24

RELIFES OF THE OCEAN BASINS

24.1 INTRODUCTION

About three-fourth of the globe is covered by hydrosphere. Out of the total surface area of the globe (509, 950, 000 km²) hydrosphere and lithosphere cover 361,060,000 km² (about 71 per cent) and 148,890,000 km² (about 29 per cent) respectively. The hydrosphere is divided on the basis of size and location into oceans, inland seas, small enclosed seas, bays etc. The Pacific Ocean (165,000,000 km²), the Atlantic Ocean (82,000,000 km²) and the Indian Ocean (73,000,000 km²) are important among the oceans whereas significant seas are Arctic Sea, Malay Sea, Middle American Sea, Mediterranean Sea, Bering Sea, Barnets Sea, Kara Sea, East Siberian Sea, Japan Sea, East China Sea, Okhotsk Sea, Yellow Sea, Andman Sea, South China Sea, Yellow Sea, Carib-bean Sea, North Sea, Celebes Sea, Labrador Sea, Beaufort Sea, Arabian Sea, Red Sea etc. Like lithosphere, the hydrosphere is also characterized by various types of relief features like mid-oceanic ridges, trenches, deep sea plains, basins, submarine canyons etc.

The average depth of the oceans is 3,800 m against the 840m average height of the lithosphere. Th ifferent height and depth zones of the lithosphere and the hydrosphere are represented by hypsographic or hypsometric curve. The ocean basins are charac-terized by four relief zones *e.g.* continental shelves, continental slopes, deep sea plains and oceanic trenches (fig. 24.1).

World's Largest Underground Ocean

The world's largest underground **'ocean'** i.e. **'subterranean water body'** was discovered in the year 2007. This massive underground ocean extends from Indonesia to the northern tip of Russia for a length of 700 to 1400 km below the ground surface. This subterranean water body has been formed due to subduction of plate carrying the bottom of the Pacific Ocean under continental plate and infiltra-tion of immense volume of water therein.

24.2 CONTINENTAL SHELF

The continental marginal areas submerged under oceanic water with average water depth of 100 fathoms (one fathom = 6 feet) and gently slop-ing (1^0-3^0) towards the sea or the oceans are called continental shelves. The width of continental shelves largely depends on the nature of reliefs of the coastal land *i.e.* (1) the shelves are narrow where high mountains are very close and parallel to the coast (*e.g.* the Pacific continental shelf along the western coast of S. America is narrow (16 km) because of the presence of the Andes mountain), and (2) the shelves are wider where the coast lands are wide plains.

Though the continental shelves are generally wider in front of river mouths but the shelf off the Mississippi mouth is exceptionally narrow. On an average, the width of continental shelves is about 48 km though Sheppard has taken 67km (42 miles) as average width. The Pacific continental shelf of South

America represents the example of narrow shelf (16 km), the Atlantic continental shelf off the east coast of North America represents the example of medium size shelves (96-120 km) and extensive shelves having width of a few hundred kilometres are found off the coast of East Indes, in the Arctic Sea, China Sea, Adriatic Sea, Arafura Sea etc. Continental shelves represent 8.6 per cent of the total area of the ocean basins. Regionally these cover 13.3 per cent, 5.7 per cent and 4.2 per cent of areal coverage of the Atlantic Ocean, the Pacific Ocean and the Indian Ocean respectively.

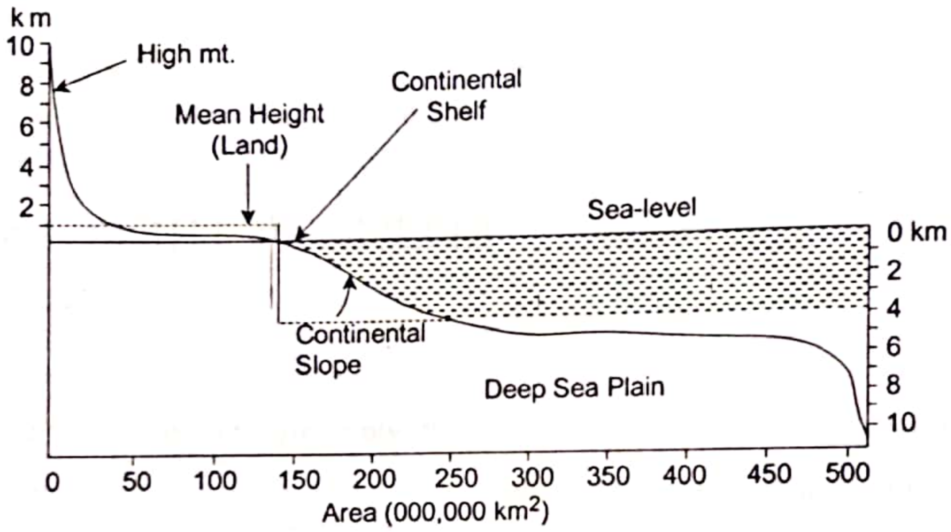

Fig. 24.1 : Hypsometric/hypsographic curve.

The maximum seaward limit of the continental shelves off the Indian coast is demarcated by 100 fathom contour. The continental shelves along the eastern and the western coasts of India are 50 km and 150 km wide respectively. The shelves are narrow (30-35 km) off the mouths of the Ganga, the Mahanadi, the Godawari, the Krishna and the Cauvery rivers but these are wider off the estuaries of the Narmada, the Tapi and the Mahi rivers. The average slope of the continental shelves off the eastern Indian coast is about 21^0 whereas it is 10^0 near Cape Comorin and only 1^0 near the Gulf of Combay.

Origin of Continental Shelves

The Nature, composition, extension and depth of continental shelves are so varied that it becomes difficult to explain their exact mode of origin through a single mechanism and process. The following different views have been expressed by several authorities to explain the complex origin of continental shelves—

(1) Continental shelves are basically the extended form of continental platforms. Marine waves and currents erode the continental margins and thus form extensive platforms which receive deposits of sediments brought down by the rivers and sea waves. These sediments are continuously consolidated under sea water and ultimately extensive continental shelves are formed. Thus, the continental shelves are the result of marine erosion and fluvial deposits.

(2) Continental shelves are formed through prolonged deposition of detritus (under sea water) brought by the rivers alone. Such type of continental shelves is formed only in those areas where sea conditions are calm so that prolonged sedimentation goes on uninterruptedly resulting into subsidence and thus allowing more and more sedimentation. Such continental shelves are constructional and are most extensive.

(3) Rising thermal convective currents from beneath the continents and the ocean basins converge along the continent-ocean boundary and descend. The resultant compressive force causes subsidence of the continental margins and thus continental shelves are formed.

(4) Some times, parallel faults are created in the continental margins. This event causes subsidence of the marginal land areas and consequent submergence under sea water. Such submerged land areas become continental shelves, which are generally called as **tectonically formed continental shelves.**

(5) Continental shelves are formed through marine erosion of the continental margins when there is negative change in sea-level (fall in sealevel) either during ice ages or due to subsidence of oceanic floors. According to R.A. Daly the sea level fell by 38 fathoms during Pleistocene Ice Age, with the result the continental margins which were previously submerged became free from sea water. These exposed land areas were glacially eroded and extensive platforms were formed. Due to deglaciation the sea level rose again and these platforms were submerged under seawater and thus extensive continental shelves were formed. This concept of the origin of the continental shelves belongs **to glacial control theory.**

(6) The coastal lands are effectively eroded through abrasive work of strong sea waves and several sea cliffs are formed. These cliffs gradually but continuously recede towards the land due to basal erosion and consequent fall of their hanging crests and thus extensive wave-cut platforms are formed. These platforms are submerged under sea water to form continental shelves.

(7) The submergence of continental margins due to tilting of land towards the sea results into the formation of continental shelves. This process also leads to the extension of existing continental shelves.

The continental shelves of India have been formed differently. The continental shelves off the Ganga, the Godawari, the Krishna and the Cauvery mouths have been formed through delta formation. The continental shelves from Midinapur to Madura are the result of sedimentation and consequent subsidence while the shelves of Andman Nicobar, Lakshadweep, Gulf of Manar (between India and Sri Lanka) are originated due to coral reefs. The continental shelves of western coast are due to faulting and consequent submergence.

24.3 CONTINENTAL SLOPE

The zone of steep slope extending from the continental shelf to the deep sea plains is called continental slope which varies from 5^0 to more than 60^0 at different places e.g. 40^0 near St. Helena, 30^0 off Spanish coast, 62^0 near St. Paul, 5^0 to 15^0 near Calicut coast (India) etc. The depth of water over continental slope varies from 200m to 2,000m. Continental slopes occupy only 8.5 per cent of the total area of the ocean basins but it varies from one ocean to the other *e.g.* 12.4 per cent in the Atlantic Ocean, 7 per cent in the Pacific Ocean and 6.5 per cent in the Indian Ocean.

The most extensive continental slopes are found between 20^0N and 50^0N latitudes and on 80^0N and 70^0S latitudes. Generally, the steep gradient of the continental slopes does not allow any marine deposits because the materials coming down from the continental shelves are immediately removed downward but in some cases a thin veneer of deposits does exist. The most significant reliefs on the continental slopes are **submarine canyons** and trenches which are generally transverse to the continental shelves and the coasts.

The origin of continental slopes has been related by various authorities to erosional, tectonic and aggradational processes. The erosion theory of the origin of continental slopes is based on the presence of submarine canyons. According to this theory slopes are formed due to erosion by marine processes mainly sea waves. According to tectonic theory faulting is held responsible for the origin of continental slopes. Some exponents believe that the continental slopes are formed due to bending and warping of continental shelves followed by sedimentation.

24.4 DEEP SEA PLAINS

Deep sea plain characterized by flat and rolling submarine plain is the most extensive relief zone of the ocean basins. These deep-seated plains having the depth from 3000m to 6000m cover 75.9 per cent of the total area of the ocean basins but this areal coverage varies from one ocean to the other (80.3 per cent in the Pacific Ocean, 80.1 per cent in the Indian Ocean and 54.9 per cent in the Atlantic Ocean). Remarkably low areal coverage of deep sea plains in the Atlantic Ocean in comparison to the Pacific and Indian Oceans is attributed to larger extent of continental shelves in the former. Though vast and extensive deep sea plains are generally featureless but a few long, narrow and elongated

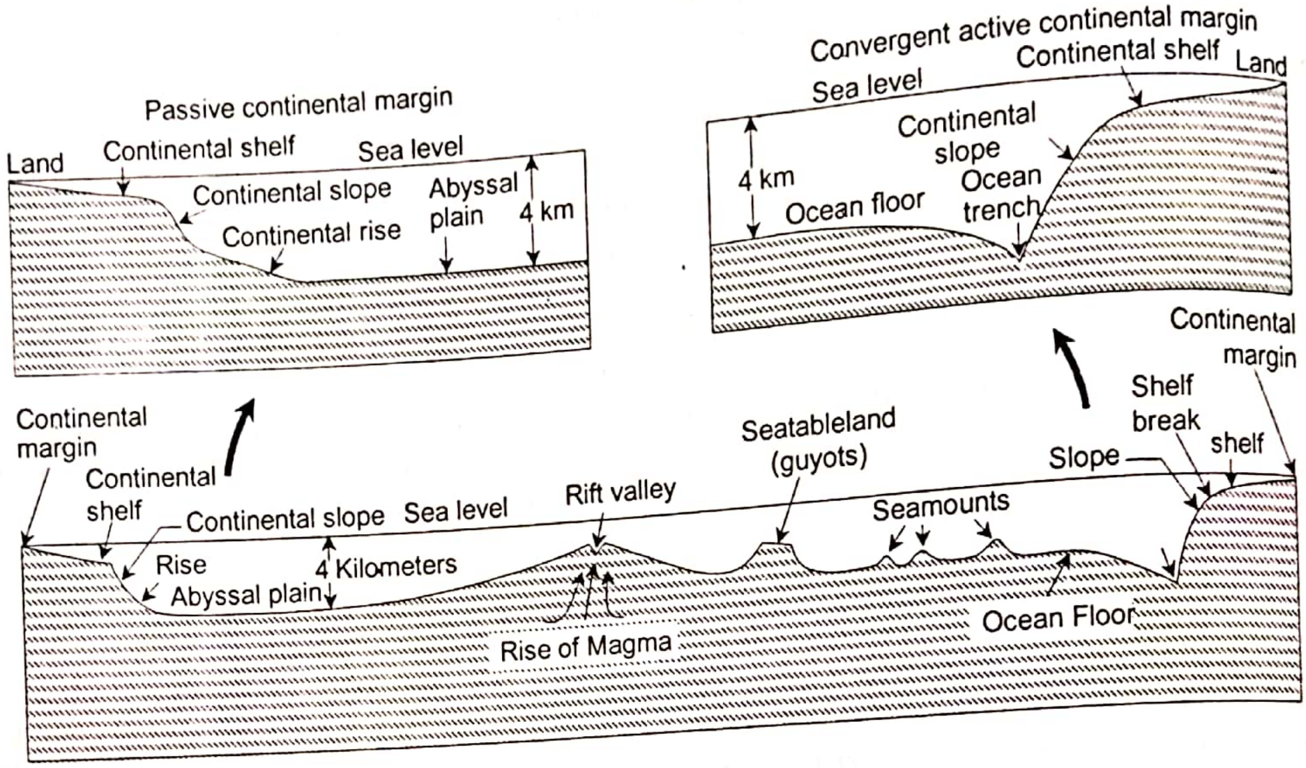

Fig. 24.2 : Configuration of ocean floors; modified from Thurman and Treijillo, 1999.

ridges, guyots etc. are significant reliefs. The sub-marine ridges with steep side-slopes some times reach the sealevel and even project above the water surface and appear as islands. Mid-Atlantic ridge, East Pacific Rise and mid-Indian Ocean ridge are typical examples. Deep sea plains are characterized by pelagic deposits of plant, marine animal and siliceous remains but there is absence of erosional debris of terrigenous origin. Volcanic deposits have been reported at few places in different oceans.

24.5 OCEAN DEEPS

Ocean deeps representing depressions and trenches on the ocean floors are the deepest zones of the ocean basins. These are generally located parallel to the coasts facing mountains and along the islands. Ocean deeps are grouped into two categories according to size viz. (1) very deep but less extensive depressions are called **deeps** while (2) long and narrow linear depressions are called **trenches.** These deeps and trenches are characterized by very steep slopes. Some times, these rise almost to verticality. These deeps and trenches have been usually named after the explorers and their geographical locations *e.g.* Murray Deep (after J. Murrary), Japan and Sunda Trenches (after geographical location). Out of the explored and surveyed 57 deeps, the Pacific Ocean, the Atlantic Ocean and the Indian Ocean account for 32, 19, and 6 deeps respectively. Mariana Trench located to the west of Philippines in the North Pacific Ocean is the deepest (11.02 km deep) of all the ocean deeps.

Table 24.1 : Major Ocean Deeps

	Name	Location	Depth in metres
1.	Challenger or Mariana Trench	N. Pacific	11,022m
2.	Aldrich or Tonga Trench	Central S. Pacific	10,882m

3.	Swire or Philippine Trench	N.W. Pacific	10,475m
4.	Nares or Puerto Rico Trench	Off West Indian Islands	8,385m
5.	Kurile Trench	Off Sakhalin, Kamchatka	10,498m
6.	Tizard or Romanche Trench	S. Atlantic	7,631m
7.	Java Trench	E. Indian Ocean	7,450m

24.6 SUBMARINE CANYONS

1. Introduction

Long, narrow and very deep valleys or trenches located on the continental shelves and slopes with vertical walls resembling the continental canyons are called submarine canyons because of their location under oceanic water. On the basis of morphogenetic processes these are classified into (i) **glacially eroded canyons** and (ii) **non-glacial canyons.** The non-glacial submarine canyons being more in number than the glacial canyons and widely spread in all the oceans have been studied in much detail. The non-glacial canyons, thus, will be described as submarine canyons in the following discussion. These, besides a few exceptions, are found transverse to the coasts and in front of the mouths of major rivers.

On an average, there is little difference in the transverse and longitudinal profiles of submarine and subaerial (continental) canyons. According to Sheppard the submarine canyons are similar to the youthful river valleys on the land but are decidedly deeper and a few of them have dendridtic pattern of tributaries of secondary canyons. The longitudinal course of submarine canyons is usually sinuous while that of the subaerial canyons is generally

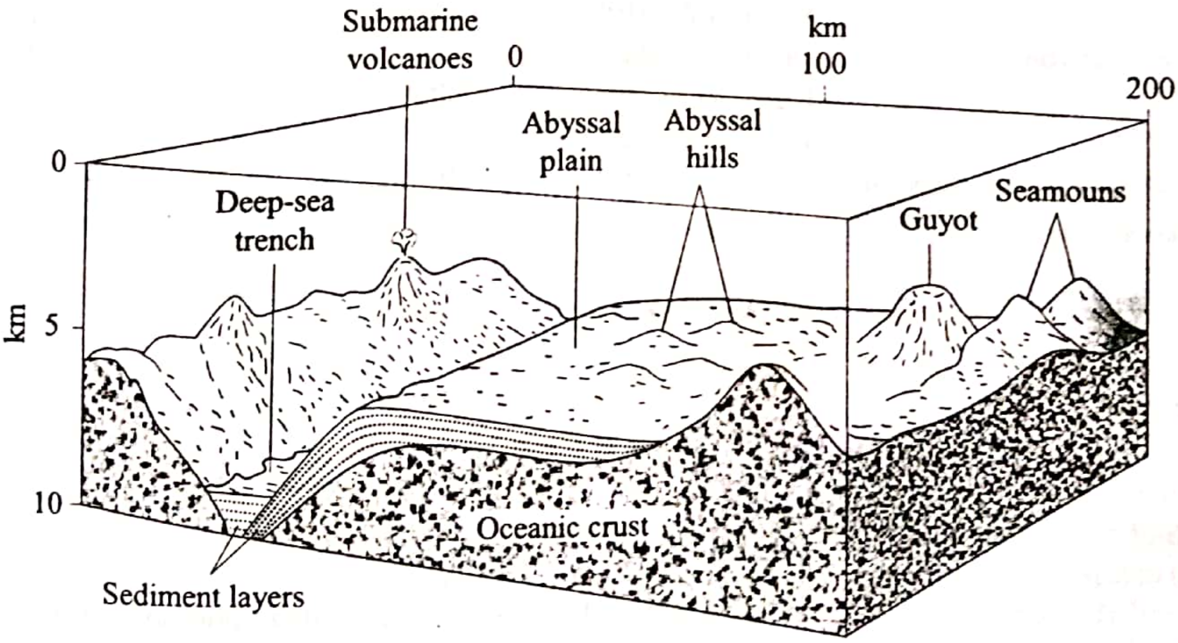

Fig. 24.3 : Morphology of ocean basins. source : based on P. R. Pinet, 2000.

straight. The gradient of submarine canyons is steeper than the continental canyons. The submarine canyons are generally several kilometres wide at their heads and their average length is 16 km.

Though the gradient of longitudinal profiles of the canyons varies significantly but on an average it is 1.7 per cent. The canyons facing the river mouths are usually long (*e.g.* Congo Canyon) but have gentle gradient. The canyons located near the island are deep with steepest gradient (13.8 per cent). According to the studies of 102 submarine canyons by Sheppard and Beard average gradients of the upper, middle and lower segments of the canyons are 11.62 per cent, 6.63 per cent and 4.76 per cent respectively. The depths of submarine canyons vary from 610m to 915m. At few places the depth has been noted upto 3,048m. The submarine canyons carry various types of ocean deposits but the steep valley sides are devoid of unconsolidated materials. The floors of the canyons have coarser materials than the adjacent continental shelves. The deposits include sands, clays, silt, gravels and pebbles.

Table 24.2 : Submarine Canyons on the East Coast of India

Name of the canyons	Location	Depth	Shape of the valley
1. Cuddalore Canyon	11°35'N-79°56'E	329m	V
2. Pondichery Canyon	11°50'N-80°OO°'E	466m	U
3. Palar Canyon	37km SSE from Palar river mouth 12°06'N-79°52'E	1,141m	V
4. Pulicat Canyon	13°45'N-80°25'E	—	V
5. Armagon Canyon	13°45'N-80°25'E	—	V
6. Swarnamukhi Canyon	14°14'N-80°19'E	80-108m	—
7. Gudur Valley	14°24'N-80°19'E	30-40m	U
8. Penner Canyon	East of Penner river mouth 14°41'N-80°16'E	225m	U
9. Krishna Canyon	Opposite to the Krishna river mouth 15°35'N-80°50'E	30m	V
10. Vasishta Godavari Canyon	16°10'N-81°50'E	30-60m	—
11. Godavari canyon	16°45'N-82°32'E off the mouth of Nilarevu river	60-250m	—
12. Kakinada Canyon	16°55'N-82°30'E	10-20m	—
13. Mahadeva Canyon	18°00'N-84°00'E	350m	V
14. Paradip Depression	20°5'N-86°42'E	—	—
15. Ganga Canyon (Swatch of No Ground)	Off the Ganga Delta 21°15'N-21°23'N 89°28'E-89°33'E	variable 278 to 421m in the northern portion; 543 m to 892 m in the middle portion; a few depressions are 1,050 m to 1,088 deep	V

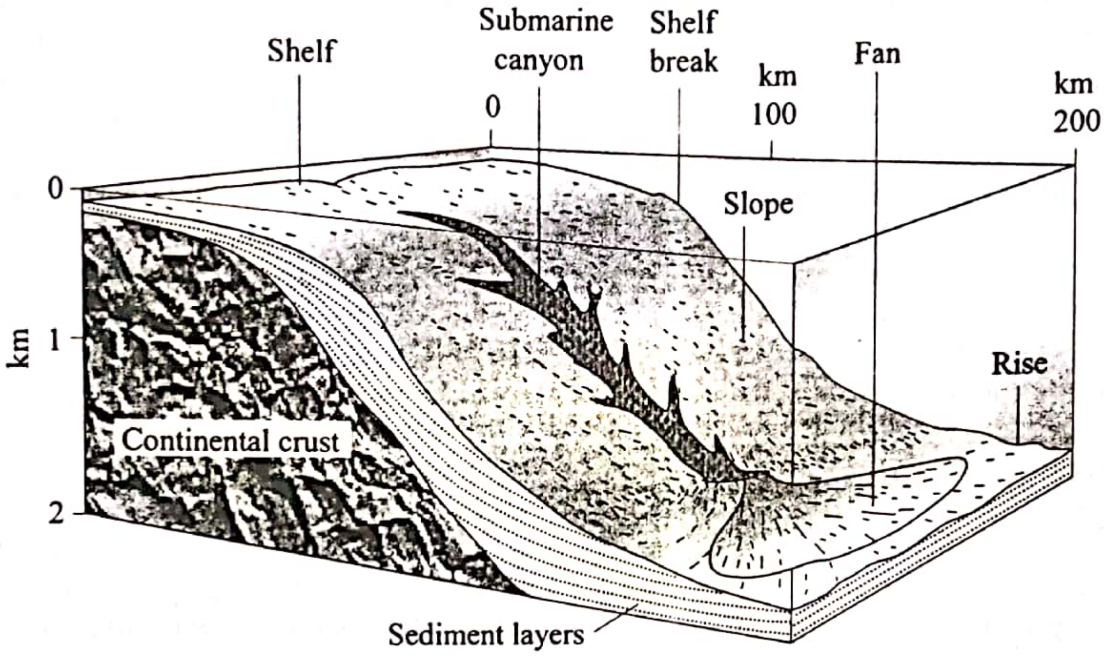

Fig. 24.4 : Continental slope and submarine camyons, Source : based on P. R. Pinet, 2000.

2. Distribution of Submarine Cayons

The world distributional pattern of submarine canyons does not reveal any control of latitudes on their distributions and location. Francis Sheppard and Charles Beard have located 102 submarine canyons in the world on the basis of soundings of the continental shelves and slopes.

Generally, submarine canyons are more abundantly found along the straight coasts than highly indented and crenulated coastlines. They are found along the stable and unstable coasts alike. They are more commonly found off the east coast of the USA from Canada to Cape Hatteras; off the Californian and Mexican coasts; along the north Mediterranean, Philippines, Jappan and Aleutian islands; off the coast of west Africa; off the east coast of India etc.

Atlantic Ocean—Significant submarine canyons of the Atlantic Ocean are Hudson Cayon (facing the mouth of the Hudson river, 827m deep), Chesapeak Canyon, Mississippi Trough, Fosse de Cape Brenton Canyon (in the Bay of Biscay off the south-western coast of France), Nazare Canyon (off the western coast of Portugal, 4000m deep), Congo Canyon (near the mouth of the Congo river) etc.

Pacific Ocean—Columbia Canyon; Monterey Canyon (which has several tributary canyons like Ascension canyon, Soquel canyon, Carnel canyon etc.); Mugu canyon, Scripps canyon and Dume canyon (all are off the Californian coast); Panama canyon (off Burica Peninsula) etc. are the important canyons on the western coast of North America while Piseu Chang canyon (off the coast of Korea), Philippine canyon (on the main coast of Luzon), Saganin canyon, Fizi canyon etc. are a few prominent canyons of the western Pacific Ocean.

Indian Ocean—Canyons are found along the eastern coast of India (table 24.2), in front of the Indus river, along the north-eastern coast of Sri Lanka, along the eastern coast of Africa etc.

3. Origin of submarine canyons

Though there are divergent opinions about the mode of origin of submarine canyons but majority of the exponents consider them as recent geologic phenomena of Canozoic era, mainly of Quaternary period. A few canyons are still in the process of formation. The following theories have been put forth to explain the origin of submarine canyons.

(1) Diastrophic theory—A few exponents (Andrade, Lawson, De la Roche Ponie, J.W. Gregory, Yanasaki, Jensen, Bourcart etc.) have related the origin of submarine canyons to various types of earth movements and tectonic implications (faulting, folding, warping, sinking of sea floor etc.). The tensional forces caused by earth movement due to endogenetic forces result in the formation of faults and graben on the continental shelves and slopes. These fault-troughs and graben become submarine canyons. Similarly, warping and steep folding give birth to synclinal basins and synclinal troughs respectively which become submarine canyons.

According to De Andrade submarine canyons are formed due to creation of a series of graben - like valleys during local coastal displacements. Such tectonically originated submarine canyons have been reported by Lawson off the Californian coast, by De la Roche Ponie near the coast of Cyprus and Morocco, by J.W. Gregory (Hudson Canyon and St. Lawrence Trough), by Yanasaki (near Japan coast) etc. According to Jensen and Bourcart submarine canyons were formed during Quaternary period due to subsidence and drowning of river valleys along the continental marginal flexure.

This diastrophic theory of the origin of submarine canyons is criticised mainly on three counts. (i) Majority of submarine canyons are found transverse to the coast whereas faulting generally occurs parallel to the coasts. (ii) Many of the submarine canyons have dendritic pattern of their tributaries which cannot be explained through faulting. (iii) Not all the continental shelves and slopes show evidences of faulting. This theory may explain the formation of canyons along the Pacific coasts (western coasts of North and South Americas and eastern coasts of Asia) and Mediterranean Sea where Tertiary and Quaternary earth movements were most active but the canyons along the western (eastern coasts of North and South Americas) and eastern (off the western coasts of Europe and Africa) of the Atlantic Ocean may not be explained in the absence of such movements. The canyons on the eastern coast of North America cut across the lithology of Tertiary and Quatenary periods.

(2). Subaerial erosion theory—Several exponents (*e.g.* J.D. Dana, F.P. Sheppard, Hull etc.) on the basis of resemblance of submarine canyons to the continental canyons in shape and deposition have related the formation of the former to the entrenching of river valleys by running water and subsequent drowning of these valleys due to subsidence and submergence of continental margins. According to them the rivers eroded their valleys very deep forming deep gorges during the period of emergence when land rose higher well above the sealevel and the channel gradient was steepened. Later on the continental margins were either subsided due to earth movements or the sealevel rose (due to deglaciation) and thus these deep and long valleys were drowned and submarine canyons were formed. The drowned valleys in Java Sea, Philippine Canyon, Monterey Canyons etc. have been cited as typical examples of submarine canyons formed due to subaerial erosion because their longitudinal profiles show upward concavity like continental canyons and there is significant terrigenous deposits in them.

W.M. Davis while contradicting the above theory argued that the formation of submarine canyons through subaerial erosion required vertical oscillation of land say upheaval of the continental margins upto thousands of feet above sealevel and subsequent equivalent regional subsidence to submerge the entrenched river valleys. This would require long geological period as the aforesaid tectonic mechanism is not possible within short geological time. Secondly, if the submarine canyons are the result of subaerial erosion during emergence and subsequent drowning during submergence, these canyons must have continued over the land also but these are found far away from the river mouths. Emery and Sheppard while reacting to the first objection of W.M. Davis maintained that the lowering of sealevel upto 1000 m during Pleistocene glaciation provided ideal continental platforms for the entrenching of valleys by the rivers and subsequent rise of the sealevel due to deglaciation submerged the deeply entrenched valleys to form submarine canyons. If this explanation is accepted, the submarine canyons beyond the depth of 2000m remain unexplained.

(3) Submarine density current theory—Holimann (1883), Adolf Von Salis (1884) and Florel have related the formation of submarine canyons to the submarine density currents. These density currents are originated due to difference in density caused by temperature and salinity variations. Such density currents erode the continental shelves and form trenches while stagnant water on either side of the trenches allows sedimentation and dyke formation (levees). The density currents are originated mainly in front of the river mouths because of differences (in terms of temperature and salinity) in the water brought by the rivers and sea water. It may be pointed out that density currents are confined to enclosed seas, reservoirs and lakes only and these are seldom originated over shallow continental shelves and thus density currents may not be taken as causative factors of the formation of submarine canyons.

(4) **Turbidity current theory**—Turbidity currents having fine materials in suspension have been held responsible by several exponents (W.M. Davis, W.E. Rither, Tangier Smith, P.D. Trask, Lawson, Daly, Buchanan etc.) for the origin of submarine canyons in one way or the other. Strong onshore winds pile up water near the sea-shore with the result undercurrents are generated which flow towards the sea. These undercurrents bring fine materials in suspension and so they are called turbidity currents. The higher density of these currents due to suspended sediments with them forces them to flow seaward under the surface water. The turbidity currents erode the continental shelves and form submarine valleys and canyons. According to Daly there is increased rate of erosion of coastal land through marine waves due to fall in sea-level during glacial period, with the result turbidity of sea water is increased due to which density of sea water is also increased, consequently seaward turbidity currents are originated. These currents while moving over the continental shelves and slopes erode them in linear manner and form submarine cayons and valleys.

Many critics (Zeppelin, Heim, Bucher etc.) have doubted the efficiency of turbidity currents to form submarine canyons. According to them the velocity of these currents is not such that they can powerfully erode the hard rocks of continental shelves to form canyons. Bucher is of the opinion that currents generated through earthquakes and volcanic eruptions are more rapid and powerful and hence are more capable of eroding the continental shelves to form canyons.

Following Kunen it may be forwarded that submarine canyons in defferent localities having varying lithologies and structures should be explained separately. The canyons developed in stable areas of compact and tenaceous lithologies are formed due to drowning of subaerial valleys, while those carved in unconsolidated lithogloies might have been formed through landslides, turbidity currents etc.

24.7 BOTTOM RELIEFS OF THE ATLANTIC OCEAN

1. Introduction

The Atlantic Ocean located between North and South Americas in the west and Europe and Africa in the east covers an area of 82,000,000 km^2 which is 1/6th of the geographical area of the globe and half of the area of the Pacific Ocean. The 'S' shape of the ocean indicates the fact that landmasses (continents) on its either side were once a contiguous part. The Atlantic Ocean was formed due to drifting of North and South Americas to the west due to plate tectonics. The ocean widens to the south of equator and attains the maximum width of 5,920 km at 35^{0}S latitude. It narrows down towards the equator. It is only 2560 km wide between Liberian coast and Cape Sao Roquė. The width further increases northward and it becomes 4800 km at 40^{0}N latitude. It narrows down in the extreme north where it maintains its contact with the Arctic Ocean through Norwegian Sea, Denmark Strait and Davis Bay. The average depth of the ocean is less than the Pacific Ocean because of extensive continental shelves and marginal and enclosed seas. About 24 per cent of the Atlantic Ocean is less than 915m deep.

The Atlantic Ocean was first formed about 700 million years ago due to seafloor spreading (see fig. 5.13, chapter 5) and westward movement of the Eurasian and African plates from the mid-Atlantic ridge. About 300 million years BP (before present) the Atlantic Ocean was closed due to convergence of the American and Eurasian-African plates. The ocean again started to open about 150 million years

BP due to the movement of aforesaid plates in opposite directions. The widening of the ocean still continues which is evidenced through seafloor spreading at an average rate of 4 cm per year.

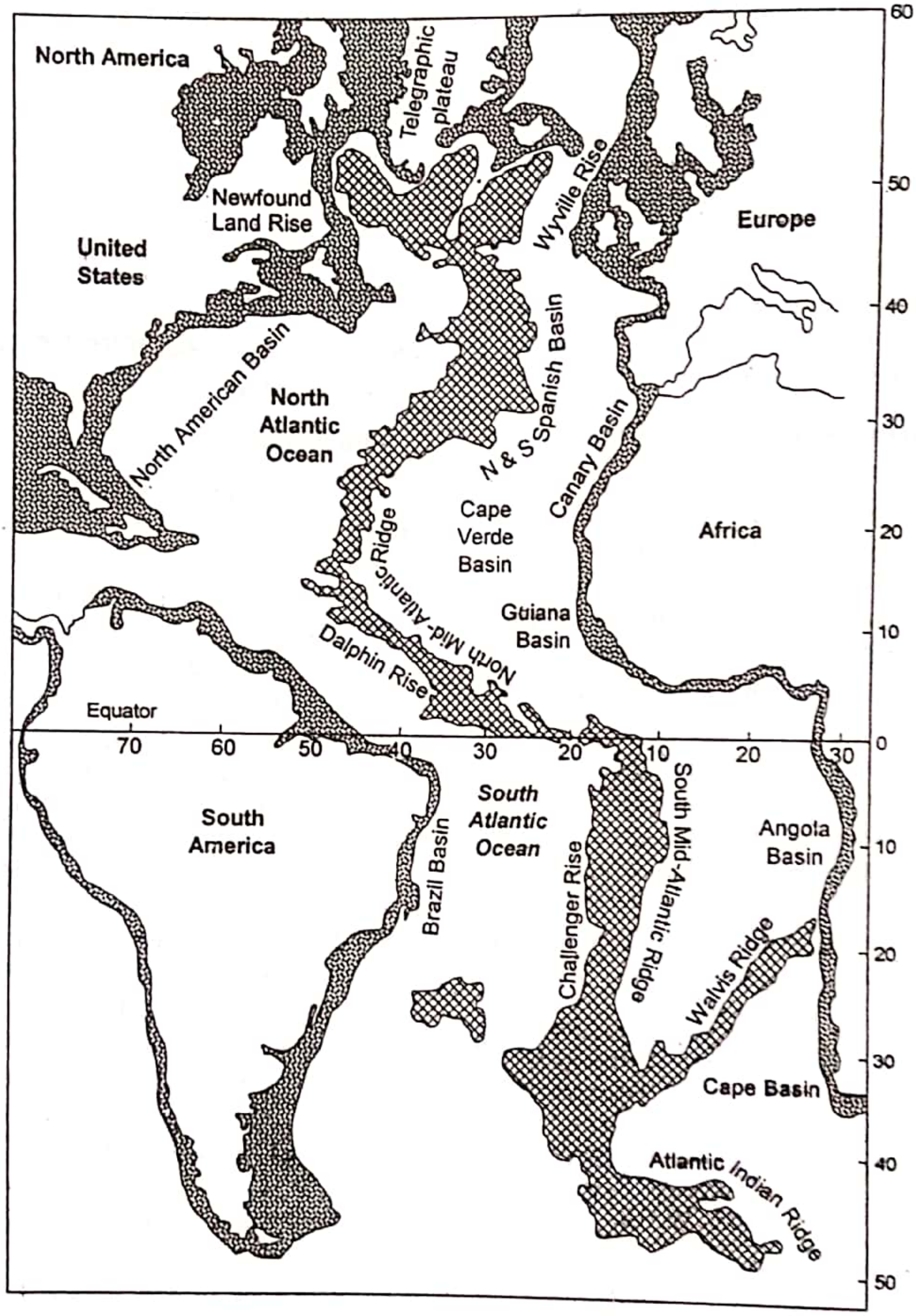

Fig. 24.5 : Bottom reliefs of the Atlantic Ocean.

(2) Continental Shelf

Continental shelves have developed along both the coasts of the Atlantic Ocean and the width ranges from 2-4 km to more than 80 km. In fact, the width of continental shelves has been largely controlled by the reliefs of the coastal lands. These become significantly narrow where mountains and hills border the coasts *e.g.* the African shelves between Bay of Biscay and Cape of Good Hope and Brazilian shelves between 5^0S and 10^0S latitudes. The shelves become 200 to 400 km wide along the north-eastern coast of North America and the north-western coast of Europe. Extensive shelves are found around Newfoundland (Grand Bank) and British Islands (Doggar Bank). Similarly, the continental shelves around Greenland and Iceland are quite wide. Very extensive continental shelves are found in the South Atlantic Ocean mainly between Bahia Blanca and Antarctica (fig. 24.2).

Many marginal seas are located on the continental shelves in the North Atlantic but such seas are practically absent in the South Atlantic. Among the continental shelf-seated seas significant are the Hudson Bay, the Baltic Sea, the North Sea, the Davis Strait, the Denmark Strait etc. The Caribbean and Mediterranean seas represent enclosed seas. There are several islands which are located on the continental shelves *e.g.* British Isles, Iceland, Faeroes, Azores, Ascension, Tristan da Cuncha, Newfoundland, West Indies, Maderia, St. Helena, Trinidad, Falkland, South Orkneys, Shetlands, Georgia, Sandwitch, Canaries, Cape Verde etc. are significant islands representing different locations and origin.

(3) Mid-Atlantic Ridge

The mid-Atlantic ridge representing the zone of divergent or constructive plate margins (American plates moving westward and Eurassian and African plates moving to the east) is the most striking relief feature which having S shape extends for 14,450 km from Iceland in the north and to Bouvet Island in the south. Though swinging west and east it maintains its central position and nowhere goes down more than 4000m below sea level. The ridge is known as Dolphin Rise to the north and Challenger Rise to the south of equator. It is known as Wyville Thompson Ridge between Iceland and Scotland. The ridge becomes quite extensive to the south of Greenland and Iceland and is called Telegraphic Plateau because first cabbles were laid down in this area. A significant branch emerges from this central ridge near 50^0 latitude and extends north-westward as Newfoundland Rise and continues upto New-foundland. Another important branch known as Azores Rise bifurcates from the mid-Atlantic Ridge to the south of 40^0N latitude and extends upto Azores Islands.

At the equator the ridge sends off two branches. Sierra Leone Rise extends towards north-east and Para Rise stretches in north-west direction. Guinea Ridge, a minor branch of the central ridge, runs north-eastward and extends upto Guinea coast. Two significant branches come out of the central ridge near 40^0S latitude. The Walvis Ridge extends towards north-east and merges with African continental shelf while Rio Grande Rise extends towards South American coast.

Though major part of the mid-Atlantic Ridge is submerged under oceanic water but a host of peaks and sea mounts project well above the water surface and form islands. The Pico Island of Azores is the highest peak which rises 8,229.6m (27,000 feet) above the sea floor and 213.36m to 243.84 m above sea level. Besides, the mid-Atlantic Ridge has several well marked fracture zones *e.g.* Gibbs Fracture Zone (near 40^0N), Atlantis Fracture zone (near 30^0N), Oceanographic Fracture Zone (32^0N), Kane Fracture Zone (25^0N), Vema Fracture Zone (10^0N), Romancha Fracture Zone (near equator) etc.

As regards the origin of this unique feature all the previous theories based on compressive and tensional forces stand redundant due to advent of plate tectonic theory. The mid-Atlantic Ridge is the result of westward movement of American plate and eastward movement of Eurasian and African plates. This ridge represents the zone of the divergent or constructive plate margins where basaltic lavas rise continuously, get solidified and are slided equally on both sides of the ridge. The divergence of plates from this ridge is evidenced by the presence of several transform faults (fracture zones, as referred to above). For details see chapter 5, 'Origin of Continents and Ocean Basins'.

4. Ocean Basins

The mid-Atlantic Ridge divides the Atlantic Ocean into two major basins (fig. 24.2) viz. East and West Atlantic Basins. There are few important basins within these two major basins (figs. 24.3 and 24.4).

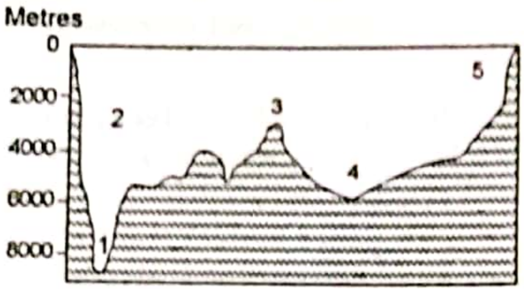

Fig. 24.6: Cross-section of the North Atlantic Ocean. 1.Puretorico basin, 2. North American basin, 3. North Atlantic Ridge, 4. Cape Verde basin, and 5. West African coast.

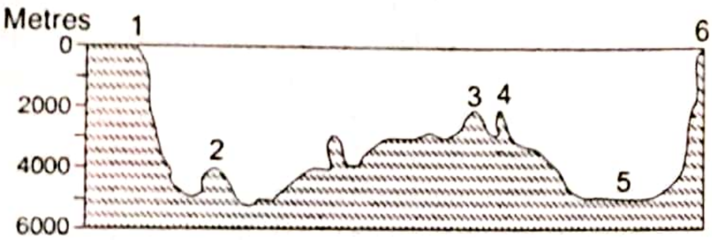

Fig. 24.7 : Cross-section of the South Atlantic Ocean, 1. east South American coast, 2. Argentina basin, 3. South Atlantic Ridge, 4. Walvis Ridge, 5. Cape basin, and 6. Cape Town.

(1) Labrador basin extends between the continental shelf of Greenland in the north and Newfoundland Rise in the south covering latitudinal extent of 40^0 N to 50^0N where the depth of the basin ranges from 4,000 to 4,500m.

(2) North American basin is the most extensive basin of the Atlantic Ocean and extends between 12^0N and 40^0 latitudes. The east-west section lies between the continental shelves off the east coast of N. America and 50^0W meridian. The depth of the basin is more than 5000m but a few deeps measure more than 6000m depth.

(3) Brazilian basin is confined between the equator and 30^0S latitude and east coast of Brazil in the west and Para Rise in the east. The depth is more than 4,000m.

(4) Spanish basin is located between the mid-Atlantic Ridge and Iberian Peninsula. It is bordered by Azores Rise in the south and extends upto 50^0N latitude. The average depth is 5,000m.

(5) North and South Canary basin is comprised of two almost circular basins and is 5,000m deep.

(6) Cape Verde basin is located between the mid-Altlantic Ridge and west African coast and extends from 10^0 N to $23.^0$ N. Average depth is 5000 m but at few places it becomes 5000 m or more.

(7) Guinea basin extends from north-east to south-west in elongated shape between Guinea Ridge and Sierra Leone Rise and measures 4,000 to 5,000 m in depth.

(8) Angola basin is located between the equator and 30^0S latitude. It stretches from the African coast in the north-east to the knot of the mid-Atlantic Ridge and Walvis Ridge in the south-west. The basin is most extensive near the African coast and narrows down towards south-west. The average depth is 5,000m.

Cape Basin (25^0S-45^0S), Agulhas Basin (40^0S-50^0S), Argentina Basin (35^0S-50^0S, depth 5,000m-6,000m) and Atlantic-Antarctic Basin are the other significant basins of the Atlantic Ocean.

5. Ocean Deeps

The number of deeps in the Atlantic Ocean is far less than in the Pacific Ocean because of the absence of the effects of Tertiary orogenic movements along the Atlantic coasts. Murray has identified 29 deeps upto the depth of 3,000 fathoms (5,486.4m) in the Atlantic Ocean. Nares Deep (6,000m), Pureto Rico Deep (8,385m), Hatteras Deep (5,445m), Columbia Deep (5,125m, south of Haiti), Valdivia Deep (3,134 fathoms), Tizard or Romanche Deep (9,370m), Buchanan Deep (3,063 fathoms), Moseley Deep (3,309 fathoms), Vema Deep (4,900m) etc. are a few important ocean deeps of the Atlantic Ocean.

The Mediterranean Sea, Caribbean Sea and Gulf of Mexico are significant marginal seas in the Atlantic Ocean. The Mediterranean Sea is divided into two major basins (East and West Basins) by 4,000m deep mid-sea ridge which runs from the southern Italian coast to the north African coast. The East Mediterranean Basin is further divided into Ionian (4,600m deep) and Lavantine Basins (2,000-3,000m deep) by the ridge located between the southern coast of Greece and the northern coast of Africa. The West Mediterranean Basin is divided into two sub-basins (Algiers-Provencal Basin and Tyrrhenian Basin) by a 1,000 m deep ridge running between Italy and Tunisia. Broad continental shelves (80km to 240km wide and 1,000 m deep) are found along Spanish (eastern), Italian (western), Greek (western), Egyptian (northern), Tunisian and Lybian (north-eastern) coasts.

The Gulf of Mexico and Caribbean Sea are separated by a 1,600 m deep ridge running between Yucatan Peninsula and Cuba Island. The prominent basins are Mexico basin and Caribbean basin. The latter is further divided into four sub-basins *e.g.* Yucatan basin, Cayman trough, Columbia basin and Venezuela basin.

24.8 BOTTOM RELIEFS OF THE PACIFIC OCEAN

1. Introduction

The Pacific Ocean, the largest ocean of the world having one-third area of the globe, extends from east to west for 16,000 km from the east coast of Asia in the west to the west coasts of Americas in the east and for 14,880 km from north to south between Bering Strait in the north to Cape Adre (Antarctica) in the south. The overall shape of the ocean is triangular if its extent in both the hemispheres is considered separately. Average depth of the ocean in 4,572m. Both the coasts (east and west) of the Pacific are paralleled by the chains of folded mountains and therefore the descent from the coast to the abyssal plains is very steep. More or less uniform broad and extensive ocean floor is characterized by several swells, rises, sea mounts and depressions (trenches and deeps).

The Ocean has the largest number of islands (more than 2,000). It may be pointed out that the western coast is studded with islands, island arcs and festoons while the eastern coast has only a few islands. The islands of the Pacific are grouped in 3 categories *e.g.* (1) **the continental islands** (Ateutian Islands, islands off British Columbia of Canada, and Chilean island), (2) **island arcs and festoons** (Kuriles, Japanese Archipilago, Philippines and Indonesian islands), and (3) **scattered smaller islands** which are further subdivided into two major sub-categories *e.g.* (i) islands based on racial grouping such as (a) **Malanesia** (Solomons, New Hebrides and Fizi), (b) **Micronesia** (Marshalls, Carolines, Gilbert and Ellice), and (c) **Polynesia** (Society, Cook, and Tuamotu) and (ii) islands formed of volcanic materials and coral reefs (Hawaii island-volcanic island, Fizi, Faunafuti, Ellice etc. coral islands).

Johnson has divided the Pacific Ocean into four sub-regions : (1) The Northern Pacific represents the deepest part of the whole Pacific where average depth ranges between 5000m and 6000m. This region makes contact with the Arctic Sea through Bering Strait. (2) The Central Pacific is characterized by largest number of islands most of which are of volcanic and coral origin. H.H. Hess has identified 160 flat-topped sea mounts in this region. There are a few subparallel island chains which have been named by E. Suess as Oceanides. (3) The South-West Pacific carries a large number of islands, marginal seas, extensive continental shelves and oceanic trenches. (4) The South-East Pacific has the most striking relief of the Pacific Ocean as the East Pacific Rise or Ridge but there is absence of marginal seas.

2. Continental Shelf

There is significant difference in the extent and characteristics of continental shelves on the eastern and western coasts of the Pacific. The shelves are quite broad and extensive along the eastern coasts of Australia and Asia where the width varies from 160 km to 1600 km and the depth ranges between 1000 m and 2000m. Several islands are seated on these broad continental shelves (viz. Kuriles, Japanese islands, Philippines, Indonesia, New Zealand etc.). These continental shelves also carry numerous marginal seas like Bering Sea, Okhotsk Sea, Japan Sea, Yellow Sea, China Sea, Java Sea, Coral Sea, Tasmania Sea, Arafura Sea etc. The continental shelve are less extensive along the western coasts of Americas because of nearness of cordillerean chains of folded mountains to the coastal lands. The average width is 80 km.

3. East Pacific Rise

The Pacific Ocean does not have central or mid-oceanic ridge like the Atlantic and the Indian Oceans, albeit there are a few scattered ridges having local importance. The East Pacific Rise or Ridge known as Albatross Plateau is 1600 km wide and it extends from north of New Zealand to the Californian coast. It sends off two branches between 23^{0}S-35^{0}S. The eastern branch merges with Chilean coast while the other branch moves southward in the name of Eastern Island Rise. A minor ridge known as Galapagos Ridge runs parallel to the East Pacific Ridge in the east between the Eastern Island Fracture Zone and Galapagos islands from where it moves in two branches viz. (i) Carnegie Ridge and (ii) Cocos Ridge in north-east direction. The New Zealand Ridge is about 200m to 2000 m below sea level and widens near Fiji island to form Fiji Plateau which is 2000 m below sea level. The Hawaiian Rise extends from north-west to south-east direction between 35^{0}N - 17^{0}N for a distance of 960 km. This is the most extensive ridge (2640 km wide) of the Pacific Ocean. The other minor ridges are Nazca Ridge off Peru coast, Lord Howe Rise off eastern coast of Australia between 20^{0}S and 40^0 S latitude. Norfolk Island Ridge between New Caledonia and New Zealand (23^{0}S-35^{0}S), Eauripik-New Guinea Rise north of New Guinea and parallel to 140^{0}E longitude, Caroline-Soloman Ridge north of Soloman Islands etc.

Besides, there are a few fracture zones running from west to east *e.g.* (from north to south) Mendocino Fracture Zone (40^{0}N), Murray Fracture Zone (30^{0}N), Molokai Fracture Zone (25^{0}N), Clarion Fracture Zone (20^{0}N), Clipperton Fracture Zone (10^{0}N), Eastern Island Fracture Zone (30^{0}S), Challenger Fracture Zone (40^{0}S) etc.

4. Ocean Basins

There are different basins of different shapes and sizes. These basins are separated by ridges and 'rises'. The following are a few important basins of the Pacific Ocean.

(1) Philippine basin is located to the east of Philippines and extends from south of Japan to 5^{0}N latitude. Kyushu - Paian Ridge runs through the middle of the basins. Average depth ranges from 5000m to 6000m.

(2) Fiji basin is located to the south of Fiji Island between 10^{0}S and 32^{0}S latitudes and the average depth is 4000m. The basin to the north of 20^{0}S is known as North Fiji Basin whereas the South Fiji Basin between 20^{0}S and 32^{0}S is bordered by Norkolk Island Ridge in the west and Karmadec - Tonga Trenches in the east.

(3) East Australian basin is situated between the east coast of Australia and New Zealand Ridge with average depth of more than 5000m.

(4) South Australian Basin also known as Jeffreys Basin is located to the south-east of Australia having average depth of 5000m.

(5) Peru basin is located to the west of Peru coast between 5^{0}S and 24^{0}S latitudes and extends upto 110^{0}W longitude. The average depth of the basin is 4000m.

(6) South-Western Pacific basin is an elongated basin stretching between 20^{0}S and 50^{0}S latitudes and 180-129^{0}W longitudes. Karmadec Trench with the depth of 10,047 m is located to the west of this basin.

(7) Pacific-Antarctic Basin is located to the south-west of Chilean coast between 40^{0}S and 60^{0}S latitudes and extends upto 130^{0}W longitude.

5. Oceans Deeps

There are several trenches and deeps in the Pacific Ocean. These depressions are located either along the island arcs or mountain chains. It may be pointed out that the trenches are found mainly in the western Pacific Ocean. The following are the significant trenches:

Table : 24. 3: Major Trenches of the Pacific Ocean

Trenches	Depth in metres	Trenches	Depth in metres
Mariana	11,002	Middle American	6,562
Tonga	10,882	Ryukyu	6,395
Kurile	10,498	Bonin	—
Phillippine	10,475	Yap Palau	—
Japan	10,375	Soloman	—
Karmadec	10,047	New Britain	—
Peru-Chile	8,025	New Hebbrides	—
Aleutian	7,679		

The genesis of oceanic trenches and deeps is related mainly to tectonic activities caused by plate motions (plate tectonics, see chapter 11, Mountain Building, For the origin of Japan Trench).

24.9 BOTTOM RELIEFS OF THE INDIAN OCEAN

1. Introduction

The Indian Ocean is smaller than the Pacific and Atlantic Ocean in areal extent and is bounded by, on all of its sides, Asia in the north, Africa in the west, Asia in the east, Australia in the south-east and Antarctica in the south. The ocean has contact with the Pacific and the Atlantic oceans in the south near Antarctica. The average depth of the ocean is 4000m. Major parts of the coastal lands of the Indian Ocean formed by the block mountains of Gondwanaland are compact and solid. The coasts of the East Indes are bordered by fold mountain chains. The marginal seas are less in number than the Pacific and the Atlantic oceans. Significant marginal seas are Mozambique Channel, Red Sea, Persian Gulf, Andman Sea, Arabian Sea, Bay of Bengal etc. Malgasy (Madagascar) and Sri Lanka are the big islands whereas Suqutra, Zanzibar, Comoro, Reunion, Secychelles, Prince Edwards, Crozet, Kerguelen, St. Paul, Rodriges, Maldive, Laccadive, Andman-Nicobar, Christmas etc. belong to the category of small and tiny islands.

Indian subcontinent in the north divides the Indian Ocean into Arabian Sea and Bay of Bengal. The ocean widens in the south. Johnson has divided the Indian Ocean in 3 zones on the basis of regional characertistics. (1) The Western Zone between African coast and the mid-Indian Oceanic Ridge has large number of islands and the average depth is 3650 m (2000 fathoms). (2) The Eastern Zone is deepest of all the zones with average depth of 550 m (3000 fathoms). The continental shelves are narrow but have steep slopes. (3) The Central Zone represents the mid-oceanic ridge where many tiny islands are located.

2. Continental Shelf

There is wide range of variation in the continental shelves of the Indian Ocean. Quite extensive shelves are found along the margins of Arabian Sea and Bay of Bengal. Similarly, extensive shelves are observed along the eastern coast of Africa and around Madagascar which is itself located on the continental shelves. On an average, the continental shelves are very wide (640 km) in the west whereas these are narrow (160 km) along the coast of Java and Sumatra. These become further narrow along the northern coast of Antarctica.

3. Mid-Oceanic Ridge

The central ridge or mid-oceanic ridge known as Mid-Indian Oceanic Ridge (fig. 24.5) extends from the southern tip of Indian Peninsula in the north to Antarctica in the south almost in north-south direction and forms a continuous chain of highlands. Wherever the central ridge or its branches emerge above the sea level, islands are formed. The main central ridge starts from the continental shelf of the southern tip of Indian Peninsisula with average width of 320 km. This part of the ridge is known as Laccadive-Chagos Rigde (also known as Maldive Ridge). The ridge further extends southward and widens near equator. It is called Chagos-St. Paul Ridge between equator and 30^{0}S latitude where the average width becomes 320 km. The ridge further widens to 1,600 km between 30^{0}S and 50^{0}S latitudes and is known as Amsterdam-St Paul Plateau. The central ridge bifurcates to the south of 50^{0}S latitude. The western branch known as Kerguelen-Gaussberg ridge extends in NW-SE direction between 48^{0}S and 63^{0}S and the eastern branch is known as Indian-Antarctic Ridge.

Branches of the Central Ridge—(1) Socotra-Chagos Ridge also known as Carlesbreg Ridge emerges from the central ridge at 5^{0}S latitude and extends in north-westerly direction upto Gardafuli Peninsula of N. E. Africa, (2) Seychelles - Mauritius ridge bifurcates from the main ridge around 18^{0}S latitude near Mauritius Island and runs in roughly north-west direction in arcuate shape upto Seychelles and Amirante islands. (3) Madagascar Ridge stretches from the southern tip of Madagascar (Malagasy) to 40^{0}S latitude. Its further southward extension is known as Prince Edward - Crozet Ridge between 40^{0}S -48^{0}S latitudes. (4) The south-western branch near 23^{0}S latitude is known as S.W. Indian Ridge. (5) Ninety East Ridge extends from the continental shelf off the Irrawadi river mouth and runs in almost north-south direction parallel to 90^{0}E longitude upto 40^{0}S where it merges with Amsterdam-St Paul Plateau.

4. Ocean Basins

The mid-Indian Oceanic Ridge divides the Indian Ocean into two major basins-the eastern and the western basins. These basins are further divided into sub-baisns by the branches of the central ridge (fig. 24.5).

(1) **Oman basin** faces the Gulf of Oman and is spread over the extensive continental shelf with average depth of 3,658 m. (2) **Arabian basin** is located in almost circular shape between Laccadive-Chagos ridge and Socotra - Chagos Ridge with the depth of 3,600m - 5,486m. (3) **Somali basin** is bor

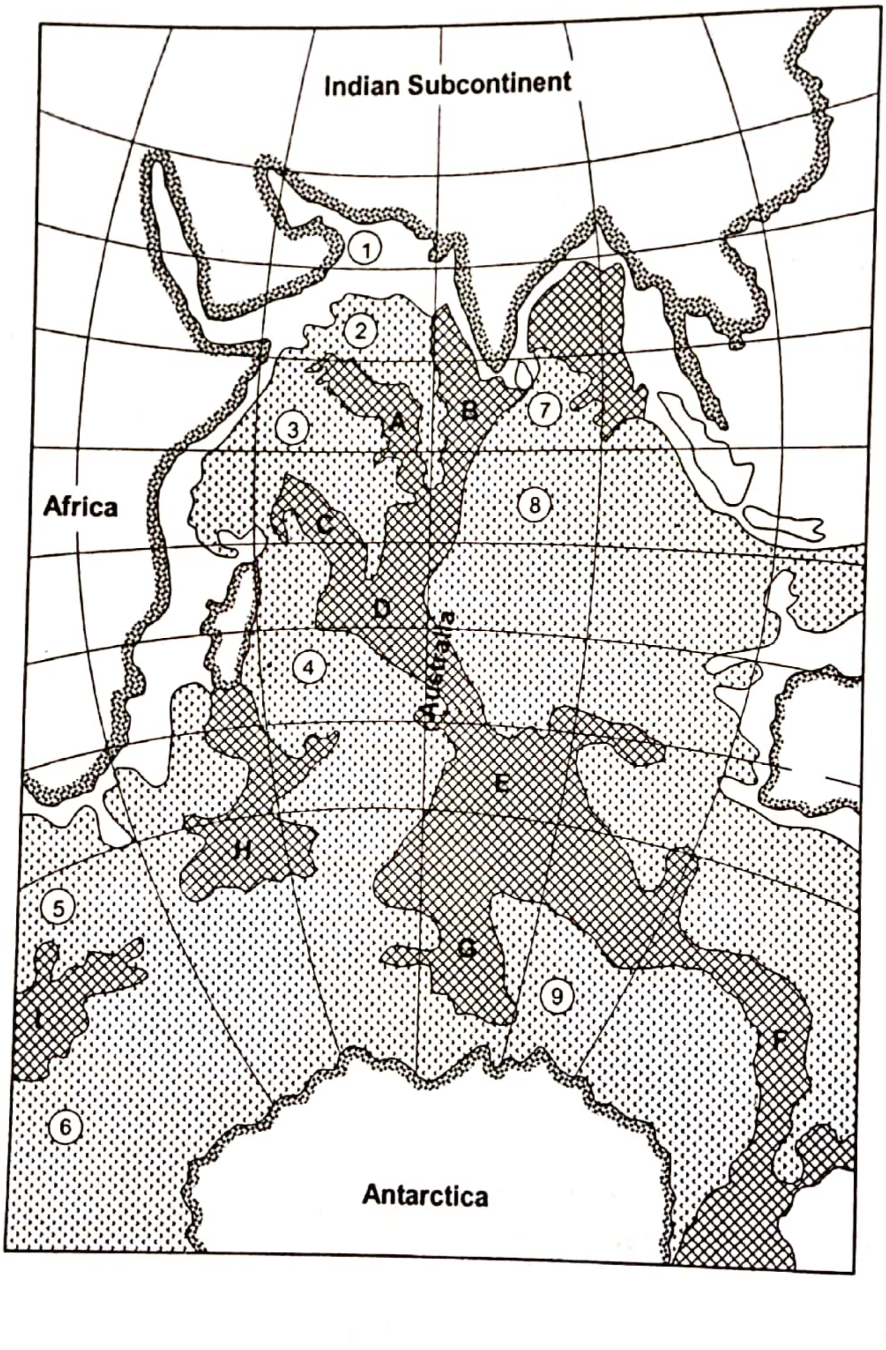

Fig. 24.8 : Bottom reliefs of the Indian Ocean. A - Socotra-Chagos Ridge, B-Chagos Ridge, C-Seychelles Ridge, D-Chagos-St. Paul Ridge, E-Amsterdam- St Paul Ridge, F-Indian - Antarctic Ridge, G-Kerguelen- Gassberg Ridge, H-Madagascar Ridge and I - Atlantic - Antarctic Ridge, 1. Oman basin, 2. Arabian basin, 3. Somali basin, 4. Mauritius basin, 5. Natal basin, 6. Atlantic - Indian- Antarctic Basin. 7. Andaman Basin, 8. Indian-Australia basin and 9. Antarctic basin.

dered by Socotra - Chagos ridge in the north-west, Central Ridge in the east, Seychelles - Mauritius Ridge in the south-west and African coast in the west. The average depth is 3,600m. (4) **Mauritius basin** is located between S.W. Indian Ridge and South Madagascar Ridge and extends from 20^{0}S to 40^{0}S latitude. The depth varies between 3,600m and 5,486 m. The deepest part measures 6,391m depth. (5) **Mascarene basin** of oval shape extends between Madagascar and Seychelles - Mauritius Ridge. (6) **Agulhas-Natal basin** is an elongated basin which is bordered by Madagascar ridge in the north and north-east, Prince Edward Crozet Ridge in the east and the S.E. African coast in the west and north-west. Average depth is 3,600m. (7) **Atlantic-Indian - Antarctic basin** is in fact the eastward continuation of Atlantic - Antarctic Basin. It stretches upto 70^{0}E longitude and is bordered by Prince Edward Crozet Ridge in the north, Antarctica in the south and Kerguelen Gassberg Ridge in the north-east. Average depth is 3,600m. (8) **Eastern Indian-Antarctic basin** is located between Amsterdam - St. Paul Plateau and Indian-Antarctic Ridge in the north and north-east and Antarctica in the south. The depth varies from 3,600m to 4,800m. Kerguelen - Gassberg Ridge separates the basin from the Atlantic - Indian-Antarctic Basin. (9) **West Australian basin** is the most

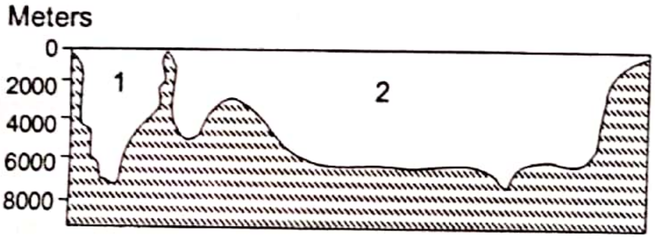

Fig. 24.9 : cross-section of the Indian Ocean, 1. Re-Union, 2. Indian-Australia Basin.

extensive basin and forms rectangular shape surrounded by S.E. Indian Ridge in the south - west, Ninety East Ridge in the west, continental shelves of Java-Sumatra in the north-east and the continental shelf of west Australia, Average depth varies from 3,600m to 6,100m but the central part of the basin is 6,459 m deep. (10) Mid-Indian basin is bordered by the central ridge in the west and the south-west, by Ninety East Ridge in the east and by the Bengal plateau in the north. The average depth of outer part ranges from 3,600m to 6,800m while the depth of the central part of the basin ranges between 4,800m and 6,100m.

5. Deeps and Trenches

There are very few deeps and trenches in the Indian Ocean. About 60 per cent of the Ocean consists of deep sea plains with depth ranging from 3,600m to 5,487m. Important deep sea plains are Somali Abyssal plain. Ceylone (Sri Lanka) Abyssal plain, Indian Abyssal Plain, (4,380m) etc. Significant trenches are Java or Sunda Trench (7,450m deep), Ob Trench (6,875m deep), Mauritius Trench, Amirante Trench etc.

24.10 IMPORTANT DEFINITIONS

Abyssal hills : A variety of hills of volcanic origin projecting above the deep sea plains (abyssal plains) are called abyssal hills, such as **volcanic hills** and **islands, sea mounts, tablemounts, guyots** etc.

Abyssal plains : known as deep sea plains are the most extensive but the flattest terrain units to be found on the earth's surface including continents.

Continental margins : represent the boundaries of lands towards oceans. In fact, continental margins represent plate boundaries having shallow seawater.

Continental rise : represents a marine depositional feature formed through the coalescence of a few deep sea fans, and having varying monphometric characteristics.

Continental shelf : The continental shelf is defined as a shelf-like zone extending from the shore beneath the ocean surface to a point at which a marked increase in slope angle occurs, this point is called **shelf break.**

Continental slope : The zone of steep slope extending from the shelf break to the deep sea plains is called continental slope, which varies from 5^0 to more than 60^0 at different places.