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Deep Crustal Structure across Krishna-Godavari Basin from Gravity Data

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ABSTRACT
Gravity data over the Krishna Godavari (KG) basin is reinterpreted primarily for attributing the causative source for the conspicuous gravity high over the southeastern side of the Tanuku horst, namely, Kakinada Terrace (KT). Three-layered crust is assumed based on DSS studies in this region. Using the available gravity data the crust is modeled along two profiles as a three-layered unit. Densities of layers required in this modeling are determined on the basis of seismic P wave velocity ranges and well log data. The models are constrained with available depth values of the basement at some places along the profiles. The resulted model supports a basement of high-density of 2.90 gm/cc below the KT instead of Archean igneous and metamorphic basement with a density of 2.76 gm/cc. In other parts of the basin this denser layer is traced below the usual Archean basement complex. Different densities and seismic wave velocities characterize these two layers with a boundary between the two terminating in KT region. A denser basement in the KT region is perhaps due to the subsidence of sedimentary sequences in southeastern parts of East Godavari sub basin that may have contributed a steep step fault zone in Paleocene basalts, known as Matyapuri -Palakollu Fault Zone (MPFZ) and subsequent tectonic readjustment. The interpretation also rules out a Moho rise below this region supporting the conclusion arrived at by DSS studies in this region.

INTRODUCTION

Krishna Godavari (KG) basin is a pericratonic basin on the east coast of India between 15° and 17° north latitudes. It is a category 1 (Awadesh Rai, Chandrasekharan & Mishra 1998 and Biswas 1998) petroliferous basin with an aerial extent of 15,000 sq.km on land and about 25,000 sq.km of adjoining offshore area up to 1000 m isobath line (Kumar 1983). The Eastern Ghat suite of Archean igneous and metamorphic complex normally forms the basement and delimits the basin on the western, southwestern and northern sides. The basin is divided in to Krishna, West and East Godavari sub basins by fault controlled horsts, namely, Bapatla and Tanuku horsts. Kaza-Kaikalur horst, again divides the West Godavari sub basin in to Gudivada and Bantumilli grabens. These horsts show northeast-southwest trend parallel to the Eastern Ghat trend. The grabens contain thick sequences of sediments with several cycles of deposition ranging in age from Late Carboniferous to Holocene (Rao 2001). The depth of the basement of these sediments has been thoroughly mapped by a number of organizations, mainly by Oil and Natural Gas Corporation Limited (ONGC) as a part of its exploratory programs. In spite of all such efforts the deep crustal structure is rarely mapped in this region. Verma (1991) based on gravity studies concluded that sediments in this region rest on Eastern Ghat suite of rocks, which in turn, is underlain by a Moho with a density of 3.25 gm/cc. With sediments having a density of 2.55 gm/cc overlying on an igneous and metamorphic basement with 2.85 gm/cc density, Verma (1991) had to postulate a 7 km rise of Moho in order to explain the positive gravity anomaly over KT region. However, DSS studies carried out along Paloncha-Narsapur by Kaila et al (1990) do not show any rise in the Moho in this KT region.

Seismic P wave velocities in this region from DSS studies (Kaila et al. 1990) registered a total increase from 5.4 km/s to 6.9 km/s in between the basement and Moho. Moho is identified with an interface registering an increase of P wave velocity from 6.9 km/s to 8.1 km/s. The southeast segment of Paloncha-Narsapur DSS profile crossing the KG basin shows the following ranges of P wave velocities below the sediment-basement interface:

i) 5.5-6.2 km/s to 6.3-6.5 km/s
ii) 6.6-6.65 km/s to 6.8-6.9 km/s
iii) 6.9-8.1 km/s

The whole crustal depth section along this DSS profile (Kaila et al. 1990) shows an intra - basement interface corresponding to the velocity increase from 5.4 -5.6 km/s to 6.2 -6.4 km/s. This indicates that within the basement the velocity varies from 5.4 to 6.4 km/s. This consideration helps us to surmise that by and large the first velocity range may correspond to the crystalline basement complex below sediments-basement interface. The second velocity range is similar to the range 6.5-6.9 km/s, commonly reported for the lower crust (Smithson & Shive 1975) and the third velocity range corresponds to the crust-Mantle interface. Further, DSS studies showed a flat Moho interface at a depth of about 40 km below KT unlike 7 km rise in the Moho proposed by Verma (1991).

The gravity data of KG basin available with one of the authors prompted us to reinterpret the data in the light of the DSS results and find a source for the gravity high over KT. Density values of different layers have been obtained from various sources including the empirical relation between seismic P wave velocities and densities (Ludwig, Nafe & Drake 1970) as noted in the following lines. Same data have also been utilized to study the deep crustal structure below the KG basin. Results of gravity interpretation of two representative profiles in this region are presented in this paper.

BOUGUER GRAVITY ANOMALY

Bouguer gravity anomaly over the KG basin and contiguous areas contoured at 5 m Gal interval with tectonic elements marked on it is shown in Fig.I. The gravity contours exhibit a general NE-SW trend in the basin area showing conformity with the structural elements of the basin. The anomaly ranges from about -50 m Gal on the west to + 20 m Gal near the coast. The conspicuous NW-SE cross-trend, named as Chintalapudi cross-trend, is a manifestation of Pranhita Godavari valley (Qureshy et al. 1968 and Bhaskara Rao, Satyanarayana Murthy & Venkateswarlu 1971). Presence of gravity highs and lows over the basin region is an indication of the presence of horst and graben features. Shenai & Rao (1982) and Verma (1991) among others described these highs and lows

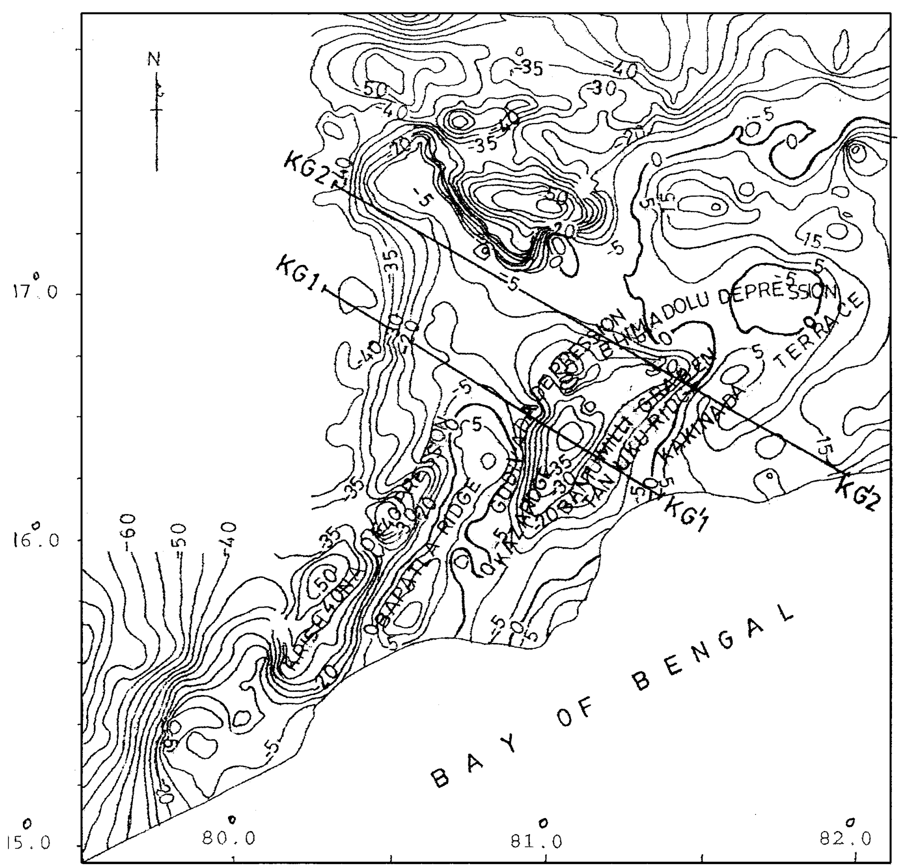

Figure I. Bouguer gravity map of Krishna - Godavari basin and contiguous areas.

and interpreted them as manifestations of tectonic features.

The KT region is of special significance here because of the following reasons: Gravity anomaly shows a high with a maximum of about +20 m Gal. This terrace is actually underlain mostly by sediments of about 5 km thickness. This information is from the wells drilled by ONGC near Narsapur and Razole (Govindan 1984 and Manmohan et al. 2003) and at some other places. In spite of this large pile of sediments, a positive gravity anomaly in this region must be due to a deep causative source. A strong regional gradient probably caused by an upwarping Moho or a relatively dense basement or any other plausible reason may compensate the negative gravity contribution of 5 km thick sedimentary pile under this Terrace. It may be pointed out here that 100-150m thick basaltic traps at depths ranging from 900m to 1700m are found in this region. They are expected to contribute a small positive gravity component to the gravity value observed at this place. But sandstones, clay stones etc., which are reported here as intertrappeans in the basaltic lava flows reduce the density of the traps and hence their gravity contribution. Therefore, only a deeper causative source is sought to exaplain the positive gravity anomaly in this KT region. To fix the causative source, two profiles KG1-KG'1 and KG2 –KG'2 across the NE-SW gravity trend are interpreted. The results are analysed in the following sections.

DENSITY CONSIDERATIONS

Based on the findings of the DSS studies (Kaila et al. 1990) a three-layered crustal model is preferred for explaining the gravity anomalies along these two profiles viz., KG1-KG'1 and KG2-KG'2. An average density of 2.4 gm/cc is assigned for the sediments filling the grabens. This value is based on the well data of ONGC. A mean density of 2.76 gm/cc is assigned to the Archean igneous and metamorphic basement complex underlying the sediment fill (Sarkar, Rajanikumar & Satyanarayana 1988). Below this, the layer registering the velocity range of 6.5-6.9 km/s, commonly reported for lower crust (Smithson & Shive 1975), is assigned a density of 2.90 gm/cc (Mishra 2002). The choice of 2.9 gm/cc is not unjustified if we recall that Tewari & Rao (1990) have identified a high velocity upper crustal zone with density ranging in between 2.8 - 2.9 gm/cc in 3 –15 km depth range in the region of Eastern Ghat Mobile Belt on the eastern margin of the Cuddapah basin. Well log data in this region also support this density value. The veracity of assignment of densities is also verified using the relation between densities and seismic wave velocities of igneous and metamorphic rocks (Ludwig, Nafe & Drake 1970).

GRAVITY MODELING

(i) Gravity Profile KG1-KG'1:

This profile with a length of about 142 km runs NW-SE in the central part of the KG basin (Fig. 2). Starting on the crystalline rocks on the NW, the profile transects NE extension of Bapatla horst, Gudivada graben, Tanuku horst, Matyapuri-Palakollu Fault Zone (MPFZ) and southwestern part of the KT and extends up to the coast. Gravity low of about - 40 mGal, a high of about -5 m Gal, a low of - 40 m Gal and again a rise to a positive value towards the coast passing through the KT are the principal features of this anomaly. Modeling of the crustal structure is carried out using the densities mentioned in the foregoing lines with the help of Geosoft (GM-SYS) package. The model is constrained with the depth values of the basement at a number of places along this profile collected from Sastri et al. (1973), Sastri, Venkatachala & Narayana (1981), isopach maps published by Rao (2001) and also well data of ONGC (Manmohan et al. 2003). Interpreted model, shown also in Fig. 2 highlights a three-layered crustal model above the Moho explaining the gravity anomaly. As expected, the sediments are thin over the Bapatla horst, Kaza-Kaikalur horst and Tanuku horst and thick in Gudivada and Bantumilli grabens. The depth scale of Fig.2 is too large to show a thin layer of sediments on horsts. Basement depth values along this profile reveal a 1.5km faulting in between 117-125km. This fault may be an indication of MPFZ.

A reflection boundary corresponding to the P wave velocity variation of 6.65 to 6.8 km/s at a depth of about 30 km is recognized in the DSS section. However, this has no expression in the density model showing an upper and lower crustal blocks with densities of 2.76 and 2.90 gm/cc respectively. The boundary between these blocks, the Conrad, is deeper on the northwest and shallower on the southeast with an average depth of about 10 km and is absent below KT region. As a result, sediments with a thickness of about 5 km are seen resting directly on the high density basement (Lower crust ?). This depth value found support from the study of this area by Prabhakar & Zutshi (1993) and Rao (2001) and also from well data (Manmohan et al. 2003).The negative gravity anomaly of this huge pile of sediments is compensated by a tectonic element as explained in the preceding lines.

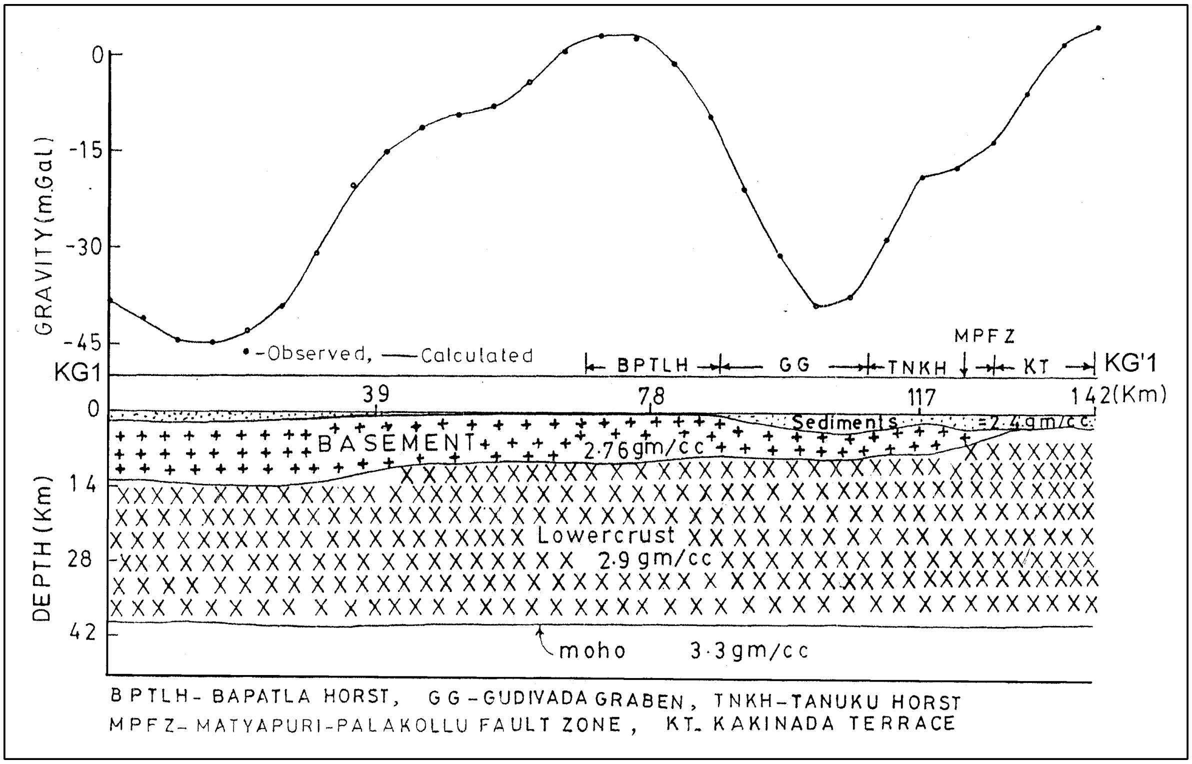

Figure 2. Gravity modeling of Profile KGI-KG'1.

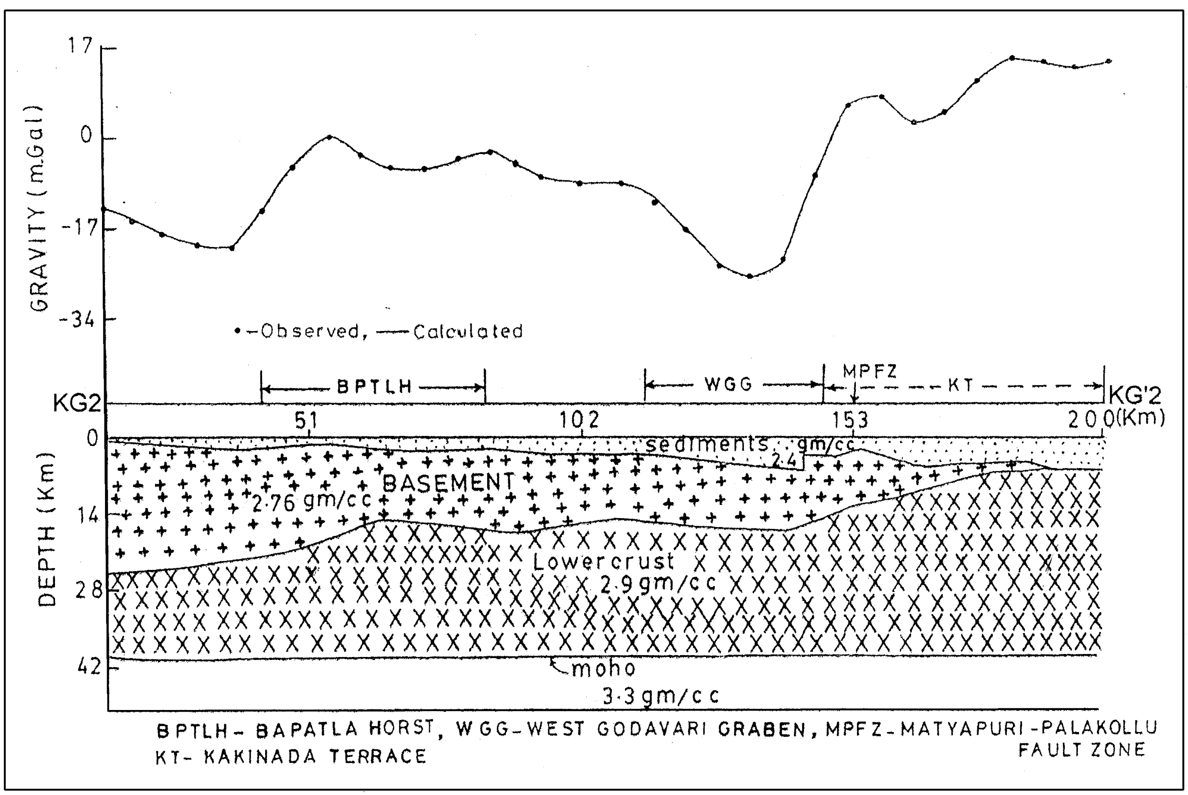

Figure 3. Gravity modeling of Profile KG2-KG'2.

(ii) Gravity Profile KG2-KG'2:

This profile, located to the NE of the profile KG1-KG'1, is about 200 km.long. Starting on the NW, this profile passes through the northwest extension of Bapatla horst, West Godavari graben, Tanuku horst, KT and ends towards east coast. A broad gravity high of -5 m Gal, a low of -30 m Gal and again a high of 13 m Gal are the important features of this profile. This profile traverses a large area of KT region. Basement depth values are available from well data on the southeastern side of this profile. Along with them, published depths from Sastri et al. (1973), Sastri, Venkatachala & Narayana (1981) and Rao (2001) are used to constrain the model interpreted by Geosoft (GM -SYS) package. The resulting model is shown in the Fig.3. The model is again a three layered one above a flat Moho at a depth of about 40 km. The boundary between upper and lower crusts shows similar features as in the earlier model with an average depth of about 16 km. The implications of this interpretation are discussed below.

DISCUSSION

The gravity analysis of these two profiles is of interest from the point of view of explaining the Bouguer anomaly over the KT region. A thick pile of sediments of the order of about 5 km with a density contrast of -0.45 gm/cc should cause a gravity anomaly of about -90 m Gal. Instead, the observed value is about + 10 m Gal near the coast. This can be explained by a deep-seated source contributing a strong regional gradient, among many other sources subjected to the assumptions already mentioned in the preceding lines. Accordingly, Verma (1991) assumed a 7 km rise in the Moho to explain this anomaly. But, DSS studies by Kaila et al (1990) showed a flat Moho in this region. So one of the possibilities may be an unusual dense layer in between sediments and the Moho. The present interpretation highlights this aspect. It results in a basement below these sediments with a high density of 2.90 gm/cc, probably representing the lower crust, instead of a density of 2.76 gm/cc, representing Archean basement, considered in other parts of the basin. The reason for the appearance of high density basement can be explained as follows: Towards southeast of Tanuku horst, according to Rao (2001), an enhancement of crustal subsidence and down faulting of sedimentary sequences occurred due to excessive sedimentation during Late Cretaceous - Early Paleocene. This might have contributed to the formation of a steep step fault zone in the early Paleocene basalts. This fault zone is known as MPFZ. This is also noted in figs 2 and 3. Tectonic readjustment has resulted in terraces and tilted fault blocks in the KT region making the sediments to rest on high density basement. It is important to note the observation of Mahadevan (1994), based on the findings of DSS, that sediments are overlying a basement with seismic velocities comparable to the lower crust in this part of the basin.

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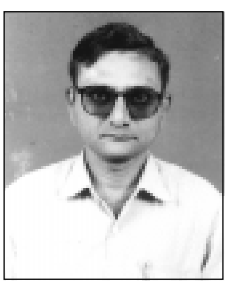

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