Integrated analysis of available Geological &Geophysical data of eastern part of Ganga Basin

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Summary

Hydrocarbon exploration in Ganga basin started since 1950s. Seismic, gravity, magnetic, aeromagnetic and few MT station data have been acquired in different blocks of the basin. Based on outcome of studies made on these data, 17 wells have been drilled. In the present study an attempt is made to integrate available G&G data for delineating basement configuration in eastern part of the basin.

For the study a Bouguer gravity anomaly map of the basin and its adjoining area is prepared. The gravity anomaly of this basin is varying between -42 milligals to -215 milligals i.e. a variation of 173 milligals. Such a scale of gravity low may not be the gravity effects of sediments deposited in the basin alone. Therefore, it supports the idea of influencing the gravity anomaly in the basin by isostatic gravity effects of Himalayas.

Residual gravity anomaly map, prepared with a high pass filter of wavelengths shorter than 100 km, could be able to corroborate with some of known tectonic features. Based on this data few known tectonic features are realigned accordingly.

Euler depth analysis of gravity data reveals the causatives of gravity high and lows in the basin are deep seated, may be more than 7 km.

Gravity modeling carried out along few seismic profiles suggests existence of sediments below unconformity surface (basement). It also brought out that some of the gravity highs in the basin are due to basement highs and some are because of intrusive in upper crust. It suggests that maximum sediments may be more than 7 km in Gandak depression and a little above 5 km in Bahraich low of Sarda depression.

Introduction

The Ganga basin (fig.1), a category III basin, has an approximate area of 190000 square kilometers (enclosed area). It extends from Delhi-Hardwar ridge in the west to Munger-Saharsa ridge in the east. It is bounded by the Himalayan foot hills in the north and Vindhyan basin in the south. Whole area of the basin is covered by alluvium. Earlier it is believed that the basin is broadly divided into two parts (i) Western and (ii) Eastern by Bundelkhand-Faizabad ridge.

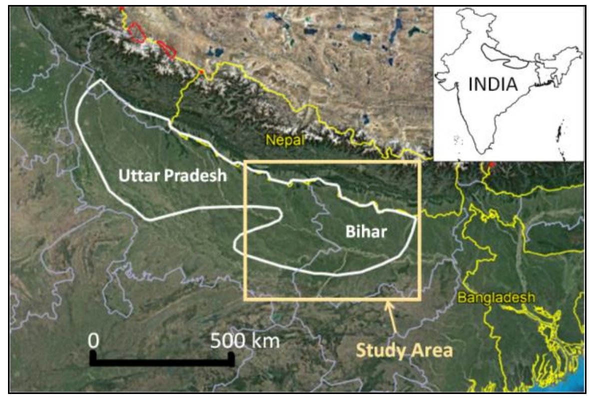

Fig.1: Location map of the study area. The white line shows Ganga Basin boundary.

The basin may be a portion of trough formed due to subduction of the Indian plates under the Asian plate. Sediments might be accumulated and subsequent subsidence in post collision era in this trough resulting in considerable pile up of sediments. Many authors believed that the sediments thickness is more than 8 km (Pant,1993 & Manglik,2015).

Based on study of Aeromagnetic, Gravity-Magnetic & seismic surveys, earlier workers, structurally subdivided the Basin into four depressions viz., (i) Sahaspur, (ii) Sarda, (iii) Gandak and (iv) Madhubani. It is reported that all these depressions are separated from one another by intervening basement ridges (Shukla,1994 & Pramanik,1996). Exploration has been carried out patch wise in these four depressions since the onset of hydrocarbon exploration in 1950s.

Few seismic campaigns, gravity & magnetic and aeromagnetic surveys have been carried out in and around these depressions. So far 17 wells have been drilled in this basin of which few wells have indicated presence of hydrocarbon but till today no significant discoveries has been made. Recently, DGH, under national seismic project, 2D seismic data acquisition is carrying out in 17 profiles of which 12 are in eastern part and 7 are in the western part (DGH, 2017-18).

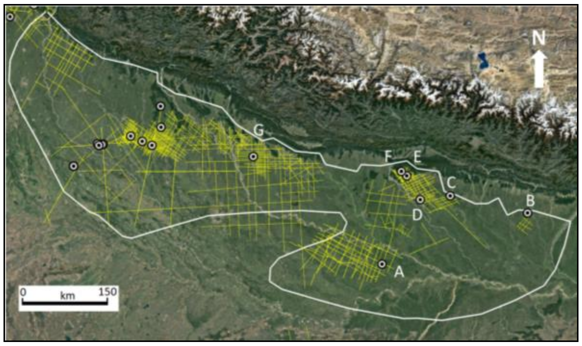

Fig.2: 2D seismic coverage and locations of drilled wells. Wells used in the study is named A-G.

Detailed studies of available seismic and well data have been carried out by Frontier basin, ONGC. Though many published and unpublished reports mentioned about the uses of gravity, magnetic and aeromagnetic data in the study and tried to correlate with tectonic features no such work is traceable.

An attempt is being made to delieate basement configuration in eastern part of the basin by integrating available gravity, magnetic, seismic and well data along with other available G&G data.

Method

A Bouguer gravity anomaly map of Ganga basin and its adjoining areas is prepared to have a regional view (shown in figure 3). In this map, many known gravity high and low features such as Bundelkhand craton, south Rewa basin, Son Narmada fault etc. in southern part and Chhotanagpur plateau in the east are prominent. But some other tectonic features such as Patna fault, Great Boundary fault, Moradabad fault and Munger-Sahsara ridge are masked by low gravity in the basin.

Gravity anomaly in the basin is ranging from -42 milligals to -215 milligals i.e. a variation of about 173 milligals. Some authors believed that this gravity low is due to gravity effect of low density sediments and it has no isostatic effect of the Himalayas (Datta,1974). But, for an average density contrast of -0.47 gm/cc (2.2gm/cc) the gravity effect of 8000m thick sediments could be about -157 milligals and with average density contrast of -0.37gm/cc (2.3 gm/cc) could be about -124 milligals only. The average density of sedimentary column may be more than 2.3 gm/cc indicating some other source may be lowering the observed gravity which, as anticipated by some other authors (Cattin,2001), may be the root effect of the Himalayas.

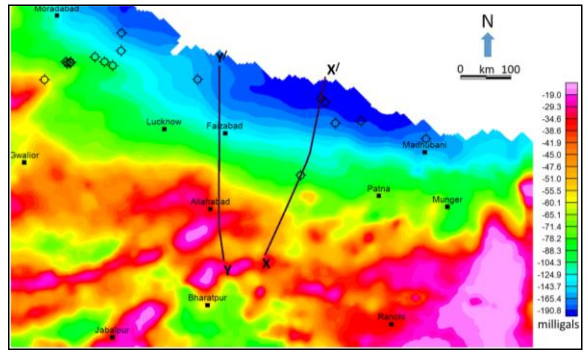

Fig.3. Bouguer gravity anomaly map of Ganga basin and its adjoining areas.

To bring out hidden gravity features in the basin, a residual gravity anomaly map is to be prepared. To find out an optimum cut off wavelength, residual gravity of observed gravity data is computed along a 360 km long north south profile, for different cutoff wavelengths of 500 km, 300 km and 100 km, shown in figure 4. Though 500 km could reproduced good gravity features it has high regional effect. Mild regional effect is seen in right side (northern part) in 300 km. The 100 km is seen as free from all the regional effects but the amplitude of the gravity features diminishes considerably. Though small in amplitude it could reproduced clearer picture inside study 100 km cut off wavelength is used.

Therefore, a residual gravity anomaly map (fig.5) is prepared by applying a high pass filter of cut off wavelength 100 km. This filter removed not only the gravity low due to root effects of Himalayas but also the gravity effects due to sediments layers. This map brought out a number of isolated gravity highs and lows features in deeper part of the basin.

About tectonic features of the basin, many workers (Shukla,1994; Pramanik,1996) in past tried to establish the outline of tectonic elements based on gravity-magnetic, drilled well and seismic data. According to unpublished report (KDMIPE, 1999) since 1962 onwards geoscientists, who had studied the G&G data of the basin, were preparing and modifying the tectonic map based on available inputs from time to time. As the studies goes on, trends of earlier designated tectonic elements had been kept on changing. Some of co-relatable tectonic features along with major gravity highs and lows are reproduced and shown in figure 5.

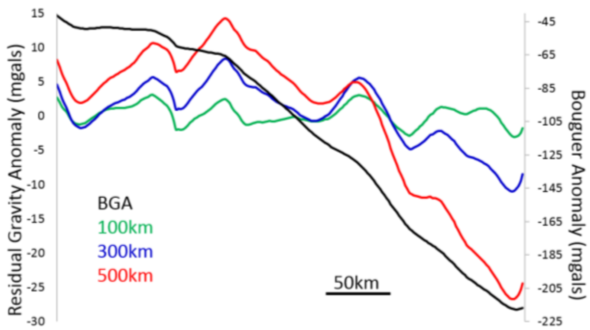

Fig. 4. Residual gravity anomaly along a north south profile with different cut off wavelengths.

Some of the tectonic elements that can be co-relatable on this map are:

- Moradabad fault
- Great Boundary Fault
- Bundelkhand Faizabad ridge (orientation changed)
- Sharda Depression (Puranpur and Bahraich low)
- Gandak Depression
- Madhubani Depression
- Patna fault
- Narmada Son lineament

The orientation of well-known Bundelkhand-Faizabad ridge as seen in earlier tectonic maps (Sukla,1994) & (Pramanik,1996) is seem to be having different shape and direction as it cannot merged with Ratlam-Patna ridge (RP) which has its own distinct features different than the Bundelkhand system. Therefore, based on gravity data the probable boundary and orientation of this ridge may be redrawn as shown in fig.5.

Further, a series of small gravity high starting from south east of Shikohabad can be seen up to Farenda which may be the Shikohabad-Lucknow-Farenda ridge (Sukla,1994) or Lucknow-Farenda ridge (Pramanik,1996).

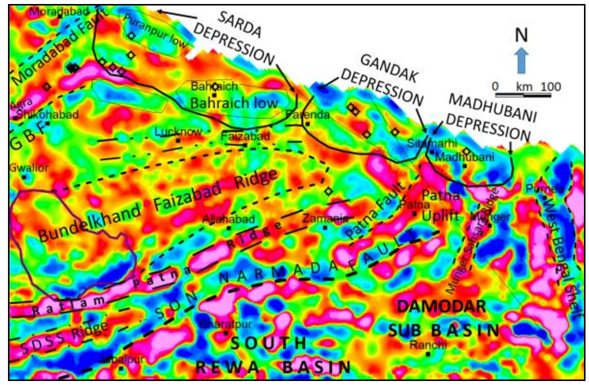

Fig. 5. Residual gravity anomaly overlain by surface exposure and tectonic features of Ganga basin and its adjoining areas. Warm colours represents gravity highs and cold colours gravity lows.

Moreover, it is seen on this map that wells B, C, D, E, F and G were drilled in gravity highs where sediment thickness may be lesser in comparison to nearby gravity lows.

To correlate the gravity features with seismic data, observed gravity and residual gravity are overlain on seismic section as shown in figure 6a & 6b.

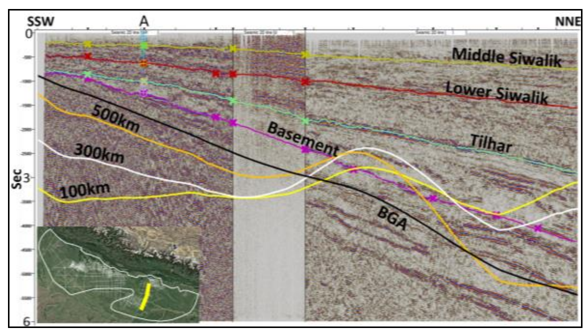

Fig.6a: Seismic section falling along part of profile XX/ in Gandak Depression

Here it can be seen that all the horizons viz. Middle Siwalik, Lower Siwalik, Tilhar and Unconformity (Basement from well A) are seen dipping towards north. The gravity high features in the middle of profile cannot be explained by seismic data as all the horizons are seen dipping northward.

Similarly, the observed gravity is increasing towards north while the seismic horizons are dipping as seen in figure 6b. This indicates that there are unaccounted deep seated features/structures below the unconformity surface.

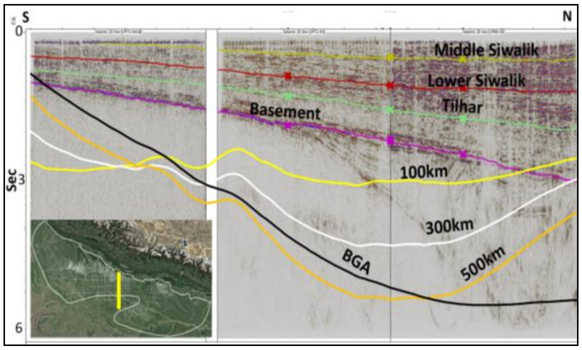

Fig.6b: Seismic section along profile YY/ falling in Bahraich low of Sarda Depression.

To ascertain these deep seated features, further analysis of gravity data is carried out by employing Euler 3D deconvolution method to find out the depth of causatives. For this, all the possible depth solutions of one structural index are computed for different window length. And these solutions ranging from 0 km to 60 km are plotted one upon another to check the convergence of the solutions and shown in figure 7a. It is seen from this figure Ganga basin has lesser solutions in comparison to its adjoining areas.

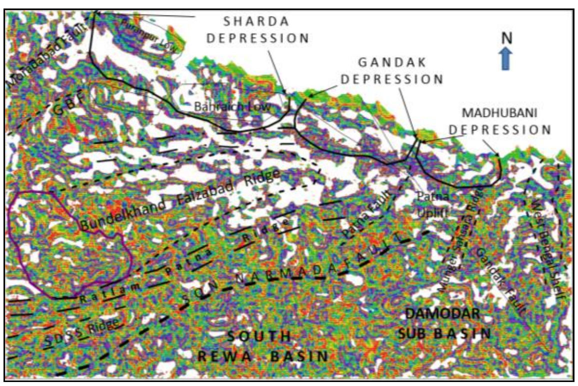

Fig.7a: Euler solutions of all the windows of structural index 1.

For further study these solutions are separated into two groups, one with solution depth window 0 to 7 km and another with 7 to 60 km as shown in figures 7b & 7c.

The depth solutions in fig 7b suggest that the top layer upto 7 km in the basin is less disturbed in comparison to its adjoining areas. Therefore, large structural changes which arises a change in observed gravity may not be present in this upper 7 km.

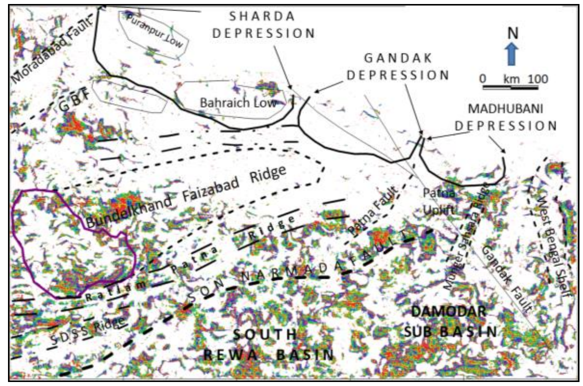

Fig. 7b: Euler solutions restricted to depth 0-7 km.

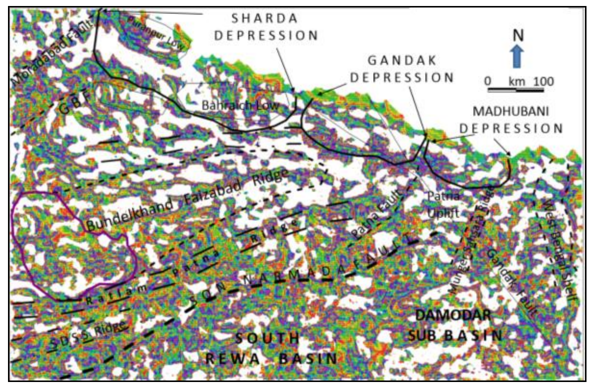

Fig. 7c: Euler solutions of depth 7-60 km.

But there is abundant depths solutions which are deeper than 7 km (fig.7c) indicating that the features seen in residual gravity (fig.5) is caused by some deeper causatives, which is in agreement with seismic sections (6a &6b).

Gravity & Magnetic Modeling

The profile XX/ is the extension of seismic line shown in fig. 6. It is extended to south and north to incorporate long wavelength gravity features. It starts from northern bank of Son river near Shahganj, Jaunpur district of Uttar Pradesh and ending at Kawasoti in Nepal, having a total profile length of 368 km connecting two wells A & F. Out of the total profile length 158 km is falling along available 2D seismic lines. This profile crosses Gandak river twice, once inside India and another in Nepal.

Gravity anomaly along this profile is varying from -41.47 milligals to -216.79 (extrapolated by gridding) as shown in figure 8. Magnetic data used in modeling is digitized from unpublished reports and no details of which are available except it were acquired in early 1960s.

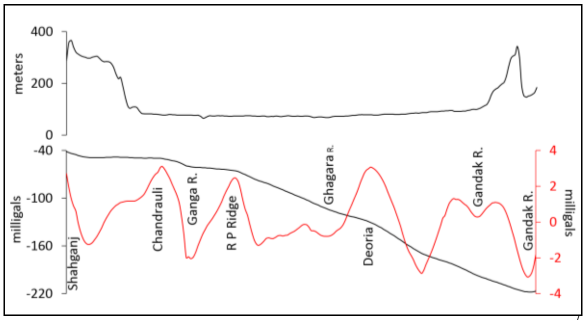

Figure 8: Observed gravity along the profile XX/ along with residual gravity and SRTM elevation.

The gravity high and low, at beginning of the profile, to the south and north of Shahganj may be due to the structural changes at Son-Narmada Geofracture. The other gravity lows are attributable to river basins of the Ganga, the Ghagara and the Gandak as shown in figure. The gravity highs along this profile are of isolated type (fig.5) except the gravity high due to Ratlam-Patna ridge and at Deoria.

Gravity modeling is carried out by constraining the seismic horizons and well data (shown in figure 9,10 & 11). Densities used for the modeling are shown in table-1.

Table-1

Formation	Densities	Symbol
Recent	2.00-2.10	-
Upper Siwalik	2.10-2.15	US
Middle Siwalik	2.20-2.25	MS
Lower Siwalik	2.30-2.35	LS
Karnapur	2.50-2.55	KR
Tilhar	2.55-2.57	TR
Ujhani	2.57-2.60	UN
Bahraich	2.60-2.62	BH

To simplify the model, Vindhyan sediments are taken as single entity at start of profile where variation in observed gravity may be mainly due to changes in different formations in this layer.

Along the profile XX/, the gravity modeling demands the mantle to be dipping gently towards north from about 42 km at start of profile to more than 50 km at end of profile.

Intrusive are introduced in upper basement to explain observed gravity highs of RP ridge and Deoria area, the actual size and depth may be different as it is introduced to produce the gravity effects only.

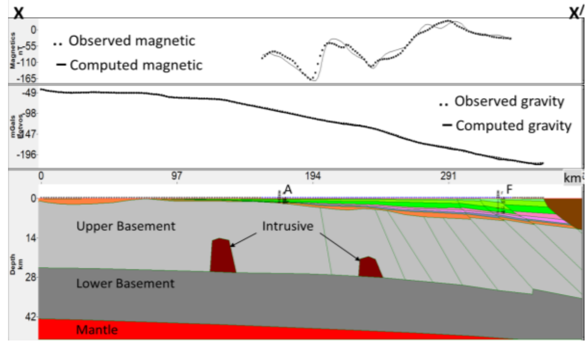

Fig.9. Gravity model along profile XX/.

Magnetic modeling along this profile suggest breakup of the upper basement with slight variations in inclination and declination values. But it suggests same polarity of magnetization for this part of crust.

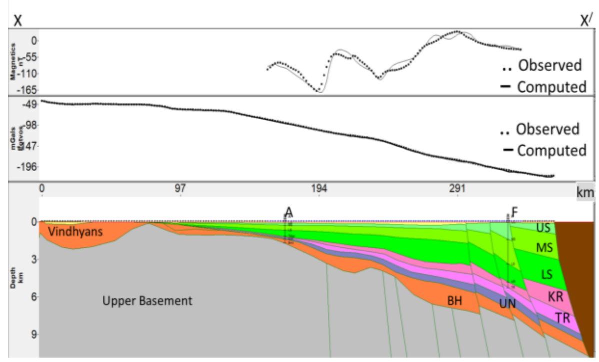

Fig.10. Close-up view of the gravity model shown in figure 9.

The sediment thickness at Gandak depression may be expected up to 11 km at the areas near main boundary thrust. Whereas sediment thickness at areas of gravity low to the north of Deoria (fig. 8) may be more than 7 km.

Similarly, gravity modeling along profile YY/ (fig.11) is carried out by converting the seismic time horizons into depth with densities in table-1. The sediment thickness in this profile may be a little above 5 km at the end of profile. But as seen in seismic section in fig.6b the reflection below the unconformity surface is comes out to be sediments as demanded by gravity modeling. Similar to XX/ the variations in observed gravity at beginning of the profile may be due to

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changes in different Vindhyan layers but to simplify the modelling, it is taken as single layer.

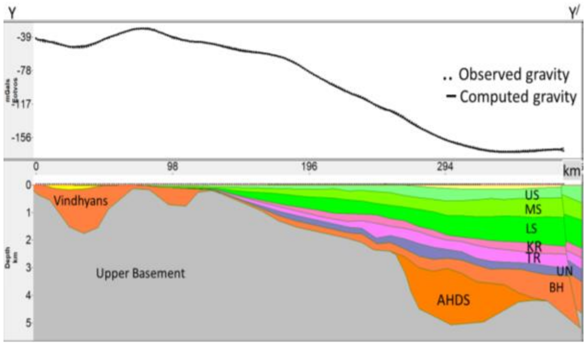

Fig.11. Gravity modelling along profile YY/. (AHDS: Additional Higher Density Sediments)

From integrated study along these profiles, it can be inferred that sediment thickness in Gandak depression is more than Bahraich low of Sarda depression. As gravity lows are having thicker sediments this areas may be a good target for hydrocarbon exploration.

Conclusions

- Observed gravity anomaly in Ganga basin is varying between from about -42 milligals to -215 milligals i.e. gravity anomaly in the basin is lower by 173 milligals than its margin.

- Thick accumulation of sediments alone may not be the cause of low gravity in the basin, but it may also has the isostatic effect of the Himalayas.

- Euler depth analysis reveals sources of gravity high and lows in the basin are deeper.

- Gravity modeling suggests maximum sediments may be more than 7 km in Gandak depression and a little above 5 km in Bahraich low of Sarda depression.

- Modeling suggests gravity highs are due to basement high and deep seated high density intrusive.

- As gravity lows are having thicker sediments these areas may be a good target for hydrocarbon exploration.

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