Study of geomorphic features along ECMI by GIS

Bathymetry is the science of measuring water depths (usually in the ocean) in order to determine bottom topography[1]. The bathymetry Digital Elevation Model (DEM) is useful to delineate coastline accurately, specifically in the regional scale. In addition to this, GIS technology has significant spatial tools to interpret and analyse various morphometric parameters from available present-day Earth Topography Digital Dataset (ETOPO) bathymetry image. This study is an attempt at quantitative interpretation of continental margin features using bathymetric DEM and GIS. The Eastern Continental Margin of India (ECMI) represents a rifted passive margin that has formed due to continental rifting. In the absence of high-resolution geophysical data, this concept has tremendous scope for research to understand geological concepts of offshore sedimentary basin. Ocean and land contacts are differentiated by water line and other influential factors like tide, current, winds, etc. Thematic maps and ocean charts are frequently referred for identifying the coastline and related zones. Various geometrical attributes like contour (isobaths), dip, slope, aspect, flow direction, stream orders and slope profiling are calculated using ArcGIS spatial tool and are being used for the demonstration of coast, shelf, slope and deepwater basin areas. Geomorphic analysis and various types of geotechnical features along the continental margins based on basin configuration are represented in Figure 1.

Understanding the continental margins, basin evolution and their architecture is a dynamic process. Integration of a new set of data coupled with regional concepts has redefined the exploration frontiers which are more complex and challenging[2]. The deep waters of both the Eastern and Western Continental Margin in the Indian context therefore need to be studied in an intensive and extensive manner.

The study area comprises the seafloor from ECMI towards the deeper part of the basin up to a depth of about 4200 m. The major peninsular rivers flow easterly contributing to the deposition of enormous sediments along the continental margin. The ECMI has been categorized into seven sedimentary basins[3], namely Ganga–Brahmaputra (Bengal Basin), Mahanadi, Visakhapatnam Bay, Krishna Godavari, Pennar–Palar, Cauvery and Gulf of Mannar from north to south based on integrated interpretation.

ETOPO images are available as global relief model of the Earth's surface that integrates land topography and ocean bathymetry. It was developed from numerous global and regional datasets created by the National Geophysical Data Center of National Oceanic and Atmospheric Administration (NOAA). These datasets are presented in various versions; ETOPO2 has been used for this study and downloaded from the NOAA website, http://www.ngdc.noaa.gov/. ETOPO2 has been generated from digital databases of seafloor and land elevations on a 2-min latitude/longitude grid (1 min of latitude = 1 nautical mile, or 1.15 statute mile). ETOPO2 is a combination of satellite altimetry observations, shipboard echo-sounding measurements, and data from the digital bathymetric data. The horizontal datum is WGS 84 geographic and the vertical datum is sea level. It is moderate-resolution DEM, which is well suited for this kind of regional study.

Bathymetry DEM obtained from ETOPO was processed using ArcGIS software to extract various spatial derivatives. The in-built algorithm of GIS embedded as spatial tools is used in this case. Hydrological feature analysis model is used to extract various topographical and ocean bottom features. The advanced GIS tools like 3D analyst for profile plotting and spatial analyst for spatial correlation are used for spatial analysis to determine logical features. The complete process is shown in Figure 2.

Continental margins of the world's oceans assume tremendous significance in light of the fact that they have been exploited for mineral resources. Continental margin is the offshore zone, consisting of the continental rise, shelf and slope that separates the land of a continent from the deep ocean floor and the ocean floor from the continental slope to the abyssal plain. Morphology of margin area includes the continental shelves, which are underlain by thick sequences

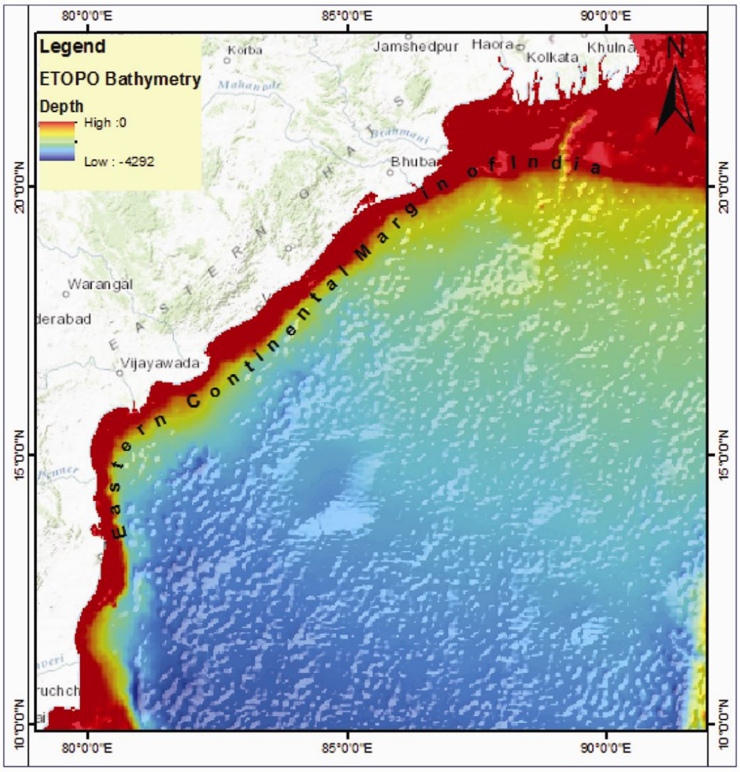

Figure 1. Study area showing Earth Topography Digital Dataset bathymetry with *Google* topography of land area along Eastern Continental Margin of India.

of sedimentary rock whose structural pattern may be complex. Tectonic, depositional and erosional modifications can lead to a variety of margin types. Deposition in deep water basins is controlled by many factors like basin tectonics, sediment supply and relative sea-level changes[4].

Continental margins are made of thick accumulations of sedimentary rock, in which oil and gas generally occur. Most of the sedimentary rocks exposed on the continents were originally deposited on continental margins; thus, even the hydrocarbon deposits found on land were formed for the most part on ancient continental margins. The largest mineral resources to be exploited from continental margins are oil and natural gas. Exploration of the continental margins by major oil companies globally has intensified and is expected to continue in the foreseeable future, because the margins are most likely the sites of giant undiscovered petroleum deposits. This study aims to extract ocean topographical features of ECMI and few geomorphic attributes like slope, azimuth and flow accumulations which are preliminary highlights of quantitative analytical techniques using ArcGIS 3D spatial tool. The features like coastline, channel, canyon, slope, shelf break, shelf area, rise, abyssal zone and trend surface are interpreted and extracted from the bathymetry DEM in this study area.

Coastline is defined as the water/land interface and shoreline is a more general term than ‘coastline’[5]. Local variations are also counted in some cases to chart the coastline considering the areas affected by tidal fluctuations. The continental margin is the surface morphological expression of the deeper fundamental transition between the thick, low-density, continental igneous crust and the thin, high-density and chemically different oceanic igneous crust. Covering the transition are thick sediment accumulations comprising over half the total sediments of the ocean, so that the precise morphological boundaries often differ in position from those of the deeper geology. Continental margins are classified as active or passive depending on the level of seismicity. Active continental margins are divided into two categories, based on the depth distribution of earthquakes and the tectonic regime. Slope is defined by a plane tangent to a topographic surface, as modelled by the DEM at a point[6]. Curvature as the second derivative of slope is used here to interpret the shelf edge extending to deep water basin. The curvature slope with shelf break zone is shown in Figure 3 and the sediment dispersal pattern is shown in Figure 4.

The coast is extracted using spatial tool (contour list function) by calculating the water depth value to zero, i.e. DEM pixel value as zero. This defines the land–water contact enabling the depiction of regional coastline (Figure 2). The slope and shelf breaks are identified by close contour and curvature raster by interpolation of second derivative of slope. This clearly shows the shelf edge and is also correlated with the elevation profile graphs drawn along ECMI. Channels are extracted using hydrological analysis tools performing few spatial calculations like flow direction, flow accumulation and stream order. Converting the stream order up to highest five into linear network feature using Strahler order method D8 formula[7] of joining downward pixels

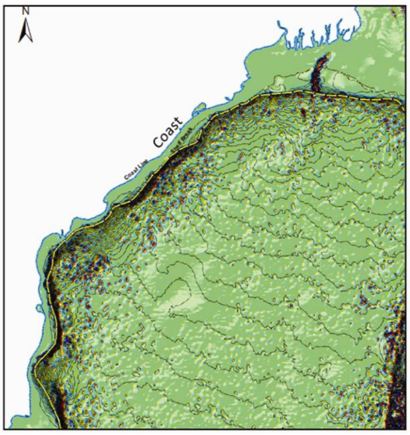

Figure 3. Curvature slope map highlighting coast (blue line) and shelf break zone (yellow line) with isobaths counter (100 m). This second derivative of slope is used in defining shelf, slope and basin.

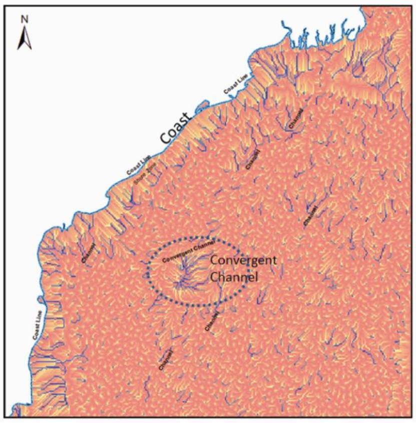

Figure 4. Flow accumulation showing the shallow as well as deep water channel (blue colour) forms responsible for the present-day sediment dispersal pattern.

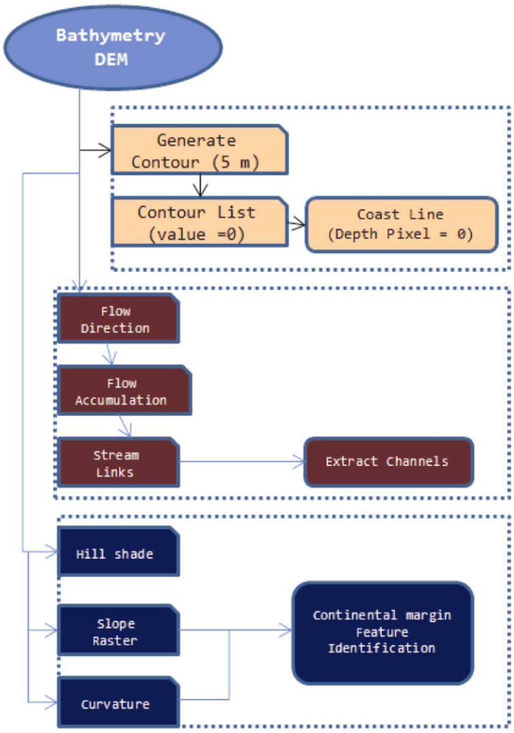

Figure 2. Work flow for delineation of various continental margin features.

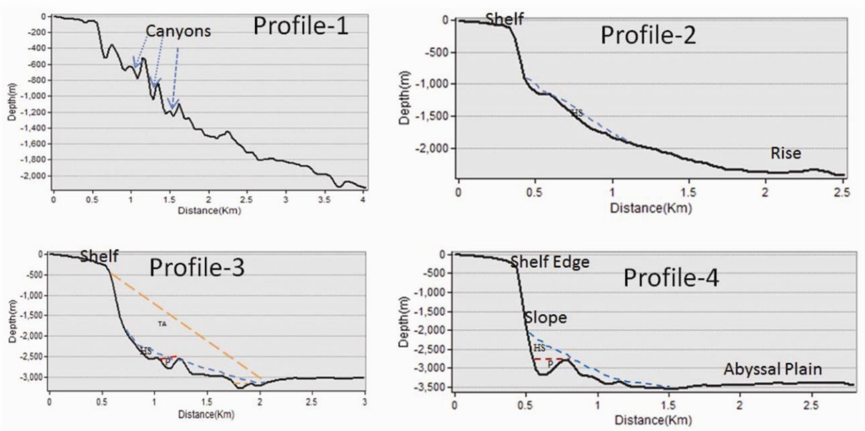

Figure 5. The four profiles drawn on bathymetry to identify features like canyons, slope, shelf and the deeper zone, i.e. abyssal zone. Trend surface depicting the accommodation types along these profiles and their positions is shown Figure 6. P, Ponded accommodation; HS, Healed slope accommodation; TA, Total accommodation.

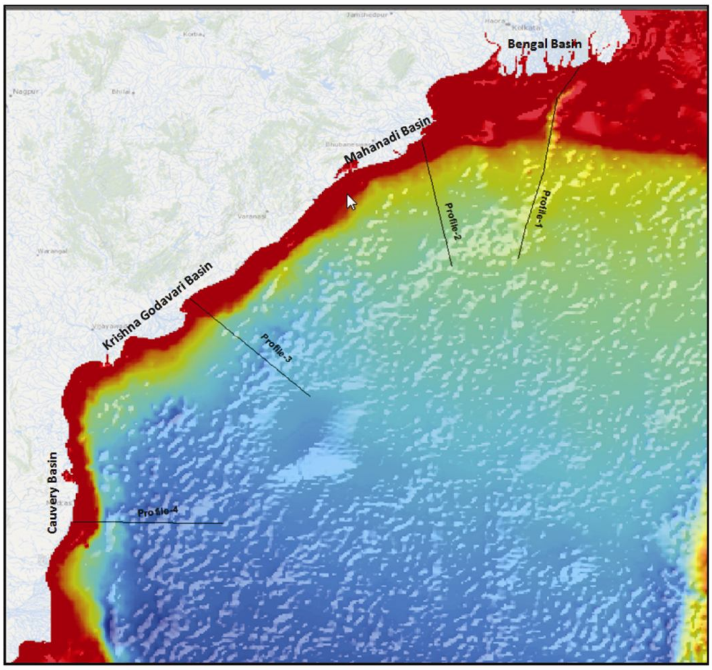

Figure 6. Map showing present-day bathymetry with depth profiles along Eastern Continental Margin of India.

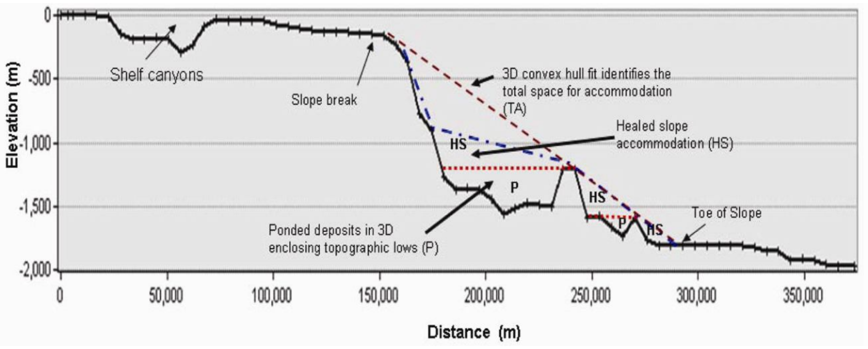

Figure 7. Schematic diagram showing the various types of accommodation used in the study along a dip profile.

cell-by-cell, the sea-bed channels are prepared (Figure 3). This shows the present-day channel systems.

The depth contours over ECMI follow a nearly NS trend in the southern region and NE–SW trend up to the Bengal basin in the north, hence running sub-parallel to the coastline, which supports the earlier work on this basin. The deep water area beyond 400 m water depth up to 250 nautical miles (EEZ) distance from the coast forms a separate category and is considered highly prospective. The minimum shelf width of about 30 km is observed off Puducherry in the south and a maximum shelf width of about 60 m off Godavari and Paradip area.

Trend surface profiles (Figure 5) help identify various zones of deposition, e.g. ponded, healed slope and slope accommodation. In Figure 6, the depth profiles are shown on bathymetry map. The trend analysis helps in understanding depositional pattern in the deep water slope system. This describes the 'fill and spill' deposits proposed by Satterfield and Behrens[8]. Fill and spill describes the process of intraslope basins filling from updip to downdip. The important feature of understanding the fill and spill process is the concept of accommodation.

The deep water basin configuration is important in influencing deep water sedimentation[9]. Deep water basin configuration includes continental slopes and architecture. Preliminary continental slope may be above grade or graded slope. General graded slopes are gentler with almost no varying topography, while above grade slopes are characterized by the presence of step-like features or irregular topographic lows. These slopes are divided based on the types of accommodation available on them.

The accommodations can be described as ponded, healed slope and slope based on their geometry (Figure 7). Ponded accommodation occurs within three-dimensionally closed topographic lows[10]. This type of accommodation results in deposition in a confined basin. Healed slope accommodation develops in the space above the stepped equilibrium profile. These deposits actually wedge out towards the basinal part. Steffens *et al.*[9] defined healed slope accommodation in 3D as the space between top of ponded accommodation and below a 3D convex hull fit to the rugose seafloor topography, and the same principle is being used in this study. Slope accommodation is the space between the highest stable graded slope angle and the top of healed slope accommodation. In case of the graded slope, no ponded accommodation occurs and hence there is predominance of the healed slope or slope accommodation. So in this case there is greater bypass of sediments on the upper part and more deposition towards the basinal side[11]. Total space available for deposition is measured by fitting a 3D convex hull from the shelf slope break to the toe of the slope. Ponded accommodation is interpreted where there are three-way closing lows. Healed slope accommodation is the difference between the total slope and the ponded slope accommodation.

This study reveals that moderate resolution bathymetric data are suitable for automated feature extraction. Further, data processing is faster and results are fairly accurate in GIS system. Based on present-day channel system and sediment transport pattern along ECMI interpreted on a regional scale, the road map ahead calls for efforts to undertake further research to scale down high-resolution data like seismic imaging, gravity magnetic profiles and multibeam side scan image. This may help provide deeper understanding on depositional elements and establish petroleum systems in the respective sedimentary basins. Such studies can be combined with subsurface geological information and regional anomalies (gravity, magnetic, etc.) to derive more geomorphic parameters of deeper regime horizontal and vertical profiles of depositional systems. Remote sensing data are a viable alternative, as they are less expensive as compared to any other geological data and the results provided are promising. They can be a valuable tool for oil and gas exploration research in the days to come.

1. Ellis, M. Y., *Coastal Mapping Handbook*, Department of the Interior, US Geological Survey and US, Department of Commerce, National Ocean Service and Office of Coastal Zone Management, U.S. GPO, Washington, DC, 1978.
2. Bastia, R., In Proceedings of the 8th Biennial International Conference and Exposition on Petroleum Geophysics, Hyderabad, 2010, p. 419.
3. Bastia, R., *The Leading Edge*, July 2006, vol. 25, pp. 818–829.
4. Mutti, E. and Normark, W. R., In *Seismic Facies and Sedimentary Processes of Submarine Fans and Turbidite Systems* (eds Weimer, P. and Link, M. I.), Springer, New York, 1991, pp. 75–106.
5. Reed, M. W., *Shore and Sea Boundaries, Volume 3*, US Government Printing Office, Washington, DC, 2000.
6. Burrough, P. A., *Principles of Geographical Information Systems for Land Resources Assessment*, Oxford University Press, Oxford, 1986, pp. 147–166.
7. Strahler, A. N., *Am. Geophys. Union Trans.*, 1957, **38**, 913–920.
8. Satterfield, W. M. and Behrens, W. E., *Mar. Geol.*, 1990, **92**, 51–67.
9. Steffens, G. S., Biegert, E. K., Sumner, H. S. and Bird, D., *J. Mar. Petr. Geol.*, 2003, **20**, 547–561.
10. Prather, B. E., *Mar. Petr. Geol.*, 2000, **17**(5), 619–638.
11. Prather, B. E., *Mar. Petr. Geol.*, 2003, **20**(6–8), 527–543.

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Occurrence of Neoproterozoic animal embryos in the Chambaghat Formation of Himachal Lesser Himalaya, India

We report here the occurrence of definite Neoproterozoic animal embryos showing internal morphology through micro-CT from the phosphatic chert lenticles associated with quartz arenite of Chambaghat Formation, Krol Group, Lesser Himalaya, Himachal Pradesh (HP). The phosphatic chert samples yielding animal embryo were collected from Sauti area of Kamlidhar Syncline of Sirmaur district, HP (Figure 1). Earlier, animal eggs and embryos have also been interpreted from a similar horizon[1,2] without high-resolution internal structure.

The black phosphatic chert samples were subjected to maceration by soaking in 10–15% acetic acid for a fortnight and then washed, dried and sieved. Different fractions of sieved material were screened under a microscope which yielded

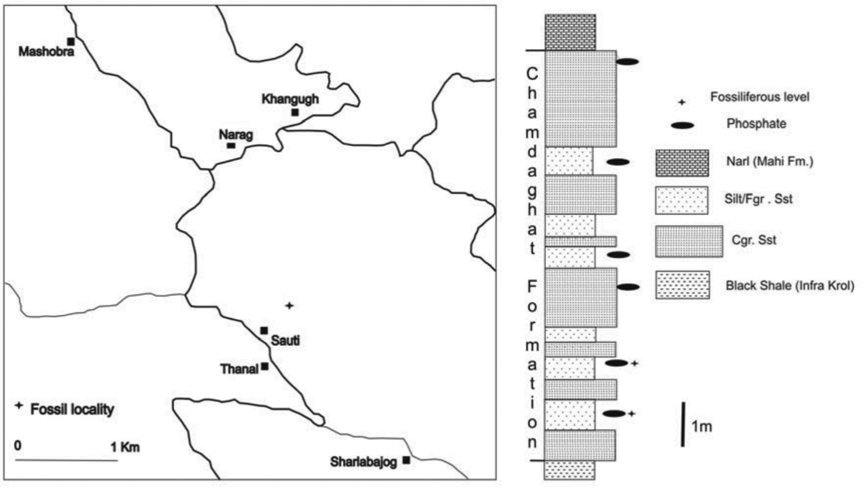

Figure 1. Fossil locality map and litho-section of Chambaghat Formation as measured in near Sauti village.