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Application of the Relaxation Technique in Mapping of Crustal Discontinuities from Bouguer Anomalies over Central India

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ABSTRACT

The performance evaluation of least squares orthogonal polynomial and relaxation techniques depicts that the relaxation method provides reasonable results in separating out the regional/residual fields from the Bouguer anomalies. Applications of relaxation technique to the Bouguer anomaly map of central India and Jaipur-Raipur gravity profile have provided regional/residual anomalies of various wavelengths by changing the data spacing. The quantitative interpretation of these separated anomalies has been substantiated by the spectral analysis which reveals the presence of three density layers at depths of 34, 16.7 and 3.8 km along Jaipur-Raipur transect. The Bouguer anomaly has then been deconvolved into the gravity effects associated with the layers at these depths by means of suitable matched filters. On comparison, the relaxation regional with 5 km data spacing is found to match well with the deconvolved gravity effect of the Moho interface. Thus, the relaxation regionals obtained with spacing of 10 km and more can be attributed to still deeper sources than Moho, i.e., in the upper mantle. Three dimensional Moho configurations have been computed from the relaxation regional with 5 km spacing and matched filter anomaly corresponding to Moho by the Tsuboi's inversion scheme. These Moho maps, having matched fairly with DSS results, have offered good perspective in visualising the tectonic scenario of the Narmada rift zone and contiguous structures.

INTRODUCTION

Gravity anomalies, despite the inherent ambiguity in interpretation, can be adapted in determining the crustal structure of the earth because of their one to one correspondence with the density of the subsurface geological formations. However, observed gravity anomaly is a cumulative effect of all the density inhomogeneities occurring at various depth horizons within the interior of the earth. Therefore, the Bouguer anomaly has to be separated properly into its constituent parts by a suitable analytical approach. Amongst the existing analytical techniques, least squares orthogonal polynomial (Oldham and Sutherland, 1955) and relaxation (Paul,1967) techniques have been considered here. The least squares orthogonal polynomial technique involves approximating the regional anomalies due to deep seated sources as a polynomial of the optimum order inherently present in the data. This method was found advantageous over the conventional least squares techniques for providing the most optimum order of polynomial and its ease in the computation. However, the regional/residuals obtained by these methods are always associated with some spurious anomalies which may result in a wrong interpretation. Paul (1967) has suggested the relaxation technique which assumes a linear trend between any two consecutive grid points and hence the wavelength of the regional anomaly can be varied by altering the data spacing. After evaluating the performances of least square orthogonal polynomial (Oldham and Sutherland, 1955) and relaxation techniques on several synthetic and field examples, Agarwal and Sivaji (1992) have advocated adaption of the relaxation method for regional/residual separation. The regional/residuals of various wavelengths obtained from relaxation techniques, however, cannot be interpreted quantitatively in the absence of any information on depth to the anomalous masses. At this stage the spectral analysis appears to be the appropriate tool to yield some constraints on depth to the mass inhomogeneities.

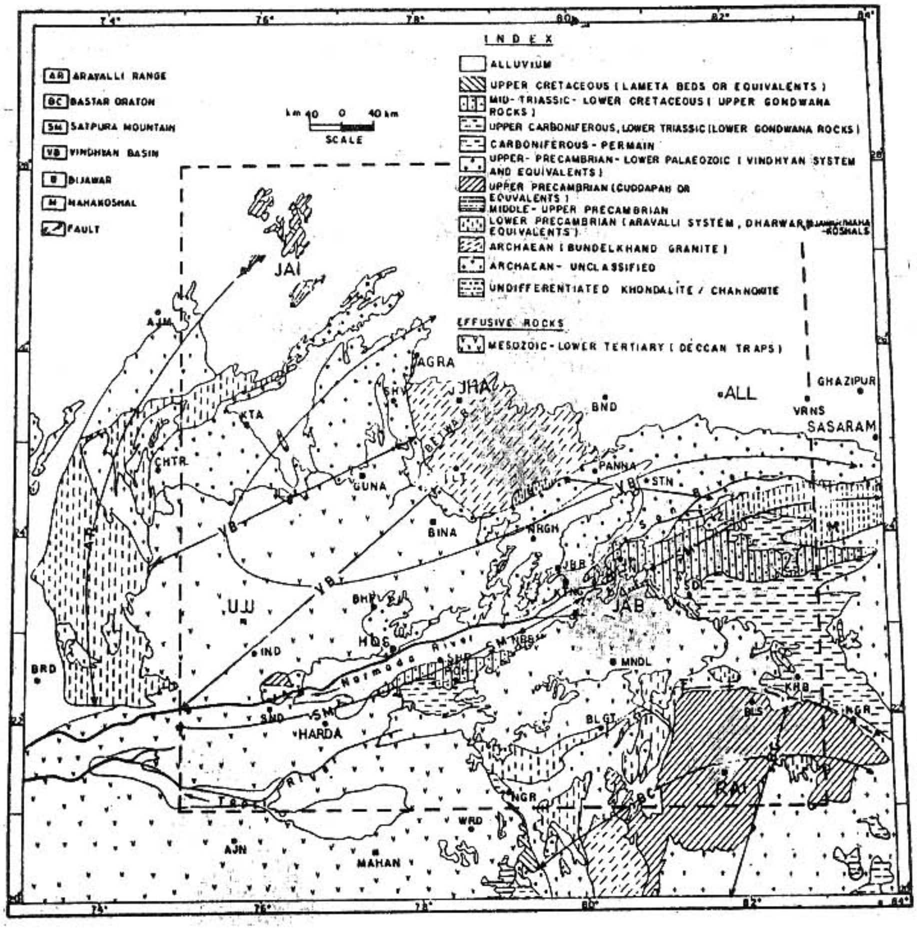
The present study consists of two stages. The first stage involves computing the regional anomalies of different wavelengths by relaxation technique and attributing them to density variations occurring at various depth levels obtained from spectral analysis and matched filtering techniques (Spector and Grant, 1970; Syberg,1972; and Spector 1975). Secondly, the deconvolved gravity effects from relaxation and matched filtering techniques are subjected to single density interface gravimetric inversion scheme of Tomoda and Aki (1955) for determining three dimensional depth configurations for Moho and Conrad discontinuities and inferring major structural trends beneath the central Indian region.

The study on the performance evaluation of the relaxation and the least squares orthogonal polynomial techniques does favour the superiority of the former over the latter (Agarwal and Sivaji, 1992). The study also suggests the stability of the relaxation method in yielding improved regional/residuals over a major central portion of the profile, even though different sets of residuals - a primary prerequisite for relaxation technique - at the ends of the profile are used. However, the relaxation regional/residuals being sensitive to the changes in the data spacing, warrants the study of the effect of data spacing on the results. For this purpose, the authors have examined the effect of change in data spacing by analysing numerous models and field exmples (Sivaji, 1992). This study has demonstrated that the anomalies due to density inhomogeneities occurring at various depth levels can be resolved individually from observed gravity field by choosing an optimum data spacing while analysing with relaxation technique. This observation has provided a new perspective in understanding the relationship between data spacing and the depth of the causative sources. An attempt has been made here to adapt the relaxation technique to resolve the Bouguer anomaly map of central India and along the Jaipur-Raipur transect.

JAIPUR TO RAIPUR TRANSECT OF CENTRAL INDIA

The region bounded by 21°-28°N latitudes and 75°-83°E longitudes (shown as dashed boundary in Fig.1) has been considered for this study.

The central Indian region consists of various geological units whose structure and lithological composition are distinct from each other. The northern part of the map is occupied by the Indo-Gangetic plains characterized by recent alluvial deposits. Though its surfacial expression seems to be uniform, the Gangetic plains consist of concealed subsurface lithological units, ridges and faults of diversified character (Rao,1973). On the southern edge of the Ganga basin, a huge Archean granitic body, called Bundelkhand granite massif is engulfed by an oval shaped Proterozoic Vindhyan basin. The southern fringe of the Bundelkhand granite is occupied by a small patch of exposures of Bijawar rocks of volcanic origin. The NE and SW extensions of Vindhyans are veiled by the alluvials of the Ganga basin (Narain and Kaila, 1982). The Vindhyan basin is limited by the Great Boundary Fault in the NW and an ENE-WSW striking Narmada-Son Lineament in the south. This lineament has been viewed as a major zone of weakness which demarcates the Vindhyan in the north and the Gondwanas in the south (West, 1962;Choubey,1971). The SW part of the map is occupied by a vast tract of Deccan basalts. The southern part of the map, represented by the Satpura orogenic belt and the Chhattishgarh basin around Raipur area, is covered by Upper Precambrian rocks of Cuddapah Formations.



Fig, 1 Simplified geological map of Central India. The dashed boundary represents the study region.

ANALYSIS OF THE PROFILE FROM JAIPUR TO RAIPUR

The gravity data compiled by the National Geophysical Research Institute has been replotted and contoured with an interval of 5 mGal on 1:1,000,000 scale. The Bouguer anomaly map (Fig.2) is now convenient for digitization with 5 km grid spacing. The analysis has first been attempted along the profile from Jaipur to Raipur and later extended over the entire central Indian region for understanding three dimensional extensions of major structural features.

The following are the names of various stations marked on some of the Figures as abbreviated form in this paper.

AGR-Agra; AJM-Ajmer; ALL-Allahabad; B'AW-Bawanbir; BET-Betul; BHE-Bherughat; BHO-Bhopal; BIJ-Bijawar; BIN-Bina; BLGT-Balaghat;BND-Banda; BRD-Baroda; CHA-Chattarpur;CHP-Chipaner; CHH-Chhindwara; CHI-Chicholi; DAM-Damoh; DAR-Darwa; DAT-Datia; FAI-Faizabad; GAN-Gangpur; GWA-Gwalior; HAR-Harda; HAT-Hathras; HIR-Hirapur; HOS-Hoshangabad; IND-Indore; JAB-Jabalpur; JAI-Jaipur; JBR-Jabera; JHA-Jhansi; KAT-Katni; KHA-Khandwa; KHJ-Khajuriakalān; KRB-Korba; KTNG-Katangi;MAN-Mandla; MAS-Masod; MAT-Mathura; MUL-Multai; NEP-Nepanagar; NRGH-Narsingarh; NRS-Narsingpur; PCH-Pachimarhi; RAH-Rahatgoan; RAJ-Rajgarh; RAI-Raipur; RAT-Ratlam;REW-Rewa; SAT-Satna; SEH-Sehore; SEO-Seoni; SID-Sidhi; SND-Sanwed; SNR-Sanwer; TIM-Timurni; UJJ-Ujjain; VAR-Varud.

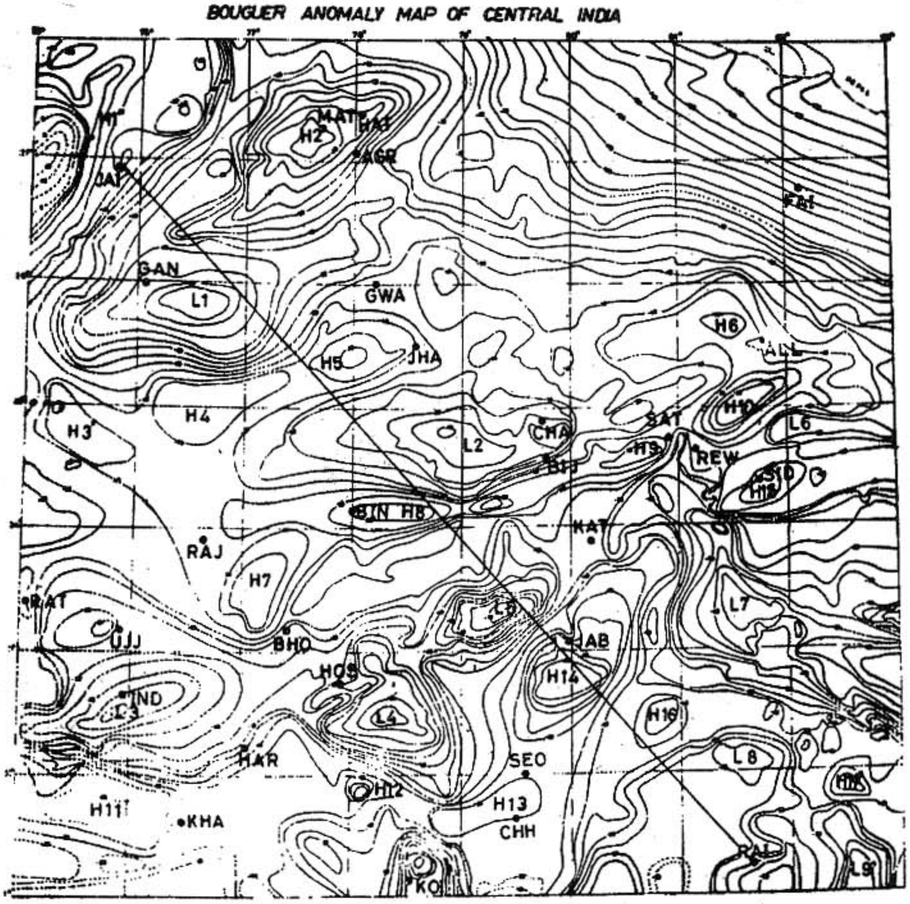


Fig. 2 Bouguer anomaly map of Central India with a contour interval 5 mGal (based on NGRI gravity data).

The gravity anomaly profile along Jaipur to Raipur transect has been subjected to the relaxation technique with data spacings of 5 (Fig.3a), 10 (Fig.3b), 15 (Fig,3c) and 20 km (Fig.3d) in order to estimate the contribution of long wavelength anomalies. It is observed from Figure 3 that the regional anomaly becomes flatter and flatter with increase in data spacing. The width of the residual anomaly becomes wider attaining progressively large magnitudes. These regional/residual anomalies of various wavelengths cannot be interpreted quantitatively unless there are certain constraints on the depth of the causative sources. Spectral analysis might be a suitable approach to determine the depths of the horizontally stratified layers.

The spectral depth estimation approach is based on the fact that the logarithm of spectral energy can be divided into several frequency bands within which the decay of the spectral energy assumes a linear trend. The low frequency part of the computed spectrum of the gravity anomaly along Jaipur-Raipur profile (Fig.4a) appears to oscillate in the form of narrow peaks which resemble the Sinc function due to finite width of the causative sources. Due to

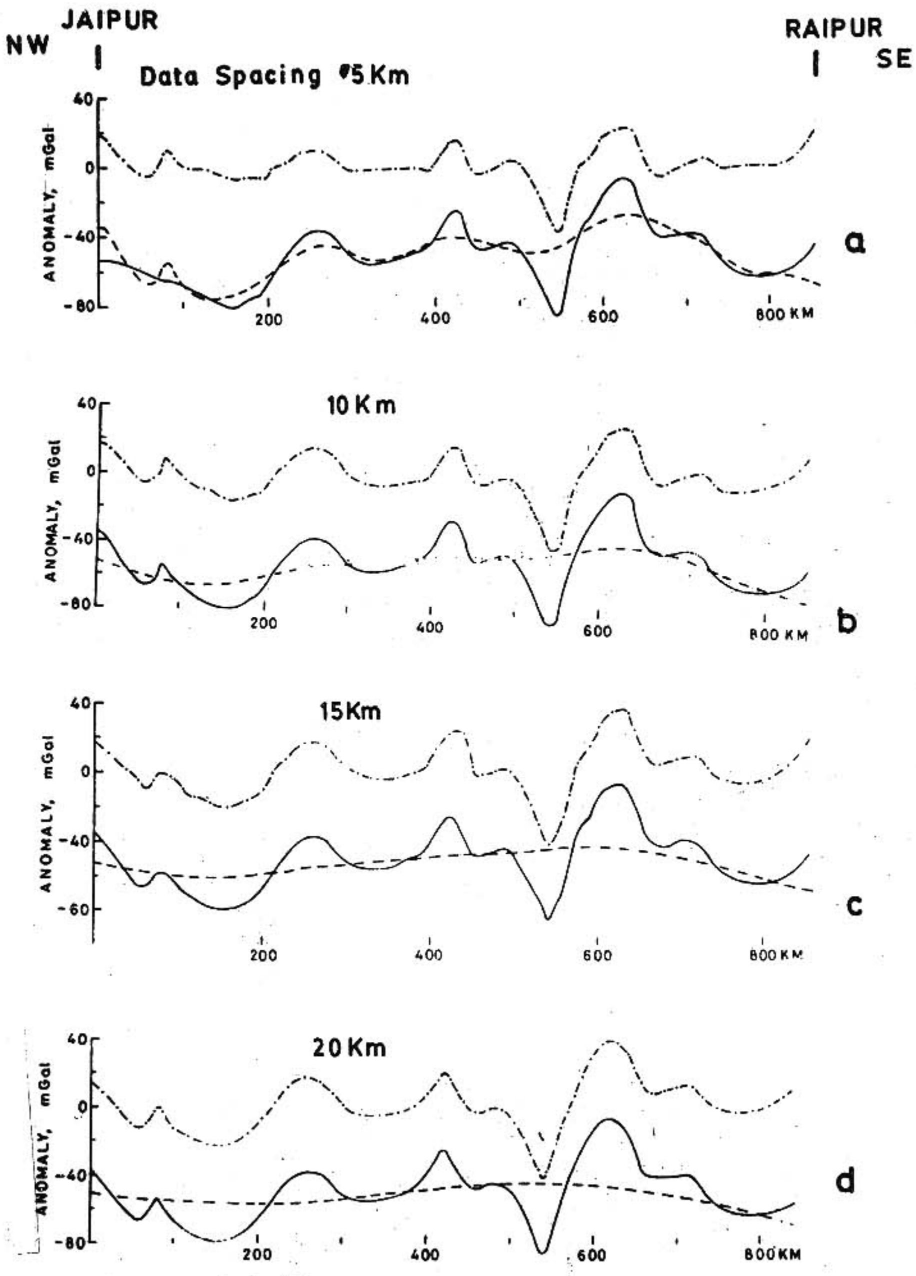


Fig. 3 Bouguer anomaly profile from Jaipur to Raipur alongwith the relaxation regio-nal and residual anomalies computed with data spacing of (a) 5; (b) 10; (c) 15; and (d) 20 km.

large scatter of the energy density values of this part, all the peaks are joined to obtain a linear segment and to identify the sharp boundary between I, II and III segments counted from left side of the figure. However, the last two may be equivalent to least squares fit. The computed energy density spectrum (Fig.4a) along the Jaipur-Raipur transect reveals that there are three layers at depths of 34, 16.4 and 3.8 km corresponding to the Moho, the Conrad (a boundary between upper and lower crust) and the basement respectively. Making use of these depths and the intercepts of the straight line segments of the spectrum, a suitable matched filter (Chakravorty and Agarwal, 1992) has been developed to deconvolve the gravity effects due to the undulations in the density layers at these depth horizons. It is observed that the sum of all these deconvolved gravity effects (Fig.4b) equals the observed Bouguer anomaly which in turn shows that there is no loss of any frequency components during the filtering. A comparative study of the gravity effects (Fig.4b) obtained from matched filtering and the relaxation regionals com-

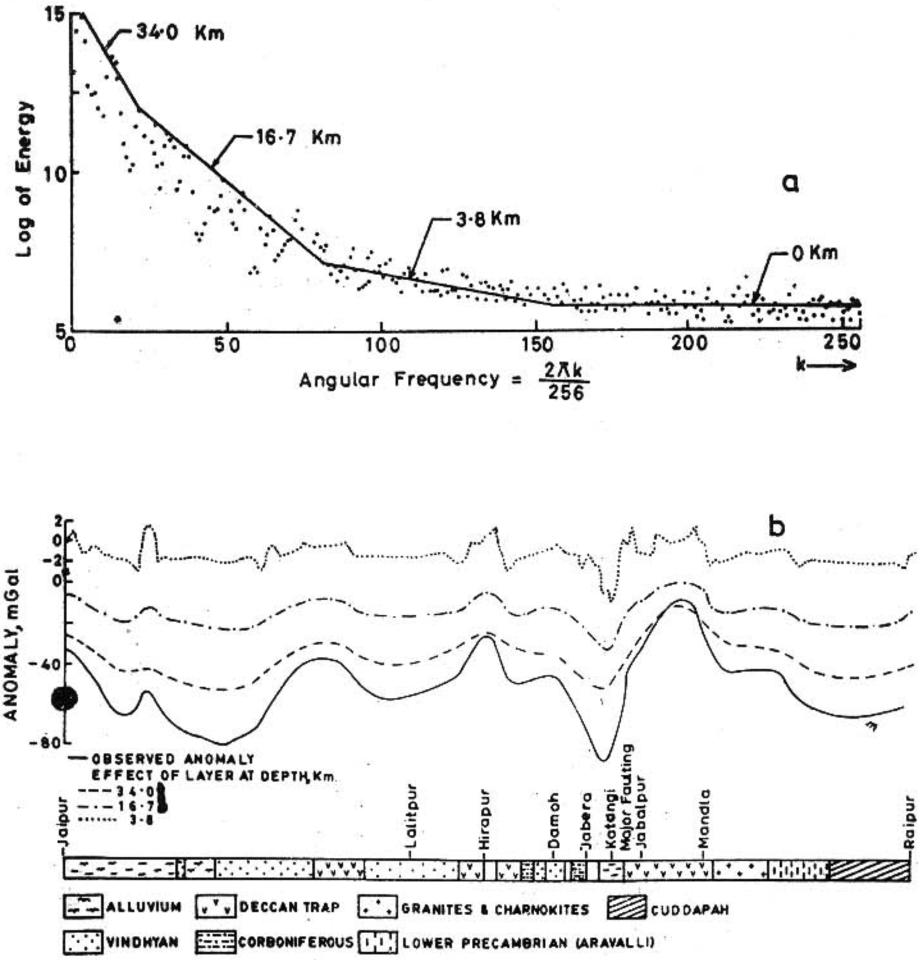


Fig. 4 (a) The plot of logarithm of energy of gravity field versus angular frequency for a gravity anomaly profile along Jaipur to Raipur. The values on the linear segments are the ensemble average depths to the sources; (b) deconvolved gravity effects associated with each of the linear segments alongwith the observed gravity profile

puted with different data spacings, reveals that the regional anomaly with 5 km (Fig.3a) spacing closely resembles the gravity effect of layer at 34 km. Thus, it may be visualised that the relaxation regional with 5 km data spacing corresponds to the sources at the same depth level. It seems reasonable to attribute the relaxation regional anomalies with 10,15 and 20 km spacings to the density variations occurring at still deeper levels than Moho, i.e., in the upper mantle regions. It is interesting to note that the relaxation regional exhibits broad wavelengths while the matched filter anomaly (34 km) may include marginally the effects of the shallow features. Further, it may be visualised that the relaxation technique is capable of yielding regional anomalies of longer wavelengths than the spectrum because the latter cannot resolve the long wavelength anomalies near the zero frequency even with the decrease in the data spacing.

ANALYSIS OF THE BOUGUER ANOMALY MAP

The Bouguer anomaly map (Fig.2) displays a complex contour pattern consisting of wide range of wavelengths which has to be resolved into its constituent parts. The gravity data digitized at 5 km grid interval has been subjected to relaxation techniques by supplying the boundary values of residuals obtained from least squares orthogonal polynomial method. The data with 10 km spacing has then been analysed for elucidating the effect of data spacing as in the case of profile data.

QUALITATIVE APPRAISAL OF RESIDUAL ANOMALY

The residual anomaly maps obtained for 5 and 10 km data spacings reflecting surface geology resemble each other except a comparatively higher magnitude for 10 km interval. The relaxation residual with 10 km spacing is presented in Figure 5. The residual anomaly depicts the presence of several subsurface structures. The gravity high (H1) of +10 mGal over Gangetic alluvium can be explained in terms of basement ridge (Narain and Kaila, 1982) below Mathura-Hathras-Agra zone. The low (L1) corresponds to the Vindhyan sediments deposited in a narrow basin between Bundelkhand granite massif (L2) and the foot of the Jaipur horst in the northwest. A prominent chain of highs (H2,H3) may be due to the underlying greenstone belt beneath the Gangetic alluvium (Valdiya, 1982). The high (H4) can be explained in terms of elevated basement ridge at Faizabad (Agarwal, 1973; Narain and Kaila, 1982).

The residual low (L2) can be explained as short wavelength part of the Bundelkhand granite low. A narrow anomaly south of low (L2) is a linear gravity high (H5-H6-H7) which depicts the underlying Bijawar rocks (Qureshy and Warsi, 1975).

Another chain of residual lows (L3,L4,L5 and L6) can be inter-

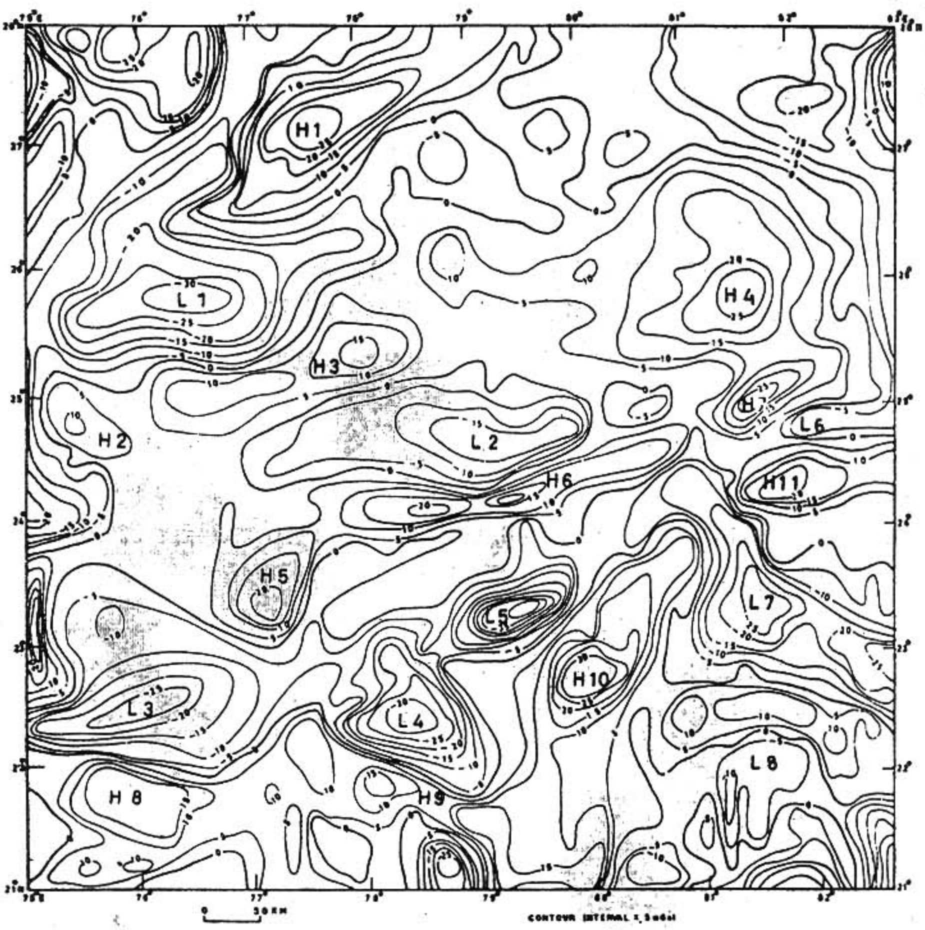


Fig. 5 Residual anomaly map of central India corresponding to Figure 2 obtained by relaxation technique for a grid spacing of 10 km by using a 6th order polynomial residuals along the boundary of the map.

preted as a narrow sedimentary infilling along the Narmada-Son rift valley. The -30 mGal anomaly (L4 and L5) is associated with the thick pile of Vindhyan sediments deposited in the deepest part of the basin (Kailasam, 1976). A localised high (H11) between two lows L6 and L7 is situated over a high density Mahakoshal/Bijawar volcanics around Sidhi area. The low (L7) corresponds to the Mahanadi sediments in Gondwana basin. The gravity highs (H8, H9 and H10) fall over the exposed Deccan Traps along the southern margin of the Narmada-Son rift zone.

INTERPRETATION OF THE REGIONAL ANOMALY

The regional anomalies obtained by relaxation technique with 5 and 10 km spacings (Figs.6 & 7) exhibit broadly the same features. The 10 km regional anomaly contains more long wavelenth anomalies than the 5 km one. The regional anomaly map (Fig.6) exhibits broad regional trends which can be correlated with the mega structures of the central Indian region. The Indo-Gangetic Plains, represented by a WNW-ESE trending large amplitude regional anomaly, appears to be a deep seated regional feature. The increase in the magnitude of the anomaly towards north suggests that the thickness of the crust beneath the Ganga basin increases northwards.

The regional closures of -40 mGal over Mathura-Hathras-Agra (H1) and south of Faizabad (H2) (Fig.6) reveal that the deep platforms are relatively uparched under these regions. The -70 mGal anomaly (L1), south of a high (H1) may be due to a synclinal feature of the Vindhyan basin. The -60 mGal (L2) observed over Bundelkhand granite suggests that the batholith might extend to lower crustal levels. The region south of Bundelkhand granite low and north of lows L3 and L4, is a relatively high region. The lows L3 and L4 of magnitude -60 mGal point to the Narmada rift zone as a very deep-seated feature extending upto the crust-mantle boundary. The highs

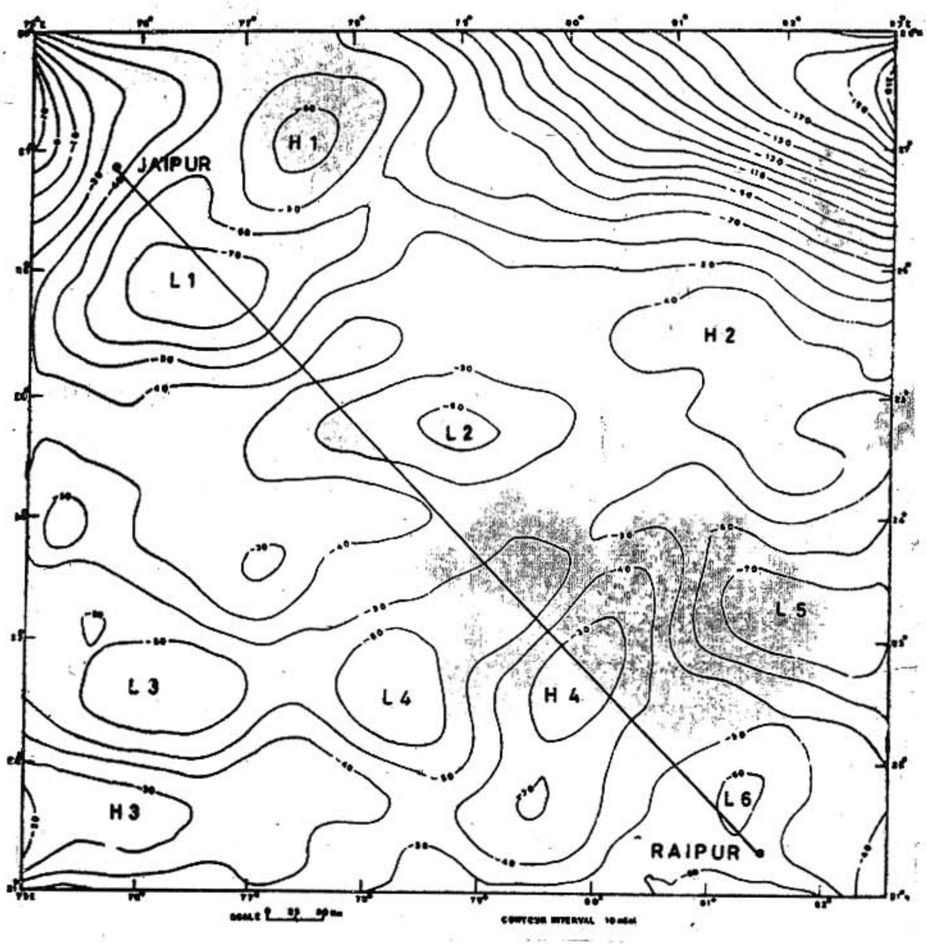


Fig. 6 Regional anomaly map of central India corresponding to Figure 2 obtained by relaxation technique for a grid spacing of 5 km.

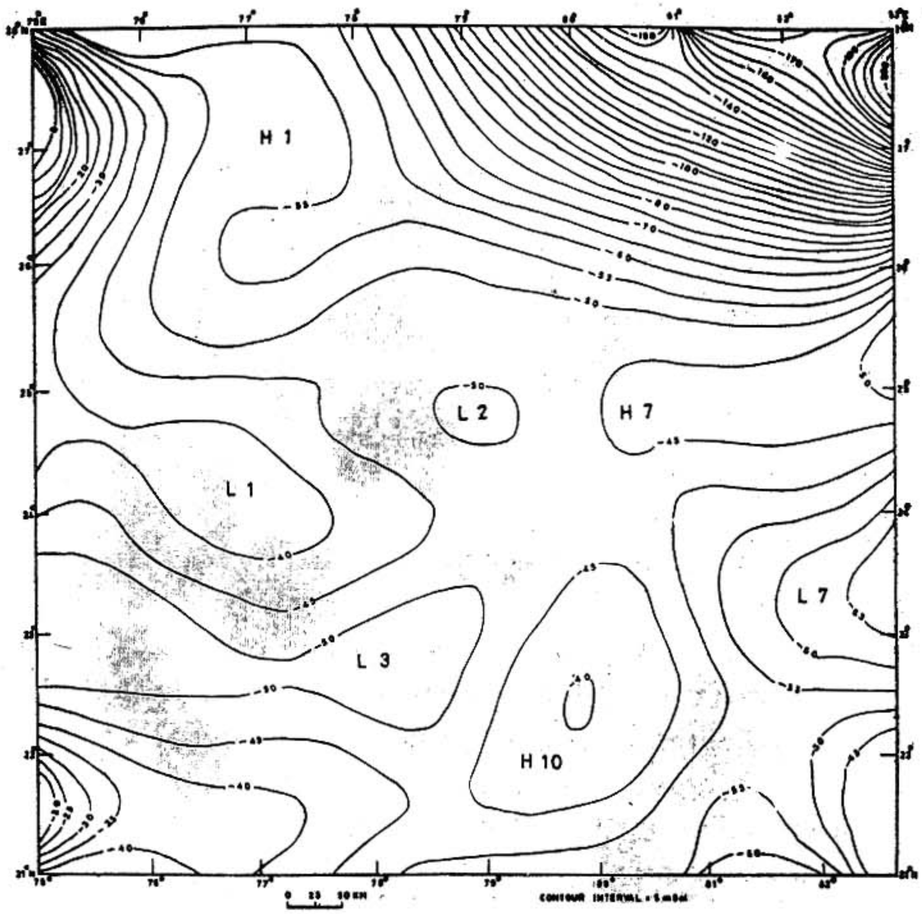


Fig. 7 Regional anomaly of central India corresponding to Figure 2 obtained by relaxation technique for a grid spacing of 10 km by using a 6-th order polynomial residuals along the boundry of the map.

H3 and H4 represent the Satpura horst at the deep levels of the crust. The broad low (L6) is represented by Chhattisgarh depression. The regional anomaly map (Fig.7) can be attributed to the comparatively deeper sources than that of the 5 km one. The quantitative appraisal of this map will be furnished in the follwing sections.

Though the long wavelength anomalies are very useful in delineating deeper structures, their attribution to any particular depth is not possible without any constraints on depth of the sources, from independent geophysical data. At this juncture, the spectral analysis (Spector and Grant, 1970; Syberg, 1972; Spector; 1975) can provide some useful constraints on depth to the inhomogeneities as observed in the case of Jaipur-Raipur transect. The radial energy spectrum (Fig.8) has been computed for the entire central Indian region which shows four prominent frequency bands over which the decay of spectral energy is linear. The calculated depth of 37.8 km associated with the first segment corresponds to the crust-mantle boundary; the 19.4 km to the boundary between upper and lower

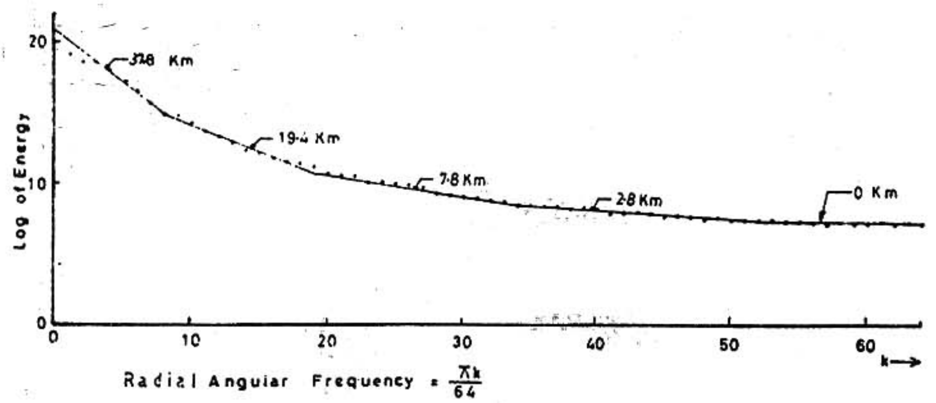


Fig. 8 Plot of logarithm of energy of the observed gravity field (Fig. 2) versus radial angular frequency. The values on the linear segments represent depths to various density inhomogeneities beneath central India.

crustal layers (or Conrad discontinuity) and the depths 7.8 and 2.8 km to the density inhomogeneities occurring within the upper crust. The Bouguer anomaly has been deconvolved into various constituent parts by applying suitable matched filters (Chakravorty and Agarwal, 1992) designed from depths and intercepts of the straight line segments of the spectrum (Fig.8). These deconvolved components corresponding to the depths 7.8 and 2.8 km exhibit large fluctuations

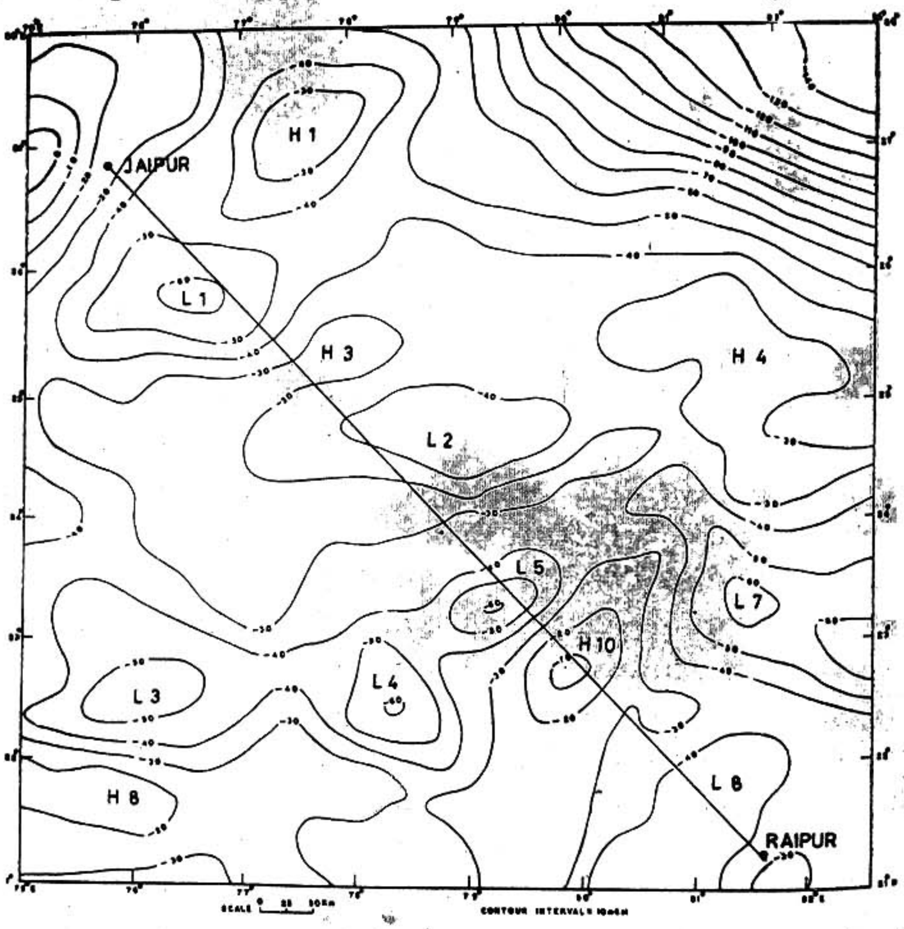


Fig. 9 Long wavelength gravity anomaly representing deconvolved gravity effect due to undulations in the interface at 37.8 km by matched filtering technique.

representing the random density distribution in the upper crust (Sivaji, 1992). This may be attributed to the fact that the assumption of horizontally stratified layer having uniform density does not hold good in the topmost part of the crust because of the presence of lateral density inhomogenities in the geological formations. The effects of layers at 19.4 and 37.8 km, however, represent the anomalies due to the undulations in the Conrad and Moho interfaces.

A comparative study of the regionals obtained by relaxation technique with 5 (Fig.6) and 10 km (Fig.7) grid spacings with the deconvolved gravity effect due to Moho interface (Fig.9) obtained from matched filter reveals that there is a good resemblance between the relaxation regional with 5 km and the effect of layer at 37.8 km (Fig.9) as observed earlier for the Jaipur to Raipur profile. Thus, it may be seen that the regionals obtained by relaxation technique, for a profile data with 10,15,20 km (Fig.3) and 10 km for two dimensional data (Fig.7) can be attributed to sources at depths greater than Moho depth.

MOHO DEPTH CONFIGURATIONS

The Moho depth configurations (Figs.10 & 11) over the central Indian region have been obtained from the single density interface gravimetric inversion (Tomoda and Aki, 1955) of matched filter anomaly (Fig.9) due to the 37.8 km computed from the spectrum. This average depth of Moho is quite consistent with (1) a depth of 38.7 km obtained from the study of earthquake data in central India (Bhattacharjee, 1989), (2) 37-42 km from Deep Seismic Studies across the Narmada-Son lineament (Kaila, 1988) and (3) a crustal thickness of 40 km over the central Indian region from gravity studies (Qureshy, 1970).

The Moho configurations (Figs.10 & 11) over central India reveal that this interface is undulating considerably with many prominent up- and down-warps. The sharp gradients in the Moho depths exhibited by matched filter Moho (Fig.10) may be due to the inclusion of the high frequency components in the effect of layer at 37.8 km. However, the Moho obtained by relaxation regional (Fig.11) exhibits reasonable variations with broad undulations. The depth to the Moho boundary over the Indo-Gangetic Plains increases from 38-46 km in the NE direction due to a dipping crust-mantle boundary. These values are in good agreement with 43 km of Moho depth

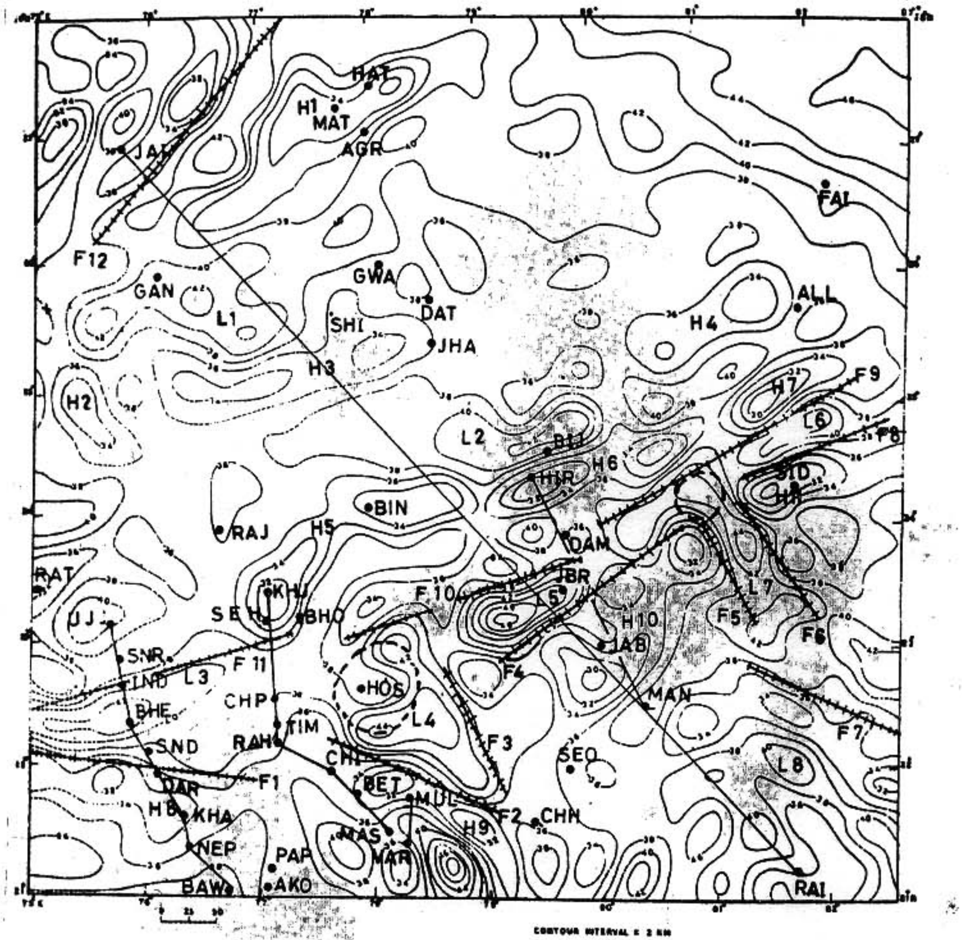


Fig. 10 Three dimensional Moho configuration obtained from gravimetric inversion of the long wavelength anomaly (Fig. 9). The crossed lines and the dashed circles represent major deep seated faults and triple junctions inferred from the present study respectively. The lines connecting different stations are DSS profiles after Kaila (1988).

obtained from Love wave dispersion studies (Chattarjee, 1971). Similar values have also been reported by Tandon and Chowdhary (1964) and Gabriel and Kuo (1966) from both Rayleigh and Love waves dispersion data. Qureshy (1970), on the other hand, has indicated 36 km of Moho beneath the Indo-Gangetic basin which seems to be somewhat on the lower side when compared with the seismological studies.

An arcuate zone of Moho downwarp (40 km) engulfs the Mathura-Hathras-Agra ridge structure showing a domal uplift (34 km) and merges into the Indo-Gangetic depression (Figs.10,11). This downwarp L1 is embedded between the Great Boundary Fault (F12) in the NW and Bundelkhand granite massif in the SE directions. This zone, representing the Aravalli foredeep, could be related to orogenic movements.

A domal upwarp (H1) in Moho interface over Mathura-Hathras-Agra region and a line of highs, H2 to H4, have been delineated by the

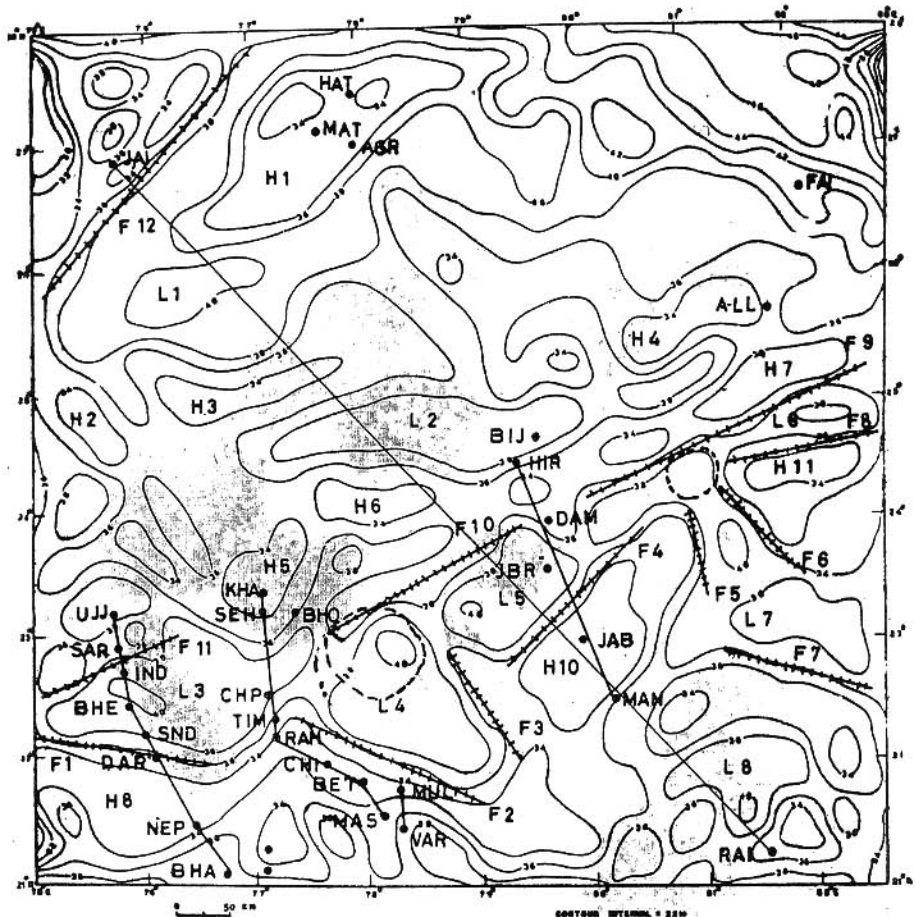


Fig. 11 Three dimensional Moho configuration obtained from gravimetric inversion of the relaxation regional anomaly (Fig. 6). The crossed lines and the dashed circles represent major deep seated faults and triple junctions inferred from the present study respectively. The lines connecting different stations are DSS profiles after Kaila (1988).

present analysis (Figs.10 & 11). The line of these highs can be interpreted as the southern edge of the Indo-Gangetic depression from where the first bending of the lithosphere might have started. This can be correlated with the first flexural node inferred from the flexural models of the Himalayan mountain (Kerner and Watts, 1983). This uparching in Moho suggests that the Indian shield was subjected to severe crustal folding due to compressive pressures generated during the collision of India with Eurasia. The region of Bundelkhand granite (L2) shows a relatively high crustal thickness (38-42 km). The Airy-Heiskanian isostatic anomaly of -30 mGal over the Bundelkhand granite massif (Narain, 1975) implies that the root formation in the crust may be slightly more than actually assumed in computation of isostatic anomaly. Hence, the computed crustal thickness of 42 km matches well with the nature of the compensation over the region of the Bundelkhand granite. It may be argued that due to large thickness of the granitic massif, the lower crust might have sagged down causing downwarp in the upper mantle. South of Bundelkhand granite, a linear trend of Moho upwarp (H5, H6 and H7) passes through

Satna and westward upto Bina and bifurcates into two separate zones, the one passing northwestward through Rajgarh and merges with Aravalli horst structure, while the other trends towards Ratlam.

NARMADA-SON LINEAMENT : A CONTINENTAL RIFT ZONE

The present line of Narmada-Son rivers follows the river course, along narrow gravity low (Qureshy, 1981; Valdiya, 1984) corresponding to a depressed basin (Fig.2) The Bouguer anomaly highs on southern and northern boundaries of this line represent the shoulders of the rift basin. The Moho configuration along Narmada-Son line shows that the zone is highly disturbed by intense crustal movements. The inferred fault pairs (F1,F11), (F2, F3), (F4, F10), (F5, F6) and (F8, F9) represent the inward dipping funnel shaped normal faults as observed in Red Sea area (Bhattacharji and Koide, 1978). The region bounded by these faults corresponds to the area of subsidence forming a central trough of the rift valley. The faults F9, F10 and F11 exhibit southward dip and the faults F1, F4 and F8 dip northward towards the central rift valley.

These southern and northern faults might have acted as fissure zones through which molten magma has erupted and emplaced on either side of the rift zone. Magmatic eruptions were not probably equally distributed on either side of the rift. The emplacement of basaltic flows on the southern margin is more conspicuous than in the north. The magnitude of the gravity highs (Fig.2) observed over Jabalpur-Mandla region is attributed to the large thickness of basalt. The northern highs H5 to H7 (Fig.2), observed over the low density Vindhyan sediments, are interpreted as being due to the underlying Bijawar (Qureshy and Warsi, 1975). The Bijawar being composed of volcanic material could have solidified within the upper crustal layers before erupting fully on to the surface. The northern faults were not so active in triggering eruption of mantle material and their emplacement at the surface. Hence, they are not conspicuously seen on surface (Valdiya, 1984). Pal and Bhimasankaram (1976) have observed that the lavas on either side of the rift zone belong to different eruptive cycles.

Further, a zone of southern faults F1 to F7 flanked by gravity high represents a major deep-seated fault which is often referred to as the Narmada-Son Lineament (NSL) in literature. This lineament is considered as major zone of weakness which divides the Indian continent into northern Vindhyan and the southern Gondwana basins (West, 1962; Choubey, 1971; Kaila, 1988). Further N-S lineament is not a continuous feature (Jain *et al.* 1984) and its trend is abruptly truncated by two transverse trends associated with two sets of faults (F2, F3) and (F5, F6). These two transverse fault zones representing the NW extension of Godavari and the Mahanadi rifts, are probably related to the formation of the NSL. These transverse trends represent the Y-shaped triple junctions which are generally associated with rift valley tectonics (Valdiya, 1984). These triple junctions are identified by dashed circles on the Moho maps (Figs.10 & 11) and are similar to other continental rift zones like Anajan, Pali and Yala rift zones in Africa (Burke and Dewey, 1973).

For the sake of comparison, the Moho depths obtained from the present study and those from the Deep Seismic Studies conducted by the National Geophysical Research Institute (Kaila, 1986, 1988) across the Narmada-Son lineament are presented in Table I. A study of this

TABLE I Comparison of Moho depths obtained from present study with those from DSS studies (Kaila, 1986 & 1988)

	Moho depths in km by		
DSS stations	DSS	Matched Filter	Relaxation
Sanwer	36	36	37
Indore	37	39	39
Bherughat	39	42	40
Sanwad	39	38	39
Nepanagar	41	36	34
Bhawanbir	38	38	37
Papatkheda	40	36	34
Akot	40	40	40
Sehore	35	32	34
Chhipenar	39	38	38
Timuri	40	36	36
Rahatgoan	39	36	34
Chicholi	37	34	34
Betul	37	34	34
Multai	34	34	34
Damoh	40	37	36
Jabalpur	40	36	34
Jabera	42	43	40

table reveals that the Moho depths obtained from the present study are in good agreement with those from DSS studies within a range of 1 to 3 km. The comparison over the entire region of study, however, could not be attempted due to lack of adequate DSS coverage.

CONRAD DEPTH CONFIGURATION

The spectral method of depth estimation has revealed an average depth of 19.4 km, corresponding to Conrad discontinuity, which is in good agreement with 20.4 km obtained from the study of earthquake data (Bhattacharjee, 1989). The gravity effect (not shown) due to the undulations along this layer has been inverted by the method of Tomoda and Aki (1955) with a density contrast of 0.23 gm/cc between upper and lower crustal layers. The resulting Conrad discontinuity map (Fig.12) shows considerable undulations with depth varying from 14 km in the upwarped regions to 24 km in the depressions like Narmada-Son rift zone and Indo-Gangetic plains.

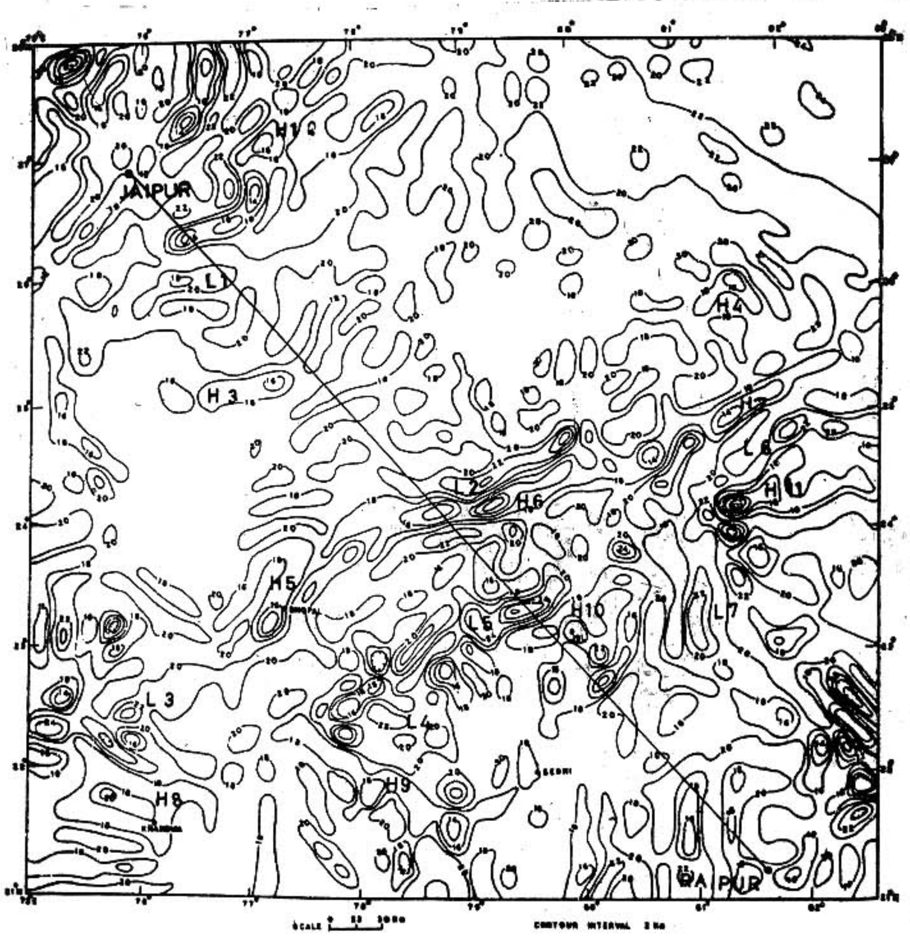


Fig. 12 Three dimensional configuration for Conrad discontinuity obtained from gravimetric inversion of the medium wavelength anomaly.

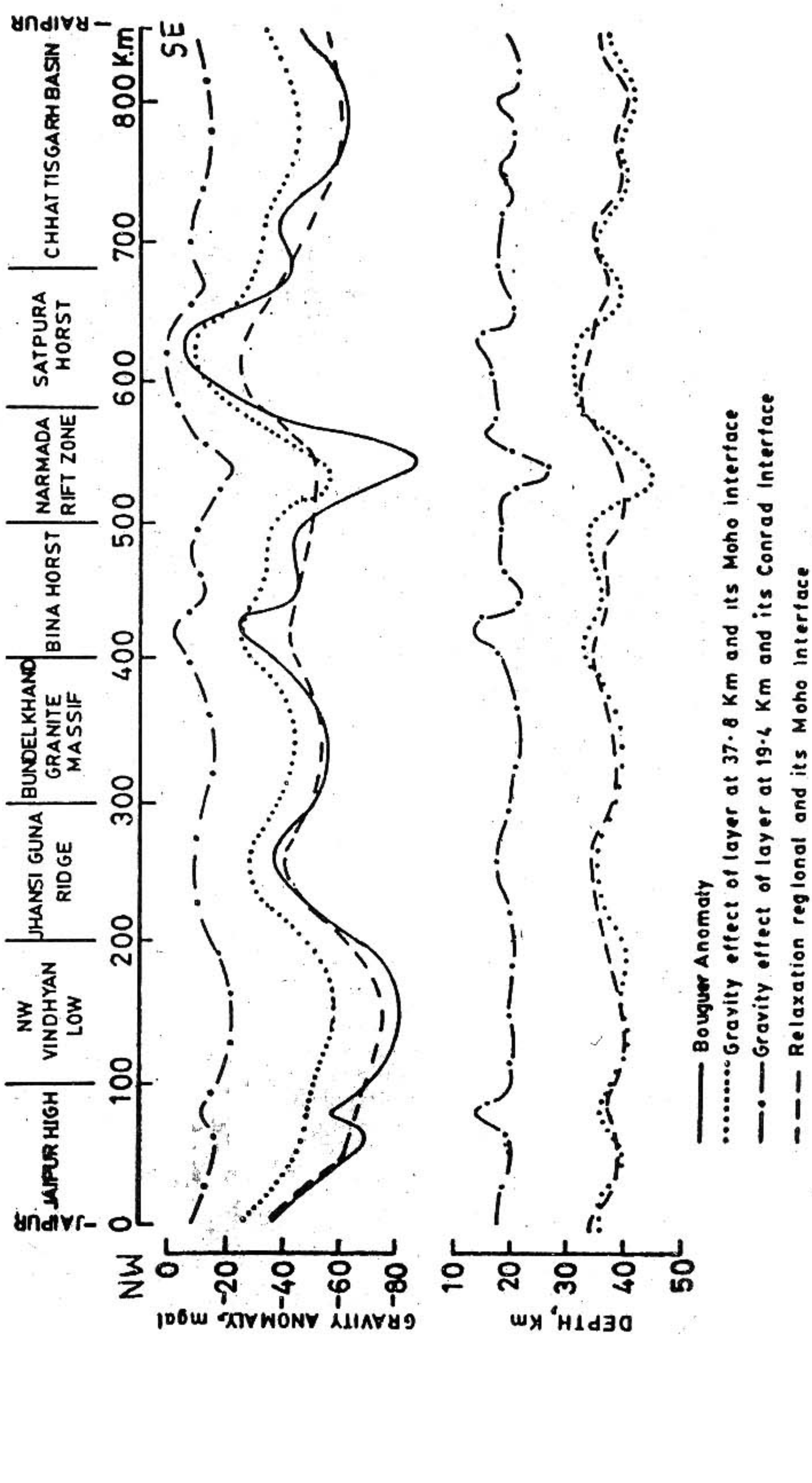


Fig. 13 Crustal depth cross section along a gravity profile from Jaipur to Raipur.

CRUSTAL STRUCTURE ALONG THE JAIPUR-RAIPUR TRANSECT

In order to elucidate the crustal structure along the Jaipur - Raipur transect, gravity anomalies and crustal depths have been digitized from their respective maps (Sivaji, 1992). For the sake of convenience in interpretation, the entire profile (Fig.13) has been divided into several tectonic blocks. The Narmada-Son rift zone has been represented by central rift valley flanked on either side by shoulder upwarps which are identified as the Bina and Satpura horsts to the north and south respectively. These shoulders represent a part of the broad domal upwarp which developed prior to rifting (Bhattacharya and Koide, 1978). The southern shoulder of the rift appears prominent in the entire tectonic scenario of the Narmada rift zone.

MASS INHOMOGENEITIES IN THE UPPER MANTLE

The long wavelength regional anomaly map (Fig.7) obtained from relaxation technique with 10 km spacing can be considered to exhibit density variations occurring in the upper mantle region. Such density variations in the upper mantle have been reported by many workers (Bott, 1971; Qureshy, 1981; Bowin, 1985; Misra, 1989). The global gravity anomalies (Bott, 1971; Bowin, 1985) of long wavelength have been interpreted as due to density variations occurring at great depths near to core-mantle boundary.

The zone of regional gravity low (L3) between 22°N and 23°N latitudes can be explained as a local decrease in the upper mantle density. Qureshy (1981) has suggested that these low density zones in the upper mantle under the cover of Deccan Traps are probably due to the deep seated phenomenon responsible for the epeirogenic uplift of the Deccan Plateau. The regions of NW Vindhyans basin (L1), Bundelkhand granite massif (L2), Narmada rift zone (L3) which extend upto the lithosphere (Agarwal, 1986) and Mahanadi rift (L7) are represented by the low density zones in the upper mantle. Further, the strong regional gradients (NE portion of Fig.7) indicate the underthrusting of the Indian lithosphere into the mantle.

CONCLUSIONS

The study on the effect of data spacing in relaxation technique has revealed that the relaxation regional becomes progressively flatter and flatter with increase in data spacing. Thus, a regional anomaly with sufficiently large data spacing can be attributed to the density inhomogeneities occurring at large depths, even at upper mantle depths. However, these broad regional anomalies are difficult to interpret quantitatively in the absence of any relationship between wavelength of the anomaly and.depth to the causative source.

The spectral analysis of the Bouguer anomaly map of central India has revealed the presence of four major density discontinuities. The deepest density interface of 37.8 km depth represents of the crust-mantle boundary and the depth of 19.4 km corresponds to the Conrad discontinuity or the boundary between upper and lower crustal layers. The other two depths 7.8 and 2.8 km may represent density variations occurring within the upper crustal layers. The depth obtained for Moho has been substantiated in the interpretation of the relaxation regional anomaly maps.

The Moho configuration obtained from matched filtering and relaxation regional resemble fairly well with each other. The large gradients and sharp variation in magnitude of the Moho depths from matched filter approach may be attributed to the merging of the shallow features with that of the deep seated ones. However, the Moho map obtained by relaxation regional exhibits broad wavelengths with moderate undulations as expected for normal Moho surfaces in continental regions. The Narmada-Son rift zone has been identified as a major zone of continental subsidence bounded by riftward dipping normal faults extending into the mantle. The two inferred transverse fault zones from the Moho configuration, one at Narmada-Godavari-Son and the other at Narmada-Mahanadi-Son junctions represent two triple junctions which are mostly associated with continental rift zones and contiguous structures.

The magnitudes and the wavelengths of anomalies in the relaxation regional map (10 km spacing) has been visualized to represent the localized density variations in the upper mantle region. The present analysis over the central Indian region has delineated the deep seated structural features of the Narmada-Son rift zone.

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