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Estimation of Crustal Thickness from Power Spectra of Regional Bouguer Gravity: Jadcharla-Vasco Transect

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ABSTRACT
This paper describes a procedure for rapid estimation of average crustal configuration from spectral analysis using an established relation. From the regional Bouguer gravity profile along the 600 km Jadcharla-Vasco transect in the Dharwar craton, four deep-seated faults were inferred from the undulations in the Moho, which formed the basis for tectonic classification of the craton into the western, intervening and eastern blocks. While the average crustal thickness obtained for the western block was 39 km, for the eastern block it was 37 km. The two blocks are separated by an upthrust intervening block, where the depth to the Moho at the Chitradurga thrust that occurs roughly in the middle of the block, was found to be 34.5 km.

INTRODUCTION

Evaluating the crustal configuration from geophysical inversion is a long and complex procedure, mainly because of the ambiguity involved in resolution of the subsurface. For quick interpretation, frequency (Bath, 1974) is a more useful independent variable than the corresponding time and/or space coordinates.

Computation of spectral points involves the entire data (Sundararajan & Rama Brahmam 1998) though all ranges of frequencies in the spectrum may not be useful for interpretation. Spector & Grant (1970) and Trietal, Clement & Kaul (1971) provided rough estimates of depth to the basement based on the entire data length. Cianciara & Marcak (1976), while interpreting gravity anomalies for basement mapping by means of local power spectra, suggested that smaller segments with a length of at least ten times the expected mean depth of the basement are to be analyzed to provide a set of depth values, one for each segment. While all such depths when plotted below the center of the segment enable us to map the basement, the method may not be suitable for mapping steep variations in the basement. However, considering the successive power spectra of a moving data window of appropriate length with partial overlap over the entire profile ensures that the undulations in the basement are located more precisely. Using this procedure, the basement can be mapped without the usual loss of detail that the averaging in power spectral methods of fixed segments entails.

This paper outlines a computationally quick procedure for rapid determination of the deep crustal configuration by using spectral depths in an established relation.

CRUSTAL THICKNESS FROM SPECTRAL DEPTHS

Most researchers (Worzel & Shurbet 1955; Wollard 1959; Qureshy 1970;) suggest a relationship of the sort

$$z = z_0 + K\Delta g \qquad (1)$$

to determine the crustal thickness at a given point where z and z_0 are the computed (unknown) and known thicknesses respectively, and K is a constant given by

$$K = 1/2\pi\, G\, (\sigma_2 - \sigma_1) \qquad (2)$$

where

G = Universal gravitational constant (6.678×10^{-8} cgs units)

σ_1 = Density of the homogenous overburden in gm/cc and

σ_2 = Density of the underlying layer in gm/cc

Further, equation (1) can be rewritten (Sazhina and Grushinsky, 1971) as:

$$z = z_0 + (\Delta g - \Delta g_0)\, K \qquad (3)$$

where

Δg = Bouguer gravity at any station where depth is to be computed and

Δg_0 = Bouguer gravity corresponding to z_0 (known depth, or in this case, spectral depth)

For a given profile, if σ_1 and σ_2 are known (or can be reasonably assumed), then by taking the corresponding spectral depth as the known depth z_0 in equation (3) above and assigning it to the mid point of the profile, the depth z corresponding to every gravity observation can accordingly be obtained.

However, the spectral depth is only the average thickness of the crust beneath the profile considered. To refine the computed basement or crustal configuration, the profile can be segmentally considered, for example, if the total profile consists of 600 observations, then for every discrete segment, say of 250 observations, we get a spectral depth, which can in turn be used as the control depth to determine the depth to basement or crustal thickness (depth-to-Moho) for the corresponding segment (from equation 3). Thus, instead of using one average depth to generate the basement/crustal configuration for the entire profile, we have as many average depths as the number of segments considered, which represent the basement/Moho with greater accuracy.

It is known that the gravity at any station is influenced by underlying masses as well as neighboring masses. In the procedure outlined above it is evident that while the depth estimates in the middle of a segment are well approximated, the same cannot be said for the extremities of the segment where the Bouguer gravity values (and by inference, the corresponding spectral depth) of the neighboring segments influence. To compensate for this source of error and achieve finer detail of configuration we adopt a mechanism whereby for a representative approximation of the control spectral depth (assigned to the center of the corresponding segment), Bouguer gravity values placed symmetrically about that point are considered. This is achieved by considering the power spectra of a moving window (consisting of segments of fixed length) with partial overlap between successive windows. For example, for an 80 % overlap, while the first window consists of Bouguer gravity values of stations 0-250, the following window comprises Bouguer gravity values from stations 50-300, and the next from stations 100-350 and so on. This implies that the number of depth-to-Moho approximations for each station in the central 250-station segment is maximum and progressively diminishes towards the extremities of the profile on either side. In plotting the crustal configuration all the crustal thicknesses obtained for a given observation station by taking the overlapping segments are averaged. It is evident that with this approach the configuration so obtained, as mentioned above, is well approximated for the center of the profile and poorly approximated for the extremities of the profile. But as for every measured Bouguer gravity value we obtain a corresponding depth-to-Moho, the approach is suitable for rapid quantitative estimation of the crustal configuration for long profiles.

The usefulness of the method is subject to the inherent limitations of power spectral estimates (Maus 1995) for depth that presuppose profiles of adequate length, homogenous geology and gentle undulations of the interface to which the depth is to be estimated. In general, a profile length that is at least six to seven times the maximum depth from which we require information is necessary (Naidu 1968). To map the Moho that occurs at an average depth of 35-40 km, we therefore need a profile length that is at least about 200-250 km. Further, since power spectra across varying geology yield erroneous depth estimates, it can be seen that the method is unsuitable to map the near surface features where geological variation is characteristically high. However, deeper down the lateral geological variation (along a profile) is very much subdued and spectral depths are consequently fair approximations. Therefore, the procedure outlined above is suitable for mapping regional features assuming the two-layer case.

FIELD EXAMPLE

Regional studies in peninsular India are one of the thrust areas identified by the Department of Science and Technology (DST), Govt. of India, to decipher the geological structure and composition of the crustal lithosphere. In consequence, under a DST sponsored project, regional gravity surveys were carried out along a 600 km long E-W transect that cuts across the northern part of the Archaean to Proterozoic Dharwar craton in peninsular India. This transect runs from Jadcharla (latitude 16°41′40" N and longitude 78°08′18" E) to Goa (latitude 15°23′40" N and longitude 73°48′55" E) through Raichur, Gadag, Hubli and Dharwar. It traverses almost all the major geological formations of the craton, mainly schist belts and Closepet granites, within the basement of peninsular gneisses (Fig.1). Within the craton, two sub units are proposed – the eastern Dharwar craton lying broadly to the east of the Closepet batholith and the western Dharwar craton, to its west (Rajamani 1990).

Gravity observations were made (Ramadass, Ramaprasada Rao & Himabindu 2003) with the La Coste Romberg gravimeter with a station interval of 1 km along the Jadcharla-Vasco transect. The Bouguer gravity values for the transect were computed (with appropriate reductions and corrections) using an average surface density of 2.67 gm/cc, and plotted (Figure 2-a). The effective accuracy of observations thus obtained was 0.16 mgals.

Since the deep crustal configuration is reflected by the regional component of the Bouguer gravity signal, the same was isolated from the gravity signal. Various techniques are available for the separation of the long wavelength (regional) and short wavelength (residual)

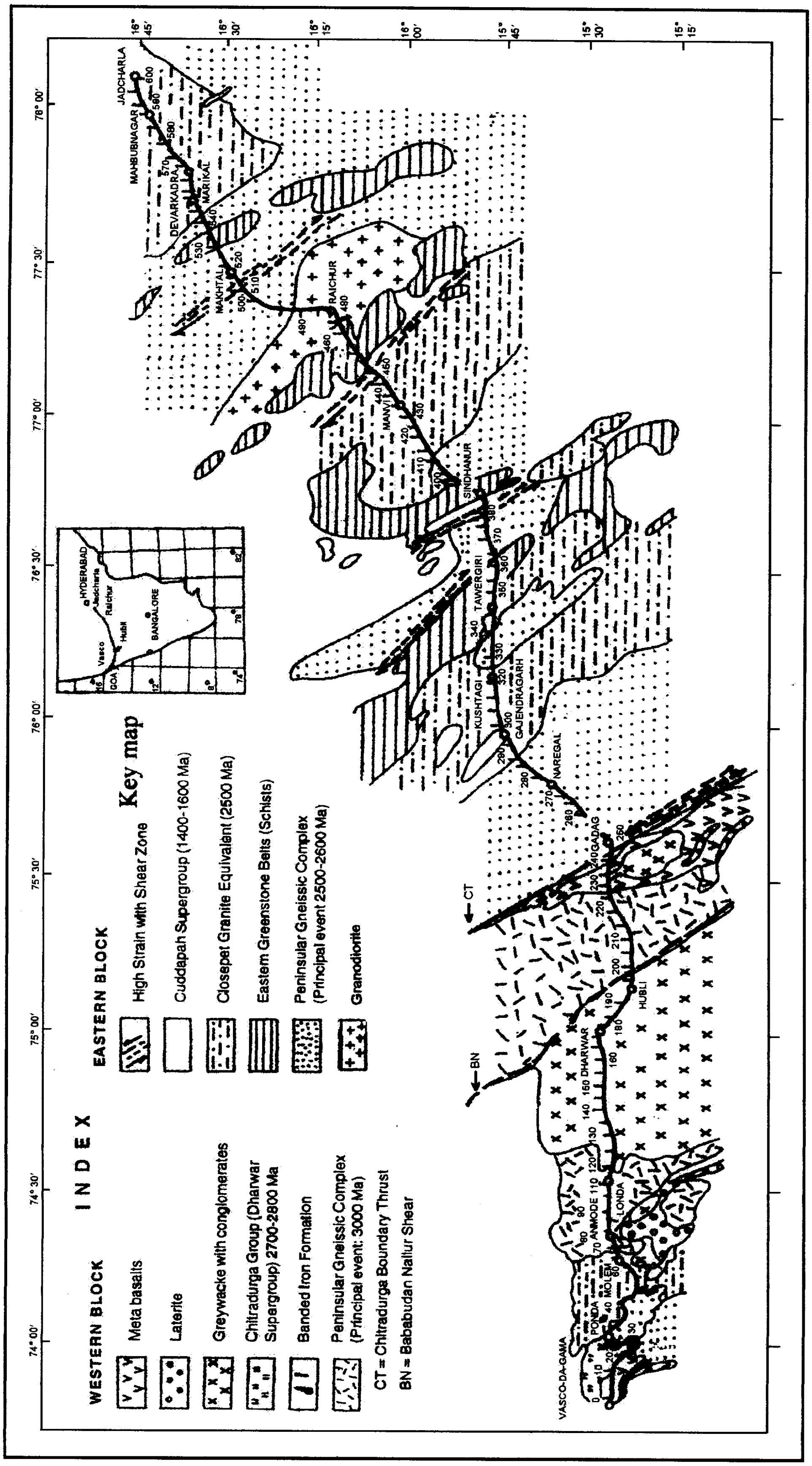

Figure 1. Geology and Layout Map along the Jadcharla-Vasco Transect (after Chadwick et al., 2000)

components of the observed signal (Agocs 1951 and Agarwal & Sivaji 1992). Polynomial fitting (Lowrie 1997) is a relatively straightforward and commonly used method that allows for a judicious mix of bias-free mathematical analysis and ground geology. Since with increasing order of the polynomial the assumed curve approaches the original set of observations, for optimal fit the appropriate order polynomial has to be selected. Of the 2^{nd}, 5^{th} and 9^{th} order polynomials fit to the observed Bouguer gravity along the Jadcharla-Vasco transect, the 5^{th} order polynomial (Fig. 2a) was found to be most representative of the expected regional and was spectrally analyzed for features of deep-seated significance.

Fig.2b consists of the power spectrum of the regional Bouguer anomaly along the transect, which shows only one dominant linear segment from which a mean depth of 37 km to the Moho is obtained. Fig.2c shows the first horizontal gradient of regional Bouguer gravity. Taking the two layer case – the crustal and upper mantle layers separated by the Moho-with assumed mean densities of 2.85 gm/cc for the entire crustal column above the Moho and 3.3 gm/cc for the mantle (Kaila & Bhatia 1981), i.e., for σ_1 and σ_2 respectively, K was obtained from equation (2). Then the control depth z_0 for each 250 km long segment considered with 80% overlap (viz., station nos. 0-250, 50-300, 100-350…etc.) was computed from the slope of the regression line (GMPAC 1999) interactively fit to the log amplitudes plotted against the wave numbers (power spectra). The depth so obtained was assigned to the mid point of the corresponding segment. Next, the depth z for every measured Bouguer gravity station of each segment was computed from the control depth z_0 and the corresponding gravity Δg_0 using equation (3), thereby obtaining an average crustal thickness down to the Moho along the transect (Fig.2d).

For the region east of station 307 (which roughly corresponds with the western margin of the Closepet batholith (Fig.1), an average crustal thickness of 37 km was obtained. Similarly, for the region west of station 198, which corresponds to the Bababudan-Nallur shear (Fig.1) and marked W in Fig.2c, the corresponding value is 39 km. These values agree well with earlier results established by Reddy et al., (2000) for the western and eastern Dharwar cratons. An average crustal thickness of 34.5 km was obtained at the Chitradurga thrust fault that falls roughly in the middle of the intervening region (stations 198-307).

From the average depths obtained for each overlapping sub-segment of the profile, the average crustal configuration for the transect as a whole was obtained. As mentioned in the previous section, the depths obtained for stations in the middle of the profile are fairly approximated, while for the extremities, the approximation is poor. However, from the section of the crustal configuration actually obtained from the first horizontal derivative (Fig.2c) of the Bouguer regional, running west to east, four major faults - F1, F2, F3 and F4 - possibly extending down to the Moho are inferred. Since data is not available west of Vasco, the position of F1 can only be estimated from the trend of the gradient and the upward inflection at the western end of the regional and is accordingly located at station 34. F2 (at station 198) corresponds to the Bababudan Nallur shear (GSI Project Vasaundhara 1994). F3 (at station 307) runs along the western margin of the Closepet batholith and F4 (at station 530) lying east of the Closepet batholith is associated with the Makthal schist.

It is evident that the regions bounded by various faults represent homogenous crustal units that may have followed different paths of geologic evolution. With a thickness of 39 km, the region bounded by fault F2 on its east (western Dharwar block, W) represents a region of crustal thickening. On the other hand, the regions bounded by faults F2 and F3 (intervening block I), and F3 and eastwards (eastern Dharwar block E) correspond to regions of crustal thinning with comparatively shallower occurrence of the Moho. Thus, the upthrust intervening block bounded by F2 and F3 separates the western and eastern blocks of the Dharwar craton.

Significantly, the results so obtained correlate well (within an error of 5%) with those obtained from modeling/inversion (Ramadass, Ramaprasada Rao & Himabindu 2003). Further, when we compare the above results with those from DSS and gravity modeling attempted by Kaila & Bhatia (1981) along the approximately E-W trending Kavali-Udipi profile further south of the Jadcharla-Vasco transect, it is seen that there is good general agreement. Though their tectonic classification is different, the crustal thicknesses obtained west to east correlate with an error of less than 5%: a down thrown western section (crustal thickness 38 km), an upthrust intervening part corresponding to the younger granites and the Chitradurga thrust (32 km) and a crustal thickness varying between 33 to 41 km for the eastern part of their profile, which includes part of, and extends further east of the eastern block of the present transect, were reported by them. However, the correlation between faults identified is somewhat less clear. While fault F1 (Fig.2c) corresponds to the west coast fault, fault F4 is not associated with the eastern ghats as they lie further east.

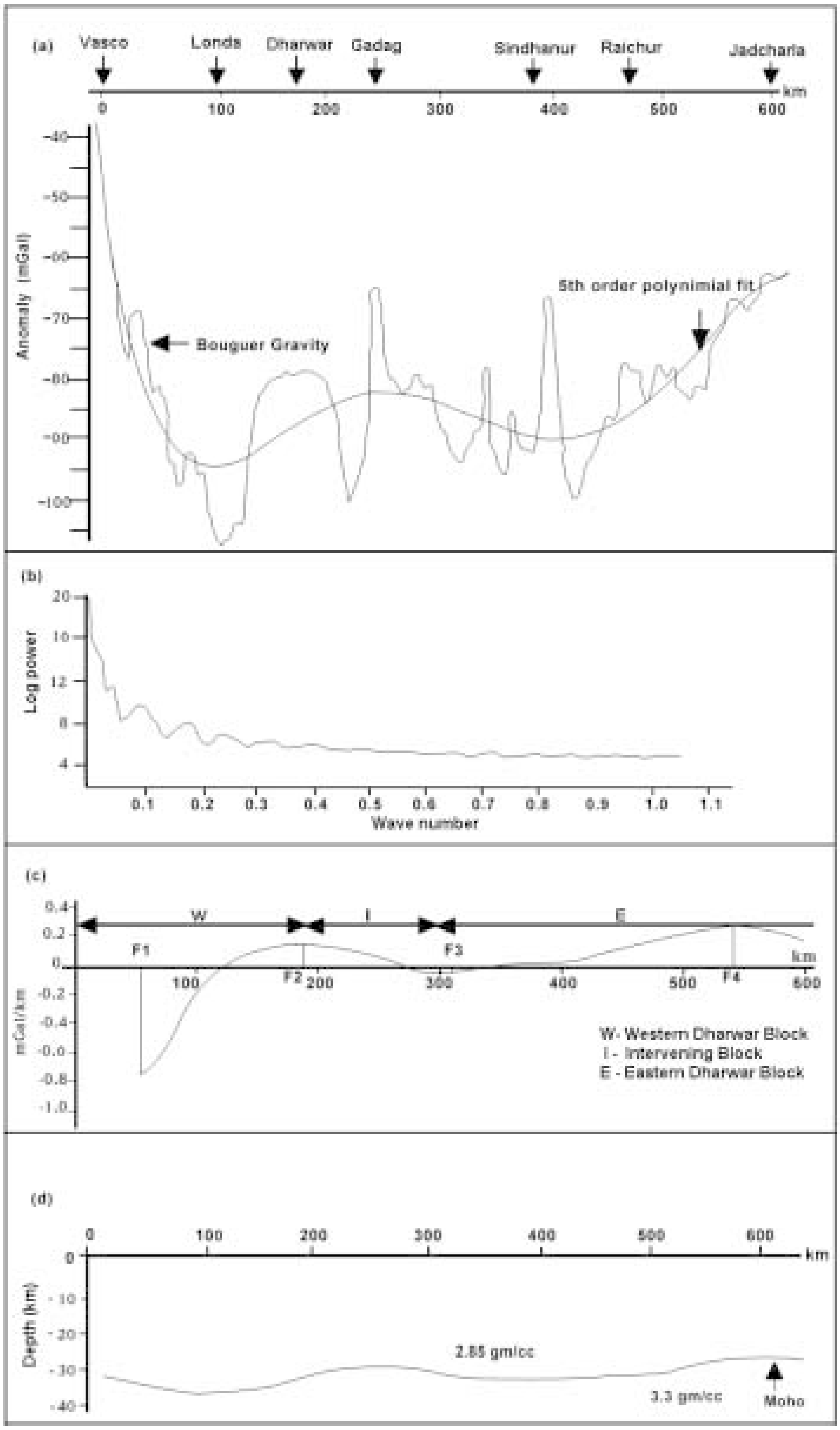

Figure 2a. Bouguer gravity and 5th order polynomial fit b) power spectrum of regional Bouguer gravity c) Horizontal gradient of regional Bouguer gravity and d) Configuration of Moho from spectral analysis (method after Sazhina and Grushinsky, 1971) along the Jadcharla-Vasco transect.

CONCLUSIONS

A method for estimating the average crustal configuration from overlapping, moving window power spectra of regional Bouguer gravity in an established relation has been described. The procedure has been applied to field data: from the successive, overlapping segmental power spectra along the entire 600 km regional Bouguer gravity (5^{th} order polynomial fit) profile of the Jadcharla-Vasco transect, the average crustal configuration was obtained. Four deep-seated faults were identified, which facilitated the tectonic classification of the Dharwar craton into the western, intervening and eastern Dharwar blocks. The average crustal thicknesses of the western and eastern blocks were found to be 39 and 37 km respectively, while a depth of 34.5 km was determined for the region below the Chitradurga thrust fault, that occurs in the middle of the intervening block that separates the two. The results obtained agree well with those established earlier by other geophysical methods.

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