CHAPTER VI

SUMMARY AND CONCLUSIONS
The eastern Arabian Sea is the deep oceanic part of the western continental margin of India (WCMI). The region comprises of several surface/subsurface structural features which include the Chagos – Laccadive ridge (CLR), Laxmi ridge, Pratap ridge and a belt of numerous horst – graben structures in the sediment filled basins bordering the west coast of India. The Chagos Laccadive Ridge and Laxmi ridges divide the eastern Arabian sea into two provinces the Western and Eastern basins. While it is widely agreed that the Western basin is underlain by oceanic crust, the nature of crust below Eastern basin is debated. Many previous workers suggested that the Eastern basin is characterised by thick transitional rift stage crust extending as far as the Laxmi and Laccadive continental ridge region, some of them observed extension of Precambrian tectonic trends into deep oceanic areas of the Arabian Sea. The observed structural features have essentially evolved as a consequence of rifting and sea-floor spreading between India, Madagascar and Seychelles.

In order to understand the rifting style, basement tectonics and early evolutionary history of the margin, it would be useful to integrate the geophysical data in the onshore as well as offshore along various segments of the margin. The main objective of the present study is to model the gravity field in terms of lithosphere structure below the WCMI, identify zones of crustal mass anomalies and other rift related features across the margin. The vast amount of seismic reflection and refraction data in the form of crustal velocities, basement configuration and crustal thickness available for the west coast as well as the eastern Arabian Sea have been utilised. For this purpose, such integration of
onshore and offshore data along the margin is expected to generate more realistic models on structural styles and processes of crustal rifting along various segments of the margin which can be interpreted in the overall realm of geodynamics of the region.

For interpretation of gravity anomalies in terms of crustal mass anomalies, surface rock density as well as crustal density data are essential. For this purpose, the crustal seismic velocities are useful to infer densities of deeper layers, whereas, the direct determination of surface rock densities are useful to infer the density of upper crustal layer. The seismic data along the WCMI and deep oceanic parts of the Arabian Sea include the wide angle reflection and refraction stations collected by various national and international agencies. For the West Coast of India, such deeper information on crust / mantle structure is available from refraction Deep Seismic Sounding profiles collected by the National Geophysical Research Institute.

The seismic data in the oceanic areas indicate that in sedimentary layers the velocities in general vary from 1.7 km/sec for top un lithified sediments to 4.9 km/sec for deeper layers above the acoustic basement. The velocities in the range of 4.0 – 4.9 km/sec observed mainly in the Eastern basin and Laxmi ridge region have been inferred as due to basal sedimentary layers related to early rifting. The acoustic basement can be inferred at a velocity of 5.0 km/sec. The crustal layers show a range of velocities between 5.2 – 7.3 km/sec (with predominantly 6.2 – 6.4 km/sec values). At few refraction stations in the Laxmi
Lasin and Laxmi ridge, velocities >7.0 km/sec are observed in the lower crust. Moho velocities of 7.9 – 8.3 km/sec have been observed at several locations in the region at an average Moho depth of 11.5 km. The seismic data clearly indicate that the western basin is underlain by oceanic crust with Moho at 11-13 km depth. Velocities observed along the Laxmi ridge indicate the continental affinity of the ridge, but, the nature of crust below the Laxmi basin is ambiguous from velocity data.

The DSS investigations in the western Indian shield bring out a clear picture regarding unstretched continental crust and the later rifting features. The inferences from DSS studies are: i) Deccan traps having velocities of 4.5 – 5.5 km/sec with a maximum thickness of 2.0 km underlain by Mesozoic sediments (velocities 4.0 km/sec) in Saurashtra; ii.) a two layered continental crust with a variable upper crustal thickness of about 10 – 20 km characterised by velocities of 5.8 – 6.5 km/sec, and a lower crust with velocities of 6.6 – 6.9 km/sec, with Moho observed at a depth of 38 – 42 km in the shield regions; iii.) general shallowing of Moho towards the coast; iv.) higher lower crustal velocities at 23 – 25 km depth and a shallow Moho at a depth of 31 – 33 km below Cambay rift basin; v.) transitional Moho and low velocity layers in the Koyna region; and vi.) continental type of crust beneath Saurashtra Peninsula.

The seismic information discussed above has been used to infer the density configuration for the continental as well as the oceanic crust based on the Nafe-Drake velocity-density relationship. In the oceanic areas, the 1.7 – 2.8
km/sec (density of 2.1 g/cm$^3$) and 2.9 – 5.0 km/sec (density of 2.3 g/cm$^3$) for shallow and deeper sediments were assigned a uniform value of 2.2 g/cm$^3$ for the sedimentary layer. A two layered oceanic crust of 2.66 g/cm$^3$ for the top part (5.1 – 6.3 km/sec velocities) and 2.90 g/cm$^3$ for the bottom layer (6.4 – 7.0 km/sec velocities) has been assigned. A uniform value of 3.3 g/cm$^3$ for the lithospheric mantle and 3.2 g/cm$^3$ for the Asthenosphere have been assumed. The velocity-density correlation of DSS in the westem Indian shield margin gives rise to, a density value of 2.67 g/cm$^3$ for the upper crust (5.8 – 6.5 km/sec), 2.85 g/cm$^3$ for the lower crust (6.6 – 6.9 g/cm$^3$), 2.80 g/cm$^3$ for the Deccan traps, 2.40 g/cm$^3$ for sediments in the Cambay basin and t-Mesozoic sediments lying below the Deccan traps. A density of 3.0 g/cm$^3$ has been assumed for the high velocity layer (7.1 – 7.4 km/sec) in the lower crust. However, the crust in the western Indian Shield south of 13° N is characterised by exhumed lower to middle crustal rocks which would imply that top crustal layers in this region have higher densities than the rest of the shield. Therefore, an average density value of 2.75 g/cm$^3$ for the exhumed mid-lower crustal layer in the SGT has been inferred.

A revised gravity anomaly map considering free-air anomalies (GEOSAT data) in the oceanic areas and Bouguer anomalies in the land area has been prepared in order to understand nature of gravity field in the region. The map shows that except in the inner shelf region, free-air anomalies are in general negative ranging from -10 to -60 mGal in the whole of eastern Arabian Sea. The bipolar edge effect anomaly i.e. a gravity high of +20 to +40 mGal in the
inner shelf region and a low of as much as -60 mGal in the slope can be seen all along the western margin, except between 12° - 16° N, the gravity field seems disturbed perhaps due to the presence of several basement ridges and isolated bathymetric features. The subdued and broadly varying gravity field of -20 to -40 mGal in the southwestern part of the map is found to increase sharply on the CLR to as much as +10 mGal. In the northwestern part, the deep Arabian Sea region is characterised by positive and negative anomaly belts. A NW-SE trending gravity low of more than -40 mGal correlates well with the Laxmi ridge.

The Bouguer anomalies over the western Indian shield margin range between -20 to -120 mGal and is characterised by a westward gravity high gradient zone striking N-S all along the coast, a gravity high in the Cambay rift basin and several isolated gravity highs hugging the coast at many places. The isolated coastal gravity highs have been inferred either due to large basic intrusives at depth or localised thinning of the crust.

Four uniformly spaced regional gravity traverses and the available seismic data across the WCMI, starting from the western Indian shield extending into the deep oceanic areas of the eastern Arabian Sea, have been utilized to delineate the lithospheric structure. The seismically constrained gravity models along these four traverses suggest that the crustal structure below the northern part of the margin within the Deccan Volcanic Province (DVP) is significantly different from the margin outside the DVP. This difference could be due to the fact that the lithosphere experienced multiple rifting episodes and massive Deccan volcanism
In the north. The lithosphere thickness, in general, varies from 110 - 120 km in the central and southern part of the margin to as much as 85 - 90 km below the Deccan Plateau and Cambay rift basin in the north. The Eastern basin is characterised by thinned rift stage continental crust which extends as far as Laxmi basin in the north and the Laccadive ridge in the south. At the ocean – continent transition (OCT), crustal density differences between the Laxmi ridge and the Laxmi basin are not sufficient to distinguish continental as against an oceanic crust through gravity modeling. However, 5-6 km thick oceanic crust below the Laxmi basin is a consistent gravity option. Significantly, the models indicate the presence of a high density layer of 3.0 g/cm$^3$ in the lower crust in almost whole of the northern part of the region between the Laxmi ridge and the pericontinental northwest shield region in the DVP, and also below Laccadive ridge in the southern part. The Laxmi ridge is underlain by continental crust up to a depth of 11 km and a thick high density material (3.0 g/cm$^3$) between 11 - 26 km. The Pratap ridge is indicated as a shallow basement high in the upper part of the crust formed during rifting. The 15 -17 km thick oceanic crust below Laccadive ridge is seen further thickened by high density underplated material down to Moho depths of 24 - 25 km which indicate formation of the ridge along Reunion hotspot trace. The large variations in the lithosphere thickness and widespread occurrence of underplated material in the lower crust in the DVP give rise to substantial density inhomogeneities which may accentuate the stress field within DVP giving rise to enhanced seismic activity in the region.
The WCMI is divided into five major sedimentary basins bounded by NE-SW trending basement arches. These basins have been developed during the rifting and sea-floor spreading between India, Madagascar and Seychelles. For detailed basin scale modeling on rift tectonics involving both onshore and offshore areas, close spaced data in the coastal areas is necessary. For this purpose, the Kerala basin covering both offshore as well as the coastal Kerala region has been considered for detailed data acquisition and interpretation in terms of crustal modeling. The data acquisition include establishment of 28 permanent gravity base stations and nearly 600 gravity measurement points in the coastal areas. A composite gravity anomaly map covering both onshore and offshore parts of the Kerala basin reveal several important structural correlations. The Bouguer anomalies in the onshore areas in general ranges from +20 to −100 mGal. The anomalies in general are gradually increasing towards the coast. A gravity high with a maximum of +20 mGal is observed at the coast between Alleppey and Quilon. The free air anomalies in the offshore show good correlation with the bathymetric features. The characteristic bipolar gravity edge effect anomaly is observed with +10 to +20 mGal positive values in the shelf and decreasing to −60 mGal with a strong gradient following the continental slope. A gravity high of 20 mGal is seen correlating with the Alleppey Platform. The Pratap ridge in this region does not appear very strongly on the gravity anomaly map. However, just east of the ridge several isolated bathymetric (circular to semicircular) features give rise to strong +ve gravity anomalies. Whether these isolated anomalies form a part of the Pratap ridge complex or not, is not very clear from this study. The
Chagos fracture zone is characterised by a gravity high of 20 to 40 mGal with a gravity low characterised by -50 mGal contour on either side. The anomalies in the Arabian basin, in general, vary from -40 to -50 mGal.

Gravity anomalies along four profiles across the Kerala basin have been considered for interpreting 2-D crustal structure. The models show that the crust, which is 35-36 km below the crystallines along the SW coast of India thins down to as much as 16 km in the deeper oceanic parts of the basin. Further, a steep rise in the Moho by 10 – 15 km is observed below the coast and shelf region. This rapid rise of the Moho is also associated with thinning of the crust seaward. Such characteristic crustal geometry across the rifted continental crust may possibly be an expression of the initial rift related faulting along the West Coast. The modeled Moho geometry based on the broad gravity anomalies in the four profiles studied here could be explained by invoking the southward extension of the West Coast fault (WCF). However, possibilities of shearing movements through a system of transform faults in the NNE-SSW direction offsetting the primary faults oriented in NNW-SSE trend render the picture of faulting more complex in the region. Therefore, more detailed and closer gravity data with better seismic constraints will be necessary before attempting to trace the primary rift related fault pattern in the region. The gravity high observed over Alleppey platform, a distinct platformal feature in the outer shelf-slope region is explained as a minor basement high with variation in thickness of lower crustal layer characterized by a Moho rise below the platform. The Chagos Fracture Zone (CFZ) which separates the Chagos Laccadive Ridge from the Chagos

85
basin is seen as a high at both upper crustal as well as Moho level with a steep Moho gradient on its western flank. The counterclockwise rotation of the Indian subcontinent during the early Tertiary period might have terminated the CFZ at the margin near Alleppey Platform. Subsequently, the motion along the CFZ also slowed down rapidly after the collision of Indian plate with Eurasian plate which might have resulted in extensive deposition of carbonate sequences over the Alleppey platform, causing the present day crustal geometry of this platformal structural feature.