Prospectivity Analysis of Ganga Valley Basin with NSP Data

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Abstract

Basin analysis is one of the most significant and complex tasks in the field of oil and gas exploration. Ganga valley basin is considered as a Category-III basin based on its prospectivity analysis of available seismic and well data. Therefore, there has been increased activity to acquire more seismic data under National Seismic Program (NSP) to further appraise this basin. Certain conditions must be met e.g., adequate sedimentary thickness, presence of source rocks; reservoir rocks with adequate porosity and permeability, traps (structural & stratigraphic), overlain by impermeable layer (cap rock or seal) within the basin. To estimate such conditions geophysical data such as seismic, gravity, magnetic are acquired and analyzed. Gravity and magnetic data are available over the entire basin. However, these potential field data must be modeled to understand basinal depth and the solution is non-unique. On the other hand, seismic data provides an image of the subsurface layers. Recently acquired 2D seismic data in the basin reveals areas of greater sedimentary thickness, and structural features which need to be analyzed further for Ganga valley basin prospectivity. Integrated geophysical studies helps to further enhance our understanding of the basin.

Introduction

Sedimentary basins are depressed or lowland areas in the Earth's crust. These basins formed due to tectonically induced long-term subsidence, in which sediments get accumulate into successions to considerable thickness during a particular period at a significantly greater rate, with the span of hundreds of millions of years by the cumulative effect of eroding material deposition, chemical precipitation, and organic material within the aquatic environment on a wide scale.

These basins play a significant role in the generation of hydrocarbon and accumulation, beneath the surface in different kinds of traps (basically structural & stratigraphic). The ultimate aim of explorationists is to determine these traps to estimate the possible presence of hydrocarbons and the extension of hydrocarbon-bearing rocks in a basin by the use of robust geophysical methods such as seismic, gravity, resistivity, etc.

The estimation of a vertical succession of rocks, either discovered by geophysical tools, by drilling a borehole, or evident in outcrop exposure, is the essential point for unraveling the history of a basin. A basic examination of the burial history is achievable if the rock type (lithologies), thickness, and ages have been adequately defined. Once the sequence stratigraphy and their ages have been appropriately recognized and the thickness set up, hydrocarbon investigation in the basinal formation is conceivable.

Basins are formed by plate tectonics, the process responsible for continental drift and they differ in origin and lithology. The Ganga valley basin is an example of a peripheral foreland sedimentary basin where oil and gas discoveries are still waiting for study. Therefore, this study is mainly focused on the Ganga valley basin which is a dominant component of the Indo Gangetic plain.

Study area

The present study accounts for the geophysical study in the Ganga basin in a view of hydrocarbon prospects. The east-west elongated Ganga basin is the largest Quaternary alluvium sedimentary terrain in the northern part of India. The basin, which is the major unit in the geology of the Indian subcontinent, was brought down by rivers draining the Himalayan range. The Ganga basin provides a present-day example of a peripheral active foreland basin (Sastri et al., 1971). This basin consists of a large, flat, monotonous sedimentary plain drained by the Ganga River and its several tributaries.

The basin extends over an area of 2,000 kilometers in length and 450 kilometers in width, covering an area of about 3,04,000 km^2. located within Long. 77° E and 88° E and Lat. 24° N and 30°N (Fig.1) (Shukla et al., 1994;Padhy & Das, 2013). It consists of alternate beds of sands and clays with intermittent calcareous poorly consolidated interbeds down to the bedrock. The course of the river in the Ganga basin is controlled by Himalayan tectonics (Sahu & Saha, 2014). The thickness of the Ganga alluvium has been estimated to be between 15 and 4.5 kilometers. According to Wadia (1957) and Krishnan (1968, 1982), beneath the alluvium, sedimentary formations of Paleozoic, Mesozoic, and Tertiary periods can be found, which is confirmed by Upper Proterozoic Vindhyan occurrences in Ujhani and Aligarh. Bundelkhand granite was reported at depths of 504 m and 2161 m at Kanpur and Ujhani, respectively. According to Sastri et al., (1971), the sediment thickness in the Ganga basin reaches 6 km along the northern boundary near the Himalayan foothills, decreasing gradually towards the south. Shallow depths in the basin are occupied by the presence of alternate layers of sand and clay with a few layers of Kankar in between until a depth of 360 m in Kasaganj (Ramachandra Rao, 1973). This thickness further grows towards Raxual in east Uttar Pradesh from 360 m to 700 m and further down to a thickness of about 1500 m. The presence of limestone was found at 620 m in Kasaganj, which further dip down and reaches a depth of 4000 m in Raxual (Sitharam et al., 2013). At some locations, Vindhyan sediments were also found at depths exceeding 4500 m. Sastri et al., (1971) highlighted the presence of younger sediments at a depth of 620 m in Kasaganj to a depth of 2000 m near Raxual.

The basement in the basin is characterized by multiple buried faults and ridges. The Delhi-Haridwar ridge, for example, is the Aravalli Mountains' expansion into the Himalayas via Haridwar. Faizabad ridge and Munger-Saharsa ridge represent the continuation of the Bundelkhand and Satpura massifs, respectively. Faults and tectonic extensions from the Indian shield run through all of these ridges. (Sinha et al., 2005).

Figure 1: Geological location of Ganga Basin (Source: DGH)

Tectonic Setting and Stratigraphy of the Study area

Ganga basin is one of the largest sedimentary basins of India located in the northern boundary of the Indian shield. In the east, basin is limited by subsurface Monghyr–Saharsa ridge and Delhi–Haridwar ridge in the west. In the north, it is bounded by the outermost Siwalik foothills of the Himalayas by the Himalayan Frontal fault (a series of reverse faults) which extends parallel to the Himalayas from west to east. The exposed Purana sediments or Vindhyan group and Bundelkhand granites/gneiss massif limit the basin in the south. Based on the study of Gravity-Magnetic, Aeromagnetic & seismic surveys, earlier researchers, structurally segmented the Basin into three important depressions namely Gandak, Sarda, and Madhubani depression (Fig.2). All these depressions are said to be separated from one another by interceding basement ridges.

The basin's stratigraphy includes the lowermost formation of the lower Vindhyan group, which is overlain by three units of the upper Vindhyan group. The Tertiary deposits are split into five formations, three of which are part of the Siwalik group. The Siwalik Group is a coarsening upward siliciclastic succession in the foreland basin that has the thickest concentration of debris sourced from the Himalayas. The deposits are continental and mostly indicate deposition in floodplains, meandering rivers, and braided rivers. Since the early 1900s, the Siwalik Group has been classified into Upper, Middle, and Lower Siwalik based on vertebrate fossil markers. The Lower Siwalik began to take shape around the Middle Miocene. It is distinguished by alternating sandstone and mudstone facies deposited in river and floodplain settings. From the upper Miocene through the Pliocene, the Middle Siwalik was deposited. Sandstone beds dominate this unit, interrupted by thin mudstone to siltstone horizons. The Upper Siwalik, which extends from the Pliocene to the Quaternary, is thought to be a sedimentary record of the last phase of Himalayan orogeny. In the upper layers of the Upper Siwalik, conglomerate facies predominate, with sandstone, mudstone, and conglomerate in the lower strata.

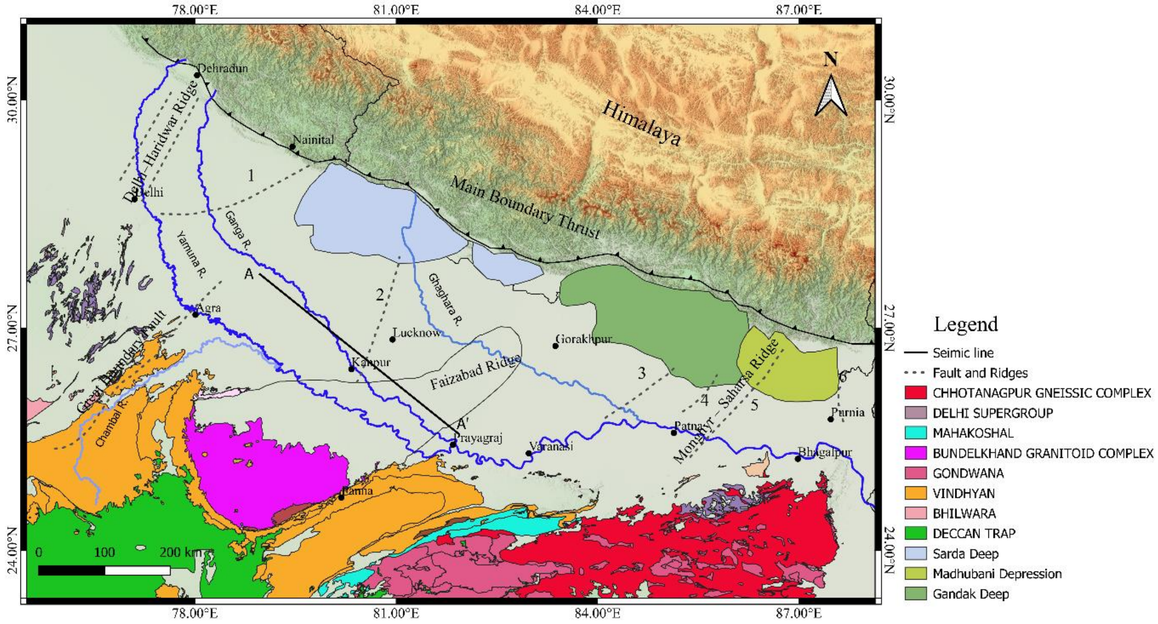

Figure 2:Map depicts lithology and tectonic structures of the Ganga basin; numbers represent the major subsurface faults identified by the use of geophysical methods. 1. Delhi Moradabad Fault, 2. Lucknow Fault, 3. West Patna Fault, 4. East Patna Fault, 5. Monghyre-Saharsa Ridge Fault, 6. Malda-Kishanganj Fault; R. River (modified from Sastri et al 1971; Rao 1973; Karunakaran and Ranga Rao 1979; Singh 2004; Sinha 2005;Srinivas et al., 2014).

Methodology

A 2D seismic line which was analyzed that was acquired under NSP. The data contain about 370 kilometers long seismic profile from NW to SE in the Ganga basin. The Bouguer gravity anomaly (BGA) data was downloaded from Bureau Gravimetrique International (BGI). Seismic section (AA') and Bouger gravity anomaly (BGA) data have been used to get information about the basement depth of the Ganga basin and its structural features. A Bouguer gravity anomaly map of the Ganga basin and its surrounding areas is created to have a general regional view of the basin (Fig.3). In this map, many notable gravity lows and highs are observed such as the Son Narmada fault, south Rewa basin, Bundelkhand craton, etc. in the southern part, whereas Chhotanagpur plateau in the east is prominent. But some other tectonic features such as Great Boundary fault, Moradabad fault, Patna fault, and Munger-Sahsara ridge are masked by low gravity in the basin. Gravity anomaly in the basin along the seismic line is ranging from -36 mGal to -214 mGal. According to some scholars, the low gravity is attributed to the gravitational influence of low-density sediments, and the Himalayas have no isostatic effect on it.

A residual gravity anomaly map was generated to highlight hidden gravity characteristics in the basin. Residual gravity anomaly map (Fig.4) is created by using a high pass filter of cut-off wavelength to look at the shallow subsurface feature. This map highlights several isolated gravity high and low zones in the basin. The residual gravity map brought out the extension of Faizabad ridge and Great boundary fault to the Himalayan orogeny. This map is also brought out several isolated gravity highs and lows features in the deeper part of the basin. Based on the gravity data few notable tectonic features are realigned accordingly in the map. Some of the tectonic features (fault and ridges) that can be correlatable on this map are Great Boundary Fault, Moradabad fault, Bundelkhand Faizabad ridge, Gandak Depression, Sharda Depression (Bahraich and Puranpur low), Madhubani Depression, Patna fault, and Narmada Son lineament.

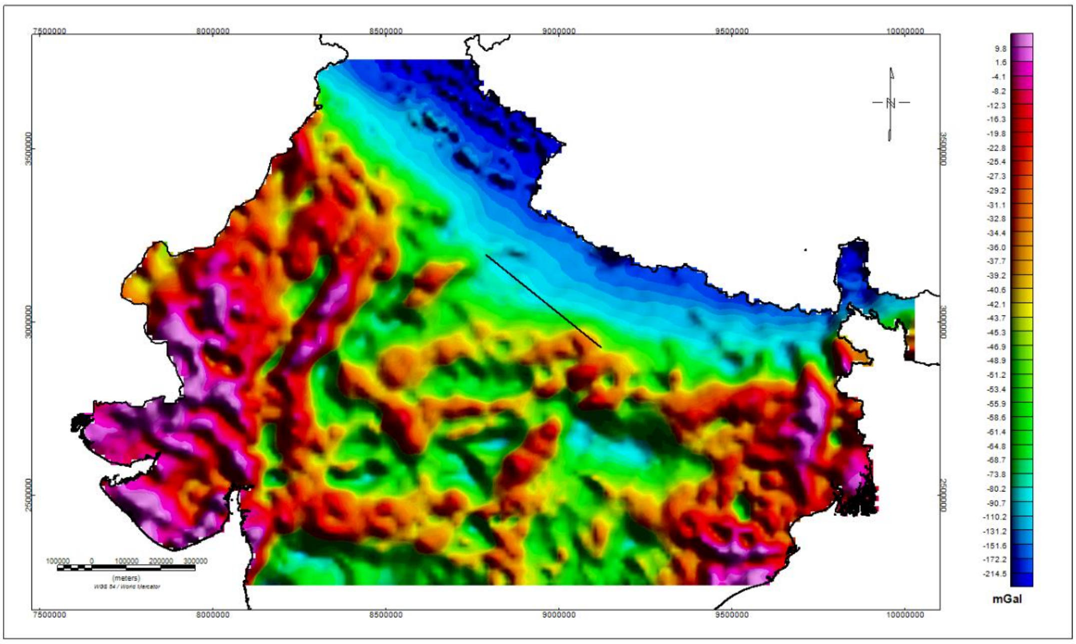

Figure 3: The map is showing the Bouguer gravity anomaly of Ganga basin and its surrounding areas.

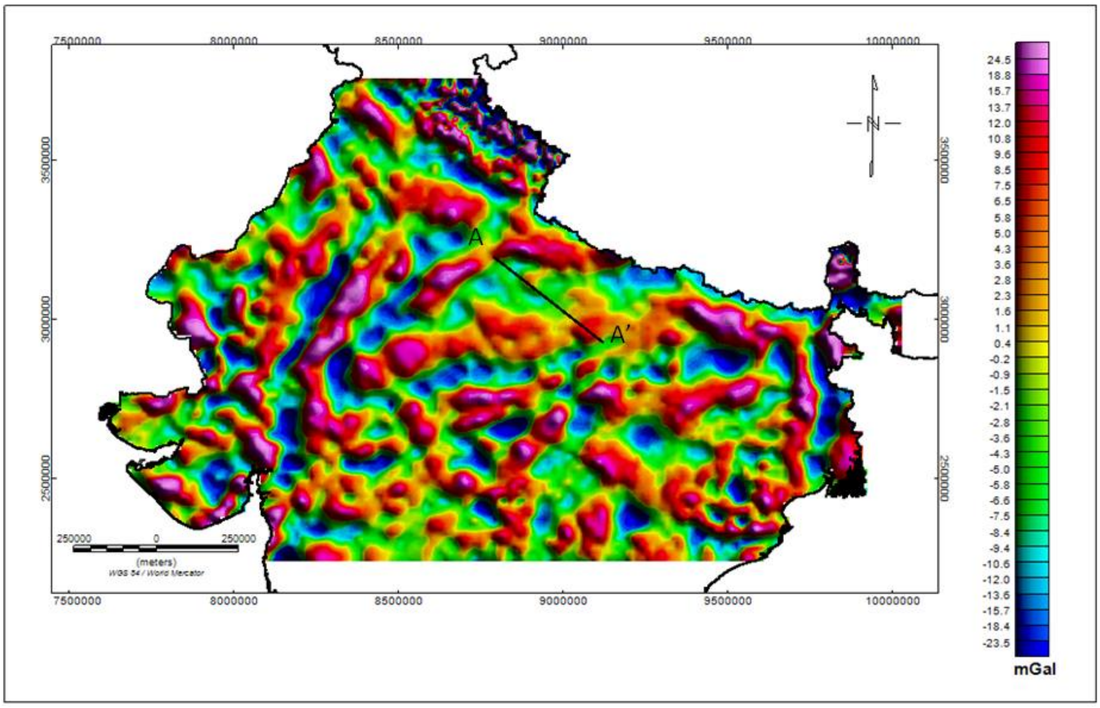

Figure 4: The Map is showing the Residual gravity anomaly of the Ganga basin and its surrounding areas.

To correlate the gravity highs and lows with seismic data residual gravity profile along the selected seismic line is overlain on seismic section (AA’) (Fig.5). It is extended from NW to SE having a total profile length of about 370 km. Here it can be seen basement of the Ganga basin. The basement depth of the Ganga basin is increasing towards NW along the selected line (AA’). The residual gravity profile shows gravity anomaly is higher (+10mGal) in the SE but it is lower(-7mGal) in the NW along the line (AA’) (Fig.5). This variation in the gravity indicates hidden, higher, and lower density subsurface material in SE and NW respectively. The gravity high value in the middle of the profile can be explained by seismic data as some external intruded feature is likely visible in the seismic section. There are some unaccounted deep-seated structures/ features below the basement are also visible in the seismic section towards NW. These anonymous structures give rise to questions such as whether they are low dense sediments below the basement or intruded magma bodies(?) To answer such questions we need to further reprocess this seismic data tie with well logs.

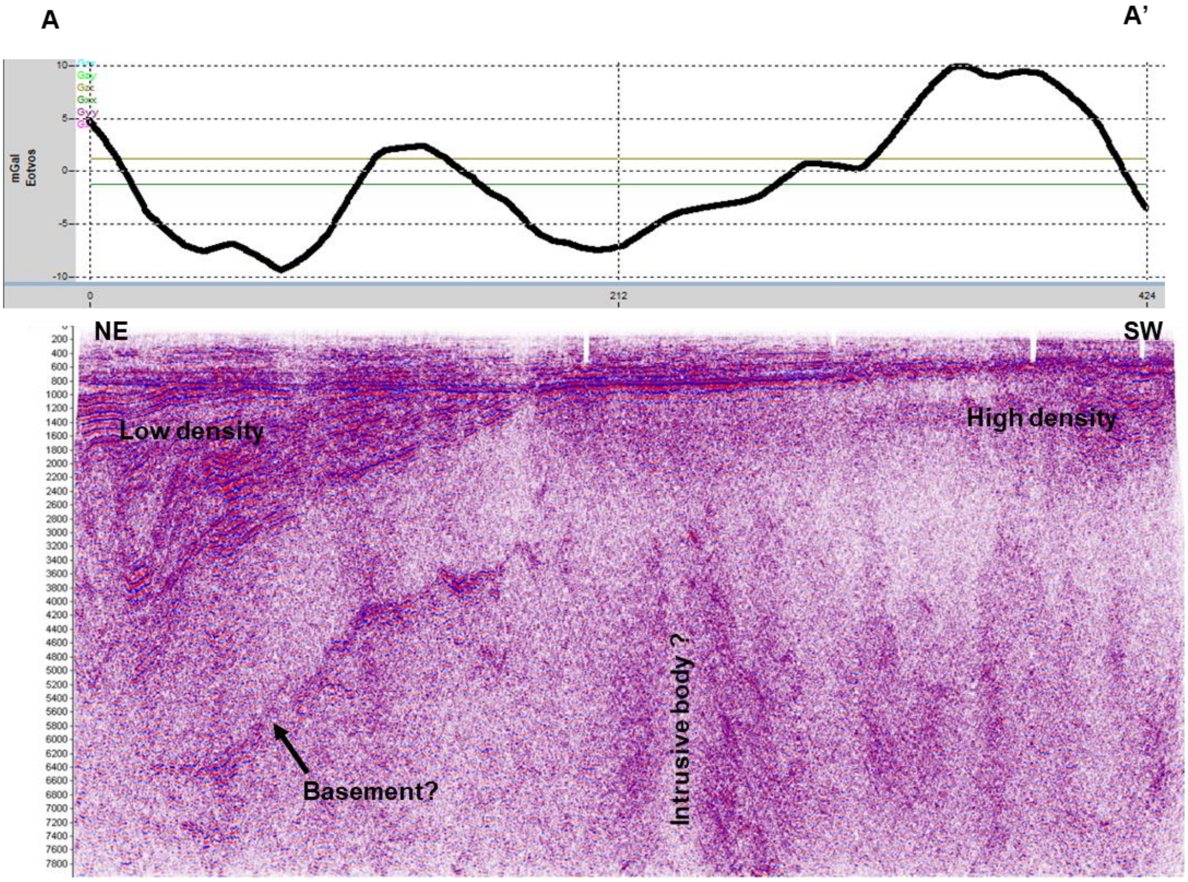

Figure 5: Map showing the 2D seismic section with superimposed Bouguer gravity anomaly profile along the selected line(AA’) from NW to SE in the Ganga Basin.

Results

Observed bouguer gravity anomaly in Ganga basin is ranging between -36 mGal to -214 mGal. Gravity anomaly in the Ganga basin is lower by -60 mGal than its margin. The seismic section shows basement depth of the Ganga basin is increasing towards NW along the selected line (AA’). The residual gravity profile shows gravity anomaly is higher (+10mGal) in the SE but it is lower(-7mGal) in the NW along the line (AA’). Low residual gravity in the basin is caused by a low dense thick pile of sediment-filled in the basin or it also has an effect of the Himalayas. Residual Gravity modeling suggests that low dense sediments are present in the NW and Highly dense sediments in the SE.

In the middle of residual gravity profile, gravity profile and seismic section suggest gravity highs are due to the deep located highly-dense intrusive body.

Conclusions

The variation in the gravity indicates hidden/sediments, higher, and lower density subsurface material in SE and NW respectively. In the NW as the value is showing gravity low indicate thicker sediments could be a good target for the exploration of hydrocarbon. To delineate detailed stratigraphy (Middle Siwalik, Lower Siwalik, Tilhar) of the Ganga basin, well logs data need to correlate. To look at hidden features/ sediments we need to further reprocess seismic data.

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