Computation of Geoid and its interpretation in Saurashtra, western India using Gravity data

Sanjay Prajapati*, Bijendra Singh** and C.C. Tscherning***

Indian Institute of Geomagnetism, Mumbai India*

National Geophysical Research Institute, Hyderabad, India**, Department of Geophysics, Copenhagen***

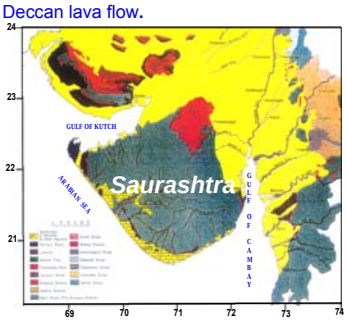
Abstract:

The geoidal anomaly is related with the density structure within the Earth. The long wavelength features are associated with deep mass anomalies (core/mantle), while the very short ones correspond to uncompensated topography and lithospheric flexure. It can also provide useful tectonic information about lithospheric structure. By applying the Least-square collocation technique (LSC), geoid undulations have been determined by combining a geopotential model, Free-air gravity anomalies and height data in Saurashtra region, Western India. A detail terrain model (DTM) has been used for removing the residual terrain effect and the terrain effect. A positive geoidal undulation of 1-2 m has been observed after removing a regional trend from the gravimetric geoid over the Saurashtra Plateau. The effects of crustal structure have also been studies by applying Airy and Pratt-type isostatic models and compared with observed gravimetric geoidal anomalies. The geoidal undulations suggest that the main source of geoidal high lies within the crust/upper mantle.

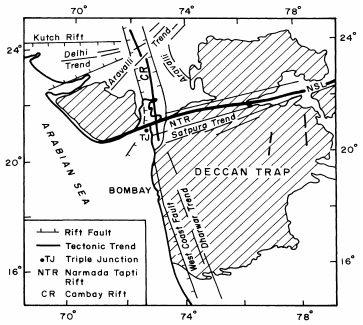
Geology & Tectonic:

Deccan trap of Saurashtra is presumed to be one of the earliest products of magma differentiation as indicated by occurrence of Picritic basalt, Gabbro and alkaline rocks in this area (Basu et al. 1993). Bulk of the Deccan basalt in Saurashtra is of tholeiitic type with several intrusions of acidic, alkaline and mafic/ultramafic plugs (Merh S.S., 1995), the major ones being Girnar, Osham, Barda, Alech in the western part and Vallabhipur, Palitana and Rajula in the south-eastern part.

The Saurashtra Peninsula, occurs as a horst block between the three intersecting rifts namely Kutch, Cambay and Narmada (Biswas, 1987). The western margin of India and adjoining regions has been affected by three major tectonic events during the Mesozoic period during the northward drift of the Indian sub-continent after the breakup of Gondwanaland. However, major geological and tectonic events of Saurashtra are confined to Mesozoic and Cenozoic Eras. The major portion of the peninsula is occupied by the Deccan lava flow.



Geology Map of Western India



Tectonic Map of Western India

Isostatic Geoid Anomalies:

Due to local type of isostasy, the geoid anomaly is related to density or mass anomalies distribution within the lithosphere. Geoid against topography relationship can be analytically and easily derived for Airy and Pratt compensation mechanism and can be compared with the observed geoid and topography. Geoid anomaly (ΔN) and topography (h) are related in Airy compensation model is

$$\Delta N = \pi G/g\ \rho c\ \{2Zm + \rho m/\rho m - \rho c\ h2\}$$

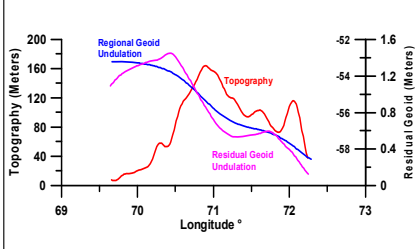
For Pratt

$$\Delta N = \pi G/g\ \rho o\ W\ h$$

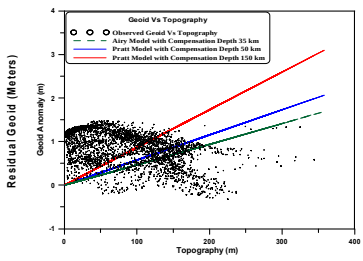
ρo (Crustal Density) = 2700 kg/m2, ρm (Mantle density)= 3300 kg/m2, g (gravity acceleration)= 10 m/s², Z_m (depth of compensation, Airy), W (Depth of compensation, Pratt). For Saurashtra region, either Airy model or Pratt model with compensation depth lower than 50 km equally explains the geoid topography ratio. Therefore the main source of geoid high lies within the crust/upper mantle. Temperature increase may cause density decrease which produces a buoyancy force to lift the lithosphere and a topography component may be created. In Pratt model, density decrease under high topography is approximately relative to normal density crust. Other possibility is increase in the depth of compensation, the percentage of density decrease may also explain the same geoidal effect .

We have also drawn a E-W profile, where regional and residual geoid undulation obtained from LSC is showing good inverse correlation with Topography.

The geoid low observed in Northeast of Jasdan has amplitude of -1.6 meters. The geoid against topography ratio for this region is not plotted because the topography signal is too low in this plateau.



Topography, Regional and Residual Geoid Undulation (m) along Navibander and Palitana Profile



Geoid Vs Topography (m)

Least Square Collocation method:

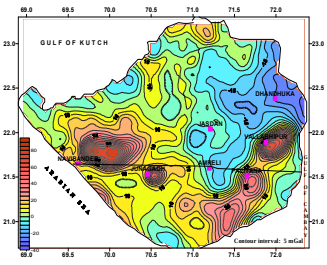
Least square collocation (LSC) technique is powerful technique to represent the elements associated with the gravity field and has been used for the computation of a geoid undulations for the Saurashtra region of Western India. Free-air gravity anomalies and height based on leveling data has been used. A digital terrain model has been used for the smoothing of the data using residual terrain modeling. The geoid has a relative error of 0.05 m. The geoid solution is derived in the form of a 0.02 degree grid. This method makes it possible to compute error estimate which takes both the data distribution and varying data quality into account.

LSC determines an approximation to the anomalous potential T as a linear combination of the observations. The quantity T is determined by solving a set of normal equation with as many unknowns as the number of observations, plus the number of contingent parameters. When T has been determined, the geoid heights are determined using Bruns equation

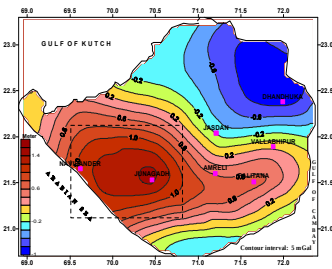
$$\zeta(P) = T(P)/\zeta$$

where ζ is normal gravity. Other quantities like deflections of the vertical or gravity anomalies may also be determined.

The area between 22-24° N and 69-72°E covered with flood basalt and some part is covered with recent sediments. The main feature of geoid anomalies are, a large wavelength 300 km length and 100 widths, trending NE, 1.5 meter amplitude positive geoid anomalies correlates with high topography. The positive anomaly partially correlates with Junagarh plug. The positive geoid anomaly is extending towards the continental margin and joins a linear sequence of same wavelength positive geoid anomaly. A circular (100-50) km in diameter 1.6 meter amplitude negative geoid anomaly is located northeast of Jasdan.



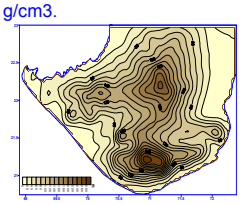
Free-air Map of Saurashtra



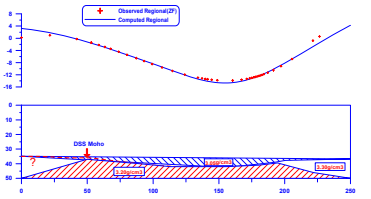
Residual Geoidal Undulation

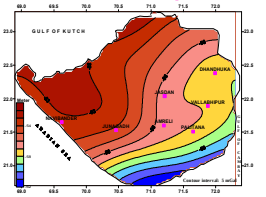
Gravity Modeling:

Presuming that isostatic regional anomalies arise due to compensating mass at crust-mantle interface, its modeling may provide information on the density contrast across the Moho interface provided Moho geometry is constrained from other information. We have carried out 2-1/2D gravity modeling using GMSYS software along an E-W profile, which covers the entire Navibandar-Amreli DSS profile. The profile shows observed and the corresponding compensated topography based on zero free air anomalies. Using Moho interface as initial constraint, modeling shows discrepancy of the order of 20 mGal, between observed and calculated anomaly for a normal density contrast of –0.4 g/cm3 between crust (2.9 g/cm3) and upper mantle (3.3 g/cm3). A fairly good match between observed and calculated is obtained for a density contrast of – 0.15 g/cm3.

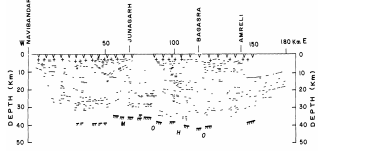


Elevation Map





Regional Geoid Map



2-1/2-D Regional Gravity Model along Navibandar –Palitana (EW) Profile

Conclusion:

- ✓ Least square collocation has been used for the computation of a geoid for the Saurashtra region of Western India. The geoid has a relative error of 0.05 m. The geoid solution is derived in the form of a 0.02 degree grid.
- ✓ A comparison between geoid undulation from the theoretical isostatic model and residual gravimetric geoid undulation from gravity anomalies shows qualitative and quantitative consistence and finding well agreement between them.
- ✓ Airy model or Pratt model with compensation depth lower than 50 km equally explains the geoid topography ratio. Therefore the main source of geoid high lies within the crust/upper mantle. Temperature increase may cause density decrease which produces a buoyancy force to lift the lithosphere and a topography component may be created.
- ✓ We had shown that Gravity anomalies and distribution earth potential (Geoidal undulations) can be used together to study the crustal structure.