CHAPTER - VI
GEOPHYSICAL MODELLING

General Statement

The Aravalli Mountain Range (AMR), presumably one of the oldest mountain system in the world, still retains some relief. Their tight synclinoriam, Aravalli Fold Belt (AFB) comprises quartzite, schist, amphibolites etc. of the Aravalli-Delhi geological cycles (2.5-0.8 b.y.).

The area was peneplained in the later Mesozoic and afterwards peneplained second time in the Tertiary in the eastern Marwar Plain which much of it is covered by veneer of older alluvium; and according to Heron (1938) has itself been recently peneplained in the Pleistocene. These Tertiary and Pleistocene peneplains meet at about 424m in the central part (Iqbaluddin, 1989). West of the AFB orographic axis the alluvium is at about 305m thick and smothered by the blown sand from the Thar Desert and Rann of Kutch.

The geophysical coverage over the AMR is available on the regional scale only. It comprises the set of the gravity anomaly maps of India by NGRI (1978), atlas of the gravity anomalies of Rajasthan and Gujarat by Geological Survey of India (1988) and the satellite based Free-air anomaly field released by the NASA, USA (1982).
An analysis of the isostatic anomaly across the Aravalli Mountain Range has been attempted to get an insight to the intracrustal density variation, possible crust-mantle relationship resulting from the isostatic compensation and clues to cratonic evolution processes in the region.

The AMR is bounded in the west by low gravity anomaly over the Thar Desert and in the east by low gravity anomaly over the Vindhyan Basin. The basic geology of the study area was studied by Hacket, (1881); Coulson, (1933); Heron, (1953) and Gupta et al., (1997). The AMR forms the most conspicuous geologic and physiographic features of the study area. It is composed the rocks of early to middle Proterozoic age. The oldest geological cycle is represented by the Bhilwara Supergroup (> 2.5 b.y.) that largely includes the metasedimentary sequence with migmatitic complex and igneous intrusives. The Bhilwaras are unconformably overlain by the Aravalli Supergroup (2.5 b.y. to 2.0 b.y.) consisting mainly of clastics with subordinate chemogenic sediments with intrusives and metamorphosed folded clastogenic sediments. The Delhi Supergroup (2.0 b.y. to 0.8 b.y.) comprises mainly the metamorphosed, ferrugeneous and clastic (with subordinate chemogenic) sediments and related concordant and discordant intrusives.

Data Collection

The data used during the study were collected from various sources, the surface geology of the area has been compiled through the interpretation of the
FREE-AIR ANOMALY MAP OF AMR, RAJASTHAN

Contour Interval 10 mGals

FIGURE - 43
remote sensing data, the geological map of the area (Gupta et al., 1982) and the published literature.

The geophysical data in the form of free-air, Bouguer and isostatic anomalies maps by NGRI (1978), the isostatic anomaly map by Qureshy (1970) and the global free-air anomaly map (NASA, 1982) were used in the course of this study.

The density measurements of the various lithounits have been carried out by estimating the density directly from the rock samples collected along the selected traverses during the field work in the area.

**Methodology**

The gravity modelling in parts of the AMR has been carried out using the isostatic anomaly variation to arrive at the permissible geological section for the selected profiles which were prepared from the geological map of the area. The geological information used in this modelling was produced through the visual interpretation of the remote sensing data in the form of image and digital picture of the LANDSAT 5 TM and IRS-1B LISS-II of the area. Talwani's two dimensional computer programme of gravity modelling was used (Talwani, 1958).

The modelling has been carried out along the said traverses. The first traverse (A-B, Fig.48a) passes from Jajiwal Railway Stations in the NW to Bijianagar and beyond in the SE. The second traverse commencing in the NW
passes through Pali and Bhilwara and beyond over the Vindhyan in the SE (Fig. 49a).

The permissible geological sections constructed for both the traverses are based on the geomorphological, geological, tectonic setting and the gravity of the area. The seismic section parallel to the profile across the AFB from Nagaur to Kota (Tewari et al., 1995, 1998) were considered. The polygons of the possible subsurface configurations of the lithounits and the crust-mantle relationship in the study area were designed using the geological map as base for extracting the litho-contacts and the isostatic anomaly profiles. These polygons were stored in a computer data file in the binary mode (GVP.DAT). The isostatic anomaly profiles were digitised manually and stored in another computer data file (BOO.DAT). The densities were entered to the computer machine to bring out density contrasts by assuming the density of the crust 2850 kg/m³ and the density of the mantle as 3270 kg/m³. Using these data files the Talwani program for 2-D gravity modelling was run. This procedure was repeated till the observed and the calculated anomalies matched or the difference became negligible. The results were plotted using computer graphic packages (Fig. 48a and Fig. 49a).

In some places along the profiles the high isostatic anomalies (+60 mGals) appeared on the Aravalli Mountain Range. The surface lithounits alone could not satisfy this amount of the anomaly. In such case the designing of high density material at the crust-mantle boundary in the form magmatic underplating was attempted to the study area for explaining the anomaly variation across the Aravalli Mountain Range.
Gravity Analysis

Density Measurements

The density of the hand specimens were measured using Walker Steel Balance. This technique is dependent on the weight of the mass in the air and the mass in the water by measuring the distance of the balance arm by weighing in the air and water. The density was calculated using the formula:

Specific Gravity = \( \frac{B}{B-A} \), where A is the length of the balance arm in the water and B is the length of the balance arm in the air. The measuring processes were repeated three times for each sample, the average weight for each sample was accepted as the density of the rock. Table- XII records the density values of the various rocks in the study area.

Table- XII

<table>
<thead>
<tr>
<th>Rock Name</th>
<th>Density, kg/m³</th>
<th>Rock Name</th>
<th>Density, kg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amphibolite</td>
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<td>Quartzite</td>
<td>2690</td>
</tr>
<tr>
<td>Augen-Gneiss</td>
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<td>Q-F material</td>
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</tr>
<tr>
<td>Arkose</td>
<td>2670</td>
<td>Meta-Volcanic</td>
<td>2700</td>
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<td>Biotite-Schist</td>
<td>2560</td>
<td>MicaPegmatite</td>
<td>2580</td>
</tr>
<tr>
<td>Bhilwara Volcanics</td>
<td>2900</td>
<td>Migmatite</td>
<td>2720</td>
</tr>
<tr>
<td>Dolomite</td>
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<td>Pegmatite</td>
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<td>Ophiolite</td>
<td>3000</td>
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</tr>
</tbody>
</table>
**Free-Air Anomaly**

The Free-air anomaly map of the study area (Fig. 43) has a maximum high +60 mGals over the southern part of the Aravalli Mountain Range and +50 mGals over the northern part near Beawar. The free-air anomaly map shows general positive anomaly over the Aravalli Mountain Range with steep gradient falling over the AFB. This positive anomaly bounded in the northwest by local low -30 mGals over the Punagarh area and Marwar basin north of Pali. The eastern Mewar plain is characterised by low free-air anomaly which decreased further towards the east upto -40 mGals along the Bhilwara-Vindhyan contact. Over Berach Granite the anomaly is -30 mGals.

To the west of the Jajiwal R.S., the free-air anomaly increases over the area where Malani Suite is exposed. The anomaly shows a value of -15 mGals. The free-air anomaly has the highest value over the Aravalli mountain Range decreasing gently towards the east and steeply towards the west.

**Bouguer Anomaly**

The Bouguer anomaly map of the study area (Fig. 44) shows a number of 'highs' and 'lows' similar to what is obtained in the free-air anomaly map. The main Aravalli Mountain Range is characterised by positive Bouguer anomaly closure with +10 mGal contour along its axis. The rest of the study area is characterised by negative Bouguer anomaly values; Bhilwara -50 mGals, Bijianagar -25 mGals, Pali -40 mGals, and Jajiwal R.S. -50 mGals. In the eastern
part of the study area the Vindhyans have the lowest value of the Bouguer Anomaly which is -70 mGals.

**Isostatic Anomaly**

The isostatic anomaly map of the study area (Fig. 45) shows a 'high' positive gravity anomaly over the Aravalli mountain Range +50 mGals bounded by 'low' gravity anomaly of -10 mGals in the northwest over the Marwar Supergroup and Punagarh Group of Delhi Supergroup. The prominent low gravity anomaly occurs over the Vindhyan basin decreasing to -70 mGals SE of the study area. The crustal thickness is in the order of 37-40 Km (Qureshy and Abdussalam, 1998) across the profile corresponding to an elevation of 0.3 to 0.6 km as calculated from the equation given by (Qureshy, 1970). \[ T = 35 - 5.9 E \].

this implies that the petrologic crust-mantle boundary is equilibrated around this depth. These values matched with Moho depths represented by controlled seismic source profiling by Tewari et al., (1995,1998) and Reddy et al., (1995). This comparison of the isostatically computed crustal thickness and Moho from seismic profiling to be in close agreement. It requires an independent explanation for the isostatic anomaly variation.

The departure in the form of the isostatic anomaly can not be attributed to the density variations within the exposed rocks along the traverses unless they are assumed to extend to depth greater than 20 km. However, the other contributor to this anomaly may be the high density masses at the crust-mantle boundary.

The isostatic anomaly values in the area range from -20 mGals to +60 mGals. However, there are zones with negative anomaly in the northwest and
southeast of the area around Sojat-Pali tract and east of Bhilwara. The high isostatic anomaly forms an elliptical shape. The steep contours on the west on the free-air and Bouguer anomaly maps compare to these on the isostatic anomaly map indicate that the elevation of the terrain of the study area has modified the gravity anomaly and shifted the maximum eastward (see Fig. 46 & 47).

The gravity anomaly departure with low magnitude over Sojat-Pali tract may be due to the low density of the young sediments of the Marwar Supergroup and Punagarh Group of rocks. Further to the west the gravity anomaly increases due to the heavy density material of the Malani volcanics which are patchy exposed in that area and may be present underneath the alluvial and sand.

Gravity Modelling

Limitation of the Model

A unique interpretation is almost impossible through gravity observations because of the superimposed effects of many mass distribution laterally and vertically. The gravity is the contribution of all these masses which give the gravity anomaly. The 2-D model using the Talwani et al., (1958) technique was used in the study. The heavy material in the form of magmatic underplating at the crust-mantle boundary were designed to satisfy the high gravity anomaly as the surface geology is not able to satisfy that anomaly values (+ 60 mGal) over the Aravalli Mountain Range. This scenario is supported by the geology and geophysics of the area and explains all the known configuration. The seismic
section across the AMR along the Nagaur-Kota traverse shows clearly a discontinuous and diffuse Moho beyond the AMR.

Construction of the Models

In order to estimate the possible third dimension (the subsurface structure and lithology at depth), two NW-SE profiles across the AMR were studied and the permissible geological sections were designed through 2-D modelling using the isostatic anomaly.

The isostatic anomaly rather than the Bouguer anomaly or free-air anomalies was used in this modelling. The reason is that the isostatic correction is based on a well established principle of isostasy. In the highly elevated terrain like Aravalli Mountain Range (MAX. 900 m and MIN. 250 m), the Bouguer anomaly is strongly influenced by large negative effect of the roots of the mountain.

The model is based on the NGRI (1978) and Qureshy (1971) isostatic anomaly map (Fig.45). They compute the isostatic anomaly by assuming a sea level crustal thickness of 30 km and for crustal and subcrustal densities of 2670 kg/m³ and 3270 kg/m³ respectively based on 3100 well distributed stations.

In this study the Moho depth were calculated through Qureshy’s (1970) empirical formula, \[ H = T - 4.45h \], where, \( T \) is the sea level crustal thickness (35 km) and \( h \) is the elevation above the mean sea level.

This relationship give Moho depth in the study area which ranges from 37 km to 40 km which conforms to the seismic section running from Nagaur to Kota.
Profiles A-B and C-D

The profile runs from the Jajiwal R.S. west of the AFB block to SE of Bijianagar in the Mewar plain. The isostatic anomaly values decrease from +10 mGals to -10 mGals over the Marwar-Punagarh tract (2500 kg/m³ density), Erinpura granite (2650 kg/m³ density) and the depth ranges from 2.5 km to 5 km. The Punagarh Group represent by Sojat Formation comprise slate and phyllites as the main lithology which may extend to shallow depth (2.5 km). The departure in the form of anomaly in further east increases steeply after the contact between Aravalli and Trans-Aravalli blocks in the form of Aravalli Frontal Fault (AFF) or Phulad lineament as by Gupta et al., (1982). The values increased to +60 mGals over the Aravallis near the town of Sendra and over the mafic rocks (density 2900 kg/m³) within the Sandmata Complex and decrease to -20 mGals at the SE end of the profile over Vindhyan outcrops with the minimum of -70 mGals falls over the Vindhyans further SE (Fig. 48a).

Fig. 48a and 49a gives the lithounits that are met across the profiles. These also show the Moho as calculated empirically which is in close agreement (37-40 km) with the Moho reported by Reddy et al., (1995) and Tewari et al., (1995, 1998) across the Nagaur-Jhalawar profile beneath the Aravallis. The magnitude of the anomaly +60 mGals may be partly attributed to the variation of densities in the depth of surface lithologies upto about 10 km. But the bulk of the ‘high’ near Sendra over the Aravallis eastern slope may be due to underplating as suggested by Qureshy (1970); Tewari et al., (1995,1998) probably due to abortive Delhi-Aravalli rift and inverse rift (Verma and Geiring, 1989). The underplating seems indicated over the controlled seismic source profile as well
Figure 48a Gravity Modelling Along A-B Profile.

Figure 48b Seismic Section Parallel to A-B Profile.
Fig. 49a Gravity Modelling Along C-D Profile.

Figure 49b Seismic Section Parallel to C-D Profile.
(Fig. 48b & 49b). Using these concepts, the permissible geological sections arrived at are shown on Fig. 48a and Fig. 49a.

The profile C-D shows departure in the anomaly values from NW to SE from Pali to Bhilwara. The isostatic anomaly decreases from +5 mGals near Marwar over Punagarh Group and Erinpura Granite. The value peak at +55 mGals near Deogarh to the SE of Aravalli axis at a gradient of 1.3 mGals/km. The anomaly reaches the maximum magnitude over the Giyangarh-Asind volcanic rocks which have an average density of 2870 kg/m$^3$. Around Pali where +10 mGals contour passes, there is flattening of the anomaly field. The -10 mGals closure around Sojat north of Pali is correlated with the Erinpura granites. The plateau-like ‘high’ south of Pali may be related to Malanis or Bambolai basaltic flow. The rocks of Kumbhalgarh and Gogunda groups of Delhi Supergroup NW of Deogarh having an average density of 2650 kg/m$^3$ appears to cause a local anomaly rise as does the exposures of Sandmata complex (density 2690 kg/m$^3$) between the volcanics of Giyangarh-Asind acidic rocks (density 2870 kg/m$^3$) and the Kumbhalgarh rocks (density 2690 kg/m$^3$). The Sandmata Complex, Pur-Banera Group and Mangalwar Complex fall along the rest of the profile. These have densities of 2670 kg/m$^3$, 2630 kg/m$^3$ and 2660 kg/m$^3$ respectively and their depths from 2 km to 5 km are stipulated. The anomaly curves down and becomes negative over the Vindhyans where the Moho depth is about 36-38 km which is of the same order in the seismic profiling and it is deeper beneath the AMR SE of the AFB. The Moho beneath the Aravallis as seen on the seismic reflection profile appears diffuse more than continuous.
Discussion and Constraints

The isostatic crustal thickness veers around 40 km (Qureshy, 1970) in the AMR which is of the same order as reported by seismic reflection and refraction profiles (Kaila, 1990; Reddy et al., 1995, 1997; Tewari et al., 1995, 1998). That is the crustal root as per the Airy concept of isostatic compensation is as expected from elevation. However, the Airy-Heiskanen anomalies which are as high +60 mGal over the AMR and Mewar plain, and 0 to -10 mGals in the Sojat area west of the AMR. The ‘high’, as stated above is probably related to lava upwelling / underplating associated with Delhi-Aravalli rift (Verma and Gerling, 1989).

The Marwar Supergroup, earlier referred as Trans-Aravalli Vindhyans, lies to the northwest in the study area forming homogeneous topography. The rocks of the Marwar Supergroup and Punagarh Group exhibit undeformed sequences. The sequences are mostly braided alluvial and low energy beach facies indicating regression and depositional transgression. The isostatic anomaly is -10 mGals over the Marwar and Punagarh rocks. The positive isostatic anomaly (+10 mGals) to the west of the said low isostatic anomaly may be related to the expected basement that is the Malani volcanics c. 0.74 b.y. The maximum sedimentary thickness of these sequences range from 2.5 to 5 km as estimated by the gravity modelling.

In the seismic section (Tewari, et al., 1998) the reflection from middle and lower crust are reasonably abundant (below 5 seconds TWT), while the upper
crust is almost transparent. The Moho is characterised by an almost horizontal 
reflection at about 12.5 s TWT indicating 38-40 km crustal thickness as that 
estimated by the empirical formula (Quershy, 1971).

The Delhi Supergroup is represented by Kumbhalgarh and Gogunda 
groups in the traverse. These sequences form the main orographic axis of the 
AFB and highly deformed. The occurrence of the ophiolites as dismembered 
odies (Sinha Roy and Mohanty, 1988) has significant bearing on the evolution 
of the AFB. The Kumbhalgarh Group represents the main sequence in the 
traverse A-B having 2690 kg/m³ density and 3-5 km depth. The Sendra Granite 
occurs in the contact between the Aravalli and Tons-Aravalli blocks.

The crustal reflectivity pattern indicates that the lower crust of the AFB 
and MeP have 40-41 km Moho depth. The Moho in this area is represented by 
three bands; the first being strong, horizontal reflection at about 12.5 s TWT 
indicating a crustal thickness of 38 km. The second band of strong reflection dip 
from 12.5 s TWT to 15.0 s TWT (38-45 km) towards SE and the third band of 
reflection dip towards SE from 14.4 s TWT to 16.0 s TWT (45-50 km), (Tewari 
et al., 1998).

The Mewar Plain in the east consists of the rocks of the Bhilwara 
Supergroup, which predominantly comprises sedimentary phyllites and mica-
slchist with intercalatory quartzite, meta-greywacke, meta-volcanics, calc-silicates, 
limestone, dolomite and marble (Gupta et al., 1997). The Bhilwara Supergroup 
comprises the Sandmata Complex, Mangalwar Complex and Hindoli Group with 
the magmatic events. Beneath the Mewar plain comprising the Sandmata and 
Mangalwar complexes the crust is of the order of 40-42 km thickness as
estimated through the gravity modelling and conformed by the seismic section of Nagaur to Kota traverse which images Moho at about 14.5 s TWT. The Moho reflection appears as bifurcate, diffuse and discontinuous probably due to the magmatic underplating and the cumulates of the magma at the crustal-mantle boundary (Cox, 1970). The isostatic anomaly values have the maximum “high” (about +60 mGal) over the Delhi-Bhilwara supergroups contact.

The last lithological unit in the traverse, the Vindhyan Supergroup, consists of undeformed and unmetamorphosed litho-assemblages comprising conglomerate, sandstone, shale and limestone. The Vindhyan basin is characterised by prominent band of strong, long and SE dipping reflection at 3.2-5.0 s TWT. The shallow depth of these reflections indicates that the sedimentary thickness in the Vindhyan basin is around 6-7 km. The reflectivity at the middle and lower crust and Moho is rather poor in comparison to lithostratigraphic units. The Moho in the Vindhyan basin is estimated to be at 36-38 km depth by gravity data.