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Gravity Field and Subsurface Geometry of the Kalpatta Granite, South India and the Tectonic Significance

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Abstract

The Kalpatta granite, of Pan-African age occurs in the southern granulite terrain of Peninsular India. Bouguer anomaly map of the Kalpatta and adjoining areas reveals a gravity low of 8-10 mGal centered over the Kalpatta granite and a minor low of 4-6 mGal over the adjacent Ambalavayal granite pluton. The residual anomaly map prepared for the Kalpatta granite has been utilized to obtain depth extent and 3-D geometry of the pluton. The analysis suggests that the Kalpatta granite is an elliptical and somewhat pear shaped body with horizontal dimensions of 6-11 km and extending to a depth of 6.5km, has steeply inward dipping contacts and the shape seen on the surface continues throughout its depth. The smooth oval shape could indicate low ductility contrast, deeper level of emplacement and permissive nature of the pluton. The 3-D depth model indicates an oblique section with much deeper levels exposed in the south, in other words, the crustal block encompassing the pluton has suffered a NNW tilt during uplift after the emplacement. It is further inferred that there was no post intrusive shape modification, the NW tilting of the region and denudation gave rise to the present outcrop pattern of the body.

Key words: Gravity, Kalpatta granite, crustal model, South India, tectonics.

Introduction

It has long been recognized that granitic intrusions occur in a variety of tectonic settings. The granite plutons in general exhibit rough circular to elliptical shapes with some degree of elongation along the structural grain of the country rocks. The viscosity contrast between the intrusive body and the country rocks is the main factor controlling the granite emplacement, which according to Pitcher(1979) is a reflection of the lithological contrast, the relative crustal level of emplacement and the time relationship between the intrusion and regional metamorphism. Granites are usually associated with large negative Bouguer anomalies caused by their relatively low density contrast with the surrounding rocks. The significance of negative anomalies to the problems of origin and mode of emplacement of these plutons has been studied in great detail (e.g., Bott, 1956). The potentiality of gravity surveys as petrological tools has been demonstrated by Bott and Smithson (1967) and according to them the gravity data over granite plutons is useful for i) revealing the subsurface shape of plutons, ii) determining the extent of gross density variations within granite plutons and iii) providing some evidence on the problems of emplacement and origin of granites. Gravity interpretation thus can provide valuable information regarding the form, structure and subsurface geometry of the granite pluton which in turn will help in understanding its tectonomagmatic evolution. In the present study, a detailed interpretation of gravity field of the Kalpatta granite pluton is attempted in order to study the structure and subsurface geometry and to infer its tectonic significance.

Regional Geological Setting

The deep crustal section of southern India, comprising dominantly granulite facies rocks, is punctured by a suite of alkali granites and syenites ranging in age from 550-765 Ma and most of them lie on or close to major late-Proterozoic lineaments (Santosh, 1989). These intrusives indicate a long-lived magmatic activity in the time span from late Proterozoic to early Paleozoic, coinciding with Pan-African events. Santosh and Masuda (1991) made a detailed mineralogical, geochemical and isotopic study of these alkali plutons and suggested magma derivation from deep crust or upper mantle. Study on oxygen and sulfur isotopic compositions of these plutons by them indicate source heterogeneties and varying degrees of fluid rock exchange or supracrustal interaction. Rajesh et al.(1996) suggested widespread occurrence of these alkali plutons along southern India due to Pan-African felsic magmatism and correlated with other felsic magmatic provinces of eastern Gondwana.

Kalpatta granite is one among these felsic plutons occurring along the southern part of the Bavali shear zone in northern Kerala. Rocks of the Wynad schist complex lie towards the northeast of the pluton and are characterized by enclaves of schists/metapelites in a background of hornblende/ biotite gneiss (Fig.1). Towards the southwestern side of the pluton, charnockite is observed in the gneiss. The area has a WNW-ESE regional structural trend. The foliation map of the area has been prepared by Kumar et al. (1998) and is reproduced in figure 2. The map shows a concentration of foliation plots in the NW part of the granite body while along SE these are less in number indicating that the granite is massive. While most of the foliations along NW are subparallel to the contact, those in the SE end are mostly transverse to the contact. However, the foliation data do not clearly bring out whether they are primary flow structures within the

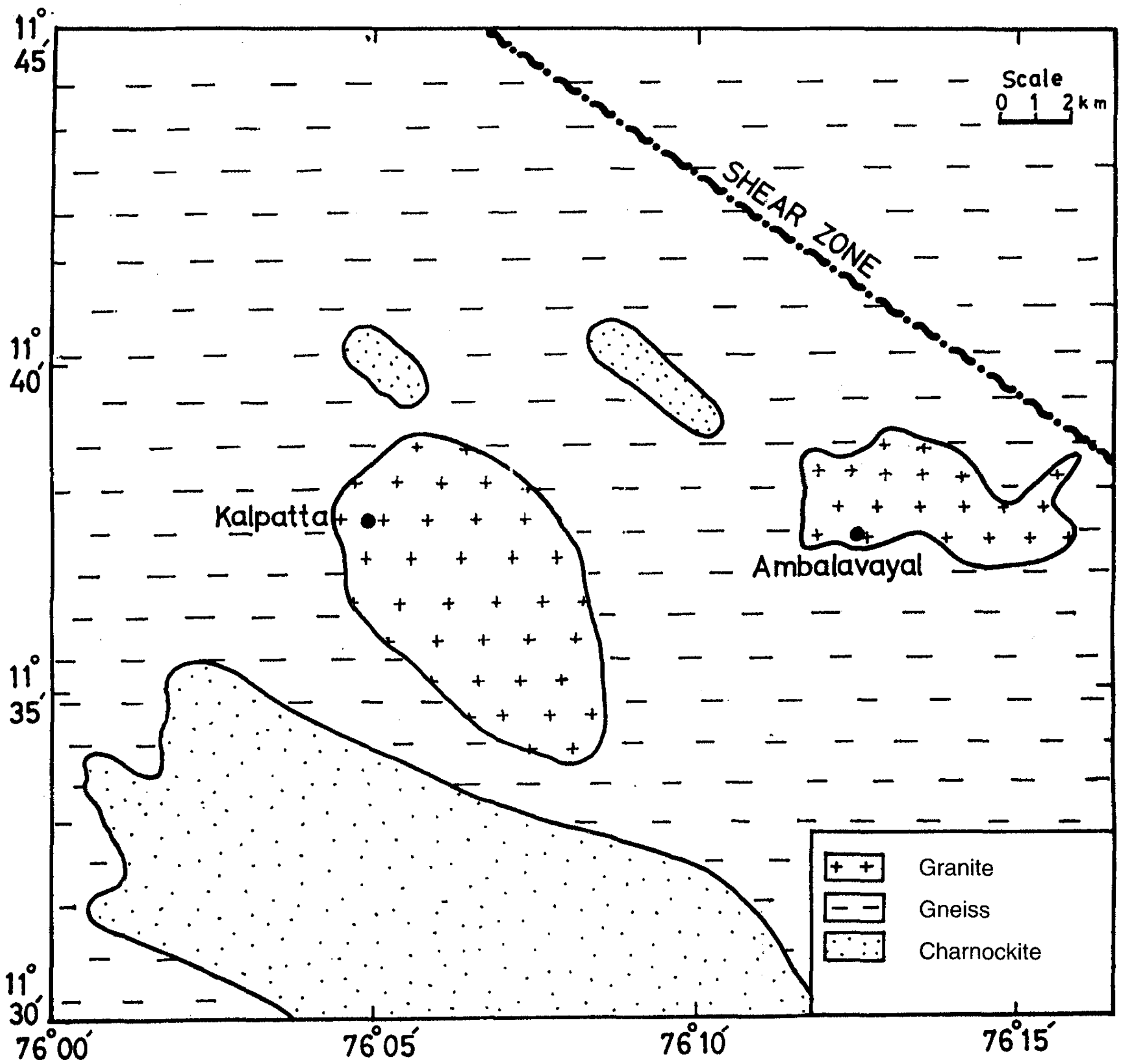

Fig. 1. Geological map of the Kalpatta granite region (compiled and modified from GSI, 1995; Kumar et al., 1998).

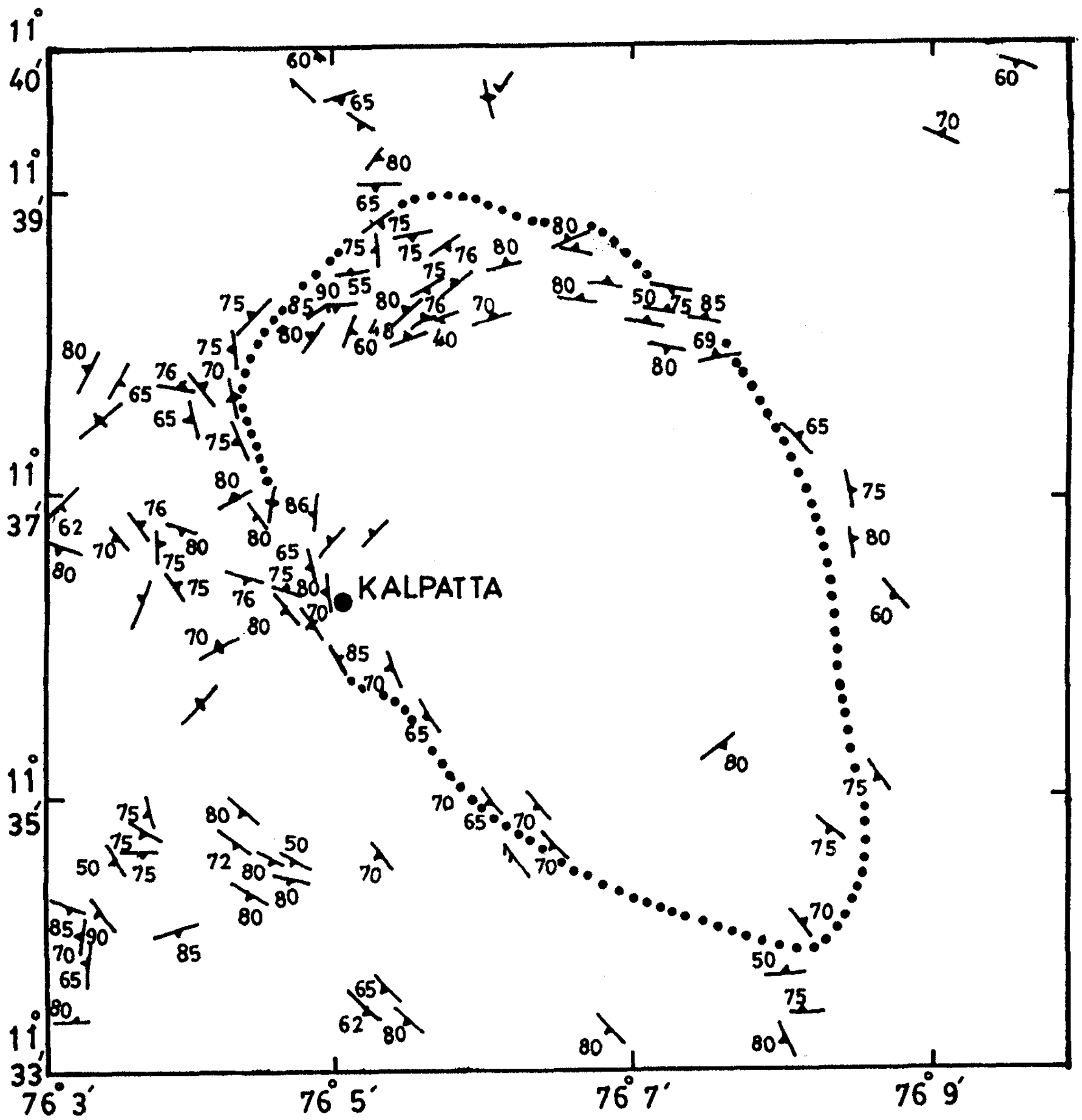

Fig. 2. Foliation map of the Kalpatta granite region (redrawn after Kumar et al., 1998). The dotted line indicates outline of the granite body.

granite. The granite is emplaced within the Precambrian gneisses as it shows rather sharp contacts with the country rock at certain locations. The pluton is an elliptical stock covering an area of almost 50 sq.km. and its overall character is suggestive of post-tectonic emplacement (Kumar et al.,1998). Nearest intrusive to this is the Ambalavayal granite which is lying around 10 km east of Kalpatta. Mineralogical and textural data suggest that both these plutons are different from each other as the Ambalavayal granite is foliated and has hornblende as the sole mafic mineral (Santosh and Masuda, 1991). The Kalpatta granite is assigned an age of 765 Ma based on U-Pb zircon dating (Odom, 1982), while K-Ar biotite dating gave an age of 512 ±20 Ma (Nair et.al., 1985). Geochemical investigations of the pluton suggest that the granites and their variants have mineralogical and geochemical characteristics indicative of a polyphased late magmatic crystallisation (Kumar et al., 1998).

Data Acquisition and Reduction

Gravity survey in this region is conducted using a W.Sodin gravimeter(dial constant = 0.24 mGal/s.d.). For the purpose of acquiring gravity data in the Kalpatta region, the nearest available base value at Nedumpoil (Radha Krishna et al., 1998) was utilized in the present study. Using this and three secondary base stations, nearly 125 gravity observations were made along all major and motorable roads in the region. The stations were selected to be at easily locatable points in the topographical map such as kilometer stones, road junctions etc. Elevation data were taken from SOI topographical map, spot heights etc. apart from altimeter data collected using an American-Paulin altimeter. The data were reduced using a standard correction density of 2.67 gm/cc and with the International gravity formula of 1930. No terrain correction was applied to the data as the area is small and not highly rugged.

Bouguer Anomaly Map and its Interpretation

Based on 125 gravity observations in the area, a Bouguer anomaly map has been prepared with a contour interval of 2 mGal (Fig. 3). It can be seen from the anomaly map that a regional NW-SE gravity gradient zone on which a gravity low of the order of 8-10 mGal has been centered over the Kalpatta granite pluton. Though data were collected along all possible roads in the region, part of the area between Kalpatta and Ambalavayal shown in the map is less accessible due to thick forest and non-availability of roads and hence data control is less here. A minor low of the order of 4-6 mGal is observed over the nearby Ambalavayal granite . The geometry of the contours as well as elliptical nature of the pluton, permit a detailed analysis of the gravity field over the Kalpatta granite.

For the purpose of regional – residual separation, 10 approximately N-S and 10 E-W profiles have been

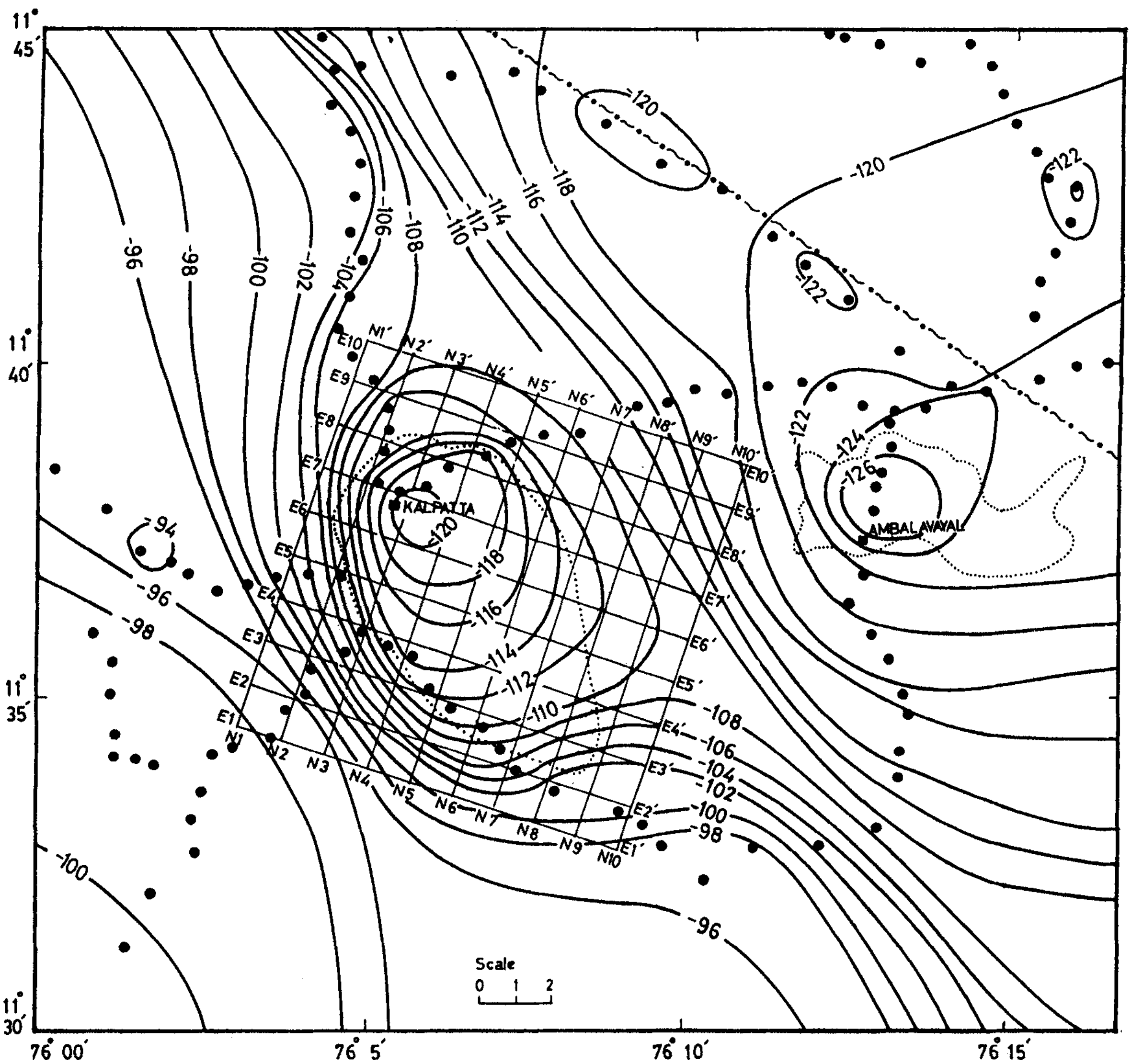

Fig. 3. Bouguer anomaly map of the Kalpatta granite and the adjoining regions (contour interval is 2 mGal). Solid circles indicate the locations of gravity observations. The small dotted lines indicate the surface exposure of the Kalpatta and Ambalavayal granite bodies. The location of the Bavali shear zone is also shown on the map. The location of the 10 approximately north oriented profiles (N1-N1' through N10-N10') and 10 east oriented profiles (E1-E1' through E10-E10') used for the preparation of residual anomaly map of the Kalpatta granite are shown.

considered covering the pluton (given as N1 to N10 and E1 to E10 in Fig. 3). The separation was made using the graphical method of smoothing. Regionals for these profiles were fixed, guided by the anomaly trends and based on the surface exposure of the pluton and by matching the regional anomaly at the intersecting points. The method is fairly reliable, particularly when sufficiently good geological information is available. The residual anomalies so obtained have been utilized to prepare a residual anomaly map as shown in figure 4. The residual anomaly map shows a gravity low of 8 mGal and correlates well with the exposed geometry of the granite.

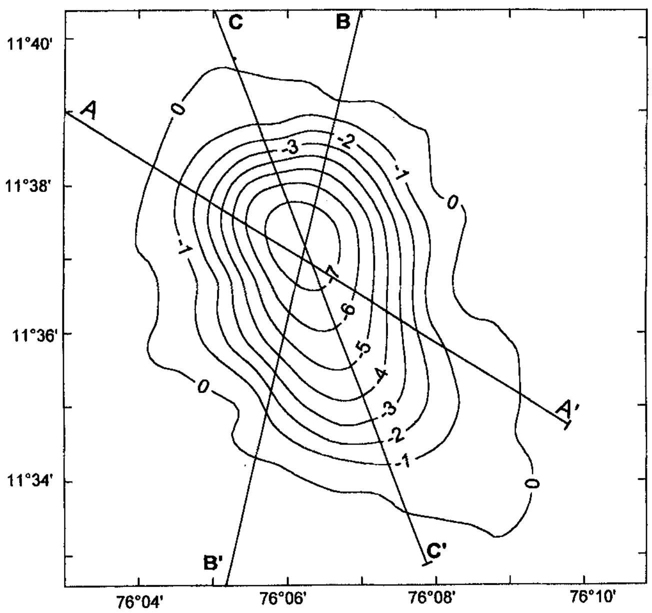

Fig. 4. Residual anomaly map of Kalpatta granite. The lines AA' to CC' indicate the profiles selected for 2-dimensional modeling.

2-D Modeling

Three gravity profiles AA', BB' and CC' across the pluton have been considered from the residual anomaly map in order to model the 2-D subsurface geometry in terms of shape, depth and subsurface extension of the Kalpatta granite body. The gravity modeling was carried out using the SAKI program (Webring, 1985). A density contrast of –0.06 gm/cc was considered for this purpose based on the surface rock density estimates of 2.67 gm/cc for granites and 2.73 gm/cc for the surrounding gneisses (John Kurian, 2000). Bott and Smithson (1967) demonstrated that in the case of no horizontal density variation in granite body, if the gravity anomaly at the surface contact falls less than half of the total amplitude of the anomaly, then the contacts of the pluton dip inward. The profiles AA' through CC' across the pluton (shown in Fig. 5) show a maximum anomaly of 6-7 mGal, while, the anomalies at the contact are around 2 mGal for all profiles. This reveals that the granitic body has inward dipping contacts. The interpreted 2-D models are shown in figure 5 and the models indicate a steep, inward dipping inclined canoe shaped outline below the surface for the plutonic body extending to a depth of 6 to 6.5 km.

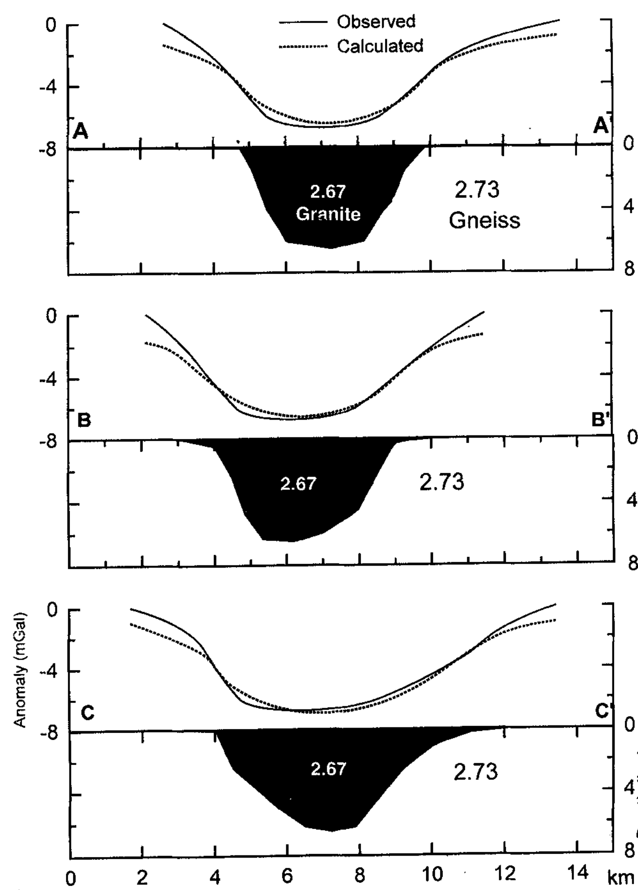

Fig. 5. Two-dimensional gravity models of the Kalpatta granite body along profiles shown in figure 4.

3-D Modeling

For three-dimensional interpretation of gravity anomalies, Cordell(1970) gave a computer program based on the formula for the gravitational attraction of a prism given by Nagy (1966). In this method, the gravity map is required to be digitized on a rectangular grid. The causative body is approximated by means of a bundle of vertical prism elements, each having a cross-section area of one square grid and a uniform density. The vertical position of each prism element is fixed with reference to a specified horizontal plane. The program calculates the vertical length of each prism element by iterations using Cordell and Henderson's(1968) approximate formula, so that the gravity effect at every grid point due to the entire causative body is equal to the observed gravity effect at that grid point. In order to fix the reference plane, in this case the bottom of the granite body, the maximum depth of 6.5 km obtained from the two-dimensional modeling of granite pluton has been used. The residual anomaly map is divided into 100 prism elements (10 x 10 grid points) with a grid width of 1.25 km. The depth of the granite body after nearly 30 iterations obtained at each prism element has been used to prepare a 3-D depth map of the Kalpatta granite as shown in figure 6. As can be seen, the 3-D depth map correlates well with the surface exposure of the granite pluton as well as with 2-D models. The plutons can be assumed originally to be of a pear shape, taking the eroded portion also into consideration.

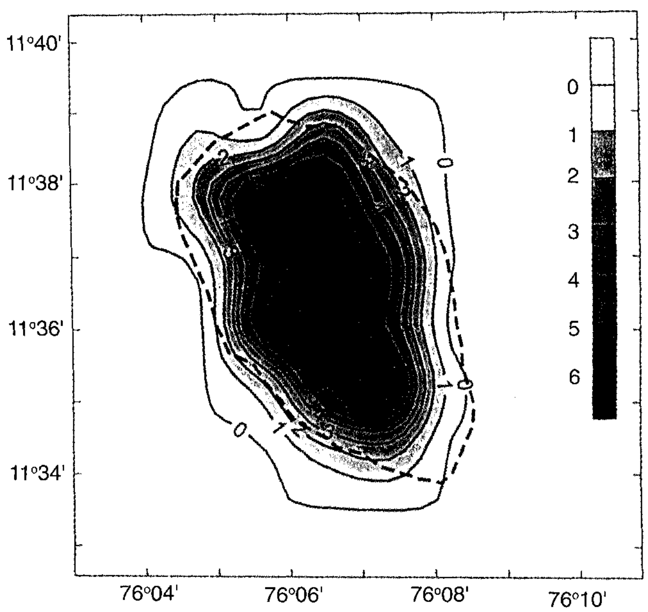

Fig. 6. Three-dimensional depth configuration of the Kalpatta granite body. The maximum depth obtained is about 6.5 km. The surface exposure of the granite body is shown as thick dashed line.

Discussion

The following are the significant aspects to be considered for discussing the emplacement and later evolution of the Kalpatta granite :

1) The granite is an ellipsoidal somewhat pear-shaped with horizontal dimensions of 6-11 km and the depth increasing towards center to about 6.5 km.

2) It has a smooth oval shaped outcrop pattern as outlined on the geological map.

3) The width of the body as seen on the surface, is wider in the NW which tapers to half its width towards SE.

4) The contacts as deciphered from the 2-D models are inward dipping approximately around 70°. The 3-D depth contour map suggests that overall shape of the body continues throughout its depth, but uniformly petering out at a depth of ~ 6.5 km.

5) The steep foliation dips around the Kalpatta granite mass as mentioned earlier do often show outward dips.

The outward dips in the foliation planes seemingly contradict the gravity model where the body dips inward. This contradiction may be explained in one of two ways, either as the steep outward dips may reverse inward in depth or the foliation dips are not primary and are unrelated to the primary structure of the granite body. However, a choice between these options calls for more detailed structural work.

The most commonly inferred shape of permissive plutons are balloons or steep-sided inward dipping cones with circular or elliptical cross sections(Pitcher, 1979). Hutchinson (1970) inferred that oblique sections through such diapirs could be tailed tadpole plutons. The smooth oval shape of the Kalpatta granite is indicative of low ductility contrast, deeper level of emplacement and permissive nature of the intrusion. The NNW elongated outline of the pluton with a tapering towards SSE and the consistent downward extension of this shape on the 3-D depth model would imply an oblique crustal section with much deeper levels exposed in the southern part. In other words, the crustal block encompassing the pluton has suffered a NNW tilt during uplift after the emplacement of the Kalpatta granite. There is also a concentration of foliation attitudes along the NW portion of the pluton where they are mostly subparallel to the contact unlike the SE end, probably indicating that the direction of ascend of the magma was from SE to NW. It can be further inferred that there was no post-intrusive shape modification and the NW tilting of the region and subsequent denudation gave rise to the present outcrop pattern of the granite body.

A regional northward tilting for the Indian Peninsular shield has been speculated by many earlier workers. The uplift of the Wynad Plateau (a portion of which is covered in the present study) and the adjoining Nilgiri hills has been ascribed to a general northerly tilt or alternately to vertical uplift (Fermor, 1936; Pichamuthu, 1953). Either of these processes can result in a local tilt in the Wynad Plateau area and thus the NW tilting inferred in the area around Kalpatta can be accomplished.

Summary and Conclusions

The gravity map of Kalpatta and adjoining areas shows a low of the order of 8 to 10 mGal centered over the Kalpatta granite and a minor low of the order of 4 to 6 mGal over the adjacent Ambalavayal granite. Regional-residual separation of the map reveals a gravity low of

8 mGal correlating well with the exposed geometry of the Kalpatta granite. Two-dimensional analysis of the granite pluton, geometry of the granite body as well as the elliptical nature of the contours enabled detailed 3-D analysis of the gravity field over the Kalpatta granite.

The Kalpatta granite has an elliptical shape with smooth arcuate contacts with an inward steep dipping surface increasing towards center to a maximum depth of 6.5 km. The shape of the surface exposure i.e., wider NW portion and narrow SE portion continues throughout its depth. The smooth and arcuate contact of the body indicates low ductility contrast, permissive and deeper levels of emplacement. The elongated outline of the granite body could represent an oblique crustal section with much deeper levels exposed in the southern part due to northward regional tilting. Inward dipping contacts of the pluton are suggestive of diapiric or bubble model and that there was no post-intrusive shape modification.

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