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Insight into the tectonic and crustal understanding of lesser Himalayas along Purnea-Sevoke transect through geophysical studies

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ABSTRACT

Geophysical investigation employing deep electrical resistivity, gravity and magnetic techniques was carried out along Purnea-Sevoke (NH-31) road. The basement depth varies from 2917-4450 m, indicating huge relief. Three basement faults have been mapped over the transect. The Siwalik floor is quite undulatory in this part of the frontal fore deep region of the Himalayas.

The gravity profile along NH-31 from Purnea to Sevoke brought out two basin structures with upliftment of basement at km st 460 and km st 490. Spectral analysis of the said gravity profile brought out the Conrad discontinuity and the basement depth at 18.4 and 3.2 km respectively. 2D gravity modeling along the above transect indicates gradual deepening of basement towards the NE in addition to the features stated above. This is due to sagging of the crustal block at the foot hill region of Himalaya.

The magnetic anomaly between km st 465 to km st 500 is of fairly high order (400-1000 nT) in the area which supports the findings from the gravity survey. These are primarily due to upwarpment of basement in these areas. However presence of traps below the sediment cover is an added probability.

Key words: Lesser Himalaya, Bouguer anomaly, 2D modeling.

INTRODUCTION

The study of crustal structure in the sub and lesser Himalaya regions has always attracted the attention of geo-scientists because of its academic and economic importance. The area was surveyed using different geophysical methods by Standard Vacuum Oil Company, Indo Stanvac Petroleum Project (ISSP), and the Oil and Natural Gas Commission (ONGC). The borehole stratigraphic studies (DST expert group report, 1995) conducted for oil and natural gas prospecting show about 2500-3500 m thick Siwalik sediments and a total sedimentary thickness of more than 6000 m in certain parts of the Siwalik region. Reddy and Arora (1993) have reported a high conductive layer in the crust at depths varying from 10-15 km below the Himalayan collision region. Intensive geophysical surveys and deep drilling in the alluvial plains of the West Bengal (Sengupta, 1966) revealed a thick section of Cretaceous and Tertiary sediments lying on a basement of basalt lava flows. To delineate the thicknesses of the lower Siwaliks/Gondwana formations above the basement and to prepare a meaningful crustal model, the area bounded by latitudes 25°52' N to 27° N; longitudes 87°28' E to 88°28' E (Figure 1) was surveyed using gravity, magnetic and deep electrical resistivity techniques. Deep electrical surveys were undertaken in the area at 10-15 km interval along Purnea-Dalkhola-Sevoke transect along with gravity and magnetic observations located at every kilometer from Raiganj to Dalkhola and Purnea to Sevoke respectively.

Geology & tectonics of the study area

The survey area (Figure 1) is totally covered by recent alluvium. However, down south, south of Sahebganj Rajmahal trap is exposed. Tectonically the area is a part of the Extra Peninsular mountainous terrain and Piedmont plain of North Bengal covered by alluvium. The Quaternary deposits of the Extra Peninsular region occurring just south of Siwalik Group, constitute boulders, gravels, pebbles, sands and silts in the higher reaches forming alluvial fans and fluvial depositional terraces; while sand, silt and clays in the lower reaches form fluvial terraces of flood plain facies. The Main Boundary Thrust (MBT) and Main Frontal Thrust (MFT) (Figure 1a) separates Siwalik Group of the sub Himalayas in the foreland from the lesser Himalaya. Gondwana Supergroup, comprising pebble/boulder beds, quartzites, sandstone, slates with anthracite coal seams, is found near Purnea in a borehole. Normally, lower Siwaliks (Tertiary) are underlain by Gondwanas and are overlain by pre-Quaternary and Quaternary alluvium (Yin, 2006; Bhattacharya, 2008). Saharsha ridge marginal fault, Malda Kishanganj fault, Katihar Nailphamari fault, a few lineaments and several strike slip faults are seen around the area of study.

Geophysical survey

In this region, geophysical survey comprising gravity, magnetic and deep resistivity methods were initiated

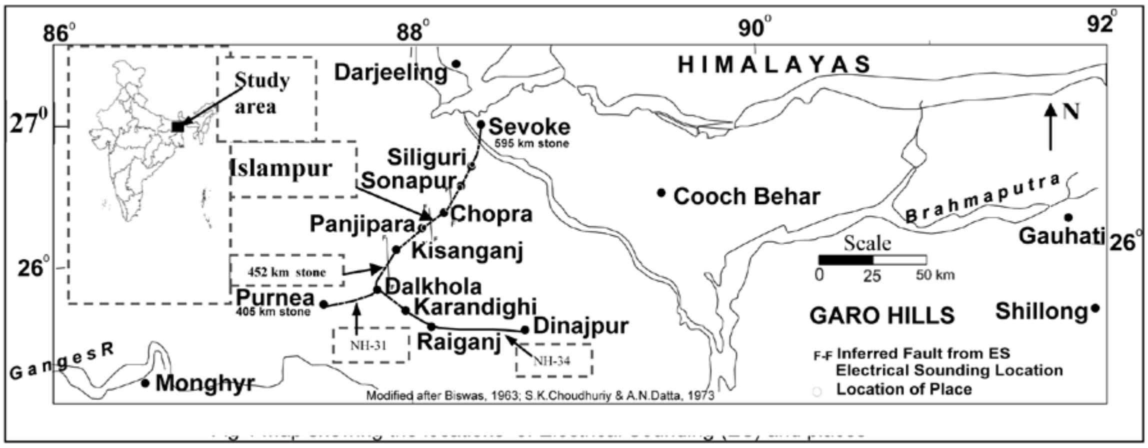

Figure 1. Map showing the locations of Electrical Sounding (ES) and places**.**

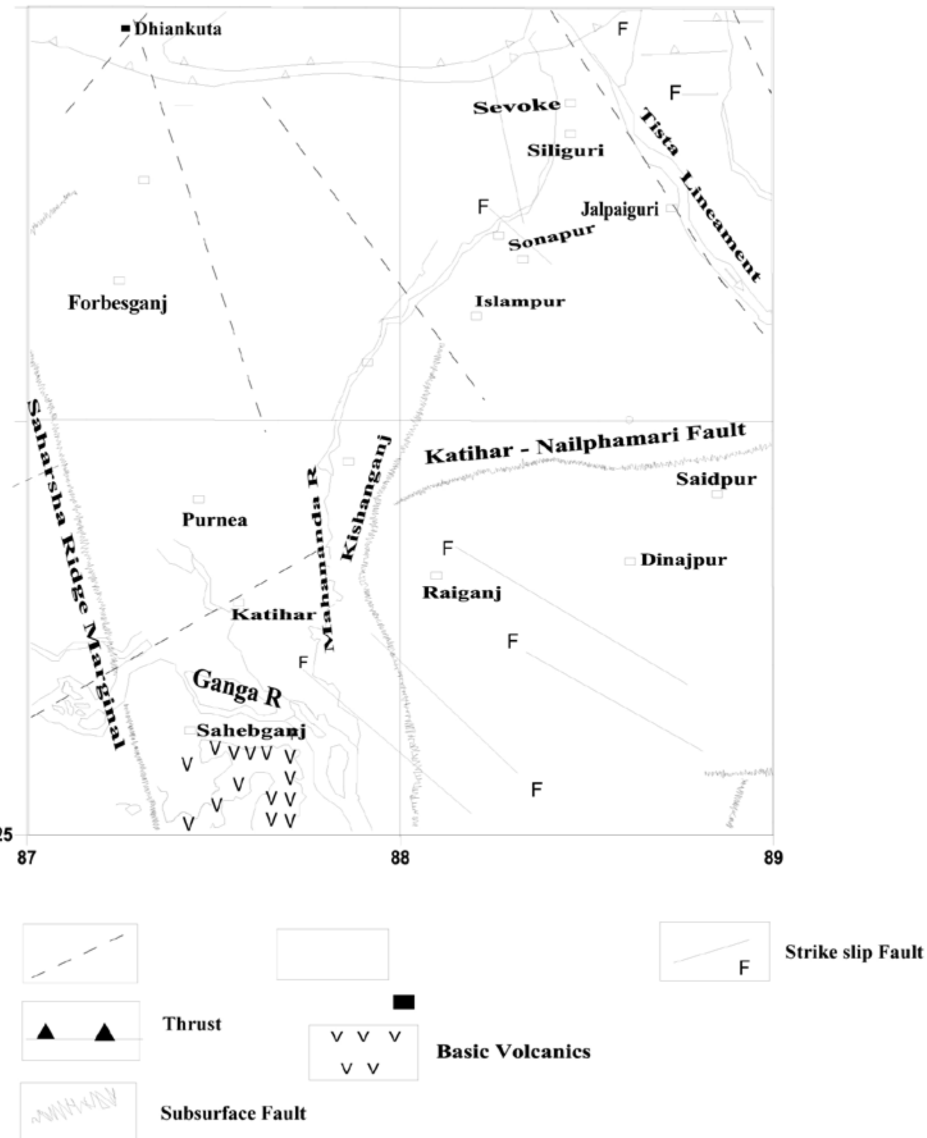

Figure 1a. Tectonic map of study area.

by the Geological Survey of India in 1993 (Figure 1). It was expected that sediments settled in the basement depressions would be indicated by broad gravity "lows". The magnetic method supplemented the gravity method in bringing out possible basement morphology. The deep resistivity soundings were taken at suitable locations to determine depths to the basement rock and to obtain character and thicknesses of the different formations overlying the basement.

The gravity survey was conducted employing Sodin (Canada) make gravimeters with a reading accuracy of 0.01 mGal and the magnetic survey was conducted employing Scintrex (Canada) make digital grade vertical force magnetometer having a reading accuracy of 1 to 10 nT. A Scintrex 10 KVA time domain resistivity unit was used for field surveys. RDC-10 receiver of Scintrex make was used for measuring the potential difference between the two non-polarisable electrodes (copper dipped in saturated copper sulphate solution).

Deep resistivity sounding

Resistivity of rocks is an important parameter for mapping crustal structures which may provide a clue on the processes of crustal evolution (Das et al., 1993). Subsurface resistivity distribution is directly related to the physical character of the lithological units. Variation in resistivity of the rocks is the main source of electrical anomaly. Alpin et al., (1966) have used this technique for crustal mapping extensively in Europe. Van Ziji (1977; 1978) effectively used this technique in South Africa. Blaine Webster (1997) successfully utilized this technique in Canada. In the present area of investigation, along the transect Purnea-Sevoke, fourteen geoelectric soundings have been carried out (Figure 1) with R (separation between transmitting and receiving dipoles) as large as 8-10 km. The shallower part upto AB/2= 3 km was covered by using Schlumberger electrode array to avoid the effects of lateral inhomogeneity. Azimuthal dipole sounding can be interpreted directly in terms of layer parameters by using two/multilayer master curves, when the azimuth angle is small (less than 10-15°). Inter-convertibility of dipole-apparent resistivities are discussed in Bhattacharyya and Patra (1968), Koefoed (1979). The resistivity sounding curves were initially interpreted using "Orellana and Mooney" master curves (Orellana and Mooney, 1966). A standard inverse modeling program 'RESIST' (Vander Velpen, 1988) has been used to get the layer parameters i.e. resistivity and thickness of different subsurface layers having distinct resistivity values. A four layer subsurface set up i.e. the Archaean basement overlain by the Gondwanas, the Siwalik and the Quaternary alluvium is normally expected in this area. Due to high conductivity of the Quaternary as well as the Tertiary formations, the penetration has been poor in most of the cases.

Resistivity interpretation along transect Purnea-Sevoke

The interpreted geological subsurface layers are characterized by a distinct range in resistivity values (Figure 2 & 3). Thus the very high order of resistivity varying from 1100-2400 Ohm-m is interpreted as a boulder bed near the surface (ES-10, 11, 12 & 14) around Sonapur, Chopra, Siliguri and Sevoke. The lowest resistivity order is ranging from 10-39 Ohm-m around Dalkhola, Purnea, Chopra and Sonapur area varying in thickness from 2495-3150 m and appears at depths ranging from 922-2495 m, minimum at around Purnea and maximum at around Dalkhola. This is interpreted as the signature of Siwaliks in the study area (ES-1, 2, 3, 4, 5, 10 & 11). Presence of lateral inhomogeneities are observed around Kishanganj and Islampur areas which may be due to the presence of faulted subsurface structures (ES-6, 7, 8).

A notable feature is observed in between Siliguri and Sevoke (ES-14) where resistivity value of 1100 Ohm-m near the surface persists with depth. However after 40 m depth this resistivity value suddenly falls. This is interpreted to be due to the presence of Siwaliks at depth. The high resistivity basement is encountered at a depth varying from 2917-4450 m around Dalkhola and Kishanganj area (ES-1 & 5). An ONGC borehole, (500 m from ES-2) towards Purnea, encountered Siwaliks (around 2 km) followed by upper (369 m) and lower (1253 m) Gondwanas over the Archaean basement.

Apparent resistivity pseudo depth section along Purnea-Siliguri Highway :

An apparent resistivity pseudo-section along Purnea-Siliguri Highway is shown in Figure 4. The section shows four distinct breaks (faults). These faults are located near km st 452, 493, 510 and north of km st 526 respectively. The relative displacements of the basement are shown by arrows depicted on the figure around the interpreted faults. Of particular interest is the zone between km st 452 and 493 where resistivities to the tune of 1000-2000 Ohm-m is mapped at comparatively shallower level. This is interpreted as the basement resistivity and the basement is up-arched (convex upwards) in this zone. This zone may be interesting for Gondwana sediments at shallower depth and/or oil and gas. In the rest of the area north of km st 493 the basement deepens further with another fault at km st 524.

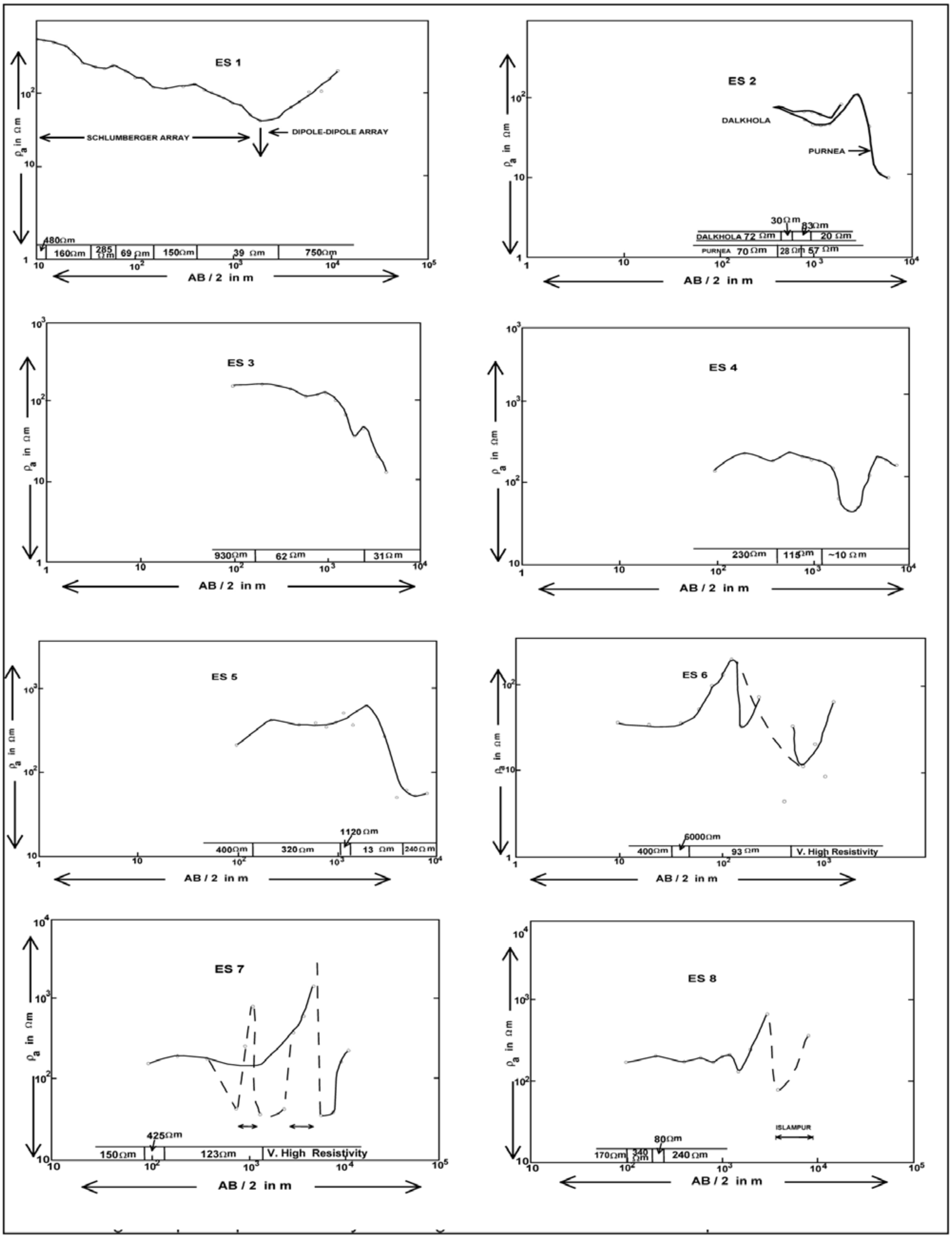

Figure 2. Dipole-dipole resistivity sounding ES-1 to ES-8 centered at respective km stone.

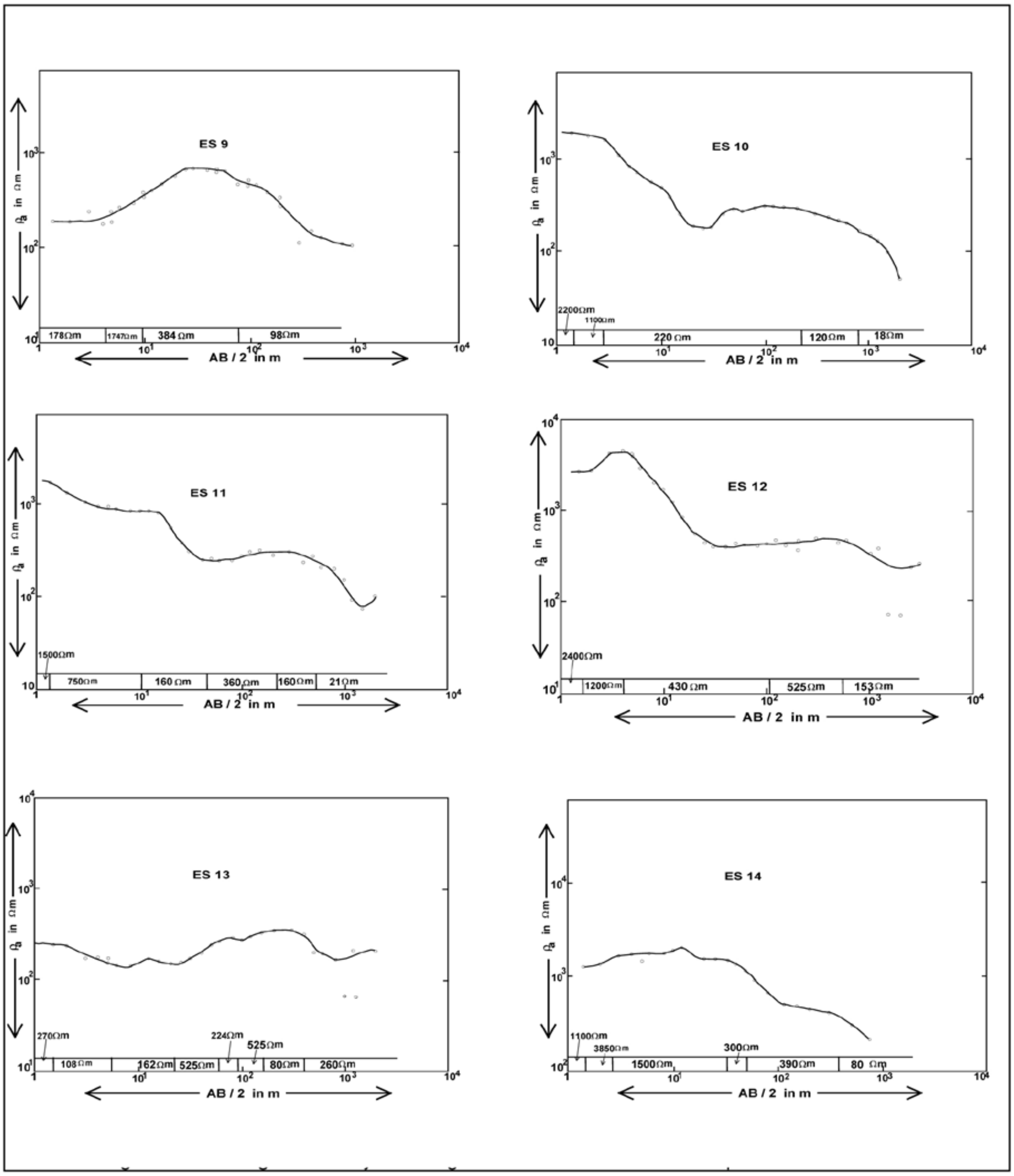

Figure 3. Schlumberger resistivity sounding ES-9 to ES-14 centered at respective km stone.

Gravity survey

As the overlying lithic fill (alluvium, the Quaternary sediment, the Siwaliks and the Gondwana together) has lower average density value (2.17 g/cm^3) than the Archaean basement (average density 2.67 g/cm^3) and its composite thickness is well over 2 km, substantial gravity anomaly was expected. With this idea gravity observations were taken at every kilometer stone from Purnea to Sevoke (NH-31) and Raiganj to Dalkhola (NH-34). Between Panjipara and Sonapur (NH-31) systematic gravity survey was also conducted covering 5-8 km on either side of the highway, just to have a look at the regional gradient of the potential fields.

The gravity values were tied with respect to a Survey of India (SOI) base (Gulatee, 1956) in this area. Station elevations were obtained from closed-loop leveling and tied up with SOI bench mark at Islampur. Position control

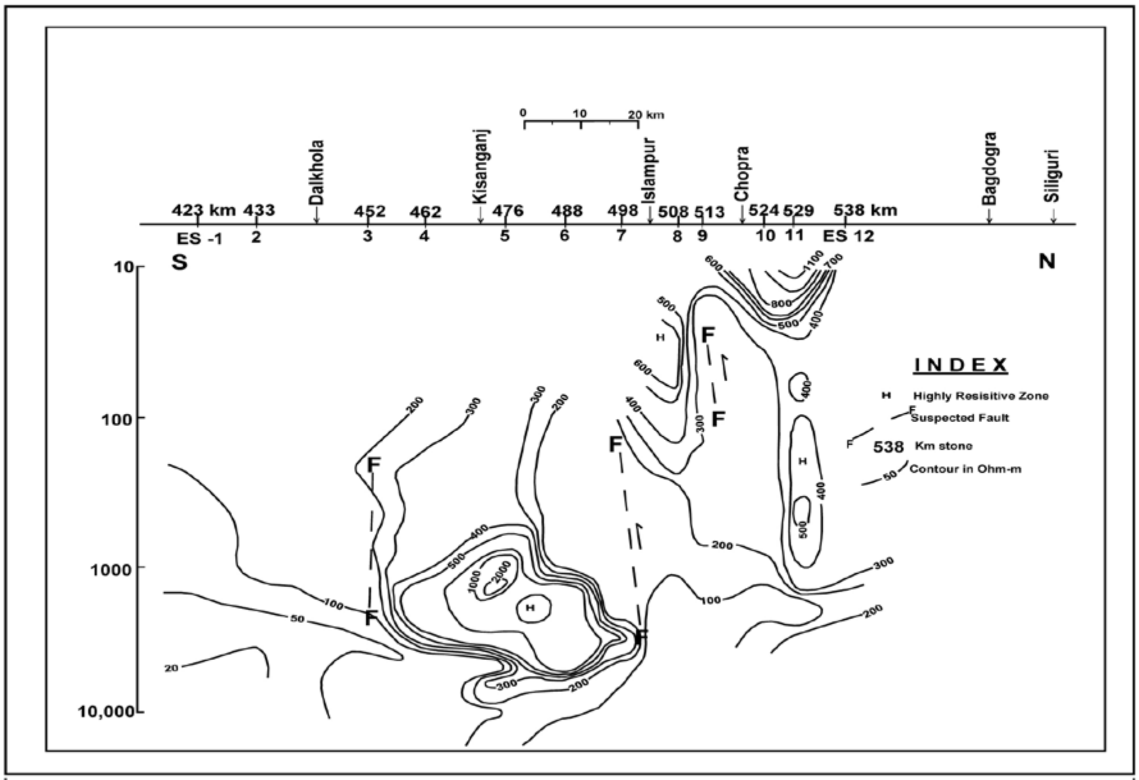

Figure 4. Apparent resistivity pseudo depth section along NH-31.

for the stations was guided by SOI topographic sheets (1:50,000 scale). The Bouguer anomalies presented here were computed according to the 1967 International Gravity Formula. A density factor of 2.67 gm/cm^3 for the slab above mean sea level was considered for combined elevation correction. Terrain corrections were not applied to the anomalies. The overall accuracy of the Bouguer anomalies in the present survey could be about ± 0.3 mGal or better. Frequency analysis of Gravity Data:

In the absence of any other collateral subsurface data which may help in the interpretation of Bouguer gravity anomaly, frequency analysis of the gravity data was done along the profile Purnea-Sevoke Road (NH-31) (Figure 5) in order to map the different crustal density inhomogeneities with depth. For this purpose gravity value at every 2.5 km interval along the above profile was digitized. The mean of the logarithm of energy associated with particular frequency was computed following Spector and Grant (1970) to obtain an average radial spectrum. The average logarithmic energy has been plotted against wave number. The plot (Figure 5) reveals the presence of two major interfaces at average ensemble depths of 18.4 km and 3.2 km. These average depths are interpreted as the depths to the Conrad interface and the basement.

2D gravity model:

In order to understand the variations of Bouguer anomaly in terms of crustal structure i.e. mass distribution, 2D gravity modeling was done over the Purnea-Sevoke gravity profile (Figure 6). A four layer crustal model was assumed keeping in view the local geology and the intercepts from the frequency analysis data. The gravity value was calculated after Talwani et al., (1959). Values of individual crustal layers are shown in the figure. The thickness of the composite sedimentary column has been varied from 0.5 km to 5.5 km from southwest to northeast (Figure 6). Two basinal features associated with equal numbers of basement rise are interpreted. Several faults at km st 425, 440, 455, 480 and 520 are also interpreted from the 2D gravity modeling.

A part of the gravity transect from Panjipara to Sonapur at NH-31 is presented as a contour map in intervals of – 2 mGal (Figure 7). The gravity values vary from – 69.6 mGal to – 130 mGal from southwest to northeast of the area. The gravity map reveals that crustal thickness increases from southwest to northeast with a break in the north of Chopra and east of Sonapur. The rate of fall decreases here suggesting a saddle like hump structure in the basement.

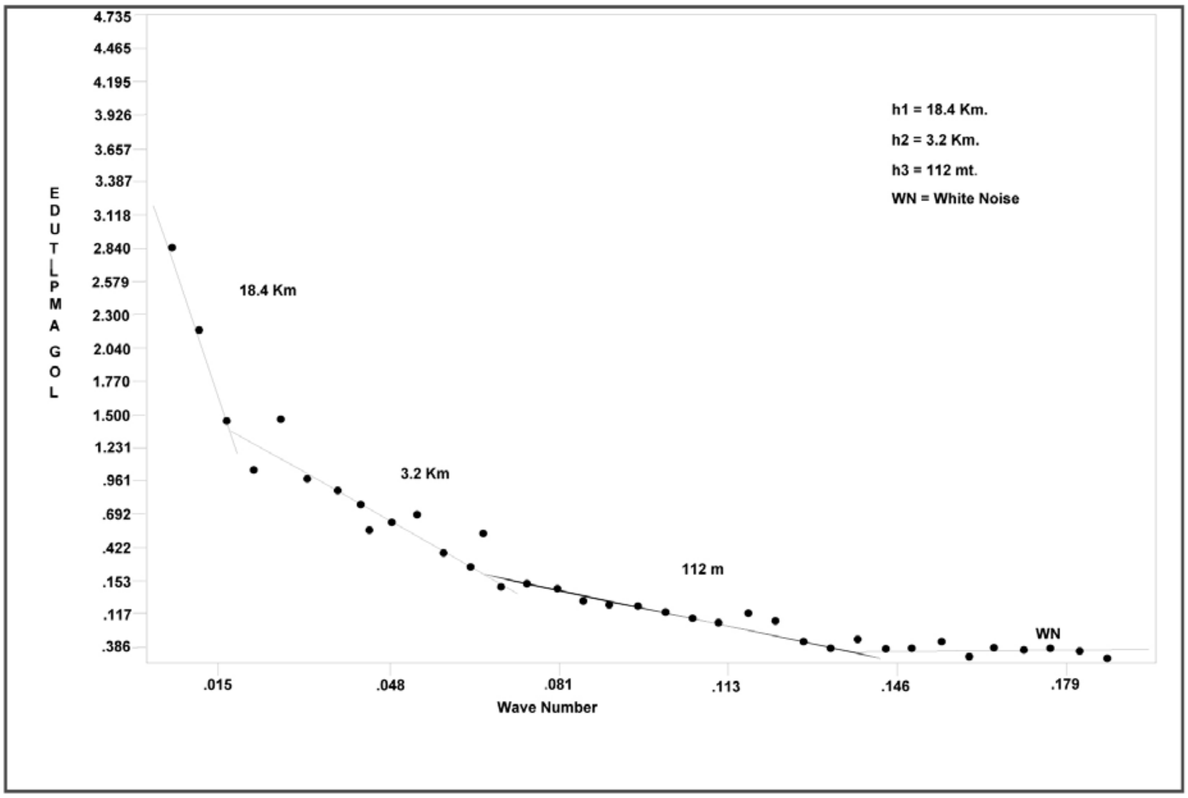

Figure 5. Spectral analysis of the Bouguer anomaly profile from Purnea to Sevoke along NH-31.

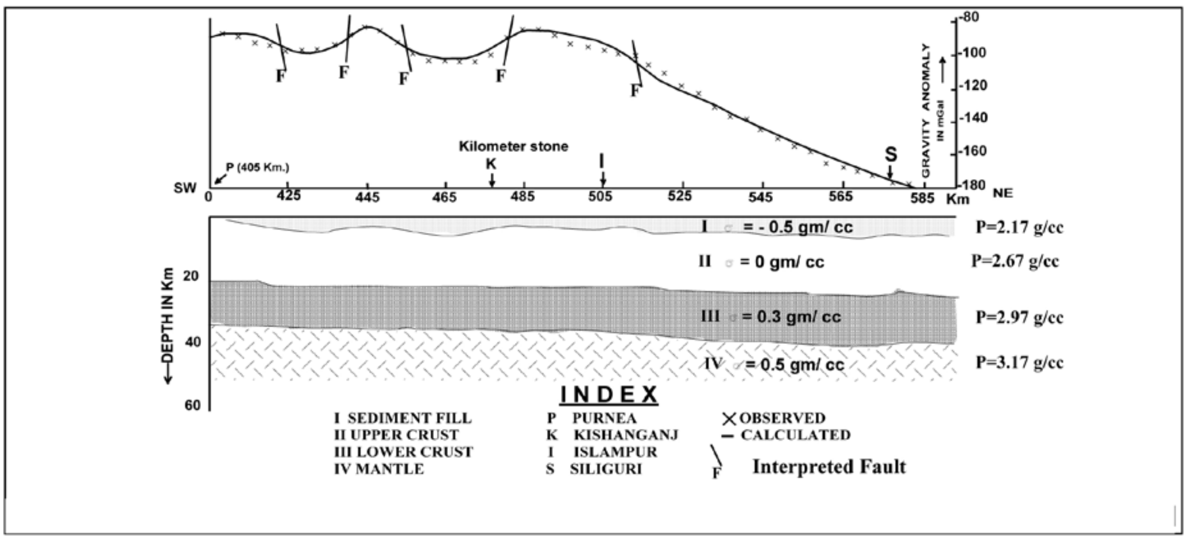

Figure 6. Bouguer anomaly profile and 2D gravity model from Purnea to Sevoke along NH-31. σ = – 0.5 g/cc represent density contrast. P = 2.17 g/cc indicates density of the layer.

A separate Bouguer anomaly profile along NH-34 between Raiganj and Dalkhola (Figure 8), shows a continuous fall of gravity anomaly at the rate of 1 mGal/km upto 425 km stone. After that a sharp fall in gravity value has been interpreted to be due to a basement fault dipping towards north at 432 km stone. This is interpreted to be the signature of the buried Malda-Kishanganj fault (Figure 1a). Thickening of crust towards north is probably due to sagging of the crustal block at the foot hill of Himalaya.

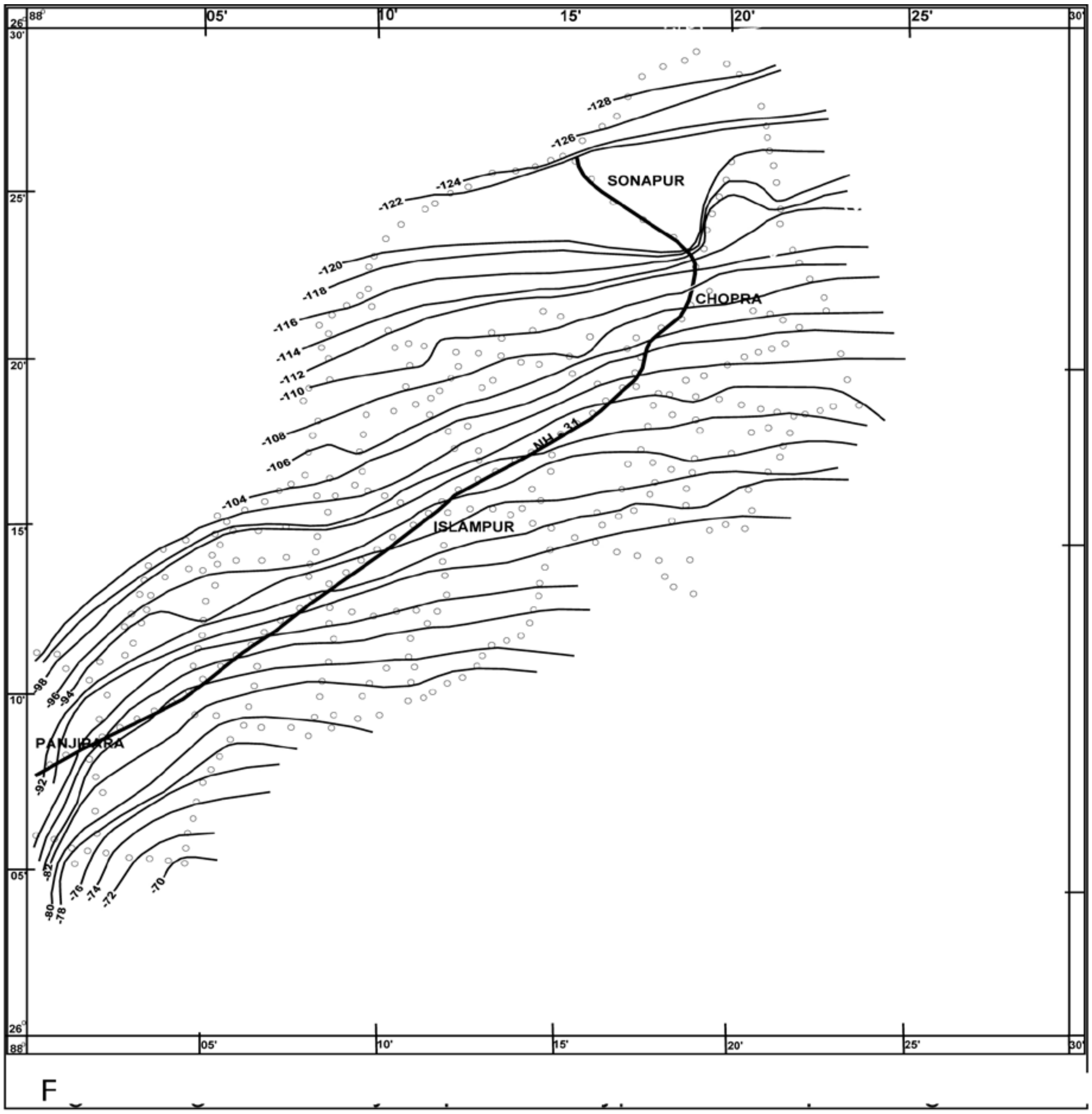

Figure 7. Bouguer anomaly map from Panjipara to Sonapur along NH-31.

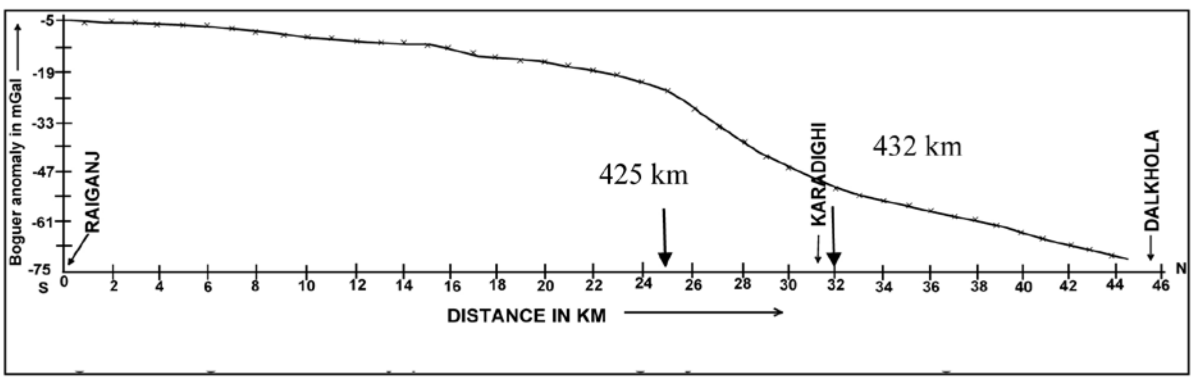

Figure 8. Bouguer anomaly profile from Raiganj to Dalkhola along NH-34.

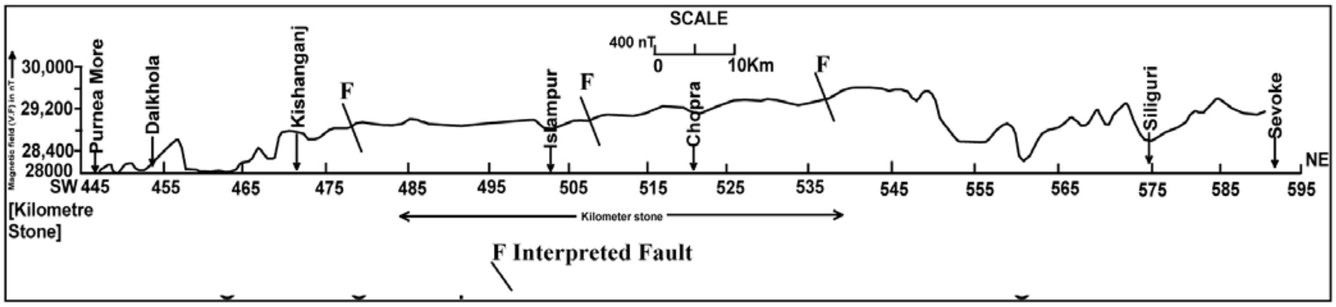

Figure 9. Magnetic profile from Purnea to Sevoke along NH-31.

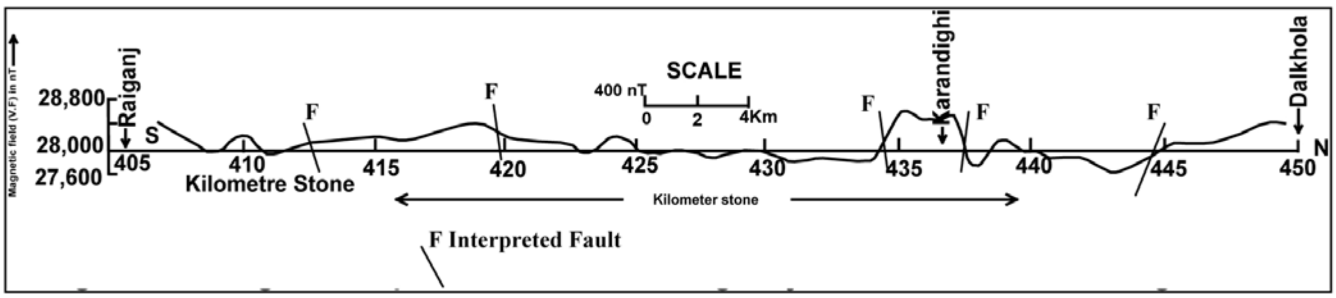

Figure 10. Magnetic profile from Raiganj to Dalkhola along NH-34.

Magnetic survey

Since the magnetic susceptibility of the composite lithic fill (alluvium, Quaternary, Siwalik and the Gondwana) in the study area is much less than the Archaean basement, substantial low magnetic relief was expected over this transect, except however, where some trap rocks (equivalent to the Rajmahals) having higher magnetic susceptibility occur over the Gondwana sediment or the basement rises up. With these ideas magnetic observations were taken at every kilometer stone from Purnea to Sevoke Road (NH-31) (Figure 9). The magnetic vertical force (VF) anomaly profile between Purnea and Sevoke shows two basinal structures, one between stations 457 km to 475 km and the other SW of it (Figure 9). This finding is supported by gravity survey. After km st 475 magnetic anomaly shows high relief rising in steps at km st 475, 510, 540 depicting the possibility of basement upwarps or presence of trap underneath. Fluctuations in magnetic anomaly are seen beyond station 550 km, possibly due to the presence of buried intrusive, within a down faulted basement

The magnetic vertical force (VF) anomaly profile between Raiganj to Dalkhola shows basinal structures (Figure 10). The basin is fairly flat and homogeneous with occasional basement highs through faulting at km st 413, 420, 433 (Malda Kishanganj Fault), 438 and445. The Gondwanas are interpreted to be shallower at Karandighi between km st 433 and 438.

CONCLUSIONS

Due to high conductivity of the overlying sediments, the basement depth could be ascertained only at a few resistivity sounding locations. The pseudo depth section of resistivity indicated four faults north of km st 452, 493, 510 & 526. The intervening zone between km st 452 & 493 shows a highly resistive bed lying unconformably over a conductive horizon. This may be a basement slice thrusted over the Siwaliks. Gondwanas are expected at shallower depth in this zone.

The FFT of gravity anomaly revealed two interfaces at ensemble depths of 18.4 km and 3.2 km which are interpreted as Conrad discontinuity and the basement depth. Thickness of composite lithic fill is interpreted to be 0.5 to 5.5 km from southwestern part of the area to northeastern part from 2D gravity anomaly. Crust becomes progressively thicker towards northeast following isostatic consideration.

The magnetic anomaly profile shows two basinal structures, one between km st 457 and 475; the other is SW of Dalkhola. Beyond km st 475 magnetic anomaly shows high plateau depicting the possibility of basement upwarp in steps and/or trap underneath. Fluctuations in magnetic anomaly are seen beyond station 550 km possibly due to the presence of intrusive, in a downthrown basement.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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