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Mapping of Subsurface Lithology Using Magnetic Data

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Summary

Geopotential surveys maybe considered as methods of Remote Sensing which can detect rock properties at a distance; information about the subsurface is masked in regions covered with Alluvium, Traps, water, Salt, Grassyland, and the like, and Magnetic Data can play a key role in resolving this issue. The data can be collected on different platforms: ground, marine or space borne instruments. In the current paper magnetic data collected using marine / ground and airborne data over three different environments are utilized to map the subsurface structure and lithology, for understanding the tectonics, seismic related information and structures prospective for hydrocarbon exploration are presented:

1) Marine magnetic data along six profiles cutting the 85 E ridge is modeled to construct the structure of the Ridge. The model incorporating seafloor spreading anomalies is constrained using Bathymetry, isopach, available seismic information and Free air gravity anomalies. The results of these models will be interpreted in terms of the evolution of the 85^0*E Ridge.*

2) Analysis of semi-detailed High Resolution Aeromagnetic data over Kutch reveals that the epicenter of the main shock of Bhuj earthquake sits on the intersection of three subsurface faults and those of the aftershocks fall on NW-SE and NE-SW faults emanating from the main epicenter; the V shaped NW-SE and NE-SW faults are related to the directional change of the compressional forces on either side of the Bhuj epicenter, as seen in the GPS data.

3) Magnetic data over a hydrocarbon bearing sedimentary basin is analysed to map the basement and subsurface intrusives. The magnetic data along available seismic profiles are analysed to identify the depth and thickness of the intrusives and help interpret the reflections seen on the seismic sections. By integrating gravity, magnetic, seismic and well data one can derive very valuable information of the basement geology that is important to understanding and evaluating hydrocarbon prospects.

Introduction

Exploration of the subsurface requires innovative techniques and the magnetic method offers an excellent opportunity to map the structure and lithology of the subsurface. The magnetic fields change when the physical properties like susceptibility and thickness of the subterranean rocks change. The magnetic data finds wide applications and is able to provide very valuable subsurface information. Modern high-resolution magnetometers are able to collect data with an accuracy of 0.001 nT; this coupled with the major strides made in the acquisition, processing and interpretation of aeromagnetic data has made it possible to use the magnetic method for identifying intra-sedimentary sources associated with hydrocarbons. Further, very large range in magnetic susceptibility values makes magnetic method a sensitive indicator of change and contributes to making the magnetic method a powerful tool for subsurface exploration. The magnetic data can be collected by ground / marine or airborne instruments. In the current paper three such case studies to map the subsurface lithology in different environments are presented.

Analysis of Marine Data to Study the Evolution of the 85 E Ridge

The Bay of Bengal (BOB) sedimentary basin is one of the largest offshore sedimentary basins of the world having the thickest accumulation of sediments which mask the underlying crust. Satellite derived Free Air Gravity (FAG) data, marine magnetic data, bathymetry, available seismic profiles and isopach maps over the Bay of Bengal are

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utilized to throw light on the nature and tectonics of the the 85°E Ridge (Anand et al, 2009). Combined analysis of gravity and magnetic data along six EW profiles of length varying from 325 to 440 km is undertaken, incorporating seafloor spreading anomalies in the model. The three-layer model of Kent et al (1993) is adopted to incorporate the sea floor spreading. The magnetic model has been generated without apriori idea of the polarity reversals; the polarities are determined through modeling. The final crustal model that reproduces the gravity and magnetic data in all the profiles, depict a very consistent reverse magnetization with thickening of the crust along 85^{o}E Ridge. Of the several theories put forth for the evolution of the 85°E Ridge, the present study supports the theory of the sagging of the crust (Shemenda, 1992) and rules out the hotspot trace and magmatic under-plating theories. With a combination of the crustal model derived from the magnetic profile analysis of the 85°E Ridge and the filtered FAG maps we find that the 85°E Ridge extends up to the Ocean Continent Boundary but thins out dramatically to the North of 15°N latitude. Analysis of gravity data along 17°N latitude profile predicts that in the northern segment the 85°E Ridge is a geo-morphological feature within the sediments above the basement whereas to the South of 15°N latitude it is a feature within the oceanic crust. Results of these models and its implication for the evolution of the 85 E Ridge will be presented.

Analysis of Aeromagnetic Data Over Seismically Active Kutch Rift Basin

The Bhuj earthquake of magnitude M_w = 7.6 was one of the most disastrous intra-plate earthquakes in recorded history. Although the earthquake caused massive liquefaction, there is no record of any surface rupture; generally such large magnitude earthquakes are associated with surface ruptures. Several Geophysical studies have been undertaken to understand this intra-plate earthquake in a region covered by Runn of Kutch (salt flats), Banni plains (grassland) and sediments. Here we analyze the recently acquired semi-detailed high resolution aeromagnetic (HRAM) data over the Kutch Rift Basin to look below the surface cover and identify tell tale signatures associated with the earthquake. This analysis (Blakely, 1995) is able to bring out signatures of several hitherto unknown faults and intrusives. A study of more than 500 aftershocks (M >2) show two trends: one in NE and other NW directions (Kayal and Mukhopadhyay, 2006). From our analysis we find that the epicenter of the main shock of Bhuj earthquake sits on the intersection of three subsurface faults identified from the Euler solutions of the HRAM data; the epicenters of aftershocks fall on the NW-SE and NE-SW faults emanating from the main epicenter and these are constrained to lie within an area defined by the faults identified from the aeromagnetic data. The V shaped NWSE and NE-SW faults are related to the directional change of the compressional forces on either side of the Bhuj epicenter, as seen in the GPS data (Reddy and Sunil, 2008). We conclude that these subsurface faults are reactivated by the Bhuj earthquake and result in subsurface ruptures. This is for the first time that the magnetic data has been able to decode the rupture information associated with an earthquake.

Analysis of Magnetic Data over a Hydrocarbon Bearing Basin

Magnetic data over a hydrocarbon bearing sedimentary basin is analysed to decipher the nature and source of the magnetic anomalies, calculate the depth to the basement, depth and extent of the intrusives and related information useful for hydrocarbon exploration. Stratigraphic section of a drilled well and some interpreted seismic sections were available over this Basin. The example shows how integrating gravity, magnetic, seismic and well data can provide much useful information of the basement geology that is important to understanding and evaluating hydrocarbon prospects. Several questions about the subsurface structures remained unanswered in the seismic interpretation especially questions like whether the reflections seen in the interpreted seismic sections represent intrusives. The depth and extent of the Magnetic sources / Intrusives are estimated using 2D Analytic signal (Nabighian, 1972) and Euler solutions over selected profiles. These are used to verify if the reflections seen on seismic sections are related to intrusives. Thus by integrating seismic data with magnetic data it is possible to resolve which of the reflections are due to intrusives. For a general idea of the distribution of intrusives, 3D Euler solutions (Reid et al, 1990) are calculated to identify the structure and extent of the sills / laccoliths in the entire basin. Also, basement depths were calculated using spectral depth estimates (Spector and Grant, 1970) over moving windows (Rajaram et al, 2009) and a basement depth map of the basin is generated. Modeling the gravity and magnetic data constrained by the seismic, well data and surface geology viable subsurface structure and lithology is determined and a crustal model of the Basin is developed. Results of this analysis will be presented.

Conclusions

Magnetic data collected using ground / marine and airborne probes over three different environments are utilized to map the subsurface. Analysis of the marine magnetic data over the 85 E Ridge constrained by Free Air Gravity, bathymetry, available seismic profiles and isopach maps could clearly bring out the evolution, structure and extent of the 85 E Ridge. Analysis of semi detailed HRAM data over the seismically active Kutch Rift Basin could show that the epicenter of the main shock of Bhuj earthquake sits on the intersection of three subsurface faults and these subsurface faults are reactivated by the Bhuj earthquake and result in subsurface ruptures. Analysis of magnetic data over a hydrocarbon bearing Basin is able to map the basement and identify the depth and extent of intrusives and identify which of the reflections seen on the seismic sections are related to intrusives. A crustal model of the Basin is developed incorporating all the available and derived information. Thus the magnetic data finds wide applications and is able to provide very valuable subsurface information.

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