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Bathymetry and Sea Floor Characteristics of Cuddalore and Pondicherry Coast - India

RM NARAYANAN[1], K J SHARMILA[1] AND K DHARANIRAJAN[2]

[1]*Dr.M.G.R.Educational and Research Institute University, Maduravoyal, Chennai – 600095, India*

[2]*Department of Ocean Studies & Marine Biology, Pondicherry University, Port Blair, India*

***Email:** narayanan.rm@gmail.com*

Abstract: The geography and the geology of the seafloor are the products of processes that occur on both human and geological time scales. The near coastal shores are subject to the greatest observed changes. Depth profiles were analyzed based on the E-W transects from the shore to observe the topography in the study area. The present observations revealed that the existence of three near shore submarine canyons starting from the southern-most canyon, these are named Cuddalore Canyon, Pondicherry (Puducherry) Canyon and Palar Canyon. These canyons are viewed as the products of resultant effects of tectonics and turbidity currents. The study indicated that the submergence of river cut valleys under the sea water was well represented from the stages of 'V' shape development in the cross section of the canyons indicating the deepening and widening of the river channels.

***Keywords:** Submarine canyons, topography, bathymetry, river cut valleys, GIS*

1. Introduction

The term bathymetry is defined as the depth of water relative to sea level. Thus bathymetric measurements can determine the topography of the ocean floor, and have shown that the sea floor is varied, complex, and ever-changing, containing plains, canyons, active and extinct volcanoes, mountain ranges, and hot springs. Some features, such as mid-ocean ridges (where oceanic crust is constantly produced) and subduction zones, also called deep-sea trenches (where it is constantly destroyed), are unique to the ocean floor (Figure 1.1).

1.1. Continental Margin

The region of the seafloor that is closed to land is called the continental margin. Continental margin are the edges of the land masses present below the ocean surface and their steep slopes that described to the seafloor. The two different types of continental margins are passive and active. When a continent rifts and moves away from a spreading center, the resultant continental margin is known as a trailing or passive margin. Continental and oceanic lithosphere is joined along the passive margins, so there is no plate boundary at the margin. As passive margin move away from the ridge the oceanic lithosphere cools, increases its density, thickens and subsides. This causes the edge of the continent to slowly subside as well. While passive margin begins at a divergent plate boundary they end up in a midplate position as a result of seafloor spreading and the opening of the ocean basin.

Passive continental margins can be subdivided into four distinct regions: Continental shelf, shelf break, slope and rise (Figure 1.2). The continental shelf is nearly flat region of varying width that slopes very gently towards the ocean basins. The shelf is narrow along the active continental margins and wide along the low lying land at passive continental margins. Passive continental margins are further modified by sea level changes and storm waves that erode the edges of the continents and in some cases, natural dams on the shelves, such as reefs, trap sediments between the offshore dam and the coast.

1.2. Continental Shelf

The continental shelves are geologically part of the continents and during the past ages they have been covered and uncovered by fluctuations in sea level. When the sea level was low during the ice ages, erosion deepened valleys, waves eroded previously eroded submerged land, and rivers left their sediment far out on the shelf. When the ice melted and the sea level rose, those areas were flooded and sediments built up in areas close to the new shore. Although presently submerged these shelf areas still show the scars of old riverbeds and glaciers, features they acquired when exposed as part of the continent, some continental shelves are covered with thick deposits of silt, sand, and mud derived from the land.

The boundary of the continental shelf on the ocean floor is determined by an abrupt change in slope, leading to a more rapid increase in depth. The change in slope is

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referred to us the continental shelf break, while the steeper slope extending to the ocean floor is known as continental slope.

1.3. Submarine Canyons

Submarine canyons are incised into the continental shelf and slope of all continental margins and they act as conduits for the transfer of sediment from the continents to the deep sea (Nittrouer and Wright,1994).Interest in the evolution, occurrence and distribution of canyons in the oceans has been driven by the need to lay cables and pipelines across the seafloor (Piper et al., 1999), to support naval submarine operations, to understand the geological evolution of continental margins and to understand oceanographic and ecological processes associated with canyons (Heezen et al., 1964; Shepard and Dill, 1966;Piper, 2005). At the down-slope terminus of canyons may be found depositional submarine fans with their often extensive fan valley complexes, which have been studied in detail as analogues for ancient deposits of economic significance (e.g. Clark et al., 1992; Walker, 1992).

Shepard (1963; 1981) recognized that submarine canyons may have several origins and restricted his definition to "steep-walled, sinuous valleys with V-shaped cross sections, axes sloping outward as continuously as river-cut land canyons and relief comparable to even the largest of land canyons".

The origins of submarine canyons are attributed to multiple causes, but chief amongst these is erosion of the slope by mass wasting events(slumping and submarine landslides) and turbidity currents (Shepard,1981).Active continental margins contain 15% more canyons (2586, equal to 44.2% of all canyons) than passive margins (2244, equal to 38.4%) and the canyons are steeper, shorter, more dendritic and more closely spaced on active than on passive continental margins. The heads of some submarine canyons terminate on the slope, making so-called "blind" or "headless "canyons. The largest canyons, however, commonly incise into the continental shelf and may even continue as shelf valleys that have a direct connection to modern terrestrial fluvial systems.

Continuation of submarine canyons some of which are remarkably long; Skene and Piper, 2006; Bourget et al., 2008); slope gullies(incised into prograding slope sediments); fault valleys (structural related, trough-shaped valleys, generally with broad floors); shelf valleys (incised into the shelf by rivers during sea level low stands, generally less than 120 m deep); and glacial troughs incised into the continental shelf by glacial erosion during sea level low stands, generally U-shaped in profile and having a raised sill at their seaward terminus (Shepard, 1981). Modelling of the formation and development of submarine canyons has revealed the importance of head ward erosion driven bysedimentflow down-cutting, in which tributaries are the precursors of larger submarine canyon systems (Pratson et al., 1994; Pratson and Coakley, 1996). Thus canyons once formed by slumping evolve by further slumping, density flow erosion and subsequent capture of smaller adjacent canyons to form dendritic complexes

The upwelling and mixing associated with canyons enhance local primary productivity and the effects extend up the food chain to include birds and mammals (Hickey, 1995).Consequently, commercially important pelagic and demersal fisheries, as well as cetacean feeding grounds (e.g. Rennie et al., 2009), are commonly located at the heads of submarine canyons (Hooker et al., 1999).Canyons that incise the continental shelf have also been implicated in the local amplification of tsunami at the adjacent coastline(Matsuyama et al., 1999; Ioualalen et al., 2007).

1.4. The Origins of Submarine Canyons

The origins of submarine canyons are attributed to multiple causes, but chief amongst these is erosion of the slope by mass wasting events(slumping and submarine landslides) and turbidity currents (Shepard,1981).

The major groups of processes that generate canyon-incising turbidity flows are transformation of failed sediment, hyperpycnal flow from rivers or ice margins, and resuspension of sediment near the shelf edge by oceanographic processes followed by down-slope transport as turbidity currents (see review byPiper and Normark, 2009).

These processes are of particular significance for canyons that incise the continental shelf edge thus connecting the canyon system to sediment sources on the shelf and adjacent terrestrial environments. Some canyons exhibit structural control where faulting and fracture of basement rock has been followed by erosion. Tectonism can also influence the course of some canyons, with the canyon thalweg being deflected along faults and structural features (e.g.Greene et al., 1991; Liu et al., 1993; Mountjoyet al., 2009).

The term submarine canyon here is restricted to those sea valleys which are to some degree similar to canyons on land in that they have V-shaped cross profiles, are sinuous in plan have tributaries, and are essentially cut in the continental slope, although some may extend back into the continental shelves (Thornbury 1985). A submarine canyon is steep sided and has a V-shaped cross section with tributaries similar to those of river-cut canyons on land (Figure 1.3). Many of these submarine canyons are associated with existing river systems on land and were apparently cut into the shelf during the periods of low sea level, when the rivers flowed across the continental shelves.

River-associated, shelf-incising canyons are more numerous on active continental margins (n = 119) than on passive margins (n = 34). Geographic areas having relatively high rates of sediment export to continental margins, from either glacial or fluvial sources operating over geologic timescales, have greater numbers of shelf-incising canyons.

1.5. Bathymetry and Ocean Floor - A Review

Fundamental Earth science questions, such as what controls seafloor shape and how seafloor shape influences global climate, also cannot be answered without bathymetric maps having globally uniform detail. The seafloor was the unknown environment to early mariners and the first curious scientists. They believed that the oceans were large basins or depressions in Earth’s crust but they did not conceive that these basins held features that were as magnificent as the mountain chains, deep valleys and great canyons of the land. As the maps were created in greater detail and as ocean travel and commerce increased, it became essential to map seafloor features in the shallower regions, but it was not until the 1950s that improvements in technology made it possible to sample the deep sea floor in detail (Sverdrup et al 2006).

The depth to the ocean floor and the roughness of the bottom vary throughout the oceans as a result of numerous geologic processes. This seafloor topography influences the ocean circulation and mixing that moderate Earth’s climate, and the biological diversity and food resources of the sea. The ocean floor records the geologic history and activity of the ocean basins, revealing areas that may store resources such as oil and gas, and generate earthquakes and tsunamis. (Sandwell et al 2002). Gille et al (2003) studied the seafloor topography and its influences on ocean circulation in two basic ways. Details of steering of ocean flows and barriers that prevent deep waters from mixing have been studied in great depth by them.

Tides are the major process responsible for mixing the deep ocean, Egbert and Ray (2000) estimated that 25% to 30% of total tidal dissipation takes place in the open ocean, and is generally associated with ridges and other rough topography. Sandwell et al (2001) discussed the ocean circulation is influenced by seafloor topography in a variety of ways, particularly at high latitudes, where stratification is low. Bathymetry can steer the path of currents, determine where upwelling occurs (and supply iron-rich sediment to upwelled water allowing phytoplankton to bloom at the ocean surface), generate topographic lee waves downstream of topography, and dissipate eddy kinetic energy. Shallow-water bathymetric data are usually collected and managed by regional organizations for regional interests. Hence, shallow-water bathymetric data are often not as coordinated internationally and not as standardized as deepwater data. This leads to the use of different sources of bathymetry data by ocean modellers. Unnikrishnan et al (1999) used a non-linear 2-D tidal model to simulate tides and tidal circulation in the Gulf of Khambhat, Bombay High, and surrounding areas. They digitized the hydrographic charts of the region to get a more accurate bathymetry to improve model results.

Bathymetric mapping involves the production of ocean and sea maps based upon bathymetric data. Bathymetric maps represent the ocean depth as a function of geographical coordinates in the same way topographic maps represent the altitude of Earth's surface at different geographic points. The most popular type of bathymetric maps are ones on which lines of equal depths (called isobaths) are represented.

1.6. Advantages of Bathymetry Maps

- To determine the effects of seafloor roughness on ocean circulation and mixing, climate, and biological communities, habitats, and mobility.
- To improve tsunami hazard forecast accuracy by mapping the fine-scale topography that steers tsunami wave energy.
- To understand the geologic processes responsible for ocean floor features unexplained by simple plate tectonics, such as abyssal hills, seamounts, micro plates, and propagating rifts.
- To map sub seafloor structure of continental margins for both geologic research and offshore resource exploration.
- For numerous other practical applications, including planning submarine cable and pipeline routes, improving tide models, and defining international boundaries on territorial claims to the seabed under the United Nations Convention on the Law of the Sea.

The aim of this study is to assess the global occurrence of large submarine canyons to provide context and guidance for discussions regarding canyon occurrence, distribution, geological and oceanographic significance and conservation.

2. Methodology for Identification of Seafloor Features

The methodology developed for the study is illustrated in

Figure 1.4. National hydrographic chart and C-map data (generated from MIKE 21 software as an ASCII files) were collected and generated for the study area. The

bathymetric contours were digitized using ArcGIS 9.1 Software and C-Map data were imported as point data in GIS. Using ArcGIS 3D analysis the Triangular Irregular Network (TIN) for the study area was generated from digitized contours and point data in GIS. Slope analysis was carried out using the created TIN file and the percentage of slope was generated and shown in the Figure 1.4. This was used for interpretation of the ocean floor. The 3D profile of the ocean floor, the bathymetry map and the slope map is shown in Figures 1.5 to 1.7.

3. Result and Discussion

3.1. The Ocean Floor in Cross-Section

The geography and the geology of the seafloor are the products of processes that occur on both human and geological time scales. The near coastal shores are subject to the greatest observed changes. Depth profiles were analyzed based on the E-W transects from the shore to observe the topography in the study area. These data area represented graphically in Figures 1.8(a), (b) and (c) for Pondicherry, Cuddalore and Porto Novo respectively.

3.2. Cross Sectional Analysis of Transects at Pondicherry A-B, Cuddalore C-D, Porto Novo E-F

The bathymetry at Pondicherry was characterized by gently sloping topography from 0 to 25m at 12 km from the shore line. The gradient increased significantly and at 21km from the shore the maximum depth of 300 m was observed. This feature appeared to be a near shore submarine canyon (Pondicherry canyon). Similar bathymetry was characterized for Cuddalore by gently sloping topography from 0 to 25 m at 18 km from the shore line. The gradient increased significantly and at 24 km from the shore the maximum depth of 470 m was observed. This feature appears to be a second near shore submarine canyon (Cuddalore canyon). However the bathymetry in Porto-Novo was characterized with slight variations i.e. the gentle sloping topography from 0 to 25m breaks around 5 km from the shore. The gradient increased significantly and at 18 km reached a maximum depth ~ 400m. This feature appears to be the third near shore submarine canyon. The cross section profile of the transects A-B, C-D, E-F are shown in the Figures 1.9 (a), (b) and (c).

3.3. Percentage of Slope on the Ocean Floor

In the present study using bathymetric analysis, it was found that near the urban area slope gradient is less than 1%, but there was a sudden increase in percentage of slope from 0-1% to 15-35% at a distance of 15-22 km and even 35-50% slopes were observed at some places and shown in the Figure 1.10. It has a concave and convex trend on ocean floor. This trend is well correlated with the recent tectonic activity at Pondicherry (Murty et al 2002) and also coincides with the fault extension of MoyarBavani shear zone (Sarma et al 2007).

3.4. Nearshore Submarine Features (Canyons)

According to Radhakrishnan (1996) it is difficult to account the origin of submarine canyons however submarine canyons may be formed through one of the following ways.

1. Submergence of the river cut valleys under the seawater
2. Submergence of glacial valleys under seawater
3. Turbidity current cut valleys
4. Erosion by underground water
5. Tsunami cut valleys and
6. The erosional features along the structurally weak planes (Faults etc...)

Shepard (1978) suggested that erosion during the rise of continental margins and later lowering followed by landslides might have developed the canyons. Daly (1936) and Kuenen (1937), proposed density of turbidity currents during the lowering of sea level due to glaciations for the origin of canyons. However of late, the canyons are viewed as the products of resultant effects of tectonics and turbidity currents. During glacial ages the sea level was at the level of shelf region, and then the continental rivers were active and carved great valleys. Turbidity currents continue to erode, mass movements the slow creep and slumping would have aided the development of submarine canyons.

The study indicated that the submergence of river cut valleys under the sea water was well represented from the stages of 'V' shape development in the cross section of the canyons indicating the deepening and widening of the river channels. The phenomenon is indicated in Figures 1.9 (a), (b) and (c) drawn from the north south cross sections G-H, I-J, K-L.

Similar results were reported by Wohl and Achyuthan (2002). They studied the substrate influences on the incised channel morphology in Pondicherry and identified that from the sandstone gorge, the channel reenters the lateritic alluvium in the sixth sub-reach, remained in this substrate until the channel reaches the coast indicated existence of river cut valleys.

The present observations revealed that the existence of three near shore submarine canyons as cited in the NIO Annual Report (1966-67) during the year 1960. The 26th cruise of INS Krishna based on the bathymetric surveys conducted during 1960 revealed the existence of three sets of distinctly different canyons cutting across the shelf and slope regions near Cuddalore and

Pondicherry. Starting from the southern-most canyon, these are named Cuddalore Canyon, Pondicherry (Puducherry) Canyon and Palar Canyon. The heads of these canyons are located around 36 to 55 meters. An examination of the longitudinal profiles for these canyons show that the Palar canyon has the steepest profile (average slope angle 6°07') while the Cuddalore canyon has a more gentle profile (average slope angle 4°17') with the slope of the Pondicherry Canyon coming in between (average slope angle 4°40')·

The analysis of satellite derived suspended sediments Narayanan (2009) revealed that there was turbidity in coastal waters around 21 km near Pondicherry. As discussed by Radhakrishnan (1996) out of the six possibilities towards the origin of canyons the three possibilities i.e. the erosional features along the structurally weak planes (Faults), submergence of the river cut valleys under the seawater, turbidity current cut valleys were met through the study which confirms the existence of submarine canyons.

In support of a submarine canyon origin, von der Borch et al. (1982) described features indicative of deep-water slope deposition. These included mass-flow deposits, turbidities with prominent climbing ripples and flute casts, channelized sands, and slumped sediments, In contrast, Eickhoff et al. (1988) and von der Borch et al. (1989) later suggested that the Wonoka canyons represented sub aerially eroded valleys that were filled during coastal onlap.

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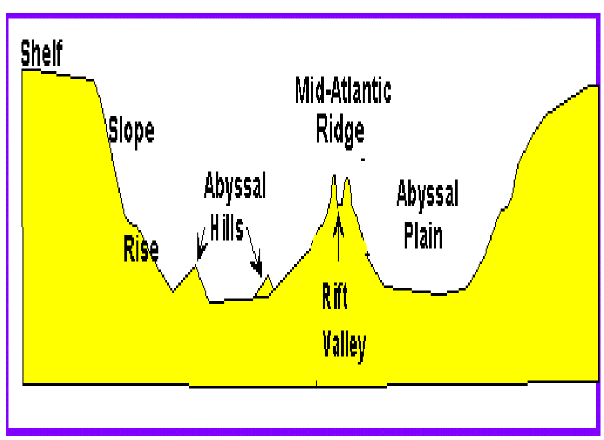
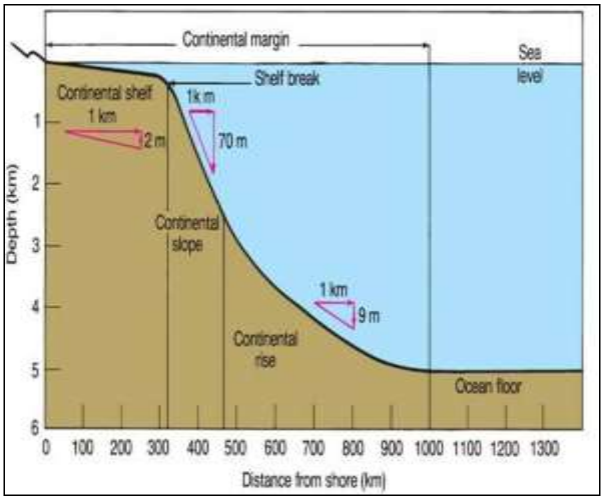


Figure 1.1 *Typical oceanographic features of the world oceans*



Source: University of Minnesota (2004)

Figure 1.2 *Continental margins in the seafloor*

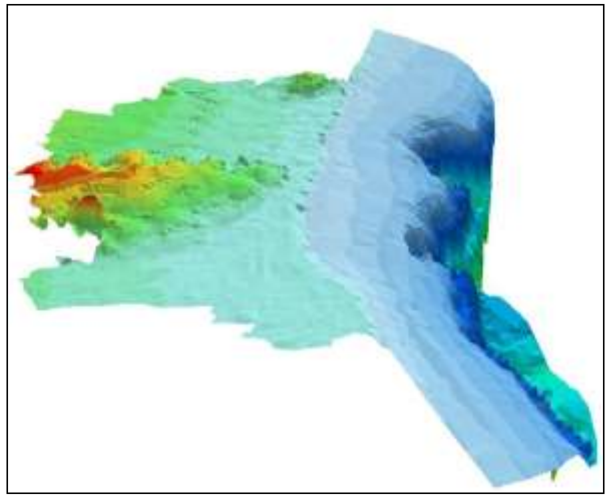


Figure 1.5 *3D profile of the Ocean floor*

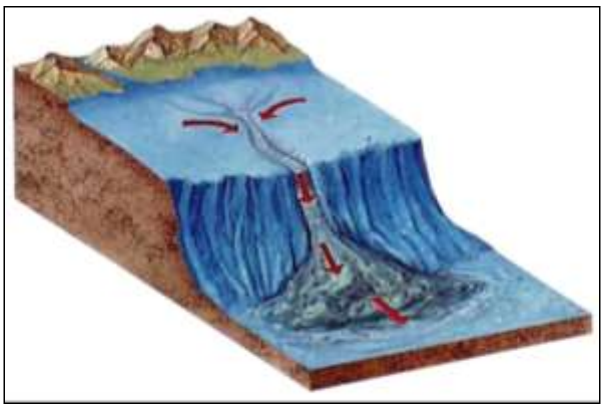


Figure 1.3 *Submarine Canyon*

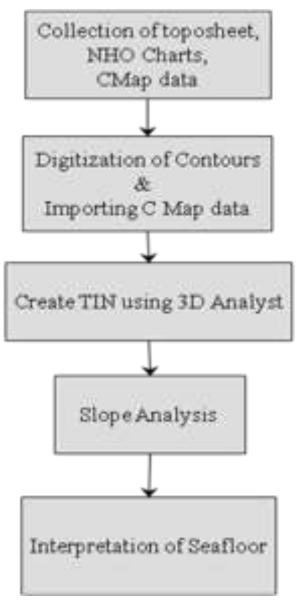


Figure 1.4 *Methodology adopted for identification of seafloor features*

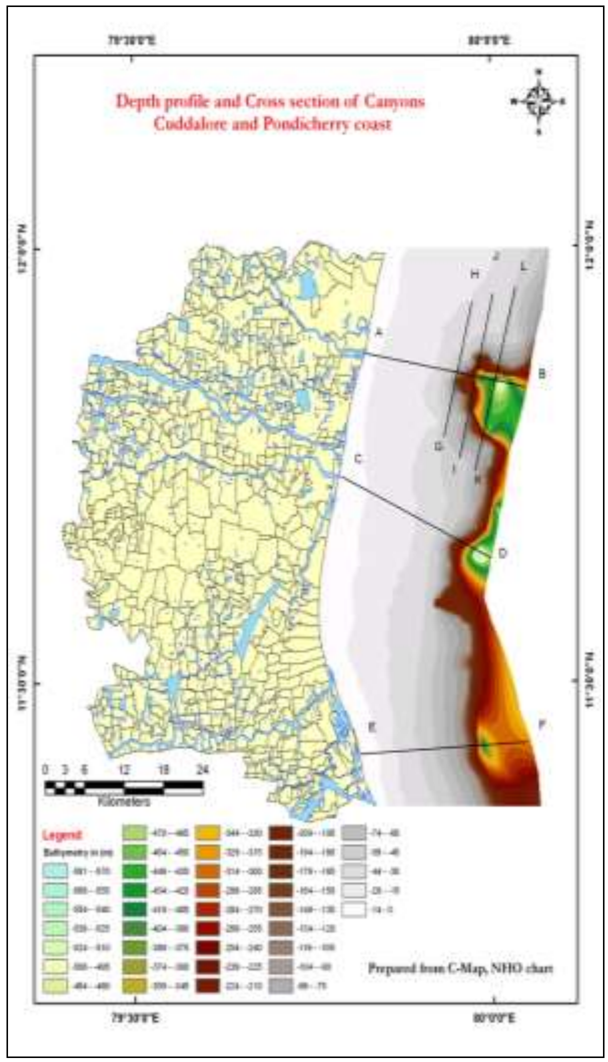


Figure 1.6 *Bathymetry map indicating various depth profiles of the ocean floor and the cross sections in EW and NS directions*

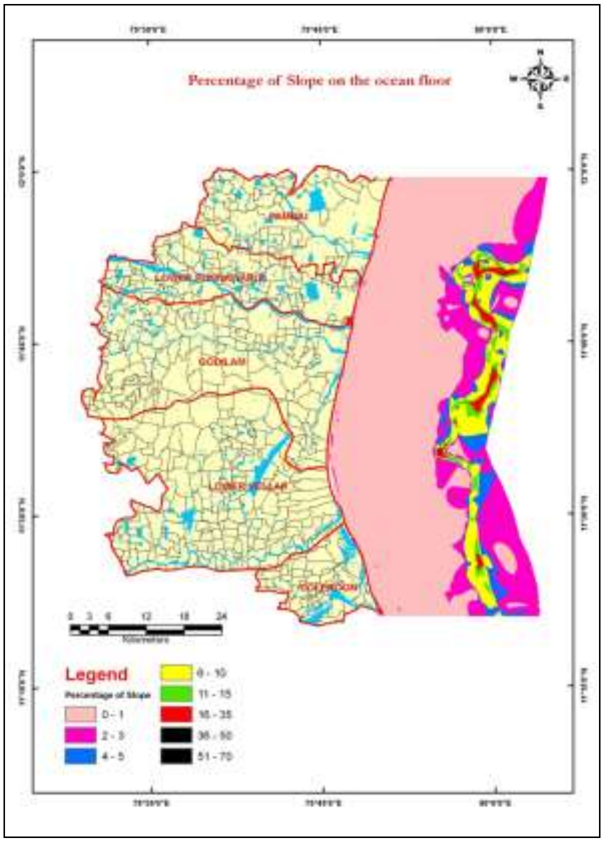
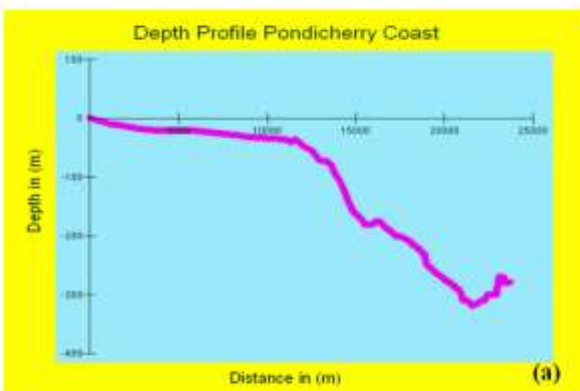
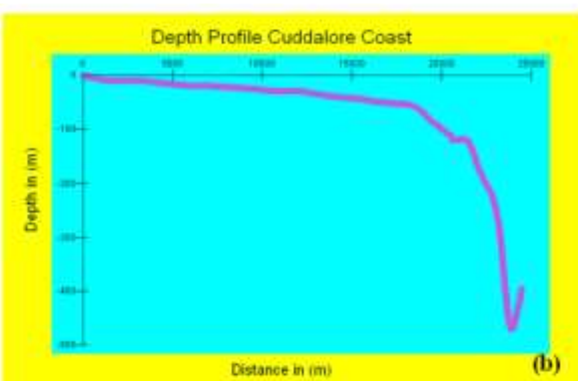


Figure 1.7 *Percentage of slope on the ocean floor*





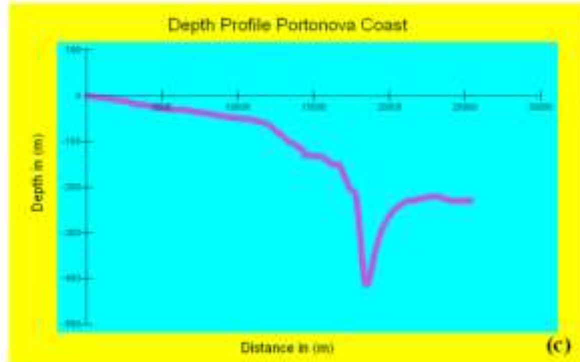


Figure 1.8 *Cross sectional profile of ocean floor a) PondicherryA-B, b) Cuddalore C-D, c) PortoNovo E-F*

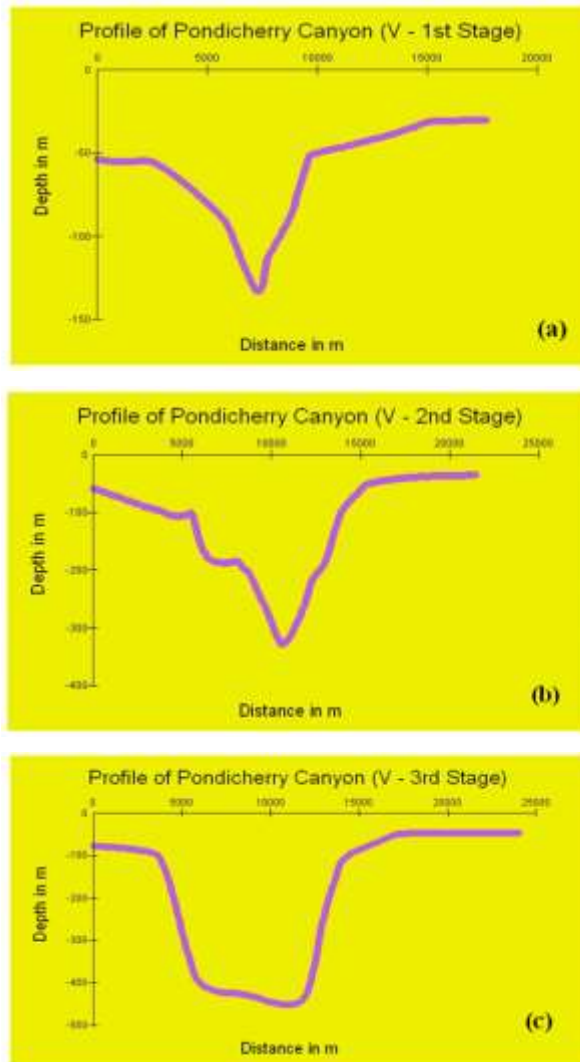


Figure 1.9 *Cross sectional profile of nearshore submarine canyons transects G-H (Stage I), I-J (Stage II), K-L (Stage III) a) Stage1 initial phase of river cut valley, b) Deepening of river cut valley c) widening of river cut valley*