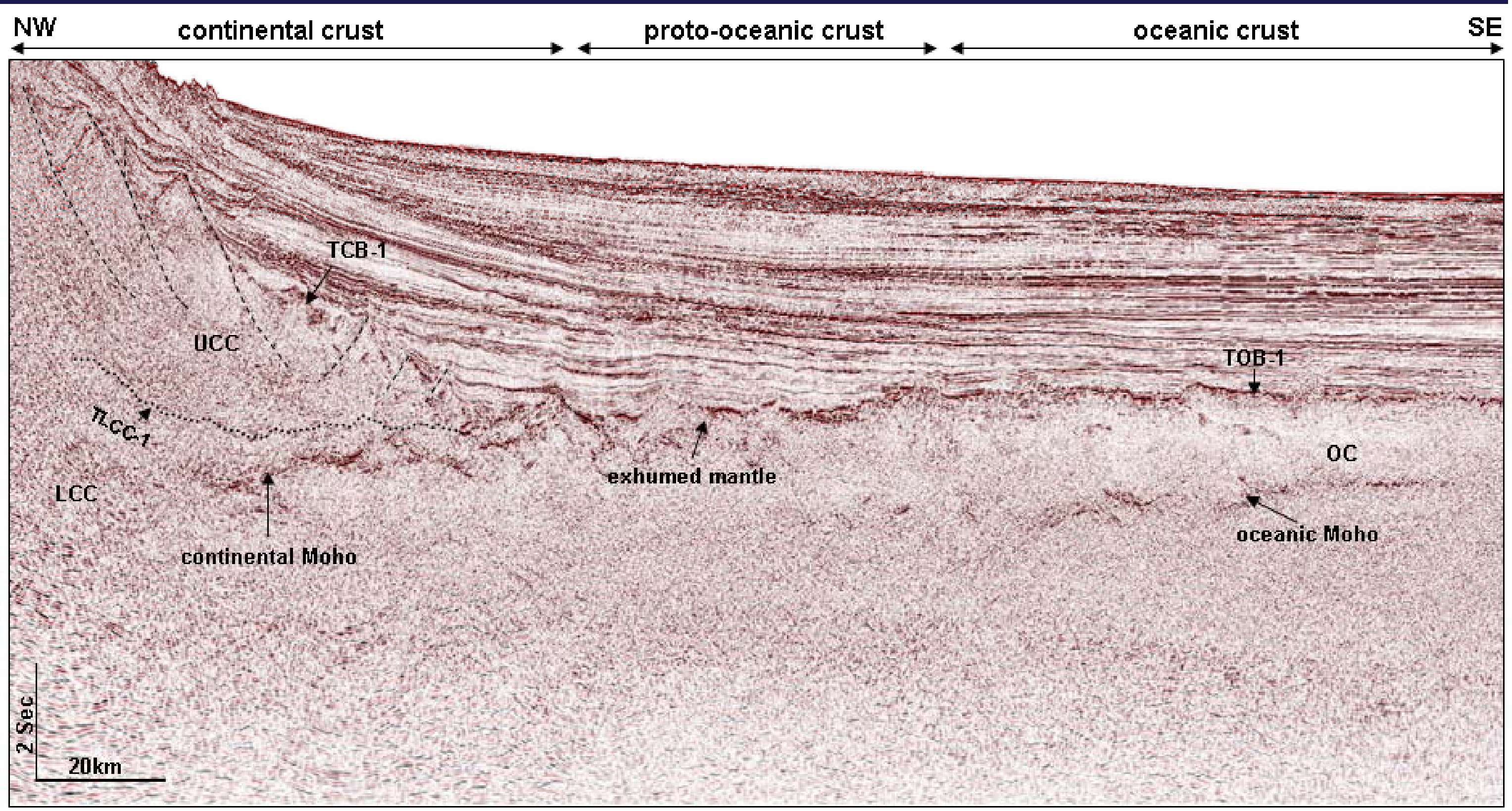


Break-up controlled by dextral strike-slip faulting (Coromondal Fault System) in the Pennar-Palar basin region along dip-oriented reflection seismic profile



Break-up controlled by normal faulting (westerly dipping) in the Krishna-Godavari basin region along dip-oriented reflection seismic profile

Seismic Interpretation of GX 1000

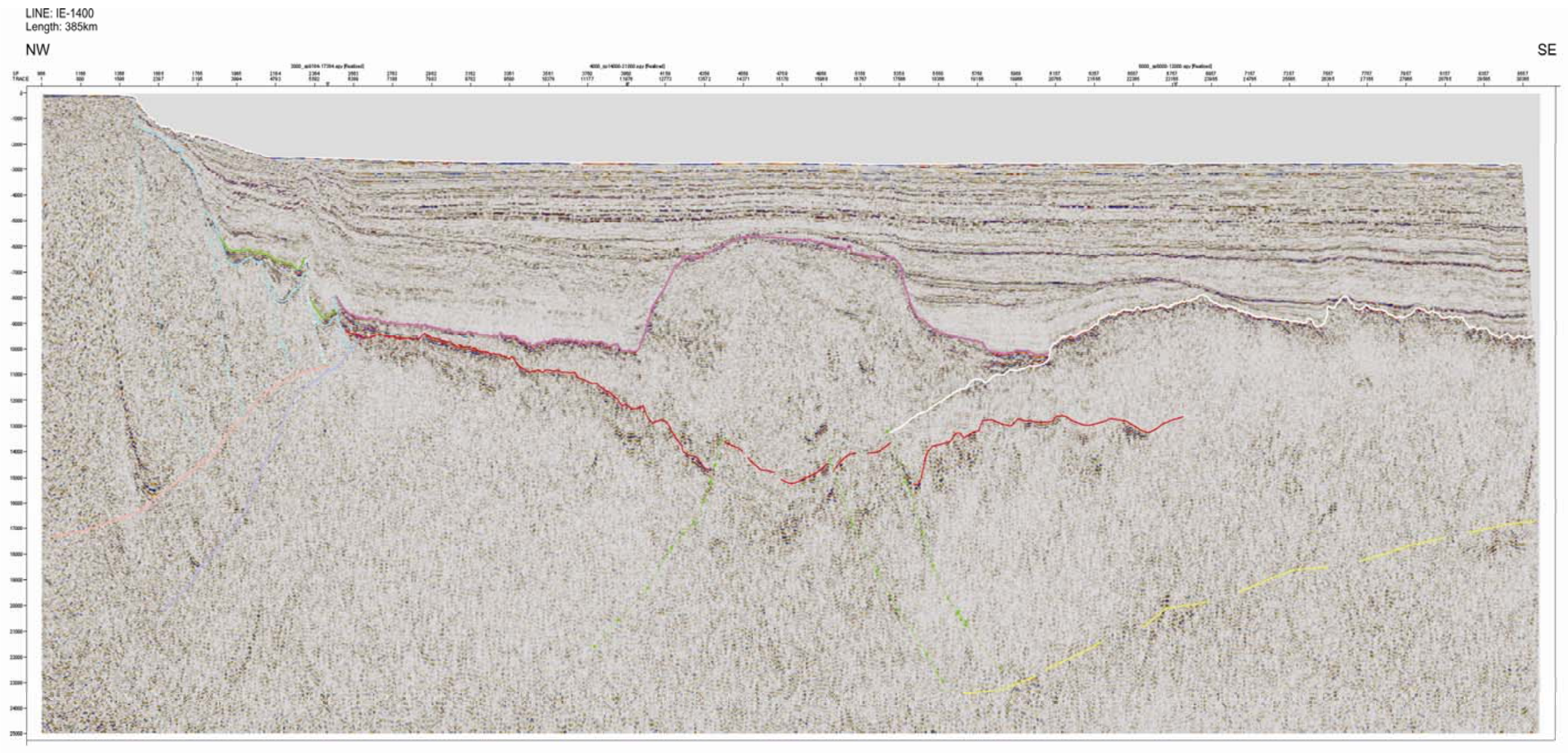


Profile GXT-1000 through the southern Krishna basin showing distribution of crustal types including thinned upper continental crust (UCC), thinned lower continental crust (LCC), proto-oceanic crust (exhumed mantle), and oceanic crust (OC), mapped as based on seismic signatures. Note the break-up initiated by normal faulting.

The continental Moho uprising towards NW is seismically very well imaged

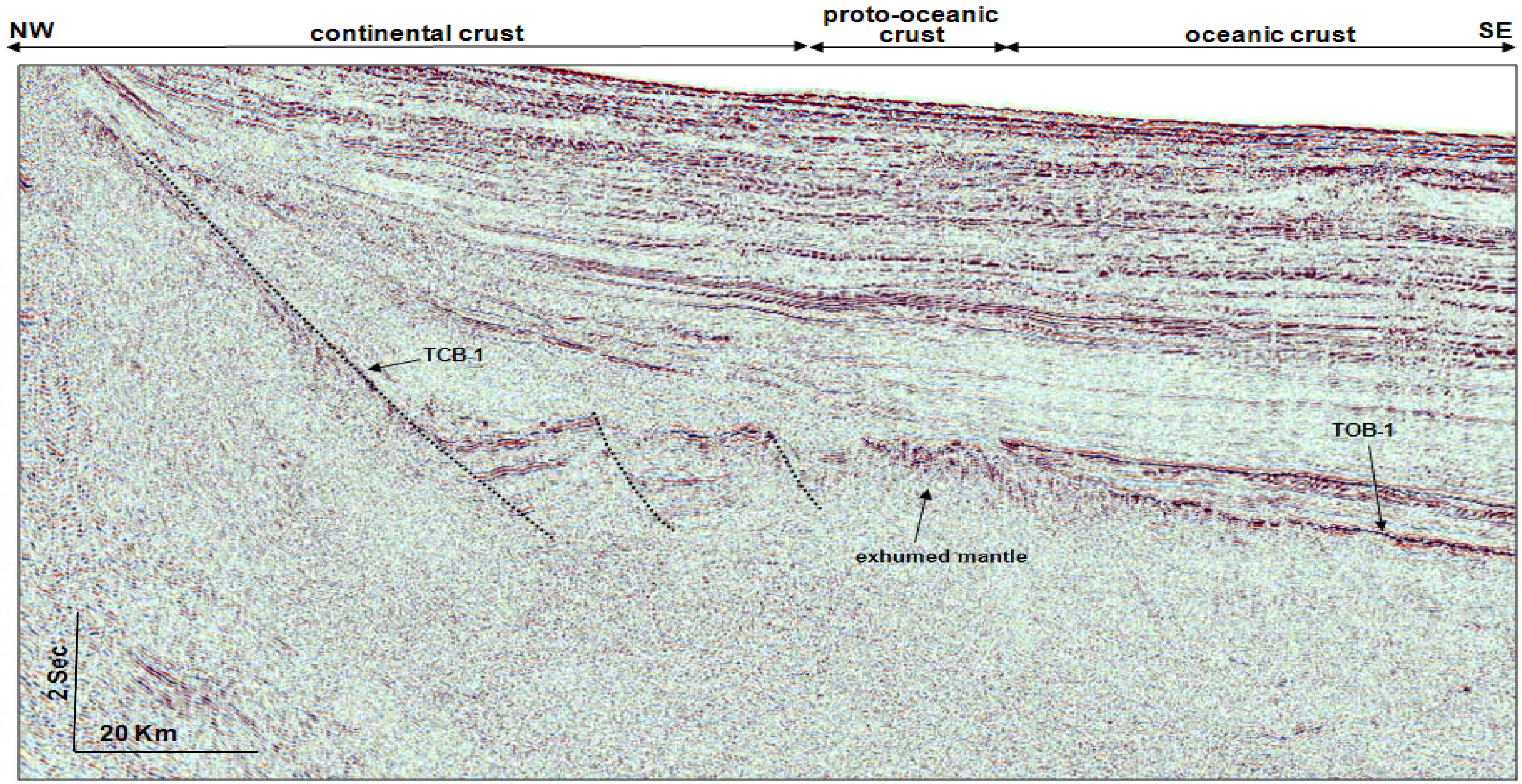
Towards SE, the more organized layered normal oceanic crust with a prominent Moho resolution (oceanic Moho) can be observed. The top oceanic basement (TOB-1) is relatively flat and tectonically undisturbed

Seismic Interpretation of GX 1400



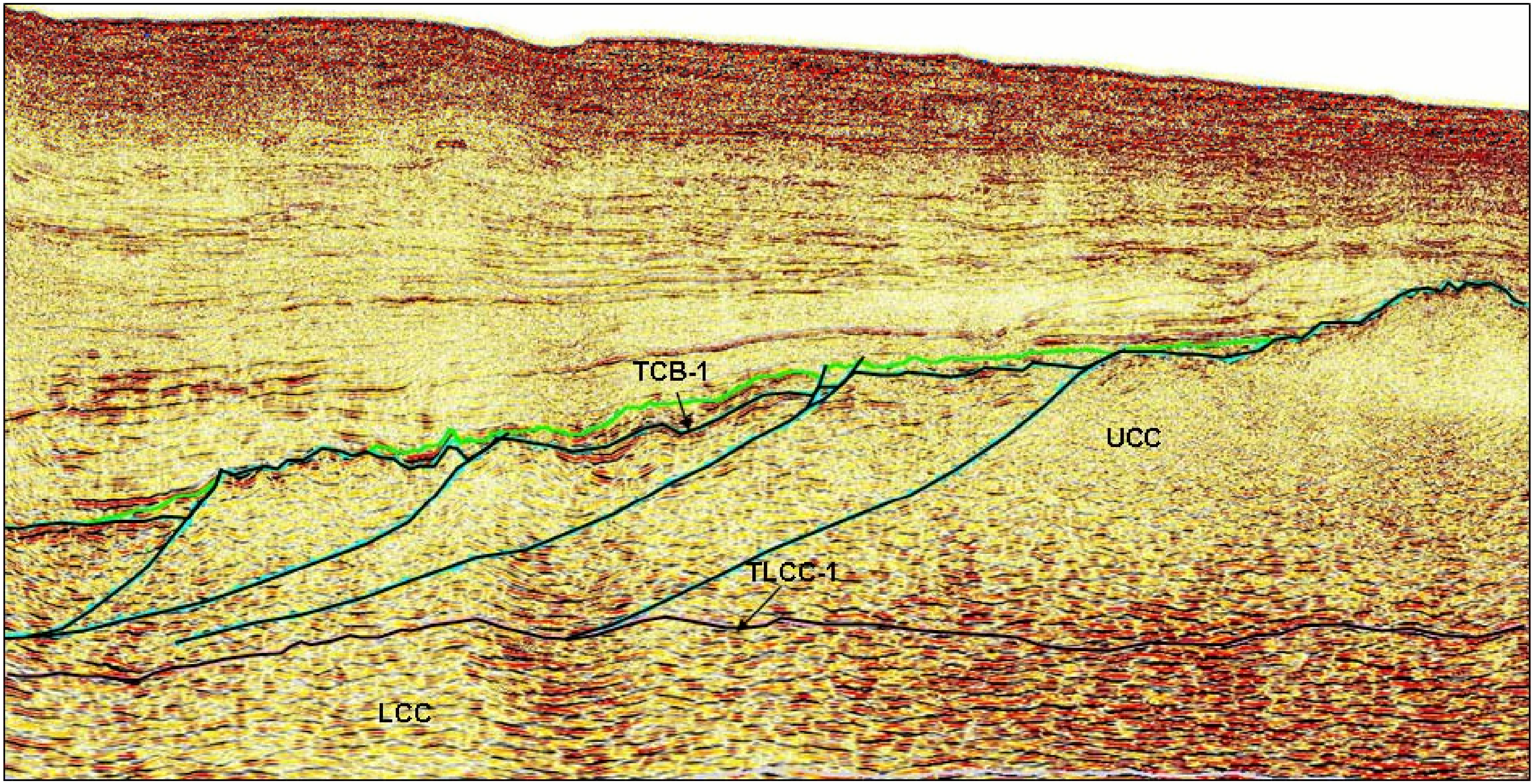
Depth-migrated seismic section of GX-1400. Note a hot spot-related volcanic load overlying the proto-oceanic crust. Due to the huge volcanic associated intrusions, geothermal fluid alteration and hot-spot associated deformation, it is practically impossible to determine the boundary between poc and oc underneath the load.

Seismic Interpretation of GX 1600



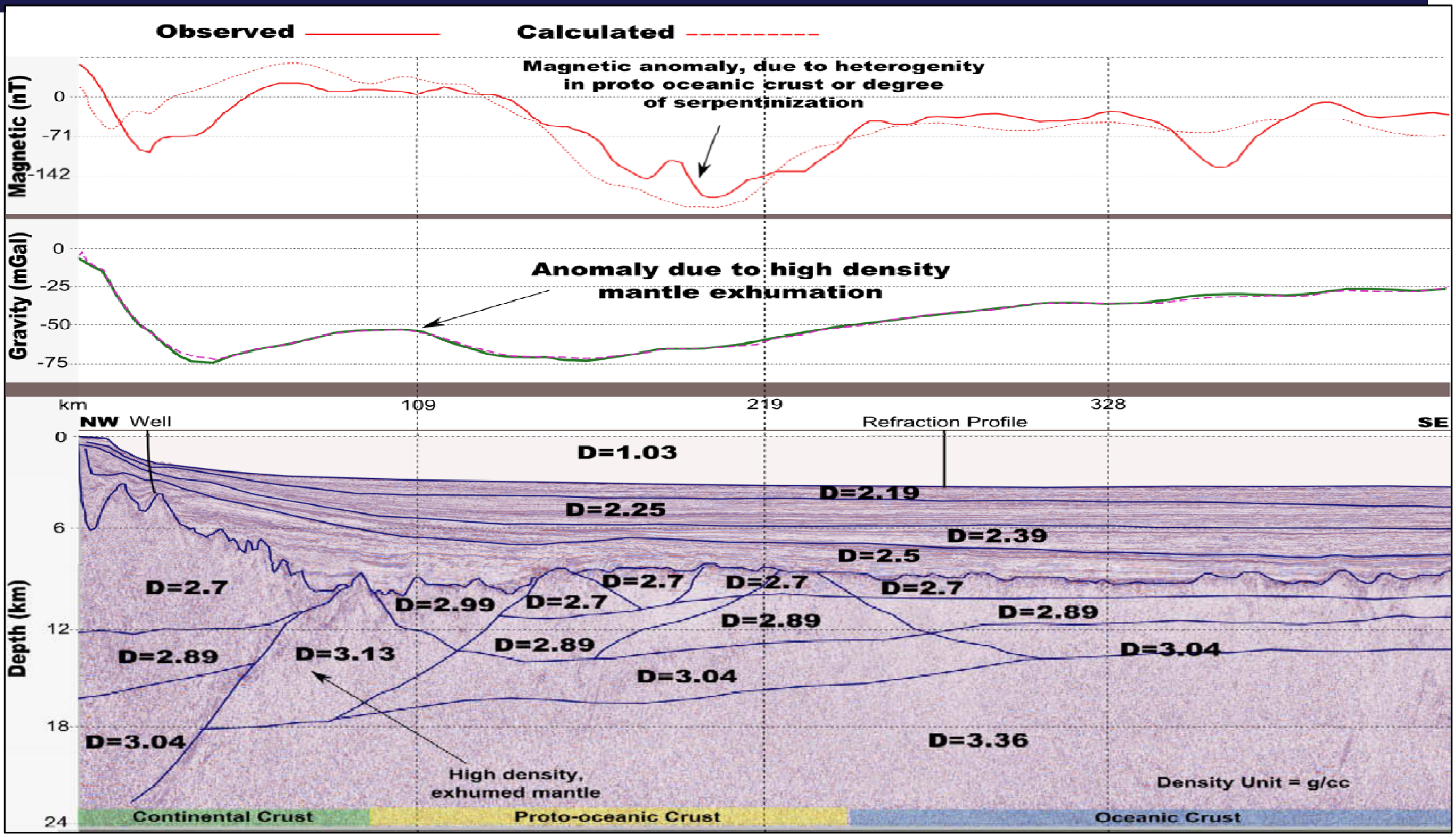
Profile GXT-1600 through the Mahanadi basin. The uprising continental Moho is not imaged well in this profile and the oceanic Moho is not very prominent. Two grabens can be seen on the continental margin. The oceanic crust is flat and strongly reflective with parallel-layered reflectors in its upper parts. Seismic image of the exhumed mantle is disturbed and characterized by wavy reflectors. Top of the continental basement (TCB-1) and top of oceanic basement (TOB-1) are interpreted on the basis of the last prominent continuous reflector in the continental and oceanic crust, respectively. The break-up was initiated with normal faulting

Differentiation of Upper and Lower Continental Crust from East India Seismic Data



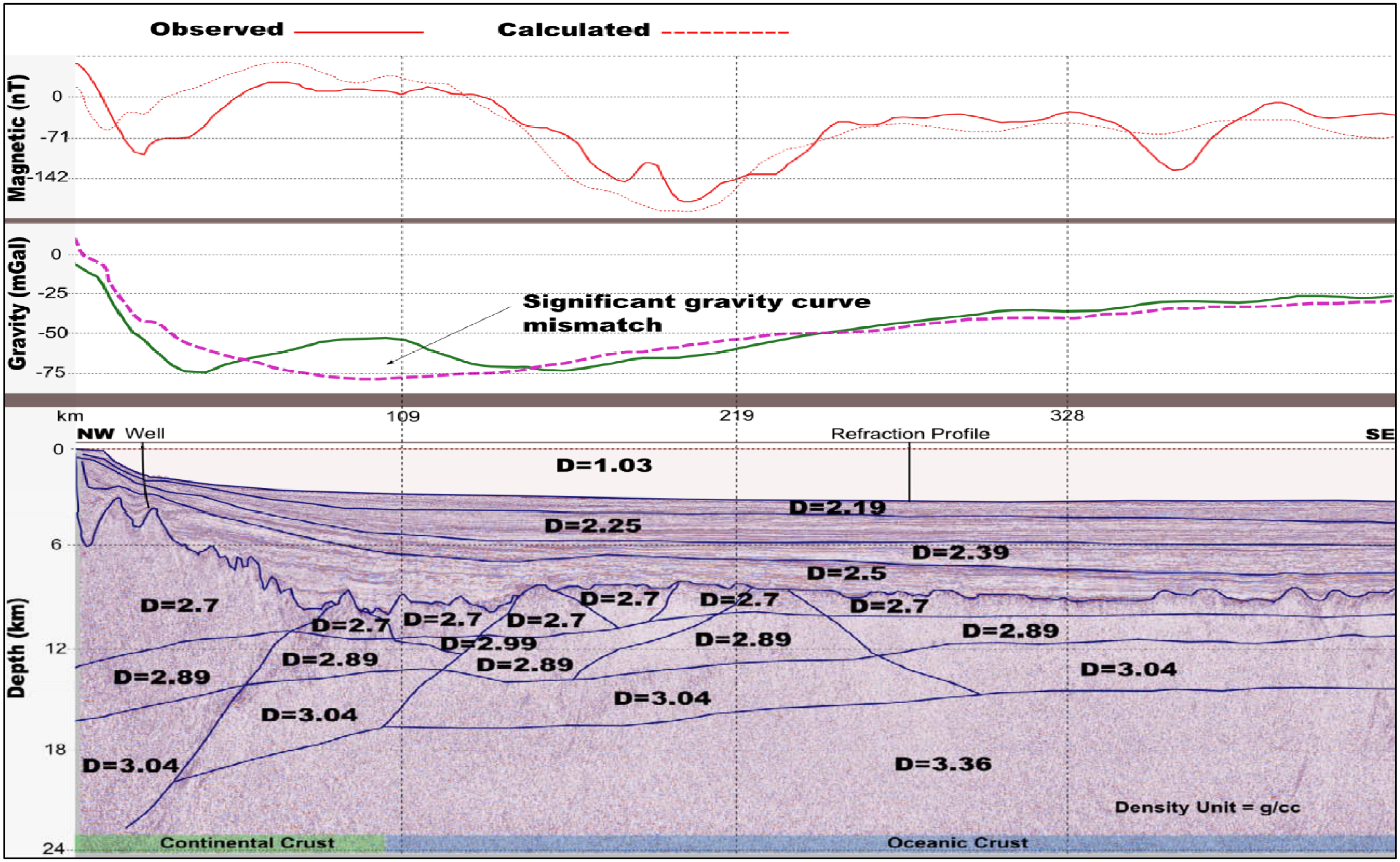
A strike-oriented seismic profile showing the continental crust in detail. Top of the continental basement (TCB-1) is faulted. The upper continental crust (UCC) is characterized by the presence of faults, shear zones and other pre-existing deformational features. It is relatively transparent in terms of reflectivity due to its brittle nature. The lower continental crust (LCC) is highly reflective with sub-horizontal reflector pattern due to its “flowable” ductile nature.

Gravity and Magnetic Modeling along GXT profile IE-1000



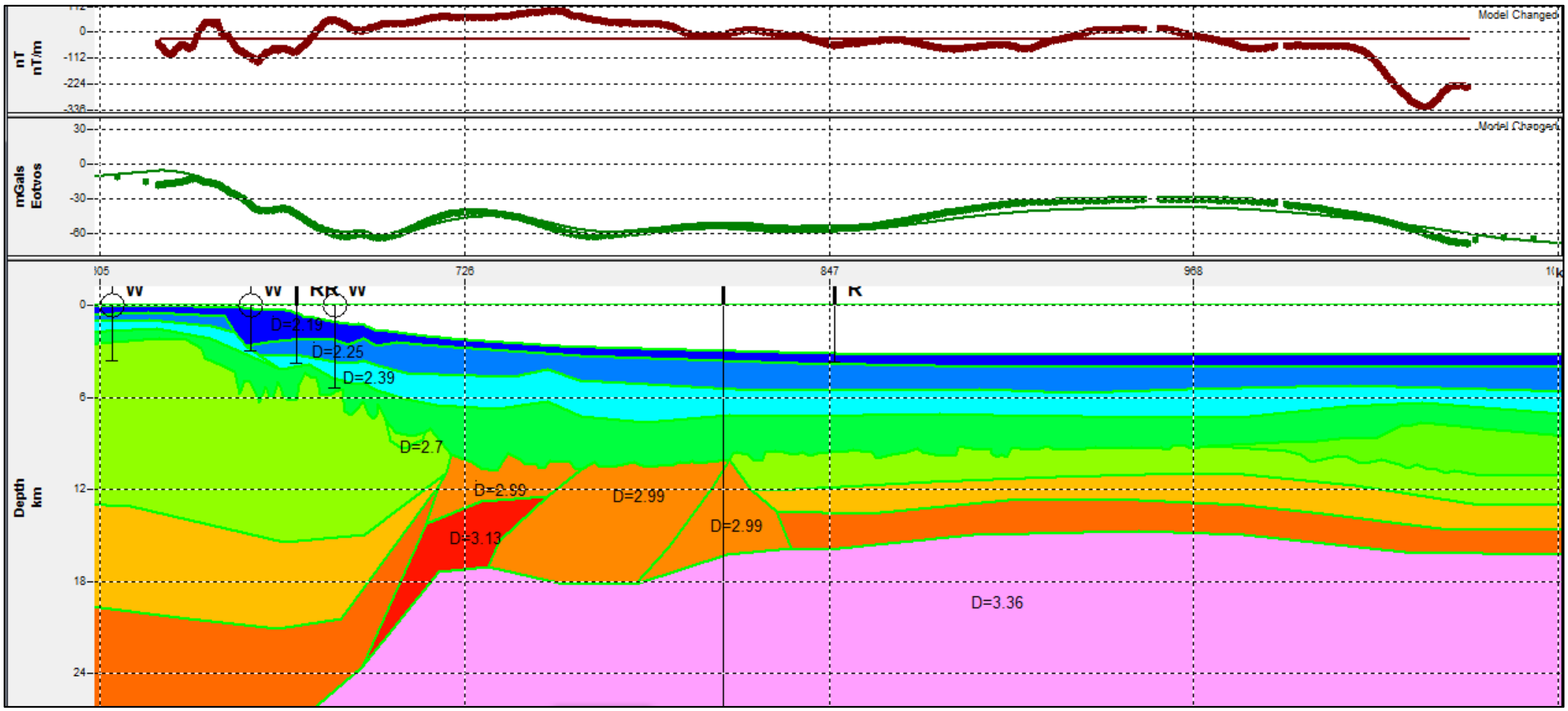
The gravity and magnetic models along depth migrated section GXT-1000 (Bird, 2008) showing a good match between observed and calculated gravity and magnetic data. The thick and thin lines show the calculated and observed curves, respectively. Profile shows a high density body with density of 3.13 gm/c3 as situated just east of the extended continental crust, indicating exhumed mantle. This is the best model for both curves for depth-migrated profile GXT 1000. The increased density of poc in sensitivity analysis does not seem to affect the model in any important way.

Gravity and Magnetic Modeling along GXT profile IE-1000



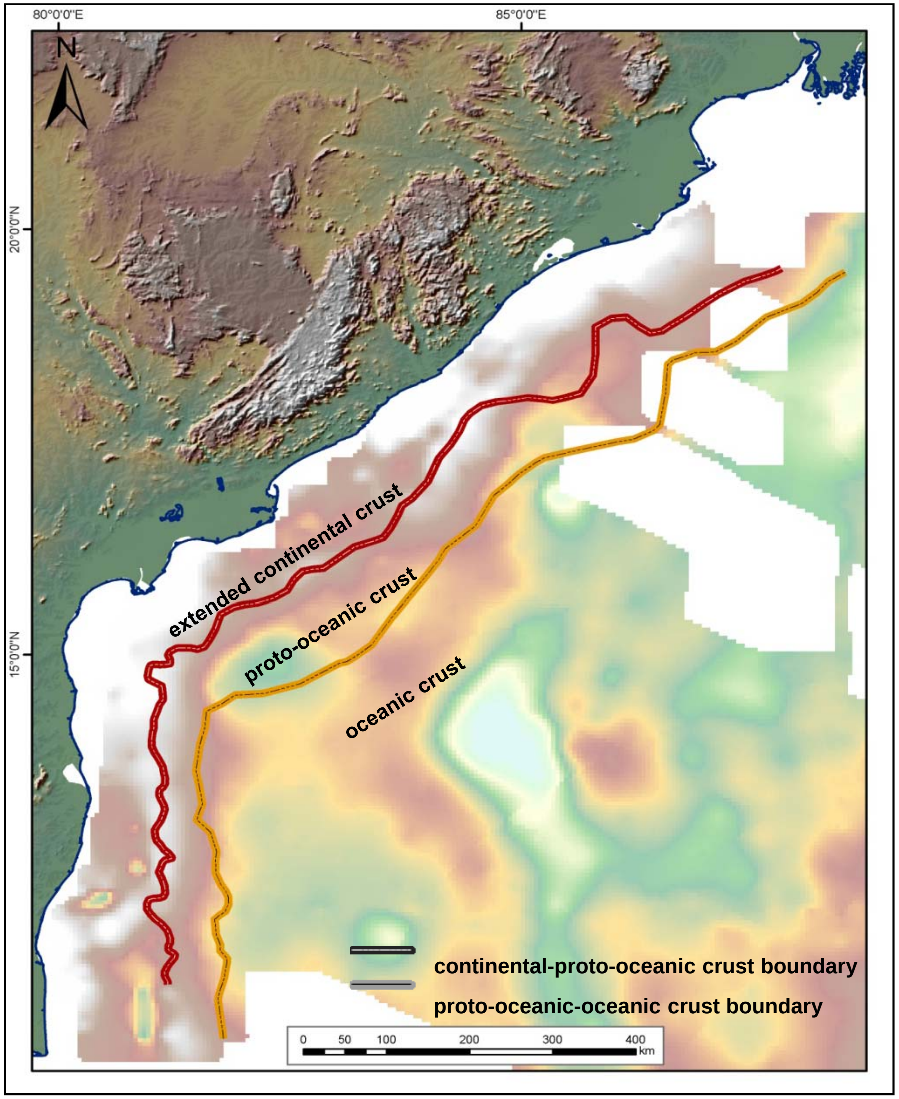
This time showing a classical continental-oceanic transition model. It shows a significant observed/modeled gravity curve mismatch at the continental-oceanic transition, indicating that the match can be achieved only with a model containing a high density material of the proto-oceanic crust formed by unroofed mantle.

Gravity and Magnetic Modeling along GXT profile IE-1200



Profile GXT 1200, gravity/magnetic model. This is the best scenario with poc for the profile. Note lower densities in several blocks caused by serpentinization. Positive anomaly at poc/cc boundary needed correction for 3D effect of gravity field. Width of the poc corridor conforms to extent of poc interpreted from seismic imaging.

Crustal Boundary Interpretation



Map of the study area showing the extent of continental, proto-oceanic and oceanic crusts and their boundaries on top of the isostatic residual anomaly map.

Note that the width of proto-oceanic crust varies along the margin.

The width seems to depend upon the break up mechanism and extension rate.

It is narrow at strike-slip-controlled margin segments.

It is wide at normal fault-controlled segments.

Conclusions

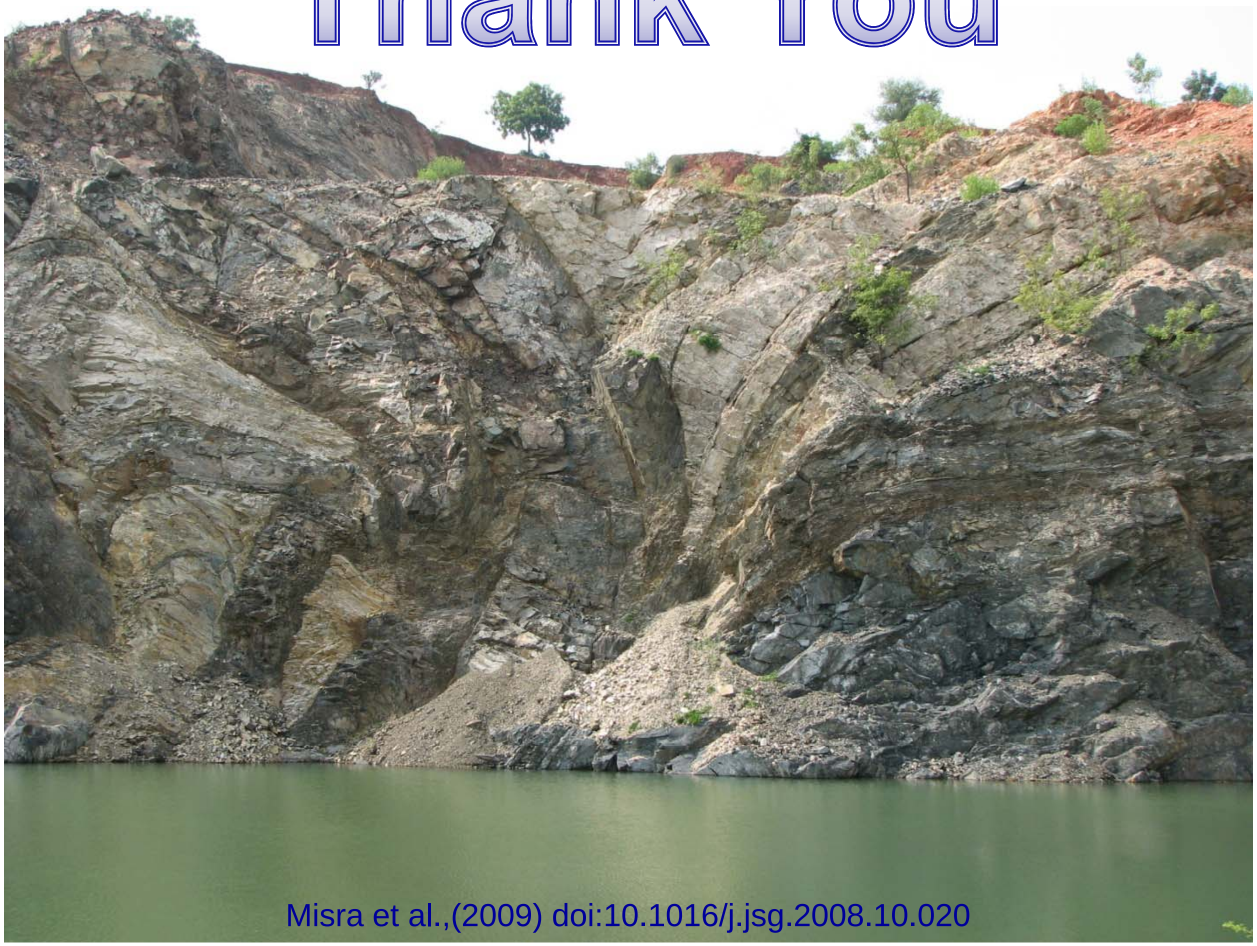
- The ocean continent transition of East India was so far based on classical continental break up concept.

- The present study indicates possible mantle exhumation along East India margin.

- The break up is controlled by normal faulting in Cauvery, Krishna-Godavari and Mahanadi region, whereas the and Pennar-Palar Basin and north Vizag basin is mostly controlled by strike slip faulting.

- The Mantle exhumation is kinematically linked with break up control mechanisms.

Thank You



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