Gravity anomalies of 2D fault structures with fault planes described by polynomial functions of arbitrary degree

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Fault planes are often listric in nature rather than planar. In contrast to the existing conventional methods which assume planar surfaces for fault planes, a new technique is presented in the space domain to compute the gravity anomalies of 2D fault structures with non-planar fault planes. Polynomial functions are used to describe the fault planes. In addition, the density contrast within the structure is also assumed to be varying continuously with depth comprehending the geological settings of passive continental margins with concomitant basinal development. Both analytical and numerical approaches are used to derive the expression for the gravity anomaly of the structure. The method is exemplified with a synthetic fault model.

Keywords: Gravity anomaly, listric faults, parabolic density, polynomial function.

One of the important geological applications of the gravity method is to trace the boundaries of structures across which the density contrast differs significantly. Fault structures play an important and indispensable role in the exploration of natural resources. From a Bouguer gravity anomaly map, the orientation and disposition of fault patterns can be studied from the flexures and dislocations of contours. The elongated and dense contours between two widely spaced regions of a high and a low can be considered to represent a fault in the basement. Unlike the case of automatic modelling and inversion strategies, the forward modelling (i.e. the calculation of gravity anomalies) over a known density distribution always yields a unique solution. The ambiguity in gravity interpretation is generally tackled by approximating the anomalous mass with an appropriate mathematical geometry having a known density, and then to invert the gravity anomalies for the optimum parameters.

In this context, the step model becomes a popular geometry in geophysical exploration to analyse the gravity anomalies observed over fault structures[1–4]. The very fact that the density of sedimentary rocks varies with depth[5,6] often demands the use of variable density models in analysing gravity anomalies for reliable results. Although the exponential density function[7,8] could provide geologically meaningful results if simple differential compaction is assumed to be the most important diagenetic process in the evolution of sedimentary basins, it becomes a strenuous task in the space domain to derive analytical gravity expressions using this density function. Even though a few other density functions such as linear[9], quadratic[10,11] and cubic[12] are in vogue to describe the density variation of sedimentary rocks with depth, each of the density functions has its own demerits in its application as described by Chakravarthi[13], and Chakravarthi and Sundararajan[14]. On the other hand, the parabolic density function[13,15] not only simulates the density depth data of sedimentary rocks as accurately as the exponential density function does, but it also paves the way to derive closed form analytical gravity expressions in the space domain. Chakravarthi and Sundararajan[16] developed an algorithm to analyse the gravity anomalies of fault structures using the parabolic density function.

Nevertheless, the enlisted methods[1–4,16] treat the fault planes as planar surfaces, which is not so in reality. Listric faults form during rifting, drifting and evolution of passive continental margins with concomitant basinal development. Therefore, the need exists to develop an appropriate forward modelling strategy using the parabolic density function to calculate the theoretical gravity anomalies of fault structures wherein the fault planes are described by non-planar surfaces.

This communication describes a new technique in the space domain to realize forward gravity modelling of listric fault structures among which the density contrast varies parabolically with depth. The validity of the technique is illustrated with a synthetic fault model.

In the Cartesian coordinate system, let the xy-plane define the plane of observation. Also, let the z-axis be positive vertically downwards with the x-axis running in the xy-plane perpendicular to the strike of a listric fault structure (Figure 1). The model is limited in the vertical direction between the limits z_1 and z_2. Along the x-axis it is bounded laterally by a polynomial function, $\zeta(z)$, on the left and towards the right it extends to infinity. Placing the origin, $O(0, 0)$, at the intersection of the fault plane and the profile AB, the gravity anomaly $g_{\text{mod}}(x_j, z_j)$ at

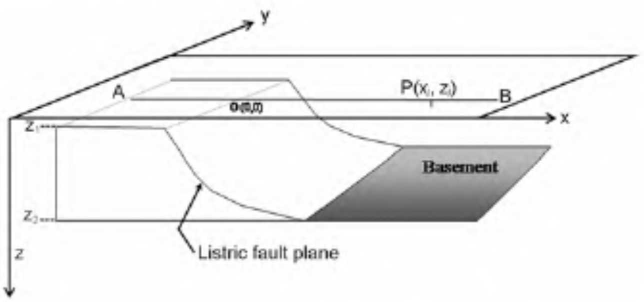

Figure 1. Schematic representation of a 2D listric fault structure. Note that the fault plane is a non-planar surface.

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any point $P(x_j, z_j)$ outside the source region can be expressed as:

$$g_{\text{mod}}(x_j, z_j) = 2G\int_s \frac{\Delta\rho(z)(z - z_j)\mathrm{d}x\,\mathrm{d}z}{(x - x_j)^2 + (z - z_j)^2}, \tag{1}$$

where (x, z) are the coordinates of an element within the structure and G is the universal gravitational constant. Here, $\Delta\rho(z)$ represents the density contrast at any given depth z, expressed by a parabolic density function[15] as:

$$\Delta\rho(z) = \frac{\Delta\rho_0^3}{(\Delta\rho_0 - \alpha z)^2}, \tag{2}$$

where $\Delta\rho_0$ is the density contrast observed at the ground surface and α is a constant that can be obtained by fitting eq. (2) to known density–depth data.

Substituting eq. (2) for $\Delta\rho(z)$ in eq. (1) and upon analytical integration with respect to x, eq. (1) takes the form:

$$g_{\text{mod}}(x_j, z_j) = 2G\rho_0^3 \int_{z_T}^{z_B} \frac{1}{(\rho_0 - \alpha z)^2} \times \left[\frac{\pi}{2} - \tan^{-1}\left(\frac{\zeta(z) - x_j}{z - z_j}\right)\right]\mathrm{d}z. \tag{3}$$

Equation (3) is difficult to solve analytically because the polynomial function $\zeta(z)$ may take any degree. In the present case, Simpson's rule is used to numerically solve eq. (3). Such an approach has the advantage that it overcomes the difficulty of deriving a lengthy mathematical expression for the gravity anomaly in addition to avoiding possible singularities. One can notice that theoretical gravity anomalies with uniform density can also be realized by letting α to zero in eq. (3).

The efficacy of the method described in the text is demonstrated with a synthetic model of a listric fault structure. A gravity profile, *CD*, across the strike of a listric fault is generated on the plane, $z = 0$, at 41 equispaced observations in the interval, $x \in [-20\text{ km}, 20\text{ km}]$, using the parameters $\Delta\rho_0 = -0.4\text{ g/cm}^3$, $\alpha = 0.15\text{ g/cm}^3$, $z_1 = 0.00001$ km and $z_2 = 10$ km. The variation of density contrast within the structure is shown graphically in Figure 2 *b*. In this case a tenth degree polynomial with a set of 11 arbitrarily chosen coefficients (Table 1) is used to describe the fault plane. The assumed fault structure is shown graphically in Figure 2 *b*. The theoretical gravity anomaly is shown in Figure 2 *a* as a continuous line. The gravity anomaly of the structure shows a larger gradient over the origin of the fault plane. Further, the anomaly asymptotically reaches zero magnitude over the foot wall and attains its maximum over the hanging wall. To study the effect of planar fault plane on the magnitude of the anomaly, forward modelling has been carried out using the scheme of Chakravarthi and Sundararajan[16] presuming 45° as the dip of the fault plane (Figure 2 *b*). The response of the structure is shown in Figure 2 *a* as a dotted line. One can notice from Figure 2 *a* that the anomaly in both cases mimics with each other at large distances on either side of the fault plane whereas they differ significantly over the length of the profile.

A forward modelling technique is presented in the space domain to calculate the theoretical gravity anomalies of listric fault structures. The fault plane along the depth axis was simulated by a generalized polynomial. The density contrast within the fault structure was assumed to vary continuously with depth, a phenomenon well observed in many sedimentary basins all over the world. Furthermore, the present technique allows one to choose any degree for the polynomial to simulate the fault

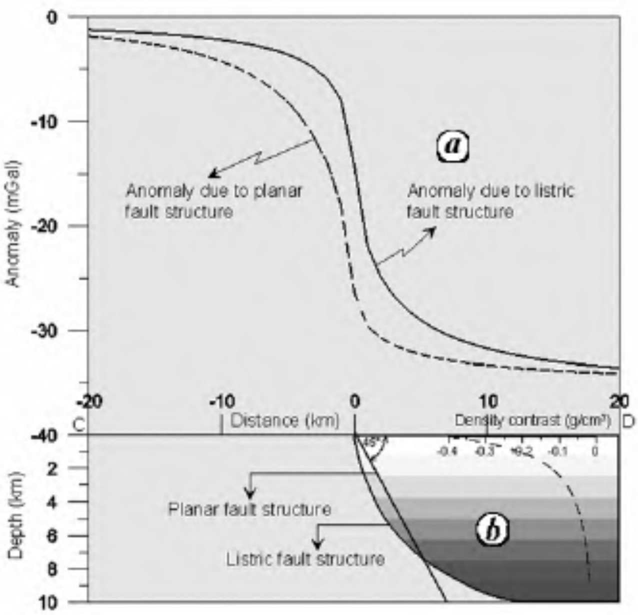

Figure 2. Theoretical gravity response (***a***) over a synthetic listric fault structure with both planar and non-planar fault planes (***b***). The hanging wall of the structure is composed of a number of sedimentary formations with the density of each formation increases with depth.

Table 1. Assumed coefficients of the polynomial, $\zeta(z)$

Coefficient	Assumed value
f_0	0.00583638771335674
f_1	–0.332117490265433
f_2	1.78357752011874
f_3	–2.32150711861801
f_4	1.59983680277849
f_5	–0.634055976222553
f_6	0.152857398576331
f_7	–0.0227831865867804
f_8	0.00205069527334211
f_9	–0.000102141383757334
f_{10}	0.00000216127403234758

planes. Further, the forward gravity modelling of a synthetic fault structure with both planar and non-planar fault planes reveals the fact that the magnitude of the anomaly differs from each other over the length of the profile.

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ACKNOWLEDGEMENTS. I thank the anonymous reviewers for their critical reviews. Director, National Geophysical Research Institute, Hyderabad is acknowledged for his encouragement and permission to publish this work. This work is carried out with the financial assistance of Council of Scientific and Industrial Research (CSIR) under the YS project.

Received 25 May 2009; revised accepted 8 July 2010

Need to intensify base metal exploration activities in Mikir Hills, northeastern India

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Precambrian shield areas are often metal-enriched. Unlike many other contemporary shields, the Mikir Hills, however, does not have any history of metal production in the past. Ultrabasic–basic–intermediate to acid and alkaline magmatics of Precambrian to Cretaceous age depict evidences of mineralization in the shield. Poor understanding of the geological and geo-chronological events is responsible for branding barren signature to the shield. Recently generated geo-chronological data on mineralized Palaeoproterozoic granitoids of the shield provide cognizance to its geological evolution. The merit of metallogenic appraisal brightens as the geochronological data produced recently indicate the existence of granitoids of Palaeoproterozoic age in this craton. Moreover, recent studies have revealed that a majority of felsic to intermediate magmatics with distinct mineralization signatures are mantle-derived I-type granitoids and their metal contents are derived from similar source region. Features of hypogene alteration found prominence in a studied mineralized porphyry granitoid of Kuthori–Bagori locality of Kaziranga magmatic suite having calc-alkaline affinity. Local and regional-scale shearing has been observed and the structural elements are oriented in NNE–SSW to NE–SW directions. They are sporadically mineralized throughout the craton.

Keywords. Base metal, craton, Palaeoproterozoic granitoids, Precambrian shield, Ur mega province.

ALTHOUGH primary base metal sulphide mineralization is predominantly associated with magmatic bodies of mantle or near mantle derivation, their association with exhalative sedimentary bodies must not be ignored. Globally, base metal production comes either from the vast territory of Palaeo-subduction zones or from rift-related centres occupying part of the present Precambrian shield areas. Unlike many productive Precambrian shields of the world, the Mikir Hills (MH) craton bears similarities in geo-tectonic evolution. The magmatic variants include complex polyphase granitoids, alkaline complexes and flood basalts of Precambrian to late Cretaceous age (Figure 1)[1]. Sedimentary and meta-sedimentary rocks, however, occupy two-thirds of the total lithounits, whereas magmatic rocks of diverse nature constitute nearly one-

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