Structures and tectonics of Son-Mahanadi rift basin, India derived from joint interpretation of gravity and magnetic data incorporating constraints from borehole and seismic informations

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Summary

Son-Mahanadi Gondwana rift basin located in the eastern part of Indian peninsular shield shows numerous mafic dykes and sills intruding the sediments posing a serious problem in seismic data acquisition and interpretation. This paper presents the results of joint analysis of gravity and magnetic (G-M) data using constraints from borehole to delineate the shallow and deep crustal structures to understand the tectonics and evolution of the basin. The Bouguer gravity anomaly map of the region depicts short wavelength gravity lows and highs due to undulations in the basement superposed on a long wavelength regional gravity low centred over the basin. The detailed magnetic map of the northern part of the basin shows linear bipolar anomalies associated with dykes. Interestingly, the regional gravity low bears an inverse correlation with the regional topography which suggests that the excess topographic load is compensated at depth and the required buoyancy might be the consequence of deep seated low density heterogeneities due to thinning of the lithosphere. Presence of high heat flow and occurrence of large number of volcanic dykes and sills of Deccan origin and its proximity to the Deccan volcanic terrain suggests impact of Deccan plume as the preferred mechanism for the uplift of Gondwana sediments.

Keywords: Joint modelling, Deccan basalt, lithosphere, palaeomagnetic, rift basin

Introduction

The NW-SE trending Son-Mahanadi basin is one of the Gondwana basins of the Peninsular India (Fig.1). These basins have large economic value due to presence of huge coal reserves. However, their hydrocarbon potential is yet to be established. This intra-cratonic basin consists of ENEWSW trending South Rewa basin (SRB) in the north and NW-SE trending Son-Mahanadi graben in the south (Chakraborty et. al., 2003). The detailed geological map of the region is shown in Fig. 2. The basin is delimited by Deccan trap in the west, Proterozoic Chattishgarh group of rocks in the southwest, Precambrian basement rocks in the southeast and east and Palaeoproterozoic Mahakosal metavolcanics in the north. Basin contains as large as 5.0km thick Gondwana sediments ranging in age from Early Permian to Early Cretaceous. The Lower Gondwana sedimentation was initiated with Fluvio-glacial and marine deposition followed by fluvio lacustrine deposition of Carboniferous to Middle Cretaceous age.
Barakar, Barren measures and Raniganj formations. The lithology of these formations is normally shale, sandstone and Coal Seams. The Upper Gondwana rocks (Lower Triassic to Lower Cretaceous) are divided into Pali-Tikhi, and Parsora formations. This basin is infected by a large number of mafic dykes and sills. It is suggested that during Deccan eruption, existing faults provided easy path for magma to be intruded as sills and dykes. An exploratory well drilled at Tikhi also shows mafic rocks within the Raniganj and at the top of Barakar sequence. The granite-gneiss basement is encountered at a depth of 3915m. Sediments were deposited within the framework of a rift graben. The basin is dissected and traversed by a number of faults (Fig.2). However, the causative factor for the rift development is not well understood due to lack of well constrained geophysical information. This paper presents the results of integrated interpretation of G-M data to delineate the shallow and deep crustal structures to understand the tectonics and evolution of the basin.

Analysis of gravity and magnetic anomaly maps

Scintrex CG-5 gravimeter and Geometric proton precession magnetometer were used for the acquisition of G-M data respectively. A total of 2500 gravity and 5000 magnetic observations were recorded at a spacing of about 1.0 km and 0.5 km respectively along available roads and tracks in the detailed study block of SRB. After applying the necessary corrections to the gravity observations, it is merged with regional gravity data base (gravity map series of India-2006) and a composite Bouguer anomaly (BA) map of the Mahanadi and surrounding region is prepared while residual total intensity magnetic anomaly (RTIMA) map of the detailed study block is prepared after removing the international geomagnetic reference field (IGRF) values.

Fig.3 presents the BA map of the region. It depicts two prominent gravity lows, one to the north of Shahdol near Tikhi and other to the south. These lows are separated by EW trending gravity high due to presence of intra-basinal transverse ridges. The E-W trending gravity high in the north adjacent to the basin coincides with the exposed high density Mahakosal group of rocks while high in the south is caused due to high density rocks of Eastern Ghat Terrain. The gravity high near Mandla indicates volcanic intrusive. The RTIMA map (Fig.4) depicts E-W trending linear bipolar anomalies which are the characteristic feature of E-W trending mafic dykes at this geomagnetic latitude. However,

Figure 2: Geological map of the Mahanadi basin and surrounding area.

Figure 3: BA map of the Mahanadi basin and surrounding area. White contour shows low pass filtered regional anomalies with cutoff wavelength of 200 km. The N-S line is used for modeling of regional anomalies.

N-S trending dykes do not produce recognizable anomalies at this latitude hence not revealed. The most significant feature of the RTIMA map is the presence of large amplitude bipolar linear anomalies near Shahdol with a prominent high towards the south suggesting basic intrusive having remanant direction different than other dykes.
Since the Bouguer anomaly represents the total sum of gravitational attraction of all subsurface causative sources, the first task in any gravity interpretation is to decompose the gravity anomaly into its component part usually called regional residual separation. Though there is no unique method for separation of anomalies, frequency domain filtering provides an efficient way to decompose the anomaly using suitable high and low pass filters (Blakely, 1998) with cut-off wavelength designed from the frequency characteristics of the radial power spectrum plot (Spector and Grant, 1970). The large wavelength regional gravity low (white contours, Fig.3) obtained from a low pass filter with a cut-off wavelength of 200 km is conspicuous as most of the rift basins are associated with positive regional due to thinning of the crust and associated mafic underplating at the base of the crust. Mishra and Tiwari (1981) inferred low density heterogeneity at sub crustal level as the causative source. Behra et al., (2004) suggested presence of low velocity layer in the middle crust and high velocity magma underplating in the Mahanadi delta region based on deep seismic sounding experiment. Mishra et al. (1999) proposed thickening of the low velocity layer above the thinned high density underplated crust. The most interesting feature of the regional anomaly is the inverse correlation with the regional topography as shown in Fig.5, which suggests that the excess topographic load is compensated at depth and the required buoyancy might be the consequence of deep seated low density heterogeneities formed due to thinning of the lithosphere. 2D modelling of the regional anomaly supports the above contention (Fig.5). Presence of high heat flow and occurrence of large number of volcanic dykes and sills and its proximity to the Deccan volcanic terrain favours lithospheric thinning due to impact of Deccan plume as the preferred mechanism for the uplift of Gondwana sediments.

Figure 4: RTIMA map of the study area showing borehole and palaeomagnetic sample locations. N-S seismic line (MP-03-02) used for integrated G-M modeling

Figure 5: 2D gravity modeling of regional anomaly along N-S profile marked in Fig.3 shows thin lithosphere (90 km)

Figure 6: Residual gravity anomaly map of detailed study block. N-S seismic line (MP-03-02) used for integrated G-M modeling
Figure 7: Basement depth derived from 3D inversions

The residual anomaly map (Fig. 6) reflects short wavelength highs and lows caused due to the shallow density heterogeneities resulting from basement undulations. The large amplitudes gravity high with a sharp gradient in the north suggests steep basement up warp. The most conspicuous feature of the map is the presence of gravity low below the Deccan traps in the south indicating presence of thick substrappan Gondwana sediments. 3D inversion of residual anomalies in terms of single density basement interface based on algorithm of Parkar (1973) using a density contrast of 0.25 g/cm$^3$ between the basement and sediments reveals number of sub-basins dissected by shallow transverse ridges. Basement depth derived from this study is in agreement with the depth of the basement depth in Tikhi well. The maximum depth to the basement is 5.5 km towards the northeast of Tikhi Well. The map depicts number of fault and lineament which has been inferred from this study. These faults are aligned mostly in Satpura trend in the north and Mahanadi trend in the south. The faults transverse to these major trends have divided the major basins into sub-basins.

**Integrated G-M modelling**

Since the subsurface model derived from independent gravity and magnetic modeling is not unique, integrated modeling is performed incorporating the results from seismic, Euler’s depth and borehole to arrive at a more plausible geological section. Constraints from seismic sections are utilized for the definition of the sedimentary layers and average density values are ascribed to the different layers on the basis of density log of the Tikhi well (Jitendra Kumar et al. 2005). Since residual gravity anomalies usually reflect the basement features hence emphasis was put to gravity anomalies while changing the basement geometry. Sediments are assumed to non magnetic, hence the source depths derived from Euler’s solutions of magnetic data provide constraints on position of the intrusive dykes linked to short wavelength magnetic anomalies. Thus, the model is expected to reveal the major trends of the basement from the residual gravity data and delineate the basic intrusive dykes on the basis of the magnetic data. While modelling the magnetic anomalies, magnetic properties of dykes and sills were assigned based on palaeomagnetic measurements of 41 rock samples collected from 11 sites in the field (Fig. 4). Palaeomagnetic measurements indicate that the exposed dykes belong to Deccan origin having direction of remnant magnetization ranging from Incl= -20° to -40° and decl= 310° -350° and intensity of magnetization as 1.0 to 7.0 A/m which belongs to normal polarity of Deccan magnetostratigraphy suggesting that dykes have intruded during the last phase of volcanism.

Fig. 8 shows the interpreted section along the N-S seismic profile derived from 2½D modeling of residual G-M anomalies. Interpreted section shows number of dykes belonging to Deccan normal polarity in the central part of the profile where as other dykes and sills belongs to reverse polarity chron corresponding to main phase of Deccan volcanism. The section reveals a high density mafic body of reverse polarity in the south to match the observed gravity and magnetic high. It is noteworthy that shot wavelength magnetic lows in the centre require normal magnetization where as gravity and magnetic high are associated with reverse polarity mafic dykes. Thus it is inferred that dykes and sills intruding the sediments belongs to main and late phase of Deccan volcanism. It is conjectured that large mafic body could act as source for late phase dyke emplacement. Interpreted section also reveals the presence of Gondwana sediments below the Deccan trap of normal polarity exposed on the surface.

**Conclusions**

Integrated modeling of residual gravity and magnetic anomalies reveals large up warps and down warps in the basement which are fault controlled. It has brought out transverse ridges separating the basin into number of subbasins. Dykes intruding the sediments belongs to
normal and reverse polarity chron of Deccan volcanism. The most significant finding is presence of thin lithosphere beneath the Mahanadi rift basin which has played a vital role in its evolution. The fact that regional gravity low bears an inverse correlation with the regional topography implies that the excess topographic load is compensated at depth and the required buoyancy might be the consequence of deep seated low density heterogeneities due to thinning of the lithosphere. Presence of high heat flow and occurrence of large number of volcanic dykes and sills of Deccan origin and its proximity to the Deccan volcanic terrain suggests impact of Deccan plume as the preferred mechanism for the uplift of Gondwana sediments.

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Figure 8: Shallow section derived from 2½D joint modelling of G-M residual anomalies using constraints from borehole. Densities are in g/cm$^3$ while magnetization and susceptibilities are in CGS emu units. Intrusive parameters are listed in the model. Anomalous densities of 2.25 g/cm$^3$ suggest presence of coal and carboniferous matters within the Barakar sequence.