Jaisalmer Basin of Western Rajasthan: A Gravity Perspective*

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Abstract

The sedimentary basins of western Rajasthan constitute a part of the shelf zone of the Indus Geosyncline and are contained in structurally controlled basins separated by subsurface basement ridges (Dutta, 1983), which extend westward into Pakistan (Aziz and Khan, 2007). The development of the Barmer, Jaisalmer and Bikaner basins of this region evolved as intra-cratonic rift basins from early Jurassic to Tertiary times. The process of rifting also generated episodes of alkaline magmatism. The Luni-Sukri lineament and the Jaisalmer-Barwani lineament dating back to at least Proterozoic times, cut across these formations. The interplay of subsurface domes and basins with these lineaments may have significance in terms of hydrocarbon accumulation. The Kadanwari Gas Field in Pakistan is a small part of the prolific Middle Indus Basin and is located very close to the border with this part of Rajasthan. Seismic data indicates depths of 3000-3500 m (Ahmad et al., 2007) for the hydrocarbon bearing formation in Kadanwari.

The surface geology of the Jaisalmer Basin consists of Quaternary sediments in the west, grading to Tertiary and then Mesozoic formations proceeding eastwards. The gravity anomaly map of the area shows the smallest values in the west of about -60 mGal, climbing to values of 40 mGal and more at the eastern edge. A medium wavelength positive anomaly is found at the southwestern border. An attempt is made here to generate a first-order crustal model based on observed Bouguer gravity along a NW-SE profile cutting across the study area. The model reveals 6-7 km of sediments in the western most part of the basin.

Introduction

The Directorate General of Hydrocarbons, GOI recognizes the Rajasthan Basin as a Category I basin onland, comprising of the Barmer-Sanchor, Bikaner-Nagaur and the Jaisalmer sub-basins. The Barmer-Sanchor is a Tertiary basin, the Bikaner-Nagaur a Paleozoic basin and the Jaisalmer is from the Mesozoic-Cenozoic. The sub-basins within the Jaisalmer Basin indicate Cambrian to Tertiary sediments (Bhowmick), where exploration by ONGC and OIL has resulted in discoveries of oil and gas reservoirs. The Bikaner Basin is a Paleozoic basin, possibly holding reserves of heavy oil, whereas the Barmer Basin is probably an extension of the Cambay Rift.

Geology of the Jaisalmer Basin has been studied by several workers (DasGupta, 1975; Pandey et al., 2006 and references therein). Surface gravity-magnetic surveys and airborne magnetic surveys have been conducted by GSI around 1955, which was continued later by Oil and Natural Gas Directorate (ONGD), GOI. Seismic surveys were taken up later by ONGC around 1968 (Avasthi, 2002). Recent production of hydrocarbons from the Jaisalmer and Barmer basins give fresh impetus for more systematic and rigorous geophysical investigations.

The present effort consists of an analysis of the Bouguer gravity field of this region as well as an attempt to define a preliminary crustal model based on geological information of the region and gravity data along a profile across the Jaisalmer Basin (from Gravity Map of India, 2006). Keeping in mind the inherent ambiguity of gravity data interpretation, a simplistic approach is preferred until more constraining data from seismic and exploratory drills become available.

Approach

The present study area lies within the box marked on the generalized geo-tectonic map of Rajasthan, shown in Figure 1. The exposed geology depicts sedimentary formations of different ages from the west to the east. Exposures of mafic intrusives of the Malani Igneous Suite are scattered in different places. The Ramgarh Fault and the Fatehgarh Fault intersect our profile in the northwest; the Luni-Sukri lineament and the Jaisalmer-Barwani lineament are the prominent features running SW-NE and NW-SE across the study area respectively.

The Bouguer anomaly map is shown in Figure 2. The gravity low at the northwestern corner of the map (the precise location of the NELP Blocks) appears to extend in a series of smaller lows towards the southeast. This trail of lows is wedged in between two medium wavelength highs in the central and southern parts. Beyond the central high, the gravity field flattens out again over the Quaternary sediments until the low over the Delhi Fold Belt is reached. Since the surface topography of the area is flat to the Delhi

Fold Belt to the southeast of the area, the Moho topography is expected to have a gentle gradient from the western marginal terrain toward the cratonic region in the east, until the steep deepening below the Delhi Fold Belt. Thus the small and medium wavelength anomalies may be inferred to arise primarily out of a combination of density variations in the upper crust as well as changes in thickness of sedimentary formations.

Power spectral analysis of the gravity data indicates two average depths of causative sources at 4 km and at about 30 km, which may be taken to coincide with the sediment-basement interface and the lower crust-upper mantle interface, respectively. The other interfaces of less density contrast are not clearly resolvable in this dataset, but may be identified in the analysis of a residual data which would be devoid of the strong effects of the Moho. Preliminary data from exploratory wells and shallow seismic data are available in the NELP blocks RJ-ONN-2005/1, RJ-ONN-2005/2 and RJ-ONN-2005/3 from the Directorate of Hydrocarbons. They indicate sedimentary formations of Jurassic age up to depths of 3500 m. A faulted basement is encountered at TWT of 3000 ms near the border with Pakistan and appears to shallow to 2250 ms eastward. Earlier gravity studies by Krishna Brahmam (1993) has shown that reactivation of zones of weakness lead to emplacement of high density material at shallow depths and also caused seismicity in the region.

Model Results

The top half of Figure 3 depicts the variations in elevation along the profile, along which the density model is constructed, while the bottom half shows the prominent gravity anomalies. The average topography of about 150 m is almost flat until the increased elevation of the Delhi Fold Belt. The Bouguer anomalies show a positive anomaly of about 25 mGal in the centre of the profile, gradually decreasing on either side. This high corresponds to the approximate surface exposure of the intrusives of the Malani Igneous Suite. The beginning of a sharp negative anomaly is seen at the eastern end of the profile.

The initial model configuration is based on the overall geometry provided by the Nagaur-Jhalawar velocity information (Satyavani et al., 2004) and has the approximate dimensions of 450 km in length and 50 km in depth. Here we have attempted to present the sediment formations into Quaternary (velocity 2.0 km/s, density 1800 kg/m3), Tertiary (velocity, 2.2 km/s, 2200 kg/m3) and Mesozoic (velocity 3.8 km/s, 2400 kg/) formations overlying the basement, which are represented by the Late Proterozoic (velocity 6.1 km/s, density 2700 kg/m3) and Early Proterozoic rocks (2750 kg/). The low-density layer shown in the seismic interpreted profile is not included in the density model due to lack of definite constraining information about the thickness of this layer. The Lower Crust (density 2800 kg/), followed by the crust-mantle boundary (Moho) and the Upper Mantle (density 3300 kg/) makes up the deeper part of the model.

The density model depicts the undulations of the Moho, which is deep (35 km) below the center of the basin, shallows below the gravity high representing the intrusion of upper mantle material belonging to the Malani Igneous Suite and dips again (42 km) below the Delhi Fold Belt. This basement upwarp is more prominent and may be controlled by tectonics along two major lineaments in this area. A significant thickness of sediment cover (up to 5 km) may be expected in the western basinal areas, which is underlain by a small basement-rise, corresponding to the Shagarh Ridge. The Quaternary sediments end at the Jaisalmer-Barwani Fault and the Tertiaries at the Ramgarh Fault, where the Mesozoics appear to attain the largest thickness. Farther east, a thinner layer of Mesozoic sediments continues below the Quaternary cover right up to the Luni-Sukri lineament.

A first-order fit between observed and computed gravity anomalies suggests a model configuration, which suggests depths of an average of 4-5 km for the sedimentary formations in the northwestern part. These depths will be better resolved with deep seismic information.

Conclusions

The preliminary model provides a relative quantification of the depths of the sedimentary formations and their areal extent, which are of interest in terms of hydrocarbon potential and also gives an idea of basement geometry. Incorporation of results from seismic experiments and more deep wells would enable the required detailing. A three dimensional model based on gridded gravity and magnetic data would contribute significantly towards resolving the basement structure, specially faults and sediment configurations, aiding the delineation of possible hydrocarbon sources.

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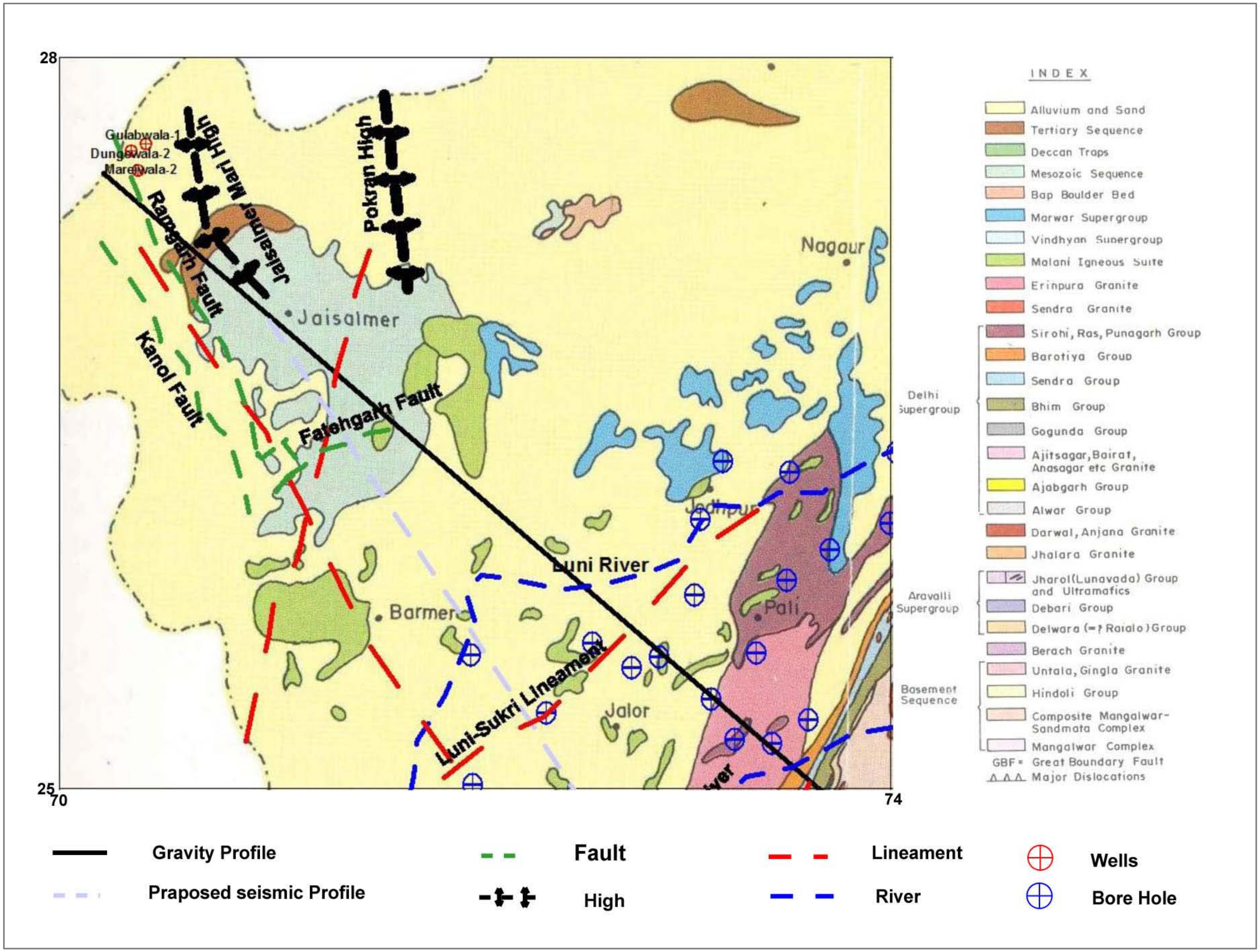

Figure 1. Geotectonic map of study area with location of proposed seismic profile from near Laungwalatar (N-W) to Mundra (S-E), along which density model is constructed.

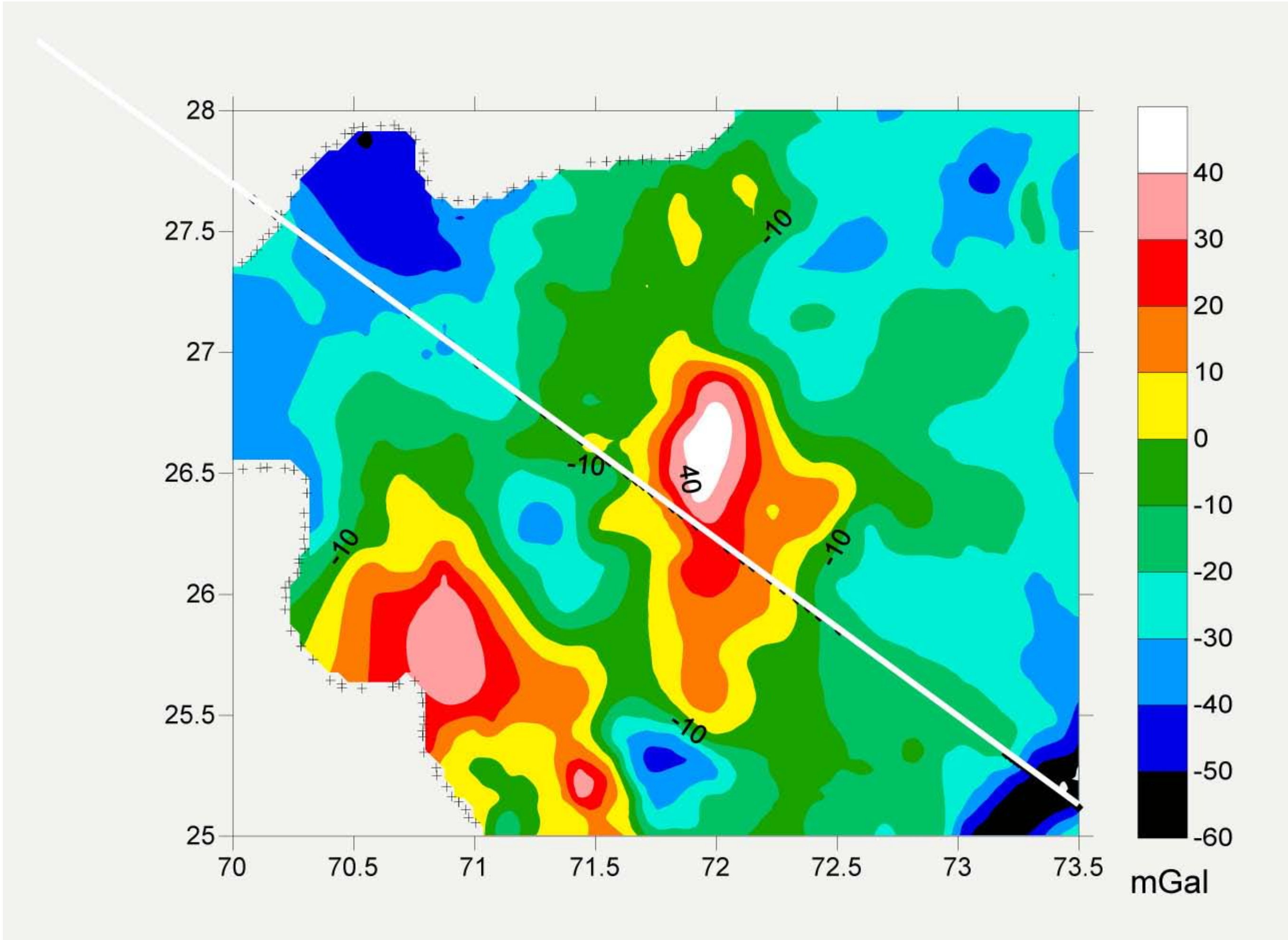

Figure 2. Bouguer anomaly map. The gravity low at the northwestern corner of the map (the precise location of the NELP Blocks) appears to extend in a series of smaller lows towards the southeast.

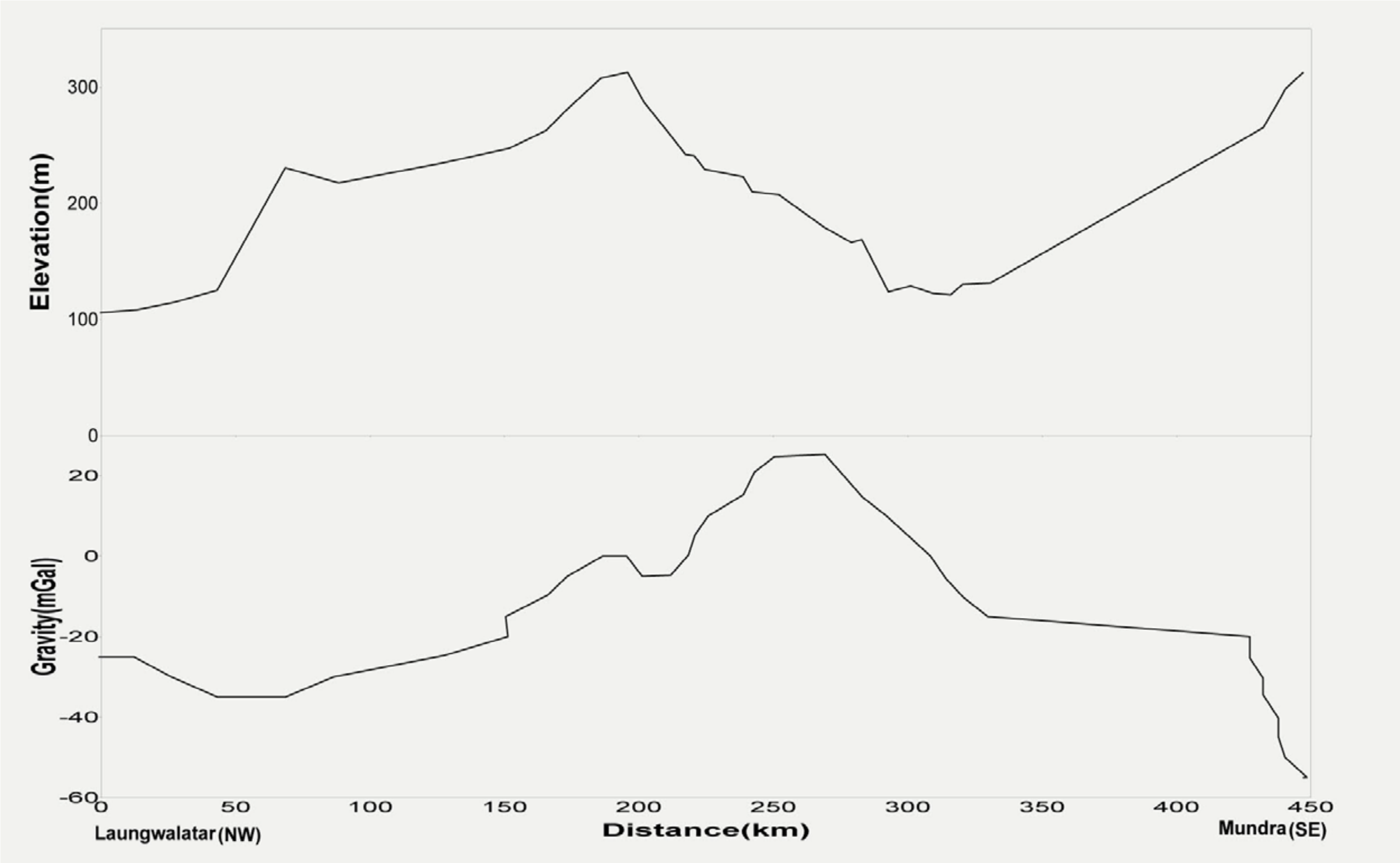

Figure 3. Top: Elevation along Laungwalatar-Mundra profile; Bottom: Bouguer gravity along Laungwalatar-Mundra profile.

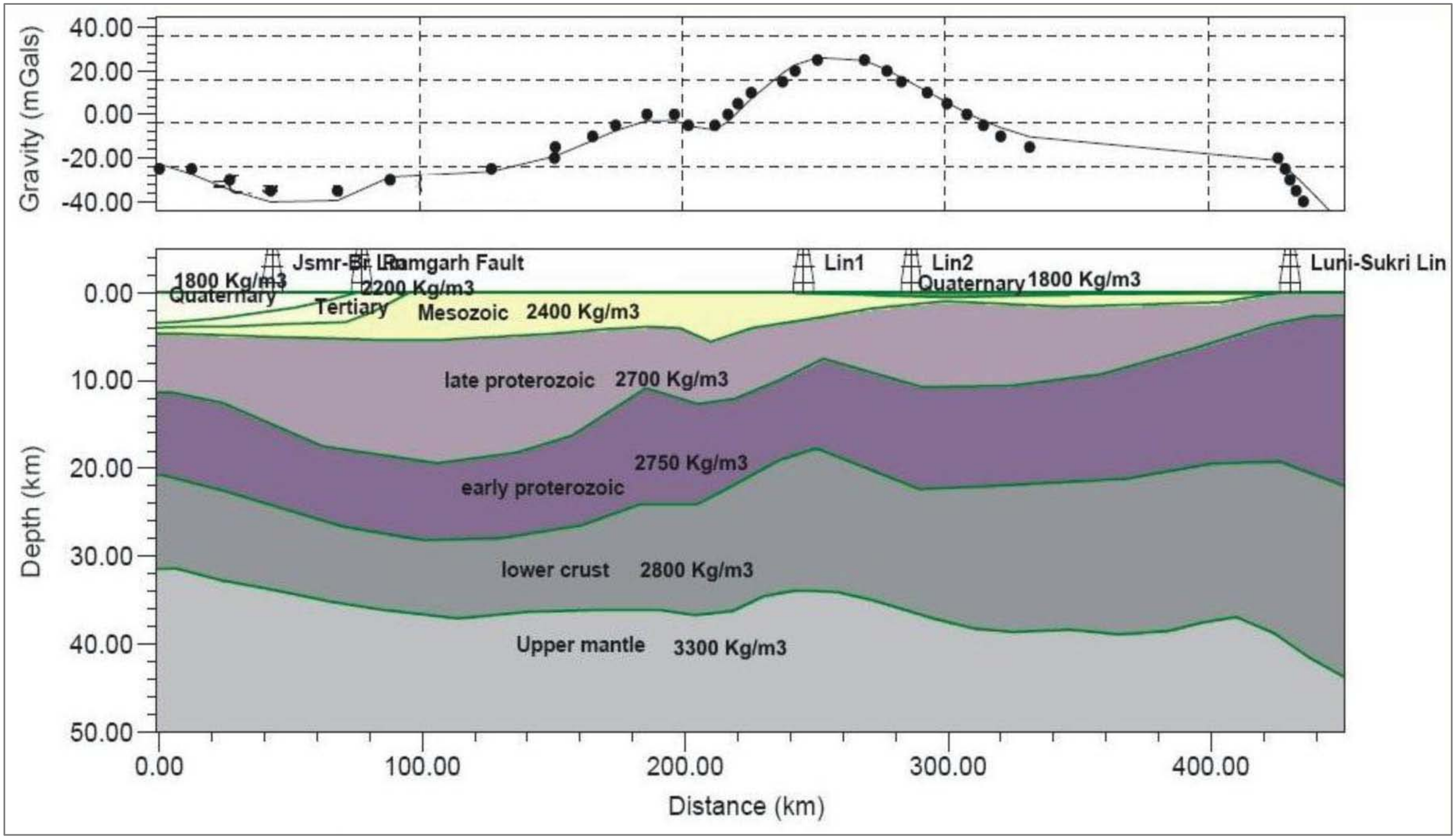

Figure 4. Preliminary model of the crustal structure.