Determining the Paleogeographic Evolution and Source to Sink Relationships of Indian Offshore Sedimentary Basins*

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Abstract

Although there are a number of large sedimentary basins along the western and eastern offshore margins of the Indian Subcontinent, the hydrocarbon discoveries to date vary considerably being focused in just one or two basins on each margin. On the western margin the productive, but increasingly mature Mumbai Basin sits adjacent to the Kutch and Konkan-Kerala basins to the north and south respectively, where little or no hydrocarbons have been discovered. Similarly, on the eastern margin, the prolific Krishna-Godavari Basin lies to the south of the Mahanadi and Bengal basins and north of the Palar, Cauvery and Mannar basins, again within which hydrocarbon discoveries are very limited. As the currently productive basins mature, exploration is looking to new, as yet untapped plays within these basins, or to the large expanses of the relatively unexplored basins. Understanding the detailed evolution of these basins and the controls on the development, distribution and interplay of the various components of the petroleum systems within, are key to unlocking further potential. In this presentation we demonstrate how the integration of plate modelling, detailed structural and paleogeographic mapping and paleodrainage analysis workflows can be applied to rigorously assess the petroleum components in the offshore sedimentary basins of India.

Structural Mapping and Plate Modelling

Synthesis of gravity and magnetic data, SRTM and Landsat images, supported by available seismic and public domain data, was used to construct a detailed structural and tectonic coverage of the region and kinematic and mechanical models for the evolution of each individual basin. 2D gravity profiles were used to help constrain crustal types and basement morphology as well as to confirm and validate basin architecture and structural models. Quantitative plate modelling was then conducted, testing various scenarios for the tectonic evolution of India and providing the base for a series of paleogeographic reconstructions (Figure 1).

Paleogeographic Mapping

The paleogeographic maps reveal the evolving landscape from the break-up of Gondwana through to the collision of India with Eurasia, with individual time slices chosen to reflect major events in the evolution of the sedimentary basins (e.g. major source rock deposition events, etc.). The key paradigm that underpins the mapping of these paleogeographic reconstructions is that of contemporary base level: depositional areas below base level (clastic sink areas) within which paleoenvironments and lithologies are mapped; and tectonophysiographic terrains above base level where net erosion has taken place (clastic source areas). These are assigned to the most recent tectonic regime responsible for their elevation and are divided by whether they represent the consequences of dominantly vertical or horizontal stress fields (i.e. divergent or convergent tectonism, flexure or hot-spot/plume activity). Since positive features have longevity, an age is assigned to these features based on the length of time that has elapsed between the last thermo-mechanical event and the time slice being depicted. Using the kinematic model developed during the structural mapping and analysis, the main active structures are combined with these depositional and tectonophsyiographic terrains and provide a visual link between tectonics and source and sink relationships (Figure 2).

These paleogeographic reconstructions provide explorationists with powerful analytical and predictive tools. They provide the user with both regional and local visual reconstructions of sediment source and sink areas, and also the link between tectonics and these source to sink relationships. They also present insights into the temporal and spatial juxtaposition of the various play elements within a basin and the dynamics responsible, and in doing so allow predictions of the extension of play elements beyond areas of available data.

Present-Day Drainage Analysis

An essential step in understanding the evolution of any landscape through time is an investigation of the modern landscape. Modern river systems are analyzed through the development of detailed drainage networks generated from reprocessed SRTM3 and SRTM30

Digital Elevation Models (DEMs). The aim of this analysis is to identify discontinuities in the landscape which may indicate changes in river systems in the past and therefore changing source to sink relationships. These hypotheses may then be tested against geological observations.

Paleolandscape and Paleoriver Analysis

The results of the paleogeographic mapping and the analyses of modern drainage networks are combined to generate paleolandscape reconstructions. The conversion to elevation is based initially on a uniformitarianist relationship between the elevational distribution typical of modern tectonophysiographic terrains and their past occurrences. These elevations are then modified using fission track and other paleoaltimetry methods, as applicable, as well as geological observations. The result is a paleo-DEM, which is a gridded representation of the past topography and bathymetry. The advantage of a paleo-DEM over a traditional paleotopographic map is that it integrates the drainage and topography to generate a 'hydrologically-correct' grid (i.e. the depicted paleodrainage network is consistent with the reconstructed topography) and is explicably testable. Analysis of the paleolandscape and paleorivers provide reconstructions of the transport pathways connecting source to sink areas and can aid explorationists in both qualitative and quantitative assessments. Qualitatively, understanding the evolution of the drainage basin and the nature of material being eroded and transported can give clues to the potential lithological makeup and quality of potential clastic reservoirs located at the paleoriver outlets. By generating successive topographies, denudation rates can be calculated systematically when combined with the results of paleoclimate analysis, and mass balance calculation made with offshore depositional systems.

Application in Indian Sedimentary Basin Analysis

The stepwise application and integration of these various disciplines to the tectonic and stratigraphic evolution of the Indian Subcontinent, and in particular its offshore sedimentary basins, has provided a powerful tool in the analysis and prediction of the various components of the petroleum systems active within them. The source to sink relationships have been used to pinpoint areas of favourable source rock and reservoir rock development. The paleogeographic maps and structural models have also been used to constrain geochemical modeling within these basins, particularly in the less well explored basins, where supporting data is limited. A number of key indicators of hydrocarbon prospectivity, particularly within the underexplored basins, that have been determined from the integration of all of these disciplines will be illustrated.

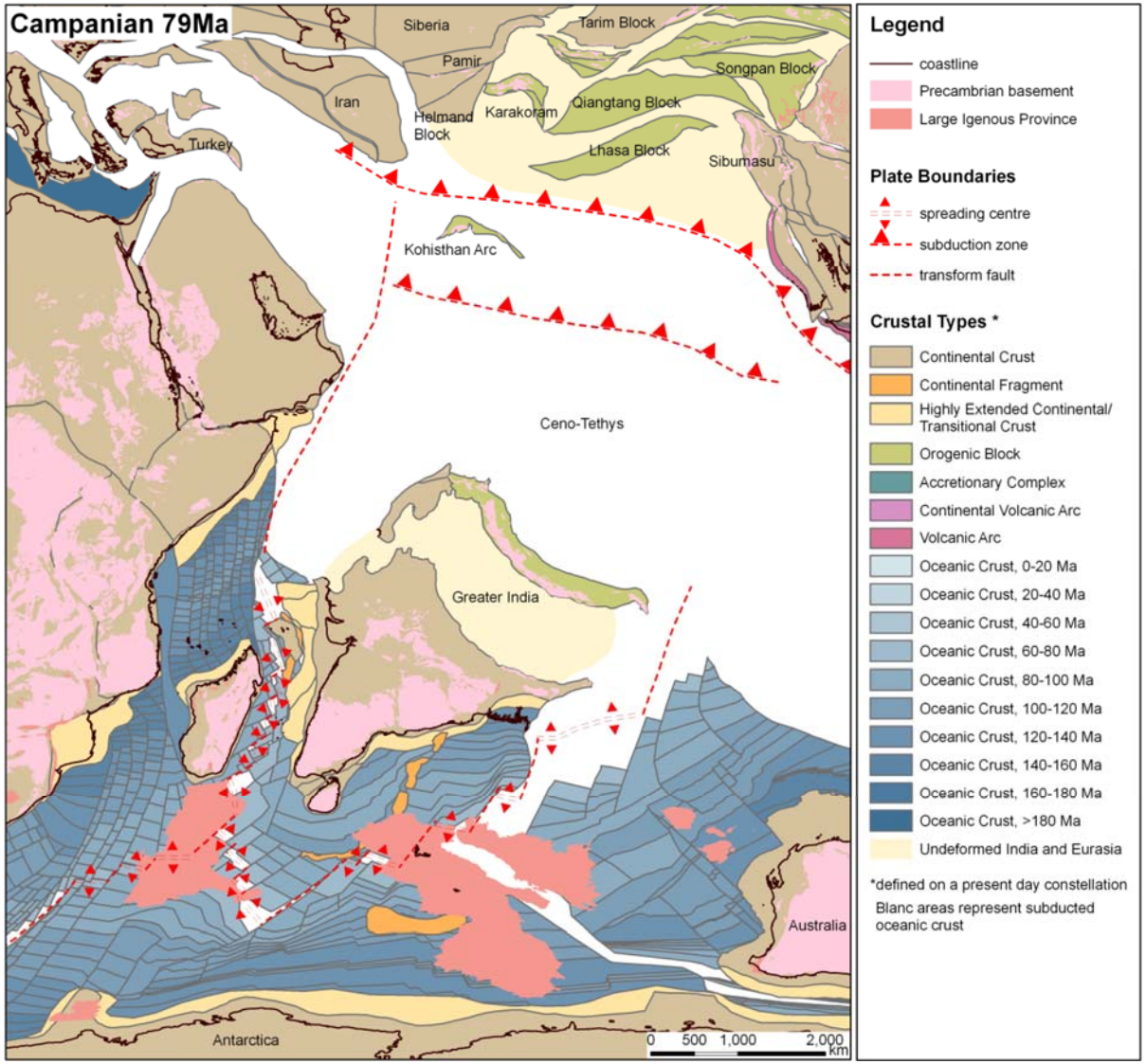

Figure 1: Plate reconstruction of the Indian Plate and surrounds during the Campanian (79Ma).

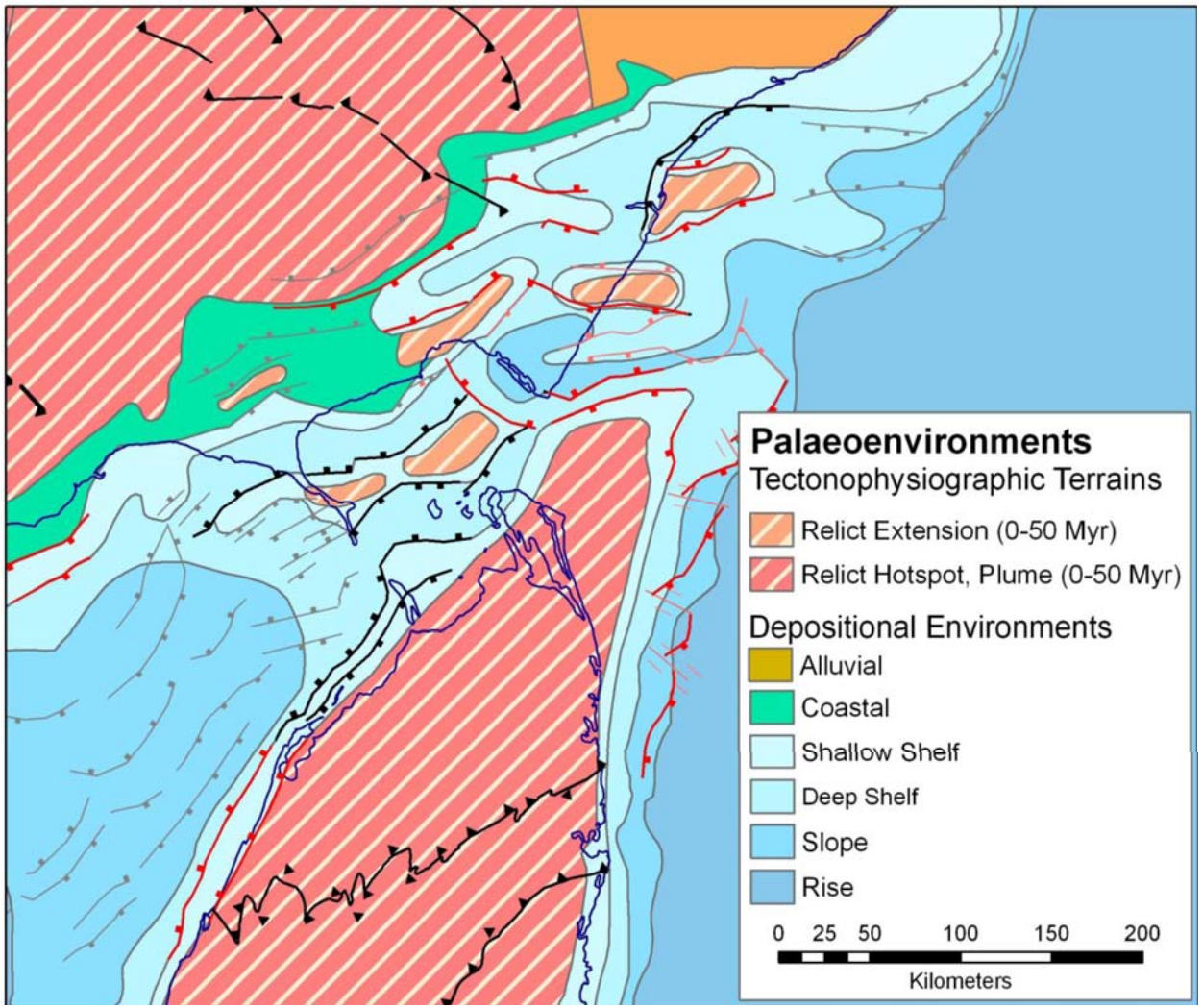

Figure 2: Campanian (79Ma) paleogeographic map of the Cauvery and northern Mannar Basin, showing the relationship between the tectonophysiographic terrains (source areas) and depositional areas (sink areas). Small highs within the southern Cauvery Basin are considered sedimentary sources for locally derived turbidites which form potential reservoirs.