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Author **Dr.Dipendu Saha , ongc , India**

Co-Authors **Dr.RGS Sastry**

Delineation of Trap & underlying Sediment thickness with depth to Basement of entire Chambal valley through 3D gravity modelling.

Abstract

Vindhyan basin located in central India is one of the largest Proterozoic sedimentary basins of India. It is believed that the basin was formed due to collision of Bundelkhand craton with Deccan protocontinent in the south and Mewar craton in the west during early Mesoproterozoic period. The basin is divided into two sub-basins viz., Son valley in the east and Chambal valley towards west. Over the Mesozoic sediments several volcanic lava flows are deposited during Cretaceous period popularly known as Deccan traps or simply traps. They are exposed on the surface in most of the Chambal valley. Chambal valley is hardly explored except northern region, where trap is absent. A Number of gas seepages of thermogenic origin have been found over Chambal valley, which indicates the existence of favorable petroleum systems. As large part of the area is exposed with trap covered, seismic studies are not favorable. In such areas potential methods can be of immense help to explore and infer sub-surface structures in a better way.

A maiden attempt has been made through this study to integrate all available geo-scientific data along with recently acquired high precision gravity data and bring out a reasonably reliable sub-surface structure and open this area for further exploration. High precision gravity data was acquired along four profiles (a total length 1100km) in logistically difficult terrain in Chambal valley to delineate the thickness of trap, sediment and depth to basement. As Northern part of the study area is devoid of trap and over which few seismic profiles of good quality are passing, they are integrated with other data sets of the study region, viz., vintage gravity, aeromagnetic, seismic, remote sensing, rock properties, topographical and geological data.

Thickness maps of trap, sediment and depth to basement in Chambal valley have been inferred by our integrated approach, thereby leading to 3D models of subsurface in the study region. The study has shown a way forward to use an integrated geophysical approach for determining sediment thickness below trap and depth to basement in Chambal valley for hydrocarbon exploration. The designed methodology and achieved result could lead to better depth model along with acquisition of 2D and 3D seismic for targeting Mesozoic sand below the trap covered area of Chambal valley. The paper could be a reference mark for further research for estimation of trap thickness and sediments below it in a localized pool as search for hydrocarbon prospects in sediments underlying basalt have given a new dimension to exploration activities now a days.

Introduction

The Vindhyan basin in the central part of the India is a large intra-cratonic super order negative structure with a succession of sandstone, shale and limestone/dolomite with of volcaniclastic sediments (Porcellanite) particularly in lower part. The basin is divided into eastern sector (Son valley) and western sector (Chambal valley) and is sickle-shaped, girdling the basement of Bundelkhand Granite-Gneiss complex in the middle. The Bundelkhand Granite Massif particularly in the central part of the basin gives an arcuate shape with Proterozoic sedimentation having taken place all around the massif. Vindhyan basin is bounded by two deep crustal fractures namely GBF on north-west and Son-Narmada lineament in south-east and their periodical rejuvenation has exerted significant control over the geometry and evolution of basin.

Chambal valley (Fig.1a) of Vindhyan basin occupies southeastern part of the states of Rajasthan and southwestern parts of Madhya Pradesh. The 3-D model elevation map is shown in Fig.1.1b.Its terrain is drained towards northeast into Yamuna river through the catchments of Chambal river basin and comprises of tributaries like Parbati, Kali-Sindh, Parwan, Ahu and Mej. The drainage map of Chambal valley sector is shown in Fig.1.1b. The Gandhi Sagar and Rana Pratap Sagar water reservoirs on Chambal River are prominent landmarks of Chambal valley and their distinct features is seen in satellite images of Fig.1.1d & 1.1e. Chambal valley is delimited to the west and northwest by the Great Boundary Fault (GBF), by the Bundelkhand Granite Massif (BGM) in the east. Towards north near Dhoulpur, it grades into the Gangetic plains, whereas in the south Deccan traps envelopes the sediments of Chambal valley which is inferred to extend up to Dhar.

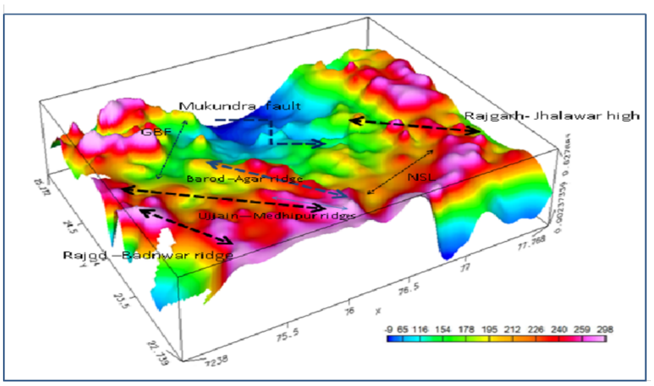


Fig. 1a) Geological map of Vindhyan basin

Fig. 1b) 3D Elevation model of Vindhyan basin

. (Source: Geological Survey of India)

Fig.1.1b) Drainage map of Chambal valley (Source: ONGC).

Fig. 1.1c) Tectonic elements of Chambal valley

Study area

Trap covered part of Chambal valley shown in Fig.1.1c and 1.2a has been considered for estimation of sediments and trap thickness though data was considered for entire Chambal valley. The study area is bounded between 74º45' & 77º45' longitude and 22º45' & 25º15' latitude i.e. 330 km x 275 km = 90,750 sq.km. Trap covered area is bounded between 75º15' & 77º30' longitude and 22º45' & 24º30' latitude approximately which works out to 192 km x 192 km or 36,874 sq.km.

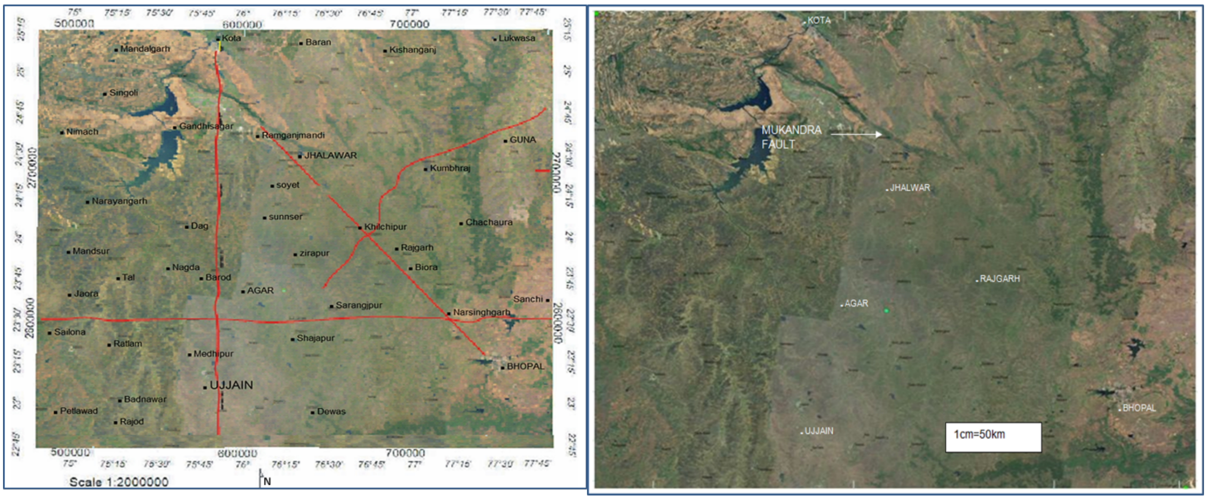


Fig- 1.1d) High precession Gravity profile (red) on satellite image of study area. Fig-1.1e) Zoomed satellite image of Chambal valley.

Objectives of study

Prime objective of study is to map sediment thickness below trap in Chambal valley. It is in this context that the work has been carried out, by undertaking a systematic evaluation of available geological, gravity, magnetic, seismic, rock properties and remote sensing data. Thus the overall objectives are as follows:

1. Integration of high precision gravity data along four profiles in trap covered Chambal valley and integrate with regional gravity data.

2. To utilize available seismic and aeromagnetic data for constraining the sub-surface gravity models.

3. To infer thickness of trap, sediment and depth to basement.

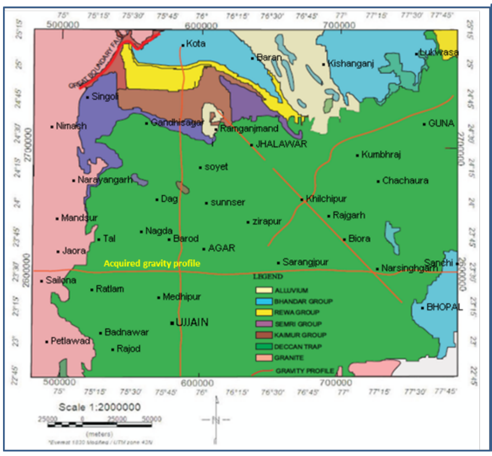


Fig. 1.2a) Study area along with different stratigraphic units.

(High-precision gravity Profiles in red /black colored lines)

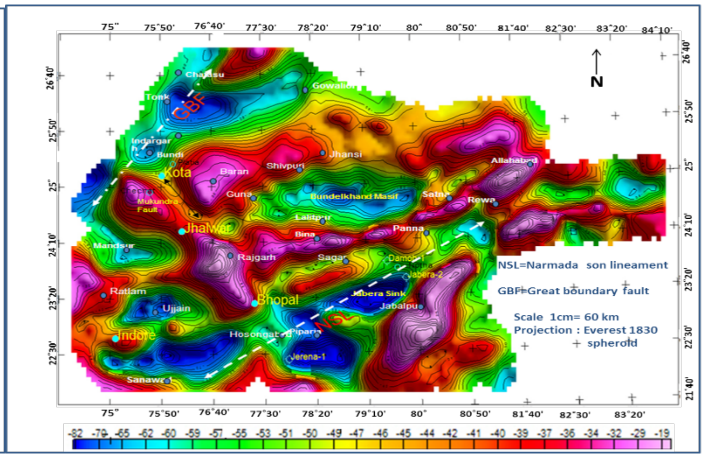


Fig. 1.2b) Compiled Bouguer anomaly map of Vindhyan basin

Gravity and Magnetic data processing

Gravity data

Regional and newly acquired gravity data were reduced to 250m datum above MSL as minimum elevation in the study area was 250m to preserve shallow causative source effects. Latitude correction using Cassinis formula (1930) was applied to our recent high precision gravity data also depth to make it consistent with earlier regional gravity. Subsequently whole volume of data was merged and Bouguer anomaly values were calculated with a Bouger density of 2.65 gm/cc, which was arrived after measuring the bulk density of rock samples collected from field.

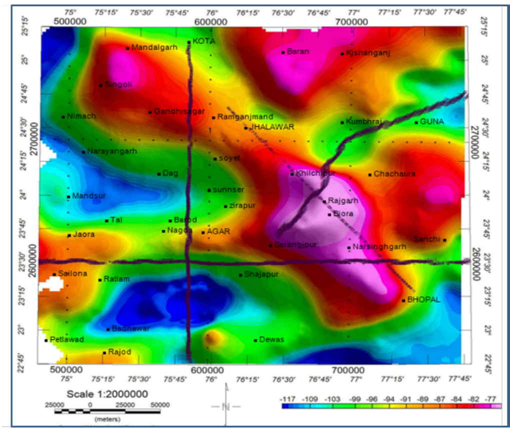


Fig. 2.1.1 Bouguer anomaly map of Chambal valley

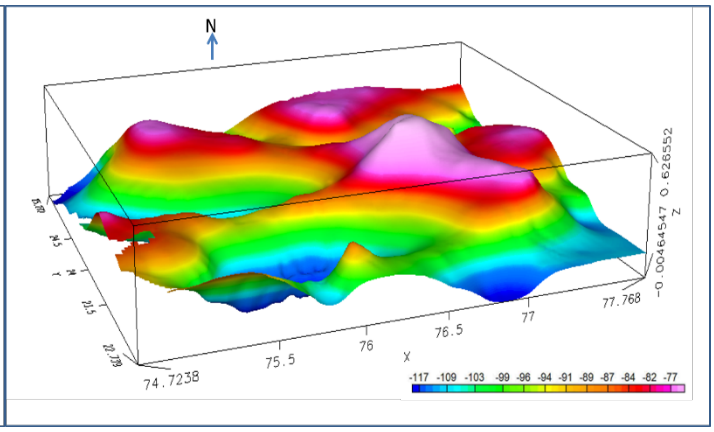


Fig 2.1.1a 3-D view of Bouguer anomaly over Chambal valley

Terrain corrections are computed based on industry standard Plouff method. In this case, terrain is modeled as a set of vertical rectangular prisms representing difference of terrain shape referred to the Bouguer layer. Satellite Radar Terrain Model (SRTM 3) was used up to a diameter of 120 km in radius from each gravity station. Finally, complete Bouguer anomaly map with contour interval of four mgal for entire Vindhyan basin was generated for regional understanding (Fig.1.2b). A separate Bouguer anomaly map of study area (Chambal valley) is also generated and is shown in Fig. 2.1.1. A 3-D view of Bouguer anomaly of Chambal valley has been prepared (Fig. 2.1.1a.)

In Fig 2.1.1a, Bouguer anomaly values varies between - 56 and – 117 mgal over Chambal valley. Tectonic and geomorphic elements like faults, ridges, lineaments which influence gravity features. The major features of this area are punctuated by several smaller features having diverse trends. Salient features of Bouguer anomaly map are briefly described below**:**

1. Most important feature is NW- SE trending gravity high along Kota –Rajgarh – Bhopal sector terminated at the GBF near Bundi and at Sanawad –Hoshangabad low.

2. Another NW- SE trending gravity low, running parallel to the above mentioned gravity high roughly coincide with Mukandra fault.

3. Towards west of Mukundra fault lies Mandsaur gravity low which appears to coincide with thicker pre-Vindhyan sediments as seen on seismic section. Similarly, the gravity low in Sanawad–Hoshangabad area also coincides with inlier of Central Indian Granite with Vindhyan sediments towards west side surrounded by Deccan traps in north, west, and south. Son –Narmada lineament (SNL) significantly influences gravity anomaly in this area.

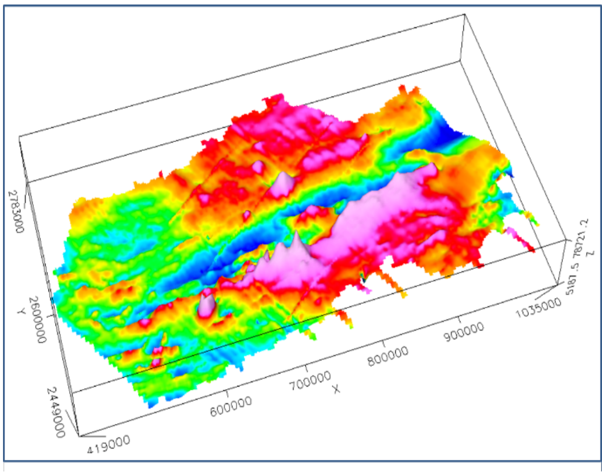
4. A small gravity low, observed south of Guna, appears to be connected with the famous gravity low of Bundelkhand craton.

Magnetic data

The aeromagnetic data was acquired through National Remote Sensing Agency (NRSA), Hyderabad in two phases during 1993-94 and 1994-95 at an elevation of 1500 meter and 2500 meter respectively. The data has been processed and anomaly maps are generated for Phase-I and Phase-II. Subsequently the data was merged to a common elevation of 2000m and a composite anomaly map (Fig. 5.2) was generated

Removal of any residual leveling errors

Magnetic anomaly values were computed from the above corrected Total Magnetic Field Intensity data after applying International Geomagnetic Reference Field (IGRF) model.Finally aeromagnetic anomaly map of Chambal valley is prepared which shows that a dominant E-W trending low in the central part. A high towards north-east may be due to Bundelkhand massif (Fig. 3.1). A 3-D viewof aeromagnetic anomaly distribution over Chambal valley is generated where a prominent east-west trending low is observed Fig.3.1.1.



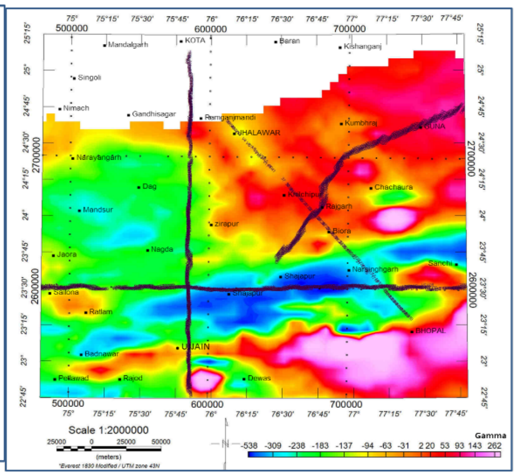


Fig. 3.1.1 3-D view Aeromagnetic anomaly of study region. Fig. 3.1 Mag anomaly map with superimposed high-precion gravity profiles in black colour

Residual gravity

Four different residual gravity anomaly maps were prepared using spectral filtering (wavelengths of 32 km, 29 km, 18 km and 10 km.) Out of these 32 km cutoff wavelength found to be the most suitable map as it validated prominent geological features of the area. It has brought out all known tectonic elements of the area like Mukundra faults, NSL, Asmara lineament, etc in addition to locating isolated highs and lows which can be termed as local high such as Baran high, Gandhisagar low etc associated with name of places. Series of SSW-NNE oriented parallel faults system have been observed in south which may be attributed to NSL zone. In addition many transverse faults in SSE-NNW direction have been marked which are originated due to the GBF and terminated at NSL zone or against Asmara lineament (Fig. 4.1). where the blue coloured lines indicate inferred faults.Yellow dash line seems to represent a major fault.i.e Asmara Lineament. High precision gravity profiles (in blue colour) are also shown

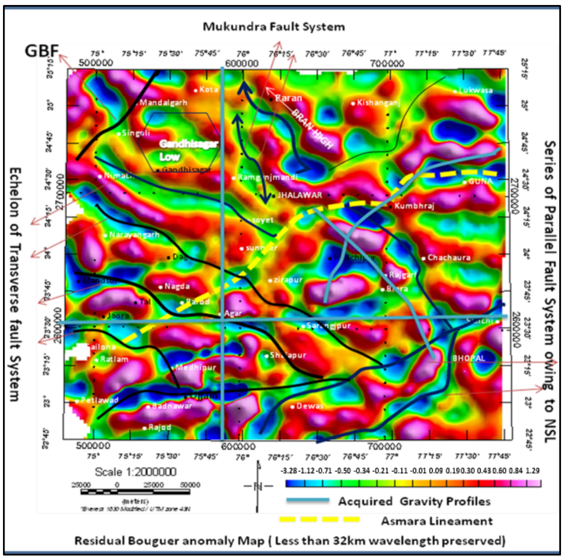


Fig. 4.1. Inferred faults and tectonic elements on residual gravity map.

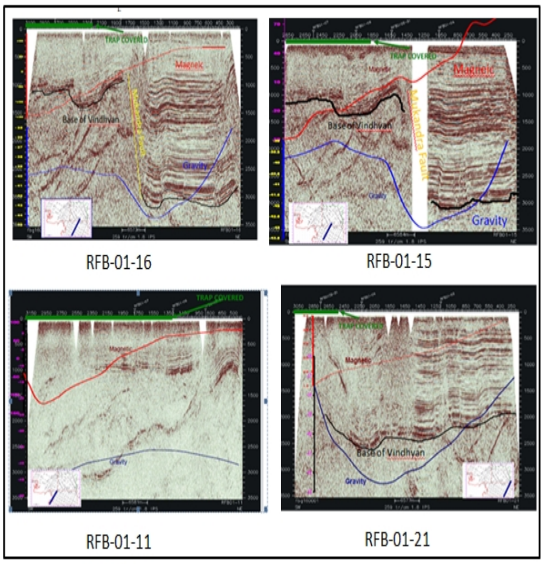


Fig. 4.2. Gravity - Magnetic signatures superimposed over Seismic

Gravity modeling along seismic profiles

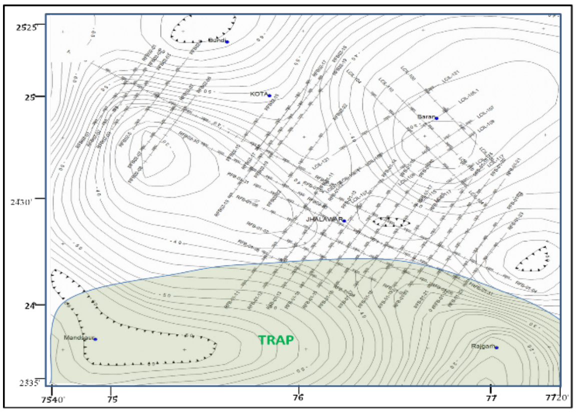


Table-1

Formation	Density contrast gm/cc
Bsement	0
Down thrown block of Basement	0.3
Vindhyan sediments	-0.155
Trap	0.15

Fig. 4.3 Gravity Magnetic signatures superimposed over seismic sections along four profiles

Gravity (blue) magnetic (red) signature along seismic profiles RFB-01- 16, 15, 13, 11, 19, 20, and 21 have been plotted, out of which in only four seismic profiles (RFB-01-16, RFB-01-15, RFB-01-11 and RFB-01-21 where effect of trap, sediment and the Mukundra fault (Fig. 4.2 and 4.3) can be seen.Modelling constraints are shown in Table-1.

Along each of the above mentioned eight seismic profiles, quantitative gravity modelling has been carried out available constraints such as with seismic markers, location of faults and geological sections. Gravity derived depth models of two such seismic profiles have been presented in (Fig. 4.4). These gravity profiles were extended up to 60 km on both sides of seismic profile on the basis of gravity values and topographical features to understand basement configuration in the sediment as well as in trap covered area.

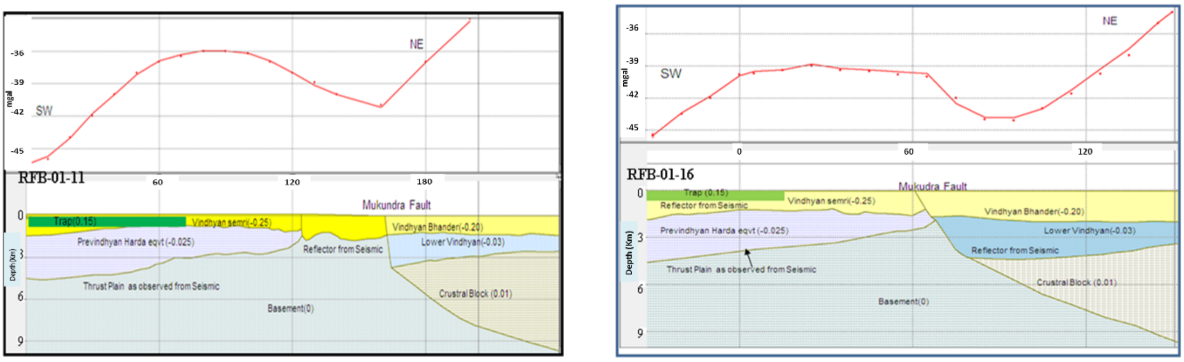
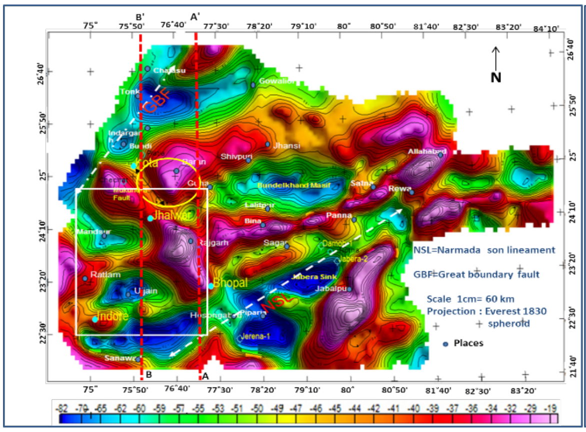


Fig. 4.4 Gravity modeling along seismic profiles RFB-01-16 & RFB-01-11

A sharp rise of gravity, east of Mukundra thrust has produced only a gentle rise on seismic section in this area (Fig. 4.2). For example, there is a fall of about 5 mgal across the thrust for a throw of 1 sec on seismic section. This is followed by gravity rise ranging from 8 to 10 mgal towards Baran high in northeast although seismic features are almost flat. This suggests the presence of a high density crustal block towards northeast. Further, this rise is partly due to elevated basement and partly due to high density of crustral block. Gravity modeling has taken care of these facts otherwise this rise cannot be explained using simple seismic data. The density contrast values used in modeling include inTable-5.

Gravity modeling along regional profiles

Two regional profiles are choosen along 76⁰E and 77⁰E longitude north-south (AA' and BB') to cut across gravity features in the study area (Fig. 5.1). These profiles (B'B shown in fig.-5.2) help us to know regional effect of trap, sediment and basement from known to unknown. They begin from seismic covered sediment area in the north and ends up over trap covered area towards south. Quantitative gravity modeling has been carried out along these profiles using results and information obtained from gravity modeling over earlier eight seismic profiles.



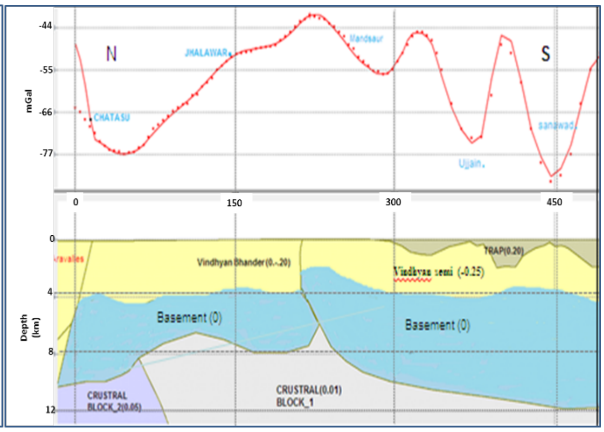


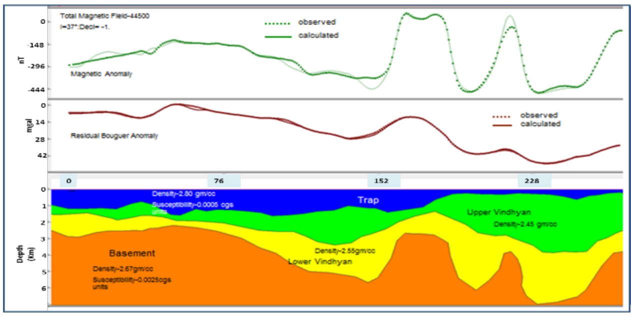
Fig. 5.1 Location of two N-S marked by red dashed lines regional profi**les.** . Fig. 5.2 Gravity modeling along Profile B'B

A'A and B'B (oval, rectangle and arrows denotes seismic coverage, study area and position of NSL and GBF respectively)

Depth information obtained from these two models gave general idea of trap, sediment and basement behaviour. The results confirm that there are two major crustral blocks in the area one north-west part of Mukundra thrust and the other towards southern part of study area.

6.1.7 Gravity magnetic modeling along high precision data Profiles.

Gravity modelling results such as **AA' and BB'** along with seismic profiles served as constraint for gravity modelling along four acquired profiles of high precision gravity data over trap in different segments of Chambal valley. These interpreted 2-D gravity magnetic modeling sections are induced in Figs. 5.3 &5.4.



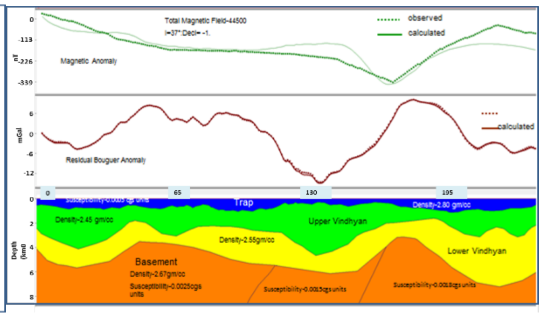
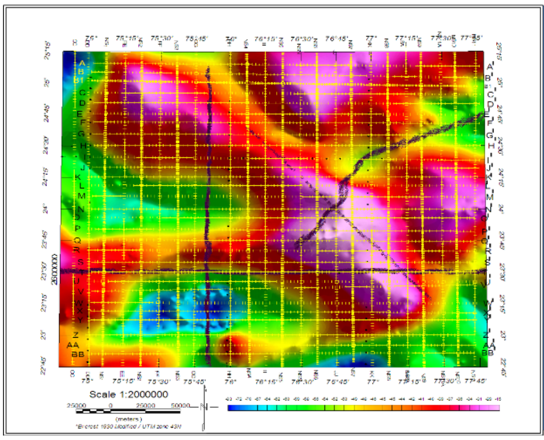


Fig. 5.3. 2-D Gravity and magnetic modeling along W-E profile Fig 5.4 2-D Gravity and magnetic modeling along N-S profile

These illustrations have brought out better imaging of sediments below trap along with basement undulatios. Now, we have gathered sufficient information of depth to basement, sediments and trap over different segments of Chambal vellay from seismic profiles, two regional profiles and four acquired gravity profiles.

Gravity Modelling over entire study area

By keeping achieved results and geological features in mind modeling exercise over entire Chambal valley has been intiated to generate thickness map of both trap and sediment.In order to achieve this objective, twenty eight vertical and thirty two horizontal gravity profiles in a grid (Fig. 6.1) have been constructed over entire study area cutting across tectonic elements with a grid size of 8 x 8 km. Depth models have been generated for all these sixty profiles by honouring our earlier models. Figures 6.1&6.2 represent one of such generated profile.



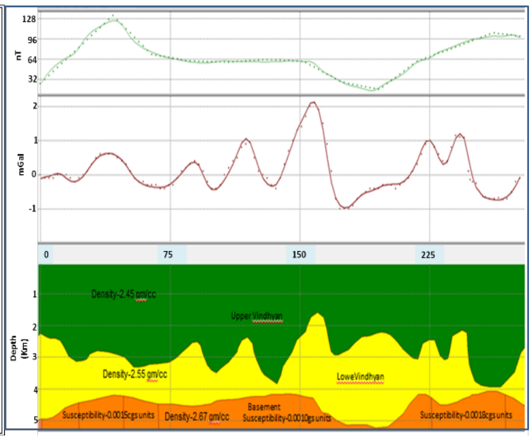


Fig. 6.1) Location of modeled gravity profiles, AA',

Fig. 6.2) 2-D Gravity and magnetic modeling along profile AA'

3-D modeling of the study region

Depth information of trap, sediment and basement derived from all those sixty gravity and magnetic profiles is used to generate 3D model of trap covered area Fig. 6.3. The advantage of 3D depth model is that in any desired direction a profile can be drawn to validate important tectonic features of interst.

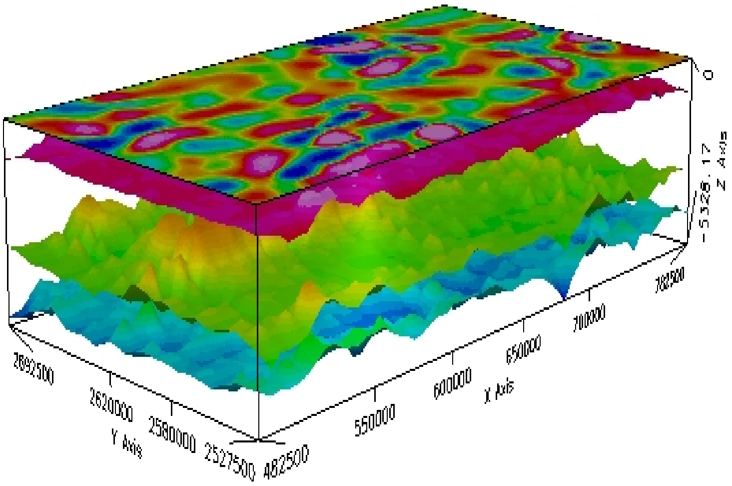


Fig 6.3 Inferred Trap, sediment (below trap) and basement -3D depth model. The top layer represents residual gravity in image format. It is underlain by trap (in pink), sediment (in green) and basement (in blue**).**

Two of such reconstructed profiles passing through Bhopal-Rajgarh-Jhalawar and that through Topic of Cancer are presented in (Fig.6.4).

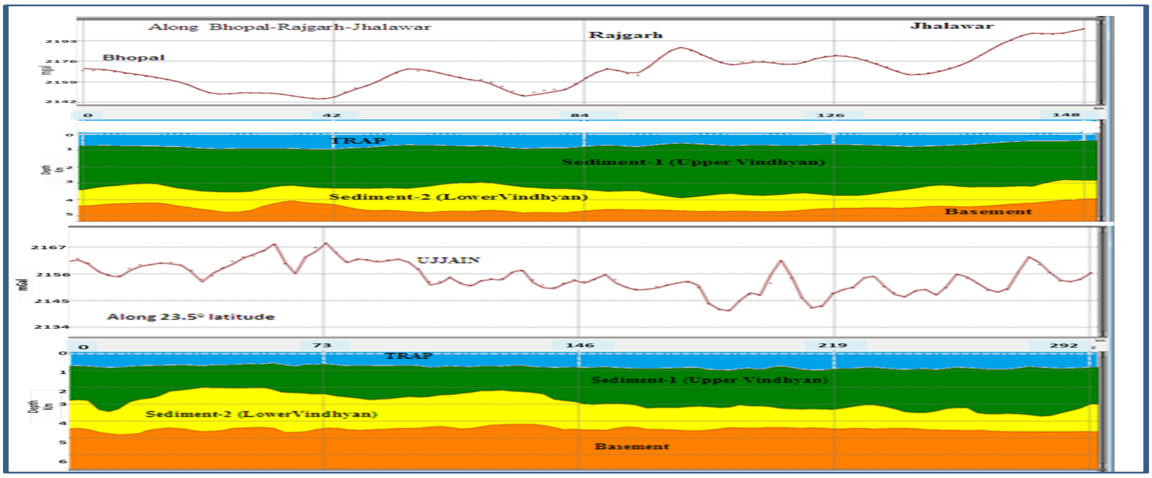


Fig 6.4. Depth profile extracted from 3-D model

7.1 Results

Depth information of trap, sediment and basement derived from integrated study of gravity, magneti, seismic, geological and topographical data over the trap covered area has been used and generated thickness map of trap, sediment and depth to basement which are shown in (Figs. 7.1a; 7.1b; and 7.1c.)

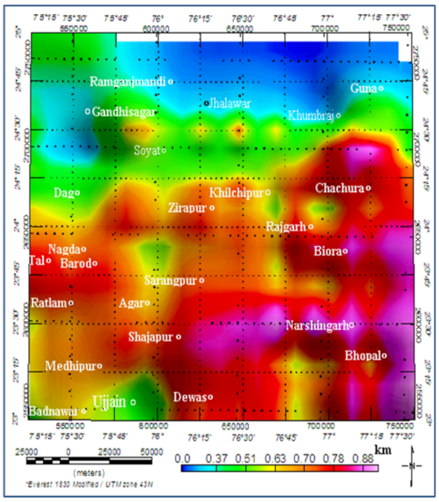


Fig. 7.1a) Inferred trap thickness map

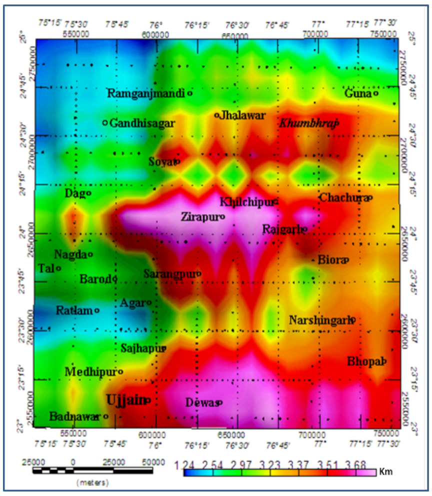


Fig. 7.1b) Inferred sediment (below trap) thickness map

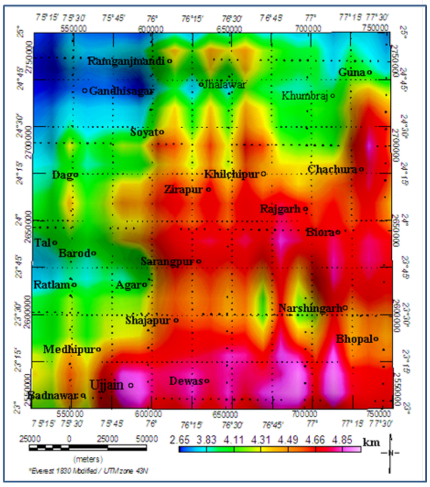


Fig. 7.1c) Inferred depth to Basement map

The results indicate that thickness of sediment in northern part of Chambal valley is varying from two to three kilometers. Over trap covered area sediment thickness is one to four kilometers depending upon trap thickness. In general, trap thickness is 300m - 700m except in some particular patches, where high gravity and magnetic values are observed, the thickness may reach nearly one kilometer like in Rajgarh and Sarangjpur. Depth to basement is varying from 2.5 - 5 km from north to south.

In addition, regional faults, structural highs and lows of Chambal valley and also their trends have been identified from residual map of gravity Fig. 4.1d. Some of them are corrobareted with topographical and suface data such as Asmara lineament, Mukundra thrust, etc. Also we have obtained esimated depth of Lower Vindhyan and Upper Vindhyan sequences over northern part of Chambal valley based on seismic data.

Conclusions

1. Surface geology, measured physical properties on representative rock samples, meagre boreholes (2No.), seismic reflection profile network at the northern boundary of study region, aeromagnetic data over study region, limited high-precion gravity profile data (Four profiles) and compiled gravity data have enabled us to infer 3-D structure of sediment thickness below trap covered study region.

2. Residual gravity map of area has identified several local gravity highs and lows and their orientation. The corridor of main low of Chambal valley is passing though places like Barod, Suser, Agar and south of Jhalawar. This low is cutting across the Chambal valley in northeast and southwest direction and probabely this represents the boundary of southeastern and north eastern custral blocks.

3. Broadly, the inferred sediment thickness varies from 2 to 4 km and it increases from north to south in the study region.

4. Trap thickness increases to one km approximately from north-south in the study region

5. Inferred basement depth varies from two to five km from north to south in the study region

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