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EFFECTS OF CRUSTAL FEATURES ON THE GRAVITY FIELD AND ISOSTATIC COMPENSATION

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13. ABSTRACT

The main purpose of the gravity analysis was to investigate the effects of crus features and major geologic units on gravity anomalies and on isostatic compensation The study of isostatic compensation utilized the theory of Dorman and Lewis in which topographic features were assumed to be related linearly to compensation and its corresponding Bouguer anomaly. An isostatic response function was derived directly from the relation between topography and Bouguer anomalies in the southeastern Unit States. The results of the analysis indicate over compensation with either undercom pensation at 150 km depths or lateral compensation. Another possibility is lateral crustal inhomogeneity. Interpretations with lateral inhomogeneities are preferred because detailed gravity data have revealed numerous anomalously shallow high-densit crustal structures in the southeastern United States.

In general in the southeastern United States lateral inhomogeneities in the cru are significant and must be considered in any analysis of the crustal response to applied stresses. This fact was particularly evident in attempting to compute an isostatic response function. The analysis also strongly supports vertical movement crustal blocks as a major tectonic mechanism in the southeastern United States.

14. KEY WORDS	LINK A		LINK B		LINK C	
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Georgia						
South Carolina						

EFFECTS OF CRUSTAL FEATURES ON THE GRAVITY FIELD AND ISOSTATIC COMPENSATION

Statement of Problem Studied

The main purpose of the gravity analysis was to investigate the effects of crustal features and major geologic units on the gravity field and isostatic compensation.

Crustal features and major geologic units have been examined by obtaining detailed field data near known structures or by obtaining detailed gravity data in lines across structures. Conventional analysis methods have been used to relate the observed gravity anomalies to the interpreted shape of these structures. Conventional analysis methods have also been applied to gridded regional gravity data in the southeastern United States. The analysis in these investigations was directed toward accumulating evidence implicating recent crustal movement in response to isostatic stresses as a major tectonic mechanism of the southeastern United States.

The study of isostatic compensation utilized the theory presented by Dorman and Lewis (1970) and Lewis and Dorman (1970). In application of the theory, topographic features were assumed to be related linearly to compensating masses. The object was then to derive the functional relation between the topography and the Bouguer anomalies derived from the compensating masses. Similarly density anomalies in the crust should be functionally related to Bouguer anomalies. Attempts were made to include surface densities and short wavelength anomalies in the derivation of the response function. Attempts were also made to interpret the response function in terms of isostatic mechanisms or crustal structure.

Results and Conclusions Reached

The research covered by this grant proceeded in two stages. The first stage was a preliminary analysis based on incomplete data. As a result of the preliminary analysis tentative conclusions were derived and utilized to establish more specific goals for the second stage of research. The second stage in the analysis in most cases supported the conclusions of the first stage of analysis.

Preliminary results

An isostatic response function can be derived for an area as small as the southeastern United States. However, the truncation of structures at the edge of the 512 x 512 km square area requires that the derivation of Dorman and Lewis (1970) be modified to utilize the first derivatives in the computation of the isostatic response function. Also, the numerical precision of the data must be carefully evaluated to prevent these errors from dominating the results. At wavelengths less than 30 km the Bouguer anomalies and elevation were virtually random functions and uncorrelated in the southeastern United States.

The response function derived for the southeastern United States showed a significant oscillatory character. The response function for a linear impulse in topography according to the derived function would be positive from 50 to 125 km and slightly negative from 125 to 250 km. The positives in the response function effectively balance an anomalously high ratio of Bouguer anomalies to elevation of -0.14 mgals/meter. This anomalously high value at long wavelengths implies that mountains in the southeastern United States are over compensated and should be experiencing isostatic forces compatible with uplift. Contemporary uplift is supported by releveling data (Meade, 1971). The response function for the southeastern United States also showed significant asymmetry which is probably related to the asymmetry of the continental margin.

The existence of oscillations in the response function as opposed to the nearly uniform decay such as observed by Dorman and Lewis (1970) has significant tectonic implications. Primarily, the response function observed contains wavelengths much shorter than typically observed in crustal loading or unloading such as caused by glacial rebound. The significance of this difference is perhaps that two independent mechanisms are involved. The mechanism for glacial rebound is a short-term elastic deformation of the crust, in which the rate of deformation is controlled primarily by the viscosity of the upper mantle. The mechanism for the observed isostatic response function is perhaps a non-linear deformation of the crust. The causitive stresses would be long-term stresses related to the inherent isostatic inequilibrium of crustal structures (Artyushkov, 1974). For the longer durations involved the mantle is virtually a perfect fluid.

Inversion of the isostatic response function requires that constraints be applied to obtain a solution because potential data are inherently non-unique. The most common restraint for isostasy is to assume local compensation (Dorman and Lewis, 1972). For the southeastern United States a solution constrained by local compensation would require significant negative compensation below 150 km. A physical mechanism which can explain the existence of negative compensation at depths of 150-200 kilometers can be derived from recent movement of the North American plate. This mechanism requires that the roots of the mountainous regions displace the upper mantle downward. Because the downward displaced material is cooler, the equilibrium depths of phase changes in the crystalline structure shifts upward causing increased density of the material and consequently negative compensation. This mechanism introduces a momentary density instability in the mantle which has been utilized as a driving mechanism for a model of mantle convection (Lowell and Bodvarsson, 1973). However, significant phase transformations are currently unknown in the depth range of 150 to 250 km. This physical model could have also explained the existence of asymmetry in the response function.

While the physical model for negative compensation at depth is plausable, the model is not supported by gravity data which indicate that many of the geologic structures which undoubtedly contribute to the oscillation of the response function are within the crust. The oscillation wavelength of the isostatic response function indicates that a block width of 50 to 100 km would be appropriate for lateral compensation. At least three physical models can explain the existence of the lateral inhomogeneity of the crust. The first is an isostatic reaction of crustal blocks to erosion or depositional loading such as has occurred in the coastal plain regions of the southeastern United States. The second is an attachment of island arcs or crustal fragments onto the southeast edge of the North American Plate during the closing of a proto-Atlantic ocean. Evidence for island arc configurations exist in the Piedmont Province of Georgia and South Carolina (Denman, 1974). The third is the intrusion of basic rocks during the early development stage of the Atlantic ocean. (See Long and Lowell, 1973).

Revised objectives

The main objective for the second stage of the gravity analysis was, as in the first stage, to investigate the effects of crustal features and major geologic units on the gravity field and isostatic compensation. As a consequence of the preliminary results from the first stage the following six more specific objectives were developed.

1. Compute and invert the response function with a revised and expanded data set.

2. Evaluate the significance in the difference between the isostatic response function and observed deformation of glacial rebound.

3. Evaluate the significance and influence of an intermediate crustal layer.

4. Compare classical models for computing isostatic anomalies to the observed response functions.

5. Model the isostatic response of the crust by use of numerical methods and include in the model the effects of temperature changes, viscosity, erosion, deposition and other parameters which might influence the isostatic response function.

6. Support detailed gravity field work.

Conclusions

The complete data set did not change the preliminary isostatic response function significantly. Consequently most of the preliminary results remain unchanged. Evaluation of the revised objectives indicate the following conclusions.

1. The isostatic response function obtained with the more complete data set was virtually the same as was obtained previously. Inversion techniques have been investigated by Dorman and Lewis (1972). However, for the southeastern United States data inversions with local compensation do not give realistic solutions for density distributions with depth. The conclusions with respect to lateral compensation are the same as given above.

2. The best explanation for the difference between the crustal response to glacial unloading and the observed isostatic response function perhaps relates to the manner in which the isostatic stresses are distributed and the character of material flow in the upper mantle. Glacial unloading at the earth's surface creates a regional or smooth stress at the crust-mantle contact which remains within the elastic limit of the crust and which excites viscus flow in the mantle. In contrast the stresses for the long-term non-elastic, non-linear deformation of the crust are localized stresses related to Moho topography or anomalous density structures in the crust. The mantle is a virtual fluid for the longer time periods involved.

3. A detailed gravity data line across north Georgia (Long, 1974) indicates that intermediate layer undulates with the topography. In the Coastal Plain an intermediate layer may not exist as a discrete layer since in places crustal material with perhaps composition similar to that expected for the intermediate layer approaches the surface. Explanations for the correlation of density anomalies at depth with topography could include the influence of vertical uplift of discrete crustal blocks and lateral variations in crustal structure generated by some currently inactive tectonic mechanism.

4. None of the classical models for computing isostatic anomalies are compatible with the strong negative compensation at greater depths or the effects of lateral variations in crustal structure like those observed in the isostatic response function for the southeastern United States. Smoothed free air anomalies were utilized almost entirely for the evaluation of isostatic equilibrium.

5. The utilization of numerical methods to generalize the crustal response was not attempted beyond the evaluation of elevation versus heat flow (Long and Lowell, 1973). Such an analysis would require computations which are significantly more involved than allowed by the available time or resources on this grant. Preliminary analysis indicates that there exists a significant potential for results through application of numerical techniques to problems of the crustal response to stress.

6. The support for detailed gravity studies in the field has made possible a number of gravity anomaly maps of significant

structures in the southeastern United States (see Long, 1974). Additional data were obtained with the objective of obtaining evidence of vertical crustal movement. In general the data support the existence of recent vertical movements.

Some of the detailed gravity studies were in conjunction with seismic monitoring in the epicentral regions of recent earthquakes. Partially as a result of the detailed gravity data a relation has been shown to exist between interpreted structures and the locations of aftershocks. In the case of Bowman and Summerville, South Carolina, high-density and high-velocity geologic units in the crust are spacially associated with earthquakes. These units have higher rigidity than the surrounding crustal material and the rigidity contrast allows amplification of low-level regional stresses. Earthquakes occur where the geometry would predict the greatest amplification of regional stress.

Recommendations

This research has shown that the lateral inhomogeneity of the crust in the southeastern United States prohibits the application of techniques which are based on uniform layers. Therefore, it is recommended that the study of tectonics or crustal deformation be investigated by numerical methods as suggested in objective 5 above.

Continued support for detailed studies are recommended so that more areas may be mapped with the one kilometer spacing required for resolution of structures in the upper crust.

Although direct computation of the isostatic response function does not always yield results directly related to isostasy, similar analyses are recommended for other areas so that the variation in the influence of lateral variations may be evaluated.

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Participating Personnel

The research has provided an opportunity to exchange ideas with researchers in southeastern universities and government agencies. At Georgia Tech the research has contributed to the education of many graduate and undergraduate students. The following students worked full time for at least one term on the research.

S. R. Bridges (undergraduate and graduate assistant) B.S. in Physics with Geophysics Minor.

G. M. Rothe (undergraduate and graduate assistant) B.S. in Physics with Geophysics Minor, M.S. in Geophysics. Mr. Rothe is continuing work toward a Ph.D. in Geophysics at University of Washington.

J. W. Champion (graduate assistant)

L. Evans (graduate assistant)

The following assisted the research in field measurements or computer programming.

J. H. McKee (graduate assistant) M.S. in Geophysics
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