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Subsurface structure of the offshore Trincomalee, NE of Sri Lanka

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ABSTRACT
Lanka basin of Sri Lanka, is an ultra-deep-water basin, which is now in focus due to economic importance, thus needed further exploration. This region consists of a prominent northeast –southwest trending gravity anomaly in the offshore Trincomalee region, which is known as a seismically virgin area. In this study, an attempt was made to generate a subsurface model using the freely available satellite and ship-borne gravity and ship track bathymetry data. An iterative algorithm was developed to calculate the gravity anomaly, caused by a two dimensional polygonal body having a density contrast with the surrounding, constrained further by available seismic data. The gravity anomaly caused by the upper mantle was obtained by arithmetic operations of the calculated gravity anomalies and the satellite derived free air gravity anomaly. Conventional trial and error method was finally employed to determine the structure of upper mantle that indicates the depth of Mohorovićič discontinuity. The lowest thickness of the oceanic crust in the basin is 2 km and the average sedimentary thickness is about 6 to 8 km. The Mohorovićič discontinuity was found to be around 12-14 km along the chosen profile. The results are of significance, as they can be used to interpret the evolution of the basin and depict the interested regional areas for further seismic surveys and oil and gas explorations.

Keywords: Density contrast, Gravity studies, Lanka basin, Mohorovičić discontinuity, Upper mantle, Seismic velocity.

INTRODUCTION

Sri Lanka occupies a unique geologic position in Gondwana land. Its location is of particular significance since Sri Lanka acts as a bridge across the main East African and Antarctica crustal fragments. Sri Lanka has a rich sedimentary base in sea area. Early Miocene age is the period where the two plates collided, Himalayan mountain range was formed and major rivers like Ganges started supply of sediments to this region (Kularathna et al., 2015a). Since then, large amount of sediments have been accumulating in the passive margins of this region. Earlier, extensive exploration work has been carried out in both Cauvery (Baillie et al., 2002; Chandra et al., 1991) and Mannar (Kularathna et al., 2015b); Ratnayake et al., 2014; Premarathne et al., 2013) basins. Though, the interest in exploration for hydrocarbon in the ultra-deep Lanka Basin has only recently been started and still not much data is available over this region (Gamage et al., 2018; Ratnayake et al., 2017). Further exploration may establish presence of hydrocarbons in the Lanka basin for future energy needs. Sri Lanka had been a part of the East Gondwana super continent and has undergone at least two prominent rifting phases during the Gondwana breakup time. The first rifting phase which is less prominent, initiated around 165 Ma ago, has resulted in the formation of NE-SW and NW-SE discontinuities in the Mannar Basin (Figure 1). The second rifting phase, which was more prominent, has commenced around 142 Ma ago and had resulted in the formation of Cauvery and Lanka Basins (Kularathna et al., 2015), the latter opening up to Bay of Bengal (Rao et al., 1997; Rao et al., 1994). Locations of the basins around offshore Sri Lanka are shown in the Figure 1.

METHODOLOGY AND DATA

For the present study, we use satellite gravity and the bathymetry data. Selected area for the study includes onshore as well as off shore areas in eastern side of offshore Trincomalee. The gravity data in a 1- minute grid was obtained from the TOPEX project web site. ESRI ArcGIS software was used to create necessary shape files and for the purpose of coordinate conversions. Sedimentary Thickness map of Lanka basin and sedimentary thickness variation along the A-A1 line (Figure 3), as acquired from a previous research work in Lanka basin (Silva et al., 2018) are shown in Figures 2 and 3 respectively.

Talwani et al., (1959) had put forward an algorithm to compute the gravity anomaly caused by a two-dimensional body in the subsurface, based on iterative modelling. The boundary of the two-dimensional body is approximated closely to a polygon, by marking the number of sides of the polygon sufficiently large. This method assumes that the anomalous body is infinitely long and parallel to the strike of the structure. The cross section of the body is replaced by countless thin rods or line elements aligned parallel to the strike (Talwani et al., 1959; Lowrie, 2007). Mathematical expression has been obtained for both the vertical and horizontal components of the gravitational attraction due to this polygon at any given point.

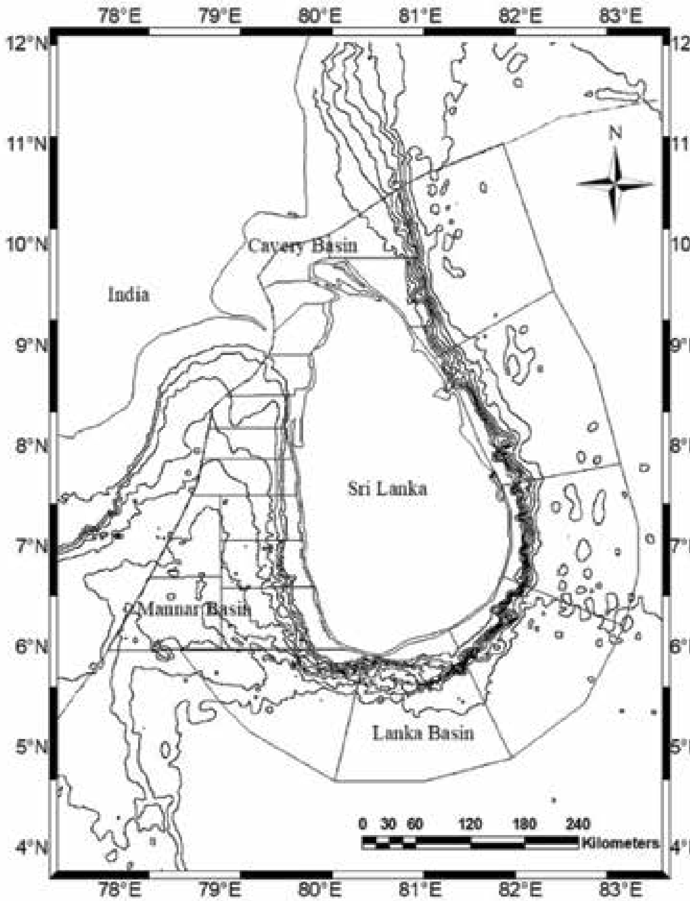

Figure 1. Basins of Sri Lanka (WGS 1984).

A simplified equation for the vertical component of given in the equation is given in the equation 1.

$$\Delta g=2G\rho\ \{[z_1 Cos\phi+Sin\phi][(\theta_1-\theta_2)Cos\phi-ln(r_1/r_2)Sin\phi] +z_2\theta_2-z_1\theta_1\} \quad -(1)$$

In order to execute this algorithm, a wolfram Mathematica program was written. The x- and z-coordinates of the vertices of the polygonal body (in km) in a counter clockwise sense were introduced in the program. The density contrast (in g/cm^3), number of vertices in the polygonal body, number of field points for the calculation of the anomaly and the interval between adjacent field points (in km), were given as inputs. Density contrast was calculated as the difference between the density of the material that had replaced the originally existed material and the density of the originally existed material.

The output of the program provides a table of calculated gravity anomaly caused by the polygonal body at each field point along the mean sea level. The variation of the gravity anomaly caused by the polygonal body along a horizontal axis on the mean sea level was plotted on a graph. Figure 4 shows the parameters used by the equation 1.

The tabulated data for each subsurface horizon were arranged in an order, such that two adjacent horizons including the free water surface, were coupled together to form different subsurface bodies or polygons. Starting from the Bengal Bay end (oceanic end), the x and z coordinates were ordered such that they defined the polygon in a counter clockwise sense.

The densities of the sedimentary column and oceanic water were taken as 2.40 and 1.03 g/cm^3 (Reddy, 2002). The density of the basement was taken as 2.65-2.8 g/cm^3, since the basement in this region was assumed to be composed of metamorphic rocks of the north-eastern area and the densities of common metamorphic rocks range from 2.65g/cm^3 to 3.03 g/cm^3(Smithson, 1971). Figure 5 shows the gravitational image of the onshore and offshore regions around Sri Lanka. Summary of the densities of subsurface layers are given in Table 1.

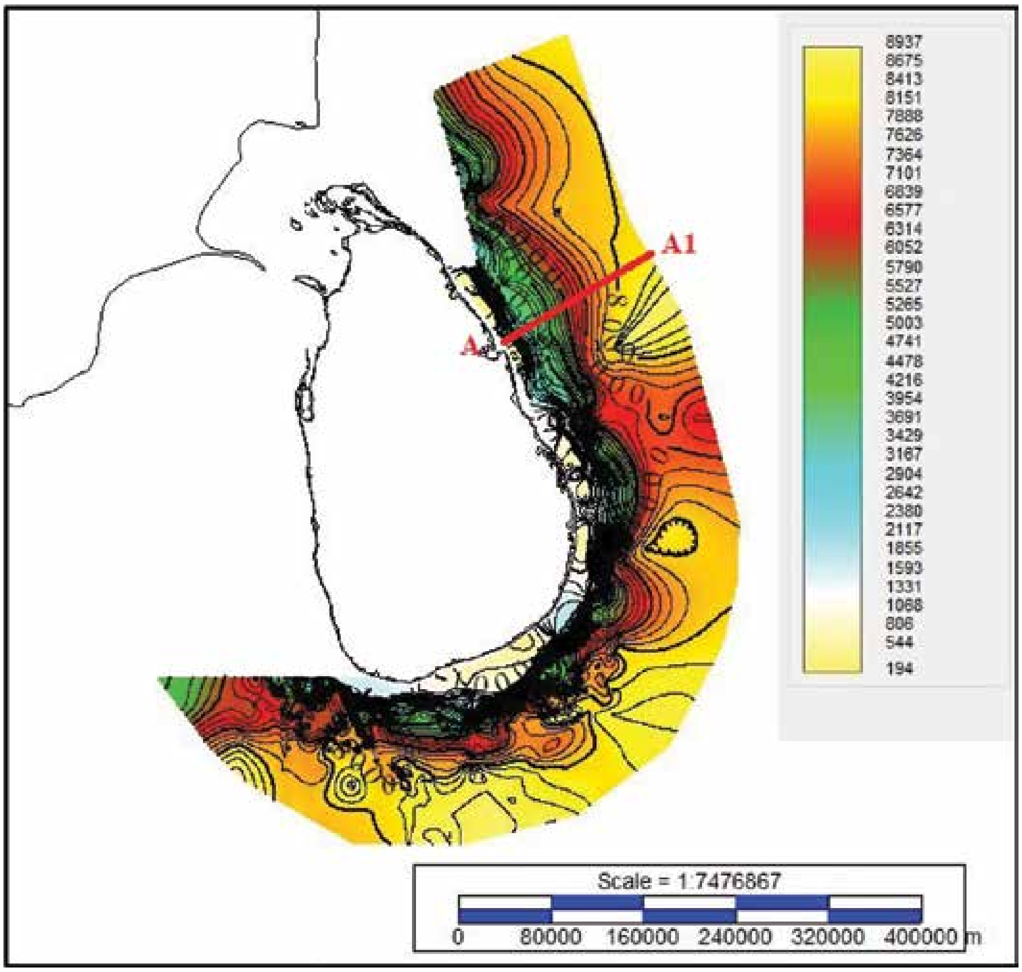

Figure 2. Sedimentary Thickness map of Lanka Basin (Silva et al., 2018)

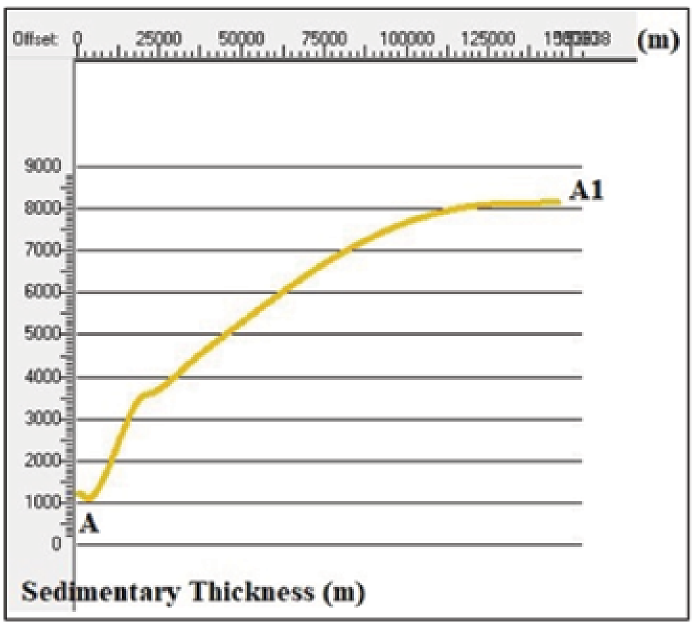

Figure 3. Sedimentary thickness along the line A-A1 (Silva et al., 2018)

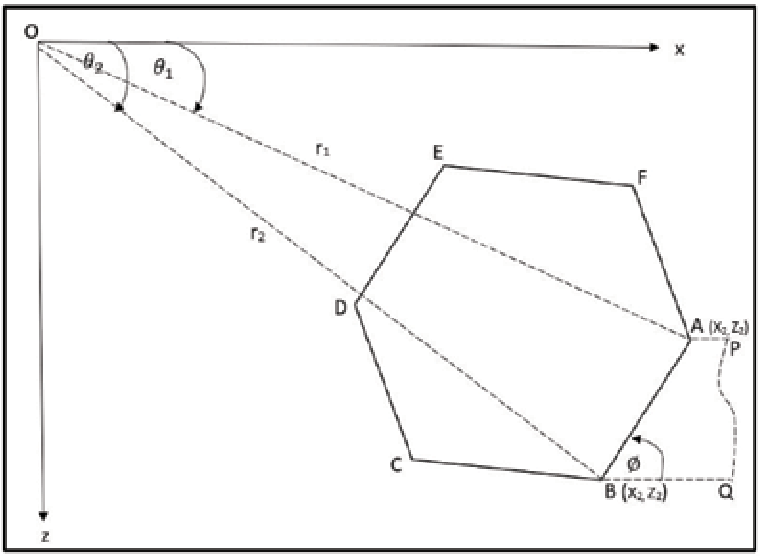

Figure 4. Geometrical elements involved in the gravitational attraction of an n-sided polygon (modified after Talwani et al., (1959))

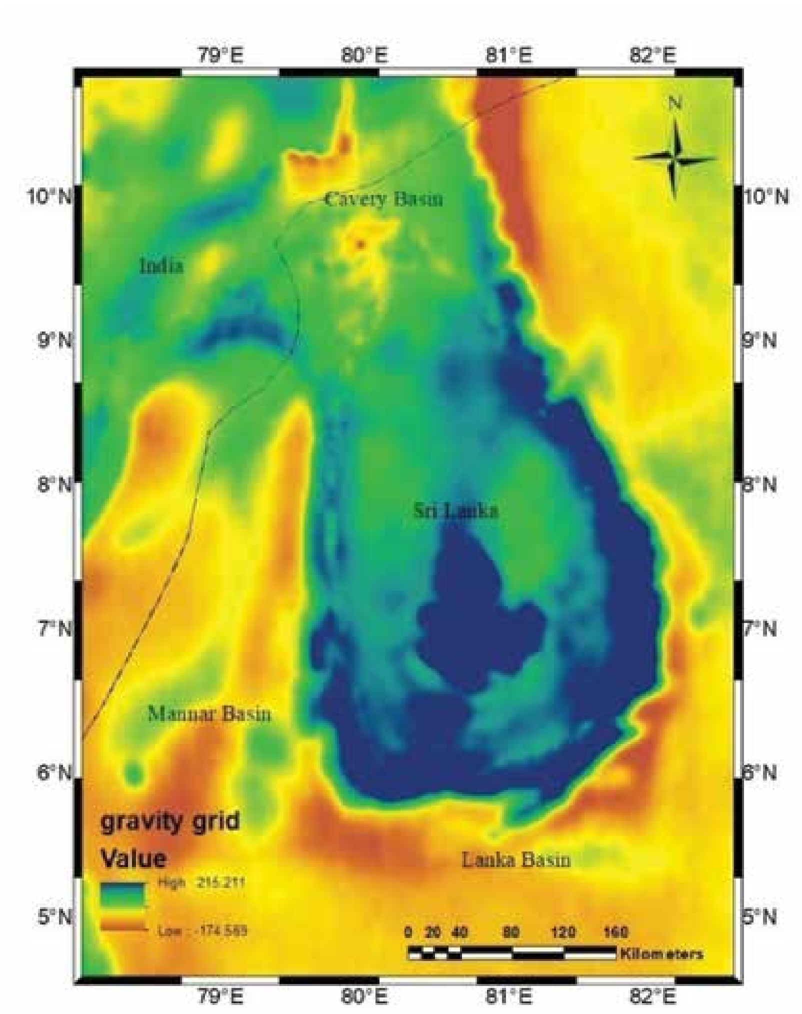

Figure 5. Gravity image map of Sri Lanka and its surrounding regions (WGS 1984)

Table 1. Summary of the densities of subsurface layers

Layer	Average Density(g/cm^3)
Water Column	1.03
Sedimentary Column	2.40
Average crust density	2.65-2.8
Mantle density	3.2-3.4

Calculated gravity anomalies for each subsurface layer were added together. Addition was then subtracted from the observed free air gravity anomaly to obtain the residual gravity anomaly. The residual gravity anomaly was assumed to be caused by the upper mantle in this region as the gravity anomaly measurements are made relative to the crust/basement. Thereafter, a model for the upper mantle was produced with the trial and error approach, such that the gravity anomaly calculated for the model with a suitable density contrast between the upper mantle and the basement, matched with the residual gravity anomaly of the upper mantle. Furthermore, the summation of all the calculated gravity anomalies including that by the model of the upper mantle was compared with the observed free air gravity anomaly. The subsurface horizons and the model of the upper mantle were combined together to represent the lithological and structural arrangement of the subsurface of the Lanka basin.

RESULTS AND DISCUSSION

Gravity profile along the section A1-A is shown in Figure 6. Along this profile, two crustal Models, A and B, have been generated, as discussed below.

(i) Model A

The gravity anomalies calculated using the mathematical program for each subsurface layer is shown from figures 7.1-7.5 for the Model A. Besides, the computed gravity anomalies and corresponding subsurface structure in the Lanka basin in case of model A, that also depicts the depth to the Mohorovićič discontinuity is, are shown in Figure 8.

(ii) Model B

Similarly, the observed free air gravity anomaly and the derived shallow structure along the Profile A1-A, in case of Model B, is shown in below.

From the two models proposed in the study, model A seems to be more realistic than the model B. Density contrast of the model A was set at 0.60 g/cm^3.The average thickness of the crust in model A came to be around 4.5 km. The value of 3.38 g/cm^3 for density of the upper mantle in the oceanic region is considered appropriate. Density contrast in model B was set at 0.55g/cm^3. In model B, crustal thickness was found to be about 7 km in most of the region which was rather unrealistic. Therefore model A is

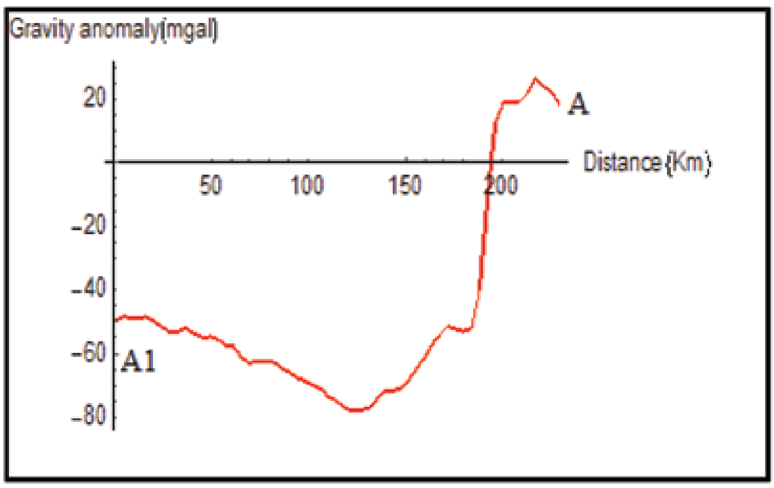

Figure 6. Observed gravity anomaly along the section A1-A.

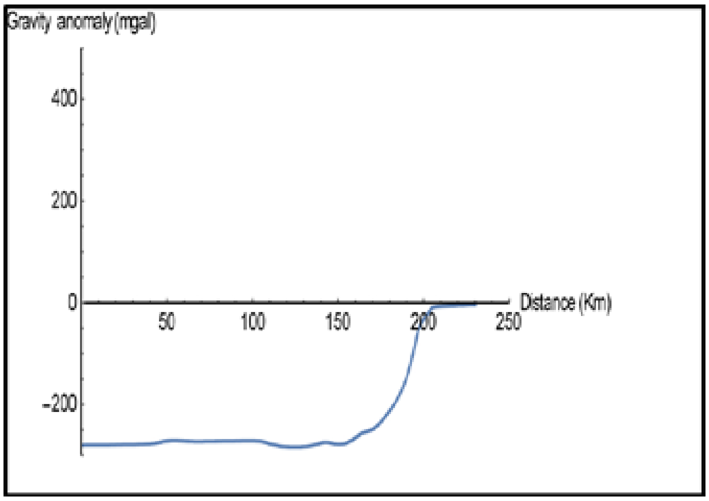

Figure 7.1. Gravity anomaly caused by water column

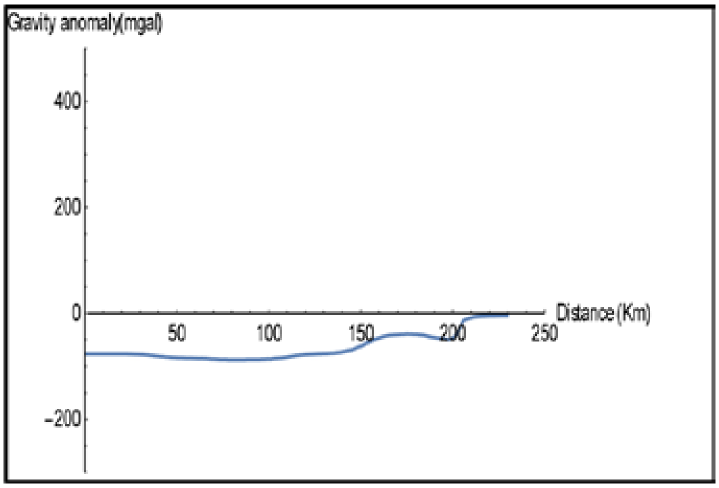

Figure 7.2. Gravity anomaly caused by Sedimentary column

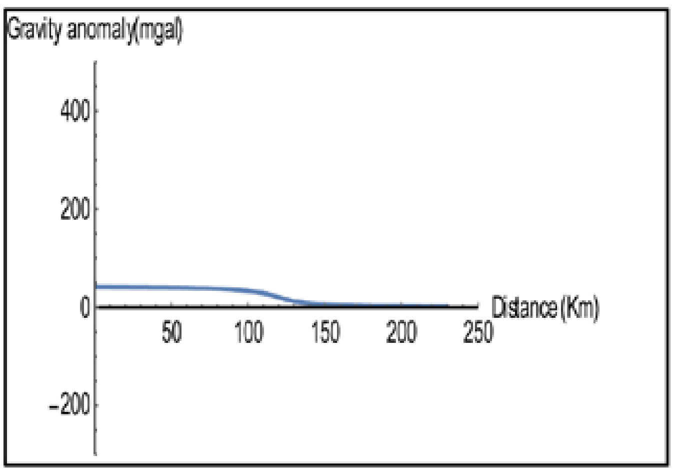

Figure 7.3. Gravity anomaly caused by crust column 1

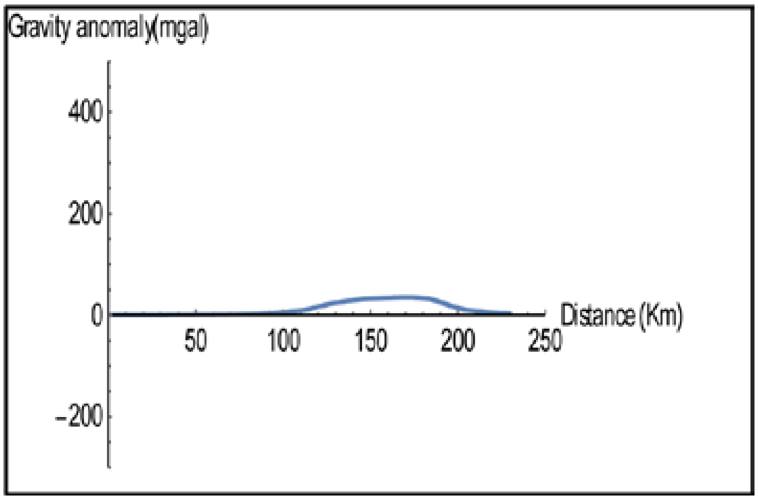

Figure 7.4. Gravity anomaly caused by crust column 2

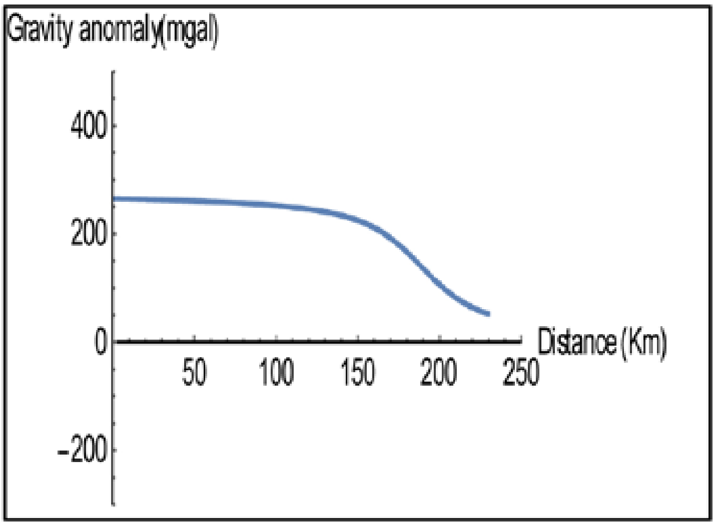

Figure 7.5. Gravity anomaly caused by mantle column.

more acceptable than the model B. The weight of overlying rocks would have cause an increase in the density of the basement rocks at greater depths. Values for the average density of basement lies between 2.6 g/cm^3 and 2.8 g/cm^3 which could be higher in the far oceanic region. In this study, we use the average densities. However, in the reality, there could be lateral density variations in the subsurface layers that yield localized gravity anomalies in the gravity anomaly profiles. This issue could have been minimized, if the densities of subsurface rock layers were available from several exploratory wells along the profile. Since the exploratory wells were not available, such localized gravity anomalies were assumed to be negligible. The horizontal components of gravitational acceleration as assumed to be negligible in this study, since it has a very minimum influence compared with the vertical component.

It can be observed from model A, that the calculated gravity anomaly and the observed free air gravity anomaly show a drastic difference at the distances between 200 km and 250 km (Figure 8(a)). At those distances, the landmasses of Sri Lanka was emerging from the sea and therefore, Bouguer gravity anomaly has to be used instead of free air gravity anomaly in such regions. Since the study was highly focused on the region occupied by the anomalous gravity which was overlain by oceanic water, free air gravity anomaly was better suited for those regions.

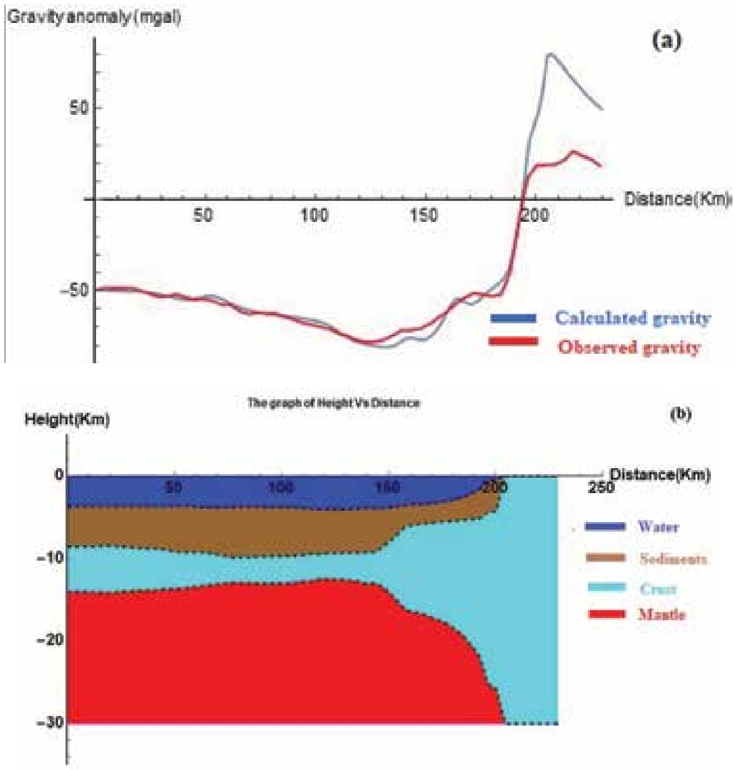

Figure 8. (a) Comparison between the observed free air gravity anomaly and the calculated gravity anomaly along the Profile A1-A for the Model A, using the densities of basement and mantle as 2.78g/cm³ and 3.38g/cm³ respectively. (b) Derived shallow structure in Model A.

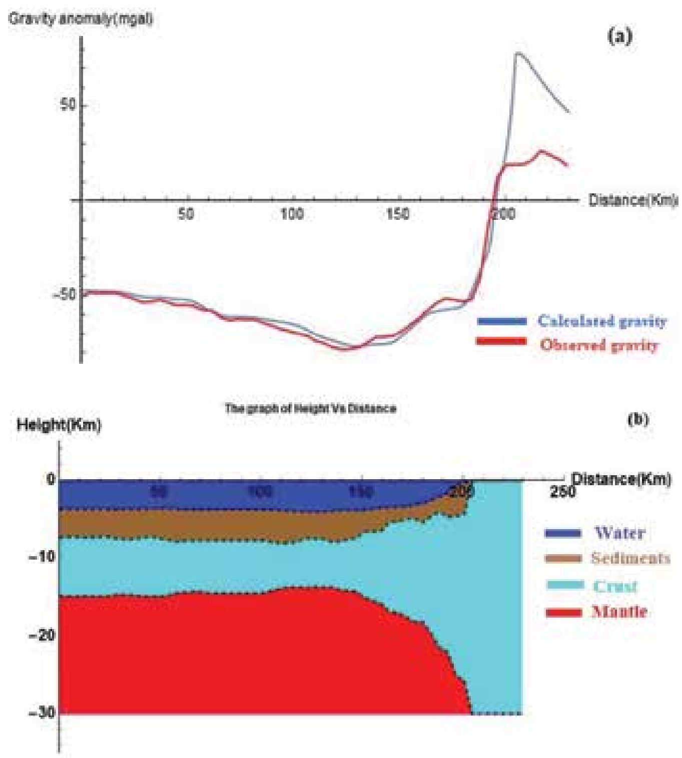

Figure 9. (a) Comparison between the observed free air gravity anomaly and the calculated gravity anomaly along the profile A1-A for the Model B, using the densities of basement and the mantle as 2.75 g/cm³ and 3.3 g/cm³. (b) Derived shallow structure in Model B.

CONCLUSIONS

Observing the structure of the Mohorovićič discontinuity and the sedimentary thickness, the primary conclusion that can be made is that off shore north eastern area are in rich in sediments accumulation, with average thickness around 6-8 Km. The Mohorovićič discontinuity below the water surface was found to be around 12-14 km along the A-A1 line, with an average crustal thickness of about 4.5 km.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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