Detection of major geological structures in the Eastern offshore of India using Geosat altimeter data

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Satellite altimetry can be used to infer subsurface geological structures analogous to gravity anomaly maps generated through ship-borne survey. The Eastern offshore was taken up for analysis using Geosat Exact Repeat Mission (ERM) altimeter data. A methodology is developed to use altimeter data as an aid to offshore hydrocarbon exploration. Processing of altimeter data involves corrections for various atmospheric and oceanographic effects, stacking and averaging of repeat passes, cross-over correction, removal of deeper earth and bathymetric effects, spectral analysis and conversion into free-air gravity anomaly. The final processed results were derived for Eastern offshore in the form of prospecting geoid and gravity anomaly maps and their spectral components. The highs and lows observed in those maps were derived in terms of a number of prominent megastructures e.g., gravity linears, 85° and 90° ridges, the Andaman trench complex etc. Satellite-derived gravity profiles along 12°N latitude match well with the existing structures.

1. Introduction

Offshore sedimentary basins surrounding India have not been sufficiently explored despite the fact that they contain large scale hydrocarbon resources (Biswas 1982; Zutshi et al 1987). Remote sensing has always played a vital role as a reconnaissance tool for hydrocarbon-bearing structure exploration on land using data in optical/thermal IR and microwave regions (Mitra et al 1984). However, conventional remote sensing has not been of much use for offshore oil exploration. In recent years satellite altimetry has emerged as an efficient alternative for much expensive and hazardous ship-borne gravity survey (Stewart 1985). A satellite altimeter measures the height of the satellite above the instantaneous sea surface with a good precision (∼10 cm for Geosat). Precise satellite orbit computations are used to derive the height of the sea surface with respect to a reference ellipsoid, called sea surface height (SSH) (Fu et al 1988). NASA Geosat (Geodetic satellite) launched in 1985 was used to measure SSH between 72°N and 72°S latitudes. SSH measured by Geosat is corrected for various atmospheric and oceanographic effects on the basis of parameters provided in the Geosat Geophysical Data Record (GDR) (Wakker et al 1988). The corrected SSH obtained using Geosat Exact Repeat Mission (ERM) data for a period of one year is averaged to minimize the effects of dynamic sea surface topography which is mainly due to currents, eddies etc. This averaged SSH is a good approximation to the classical geoid, which contains information regarding mass distribution in the entire earth. The anomalies (highs and lows) in geoidal surface are directly interpreted in terms of subsurface geological features e.g., transform faults, basement highs and lows etc. The geoidal anomalies also are converted to free-air gravity anomalies which are particularly useful in deep sea where traditional ship-borne geophysical data are either unavailable or scanty. In the eastern offshore, India, regional crustal features e.g., the 85°E ridge, the Central Basin, the 90°E ridge, the Sunda Arc and the Andaman shelf etc., have been well defined from ship-borne geophysical

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2. Objectives of the study

- Assessment of potential and limitations of altimeter-derived gravity anomaly as an alternative to ship-borne gravity survey for offshore hydrocarbon-bearing structures exploration.
- Development of Satellite Gravity Method for offshore oil exploration, and generation of prospecting geoid and free-air gravity anomaly maps over the eastern offshore beyond 200 m isobath.
- Interpretation of altimeter-derived gravity and prospecting geoidal maps for the delineation of potential offshore hydrocarbon-bearing structures in the eastern offshore basins for utilization by Oil & Natural Gas Corporation (ONGC), India.

3. Data sources and area of study

Data for the area of interest (latitudes: 6°–22°N and longitudes: 77°–100°E) are available from Geosat ERM. Size of the footprint along the satellite tracks is 6.7 km, however, the cross-track data gap is approximately 150 km at the equator. Geophysical Data Record (GDR) details are given elsewhere (Cheney et al. 1987). Bathymetry data used have been obtained from Naval Hydrographic Charts (Survey of India, Dehradun) whereas other ship-borne geophysical data e.g., gravity, sediment thickness etc., were collected by ONGC (Dehradun). Geosat data collected over a period of one year have been used in this study.

4. Methodology

Geoid is an equipotential surface approximating to the mean sea surface over the ocean. Geoid contains more information regarding mass distribution inside the earth than the gravity alone since gravity only represents the first derivative of the geopotential (Lundgren and Nordin 1988). SSH observations, when averaged, minimize the effects due to dynamic sea surface topography particularly in regions with seasonally varying currents, such as, the Bay of Bengal (Stewart 1985). The contributions in geoid can be broadly divided into three categories (Lundgren and Nordin 1988; Majumdar et al. 1994), namely, a) bathymetric contribution, b) lithospheric contribution, and c) contribution due to deeper earth.

Bathymetry data along the satellite track obtained from Naval Hydrographic Charts (available from Survey of India) are used to model geoidal contribution due to bathymetry and then removing the effects due to bathymetric anomaly. The contributions due to deeper earth are removed using GEM 10B geopotential model expanded up to degree and order 50 (Rapp 1981, 1982). The residual geoidal undulation obtained after removing the contributions due to
bathymetry and deeper earth is known as prospecting geoid which corresponds to the mass distribution in the lithosphere. This prospecting geoid is useful in delineating offshore hydrocarbon-bearing structures (Majumdar et al. 1994).

4.1 Computation of free-air gravity

The fundamental relations useful for conversion of geoid to free-air gravity anomaly can be derived on the basis of the Brun’s formula and the equation of the Physical Geodesy (Moritz 1980): The free-air gravity anomaly can be obtained from geoid using the relation (Chapman 1979):

$$ F(\Delta g) = g_0 |k| F(N), $$

where,

- $F(\Delta g)$ = Fourier transform of free-air gravity anomaly,
- $F(N)$ = Fourier transform of geoid undulation,
- $|k|$ = one-dimensional wave number associated with wavelength $\lambda$,
- $g_0$ = normal gravity.

Different components of the prospecting geoid and free-air gravity anomaly have been obtained using spectral analysis through Fourier transform. Long, medium and short wavelength components extracted in this process can be related with different geological structures.

After removing the effects due to bathymetry and associated isostatic effects, the remaining effects of the sea surface are caused mainly due to mass variations within the earth. The prospecting geoid, thus obtained, contains long as well as short wavelength components (Lundgren and Nordin 1988; Majumdar et al. 1994):

- Long wavelength component (100–400 km) – it mainly reflects crustal events of regional proportions.
- Intermediate wavelength component (50–100 km) – it investigates shallower occurrences. These undulations can give information regarding development of regional depressions and tectonic trend.
- Short wavelength component (15–50 km) – these undulations are more closely related to basement topography and overlying sedimentary cover.

![Figure 1. Prospecting geoid contour map over the Bay of Bengal.](image-url)
5. Results and discussion

5.1 Prospecting geoid contour map

The prospecting geoid anomaly map over the study area, after removal of bathymetry and deeper earth effects, is shown in figure 1. Contours as such do not follow any particular trend. Various lows and highs with northward increasing magnitude were observed. Low axis in the center may represent the distributary channels for sedimentary deposition. Lows near the Bay of Bengal and the Andaman islands represent greater sedimentary thicknesses in the Bengal foredeep and the Andaman trenches.

The geoidal/gravity high in the east of the major low is due to the Ninety East ridge. The high zone in the west of the low corresponds to continental margin high. The Ninety East ridge seems to have been disseminated by a number of NE-SW trending faults which are also supported by bathymetric features. The continental margin is made up of two major faults. One in N-S trend from east of Jaffna to the Krishna river in the southern part of India and the other is in NE-SW trend from the Godavari offshore to the latitudes of Puri (Srivastava et al 1994). Seismic profiles by Curray et al (1982) also show that 90°E ridge is a basement feature.

5.2 Long wavelength (100–400 km) prospecting geoid undulation

Figure 2 shows the longer wavelength prospecting geoid information in the wavelength range 100–400 km. A marked difference in the contour trends is observed in the E-W orientation. The values are ranging from 15 m to −15 m and, in general, the values north of 10°N latitude are observed as negative and south to 10°N as positive representing northward down buckling of oceanic crust. Near the 90°E ridge, geoidal high was observed. Lineaments based on contour gradients are marked and prominent trends are E-W, NE-SW, NW-SE, and NNW-SSE. These trends indicate inhomogeneities in the earth's crust.

5.3 Satellite-derived gravity

Figure 3 shows a profile of satellite (Geosat)-derived gravity across 90°E ridge at latitude 12°N. Continental slope as well as 85°E and 90°E ridges could be
Eastern offshore megastructures from Geosat altimeter data

50.00
0.00
-50.00
-100.00
77.00 82.00 86.00 90.00 94.00 Longitude (E)

Figure 3. Schematic free-air gravity (from Geosat) across the Bay of Bengal (Latitude: 12°N).

demarcated well along the profile (Curray et al 1982; Liu et al 1982).

6. Conclusions

From the above study, the following conclusions could be made:

- The satellite altimeter is found to be quite useful as a quick and inexpensive reconnaissance tool for mapping the megastructures in the poorly explored eastern offshore region of India.
- Geoid undulation and gravity anomaly contour maps indicate the presence of a number of highs and lows in the area of study.
- The Ninety East Ridge is observed as high in gravity as well as in the prospecting geoidal maps.
- A chain of lows was observed near the east coast of India corresponding to offshore extension of five major east coast basins. This is bounded by NE-SW trending linears which appear to be a linear fault zone.
- E-W, N-S, NE-SW, and NW-SE gravity linears are prominent in the entire Bay of Bengal and East continental margin of India.

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