INTEGRATED GEOPHYSICAL MAPPING OF SEDIMENT BELOW DECCAN TRAPS IN CHAMBAL VALLEY

A THESIS

Submitted in partial fulfilment of the
requirements for the award of the degree
of

DOCTOR OF PHILOSOPHY

in

GEOPHYSICS

by

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DEPARTMENT OF EARTH SCIENCES
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE-247667 (INDIA)
MAY, 2014

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled "Integrated geophysical mapping of sediment below Decan traps in Chambal valley". in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy and submitted in the Department of Earth Science of the Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out during December, 2010 to May, 2014 under the supervision of Dr. Ramabhatla G. Sastry, Professor, Department of Earth Science , Indian Institute of Technology Roorkee, Roorkee and Sri J. N. Prabhakarudu, Deputy General Manager (Geophysics), KDMIPE, ONGC, Dehradun.

The matter presented in the thesis has not been submitted by me for the award of any other degree of this or any other Institute.

(Dipendu Saha)

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

(J.N. Prabhakarudu) (Rambhatla G. Sastry)
Date: ____________ Supervisor Supervisor

The Ph. D. Viva-Voce Examination of **Mr. Dipendu Saha**, Research Scholar, has been held on . . . .

Signature of Supervisor (s) **Chairman, SRC** **Signature of External Examiner**

Head of the Department/Chairman, ODC

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 thesis 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.

Acknowledgement

I hereby express my heartfelt grateful to my research supervisor Dr. Rambhatla G Sastry, Professor, Indian Institute of Technology, Roorkee for his inspiring guidance and constant encouragement for research work. I am also greatly indebted to Dr. R.G. Sastry for introducing me to outstanding geophysical problems related to delineation of sediments below traps and for scientific discussions, critical suggesstion at every stage of research work right from course study of pre-Ph.D. level to final stage of thesis writing without which it would not have been possible to complete this work.

I specially thank ONGC for giving permission to do Ph.D. in Indian Institute of Technology, Roorkee. I am grateful to my internal supervisor Shri. J.N.Prabhakarudu, DGM (GP), KDMIPE, ONGC, Dehradun for his valuable guidance and lengthy scientific discussions. I also hereby acknowledge the support & suggestion rendered by him during the tenure of Ph.D. work.

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Glossary of terms

Abbreviation	Meaning
NSL	Narmada-Son Lineament
NELP	National Exploration Licence Policy
GBF	Great Boundary Fault
BGM	Bundelkhand Granite Massif
CIL	Cairn India Limited
CVS	Chambal Valley Sector
MSL	Mean Sea Level

CHAPTER-1

Introduction

Proterozoic era witnessed extensive crustal down warping and sedimentation on global scale. In India, such sedimentations are found near three cratons viz Singhbhum, Dharwar and Bundelkhand. Vindhyan basin in north-central part of India represents one of the most spectacular Proterozoic basins developed in the shadows of Bundelkhand granite massif, Aravali-Delhi and Satpura orogenic belts Fig.1.

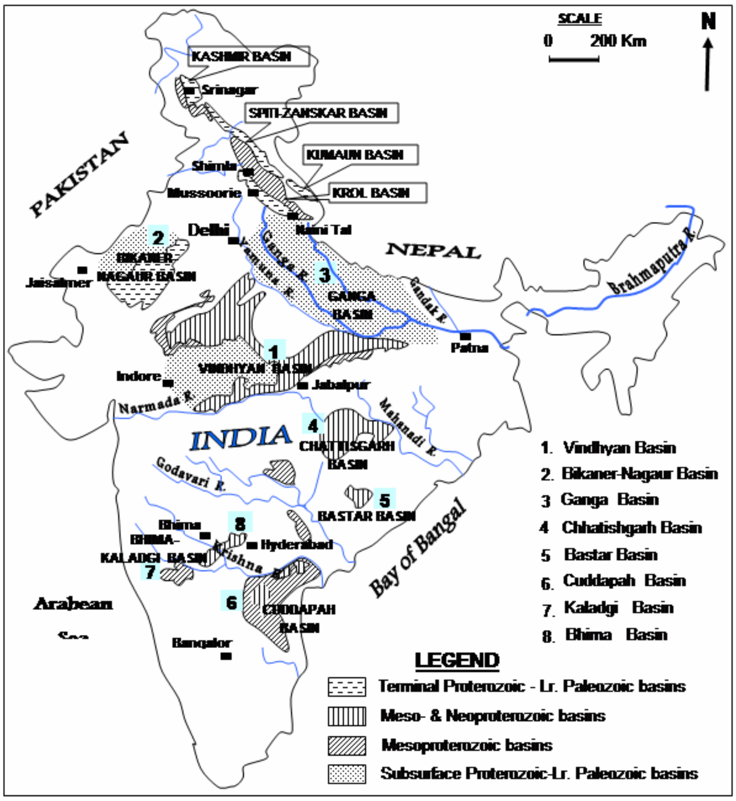


Fig.1 Map of major sedimentary basins in India (Source: ONGC)

Vindhyan basin is a classic example of Proterozoic intracontinental basin in central part of India is widely regarded as a high-risk, high-gain frontier area for exploration. This arcuate shaped basin is one of the largest Proterozoic basins of India. It covers an area of about 162,000 km^2. In addition, about 40,000 km^2 of Vindhyan equivalents lie under the Gangetic alluvium towards northeast. Northern extension of basin in Ganga valley beneath the Gangetic alluvium is postulated based on geophysical and drilling data of ONGC. However, absence of Vindhyan sediments in the subsurface sequence of Ganga valley has been reported recently based on Acritarch studies (Prasad & Asher, 2001). Vindhyan basin is divided into two sub-basins – Chambal valley in west and Son valley in east. Southern part of Chambal valley is covered under Deccan trap. Precambrian gneisses and metasediments border the basin in east and south-southeast. Delhi Aravalli orogenic belt (the Great Boundary Fault of Rajasthan) bounds the basin on west and northwest. Son-Narmada lineament limits the basin to the south. Bundelkhand massif occupies north-central part and is fringed by Bijawar rocks and their equivalent Gwalior rocks over which Vindhyan sediments lie unconformably, with outcrops veering round it Fig.1a (Basu, 2007).

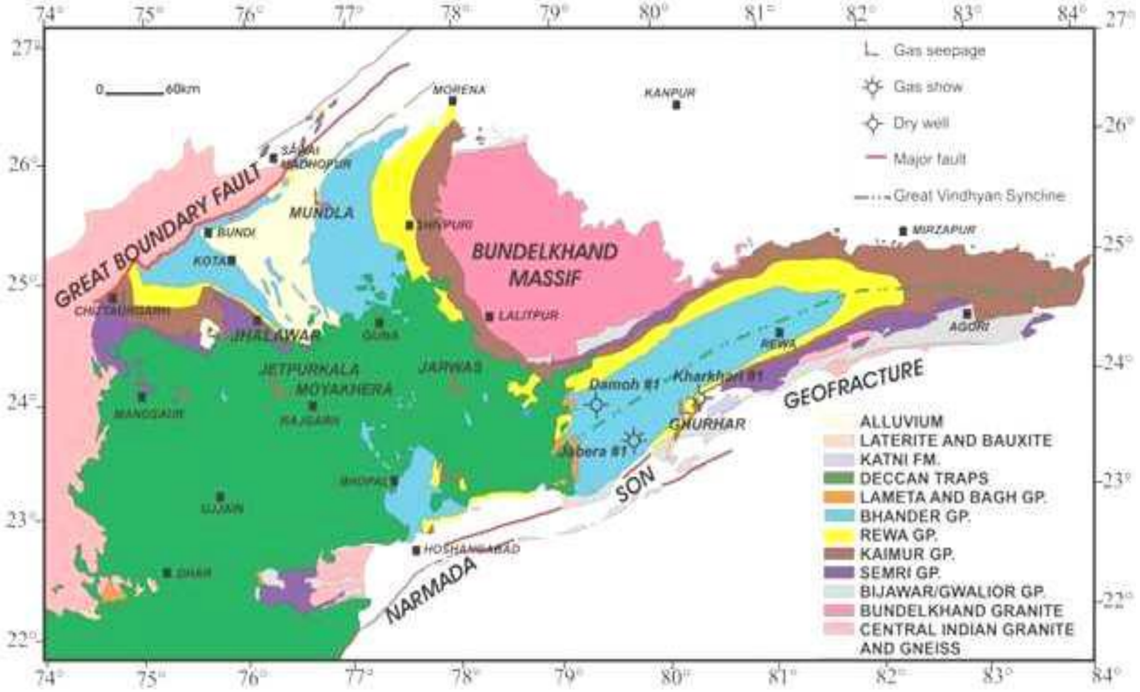


Fig. 1a) Geological map of Vindhyan basin (Source: Geological Survey of India)

The Son valley sector lies ENE-WSW and its depositional axis runs close to Son- Narmada lineament and swerves to northwest in Chambal valley. Five exploratory deep wells viz. Jabera-1 & 2, Damoh-1 & 2 and Kharkhari-1 have been drilled in tSon valley. A non-commercial gas show 2000 to 3000m³/day from fractured siltstone reservoir of Jardepahar Porcellanite formation in Jabera-1 on Jabera dome has been the only silver lining in the basin and commercial success has eluded ONGC so far. In Chambal valley two exploratory locations have been drilled over trap free zone on the northern side. The basin has evoked considerable interest for hydrocarbon exploration because a number of basins coeval to it, e.g., Lena-Tunguska petroleum province in eastern Siberia, Amadeus and McArthur basins in Australia, are known hydrocarbon producers, besides Birba (South Oman), Tarim and Sichuan (China), Bikaner-Nagaur (India) are well known among Proterozoic basins of the world which have yielded or have shown presence of hydrocarbons.

Despite perceived potential, the basin is largely unexplored as it still lacks comprehensive sub-surface information for proper evaluation. Considering its vast expanse, hardly any deep wells are drilled. Absence of well data, meager seismic coverage, handicapped structural and stratigraphic studies. The present study involves integration of gravity magnetic with available geological data in Chambal valley, Vindhyan basin for better understanding of sub-surface.

1.1 Basin extent of Chambal valley

The estimated area of Vindhyan basin is 162,000sq.km for both Son valley and Chambal valley put together Fig.1.1a. An attempt has been made to establish the basinal limits in trap covered part of Chambal valley.

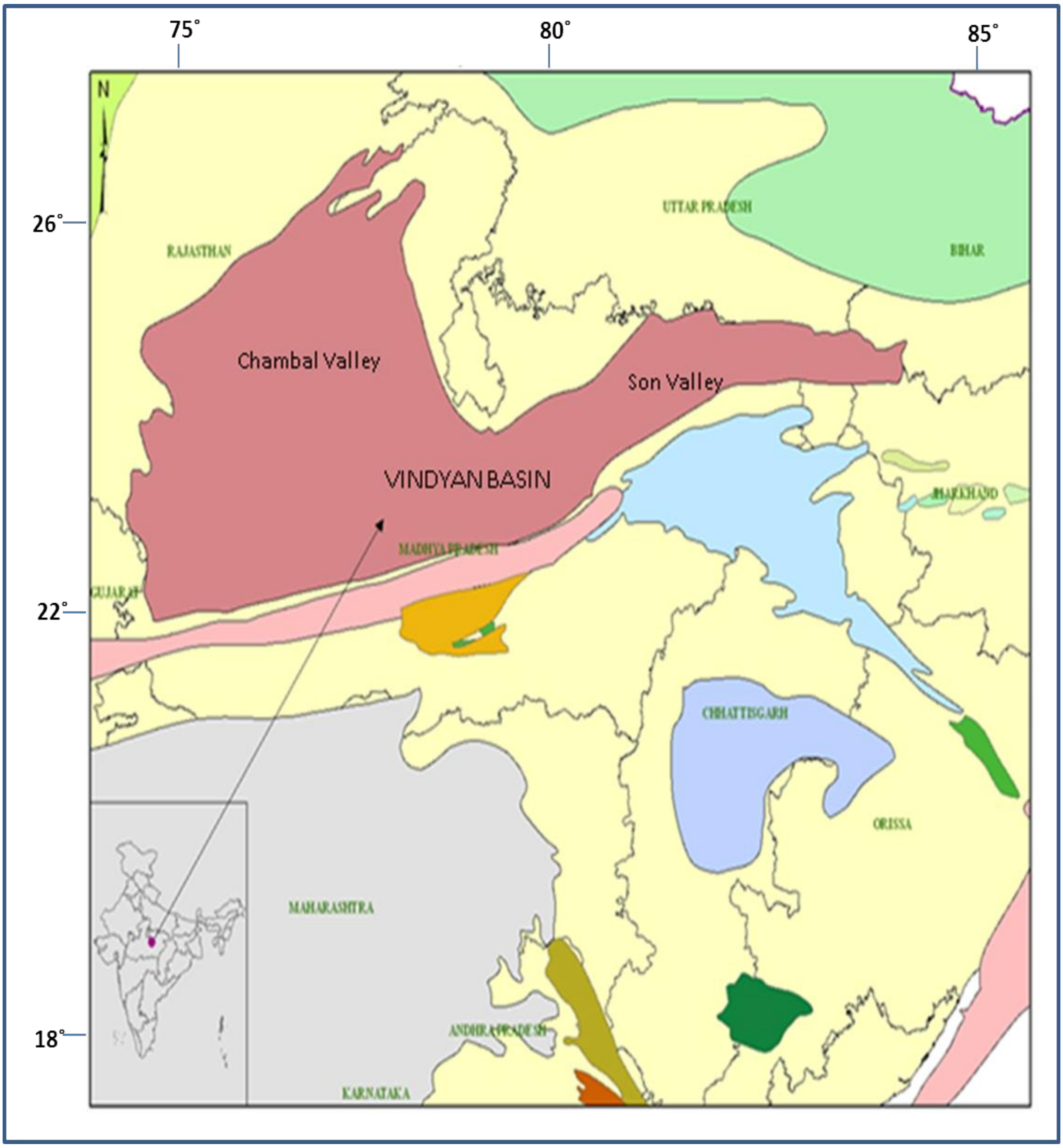


Fig.1.1a) Location map of Chambal valley. (Source: ONGC)

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

Chambal river basin has been obtained from drainage map of National Atlas of India 1983 Fig. 1.1b. Chittaurgarh to north-eastwards of the Great Boundary Fault (GBF) has been taken as western limit. Similarly, from Guna onwards outcropping limit of Bundelkhand Granite Massif (BGM) has been taken as north-eastern limit. Due consideration has also been given to stratigraphic contacts and diverse tectonic elements Fig. 1.1c.

From the above calculated area of Chambal valley is as follows:

<u>Chambal valley sector (CVS)</u>

(i) Non trap exposed area: 53,876 sq. km

(ii) Deccan trap cover area: 36,874 sq. km

(iii) Total area of CVS (i+ii): 90,750 sq. km

Trap covered part of Chambal valley shown in Fig.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 74°45' & 77°45' longitude and 22°45' & 25°15' 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.

1.2 Study area

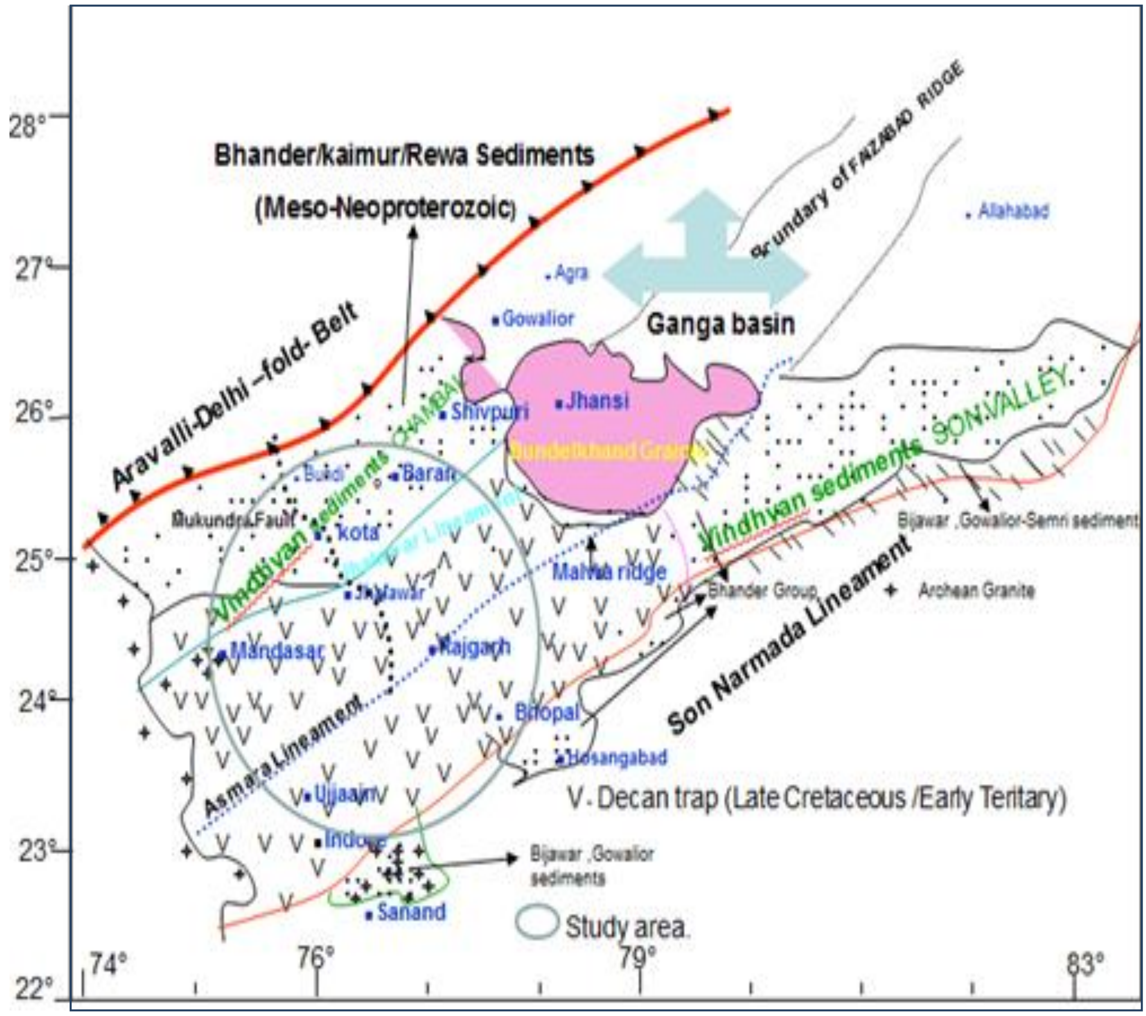


Fig. 1.1c) Tectonic elements of Chambal valley

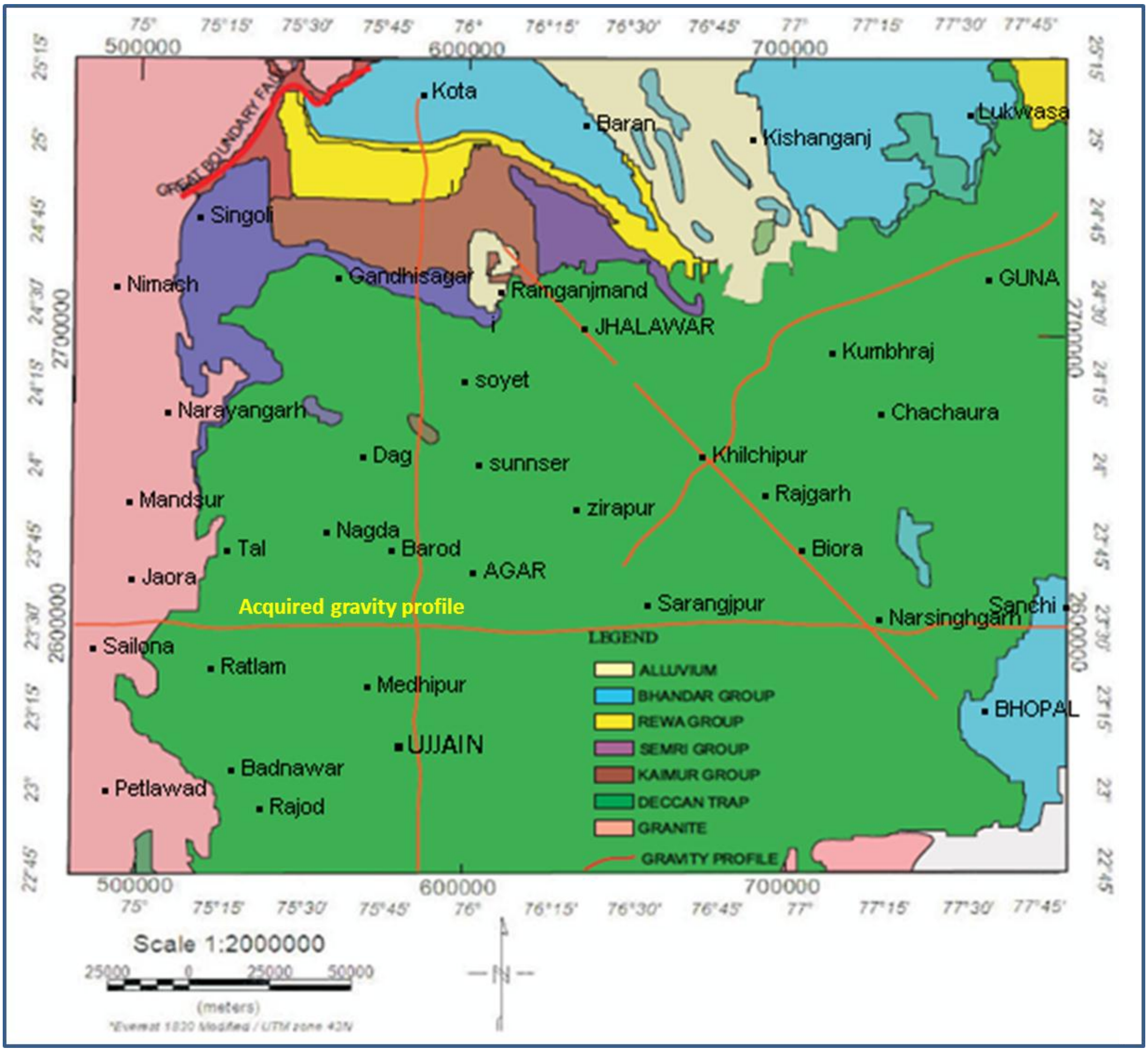


Fig. 1.2a) Study area along with different stratigraphic units

1.3 Geological aspects

Chambal valley exhibits a near orthogonal grain in relation to Son valley and the fill, which is largely deposited under shallow marine conditions, veers around the Bundelkhand massif. Ample evidences indicate that extensional tectonics prevailed during initial phase of sedimentation and compressive tectonics subsequently modified the fill giving rise to inversion structures. This is corroborated (Kalia,1989) by extrusion of lava flow (Fig. 1.3a) and seismic imaging of half-graben features at Vindhyan base, while the Kaimur, Rewa and Bhander levels exhibit structurization and subsequent reactivation.

Predominant exposed folds in Chambal valley are a) N-S trending intensely folded area of Chittaurgarh-Nimbaheranorth of Neemuch, b) NW-SE trending folds of Rawatbhata-Jhalawar area, c) NE-SW trending folds of the GBF linkage and d) NNE-SSW fold trend in Mukandara hills.

North-south trending folds occupy the area contiguous to Chittaurgarh- Nimbahera to north of Neemuch where the strike swings to NE-SW. These folds are forming a complex of second order anticlines and synclines, exposing Kaimur sediments over the hills and Semri group of rocks (Suket Shale, Nimbahera Limestone) in their cores Fig.1.3a.

These structures are wave-form open folds, discontinuous, generally asymmetrical, having steeper western limb. These folds probably have limited subsurface extension as can be deciphered from number of limestone quarries, where limbs of folds that dip 20°-25°, shallow up to 5°-8° within a depth of 20 to 30 m. These folds along with Mukundra fault are clearly visible on Google image of Chambal valley. (Fig. 1.3b & 1.3c.)

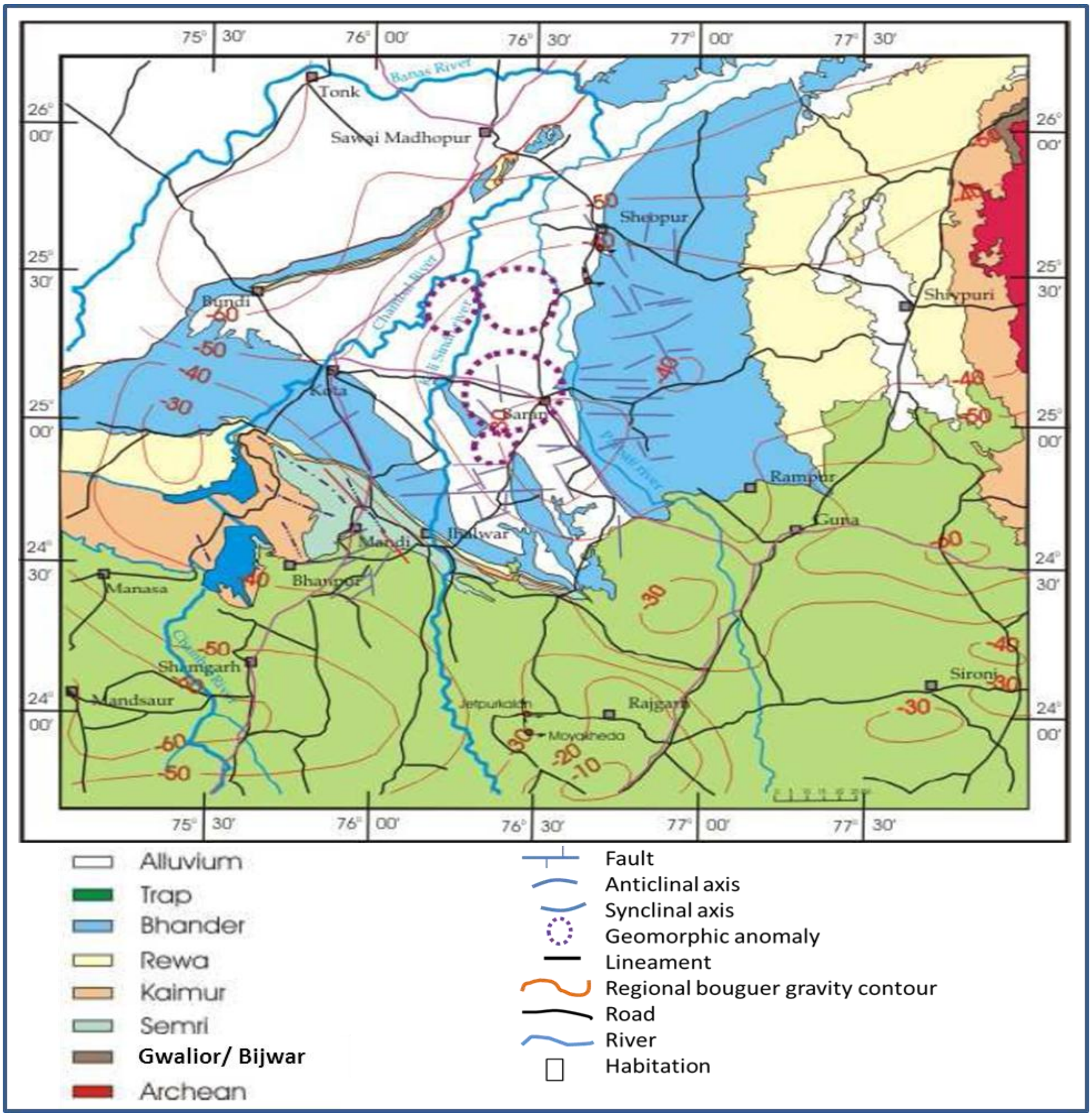


Fig. 1.3a) Geological map of Chambal valley (Source: ONGC)

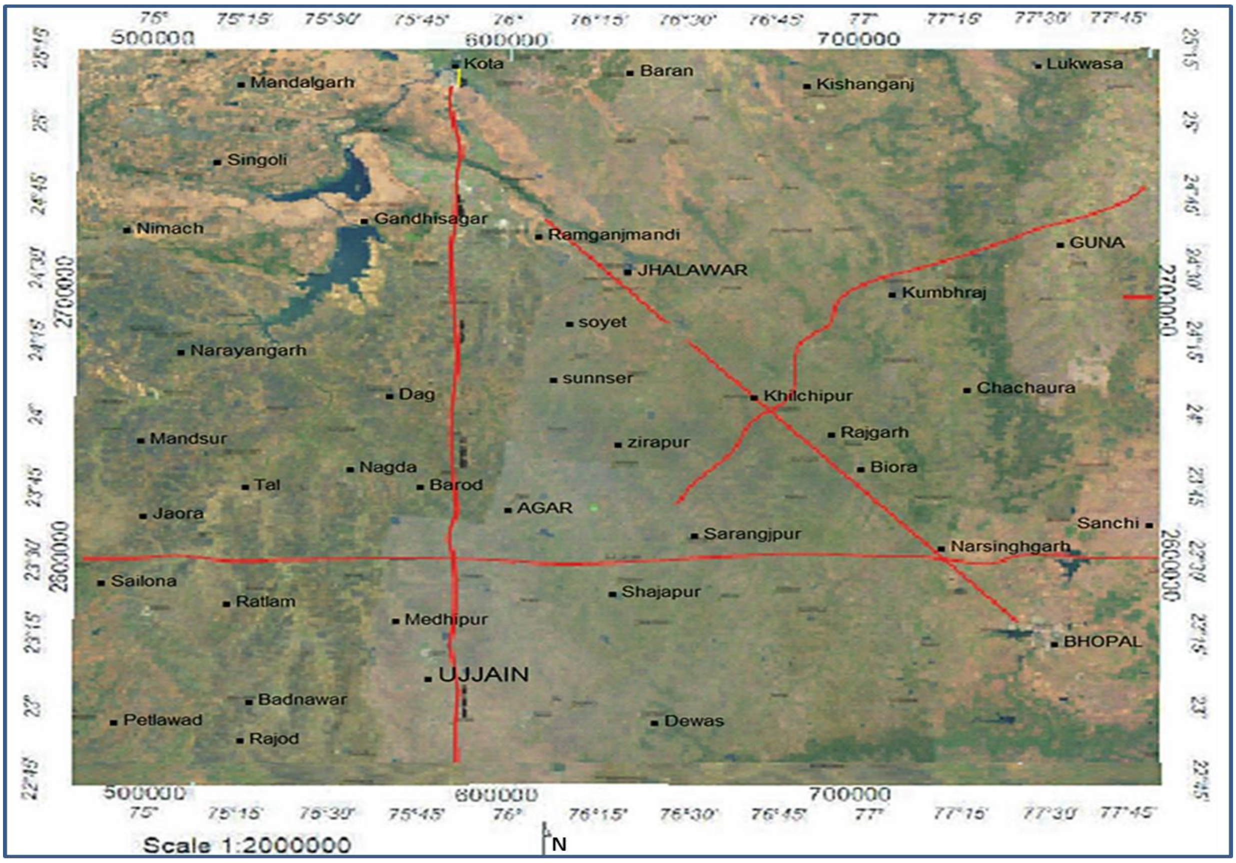


Fig. 1.3b) Google image of Chambal valley

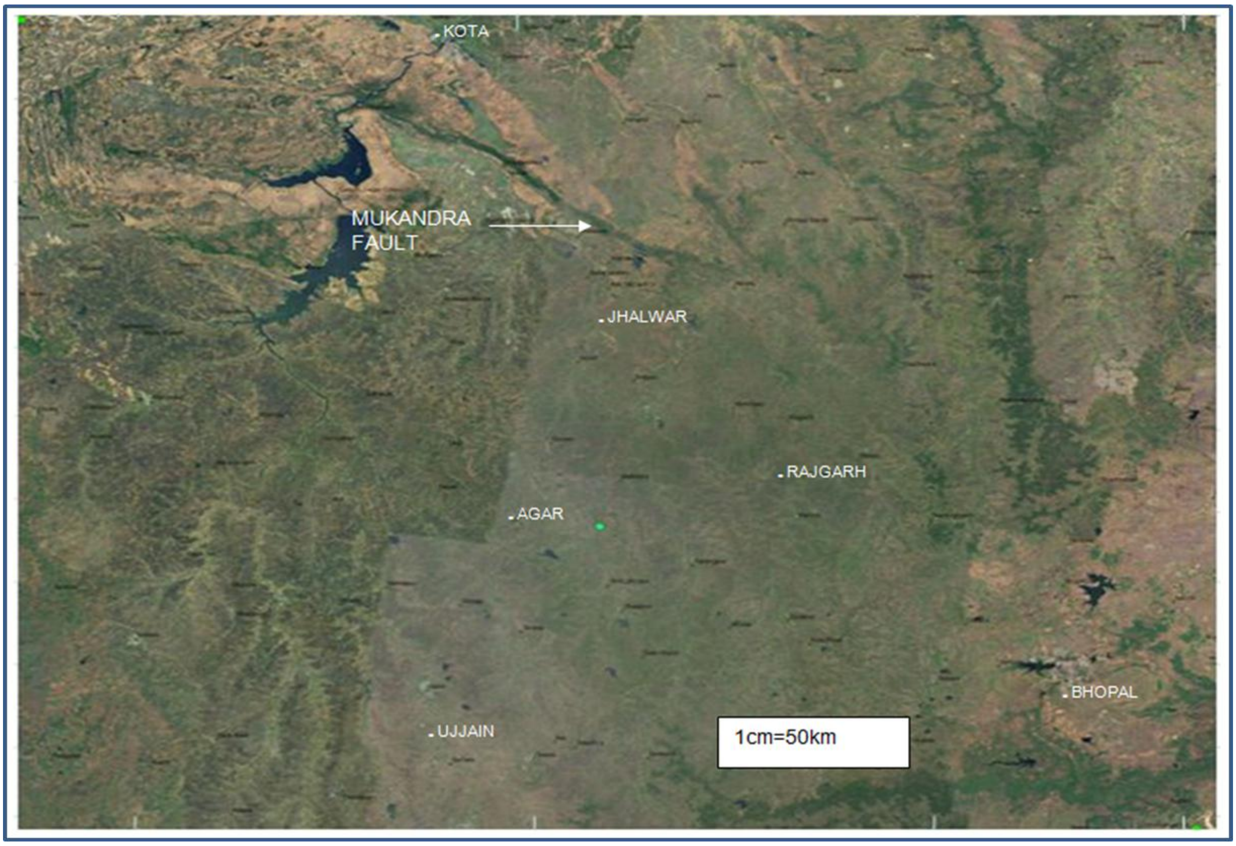


Fig. 1.3c) Zoomed Google image of Chambal valley

1.4 Review of previous efforts

Vindhyan sediments in Rajasthan and Madhya Pradesh states have been extensively mapped by geological investigations and studies of the basin being initiated from the middle of 19th century by different agencies including Geological Survey of India and ONGC in both Son valley and Chambal valley. The Basin attracted the attention of explorationists because of its large expanse of shallow marine sedimentary rocks and its huge thickness.

Medlicott (1860) took some traverses in parts of eastern Rajasthan to analyse the western extension of Vindhyans.

Mallet (1869) made a brief comment on correlating the conglomerate at base of Kaimur from Panna to Gwalior.

Hacket (1870) was the first to carry out geological investigations in Gwalior area and is regarded as the pioneer of Chambal valley. He described basement rocks around Gwalior and coined the name ‘Gwalior Series’. He also described the Bundelkhand Granites around Gwalior.

Hacket (1881) observed a boundary fault trending NE-SW for about 230 km separating the Vindhyans from older rocks between Chittor and Hindaun. He also recorded some Vindhyan outliers north of the GBF (Great Boundary Fault).

Bundi area was initially mapped by Hacket and Kishan Singh (1881) and later modified to a large extent by Coulson (1927). He overlooked the presence of Lower Vindhyan sediments in Bundi-Indergarh area and to justify it, marked a 70 km long fault. Later on GSI followed suit (Prasad, 1984).

Heron in (1922) mapped the Karauli area, initially. Heron (1936) worked in detail aboutthe geology of Chittaurgarh-Nimach, Mandalgarh, Rawatbhata and Jhalawar areas. He considered Binota shales as unmetamorphosed equivalents of Aravalli’s east of the GBF and also observed conformable contact between Suket and Kaimur. He also opined that all formations younger than Kaimur thicken towards east of Bundi and Karauli area.

Geological investigations of Vindhyans in Chambal valley commenced in 1964 by ONGC when Srivastava and Ganju (1964) first mapped the Vindhyans of Gwalior-Sabalgarh-Karauli area.

Biswas *et al.* (1972) mapped the area between Lashkar and Gwalior and correlated exposed Vindhyans to pre-unconformity sediments of Ujhani Deep well-1 in Ganga basin.

Kailasam (1976) indicated that Aravalli–Bundelkhand Craton constitutes the basement beneath the Lesser Himalayan successions, and the Quaternary alluvium of Indo- Gangetic plain.

Shukla and Porwal (1977) carried out analysis of geological data of Vindhyan Basin delineating Category-II prospective areas over exposed Vindhyans.

Rao *et al.* in (1978) mapped Chittaurgarh-Nimbahera area in western part of basin and identified numerous north-south trending anticlines and synclines which have resulted to inliers and outliers of various formations.

Prasad B (1984) has made commendable contribution for making further refinements in geology of Chambal valley and in revising the litho-stratigraphy of Vindhyans in southeastern Rajasthan.

Sastry and Moitra (1984) compiled vast information of Vindhyan supergroup and attempted to assign nomenclature and status of different litho units of Chambal valley based on Code of Stratigraphic nomenclature of India.

Pangtey *et al.* (1987) contradicted Coulson's findings (1927, op *cit*.), while mapping the area between Bundi and Sawai Madhopur and a 70 km long strike fault in Rewa shale country and mapped Lower Vindhyans in Bundi-Indergarh area. Further, they also rejected the presence Chambal limestone and Dhaulpur shale over Upper Bhander sandstone and negated the presence of Kaimur's towards north of the Great Boundary Fault.

Remote sensing studies have been carried out by Ganju *et al.* (1987),Dey *et al.* (1995 and 1996) and they have mapped Vindhyan basin using satellite data and carried out lineament analysis for understanding the basin tectonics and identified geomorphic anomalies.

Punjrath and Kumar (1988) carried out traverses in Chittaurr-Nimbahera, Karauli-Sabalgarh and Jhalawar-Kota areas of south-eastern Rajasthan for collecting samples for source rock analysis. Bagchi et al (1988) worked on the samples collected in these areas and rated these samples are of poor source characteristics.

Punjrath *et al.* (1988) studied the structural and stratigraphic aspects of the area between Bundelkhand Massif and the Great Boundary Fault and also mapped Mandalgarh-Singoli-Rawatbhata-Jhalawar area. They carried out reappraisal of Mandalgarh-Bundi-Indargarh and Karauli fault blocks and concluded that these were subsidiary fault blocks of the GBF and were listric in nature.

Kalia et al.(1989) studied four DSS profiles data across Narmada Son-Lineament in Chambal valley for crustal information. The crustal structure in this region is of a transition type which was subjected to rifting during late Cretaceous period resulting in extensive lava flows spreading in all directions.

Verma et al.(1992) inferred from gravity and DSS data that north of Narmada Son-Lineament area is charecterised by comparatively lower density crust in comparison to south of Narmada Son-Lineament.

Raza et al. (1996), studied basal Vindhyan volcanic rocks from Jungel volcanics in Son valley, Katai and Khairmalia volcanics in Chambal valley and concluded that Vindhyan succession is characterized by occurrence of rift related mafic volcanic rocks of tholeiite (Khairmalia)- Alkali basalt (Katai and Jungel) composition showing Continental Flood Basalts- Ocean Island Basalts affinity.

Kumar *et al.* (1999) have carried out isotope stratigraphy studies of Proterozoic sediments of Vindhyan basin and also studied Kota- Jhalawar section. They have concluded that positive $\delta^{13}C$ excursions associated with carbonates of Nimbahera and Nagod formations are indicative of enhancement in organic carbon burial/ productivity which may have bearing on hydrocarbon resource potential. They have also concluded that Rohtas and Nimbahera formations of Semri Group, Nagod and Lakher Formations of Bhander Group in Son valley and Chambal valley respectively which as on date are considered as stratigraphic equivalents on the basis of intra-basinal correlation are distinctly different in $\delta^{13}C$ compositions and thus require a revision in their stratigraphic position.

Prasad and Asher (2001) have carried out acritarch bio-stratigraphy studies of Vindhyan sediments of Chambal valley in parts of Rajasthan and Madhya Pradesh. The acritarch assemblages and their association with environmentally controlled taxa suggest a shallow to inner shelf depositional environment for Lower Vindhyan and littoral to marginal marine deposition environment for Upper Vindhyan sediments.

Bastia and Radhakrishna (2012a) have dealt with basin evolution and hydrocarbon aspects of Indian continental margins. Several workers have carried out detailed geological and geophysical studies in Eastern (Bastia et al. 2010; Krishna et al.2012; Radhakrishna et al. 2012a, 2012b, 2010, 2008; Sager et al. 2013; Sreejith et al. 2011, 2013) and western (Calves et al. 2011, 2008a, 2008b) offshore regions of India.

For imaging below basalts integrated geophysical approaches were undertaken by earlier workers (Chakravarthi et al. 2007; Fainstein et al.2012; Sarma and Chakravarthi, 2011; Tiwari et al.2001).Gravity seems to have emerged as a powerful tool in assessing water resource potential of aquifers on a regional scale (Tiwari et al. 2009, 2011). Recent advances in potential field modelling and inversion (Chakravarthi, 2012, 2011, 2010; Chakravarthi and Sunderrajan, 2008; Li et al. 2010; Li and Oldenburg, 2010, 2000a, 2000b, 1998; Martins et al. 2010a, 2010b; Oldenburg, 1974; Silva et al. 2010a, 2010b; Singh, 2002; Ureda and Barbosa, 2012; Zhdanov, 2002, 2009a, 1988; Zhdanov et al. 2004) and other geophysical methods (Zhdanov1998, 2009b; Zhdanov et al. 2000) are worthwhile. Also, some geodynamic studies (Calves et al. 2008b; Chandrasekhar et al. 2005; Krishna, 2011; Kumar et al. 2009; Mishra et al. 2000; Radhakrishna et al. 2012a, 2012b, 2010, 2008; Sreejith and Krishna, 2013a, 2013b, 2011; Tiwari et al. 2006) and modern interpretation methods (Barbosa et al. 1999; Silva, 1986; Silva and Hohmann, 1984; Silva et al. 2010b) are also worth considering for the present study.

Prasad and Rao (2006) have studied DSS data along Chandli-Bundi- Kota-Kunjer profile acquired by NGRI in Rajasthan area of Chambal valley. They have observed that gentle SE dipping reflection bands represent Vindhyan succession and the seismic sections depict gradual thickening of Vindhyan succession towards southeast from Bundi. Velocities of Upper and Lower Vindhyans are identified as 4.6-4.8 km/s and 5.1-5.3 km/s respectively.

Nautiyal *et al.* (2009) have carried out synergistic studies of Chambal valley based on recently acquired data of the New Exploration Licensing Policy blocks. They have concluded that surface structural manifestations and seismic data reveals a north-easterly directed compressional tectonics in the basin, resulting in NW-SE trending, en-echelon, fault bound structures.

Kumar et.al (2010) carried out Paleo-tectonic analysis based on geological traveses and seismic data towards northern part of Chambal valley and concluded that Mukundra fault is a reverse fault. They also discussed the implication of Mukundra fault in sediment covered area in northern most area of Chambal valley. Field geological observation and its synergistic integration in the geophysical data in developing a knowledge base is essential for identifying prospects areas for hydrocarbon exploration in Chambal valley.

1.5 Gaps in knowledge

The vast expanse of Chambal valley with very little geophysical data makes it difficult to come to reasonable inferences about trap, sediment and depth to basement. Earlier studies were based mostly on geological work, rock samples and surface structural manifestations. There is hardly any geophysical data except regional gravity and a few profiles of aeromagnetic data over trap covered part of Chambal valley. Also seismic data over fringes of the basin is available where trap is absent. Even these data were not consolidated and interpreted to bring out basin configuration. There is no reflection seismic and deep drilling data over trap covered sector, which restrict knowledge building about sediment, trap and basement thickness of Chambal valley.

1.6 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. To acquire 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.

1.7 Novelty

a) For delineation of Mesozoic sediments below Deccan traps a maiden attempt has been made through this integrated study in Chambal valley, India.

b) 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.

1.8 Thesis layout:

Thesis is divided into eight chapters as under:

Chapter–1 is devoted to introduction to geological concepts of Vindhyan basin. Further, it describes objectives of research work and a chapter-wise summary.

Chapter–2 is devoted to tectonic elements of the study region with special emphasis on Sedimentation process.

Chapter–3 is devoted to methodology for integrating different data sets to get a unified result for delineating trap, sediment and depth to basement.

Chapter–4 contains data sources, field acquisition and how these data sets are utilized.

Chapter–5 concerns Gravity & Magnetic data processing and analysis of attribute maps.

Chapter- 6 concerns Gravity, Magnetic and Seismic modeling.

Chapter -7 is devoted to results and validation through synergetic interpretation and discussion.

Chapter–8 is devoted to summary and conclusions along with an outline on further perspectives

CHAPTER-2

Geology of study region

2.1 General aspects

The Vindhyan basin in the central part of the India (Fig.1a) 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. 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 in satellite images Fig.1.3b & 1.3c. 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.

Eastern and central part of valley exhibits plateaus and flat land over Kaimur, Rewa and Bhander rocks. NW-SE trending scarps dominate central part of valley from Rawatbhata to Jhalawar and beyond forming linear hill range locally known as Mukandara Range and involve the Kaimur and Rewa rocks. These rocks also depict cuesta landforms towards west of Gandhi Sagar and Rana Pratap Sagar and are successively draped by basalt to south. Towards the western part, the Chambal valley exhibits N-S trending hills, also referred to as Chittaurgarh-Nimbahera folds. These are further truncated by the NE-SW trending hills which demarcate boundary with older Hindoli and Aravalli Group of metasediments.

2.2 Inferred litho- units in Chambal valley

The geographical distribution and extent of Vindhyan sediments in Chambal valley exhibits dominance of tectonic control on the distribution of different lithounits over different sectors viz. in north-south oriented in the western part, NE-SW trending outcrops in the vicinity of GBF, semi-elliptical trend of Bundelkhand area in Guna-Shivpuri-Gwalior area and NW-SE trend in the Kota- Jhalawar area.

The Lower Vindhyan sediments are exposed in the western part of Chambal valley, in an en-echelon folded pattern in Chittaurgarh-Nimbahera area extending up to Mandsaur in south. The area southwest of Mandalgarh, these are exposed over Gowta anticline and Rawatbhata, Chechat, Jhalawar, Aklera areas these assume a WNW-ENE trend and further south are covered by basalts of Deccan trap.

Upper Vindhyan sediments comprising Kaimur quartzite are exposed around Bichor over Gowta anticline and north of Bundi in juxtaposition with pre-Vindhyan rocks. It forms a distinct SW-NE trending ridge from Bundi, Lakhera to Dolara. These are also exposed on the hill of the Chittaurgarh-Nimbahera area and forms extensive plateaus north of Jawad and Rampura and around Rana Pratap Sagar and Gandhi Sagar dams. Kaimur quartzite is observed in the plunge of Chechat anticline at Rawatbhata and is also seen over northeastern flank of Jhalawar anticline up to Aklera. It is also seen to be concealed beneath Deccan trap at several places. It is exposed on the hills to the west and northwest of Gwalior in the Sank river valley and extends southeastern side up to Shivpuri and east of Guna.

The outcrops of Rewa group are observed south of Sabalgarh and east of Shivpuri, overlying Kaimur quartzite and are also present in the folds south of Sawai Madhopur, Indergarh, and in Gowta anticline northeast of Bundi. These are exposed as a narrow trace over northeastern flanks of Jhalawar and Chechat anticlines trending NW-SE and west of Ranapratap Sagar reservoir.

The sediments of the Bhander Group have vast areal extent and are seen prominently in the folded strata in Sawai Madhopur-Bundi area and in the area between Kota up to Dara and Aklera in the south, the Lower Bhander sandstone is exposed forming a subdued topography and thereafter it is concealed beneath basalt cover and in the central part of valley, these sediments are covered by a thin cover of alluvium between Kota, Sheopur and Dholpur.

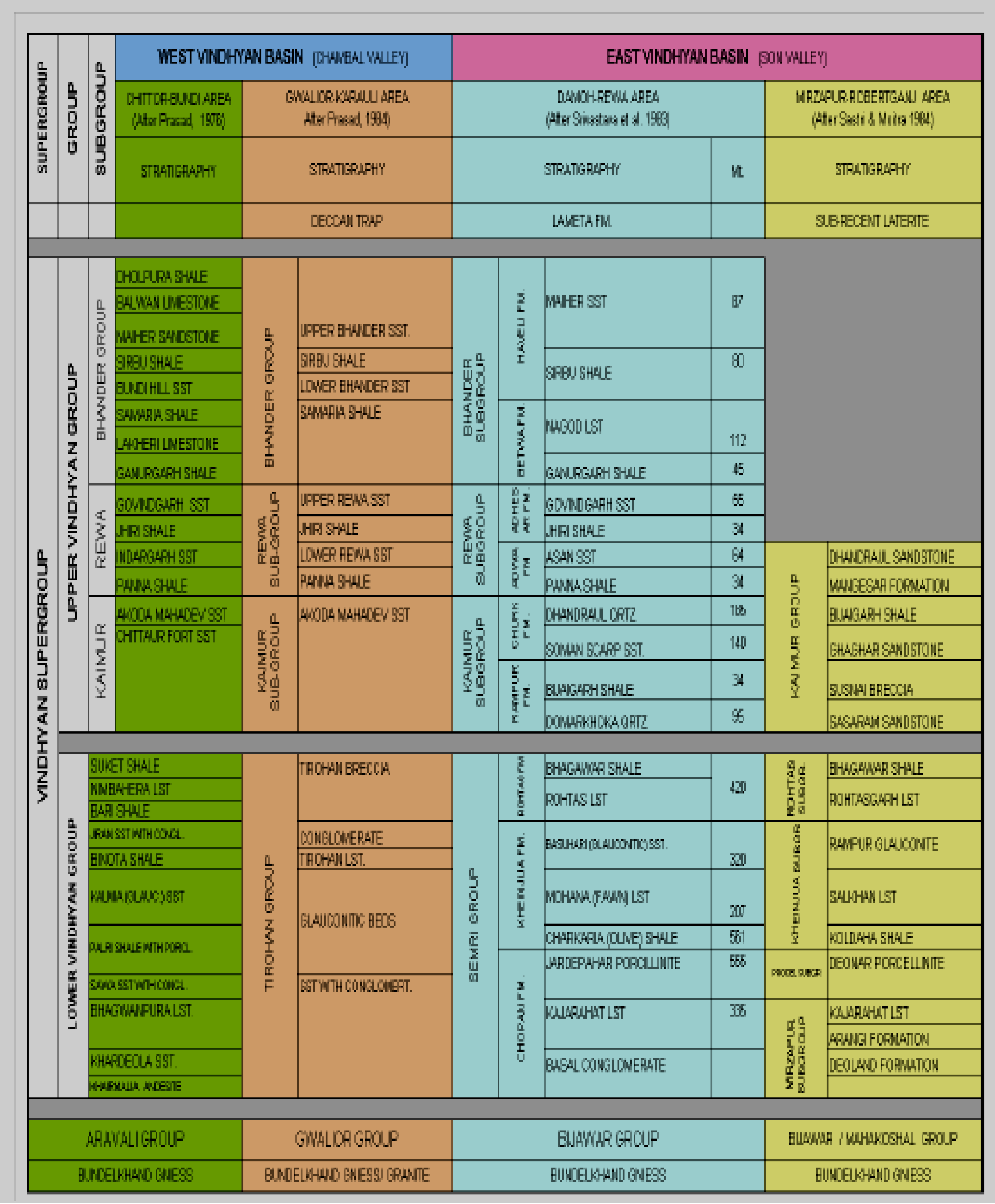
2.3 Stratigraphy and sedimentation

Pre-Aravali Bhilwara Group of metasedimentaries (Bhadesar quartzites, phyllites etc.) including Berach granite in western part and Bundelkhand granite and Gneisses and Gwalior Group of rocks in eastern and northeastern part comprise basement over which the Vindhyan sediments in Chambal Valley were deposited. The Vindhyan sedimentation commenced with volcanic activity and sediments were deposited under fluctuating conditions varying from shallow marine-lagoonal-tidal flat near shore conditions.

These metasedimentaries are overlain unconformably by Lower and Upper Vindhyan sediments comprising siliciclastic and carbonates sediments of the Sand, Satola, Lasrawan and Khorip Groups belonging to the lower Vindhyans and the Kaimur, Rewa and Bhander groups belonging to Upper Vindhyans respectively with variable provenance directions. In the south, the terrain is covered with Deccan traps (Basalts) concealing a large part of Lower Vindhyan as well as upper Vindhyan sediments.A generalized stratigraphic chart of the Vindhyan Basin showing the equivalents in Chambal valley and Son valley is given Table-1.

Table-1

GENERALIZED STRATIGRAPHY OF VINDHYAN BASIN SHOWING CORRELATION OF DIFFERENT FORMATIONS BETWEEN CHAMBAL VALLEY AND SON VALLEY (source: ONGC)



SUPERGROUP	GROUP	SUBGROUP	WEST VINDHYAN BASIN (CHAMBAL VALLEY)			EAST VINDHYAN BASIN (SON VALLEY)					
			CHITTOR-BUNDI AREA (After Prasad, 1976)	GWALIOR-KARAULI AREA After Prasad, 1984)		DAMOH-REWA AREA (After Srivastava et al. 1983)				MIRZAPUR-ROBERTGANJ AREA (After Sastri & Moitra 1984)	
			STRATIGRAPHY	STRATIGRAPHY		STRATIGRAPHY			Ml.	STRATIGRAPHY	
				DECCAN TRAP		LAMETA FM.				SUB-RECENT LATERITE	
VINDHYAN SUPERGROUP	UPPER VINDHYAN GROUP	BHANDER GROUP	DHOLPURA SHALE	BHANDER GROUP		BHANDER SUBGROUP	HAVELI FM.	MAIHER SST	87		
			BALWAN LIMESTONE								
			MAIHER SANDSTONE		UPPER BHANDER SST.						
			SIRBU SHALE		SIRBU SHALE			SIRBU SHALE	80		
			BUNDI HILL SST		LOWER BHANDER SST						
			SAMARIA SHALE		SAMARIA SHALE		BETWA FM.	NAGOD LST	112		
			LAKHERI LIMESTONE								
			GANURGARH SHALE					GANURGARH SHALE	45		
		REWA	GOVINDGARH SST	REWA SUB-GROUP	UPPER REWA SST	REWA SUBGROUP	ADHESAR FM.	GOVINDGARH SST	55		
			JHIRI SHALE		JHIRI SHALE			JHIRI SHALE	34		
			INDARGARH SST		LOWER REWA SST		ASAN FM.	ASAN SST	64	KAIMUR GROUP	DHANDRAUL SANDSTONE
			PANNA SHALE		PANNA SHALE			PANNA SHALE	34		MANGESAR FORMATION
		KAIMUR	AKODA MAHADEV SST	KAIMUR SUB-GROUP	AKODA MAHADEV SST	KAIMUR SUBGROUP	CHURK FM.	DHANDRAUL QRTZ	185		BIJAIGARH SHALE
			CHITTAUR FORT SST					SCARP SST.	140		GHAGHAR SANDSTONE
							RAMPUR FM.	BIJAIGARH SHALE	34		SUSNAI BRECCIA
								DOMARKHOKA QRTZ	95		SASARAM SANDSTONE
	LOWER VINDHYAN GROUP		SUKET SHALE	TIROHAN GROUP	TIROHAN BRECCIA	SEMRI GROUP	ROHTAS FM.	BHAGAWAR SHALE	420	ROHTAS SUBGR.	BHAGAWAR SHALE
			NIMBAHERA LST					ROHTAS LST			ROHTASGARH LST
			BARI SHALE								
			JIRAN SST WITH CONGL.		CONGLOMERATE		KHENJUA FM.	BASUHARI (GLAUCONITIC) SST.	320	KHENJUA SUBGR.	RAMPUR GLAUCONITE
			BINOTA SHALE		TIROHAN LST.						
			KALMIA (GLAUC.) SST		GLAUCONITIC BEDS			MOHANA (FAWN) LST	207		SALKHAN LST
			PALRI SHALE WITH PORCL.					CHARKARIA (OLIVE) SHALE	561		KOLDAHA SHALE
							CHOPAN FM.	JARDEPAHAR PORCILLINITE	555	PORCEL. SUBGR.	DEONAR PORCELLINITE
			SAWA SST WITH CONGL.		SST WITH CONGLOMERT.						
			BHAGWANPURA LST.					KAJARAHAT LST	335	MIRZAPUR SUBGROUP	KAJARAHAT LST
											ARANGI FORMATION
			KHARDEOLA SST.					BASAL CONGLOMERATE			DEOLAND FORMATION
			KHAIRMALIA ANDESITE								
			ARAVALI GROUP	GWALIOR GROUP		BIJAWAR GROUP				BIJAWAR / MAHAKOSHAL GROUP	
			BUNDELKHAND GNEISS	BUNDELKHAND GNEISS/ GRANITE		BUNDELKHAND GNEISS				BUNDELKHAND GNEISS	

2.4 Depositional environment

The environment of deposition of Vindhyan sediments has been discussed by Misra (1969), Chanda and Bhattacharya (1982), Prasad (1984), Akhtar (1996) and Chakraborty (2001). A brief summary based on their work is given below:

Vindhyan sedimentation commenced with synsedimentational volcanic activity in western margin followed by deposition of Khardeola gritty sandstone and stromatolitic Bhagwanpura limestone. The occurrence of conglomerate and the large scale cross bedded ferruginous sandstone indicate terrestrial conditions of deposition. Stromatolites in Bhagwanpura limestone indicate a shallow water depth in intertidal mudflats (Prasad 1984). Shallow marine environment is also indicated by glauconite for Kalmia Sandstone with olive green shale. Local euxinic conditions and deeper bathymetry is depicted by Binota shale. The Jiran to Nimbahera Limestone formations indicate shorefacies following a regression of the sea (Prasad, 1984). Desiccation cracks in the limestone are indicative of subaerial conditions. Deposition of Suket shale took place in lagoonal and inter-tidal environment. By the close of Suket time incursion of sea and penecontemporaneous tectonism is envisaged.

Deposition of Kaimur took place in sandy intertidal flat to barrier beach dune wash over flat environments. This is revealed by sedimentary structures and mineralogical and textural maturity of the sediments. Chittaur Fort Sandstone (Kaimur) is regarded as intertidal. Alternating shale and glauconitic sandstone with limestone and intercalation of limestone imply a shallow marine environment during Rewa time. The basal Panna Shale is inferred to have been deposited in lagoonal conditions. The ripple marks with rounded crests and shallow troughs in Indergarh sandstone indicate backwash of beach (Prasad, 1984). The deposition of Jhiri shale took place under distal-lower pro-delta conditions.

Ganurgarh shale and lower beds of Lower Bhander limestone (Lakheri limestone), suggest subaerial conditions of deposition. Ganurgarh shale is ferruginous, and shows frequent ripple marks suncracks and intra-formational breccia in its limestone interbeds, suggesting temporary withdrawal of sea. It was deposited in a low intertidal flat to supratidal environment. On the basis of field and petrographic characters and presence of algal stromatolites in Kota-Rawatbhata area, Bhardwaj (1973) inferred a supratidal environment of their deposition for the lower part while upper part was the product of sedimentation on a vast, shallow submerged shelf where wave energy was cut-off by extensiveness of the shelf. The overlying Samaria Shale with stromatolitic limestone indicates transgression leading to shallow marine conditions of deposition, which continued during the deposition of Lower Bhander sandstone-Balwan limestone. The blanket type of upper Bhander Sandstone together with sedimentary structures implies existence of tidal flats (Basumallik, 1962; Banerjee, 1974)

CHAPTER-3

Methodology

Different geophysical data sets and their coverage in study area are depicted in Fig.3. Adopted methodology comprises of the following steps:

i.Reprocessing of earlier potential field data along with newly acquired four profiles of high precision gravity data (Fig.3) and inducing them to a uniform datum of elevation of 250m as it is the lowest elevation in area of study so as to preserve shallow feature anomalies (traps).

ii To merge two aeromagnetic data sets acquired with 1500m and 2500m flight height were processed and brought to 250m above MSL so as to maintain coherency of both gravity and magnetic data sets.

iii. To carry out selective field checks were carried out to identify the tectonic elements with surface geological and remote sensing data.Prepared two regional seismo-geological sections across Chambal valley.

iv.To generate various attribute maps like residual, pseudo gravity; analytical signal strength, spectral depth, Euler and Werner depth from gravity and magnetic anomaly data.

v. To study existing well logs in the vicinity of the study area to identify sedimentary boundaries on seismic data which can be extrapolated to study region.

vi. Collection of representative rock samples of different geological formations to study physical properties such as density and magnetic susceptibility along 76^0 and 77^0 longitude regional profiles. These in turn can serve as both geological and geophysical constraints for framing density and magnetic susceptibility models of subsurface.

vii. Initial gravity modeling to be carried out with seismic constraints along few selected profiles that are passing through trap and non trap portion of the study area (Fig.3). For example two NS gravity profiles along 76^0 and 77^0 longitude over trap covered part of study area are considered.

viii. Gravity magnetic modeling has to be carried out along recently acquired high precision gravity profiles for which study area has been divided into a grid of 8x8 sq. km. Consistent with regional and high precision models, along each grided profile 2D gravity modeling need to be attempted to cover the entire study area.

ix. By using all the 2D models and inferred geological sections of previous step (viii) to build a complete 3-D model of trap, sediment and basement.

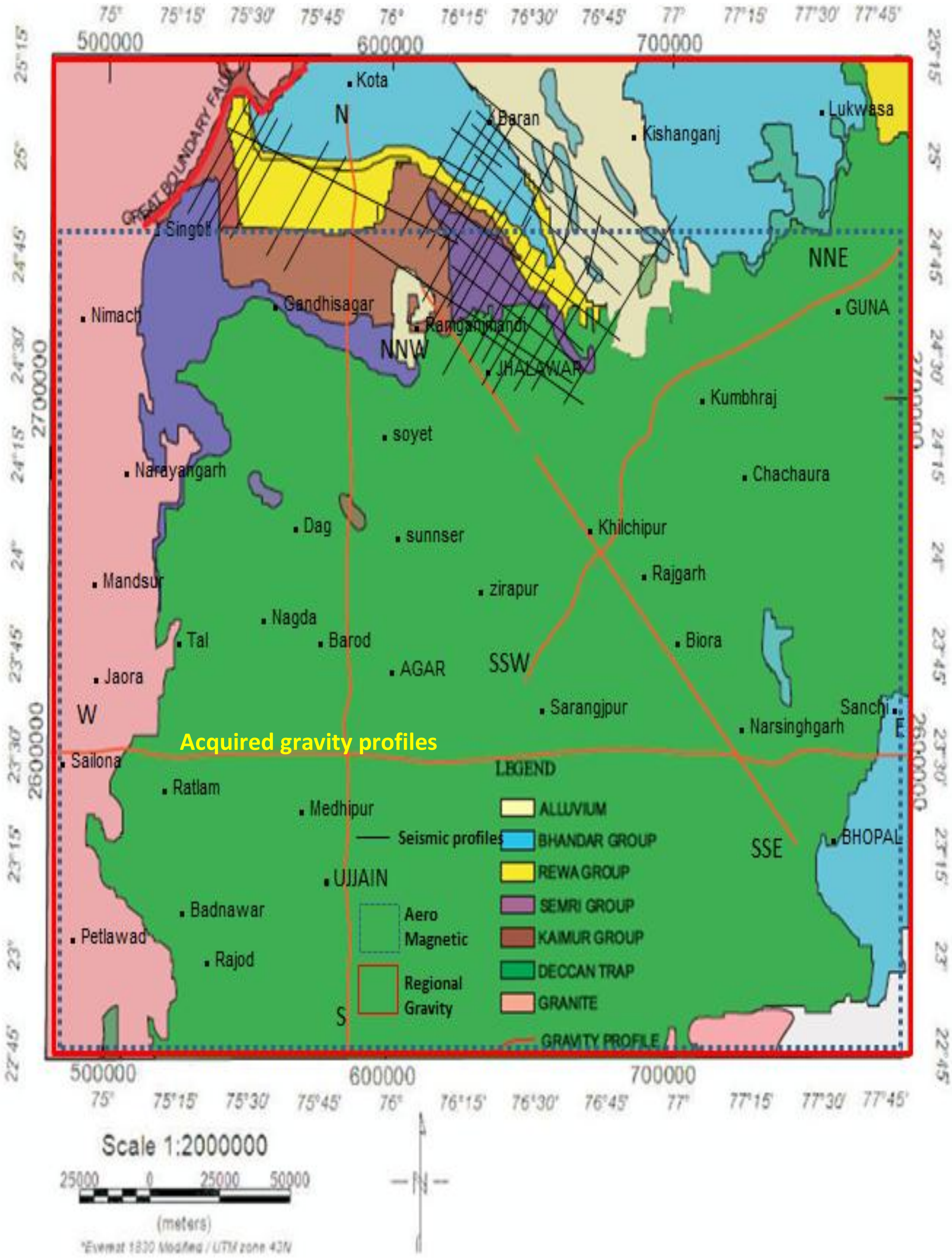


Fig.3 Geophysical data coverage map. High precision gravity data is acquired along four profiles (N-S, W-E, SSW-NNE and SSE-NNW). The dotted boundary outlines the region covered by regional gravity and aeromagnetic data. Some seismic profile network (Black coloured lines) is also shown in northern part and it covers partly non-trap and trap regions. The colour background indicates major lithological and stratigraphic units of study region.

CHAPTER-4

Gravity Magnetic and Seismic data sources

4.1 Gravity data

Regional gravity data (Fig.3) was acquired by ONGC during the years 1990 to 1995 over Vindhyan basin in six successive phases with a station spacing of 5 to 10 km. In addition, high precision gravity data with a station interval of 1km. along four profiles covering one thousand kilometer has been acquired by ONGC using CG-5 Gravimeter during 2008-2011in which the author has participated (Table 4.1) .

Table 4.1

Details of high precession gravity data acquisition (Fig. 3)

Profile	Year	No of Stations	Station interval	Length of Profile
SW-NW	2008	74	2.5km	182km
WE	2009	330	1km	330km
NS	2010	330	1km	330km
SSW-NNE	2111	225	1km	225km

4.1.1 Previous effort

The data was processed using MSL datum with a Bouguer density of 2.67 gm/cc. The regional gravity data were observed along all available road network with a grid interval of 5 km to 10km.

4.1.2 Present efforts

The objectives of high precession gravity data is to bring out major tectonic features and estimation of sediment thickness in the valley. To fulfill these objectives high precision gravity survey using CG-5gravimeter (M/S Scintrex make) was carried out along four profiles (Fig.3) with a network of 2512 stations. Prior to data acquisition elevation map of study area in Chambal valley was prepared at 1 km grid interval using GPS data. It has been observed (Fig 4.1) that minimum elevation is 250m.

Surface manifestation of ridges and faults observed on 3-D elevation image were studied and the actual dimension of these features were noted during field visit to take account while recording gravity data to minimise the errors. Combined elevation and Bouguer plot of the acquired profiles have been shown in Fig.4.1 which clearly establish the bouguer anomaly computation along four regional profiles.The vintage regional gravity data was reprocessed changed the datum from MSL to 250m above MSL as the minimum elevation of study area is found to be 250m. This has been done so as to preserve gravity signature of shallow sources within the study area.

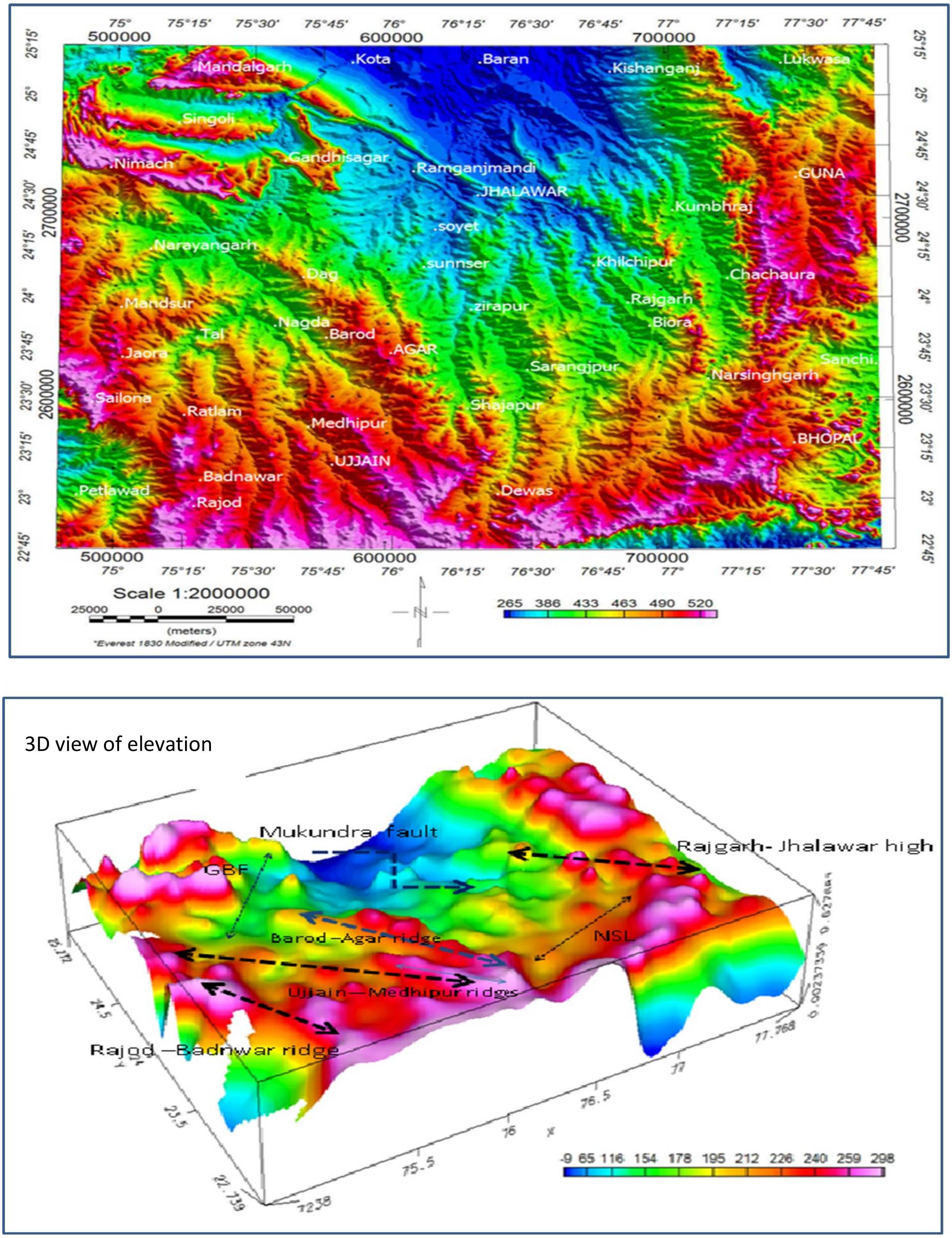


Fig 4 Elevation map of Chambal valley (Above panel) including its 3-D View (Lower panel)

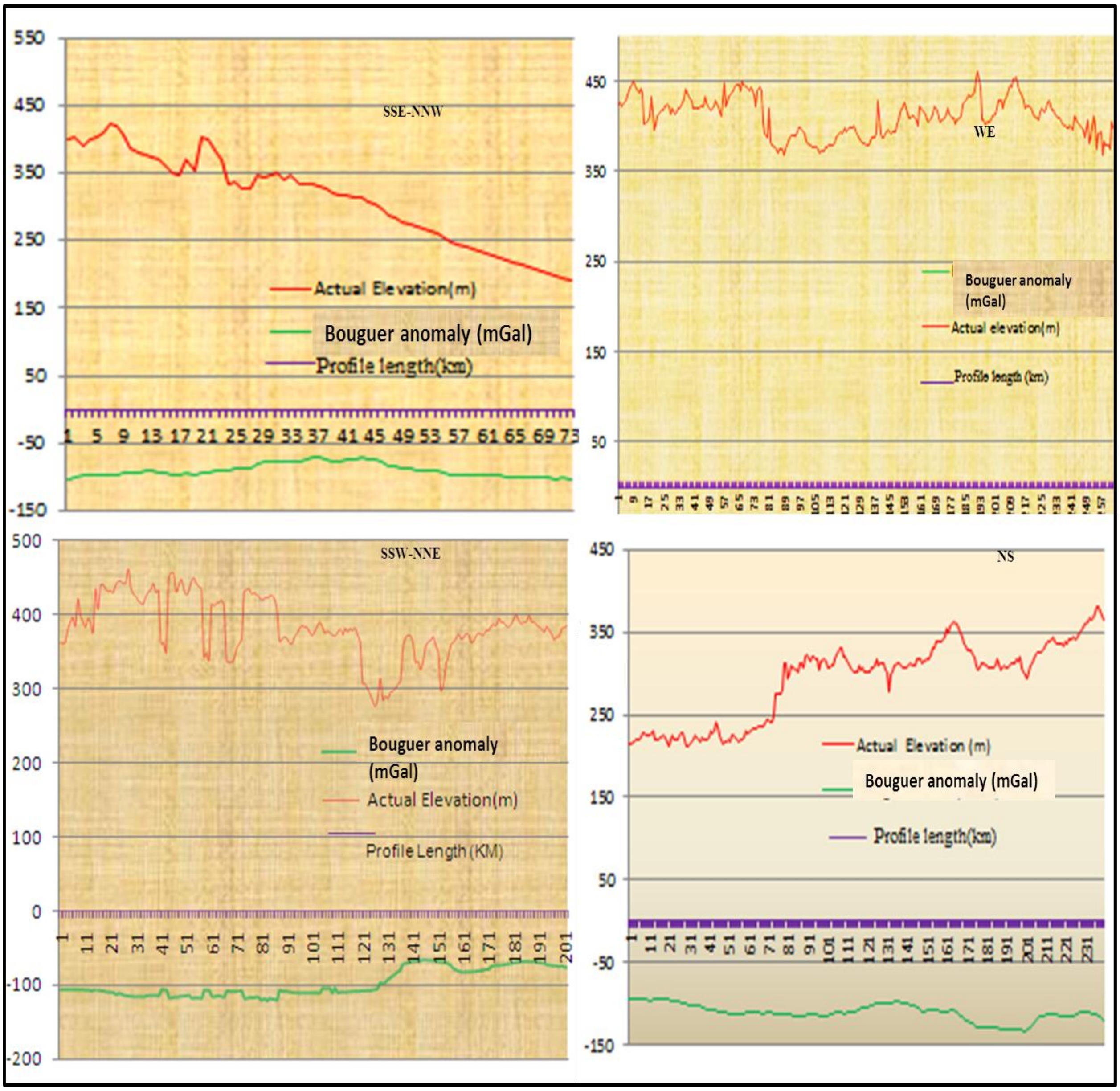


Fig 4.1) Elevaion versus Bouguer gravity over four acquired profiles

4.2 Magnetic data

Ground magnetic data over trap covered area is not suitable for any kind of interpretation as large local variations are observed in total field magnetic intensity anomalies and it is reflected in wide range of suscepitibilty of rocks (200 to 8000 S.I. units).

4.2.1 Aeromagnetic data

Aeromagnetic data in the study area was acquired by National Remote Sensing Agency (NRSA) for ONGC in 1993 and 1994 in two phases with line spacing of 4 km in the direction of SSE-NNW. Six dip profiles are shown in the figure cutting across prominent geological features (Table-3 and Fig. 4.2).

Table-3

Details of aeromagnetic data

Profile direction	Year	No of profiles	Line interval	Volume
SSE-NNW	1993	116	2.5km	22,890lkm
Tie line	1993	8	35 km	

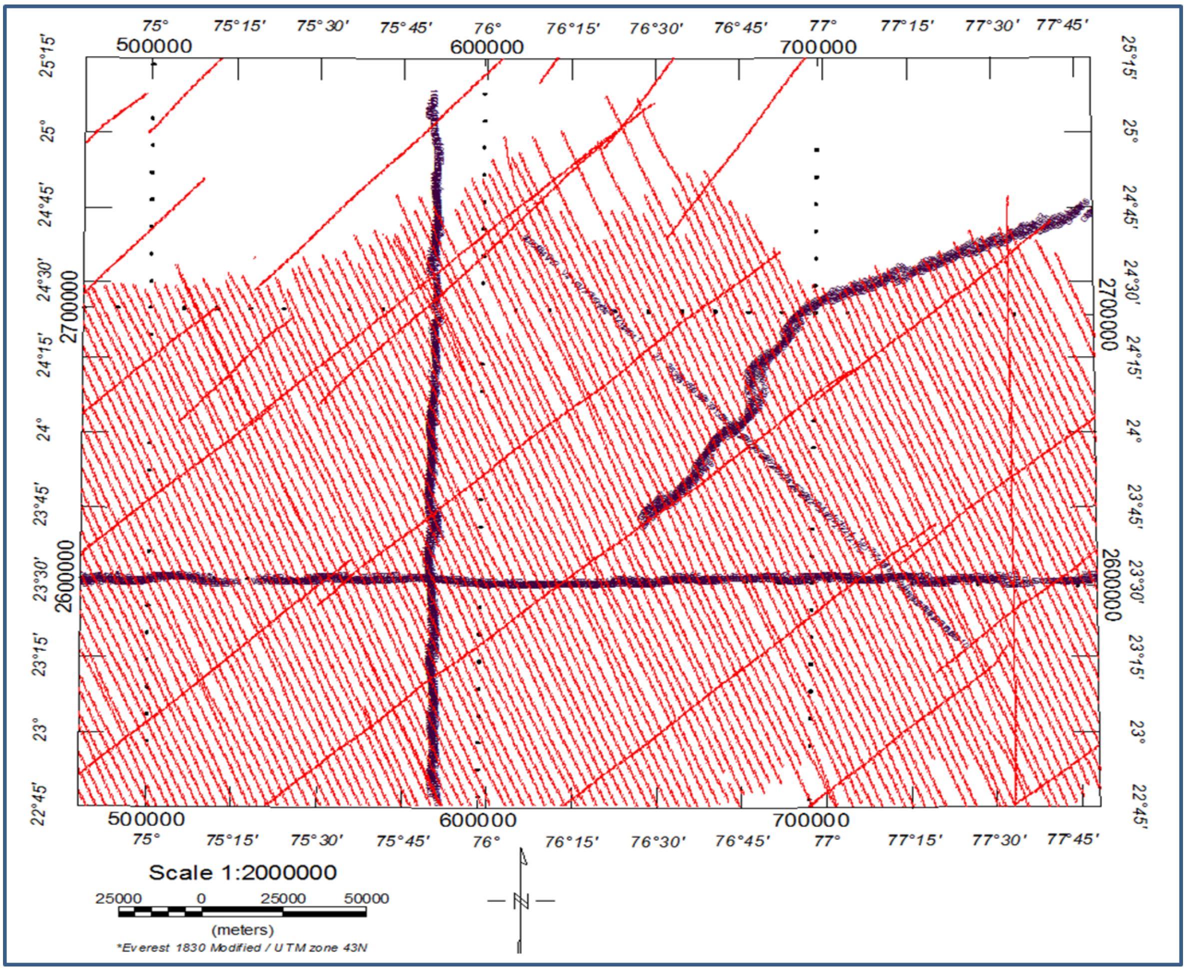


Fig. 4.2 Location map of aeromagnetic profiles. A network of parallel (in red colour) aeromagnetic profiles span the study region

4.3 Seismic data

Northern part of Chambal valley comprising Bundi-Kota-Jhalawar area where trap is absent is partially covered with seismic data acquired by ONGC Fig. 4.3. A few seismic profiles are passing through study area viz. RFB-01-11 , 12, 13, 14, 15, 16, 17, 18, 19, 20, 22 and 23 running NW to SE direction. These profiles partially fall on both trap and sediment covered areas.

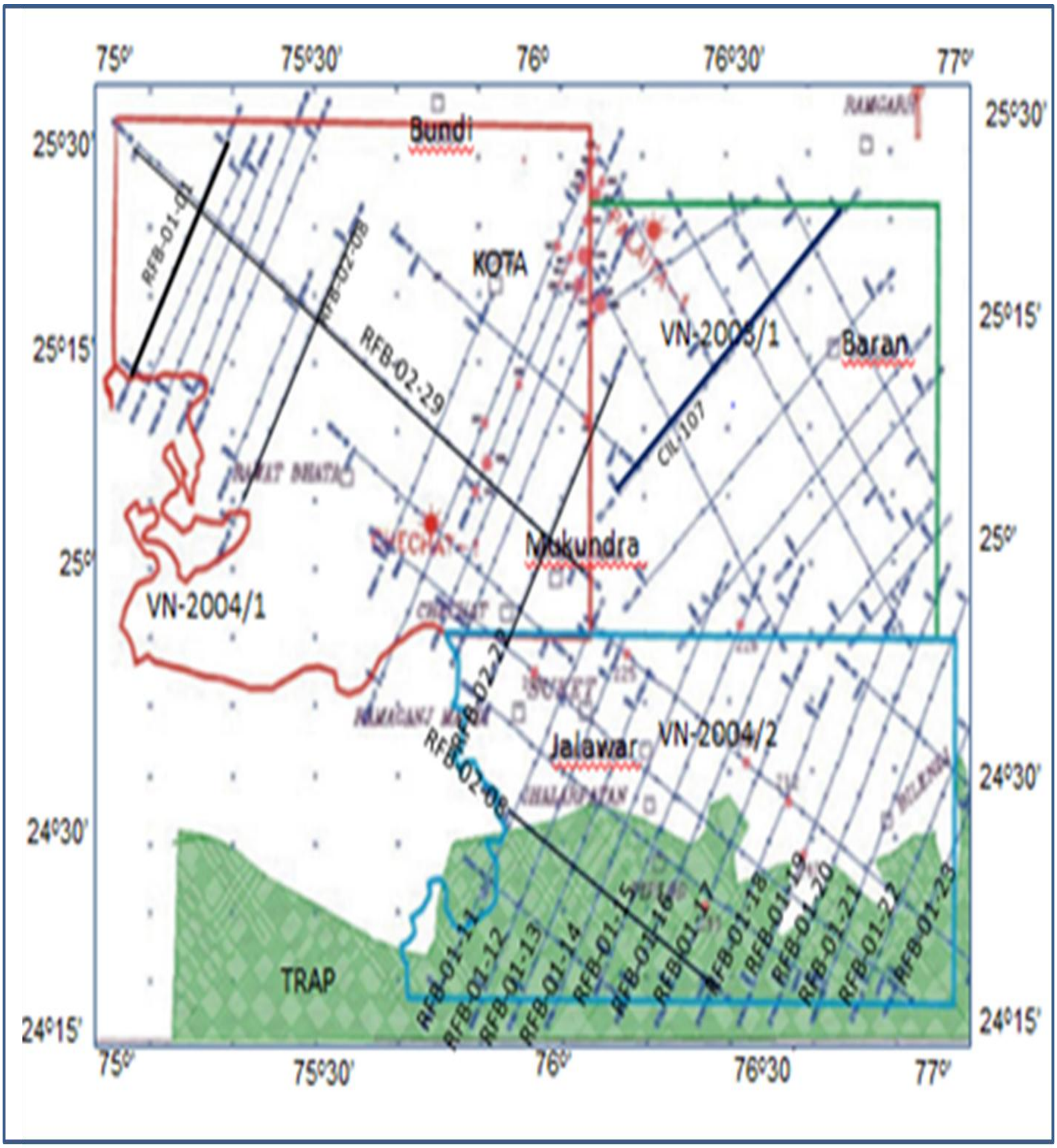


Fig. 4.3 Seismic coverage in the northern part of study region map (Source: ONGC).

Some of the seismic profiles (in blue colour) partly cover both non-trap and trap regions.

CHAPTER-5

Gravity and Magnetic data processing

5.1 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.

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.5.1). A separate Bouguer anomaly map of study area (Chambal valley) is also generated and is shown in Fig. 5.1.1. A 3-D view of Bouguer anomaly of Chambal valley has been prepared (Fig. 5.1.1a.)

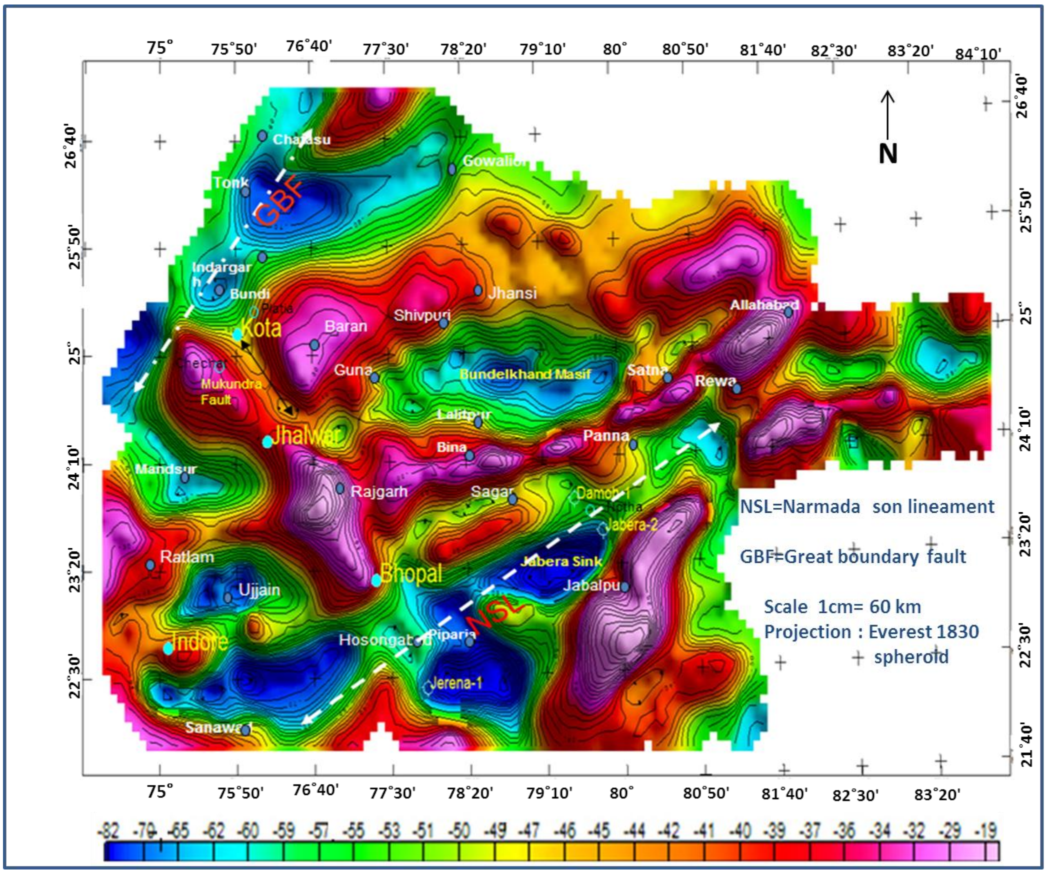


Fig. 5.1) Compiled Bouguer anomaly map of Vindhyan basin

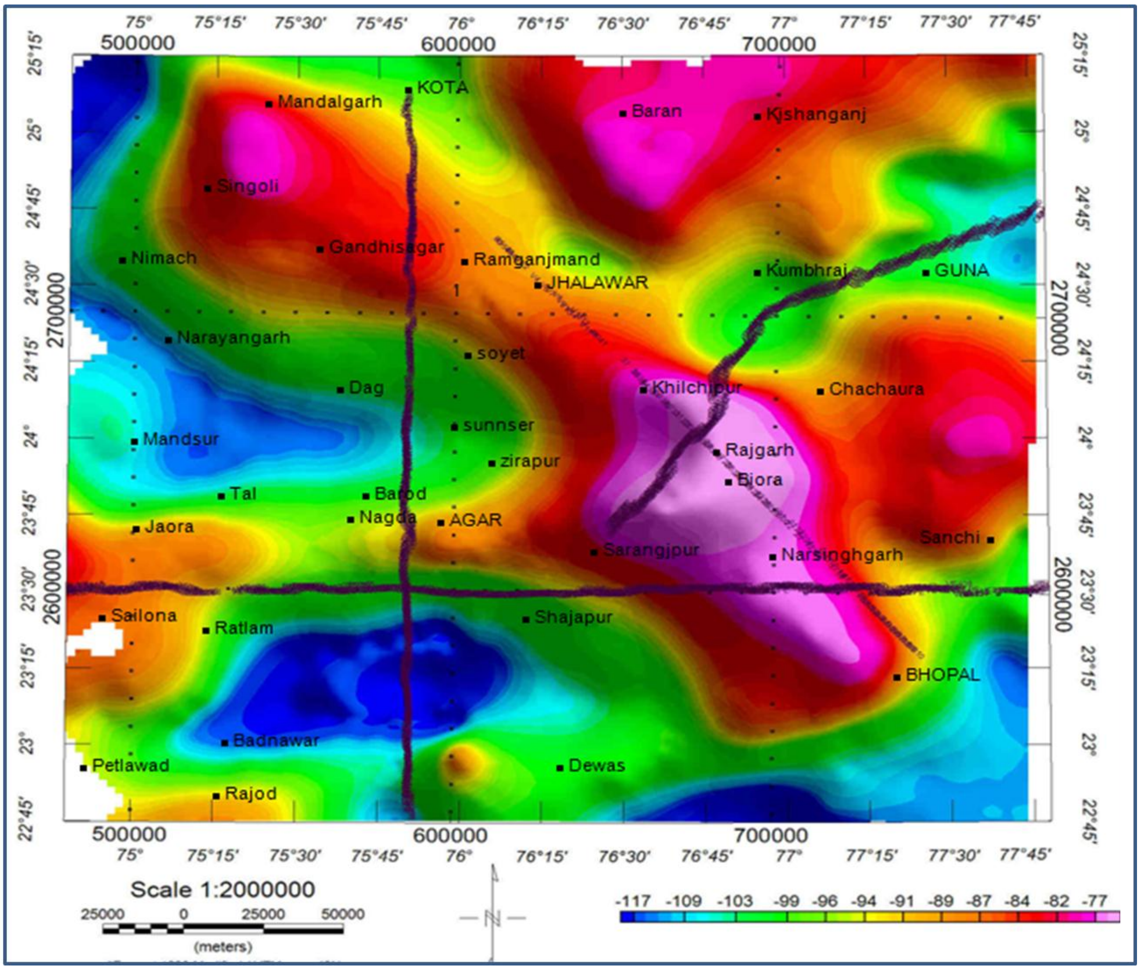


Fig. 5.1.1 Bouguer anomaly map of Chambal valley with superimposed high-precision gravity Profiles in black colored lines

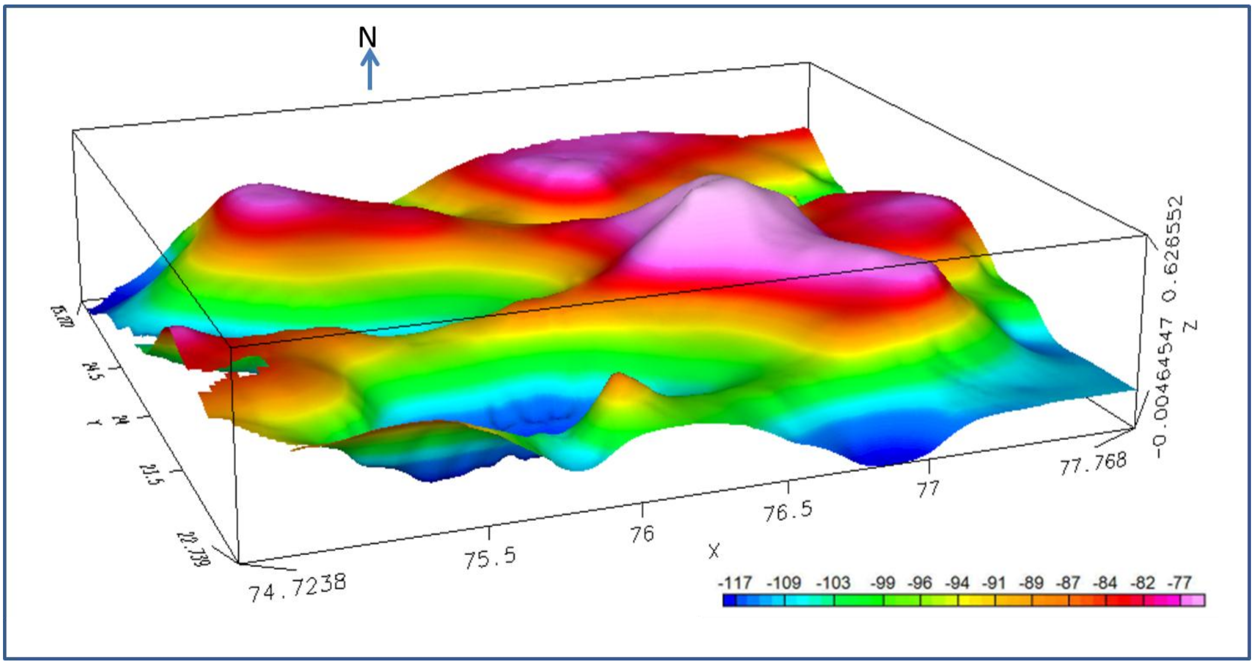


Fig. 5.1.1a 3-D view of Bouguer anomaly over Chambal valley

In Fig 5.1.1a, 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.

5.2 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 after applying following steps.

I. Verifying and editing raw data

II. Location of data in X and Y

III. Parallax corrections

IV. Dirunal corrections

V. Removing the component attributable to earth’s regional field (IGRF 1995)

VI. Levelling the data

VII. 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. 5.2. A 3-D viewof aeromagnetic anomaly distribution over Chambal valley is generated where a prominent east-west trending low is observed Fig. 5.2.1.

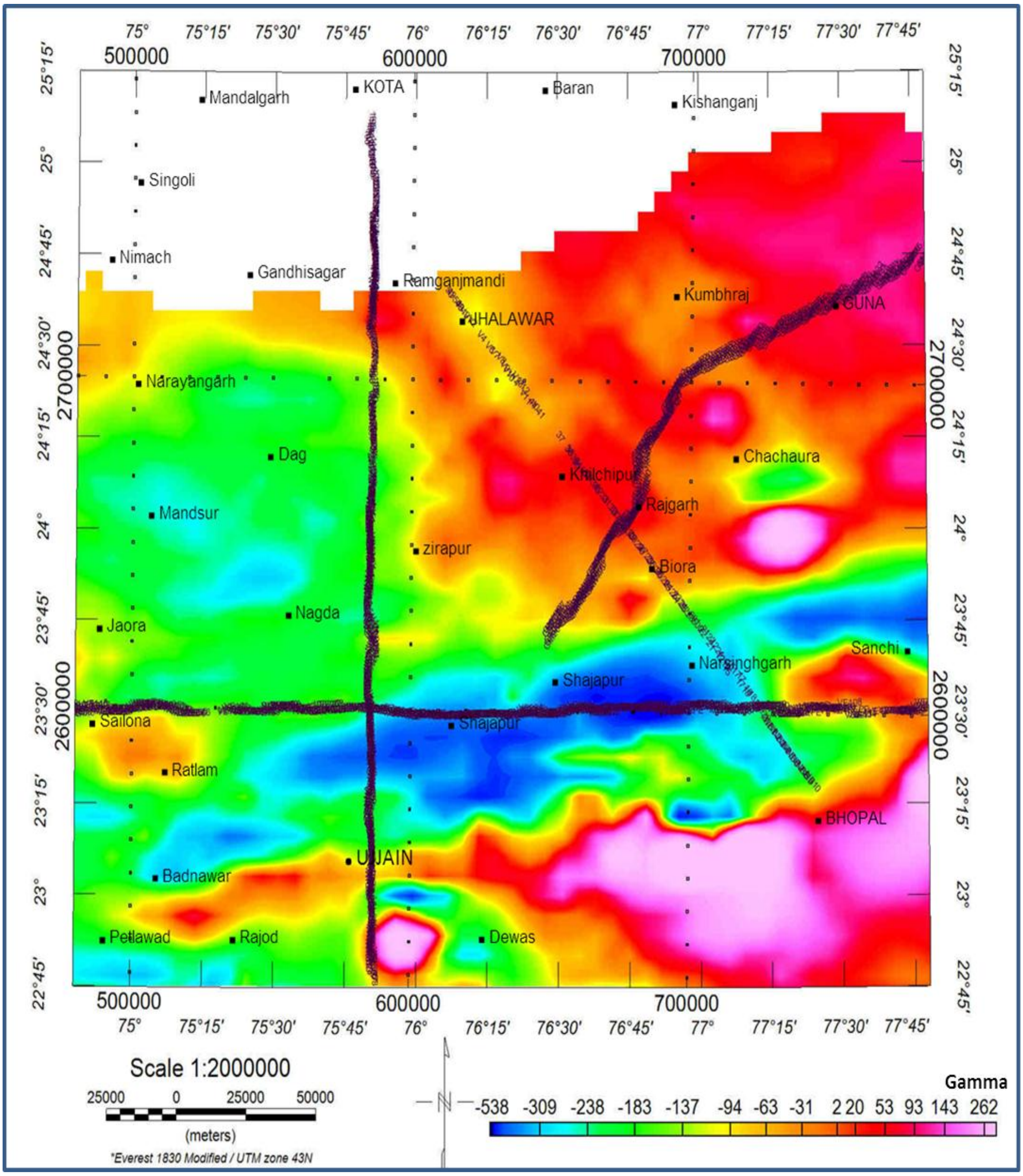


Fig. 5.2 Aeromagnetic anomaly map of study region with superimposed high-precion gravity profiles in black colour

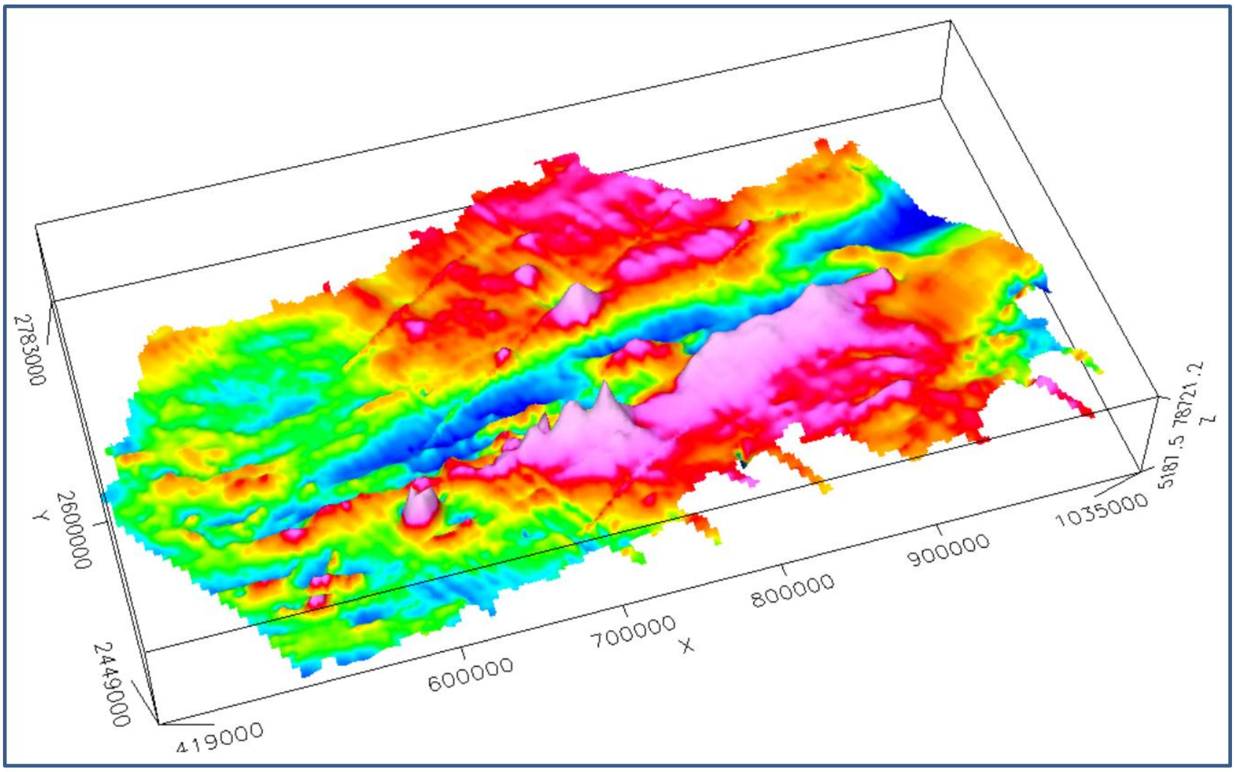


Fig. 5.2.1 Aeromagnetic anomaly 3-D view

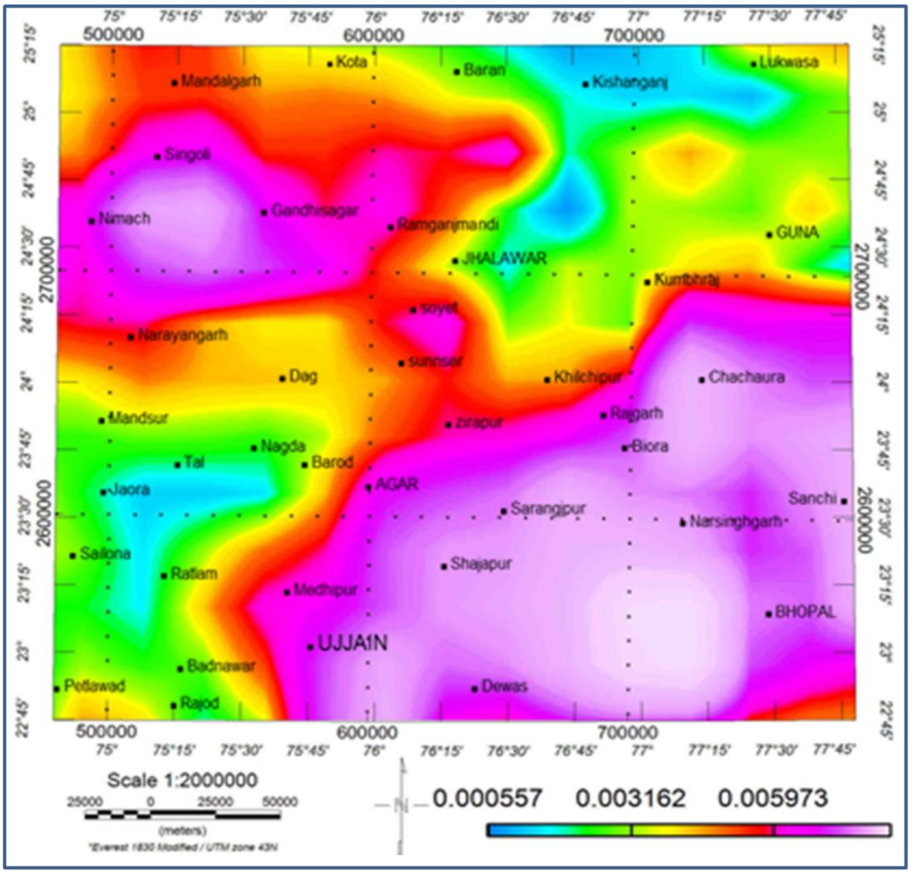


Fig. 5.3.1 Gravity analytical signal strength map

5.3 Atribute analysis

5.3.1 Gravity data

5.3.1.1 Analytical signal strength

Analytical signal strength (Nabighian, 1974, 1984; Roest et al. 1992; Roest and Pilkington, 1993) of gravity in the study area (Fig. 5.3.1) has brought out two basement blocks separated by Mukundra fault system

5.3.1.2 Euler depth

Euler depth (Marson and Klingele, 1993) to basement (Fig.5.3.1a) suggests that depth of causatives is varying between 3 to 5 km. The two basement block proposition and trends are conformable with analytical signal strength. Fig. 5.3.1a.

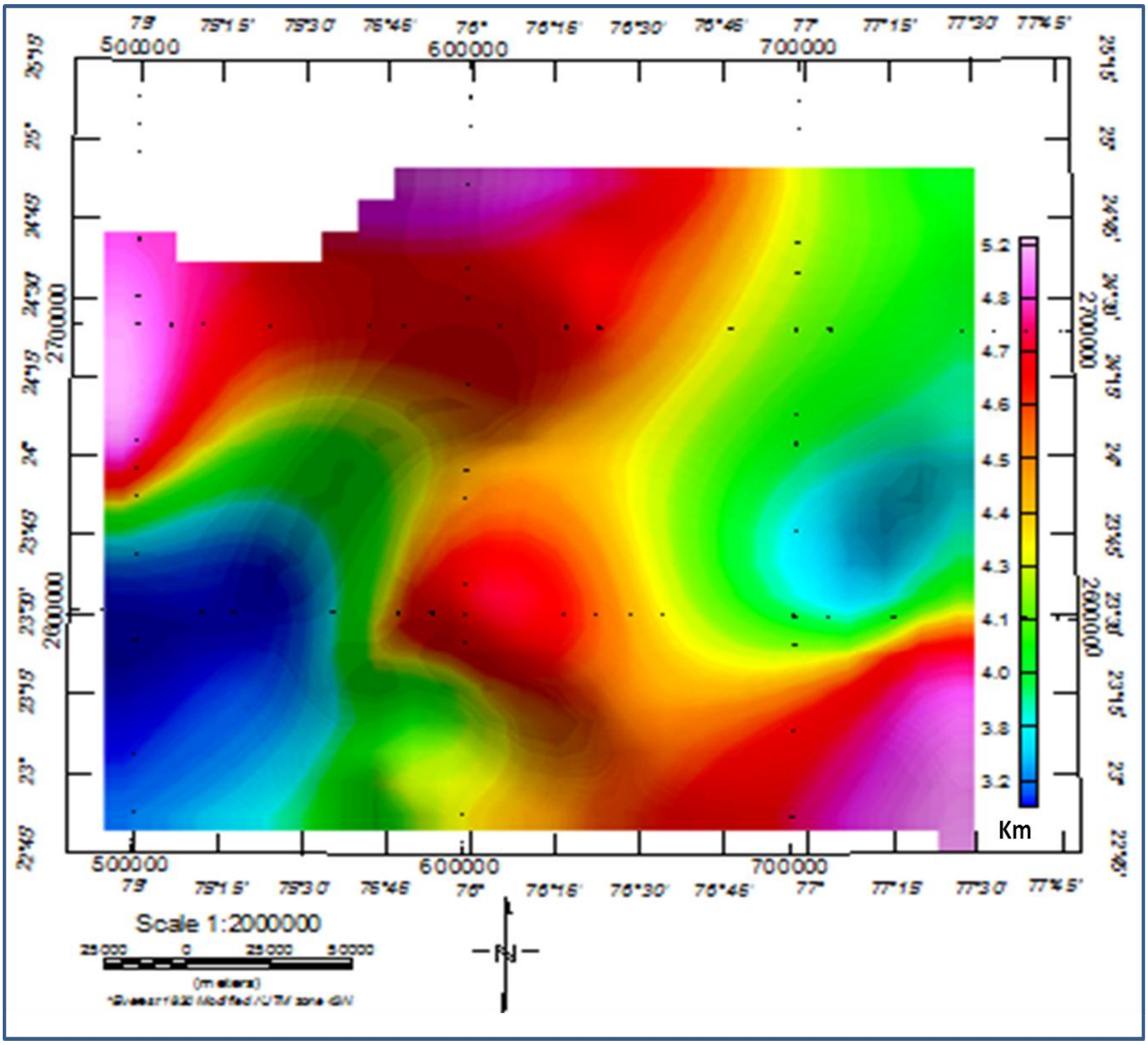


Fig. 5.3.1a Euler depth to basement map

5.3.1.3. Spectral Analysis

Amplitude spectrum (Hahn, Kind and Mishra, 1976; Mishra and Pederson, 1982) of gravity data has been prepared Fig. 5.3.1b. From the energy spectrum, slope wavelengths pertaining to different interfaces of causative depth source bodies are calculated. It is found that wavelengths of 32 km, 29 km, 18 km and 10 km are responsible for producing anomaly in Bouguer gravity of Chambal valley. These data have been used for preparing regional and residual separation.

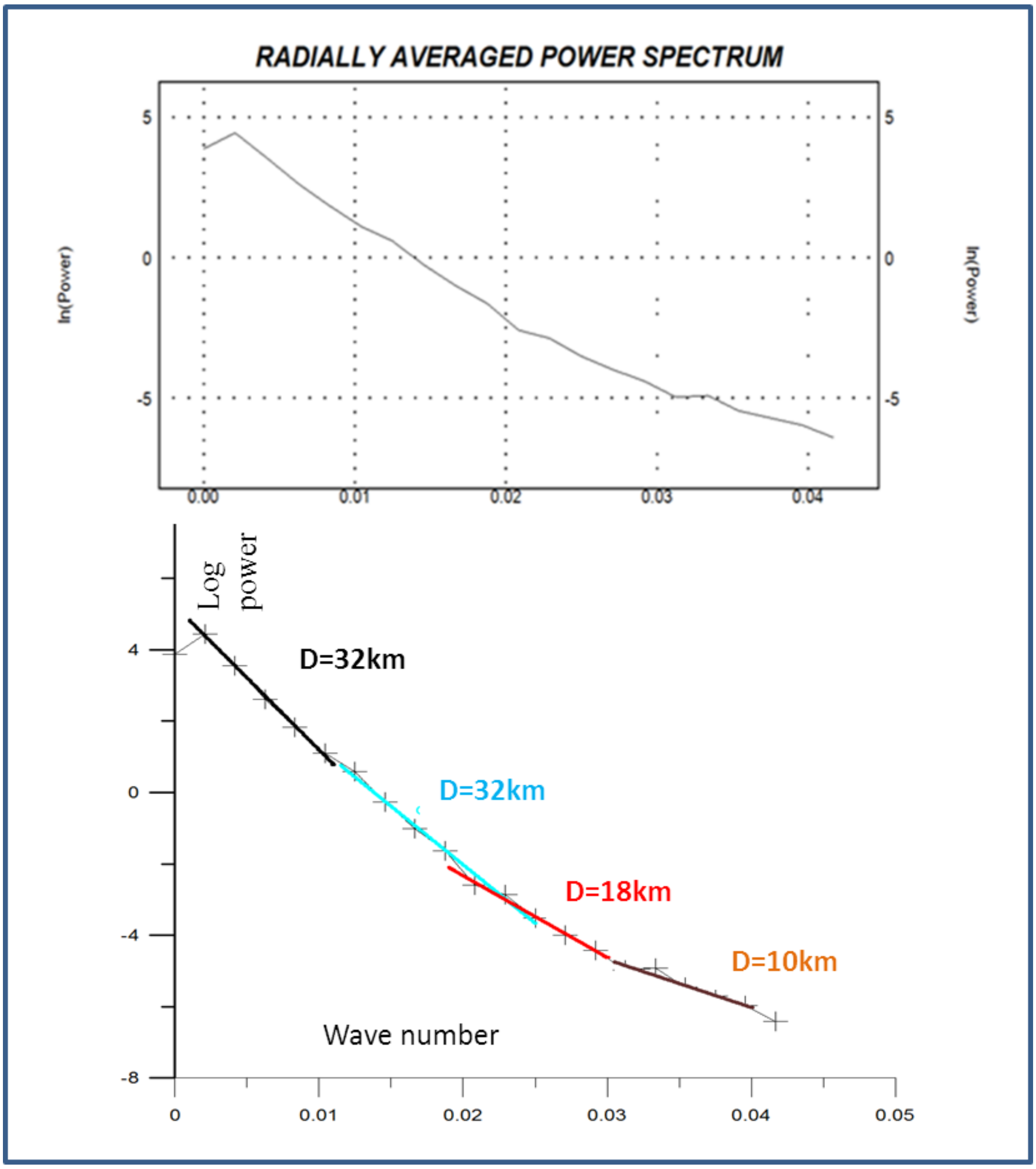


Fig. 5.3.1b Power spectrum plots of gravity data

5.3.1.4 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. 5.3.1c. & 5.3.1d.

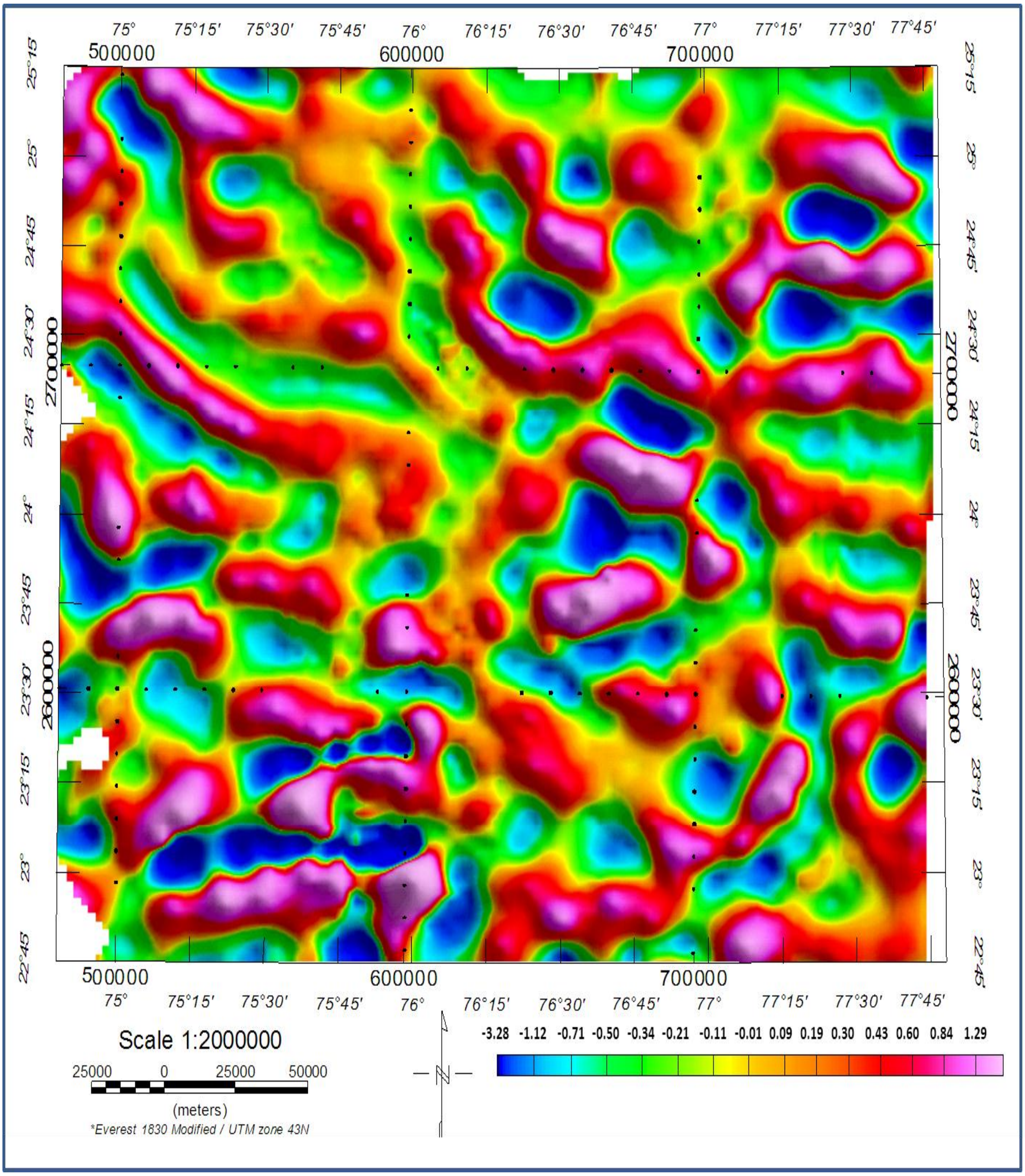


Fig 5.3.1c Residual gravity anomaly map. Colour code is in mGals.

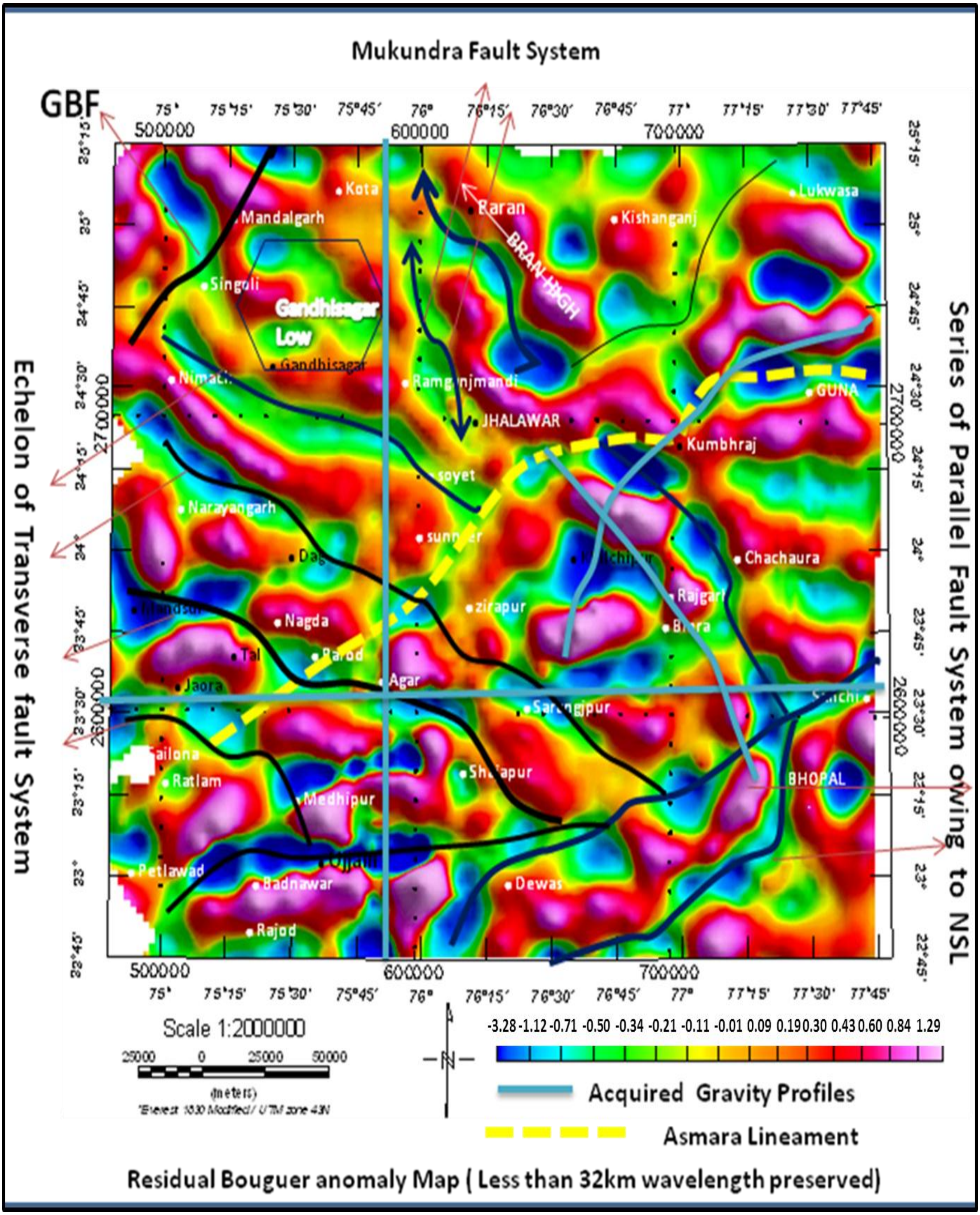


Fig. 5.3.1d Inferred faults and tectonic elements on residual gravity map. The blue coloured lines indicate inferred faults.Yellow dash line seems to represent a major fault.i.e Asmara Lineament. High precision gravity profiles (in blue colour) are also shown.

5.3.2 Magnetic data

5.3.2.1 Aeromagnetic anomaly – Reduction to pole (RTP) processing

Aeromagnetic anomaly Reduced to Pole, RTP (Baranov and Naudy, 1964; Silva, 1986; Emilia, 1973; Bott and Ingles, 1972; Arkani-Hamed, 1988;Hansen and Pawlowski, 1989;Pearson and Skinner, 1982) map (Fig.5.3.2) is prepared, where magnetic anomaly causative sources are aligned in SSE-NNW direction mimicking prominent gravity anoamly features (Fig. 5.3.1c). RTP is related to gravity gradient (Telford.et.al, 1976). Each magnetic high and low represents separate basement blocks and shear zones on the intervening boundaries, or gradients. These observations have helped to identify basement fault pattern in trap covered areas where no seismic data is available.

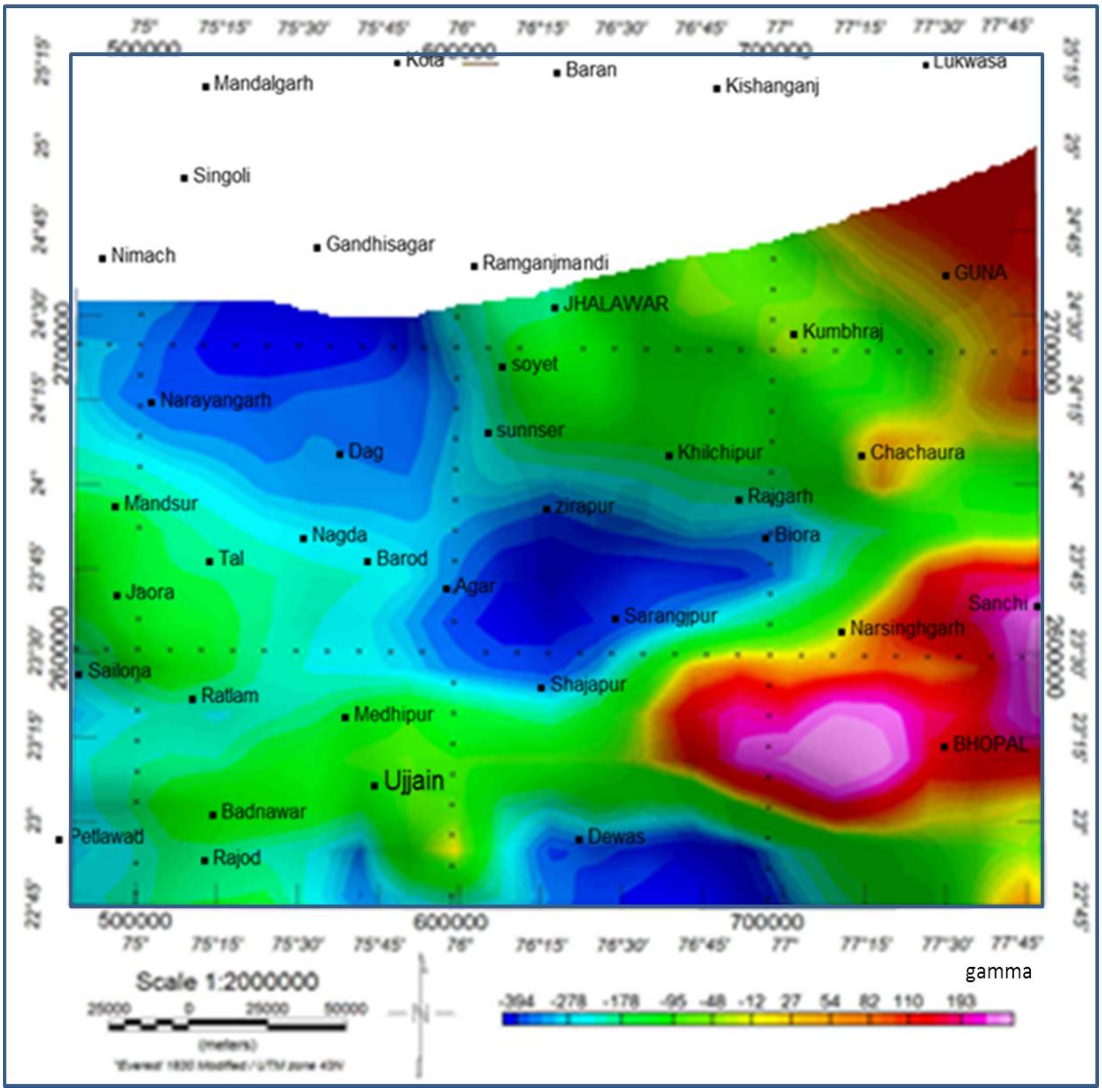


Fig. 5.3.2 Reduction-to–Pole (RTP) map of aeromagnetic data of the study region. RTP is equivalent to vertical gravity gradient.

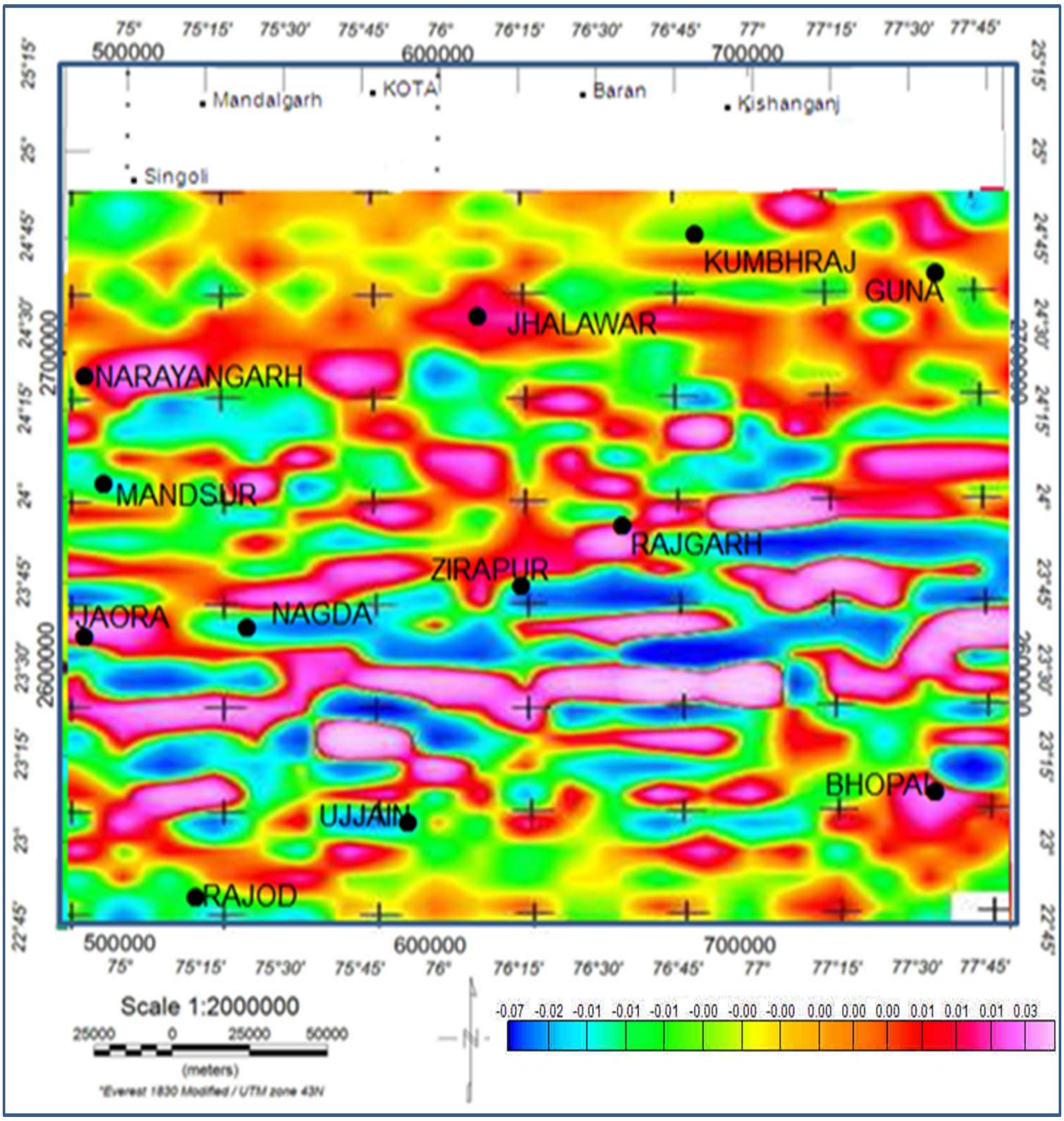


Fig. 5.3.2a First vertical derivative map of RTP reduced aeromagnetic anomaly

5.3.2.2 First vertical deriavative of RTP aeromagnetic anomaly (FVD)

First vertical deriavative (Grant and West,1965; Telford et al.1976) of RTP corrected aeromagnetic anomaly map depicts the shallow causative sources of magnetic bodies (Fig. 5.3.2a). The FVD map is qualitatively similar to that of gravity residual map (Fig. 5.3.1c and brought out all the shallow features indicating trap's (high density and magnetized) significant role in the study area. Infact FVD of ΔT anomaly is related in higher order gravity gradient (Telford et al.1976)

Identification of faults can be made from aeromagnetic data due to changes in magnetic susceptibility across basement faults. Each magnetic high and low represents a separate basement block and the faults (shear zones) occur on intervening boundaries, or gradients. This observation has helped in identification of basement fault pattern in trap covered area (Fig.

5.3.2b). Two sets of faults can be observed on aeromagnetic map one in NW-SE direction and another in NE-SW which is similar to fault pattern identified on residual gravity map, Fig. 5.3.1c.

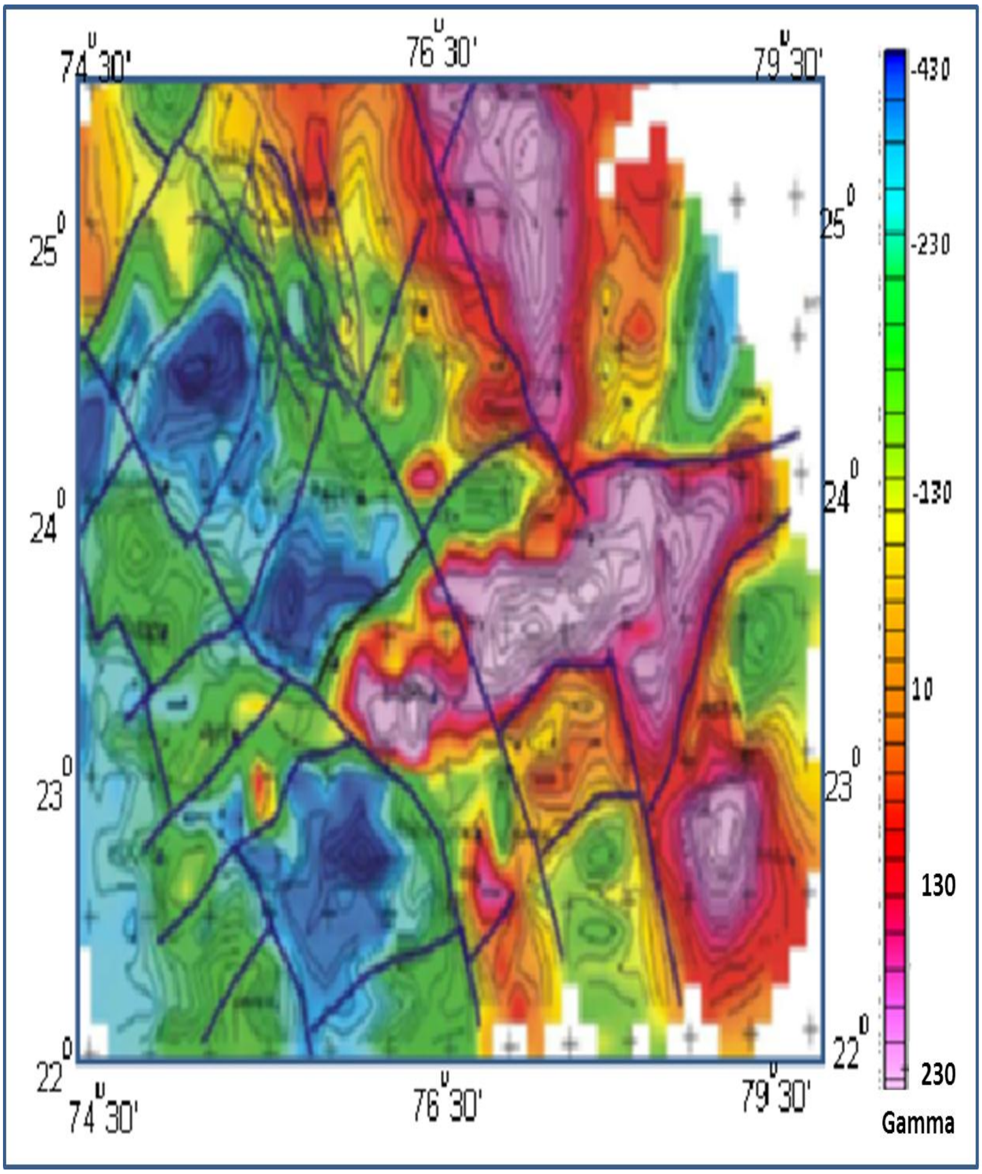


Fig. 5.3.2b Fault map derived from RTP aeromagneic map (Fig. 5.3.2) for the study region.

Inferred faults are shown as crooked lines in black colour

5.3.2.3 Euler depth Map

Euler depth (Thompson, 1982; Barongo,1984; Reidetal.1990;Marson and Klingele, 1993) map has been prepared from causative points obtained through Euler filter where structural index of magnetic dike has been considered. The maximum depth of magnetic source bodies is about 4500m which is tallying with that of gravity (Fig. 5.3.2c.)

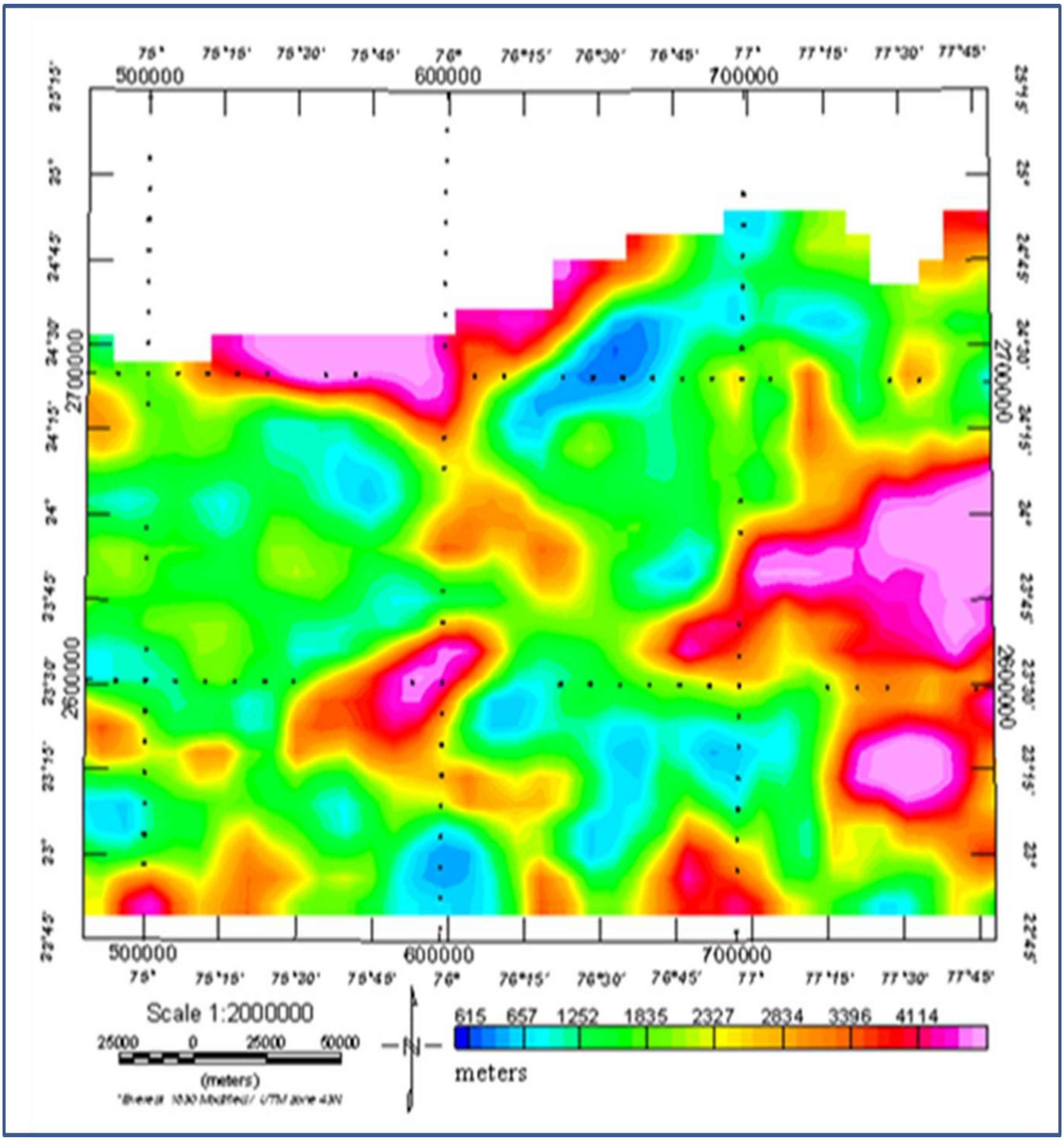


Fig. 5.3.2c Euler depth map derived from aeromagnetic data (Fig. 5.3.2b) for the study region

5.3.2.4 Pseudo - gravity computation

Pseudo - gravity (Baranov, 1957;Kanesewich and Agarwal, 1970; Bott and Ingles, 1972; Cordell and Taylor, 1971;Chandler and Malek, 1991), which again confirms the most prominent SSE-NNW feature observed in gravity Fig. (5.3.2d). It also confirms the gravity features associated with NSL, Mukundra fault etc. This map proves the autheticity of gravity and magnetic data and vice-versa.

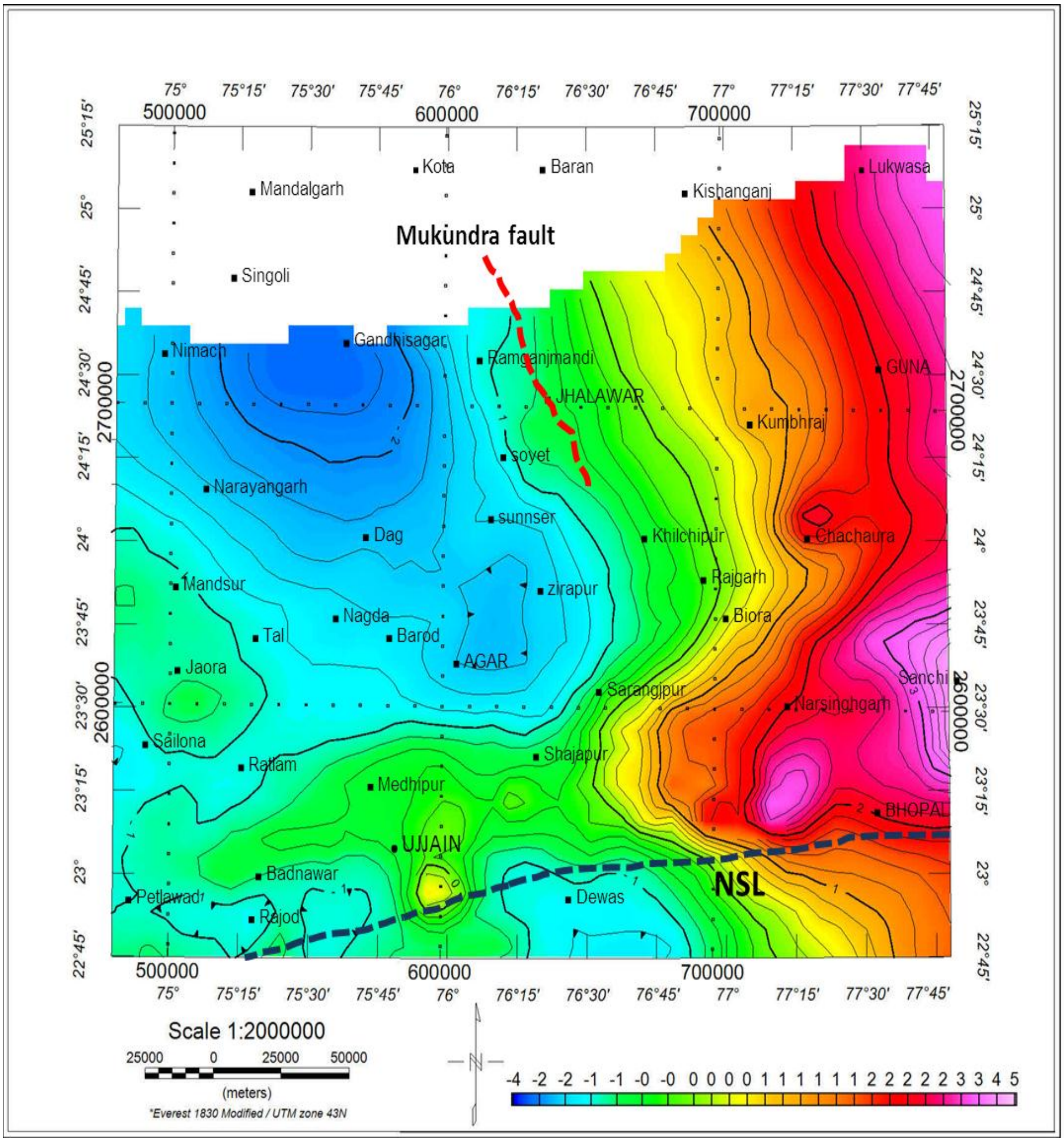


Fig. 5.3.2d Pseudo gravity map. Mukundra fault and Narmada-Son lineament (NSL) are also shown on this map.

5.3.2.5 Werner deconvolution depth computation

Deccan traps are exposed over large parts of Chambal valley, so it is important to know the effect of trap on aeromagnetic data. A profile passing through trap covered area is chosen to study effect of trap on aeromagnetic data Fig. 5.3.2e. The sources of causative bodies are clustered more in Werner deconvolution depth map(Werner,1953;Hartman, Teskey,Friedberg, 1971;Hartman etal.1971; Hansen and Simmonds,1993;Ku and Sharp,1983) at shallower depth indicating trap is masking the basement effects.

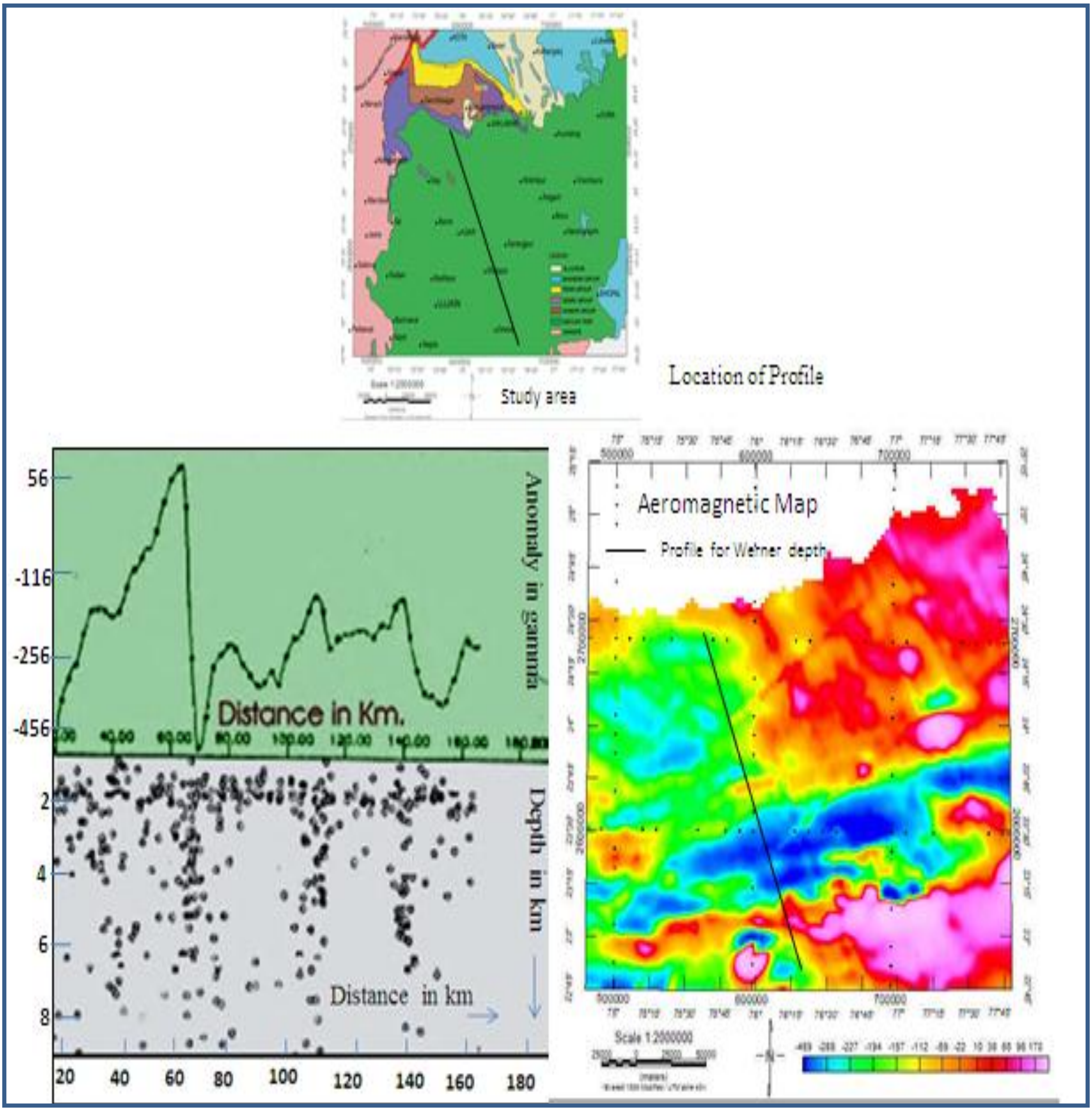


Fig. 5.3.2e Werner depth estimation along a profile over trap shown on aeromagnetic map of study region. Profile location is shown both on geological an aeromagnetic maps of study region.

CHAPTER- 6

Gravity and Magnetic modeling

Preamble

Deccan traps are exposed over a large area of Chambal valley and the study region (Fig.1.3a and Fig.1.3b) is fully covered with trap. Northern part comprising Bundi-Kota-Jhalawar area is sediment covered and south of Jhalawar is fully covered with trap. Gravity, aeromagnetic data and some seismic profiles passing over the northern side of study region are available. Seismic data is used as additional constraint for further analysis.

As indicated earlier,the prime objective of gravity magnetic modeling is to derive regional thickness of trap and then to determine depth to basement. In this study, initially a model is conceptualized with available seismic, gravity, aeromagnetic and surface geological data in northern part of Chambal valley and then the model has been extended for entire area based on the inputs from gravity data, aeromagnetic data and their attributes viz., Euler depth, energy power spectrum, Analytical signal strength, Psedo-graviy, Residual anomaly, Werner spot detpths, first derivative of magnetic anomaly. Surface exposed and subsurface rock samples were collected along the pofiles and their measured density were also used for density model parameters. In addition surface topographical, geological features viz ridges, faults, dome, exposed trap boundaries and sediments have also been considered in gravity modeling.

6.1 Modeling constraints

6.1.1 Seismic data

Northern part of Chambal valley comprising Bundi-Kota-Jhalawar area (Fig.1.3a) is sediment covered and a small extent of this area near Jhalawar is partially covered with seismic data Fig.6.1. The study area is south of Chambal valley fully covered with Decaan traps. Seismic profiles viz RFB-01-11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 22 and 23 running NE to SW direction over trap and a major portion covering sediment area. The data in trap-covered segments is generally of poor qualityIn order to see the effect of sediments and trap on seismic data and then apply the results over trap covered area, modelling has been carried out along these seismic profiles. There is no deep well in the area for stratigraphic tie of seismic horizons.

Therefore, seismic horizons are calibrated from nearby well data. Correlation from one end to other is extended based on seismic reflection character and exposed geology. The seismic signatures of the Great Boundary Fault (GBF) are also noticed on few sections including Fig. 6.1a

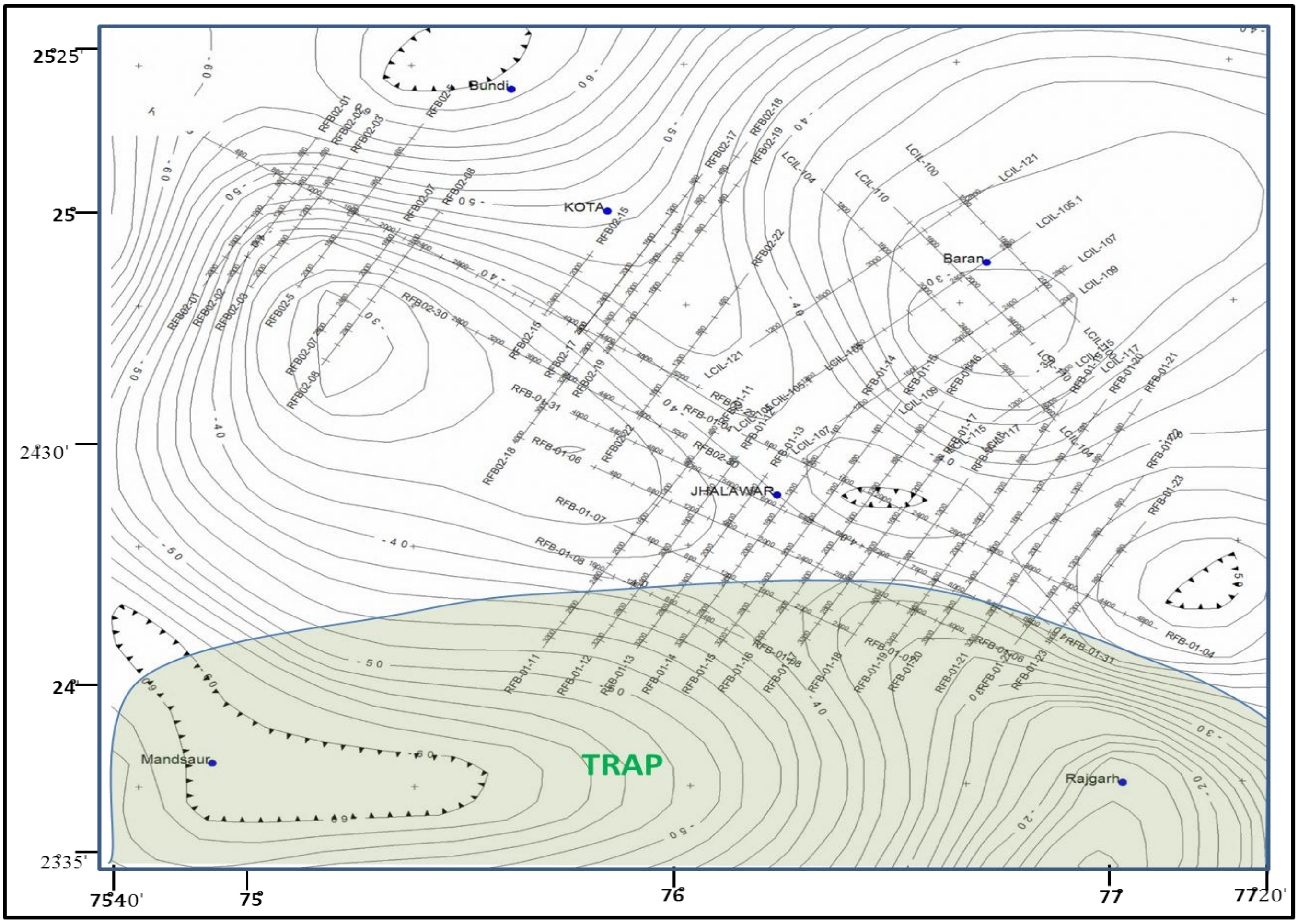


Fig. 6.1 Seismic profile network coverage superimposed over gravity map in the northern part of study region

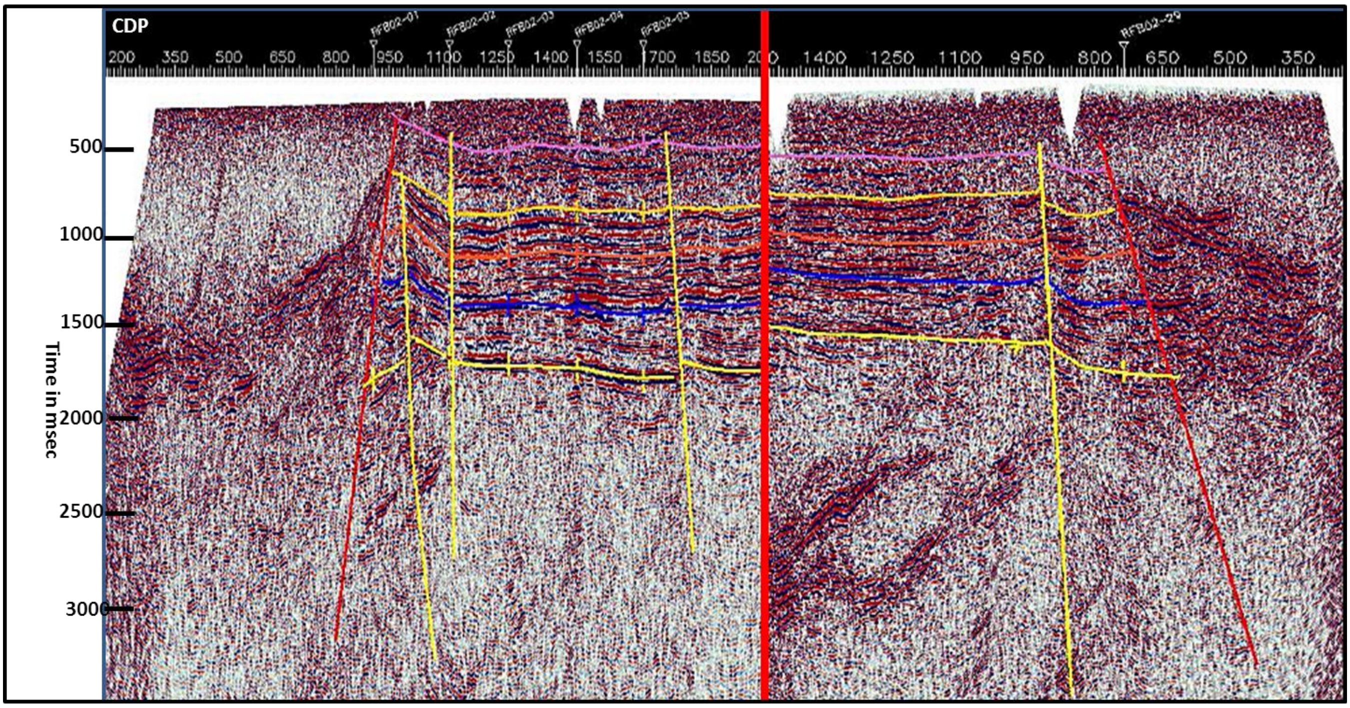


Fig 6.1a Seismic signatures of Great Boundary Fault (GBF) on profile RFB-02-01

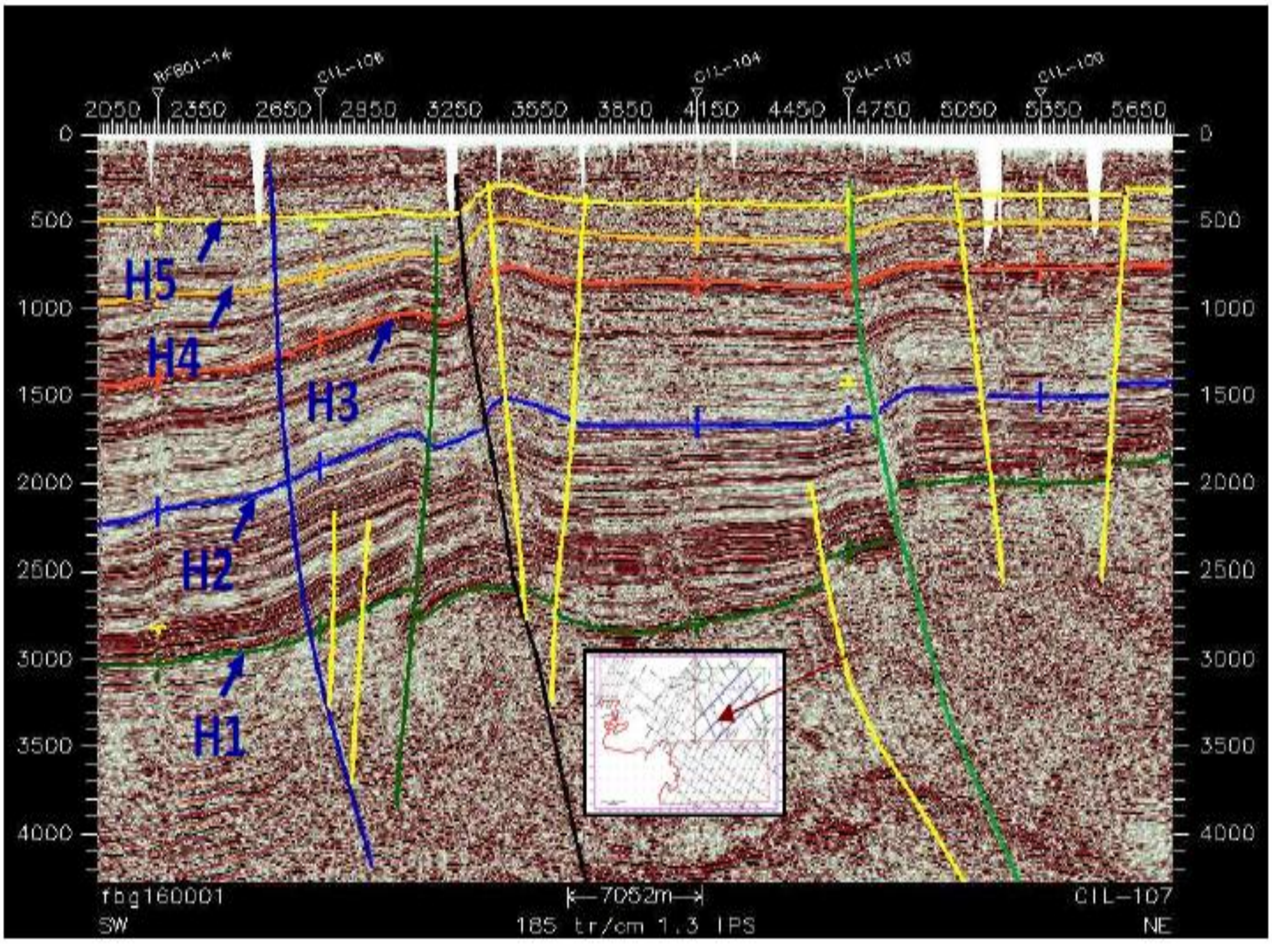


Fig 6.1b Seismic profile CIL-107 showing mapped reflectors

6.1.2 Isochrone maps

Five correlatable reflectors including base of Vindhyan have been identified within Lower and Upper Vindhyan (Fig. 6.1b). The following reflectors in Fig 6.1b are correlated and mapped:
1. A reflector close to base of Vindhyans (H1) 2. A reflector within Lower Vindhyans (H2), 3. A reflector close to top of Lower Vindhyans (H3) 4. A reflector within Upper vindhyans (H4) 5. A reflector top of Upper Vindhyans (H5).

Only two isocrone maps are shown here which correspond to a reflector close to base of Vindhyans (H1) and a reflector within Lower Vindhyans (H2) for estimation of thickness of Vindhyan sediments (Fig. 6.1c & 6.1d).

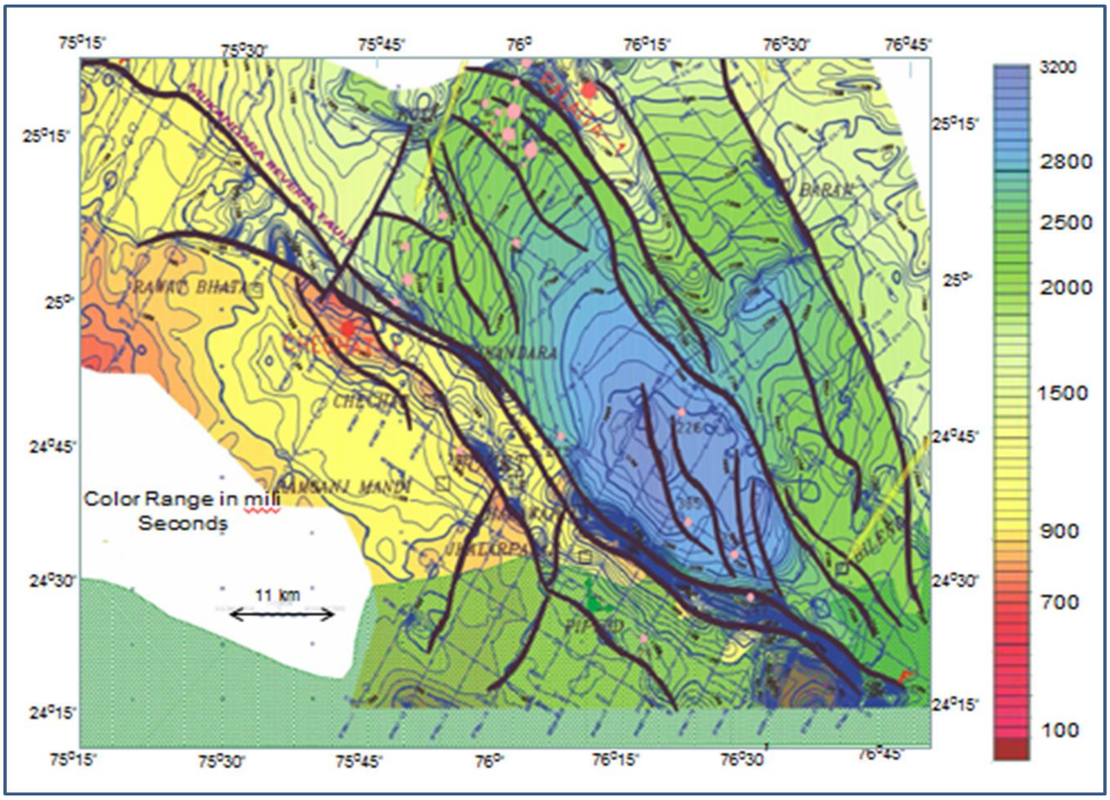


Fig. 6.1c Isochrone map of H1 level (base of Vindhyans)

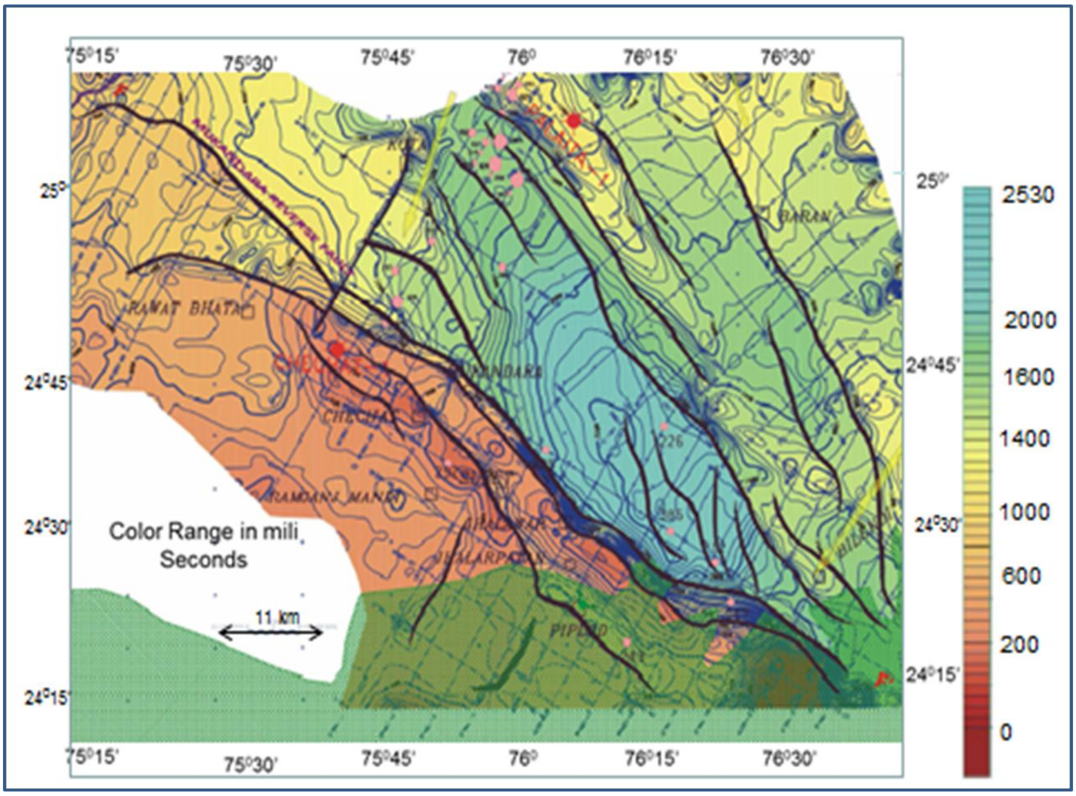


Fig. 6.1d Isochrone map of H2 level (Lower Vindhyans)

6.1.3 Isochronopach maps

In addition to isochrone maps, isochronopach maps of Lower Vindhyan (H1 – H3) and Upper Vindhyan (H3-H5) have been prepared (Fig. 6.1e & 6.1f). Sediment thickness is maximum towards south-eastern part of both the maps (Fig 6.1e &6.1 f)

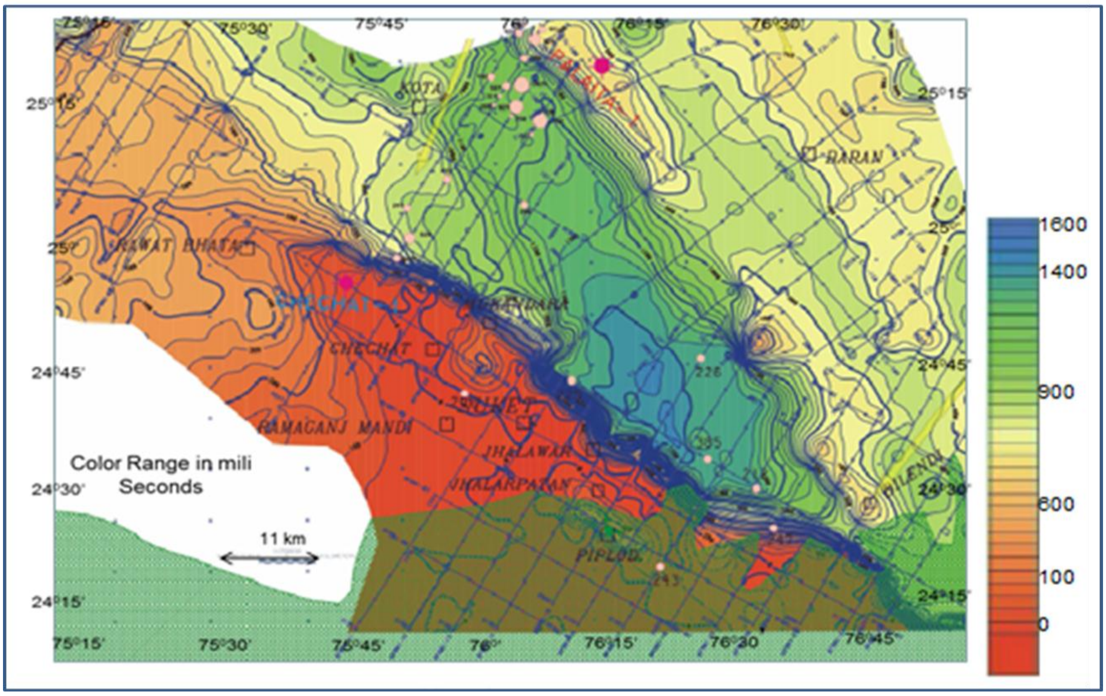


Fig. 6.1e Isochronopach map of lower Vindhyans

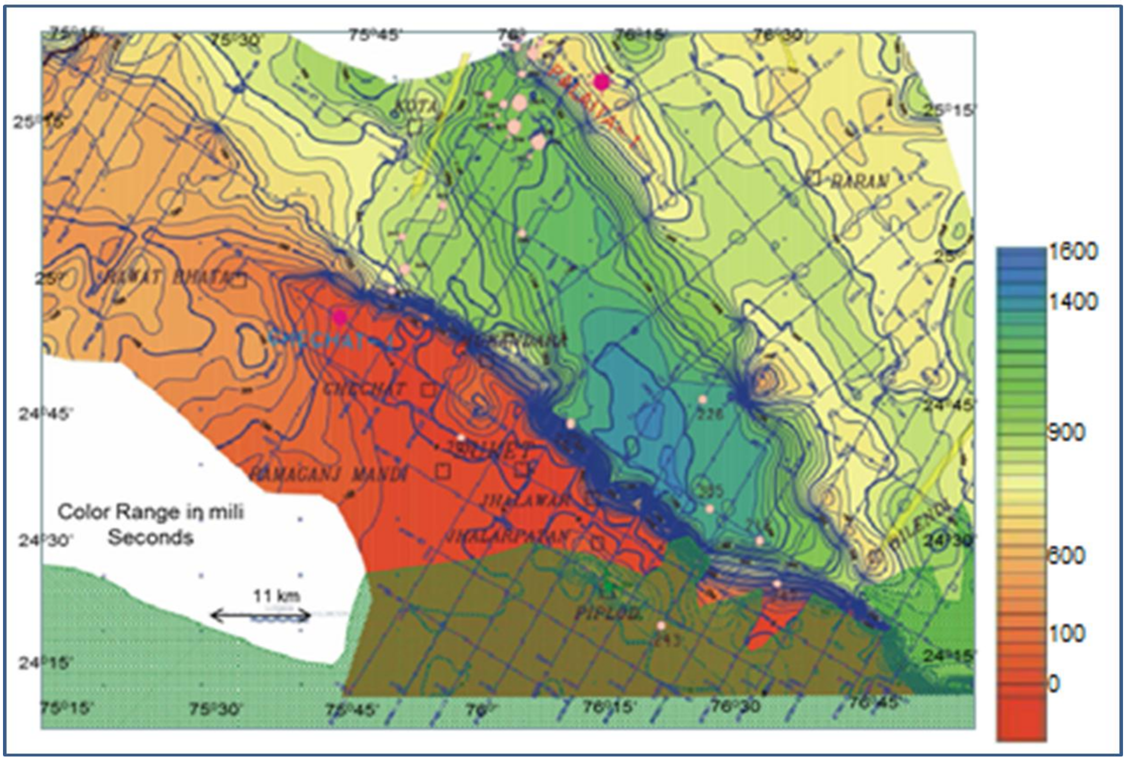


Fig. 6.1f Isochronopach map of upper Vindhyans

6.1.4 Seismogeological sections

In order to estimate sediment thickness over trap covered area, seismogelogical sections have been prepared on sediment part to trap covered area for better understanding of sub-surface Fig. 6.1g, 6.1h., 6.1i & 6.1j

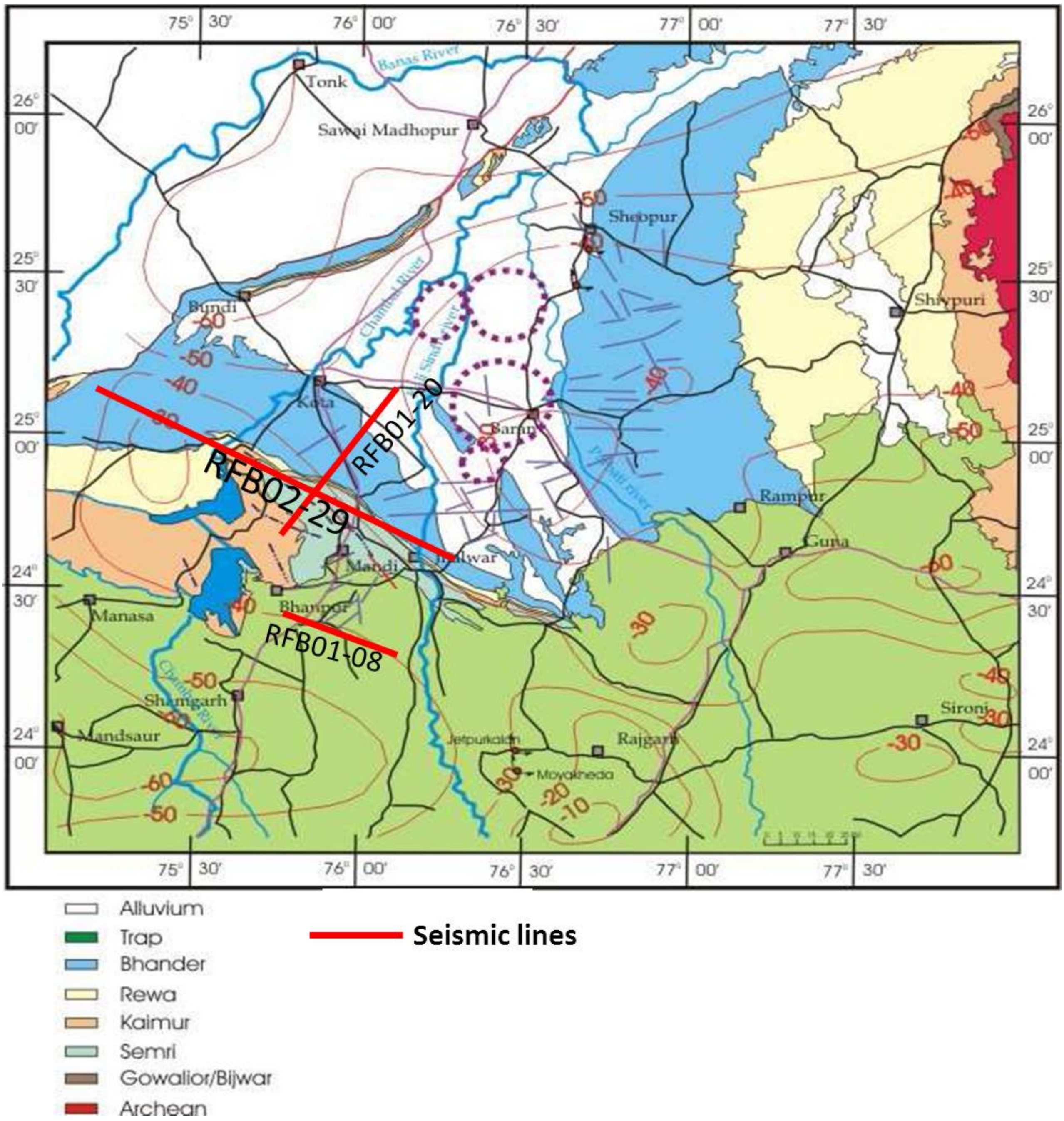


Fig. 6.1g Location of the seismic profiles along which seismogeological sections are made

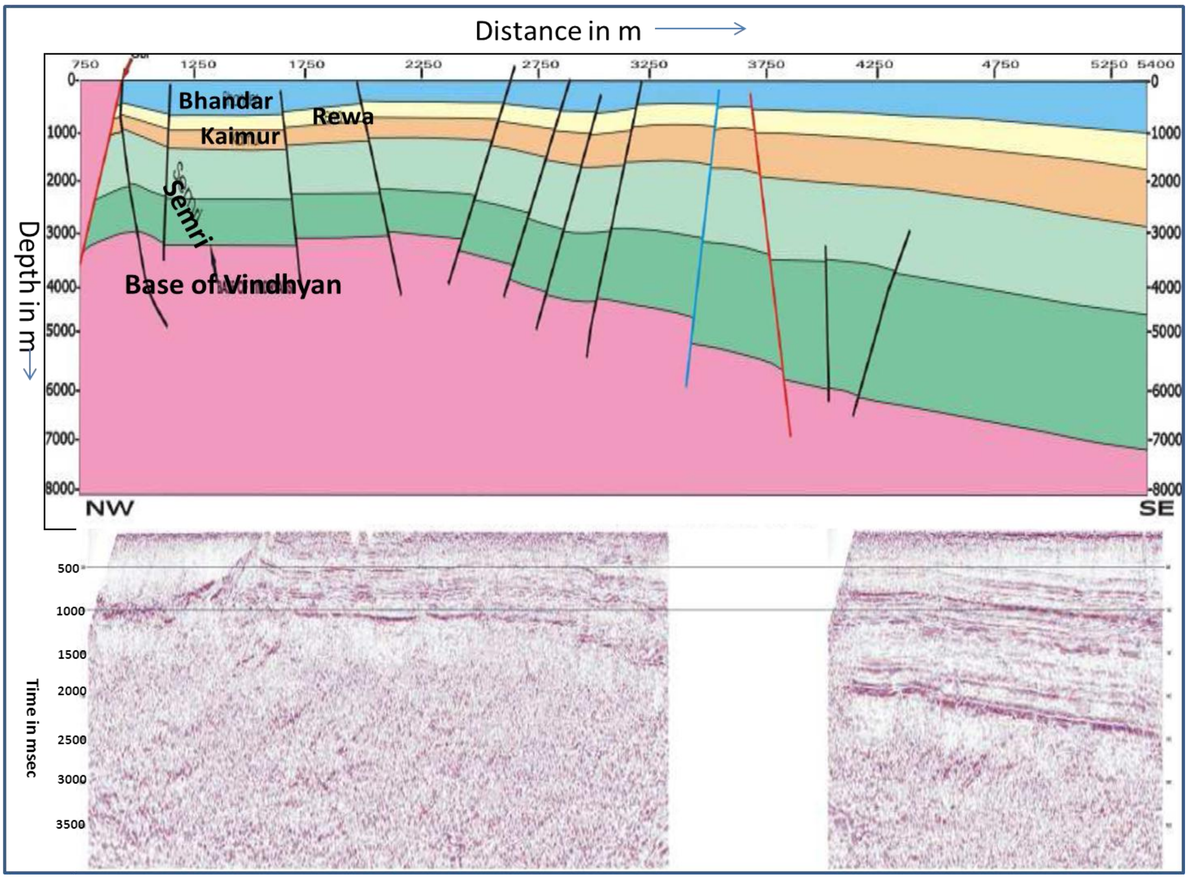


Fig. 6.1h Seismogeological section along profile RFB02-29

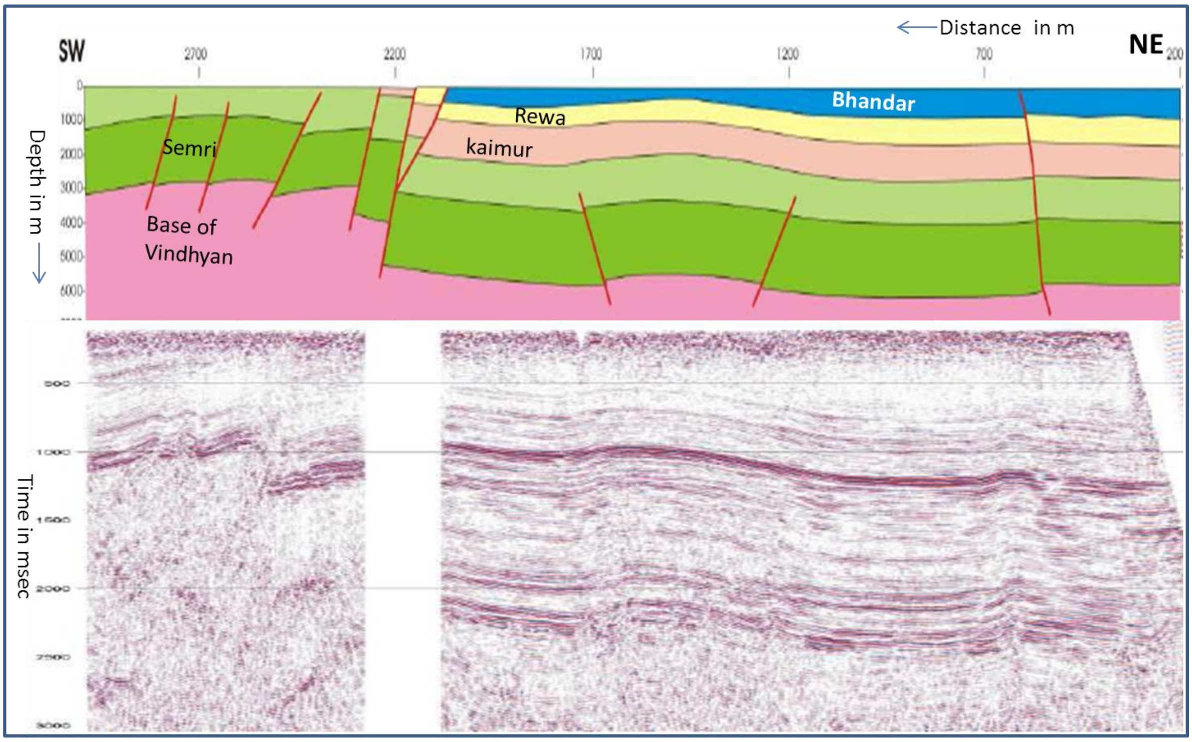


Fig. 6.1i Seismogeological section along profile RFB-01-20

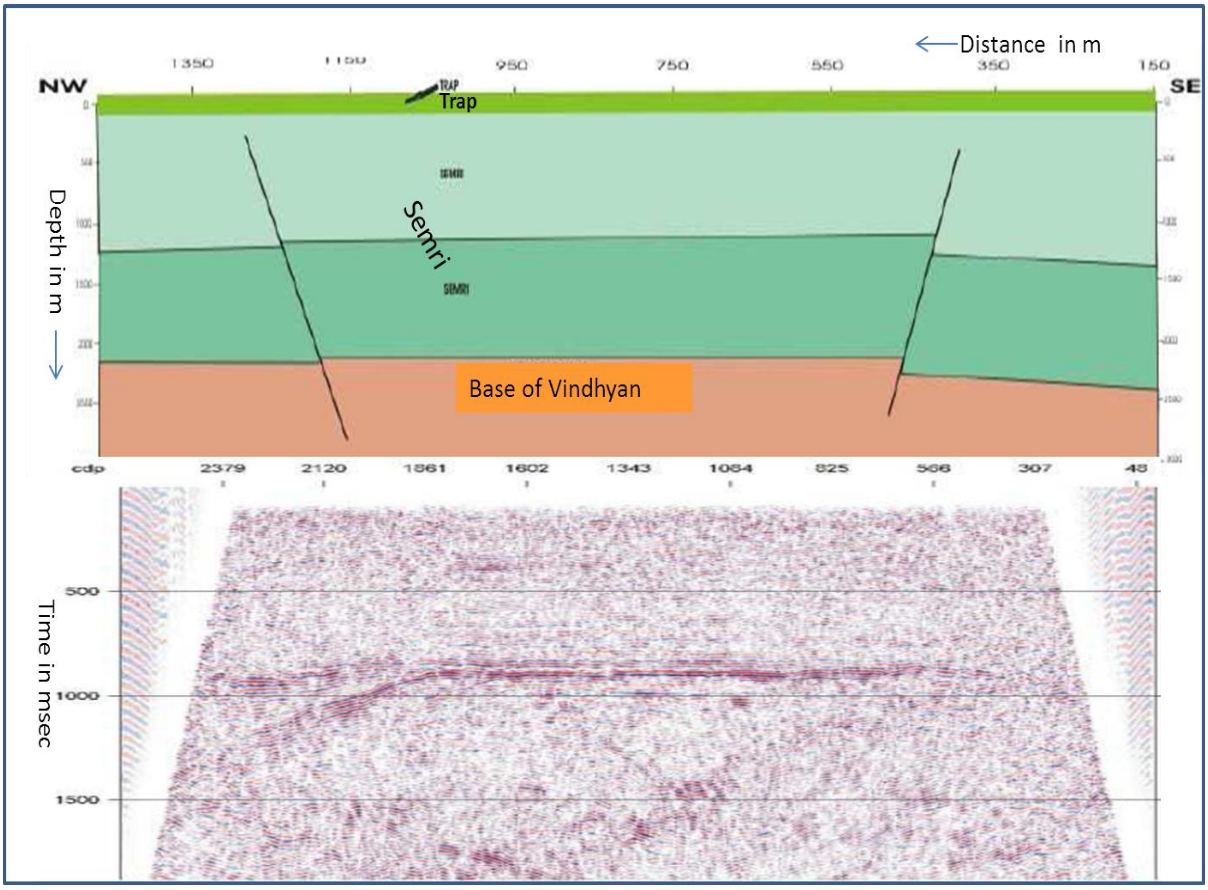


Fig. 6.1j Seismogeological section along profile RFB-01-08

6.1.5 Gravity modeling along seismic profiles

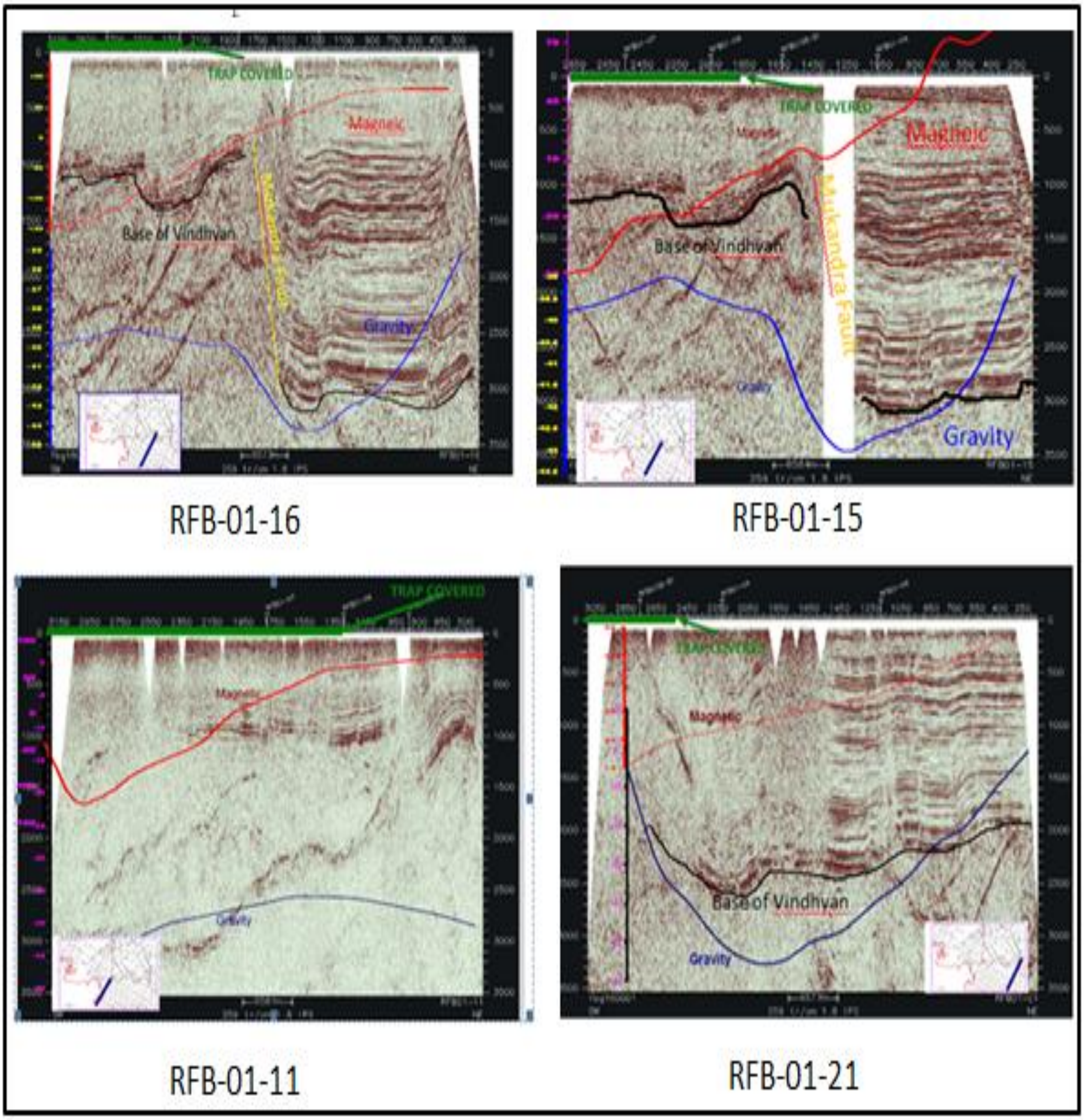
As per earlier mentioned during determination on relevant rock sample (Table 4) were used in gravity modeling.

Table-4

Rock samples collected and their density

Formation	Density gm/cc
Alluvium	2.3
Upper Vindhyan	2.70
Lower Vindhyan	2.72

Fig. 6.1k Gravity Magnetic signatures superimposed over seismic sections along four profiles



RFB-01-16

RFB-01-15

RFB-01-11

RFB-01-21

Gravity magnetic 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. 6.1k) can be seen.

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. 6.1j. 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.

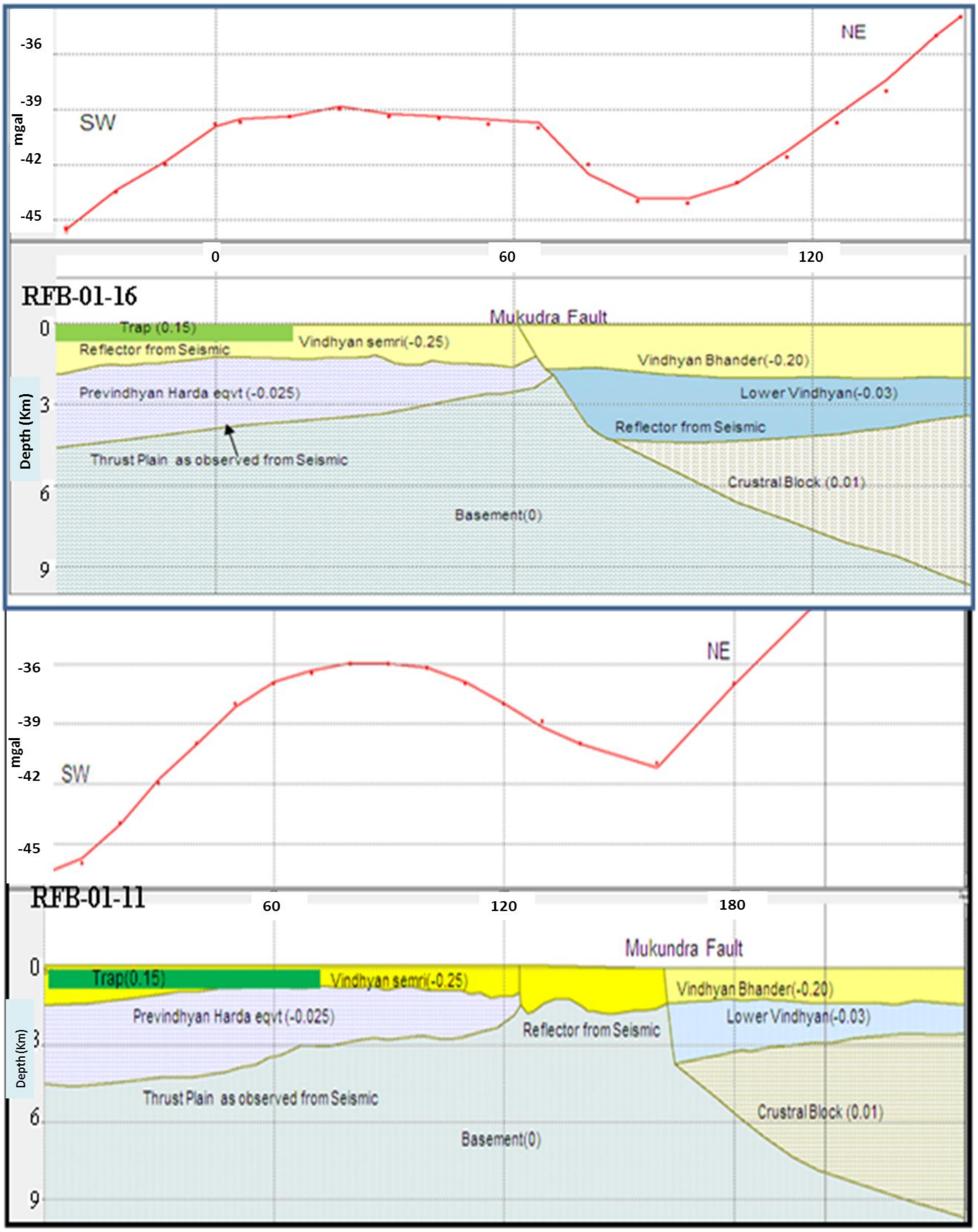


Fig. 6.1l Gravity modeling along seismic profiles RFB-01-16 & RFB-01-11

A sharp rise of gravity, east of Mukundra thrust has produced only a gentle rise on seismic section in this area (Fig. 6.1k). 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.

Table 5 Density contrast valuesused in gravity modeling

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

6.1.6 Gravity modeling along regional profiles

Two regional profiles are choosen along 76^0E and 77^0E longitude north-south (AA' and BB') to cut across gravity features in the study area (Fig. 6.1m). These profiles (Figs. 6.1n and 6.1o) 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. 6.1h - 6.1s).

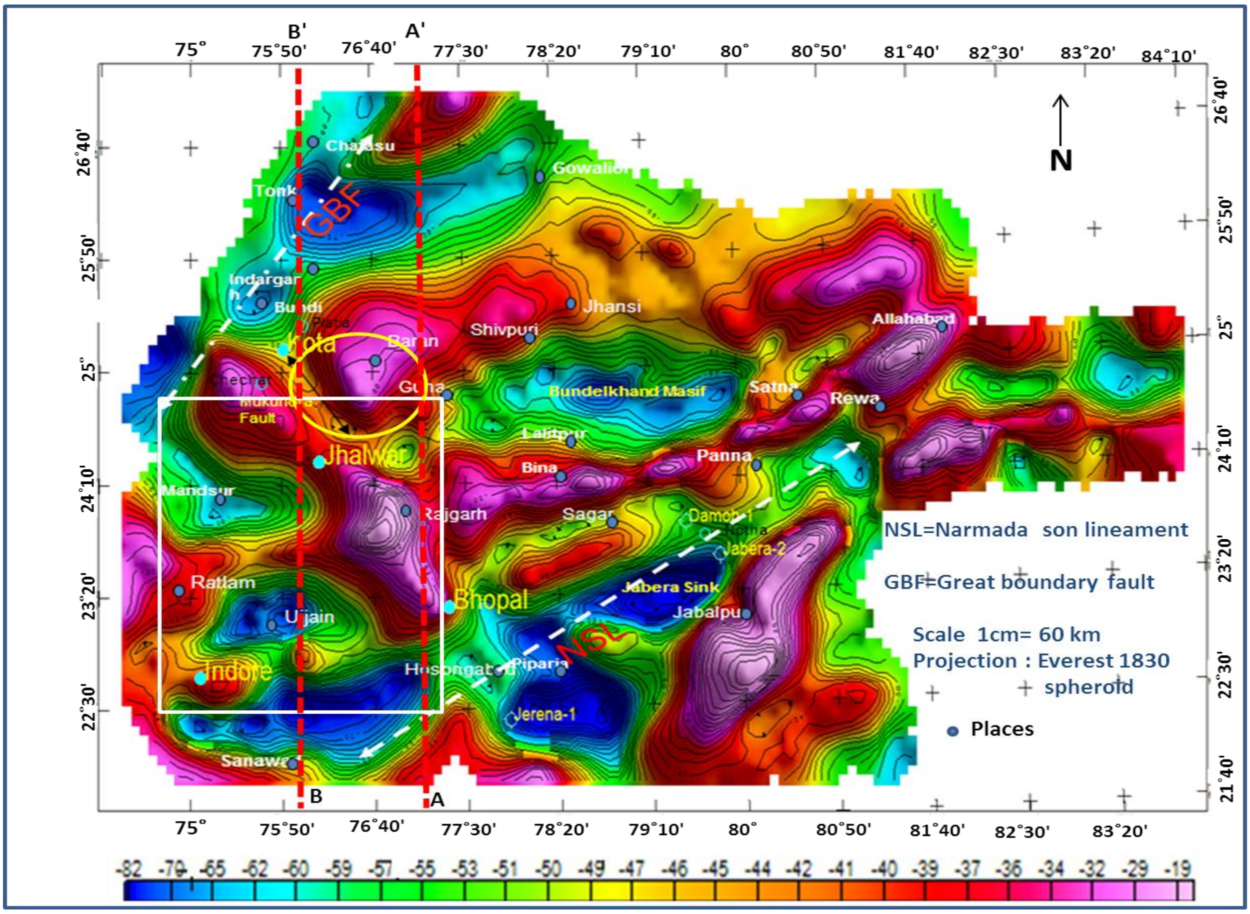


Fig. 6.1m Location of two N-S marked by red dashed lines regional profiles, A'A and B'B (oval, rectangle and arrows denotes seismic coverage, study area and position of NSL and GBF respectively)

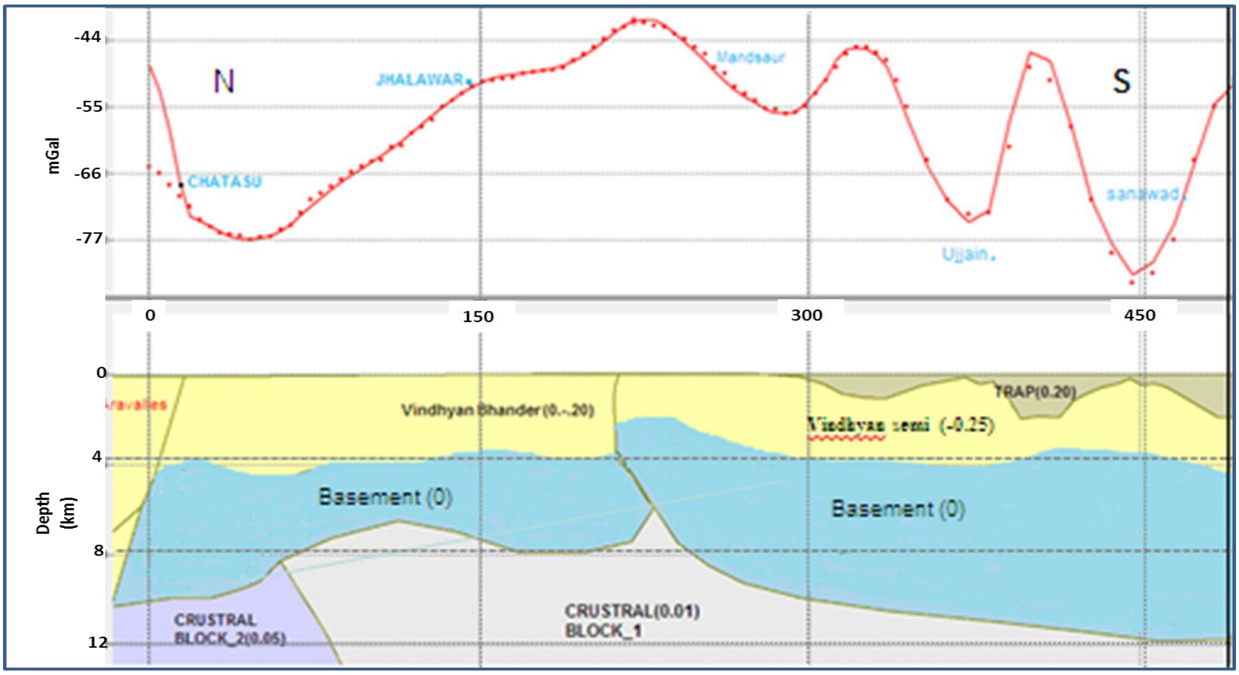


Fig. 6.1n Gravity modeling along Profile B'B (Fig. 6.1m)

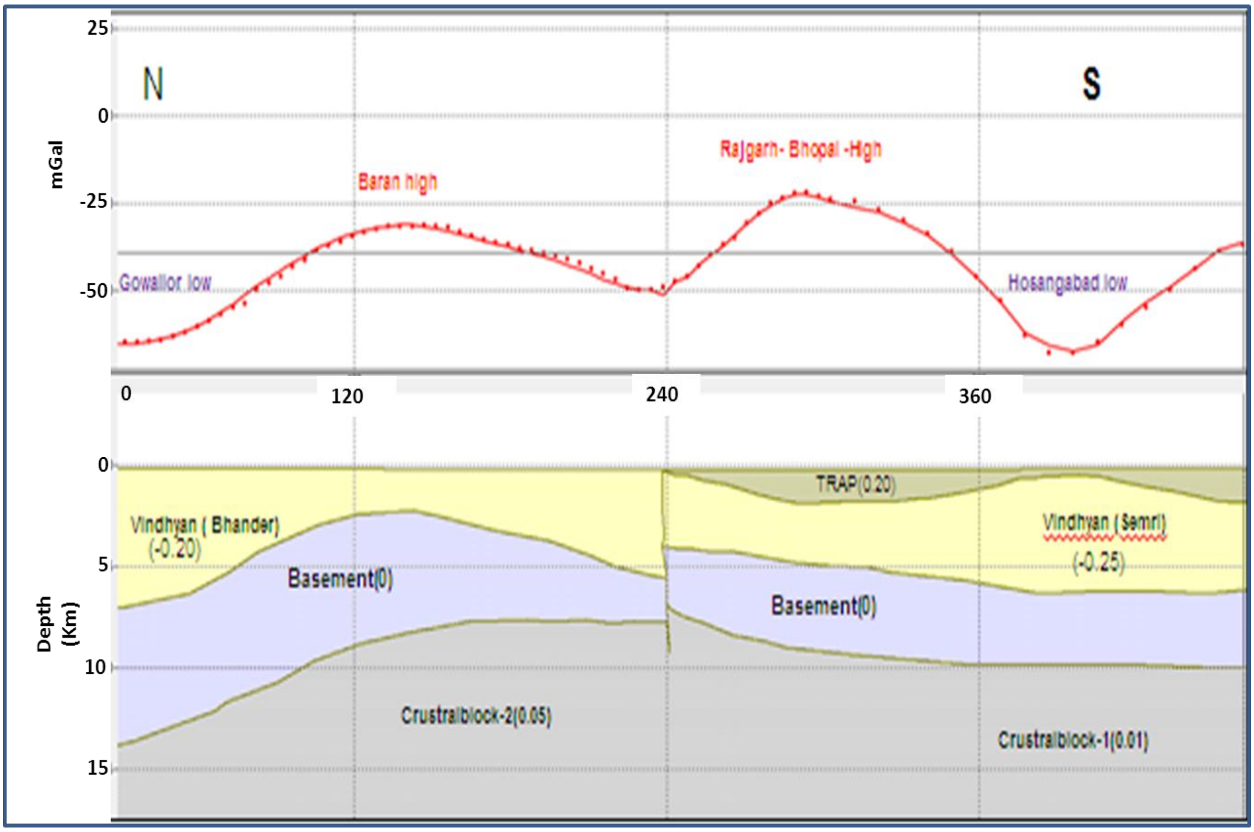


Fig 6.1o Gravity modeling along profile A'A (Fig. 6.1m)

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. This is supported by earlier analytical strength map shown in previous chapter (Fig. 5.3.1).

6.1.7 Gravity magnetic modeling along high precision data Profiles (Fig 5.3)

Earlier results (Fig 6.1h-6.1k) served as constrint for gravity modelling along four acquired profiles of high precision gravity data over trap in differen segments of Chambal valley. Also physical properties magnetic susceptibility (Pal et al. 1971) and density data rock samples Tables 4 and 5 were also used in modelling. These interpreted 2-D gravity modeling sections are induced in Figs. 6.1p-6.1s.

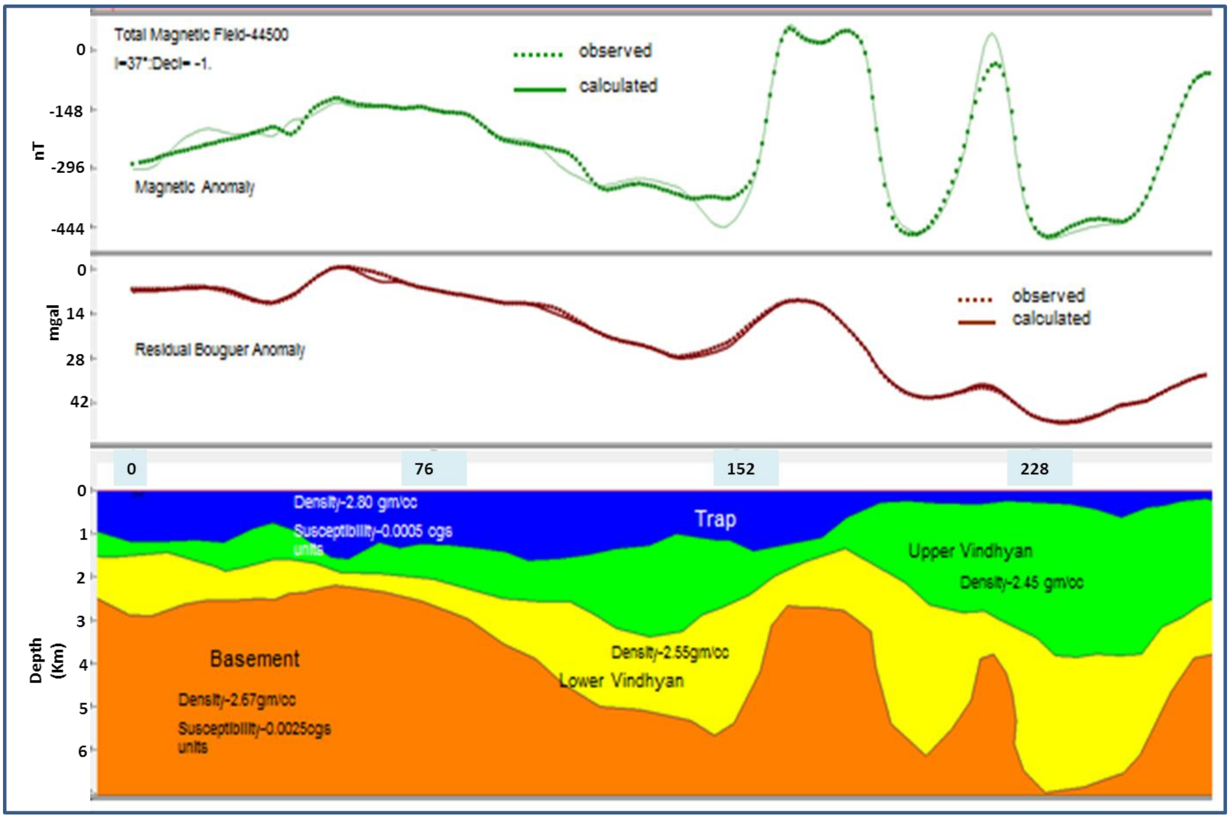


Fig. 6.1.p 2-D Gravity and magnetic modeling along W-E profile (Fig. 5.3)

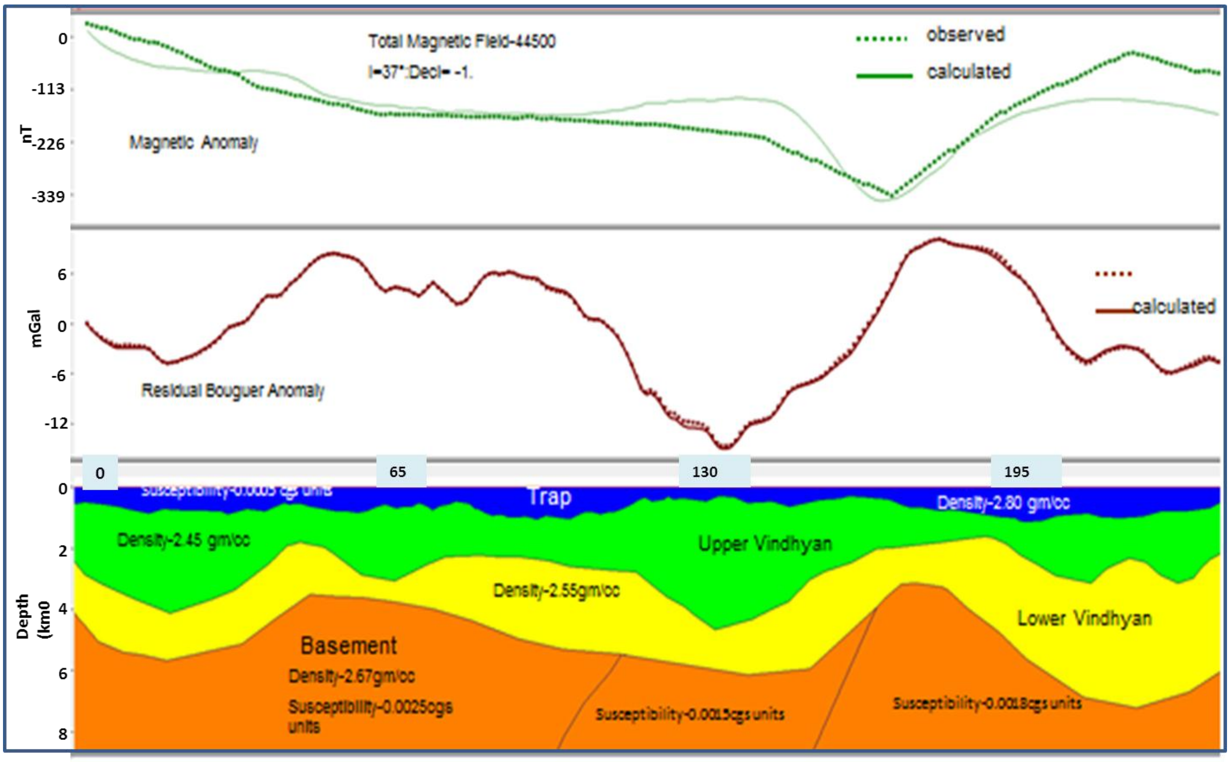


Fig 6.1q 2-D Gravity and magnetic modeling along N-S profile (Fig. 5.3)

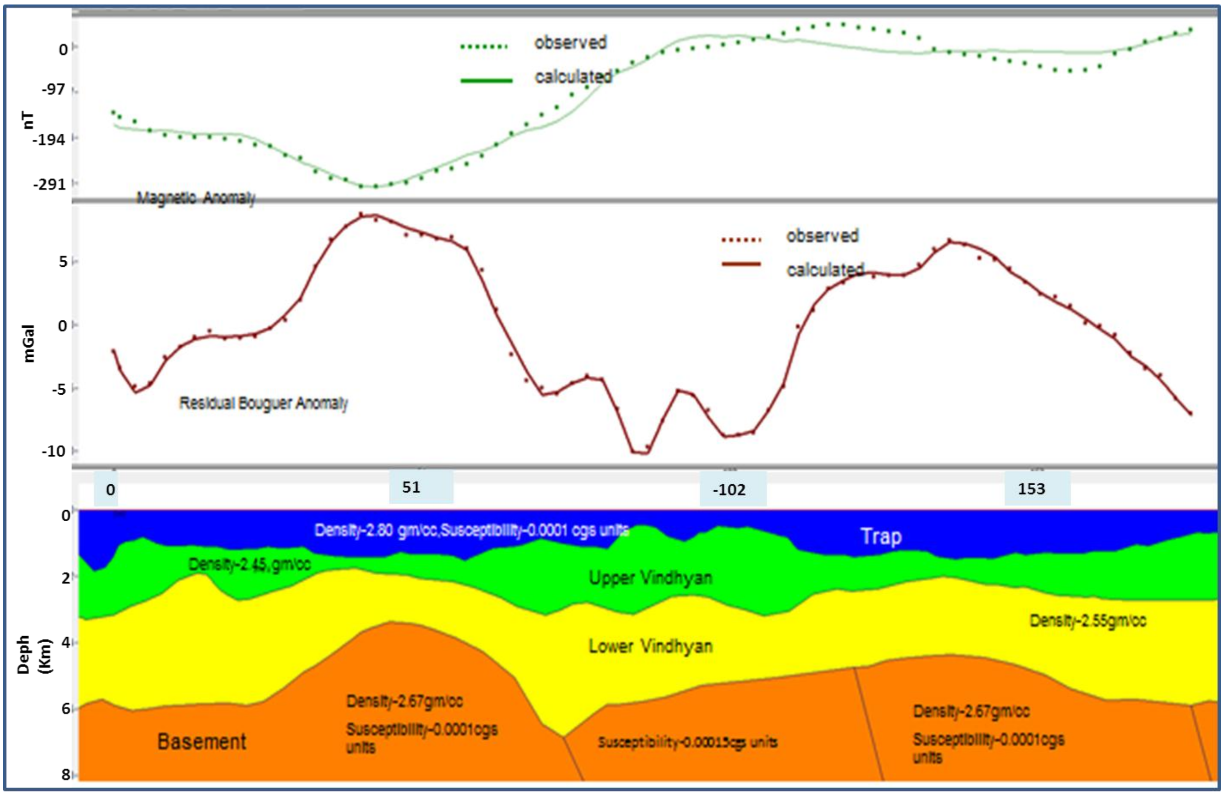


Fig 6.1r 2-D Gravity and magnetic modeling along SSE-NNW profile (Fig. 5.3)

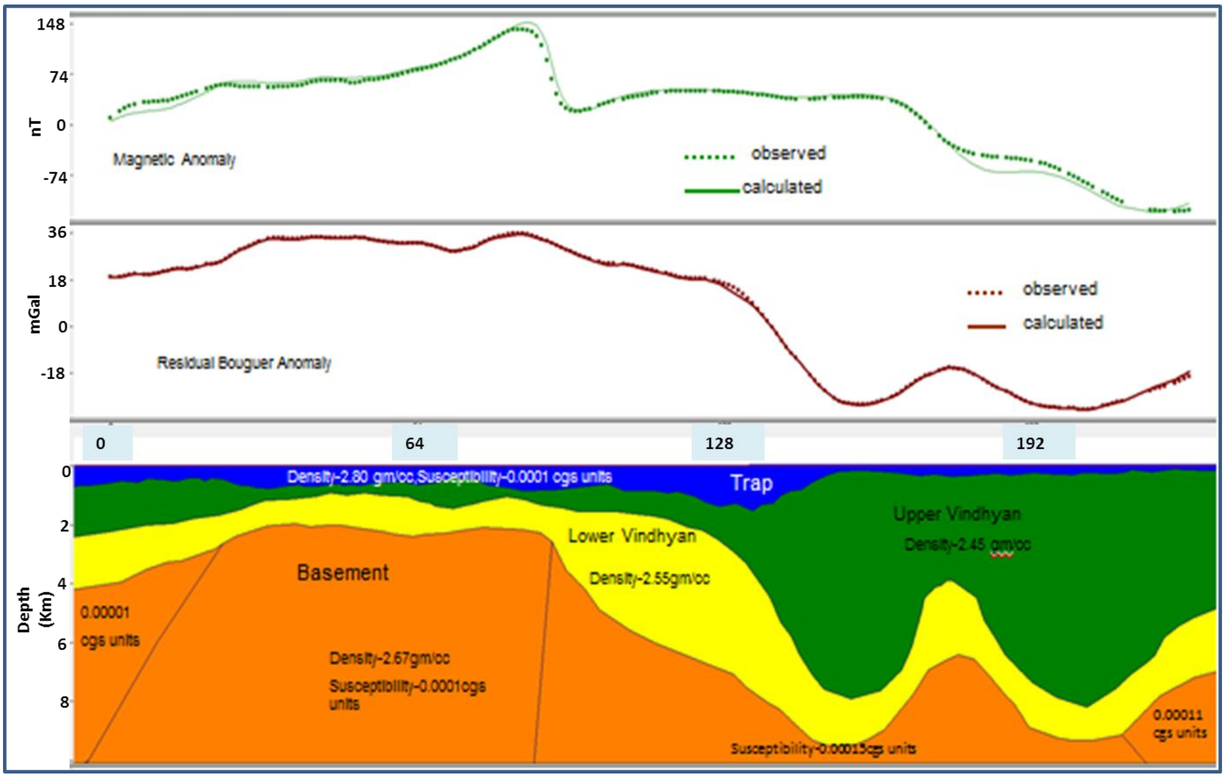


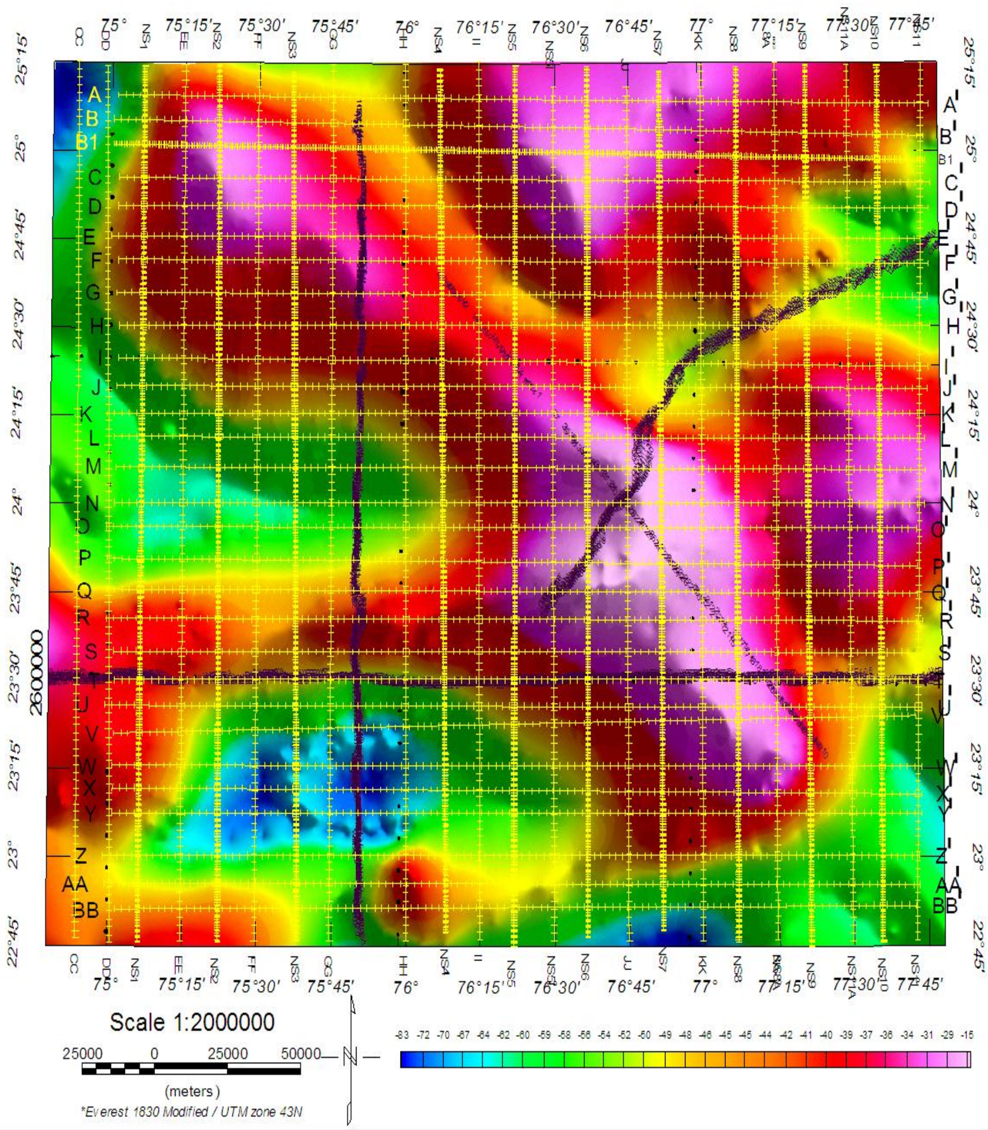
Fig. 6.1s 2-D Gravity and magnetic modeling along **SSW-NNE** profile (Fig. 5.3)

These (Figs.6.1p; 6.1q; 6.1r; and 6.1s) 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.

6.1.8 Gravity Modelling over entire study area

By keeping achieved results (Figs.6.1n-6.1s) has been intiated 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. 6.1t) 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 (Fig. 6.1h-j, 6.1l, 6.1n-s). Figures 6.1u-w serve as examples for such an exercise.



6.1t) Location of modeled gravity profiles, AA', CC' and HH' on Bouguer anomaly map

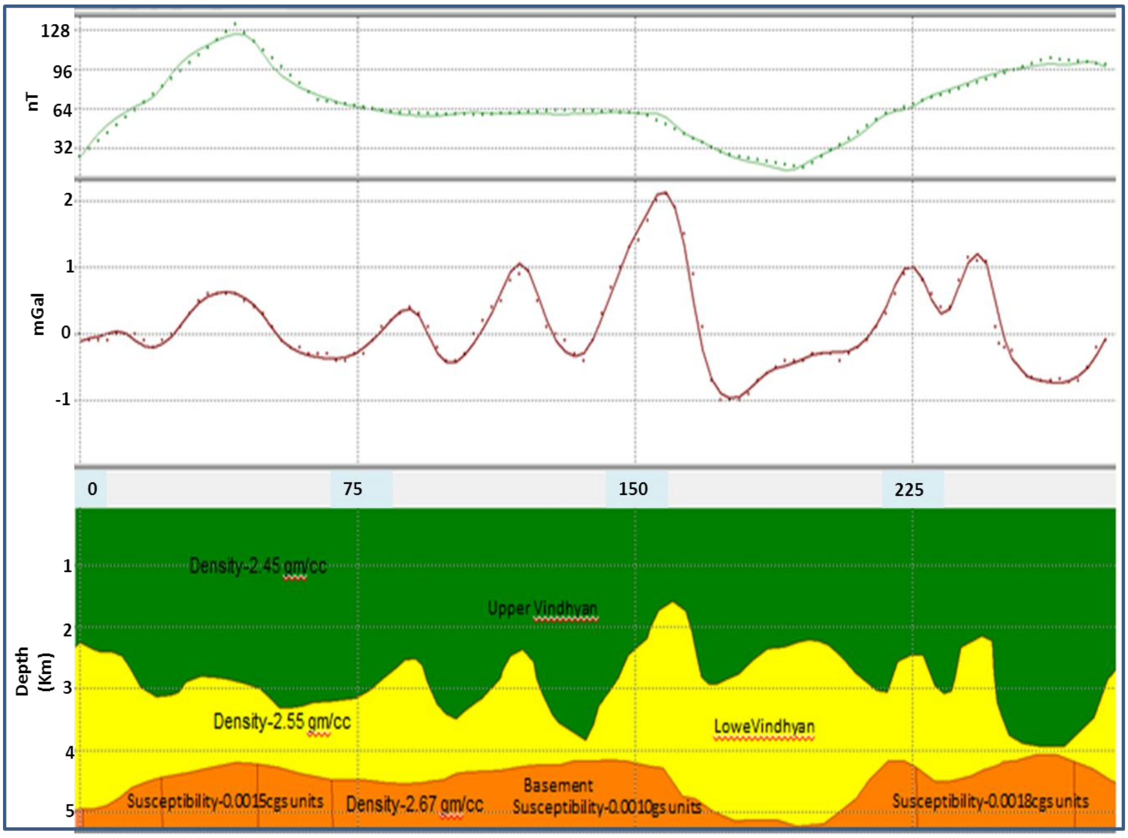


Fig. 6.1u) 2-D Gravity and magnetic modeling along profile AA'

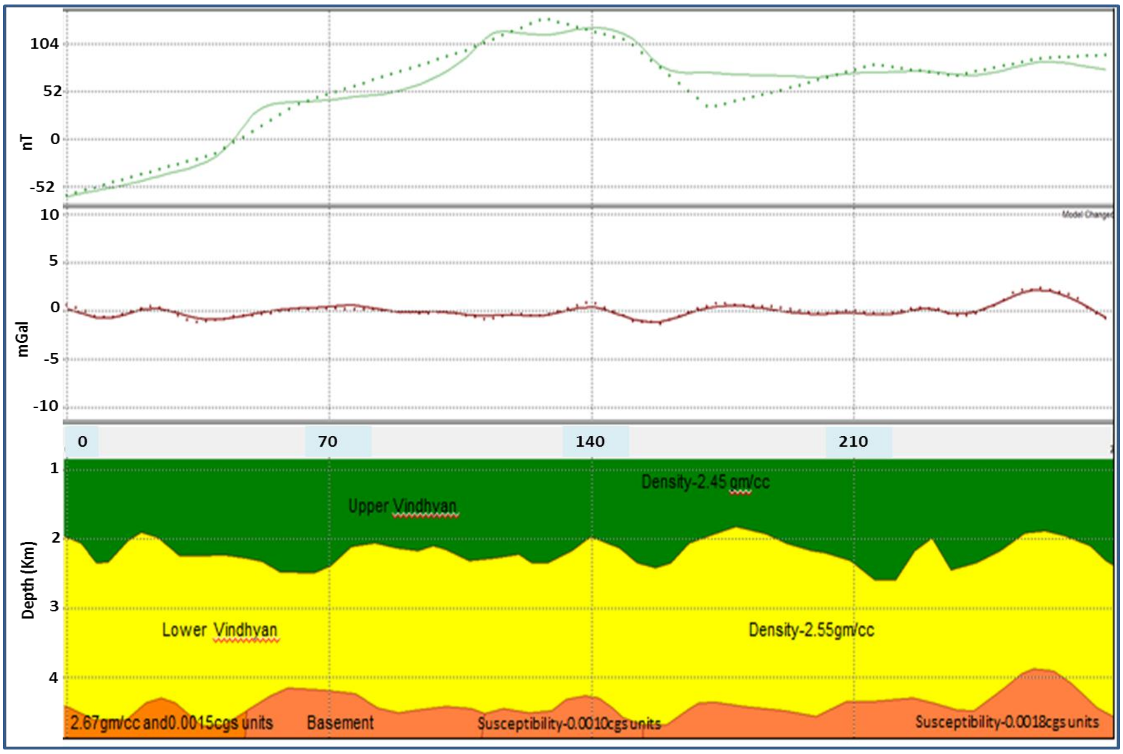


Fig. 6.1v) 2-D Gravity-magnetic modeling along profile CC' (Fig. 6.1t)

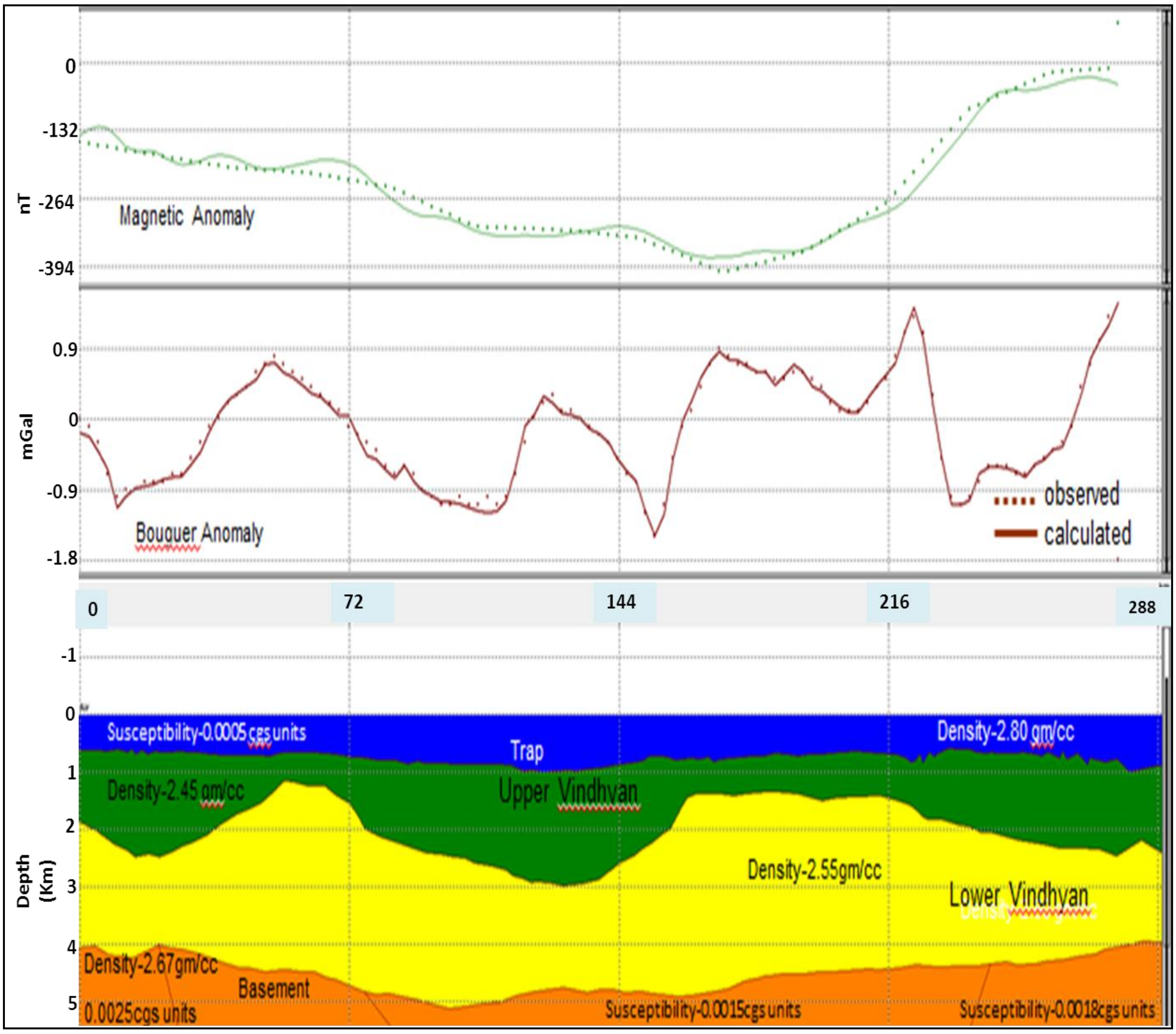


Fig. 6.1w) 2-D Gravity-magnetic modeling along profile HH' (Fig. 6.1t)

6.2 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. 6.2. The mismatch at tie points of inline and cross lines have been minimized. An error grid has also been prepared along with calculated grid (Fig. 6.2.1a and Fig. 6.2.1b).

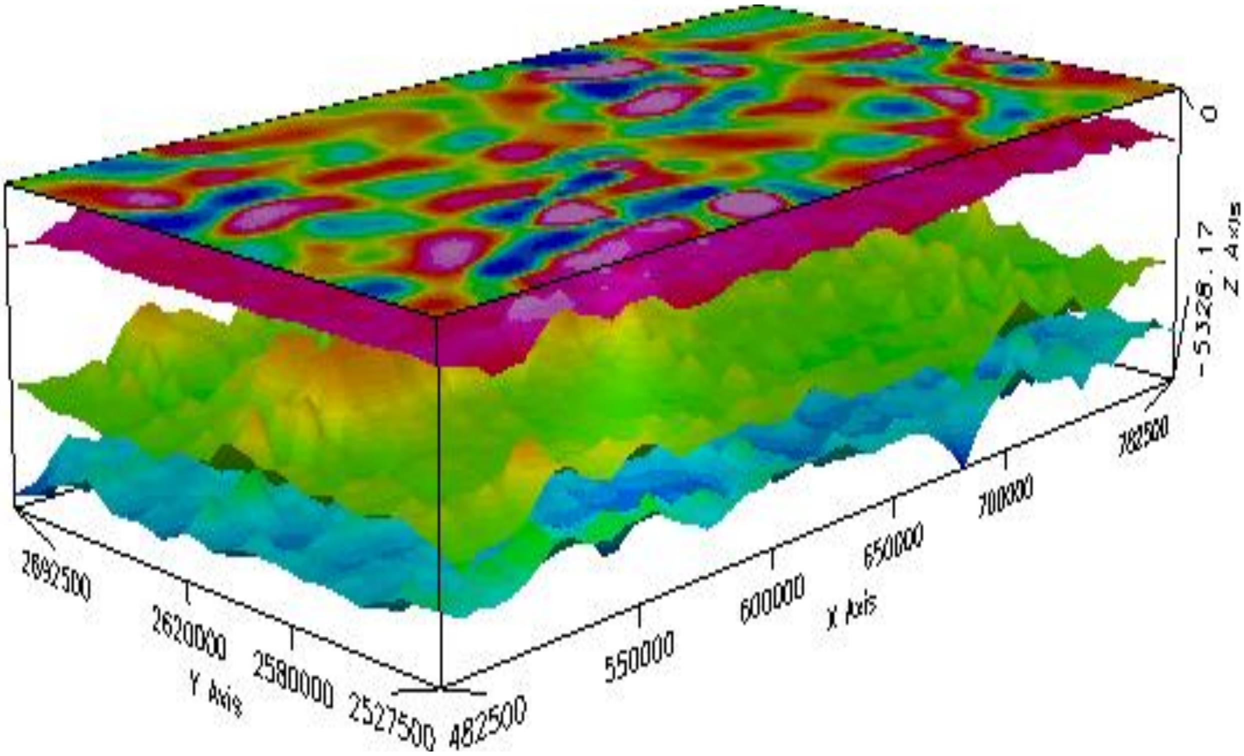


Fig 6.2 Inferred Trap, sediment (below trap) and basement -3D depth model. The top layer represents residual gravity in image format. It is underlain by trap (in pink), sediment (in green) and basement (in blue).

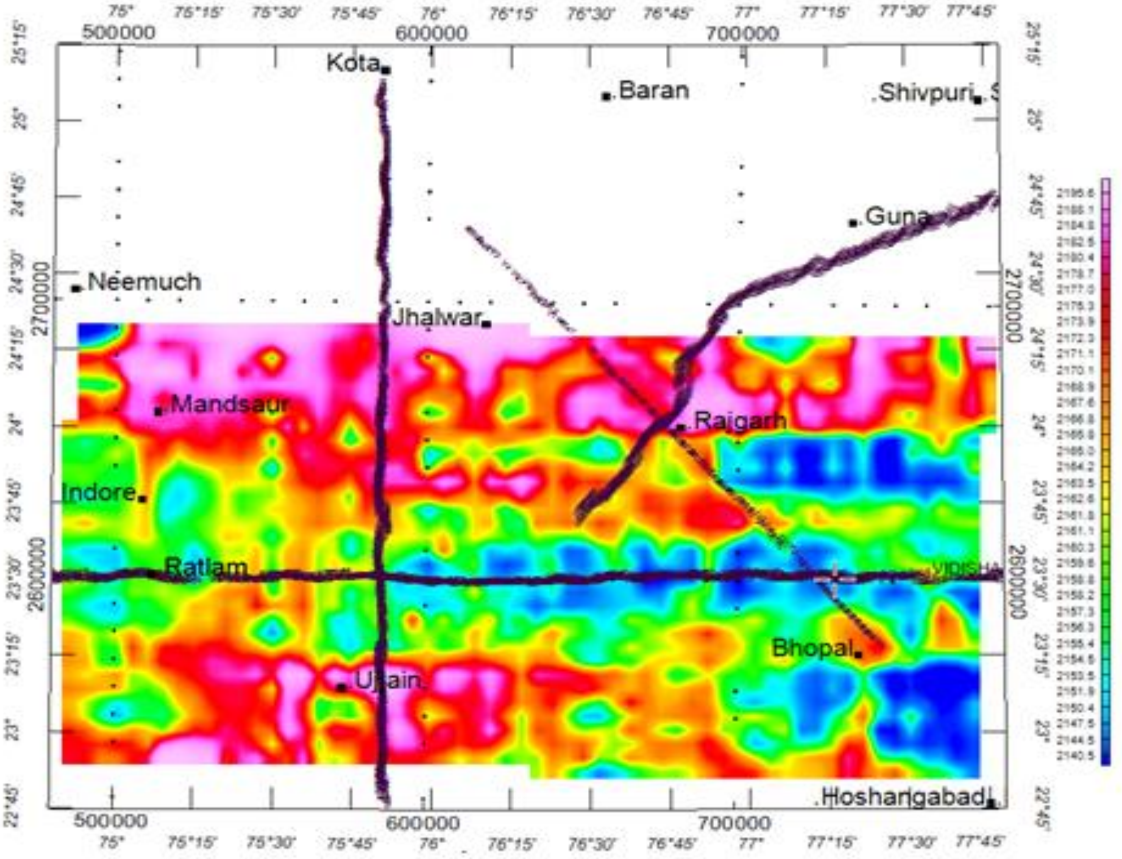


Fig. 6.2.1a) Calculated grid for 3D

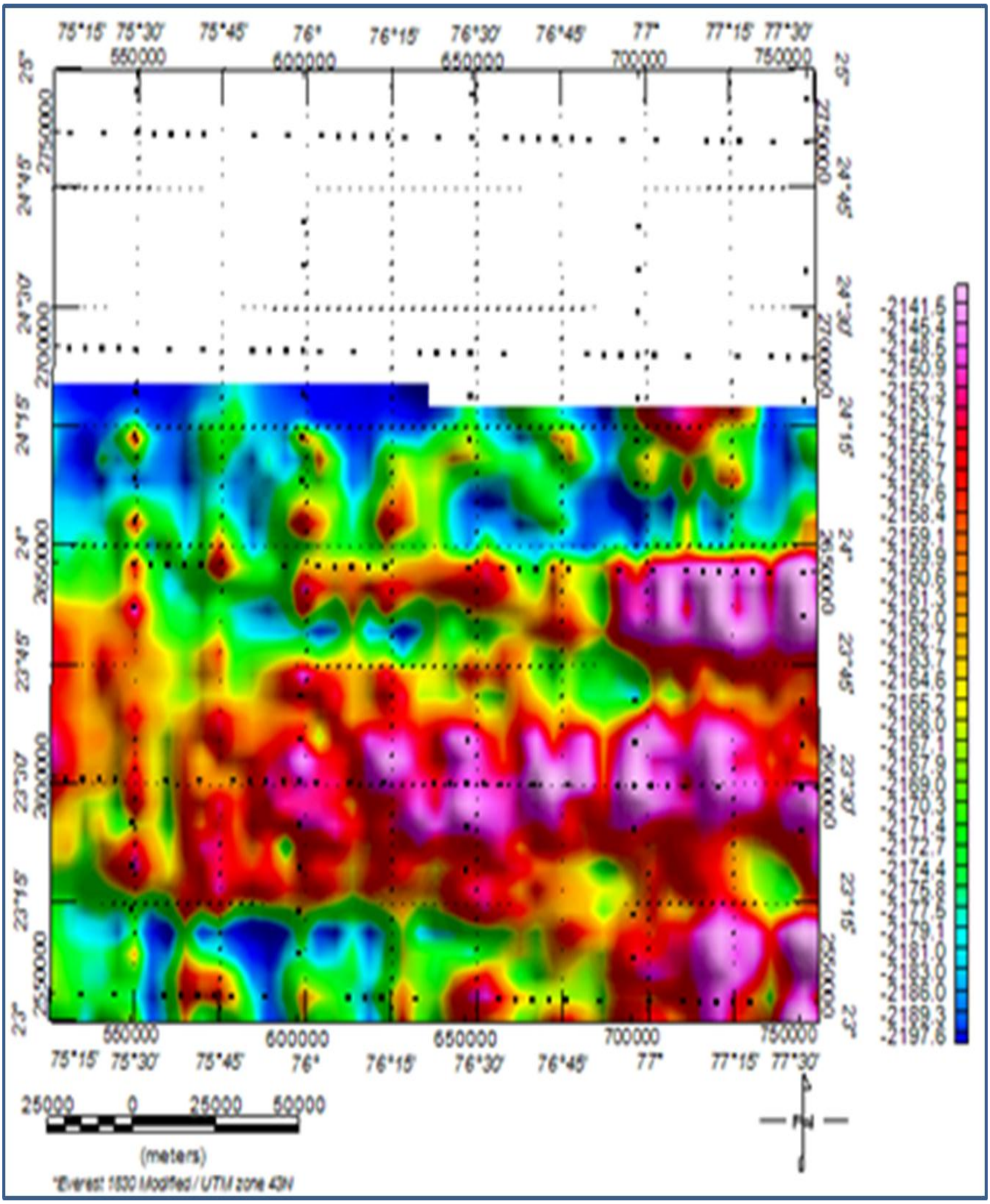


Fig. 6.2.1b) Error grid map.

The advantage of 3D depth model is that in any desired direction a profile can be drawn to validate important tectonic features of interst. Two of such reconstructed profiles passingthrough Bhopal-Rajgarh-Jhalawar and that through Topic of Cancer are presented in Fig.6.2.1c

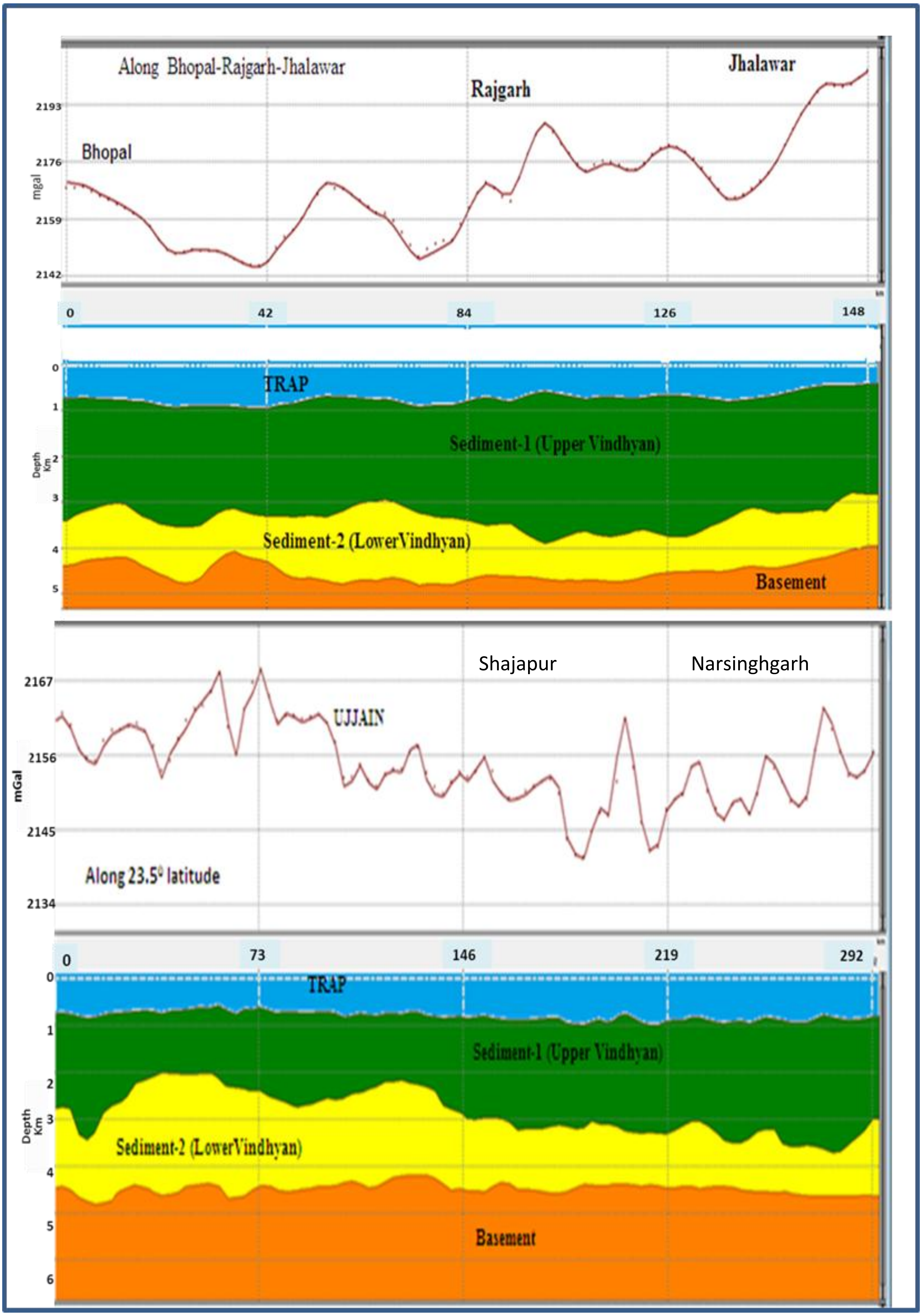


Fig. 6.2.1c) Inferred 2-D sections along two profiles from 3-D model (Fig. 6.2), viz., Bhopal-Rajgarh-Jhalawar and Ujjain, Shajapur and Narsinghgarh Profiles

CHAPTER - 7

Results and discussion

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 Figs. 7.1a; 7.1b; and 7.1c.

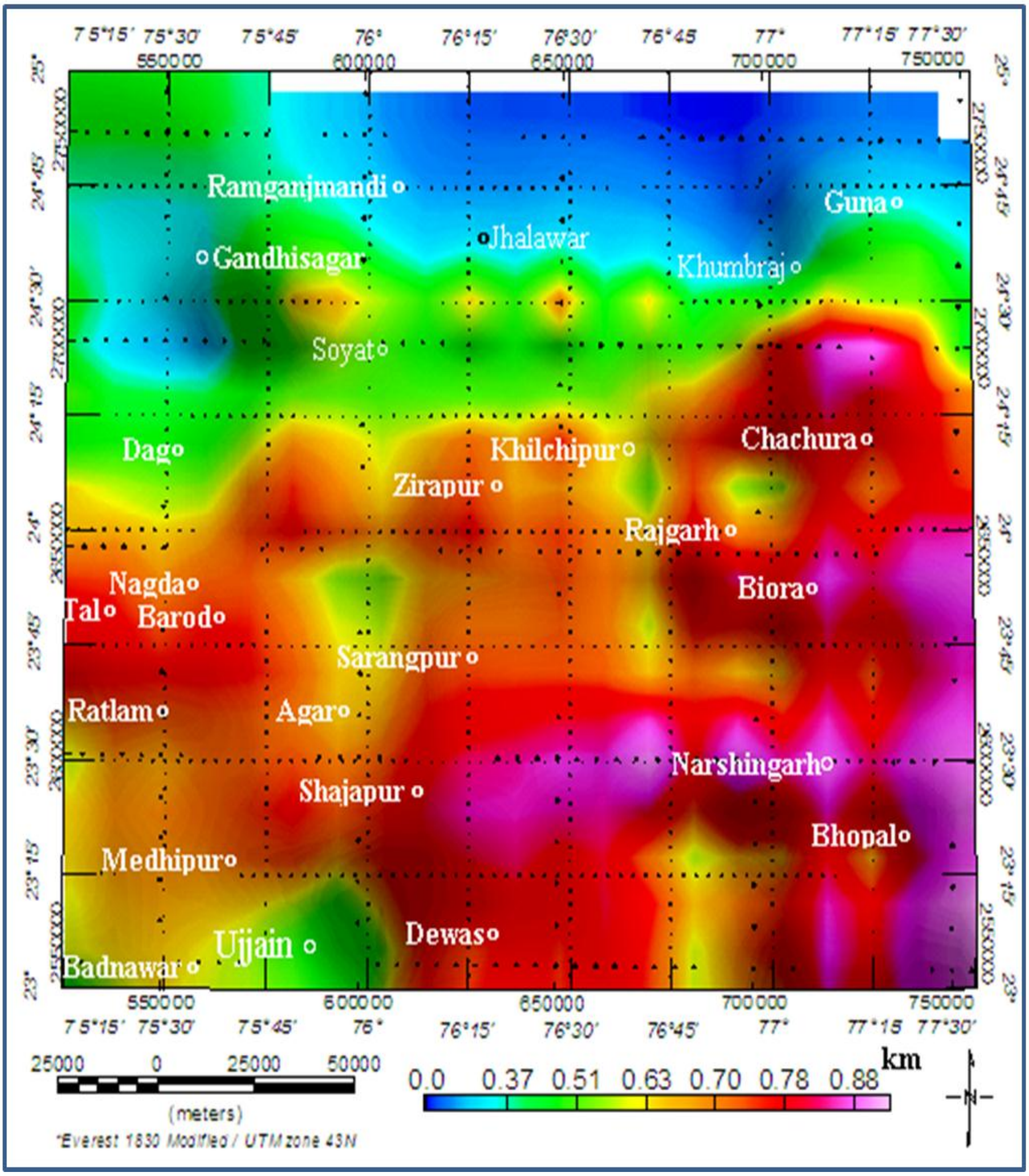


Fig. 7.1a) Inferred trap thickness map

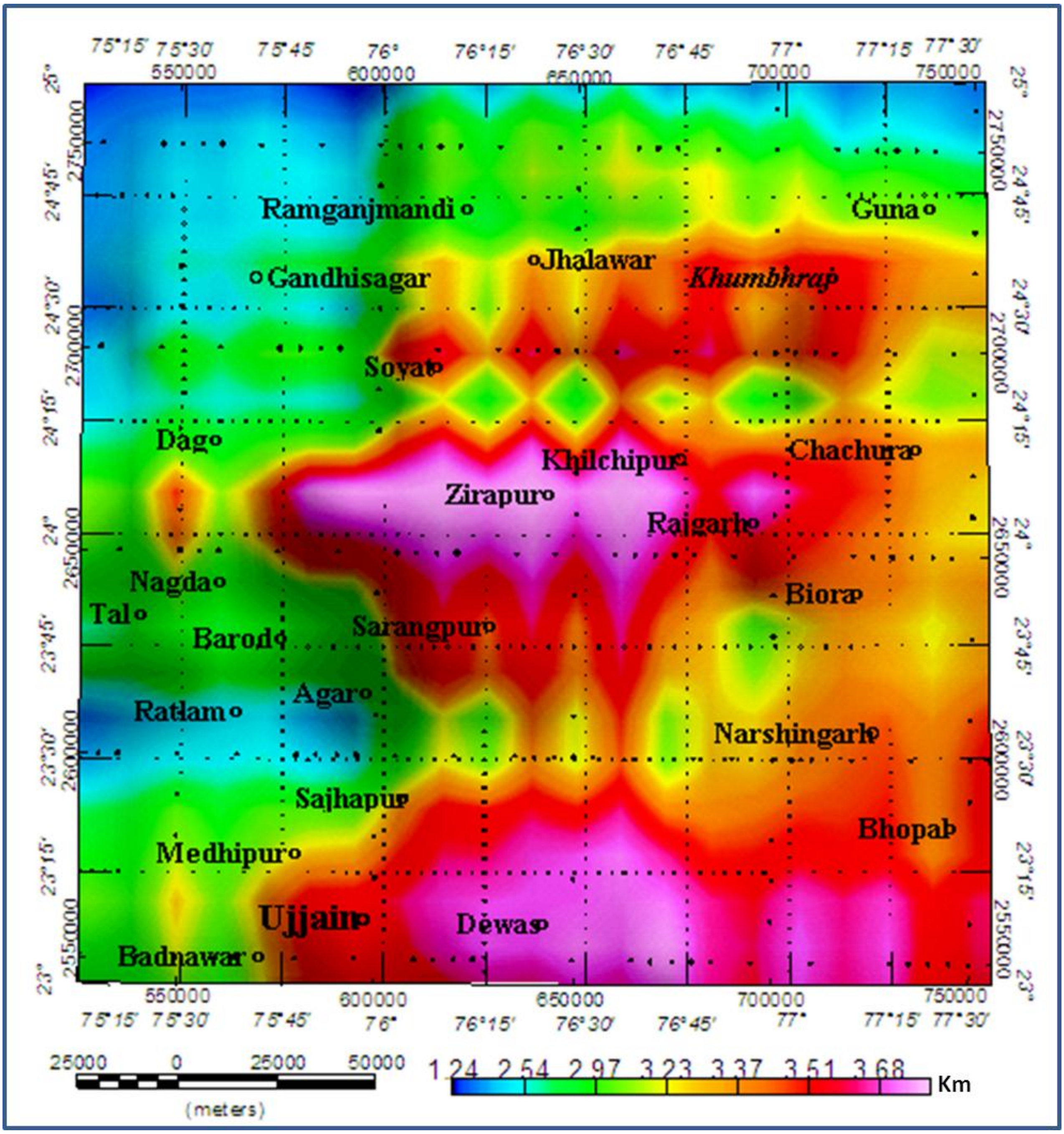


Fig. 7.1b) Inferred sediment (below trap) thickness map

Results pertaining to depth to basement, sediment and trap with respect to some of the prominent places of Chambal valley are presented in Table-6. In addition, regional faults, structural highs and lows of Chambal valley and also their trends have been identified from residual map of gravity Fig. 5.3.1d. 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.

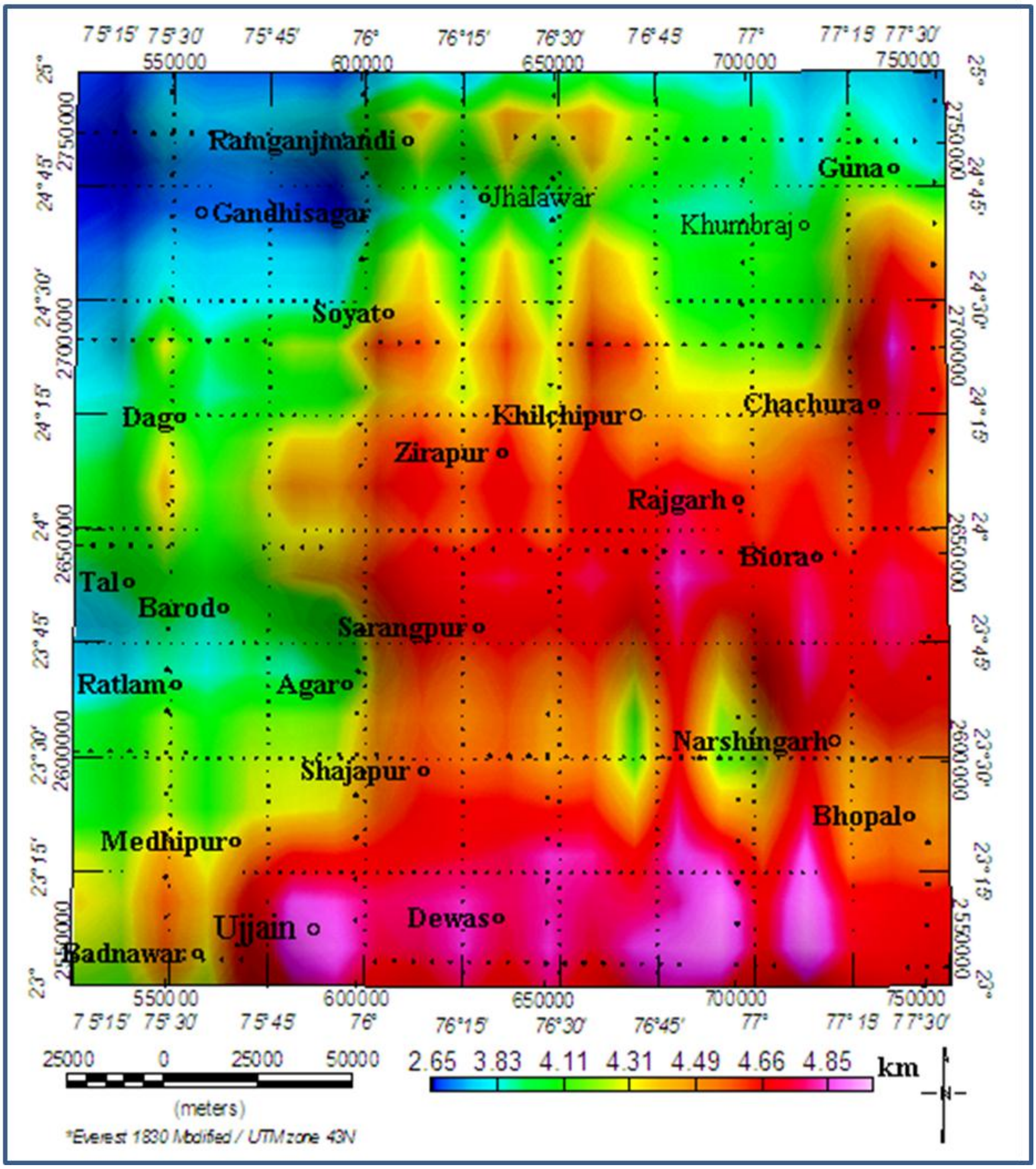


Fig. 7.1c) Inferred Basement depth map

General remarks:

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. Table 6 lists interval increases of trap and sediment and basement depth at prominent localities in the study region.

Table-6

Trap, Sediment and Basement thickness in Chambal valley

PLACES	TRAP (km)	SEDIMENT (km)	BASEMENT (km)
Kota	0	2	3.83
Jhalawar	0.54	3	4.31
Ramganjmandi	0	2.9	4
Gandhisagar	0.5	2	2.65
Guna	0.52	3	4.35
Kumbhraj	0.78	2.97	4.6
Soyet	0.5	3.2	4.49
Sunser	0.3	3.5	4.7
Dag	0.5	2.97	3.9
Sarangipur	0.7	3.0	4.65
Biora	0.88	2.9	4.8
Rajgarh	0.68	3.6	4.2
Medhipur	0.7	3.23	4.6
Chachaur	0.78	3.0	4.49
Bhopal	0.89	3.3	4.5
Jaora	0.3	1.24	4
Tal	0.7	2.92	2.68
Nagda	0.68	2.85	4.1
Biora	0.85	3.1	4.8
Dewas	0.78	3.68	4.2
Ratlam	0.7	2.98	4.37
Badnawar	0.5	3.1	4.15
Agar	0.63	2.4	4.6

7.2 Discussion

Chambal valley depicts a large scale structural deformation readily evident by multitudes of eye catching surface morphological entities. The author has attempted to bring out subsurface details of tectonic elements and regional structural style of Chambal valley. The observations thus gathered have aided in developing an understanding of the causatives of this structural vividness.

In the present effort the following aspects need to be considered:

1. ***Choice of common Bouguer datum:***
   Earlier Bouguer gravity data was referred to mean sea level (MSL) and it was undertaken in different scattered gravity campaigns. All such data was carefully compiled and reduced to a common datum of 250 m above (MSL) to preserve the trap effect. Our own high precision gravity data (Four regional profiles, N-S, W-E, SSW-NNE and SSE-NNW in Fig. 4c) was also reduced to same datum and these were used to check the quality of compiled Bouguer gravity map along those profiles.

2. ***Preference of aeromagnetic data over ground magnetic data***:
   As highly variable magnetization and susceptibility is associated with traps, aeromagnetic data was preferred over that of ground data for further analysis and interpretation.

3. ***Expected low density contrast at basement surface:***
   The most important interface from gravity point of view for modeling is the interface between Vindhyan sediments and basement as the density contrast is very low of 0.02 $g.cm^{-3}$. Therefore, any change in depth of this interface has very low influence on gravity response.

4. ***Combined gravity and magnetic modelling:***

   It is known that trap is highly magnetic and of high density. That is why aeromagnetic data has been used to avoid shallow causative effects. Thick trap layer also affects gravity data significantly. So, to see the effect of trap residual gravity map has been prepared and validated with seismic and other geological features. In addition different crustal blocks that were responsible for large gravity gradients have been considered while modeling.

   It is known that, potential field data gives combined response of all subsurface matter. Hence, it is expected that a minor variation in mass distribution or presence of magnetic substances may cause large variations in observed data. Therefore, integrated study is a must for better understanding of subsurface strata.

5. ***Residual gravity through spectral analysis and filtering:***
   By using spectral analysis and filtering method, residual gravity map for the study region is prepared, which reflects the combined gravity effect of trap, sediment and basement.

6. ***Non-uniqueness of potential field interpretation:***

   The trap covered area is a block box till date. In the present study every care has been taken at each step of data acquisition processing and interpretation. At every stage data has been linked or cross checked with available topography, surface geological features, seismic, density and suceptability of rocks, and cross validation with different attribute anomaly maps. Different data sets were reduced to a single datum for integration. Any presence of high density materials or magnetic substances underneath the trap may mislead the interpretation.

Further, one can’t outrule the possibility of non-uniqueness in gravity and magnetic interpretation as per tenets of potentialfield theory.

7. ***Rational use of meagre log data as constraint in interpretation:***
   In the study region, neither boreholes nor well log data are available. Two boreholes and log data outside the study region were optimally exploited in the current study.

8. ***Quality of sediment thickness map:***
   By considering the limitations of potential field data, processing and interpretation an integrated approach is adopted. However, lack of borehole information in the study region is a major stumbling block in assessing the quality of inferred sediment thickness below trap. So, the inferred sediment thickness from the current study is a tentative estimate only subject to future verification by independent drilling and logging.
9. ***Limitations of seismic in trap covered region:***
   In sedimentary basins, seismic reflection method is very successful. However, in trap covered regions, its success is very reflected owing to strong reflection characteristics of trapmaterial. In such cases, limited success is reported in geophysical literature by adopting wide angle seismic campaigns, though very costly exercise.

CHAPTER-8

Summary and conclusions

8.1 Summary

General

The prime objective of study is to estimate sediment thickness underneath trap exposed areas of Chambal valley. Initially, available seismic, gravity, aeromagnetic, topographical and other geo-scientific data were collated and processed independently and brought to same datum. High precision gravity data was acquired along four profiles. Gravity magnetic anomaly maps along with their deivatives and attributes were generated and interpreted. Sixty gravity profiles were constructed over study area and modeled. 3D model of the trap covered area has been generated. Finally, thickness map of trap, sediment and depth to basement were prepared based on modeling results. Structures associated with these faults where sediment thickness is more may be targeted for future hydrocarbon exploration.

At different locales in study area thermogenic gas seepages are noticed. But, the entire area of Chambal valley remained like a black box due to thick cover of trap for hydrocarbon exploration. Present study has estimated thickness of sediment including trap with available data.

Specific Points

1. By a careful effort, all previous gravity data was compiled and processed to yield a regional Bouguer gravity map for the Vindhyan Basin including the study region (Figs. 5.1 and 5.1.1). The Bouguer datum was chosen 250 m above MSL to take care of trap influence on gravity data.

2. The quality of compiled gravity is cross checked with our high precision gravity profile data (Four profiles in Fig. 3)

3. Residual gravity map (Fig. 5.3.1c) is prepared through spectral analysis (Fig. 5.3.1b) and filtering.

4. Traditional depth estimates were made on Bouguer gravity (Figs. 5.3.1, 5.3.1a-c) and from residual gravity map several faults and tectonic elements were inferred (Fig. 5.3.1d).

5. By considering the inherent difficulty in handling ground magnetic data aeromagnetic data (Figs. 5.2, 5.2.1) was preferred. Conventional processing included RTP (Fig. 5.3.2), FVD (Fig. 5.3.2a), Euler depth map (Fig. 5.3.2c), pseudo-gravity map (Fig. 5.3.2d) and Werner deconvolution depth map (Fig. 5.3.2e). These served as input for magnetic modelling and as constraint for gravity modelling. Inferred fault map (Fig. 5.3.2b) is also a worthwhile exercise towards interpretation.

6. The available seismic profiles in the northern boundary of study region were carefully interpreted (Figs. 4.3, 6.1, 6.1a-f). These are of special interest for our study as they partly cover non-trap region also. These served as a good constraint for gravity interpretation, especially the role played by seismo-geological sections (Figs. 6.1h and 6.1i, 6.1j) and integrated seismic, gravity and magnetic approach (Fig. 6.1k).

7. By a careful study of all the results in the above analysis, gravity interpretation is undertaken step-wise along different profiles (Figs. 6.1l, 6.1 n-r and 6.1u-w). In this effort, all available data sets including physical properties of representative rock samples, meagre borehole data, seismic and magnetic data have served as constraints

8. 3-D gravity modelling answering the processed residual gravity and incorporation of all the previous steps have led to trap, sediment thickness (below trap) and basement depth map (Fig. 6.2). From Fig. 6.2, two regional sections (Fig. 6.2.1c) were derived as examples. Additionally, in Table 6, we include inferred trap, sediment and basement depth information from Fig.6.2 at prominent localities spanning the entire study region.

9. Further, using Fig. 6.2, separate maps answering the goals of the present study, viz., trap thickness (Fig. 7.1a), sediment thickness (Fig. 7.1b) and basement depth (Fig. 7.1c) were arrived at.

10. Several transverse faults and lineaments in northwest southeast direction have been identified for the first time on the basis of gravity data in Chambal valley. Origin of these faults can be thought interaction between two crustral blocks - one associated with the Great Boundary Fault and other associated with Son Narmada lineament and a subsequent interaction with Bundekhand block. This concept is illustrated by gravity modeling of our study region. The teconic map of Chambal valley derived from aeromagnetic data also suggest similar fault pattern, which supports gravity data.

8.2 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

8.3 Further perspectives

i) To pin point the probable hydrocarbon accumulations it is necessary to conduct a detailed MT studies in the study region.

ii) It is recommended to drill a deep parametric well south-east of Mukandara fault where thick sediments are envisaged.

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List of publications

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1. *Saha, D. and Rambhatla G. Sastry, 2013, Analysis of Gravity Magnetic signature of Chambal valley sector of Vindhyan basin estimation of trap and sediment thickness: Geohorizon, Journal of SPG, Vol-28.*

Articles in Conferences

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