Subduction Tectonics and its Gravity and Magnetic response in Andaman Sea

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Summary

The convergent Andaman basin, India in the southeastern part of Bay of Bengal is a part of a large island-arc system. It has long been an exploration target because of the established gas fields in the Irrawady delta system in Myanmar in the north and in the tertiary basins of Sumatra in the south in the same island-arc system.

In the present study, gravity and magnetic data in three contiguous deepwater blocks in the basin have been processed followed by integrated interpretation for basement configuration. For having an idea of various subduction related tectonic elements in the area, satellite gravity data too, have been used. Based on gravity data, the study area can be divided into two major parts, the low in the west and the high in the east, separated by a set of dense contour corresponding to the west Andaman fault. The western low corresponds to the forearc low and the high in the east is related to the volcanic arc.

Higher anomaly and high frequency features in the east suggest thinner crust and presence of volcanics. Modeling shows that the basement in the area, particularly in the lows in the western flank of the forearc is much deeper than what is apparent from seismic data. These lows filled with thick sediments are likely to be good source areas. All the wells in the basin lie either on a fault zone or to the west of the fault while the lows are in the east of the fault. This fault system has possibly hindered westward migration of hydrocarbons generated in the lows. Considering the source potential of the lows, structurally favorable locations between the lows but to the east of the fault are prospective locations.

Introduction

The convergent Andaman basin, in the southeastern part of Bay of Bengal (figure 1), is a part of major island-arc system. It evolved as a result of subduction of the Indian plate underneath the southeast Asian plate following the break up of Gondwanaland in the early Cretaceous. The basin has an area of about 50,000 km² with a thick sedimentary cover ranging in age from Cretaceous to recent. Exploration in the basin, hitherto a poorly understood marginal sea received a fillip because of the established gas fields in the Irrawady delta system in Myanmar to the north and in the tertiary basins of Sumatra to the south in the same Island-arc system. Considerable volume of geophysical data including seismic and gravity and magnetic data have been acquired in the basin. Fifteen wells have been drilled in the basin so far in one of which gas flowed. Also, presence of gas in middle Miocene is indicated in several wells.

Figure 1. Location map of the area. Study area.

The present study area comprises three contiguous deepwater blocks covering an area of about 22,000 km². Bathymetry in the area ranges from 200 meter to 2000 meter. The major portion of the blocks are confined to the volcanic arc, only small parts of two blocks fall in the east of the forearc basin adjoining the Andaman-Nicobar
GM data in Andaman Sea

island chain. About 7000 LKM of gravity and magnetic data have been acquired in the blocks. There is no well in the study area. IGRF 2005 has been used for magnetic data. For diurnal correction, data recorded at Pondicherry observatory of IIG have been used. The present study deals with processing and analysis of gravity and magnetic data, and integrated modeling for basement configuration and exploration leads.

Geologic set up

Andaman basin in the north eastern part of Indian Ocean is a part of the Island-arc system associated with the convergent plate boundary between the Indian plate subducting under the southeast Asian plate along Sunda arc. Trace of subduction is present in the Ophiolite exposure in the western boundary of Andaman- Nicobor ridge (Curry, 1979). The basin extends from Myanmar in the north to Sumatra in the south and from Malay peninsula in the east to Andaman- Nicobor ridge in the west. The Burmese and the Andaman arc together constitute a long continuous tectonic belt which links the eastern Himalayan collision zone in the north to the Indonesian arc in the south through the Sunda arc (figure 2).

Andaman arc is linked to the western Pacific arc system through the Sunda arc forming a long chain of island-arc system (figure 3). There was considerable variation in the speed and direction of convergence between the Indian and southeast Asian plates. Oblique subduction, volcanism and other factors have added to the tectonic complexities of the area. The western part of the area with N-S trending faults and arc parallel seamount chain is more complex compared to the eastern part.
The magmatic arc in the area runs roughly north-south in a curvilinear fashion to the east of the accretionary prism. Following the definition that the forearc is the area between the volcanic arc and the outer edge oceanic trench (Dickinson and Seely, 1979), the area to the west of the volcanic arc has been taken as the forearc basin. Considering the volcanic Narcondam and Barren islands to be part of the present day volcanic arc, Raju (2005) placed the back-arc basin to the east of the Narcondam-Barren islands chain. Alcock and Sewell seamount complexes are two major morphological features in the area. These two seamounts are considered to be part of a single complex which was split into two by a phase of rifting during Miocene (Raju, 2005). Andamann-Nicobor ridge is filled with Bengal fan sediments sourced from the subducting Indian plate and is overlain by autochthonous shallow water forearc sediments (Curray, 1978). The structural style in the western part of the forearc basin has been interpreted to be caused by shale tectonics and wrench movements leading to a series of structural highs and intervening lows adjoining the Andaman-Nicobor island chain.

Gravity and magnetic anomaly data

Gravity anomaly map: Only a few subduction related tectonic elements are seen in ship-borne gravity data because most of the covered area is confined to the forearc and volcanic arc. Free air anomaly map of the area is shown in figure 6. A prominent feature in the map is the significant rise in anomaly value from about -150 mGal.
in the east (forearc) to about +116 mGal in the west (volcanic arc). The two areas are separated by West Andaman fault (WAF). Large positive gravity anomaly in the east indicates emplacement of large amount of volcanics and probable oceanic crust as identified by Curray et al (1978). However, low gravity (about - 160 mGal) in the west indicates a huge pile of sediments and possible continental crust. The major features in the ship-borne gravity anomaly map are:

- A set of dense west dipping contours trending NNE-SSW corresponding to WAF, which takes a sharp U-turn towards west in the west of the active Barren island volcano and then regains the trend to continue northward and turn to NE in the northern end of the working area.

- A chain of dominantly N-S trending highs of small areal extent associated with the volcanic islands and lows of small areal extent to its east with axis roughly parallel to the volcanic island chain.

- Three lows marked as L1, L2 and L3 and a low trend further south from north to south in the west of the forearc.

- A prominent break in the volcanic high axis with shift towards west in the west of Barren island in the southern part of the area. This, together with the westward turn of the contours associated with the WAF and change in the trends of the lows, i.e, from mainly N-S for the low L2 to NE-SW for the low L3 suggest strike-slip movement.

**Satellite altimeter derived gravity data:**

Satellite altimeter derived free air anomaly data (figure 7), covering larger area, shows following prominent features.

- A gravity high on the accretionary prism to the west of WAF and a low to the west of the prism corresponding to the trench.

- Prominent gravity high with characteristic high frequency feature of volcanic arc to the east of the forearc low.

- Large amplitude highs having small areal extent for the intrusives and seamounts.

- A linear NE-SW trending low trend related to Andaman rift which separates Alcock and Sewell seamounts. This trend changes to north-south both in the north and in the south.

- A roughly north-south trending low in the backarc related to the deep terrace to the west of Alcock and Sewell seamount complex and an area of positive gravity anomaly value to its east.

A chain of lows of small areal extent with axis roughly parallel to WAF is seen in the western flank of the forearc in satellite altimeter derived gravity anomaly map. This forms part of the basin interpreted as ponded fill basin.
GM data in Andaman Sea

Figure 7. Satellite altimetry derived free air anomaly map of Andaman basin and adjoining area. Explanation: AP - Accretionary prism, FA - Forearc, VA - Volcanic arc, SS - Sewell seamount, AS - Alcock Seamount, ASR - Andaman sea rift. Outline of the blocks under study is shown in black.

Magnetic anomaly data: Magnetic anomaly map of the area is shown in figure 8. The imprint of volcanism is well developed in the eastern part of the area. The other major features are discussed below.

- Most of the high frequency features in the magnetic anomaly data show strong correlation with features in seismic data (figure 9) and they show reverse magnetisation.

- A well developed low in the northwestern part of the area, but the prominent gravity lows L1 and L2 are not resolved in magnetic data but seen together as a comparatively broader low.

Modelling approach: Two major gravity features in the area as already discussed are a low in the west and a sharp rising trend towards the east. Gravity modeling has been done keeping in view these gravity features. The sharp drop in gravity value (from about 25 mGal to -160 mGal) in the
Based on these, a depth section was prepared by extending the model obtained from seismic data along the line A1 beyond the subduction trench in the west and into the backarc in the east. The part of the depth section from 0 km to about 250 km is largely constrained by seismic data. Result of gravity modeling is shown in figure 10. The depth model has fairly reproduced the main observed satellite gravity anomaly features which are:

- The low to the west associated with Andaman-Sunda trench and another low for the forearc about 300 km east of the inner trench. These two lows are separated by the high related to Andaman-Nicobor ridge.

- Typical gravity response of volcanic arc with intrusives and seamounts in the eastern part of the model.

- High frequency- high amplitude features of intrusives.

Taking cue from the modeling of the above profile, modeling of ship-borne gravity data has been done along a number of E-W seismic profiles with initial depth model based on seismic data. Results of modeling along the line...
GM data in Andaman Sea

B1 in the north and C1 in the south are shown in figure 11 and 12, respectively. For most of the lines, modeling shows that the basement is deeper in the lows in the west of WAF than what it appears from seismic data. The extra sediment obtained from gravity modeling is shown in yellow underlying the sedimentary column interpreted from seismic data marked in green.

The depth models obtained by gravity modeling have reproduced fairly well the main tectonic and physiographic features in the area. The estimated maximum sedimentary thickness in the forearc is about 11 km. Sedimentary thickness in the low ranges from 8 km to 10 km in the north while it is 8 km to 9 km in the south. The eastern part of the area is characterised by volcanic plugs and thick basalts with a veneer of sediments. Thickness of the sediments overlying the basalt ranges from 1 km to 2 km in the lows in the east.

Figure 11. Modeling along profile B1.

Figure 12. Gravity modeling along profile C1.

Exploration leads from GM data

The lows with thick column of sediments in the western flank of the forearc are likely to be good source area for hydrocarbons. Gas shows in quite a few wells just outside the study area (in the west) indeed, lends credence to the generation potential of the lows. Incidentally, all the wells in the area lie either in a fault zone or to the west of the fault (figure 7) which has possibly been a barrier for westward migration of hydrocarbons generated in the lows. The lows lie to the east of the fault.

Considering the source potential of the lows, structurally favourable locations between the lows but to the east of the fault zone will be interesting. One such location is the saddle like structure between the lows L1 and L2 where antiformal closure in the Neogene sediments is seen in seismic data.

Conclusion

- Gravity modeling has reproduced fairly well the subduction related tectonic elements in the area with good quantitative agreement between observed and computed gravity values.
- The basement is much deeper than what it appears to be from seismic data, particularly in the lows in the western part of the forearc.
- Western flank of the forearc low holds thick sedimentary column. Sedimentary thickness in the
GM data in Andaman Sea

- Sedimentary thickness in the north ranges from 9 km to 11 km. Sedimentary thickness in the other lows is in the range of 8 - 10 km.

- Eastern part of the area is characteristic of a volcanic arc. There are a few lows in the east where the thickness of sediments overlying the volcanics ranges from 1 km to 2 km.

- The crust thins considerably towards east of WAF but it is not possible to infer about the nature of the crust because of presence of intrusives and volcanics.

References


Acknowledgement

The authors are grateful to Oil and Natural Gas Corporation Limited for permission to present and publish this paper.