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PROJECT ADMINISTRATION DATA SHEET

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Project Director: Dr. Jean-Claude Mareschal School/Lab Geo Sciences

Sponsor: National Science Foundation

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Title: State of Stress and Seismicity in the Southeastern United States

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RESTRICTIONS

See Attached NSF Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval — Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

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COMMENTS:

*Includes a six-month unfunded flexibility period.

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SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 8/23/85

Project No. G-35-632 School/XXX Geo. Sci.

Includes Subproject No.(s)

Project Director(s) Dr. Jean-Claude Mareschal GTRC / XXX

Sponsor National Science Foundation

Title State of Stress and Seismicity in the Southeastern United States

Effective Completion Date: 6/30/85 (Performance) 9/30/85 (Reports)

Grant/Contract Closeout Actions Remaining:

- [ ] None
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FINAL PROJECT REPORT
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PART I—PROJECT IDENTIFICATION INFORMATION

1. Institution and Address	2. NSF Program	3. NSF Award Number
School of Geophysical Sciences Georgia Institute of Technology	Earth Science: Geophysics	EAR 82 18779
	4. Award Period From 07/15/83 To 06/30/85	5. Cumulative Award Amount $39,200

6. Project Title

State of Stress and Seismicity in the Southeastern United States

PART II—SUMMARY OF COMPLETED PROJECT *(FOR PUBLIC USE)*

The stresses induced by the topography and by density heterogeneities within the lithosphere were computed for different models of the lithosphere in the Appalachians. These two-dimensional calculations along cross sections that are perpendicular to the strike of the Appalachian Mountains indicate that stress and stress differences are largest beneath the Blue Ridge and the Valley and Ridge provinces and extend to lower crustal depth. The level of stress is lower and the stresses are confined to the shallow crust in the Piedmont and Coastal Plain. The calculations show a good correlation between the high stress level and the seismicity, and they could explain the level of seismic activity in southeastern Tennessee.

PART III—TECHNICAL INFORMATION *(FOR PROGRAM MANAGEMENT USES)*

1. ITEM *(Check appropriate blocks)*	NONE	ATTACHED	PREVIOUSLY FURNISHED	TO BE FURNISHED SEPARATELY TO PROGRAM: Check (√)	Approx. Date
a. Abstracts of Theses				X	Sept. 1986
b. Publication Citations	X				
c. Data on Scientific Collaborators		X			
d. Information on Inventions	X				
e. Technical Description of Project and Results		X			
f. Other *(specify)*					

2. Principal Investigator/Project Director Name *(Typed)*	3. Principal Investigator/Project Director Signature	4. Date
J.-C. Mareschal		8/12/85

NSF Form 98A (3-83) Supersedes All Previous Editions

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INTRODUCTION

The cause of seismicity in the plate interiors is one of the major unresolved questions in tectonics. The relative importance of plate tectonic stresses and internal stresses and their effect on the tectonic plates are at the focus of the debates. The purpose of this study was to evaluate the importance of the topography and density heterogeneities in generating the stresses within the lithospheric plates. The model calculations shown below indicate that they can produce stresses that are large enough to account for the observed seismicity in the southeastern United States. Plate tectonic stresses are of the same order of magnitude, but the combined effect of the internal and tectonic stresses has not been evaluated yet.

STATE OF STRESS, SEISMICITY,
AND VERTICAL CRUSTAL MOVEMENT
IN THE SOUTHEASTERN UNITED STATES

By

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April 1985

Abstract

The topography and crustal density heterogeneities induce large stresses in the lithosphere. The seismicity in the Southern Appalachians can be accounted for by the stresses generated by the topography and the crustal thickening in the Blue Ridge. The stresses are computed along a cross-section perpendicular to the Appalachian Mountains for a layered elastic lithosphere over an inviscid fluid. The density distribution is constrained by the gravity data. For different density models compatible with the data or determined directly by downward continuation of the Bouguer anomaly, the calculations show that the stresses are large and extend to lower crustal depths northwest of the Blue Ridge where the seismicity is concentrated. The stresses are smaller and shallower in the Piedmont and the Coastal Plain, but the effect of the continental margin and recent deposition would induce stresses in that region.

I. Introduction

The central and eastern United States are part of the interior of a tectonic plate. However, a few very large earthquakes (magnitude greater than 7) have occurred in historical times within this tectonically stable region. The 1755 Cape Ann, Massachusetts, the 1811-1812 New Madrid, Missouri, the 1876 Charleston, South Carolina, and the 1926 LaMalbaie, Quebec, earthquakes were the strongest of these events and had a magnitude comparable to some of the large and destructive events that occur in the western United States. These large events are part of a well-defined pattern of seismicity which has been outlined by several studies (e.g., York and Oliver, 1976; Sykes, 1978). The seismic frequency map, shown on Figure 1, shows that the activity is concentrated in several regions: the Mississippi embayment, the St. Lawrence valley, the Adirondacks, New England, and the region of Charleston, where large historical earthquakes have been reported, have the highest frequency; a consistent pattern of activity also follows the Appalachian Mountains.

The seismicity in the southeastern United States has been studied in detail by Bollinger (1973) and Sibol and Bollinger (1984). On Figure 2a, the historical events are displayed on a map where the major provinces of the Appalachian orogenic belt are delineated; on Figure 2b, the events reported by the Southeastern United States Seismic Network between 1978 and 1984 are shown. These maps outline two clusters of seismicity (in Virginia and near Charleston, SC) and a belt extending from Alabama to the Virginias; this belt does not coincide with the crest of the Appalachian Mountains, but runs parallel to the northwest.

The activity is highest in southeastern Tennessee, northwest of the Great Smoky Mountains, where the topography is highest.

Most of the earthquakes occur beneath the Valley and Ridge Province. The focal depths of the events are between 10 and 25 km beneath the thrust-faulted and folded sedimentary layers, and old faults in the (Grenville?) basement are probably involved. The focal mechanisms are interpreted as strike-slip (Johnston, 1985).

It appeared at one time that vertical crustal movements in the eastern United States were occurring near the belt of seismic activity (Bollinger, 1973; Brown and Reilinger, 1980). The amplitude of the difference between the uplift reported in the Appalachians and the subsidence of the Coastal Plain (6 mm/yr) is surprisingly large, and it is clear that these movements could not be sustained over long geologic periods. The relevelling measurements have been questioned and are currently being reinterpreted (Larry Brown, personal communication); it is doubtful that they take place at the high rate suggested above.

The trend of the Bouguer gravity anomaly map (Woollard, 1964; Haworth _et al_., 1980) is parallel to the mountain belt. The major feature of the Bouguer anomaly map (Figure 3) is the couple formed by the large negative values in the northwestern belts of the Blue Ridge and the Valley and Ridge (<-100 mGal) and the positive anomaly observed to the southeast in the Piedmont and the Coastal Plain (>40 mGal). The positive southeastward gradient is extremely high in the Piedmont. The gravity anomaly increases to the northwest of the Appalachian Mountains and tends to vanish in the interior midcontinent. The large negative anomalies along the crest of the Appalachians indicate that the topography is isostatically compensated by increased crustal thickness. The seismic refraction data are rather sparse, but the profiles obtained during the transcontinental geophysical survey show that crustal thickness increases from 40 km in the midcontinent to 50 km beneath the Blue Ridge (Warren, 1968). The isostatic gravity anomaly map (Ngoddy, 1984), shown in Figure 4, indicates that there is overcompensation below the Blue Ridge where the anomalies are large and negative. The large positive anomaly that runs north-south across Tennessee, the East Continent Gravity High (ECGH), has been interpreted as a possible rift structure in the Precambrian basement (e.g., Keller et al., 1982).

The most prominent feature of the magnetic anomaly map is the New York-Alabama lineament, a remarkable offset of the contours which cuts across surface geological boundaries (King and Zietz, 1978). This lineament has been considered to be a major boundary in the Precambrian basement, possibly the Grenville suture. North of the lineament, the magnetic and the other geophysical anomalies are no longer parallel to the trend of the Appalachians. The possible Precambrian rift corresponding to the ECGH has also a signature on the magnetic anomaly map.

Major discontinuities in the basement are suggested by the magnetic and gravity data, as well as by electrical conductivity studies (Greenhouse and Bailey, 1981; Mareschal et al., 1983). These discontinuities may delineate zones of weaknesses where the stresses are more likely to reactivate old faults.

II. Source of Stresses

The eastern United States is not near a plate boundary, and the evidence suggests that it is not tectonically active. The topography of the Appalachians is the remnant of tectonic processes that took place 300 to 500 Ma ago. The seismicity in the eastern United States is due to a high level of stresses within the plate interior. These stresses could be due to plate tectonics and/or to sources within the plates (i.e., loads, thermal stresses, flexure, etc.). The question of the relative importance of these stresses remains open (Turcotte, 1983).

The plate tectonic stresses consist of the sum of all the forces driving and opposing plate motion. The major sources are: trench pull, ridge push, plate interaction, and basal shear or asthenospheric counterflow due to relative motion between the plate and the asthenosphere. With the exception of the ridge push forces, these stresses are difficult to quantify. Attempts have been made to calculate the stress within the plates taking into account all the stresses acting on the plate (Richardson et al., 1979). If the measured state of stress in the lithospheric plates is used as a constraint, the forces that are not well determined can be adjusted in such a way that the resulting stress field fits the data. The general orientation of the stress field in the North American plate could therefore be explained by plate tectonics (Richardson et al., 1979).

The causes for local and regional variations in the stress field are the mechanical heterogeneities of the plate and/or the intraplate stresses that originate directly in the lithosphere. These stresses are easier to quantify than the tectonic stresses and their variations and should be evaluated in an attempt to understand the changes in the stress regime within the plates.

Thermal stresses are clearly not important in the southeastern United States where the heat flow is low. The major sources of stress are therefore the topography, the crustal density heterogeneities, and the stresses induced by lithospheric flexure.

Lithospheric flexure occurs when differential vertical motion of the Earth's surface follows loading or unloading. Lithospheric unflexure takes place in the Appalachians as the topographic load is slowly eroded away; flexure is occurring along the eastern United States seaboard in response to deposition of sediment along the Atlantic coast, and it may be the cause of the east coast seismicity. Because it is estimated that the erosion rate and the differential uplift in response to unloading are slow, the flexural stresses in the Appalachians are probably less important than near the Atlantic coast.

In addition, stresses are present that maintain the topography. In the Appalachians, the topography is compensated (perhaps even over-compensated) by increased crustal thickness, and the superposition of topographic load and crustal thickness variation could induce large forces in the crust.

The purpose of the present study is to determine the part of the stresses due to the topography and the changes in crustal thickness as well as to estimate the stresses available from flexure. The two-dimensional models will show that large deviatoric stresses locally larger than 30-50 MPa are induced and that these stresses extend to lower crustal depth. The seismicity occurs in the region where the stresses and principal stress differences are largest.

III. Determination of the Stresses Induced by the Topography and Density Heterogeneities

Because the geologic trends are elongated, the stresses are computed for a two-dimensional model of the lithosphere. The geometry of the model is shown on Figure 5; the lithosphere consists of horizontal elastic layers over an inviscid fluid, the asthenosphere. The viscosity of the asthenosphere can be neglected because the time constants for viscous relaxation in the asthenosphere are small compared to the geologic time constants.

A coordinate system x,z is used; z is vertical and positive downward; z=0 is the Earth's surface; the interface between any two layers k and k+1 is defined by $z=h_k$, and z=a is the lithosphere-asthenosphere boundary.

Within each layer, the stress tensor $\bar{\bar{T}}$ and the elastic displacement vector $\bar{u}$ are related by the Hooke's law

$$T = \lambda(\bar{\nabla}\cdot\bar{u})\ \bar{\bar{I}} + \mu(\bar{\nabla}\bar{u} + \bar{\nabla}\bar{u}^T) \tag{1}$$

where $\bar{\bar{I}}$ is the identity tensor, λ and μ are the Lame' parameters.

Within each layer, where λ and μ are assumed constant, the equilibrium condition is:

$$(\lambda + \mu)\ \nabla^2\bar{u} + \mu\bar{\nabla}(\bar{\nabla}\cdot\bar{u}) = 0 \tag{2}$$

It implies that the displacements also satisfy the more general biharmonic equation

$$\nabla^4\bar{u} = 0 \tag{3}$$

In addition, the stresses and displacements must satisfy boundary conditions at the surface and at the different interfaces. At the surface, z=0, the shear stress vanishes and the normal vertical stress is equal to the topographic load, $\rho_1 g t(x)$

$$T^1{}_{xz} = 0 \tag{4a}$$

$$T^1{}_{zz} + \rho_1 g u^1{}_z = \rho_1 g t(x) \tag{4b}$$

At the interface between two layers, $z=h_i$, the displacement and shear stresses are continuous, the discontinuity in the normal vertical stress is equal to the loading induced by the interface topography $(\rho_{j+1} - \rho_j) g \delta h_j$

$$u_x^j = u_x^{j+1} \tag{5a}$$

$$u_z^j = u_z^{j+1} \tag{5b}$$

$$T_{xz}^j = T_{xz}^{j+1} \tag{5c}$$

$$T_{zz}^j = T_{zz}^{j+1} + g\Delta\rho_j(\delta h_j - u_z^j) \tag{5d}$$

At the lithosphere-asthenosphere boundary, z=a, the shear stresses vanish and the normal vertical stress is equal to the load

$$T_{xz}^N = 0 \tag{6a}$$

$$T_{zz}^N = g\Delta\rho_N(\delta h_N - u_z^N) \tag{6b}$$

It is convenient to solve the equations in Fourier transform domain, where the Fourier transform pair is defined by:

$$\bar{u}(k,z) = \int_{-\infty}^{+\infty} \bar{u}(x,z)\exp(ikx)dx \tag{7a}$$

$$\bar{u}(x,z) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \bar{u}(k,z)\exp(-ikx)dk \tag{7b}$$

where k is the wavenumber.

The general solution to the biharmonic equation in wavenumber domain is

$$\bar{u} = (\bar{A} + \bar{B}\ kz)\ \exp[kz] + (\bar{C} + \bar{D}\ kz)\ \exp[-kz] \tag{8}$$

where $\bar{A}$, $\bar{B}$, $\bar{C}$, $\bar{D}$ are vectors, functions of the wavenumber that are determined by the boundary conditions.

This solution to the biharmonic equation does not in general satisfy the less general equation (2) unless the arbitrary constants satisfy four additional relationships between them. Within the jth layer, the general solution to the equation (2) can therefore be written in function of the four arbitrary constants $A^j = A_x^j$, $B^j = A_x^j$, $C^j = C_x^j$, $D^j = D_x^j$ as

$$u_x^j = [A^j + B^j\ kz]\ \exp(kz) + [C^j + D^j\ kz]\ \exp(-kz) \tag{9a}$$

$$\frac{u^j{}_z}{i} = \left[A^j - \left(\frac{\lambda_j + 3\mu_j}{\lambda_j + \mu_j}\right) B^j + B^j\ kz \right] \exp(kz) - \left[C^j - \left(\frac{\lambda_j + 3\mu_j}{\lambda_j + \mu_j}\right) D^j + D^j\ kz \right] \exp(-kz) \tag{9b}$$

and the components of the stress tensor can be written in transform domain as follows:

$$\frac{T^j{}_{xz}}{2k\mu} = \left[A^j - \left(\frac{\mu_j}{\lambda_j+\mu_j}\right) B^j + B^j\ kz \right] \exp(kz)$$

$$+ \left[C^j + \left(\frac{\mu_j}{\lambda_j+\mu_j}\right) D^j + D^j\ kz \right] \exp(-kz) \qquad (10a)$$

$$\frac{T^j{}_{zz}}{2ik\mu} = \left[A^j - \left(\frac{\lambda_j+2\mu_j}{\lambda_j+\mu_j}\right) B^j + B^j\ kz \right] \exp(kz)$$

$$+ \left[C^j + \left(\frac{\lambda_j+2\mu_j}{\lambda_j+\mu_j}\right) D^j + D^j\ kz \right] \exp(-kz) \qquad (10a)$$

$$\frac{T^j{}_{xx}}{2ik\mu} = - \left[A^j + \left(\frac{\lambda_j}{\lambda_j+\mu_j}\right) B^j + B^j\ kz \right] \exp(kz)$$

$$- \left[C^j - \left(\frac{\lambda_j}{\lambda_j+\mu_j}\right) D^j + D^j\ kz \right] \exp(-kz) \qquad (10c)$$

Practically, the surface and internal loads are Fourier decomposed. For each wavenumber, the 4N constants A^j, B^j, C^j, and D^j are determined by solving the system of equations (4a-6b); the stresses and displacements are determined in space domain by applying the Fast Fourier Transform algorithm.

IV. Crustal Models and Stresses in the Southern Appalachians

The stresses were computed for a cross section perpendicular to the strike of the Appalachian orogen; this cross section corresponds to the profile AA' on Figure 2a. The density distribution is constrained by the gravity Bouguer gravity data (Woollard, 1964; Haworth et al., 1980) and by seismic refraction data (Warren, 1968). In order to obtain a model representative of the average crust along the Southern Appalachians and to eliminate small local heterogeneities, several parallel profiles were stacked together to obtain the gravity profile used to constrain the density distribution. In addition, a density distribution compatible with the data was also determined directly from the Bouguer anomaly by downward continuation and determination of an equivalent layer. No significant differences were observed among the stress distributions obtained for various models that satisfy the gravity data.

The average Bouguer anomaly profile, the topography, and a crustal density model compatible with the data are shown on Figure 6. Several noteworthy features of this model are, from northwest to southeast: 1) there is crustal thinning, beneath the Plateau, in central Tennessee; it corresponds to the Precambrian rift that has been mentioned above; 2) there is considerable crustal thickening beneath the Valley and Ridge and in the Blue Ridge where the crustal thickness is of the order of 50 km; 3) there is a sudden change in crustal thickness between the Blue Ridge and the Piedmont. The abruptness of this change is required by the very steep gravity gradient in the Piedmont. Alternately, the

Piedmont gravity gradient could reflect shallower density variations; 4) In the Atlantic Coastal Plain, crustal thinning is accompanied by an increase in sediment thickness; 5) A few graben-like structures, parallel to the Appalachians, are found beneath the Coastal Plain, such as the one shown at the southeastern end of the profile.

A crustal model, the resulting principal stresses, and a contour of principal stress differences are shown on Figures 7a, b and c. The elastic displacements that are required for the model to be in equilibrium are shown on Figure 7d.

It can be observed directly that the magnitude of the principal stresses and the principal stress differences are much larger in the northern half. In the northernmost part, the stresses are large up to lower crustal depth. By comparison, the stresses are smaller and are confined to the shallow part of the crust in the Piedmont and in the Coastal Plain.

Differential elastic displacements imply that the stresses for the model include flexural as well as loading stresses. The elastic displacements required for the lithosphere to be in equilibrium are small (<50 m), but they correspond to the trend of vertical movement that was indicated by the relevelling data: uplift in the Blue Ridge, subsidence in the Coastal Plain. However, it is possible to find a crustal density distribution such that the gravity data are satisfied and vertical crustal movements are negligible. The principal stresses corresponding to such a model are shown on Figure 8. The structure of this model is close to and practically indistinguishable from the model shown on

Figure 7a. There is no major difference between the principal stress distribution corresponding to the flexural model (Figure 7b) and the non-flexural model (Figure 8). The large stresses and stress differences extend to lower crustal depth beneath the Blue Ridge and the Valley and Ridge Provinces; the stresses are smaller and shallow in the Piedmont and Coastal Plain.

An attempt was made to directly compute the stress from the gravity data. The procedure was the following: the Bouguer gravity anomaly is Fourier decomposed and different parts of the Fourier spectrum are either neglected or downward continued to the depth of the different interfaces depending on the wavenumber. In practice, the part of the spectrum with wavenumbers larger than 0.5 km^{-1} is neglected, the part with k larger than 0.25 km^{-1} is downward continued to 20 km, the part with k larger than 0.10 km^{-1} is downward continued to 40 km, and the rest of the spectrum is downward continued to the lithosphere-asthenosphere boundary. The mass of an equivalent layer is determined as (e.g., Bullard and Cooper, 1948):

$$\Delta\rho h(k) = \frac{g(k,z)}{2\pi G} = \frac{g(k,z=0)\exp(+kz)}{2\pi G}$$

where $\Delta\rho$ is the density contrast, h is the topography of the interface (thickness of the equivalent layer), G is the gravitational constant, and z is the depth at which the gravity data are downward continued.

The crustal density model obtained when following this procedure is shown on Figure 9a. The interfaces are more gently undulating than in the previous models; however some of the features outlined in Figure 6 can be identified on this cross section; this includes the rift beneath the plateau, the thickening in the Blue Ridge, and the thinning in the Piedmont and in the Coastal Plain. No geologic constraints were introduced and the Coastal Plain sediments are not included in the model. The resulting principal stresses are shown on Figure 9b. The similarities between this and the two previous cross sections are more important and more significant than the differences. The stresses are still largest in the northernmost part of the profile; the higher stresses in the Coastal Plain can be explained by the absence of the surface sedimentary layers; the lower stresses in the Valley and Ridge are also explainable by the nonintroduction of geologic constraints and the attenuation of the rift structures.

V. Conclusions and Discussion

For all the crustal density models, the stress distribution shows definite trends that correlate well with and could explain the Southern Appalachian seismicity. Indeed, the stresses are large and extend to lower crustal depth in the Blue Ridge and in the Valley and Ridge region. Most of the earthquakes in southeastern Tennessee occur in the Valley and Ridge and have focal depths between 10 and 25 km. The stresses are shallow and smaller in the Coastal Plain; the present clusters of activity in the Coastal Plain in Virginia have very shallow (<5 km) focal depth.

The present study has not attempted to address several fundamental questions. Firstly, the earthquakes occur in the Valley and Ridge and not in the Blue Ridge despite the higher topography and larger stresses. These earthquakes, with a focal depth larger than 10 km, occur in the Precambrian basement where major breaks have been detected. They occur southeast of the New York-Alabama lineament (King and Zietz, 1978) and northwest of the Ocoee magnetic lineament. It has been suggested that these lineaments mark the boundary of a crustal block with significantly different properties and old fractures more likely to be reactivated (e.g., Johnston *et al.*, 1985). An alternative hypothesis is that the earthquakes in southeastern Tennessee are associated with the Precambrian rift. Regardless, the stresses generated by the topography and density heterogeneities act upon and reactivate an ancient zone of weakness in the crust. The specific nature of this zone is likely to remain speculative for some time.

Secondly, the interpretation of the seismic data has shown that the focal mechanism of the Appalachian earthquakes is strike-slip. The two-dimensional models are not appropriate to determine focal mechanisms. The undertaking of three-dimensional calculations to determine focal mechanisms would be valuable because it would provide an additional constraint.

Thirdly, the seismicity of the Coastal Plain and the Atlantic Coast is not explained because the changes in crustal and lithospheric thickness at the continental margin and the recent sediment deposition have not been included in models shown here. Several authors (e.g., Bott and Dean, 1972; Park and Westbrook, 1983) have suggested that they could explain the seismicity of the coast.

Finally, the rheology of the lithosphere is much more complex than that of an elastic solid. There is evidence of a lower crustal asthenosphere (e.g., Chen and Molnar, 1983; Turcotte, 1983) with a more ductile behavior. The earthquake activity is restricted to the shallow brittle part of the crust and this explains that observed focal depths are less than 25 km. The effect of this crustal asthenosphere on the stress distribution in the shallow crust should be ascertained (see, for instance, Kusznir and Bott, 1977).

The definite solution to the problems of present crustal deformation in the Appalachians will require additional collection of data on the seismicity, vertical crustal movement, and the nature of the basement as well as modeling of the stress and deformation in three-dimensional geometry and with more complex rheologies. The study reported above demonstrates that the topography and crustal density heterogeneities generate stresses large enough to explain the crustal deformations.

Acknowledgments

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Figure Captions

Figure 1. The earthquake frequency map for the eastern United States (from King and Zietz, 1978, after Hadley and Devine, 1974). The solid line is the New York-Alabama magnetic lineament.

Figure 2a. The historical seismicity and the main geological provinces in the southeastern United States (from Bollinger, 1973).

Figure 2b. The seismic activity monitored between 1978 and 1984 in the southeastern United States. The stresses will be computed along the cross section AA'.

Figure 3. The Bouguer gravity anomaly map of the southeastern United States.

Figure 4. The isostatic anomaly map of the southeastern United States (from Ngoddy, 1984).

Figure 5. The geometry of the model, the equations, and the boundary conditions. The lithosphere is a horizontally layered elastic slab over an inviscid fluid. The surface and internal loading are introduced as boundary conditions.

Figure 6. The Bouguer anomaly profile, the topography, and a crustal model compatible with the gravity data. The profile is obtained by stacking several profiles parallel to the line AA' on Figure 2b.

Figure 7a. The lithospheric density model assumed for stress calculations.

Figure 7b. The principal stress distribution in the lithosphere for the model shown in Figure 7a. The stresses are large in the northernmost part of the cross section.

Figure 7c. The principal stress difference (absolute value) in the lithosphere for the model shown in Figure 7a. The interval between contour lines is 10 MPa.

Figure 7d. The elastic displacements that are needed for equilibrium. The displacements are everywhere small and are compatible with uplift in the northernmost half of the section and with subsidence in the Coastal Plain.

Figure 8. The stresses for a nonflexural model, i.e., a model for which the elastic displacements are negligible. The density structure is so similar that it is indistinguishable from the model shown in Figure 7a.

Figure 9a. The lithospheric density distribution obtained by downward continuation of the Bouguer gravity anomaly to interfaces where an equivalent layer is determined.

Figure 9b. The stress distribution for the downward continued gravity model. The stresses are more evenly distributed than in the previous models but are still largest in the Blue Ridge.

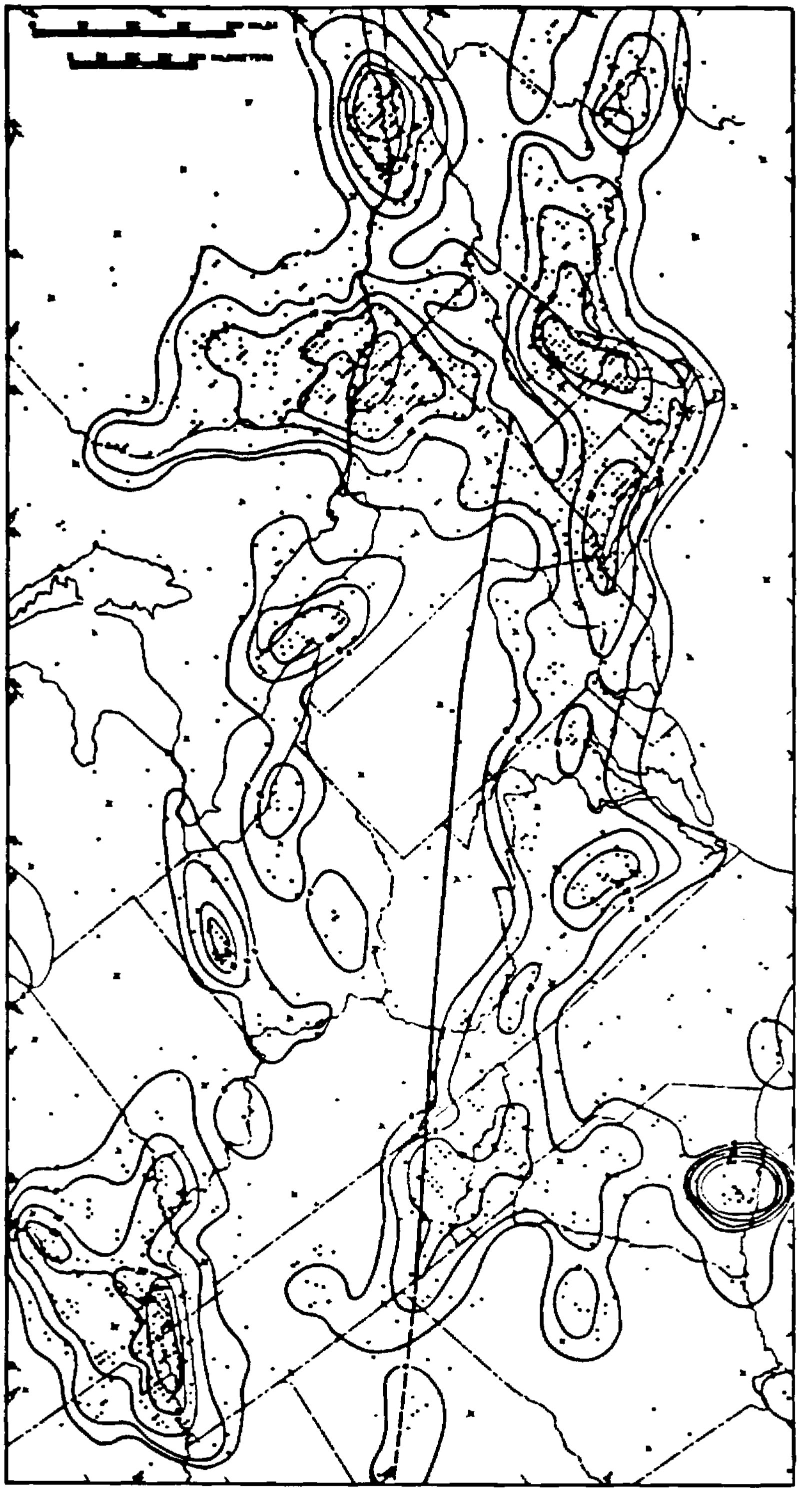


Figure 1.

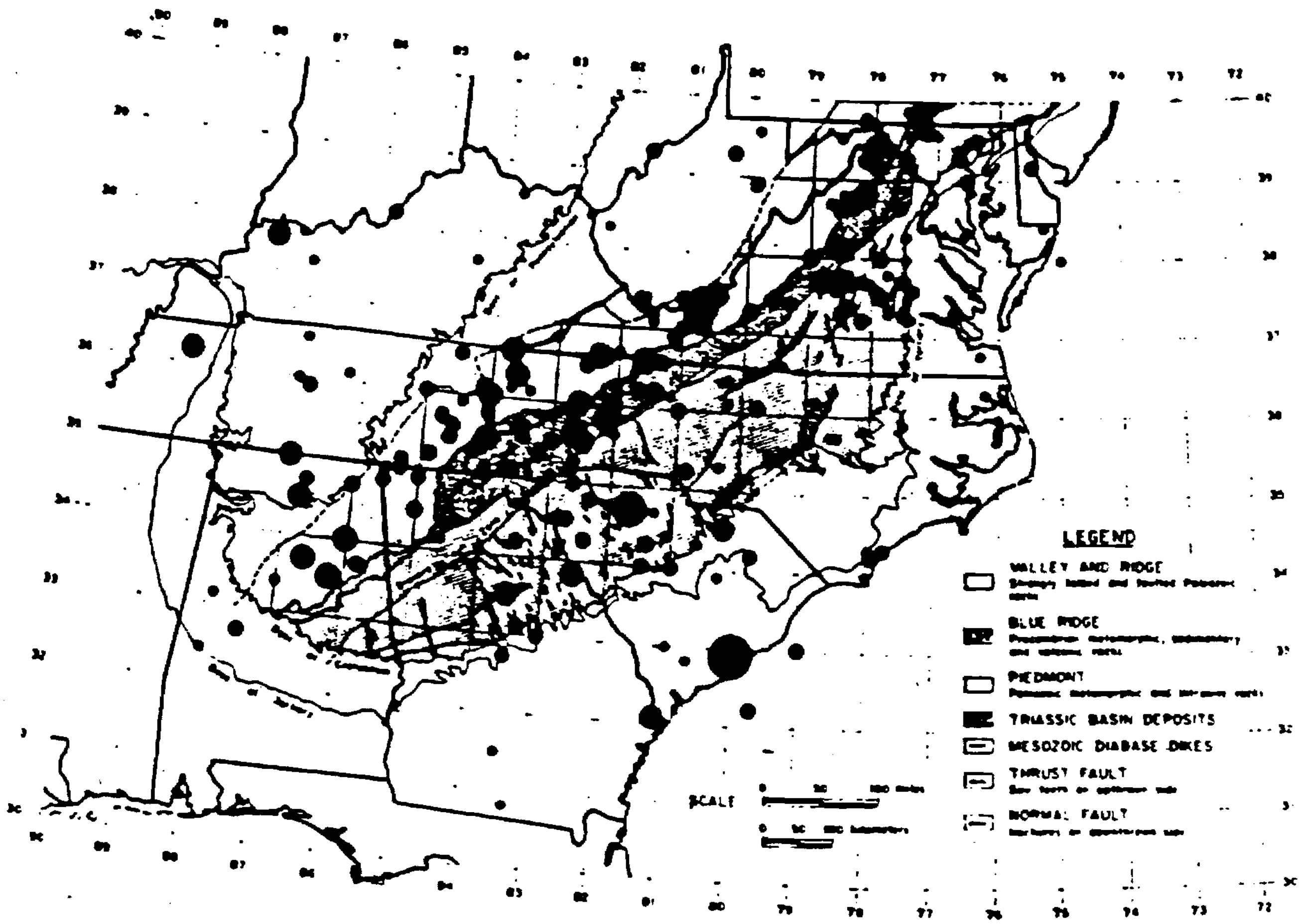
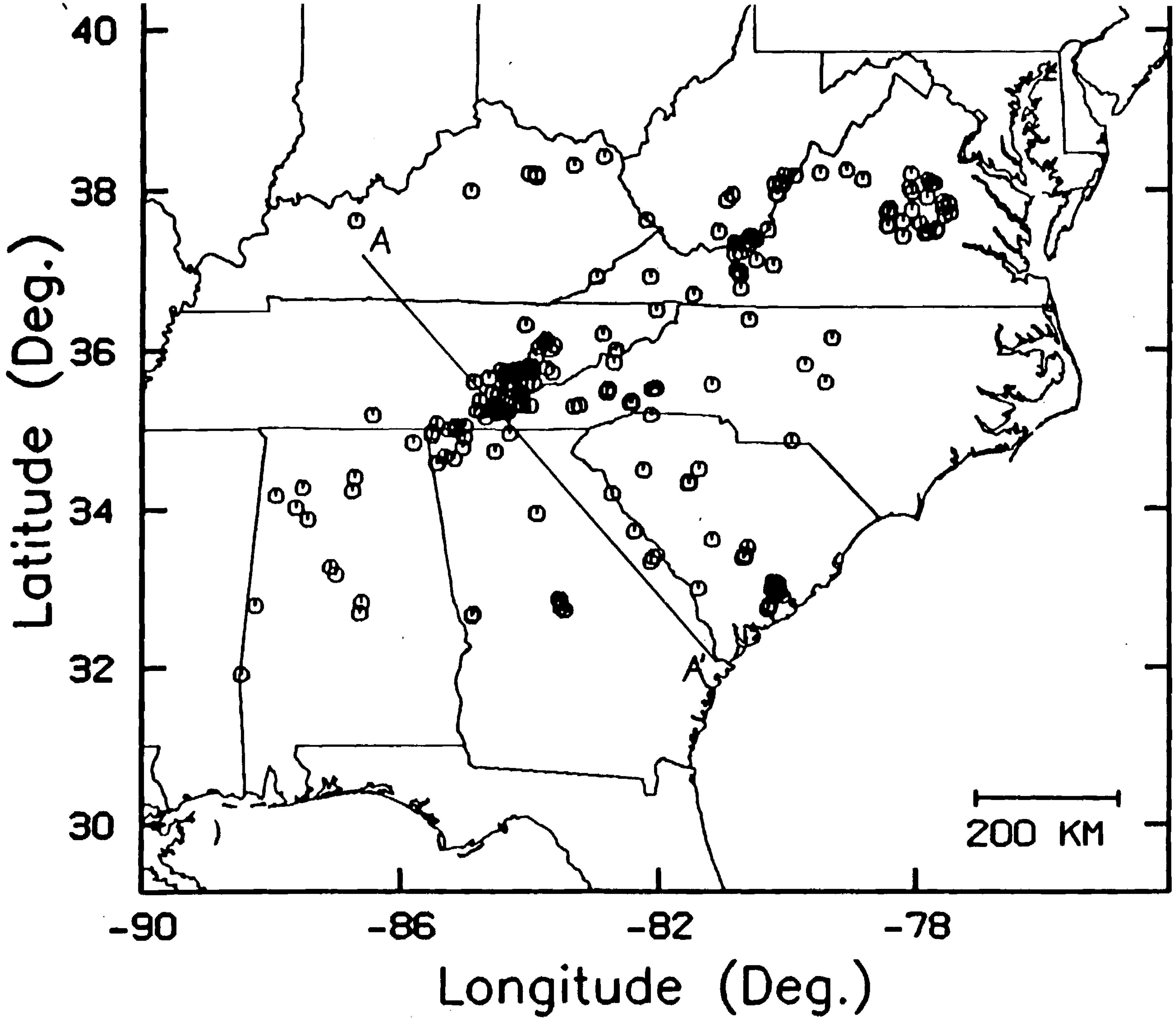

LEGEND
VALLEY AND RIDGE
BLUE RIDGE
PIEDMONT
TRIASSIC BASIN DEPOSITS
MESOZOIC DIABASE DIKES
THRUST FAULT
NORMAL FAULT
SCALE

Figure 2a.



Latitude (Deg.)
40
38
36
34
32
30
-90
-86
-82
-78
Longitude (Deg.)
A
A'
200 KM

Figure 2b.

REGIONAL BOUGUER ANOMALY OF THE SOUTHERN APPALACHIAN OVERTHRUST

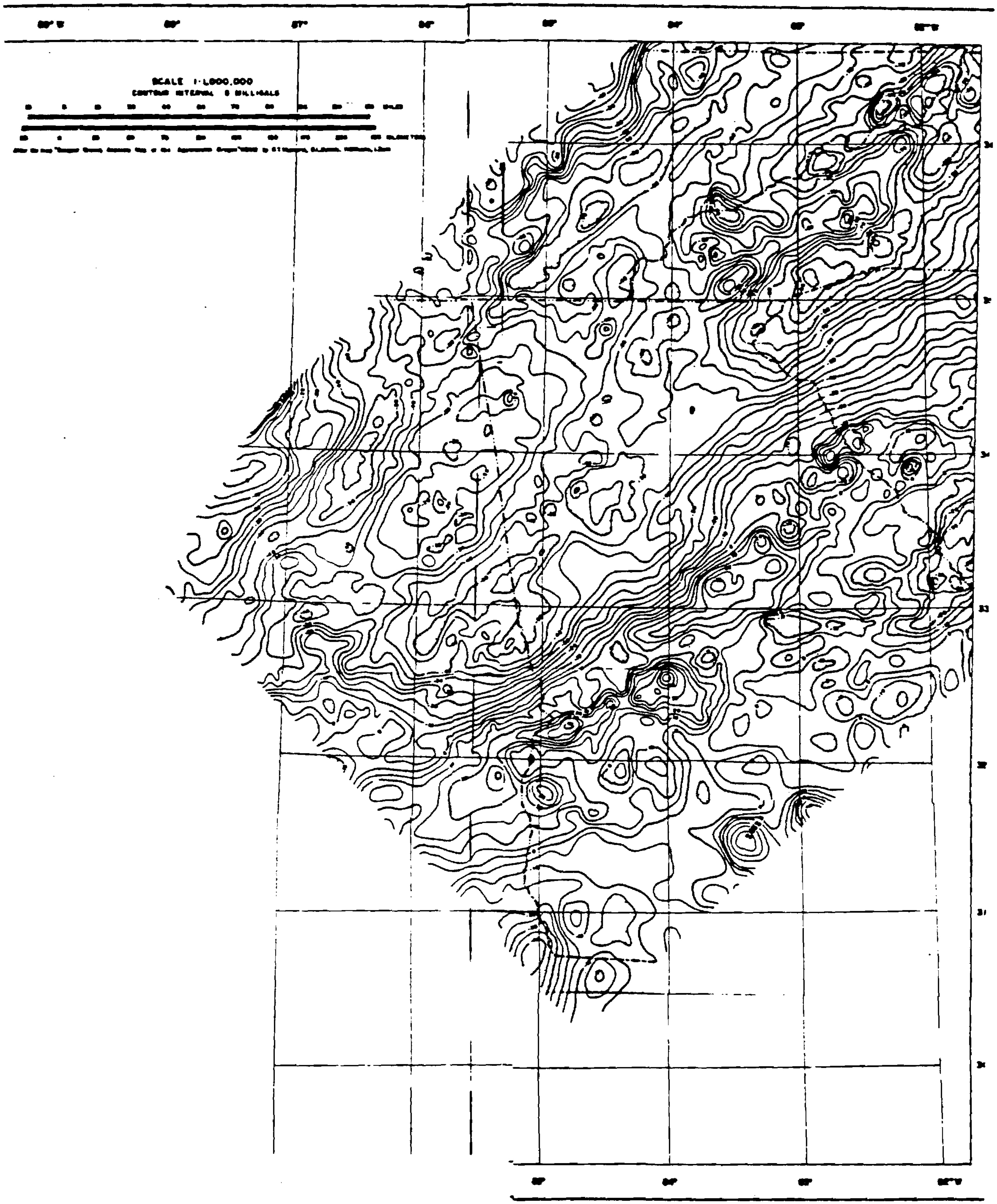


Figure 3.

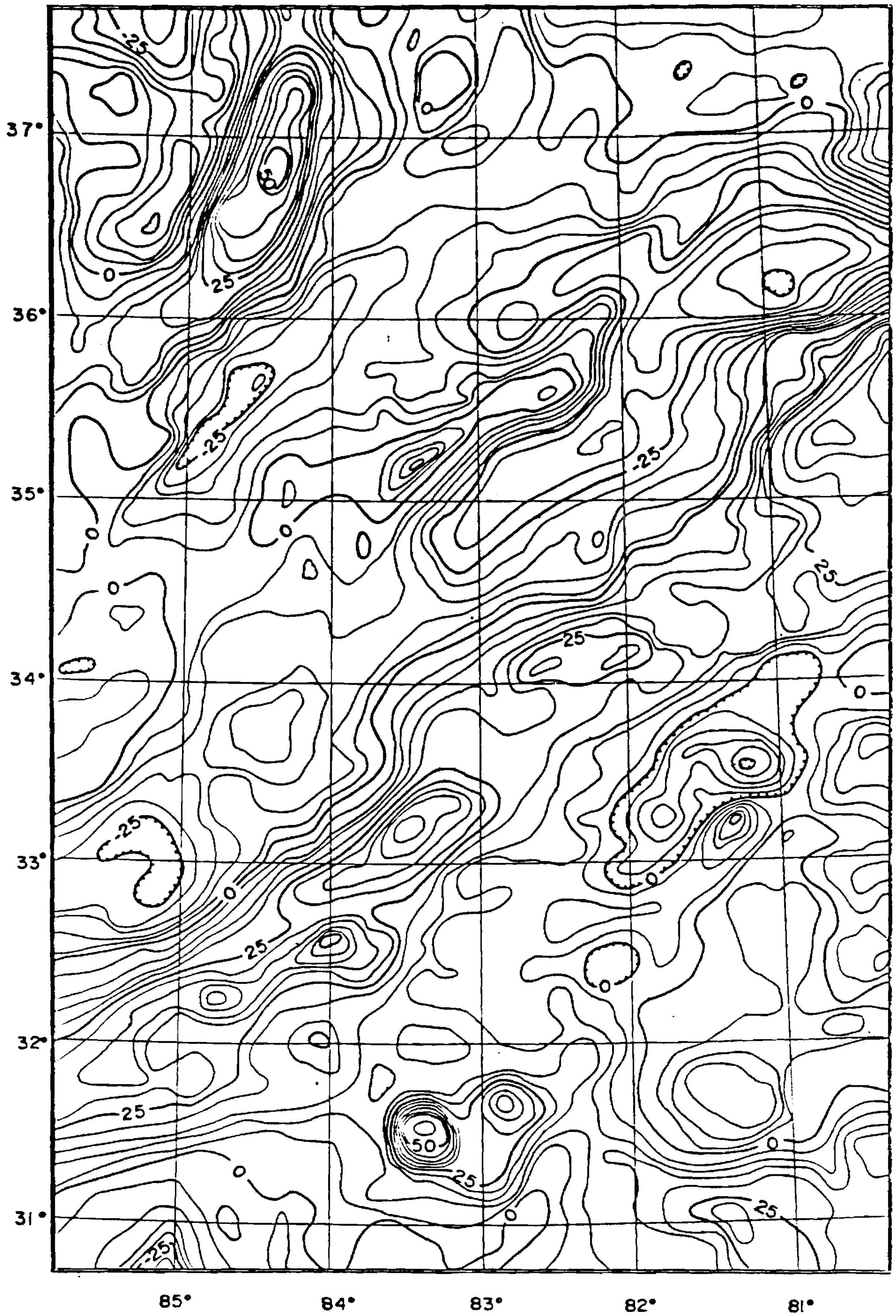

37°
36°
35°
34°
33°
32°
31°
85°
84°
83°
82°
81°
-25
0
25
-25
-25
0
0
0
25
-25
25
0
0
25
-25
0
0
25
0
25
50
25
0
0
25
-25

Figure 4.

STRESSES IN LAYERED ELASTIC SLAB OVER INVISCID FLUID

EQUATIONS AND BOUNDARY CONDITIONS

Z=0. $\quad T^{1}_{XZ} = 0. \qquad T^{1}_{ZZ} - G\rho U^{1}_{Z} = -P$

$\rho \; \lambda \; \mu$

$$\nabla . T = 0.$$

Z=H $\quad U^{N}_{Z} = U^{N+1}_{Z} \qquad T^{N}_{XZ} = T^{N+1}_{XZ}$

$U^{N}_{Z} = U^{N+1}_{Z} \qquad T^{N}_{ZZ} - T^{N+1}_{ZZ} + G\delta\rho U_{Z} = G\delta\rho(H-H_{N})$

$\rho \; \lambda \; \mu$

$$\nabla . T = 0.$$

Z=L

$T^{M}_{XZ} = 0. \qquad T^{M}_{ZZ} - G\delta\rho U^{M}_{Z} = -P$

$$T = \lambda \, \nabla . u \, I + \mu \, (\nabla u + \nabla u^{T})$$

Figure 5.

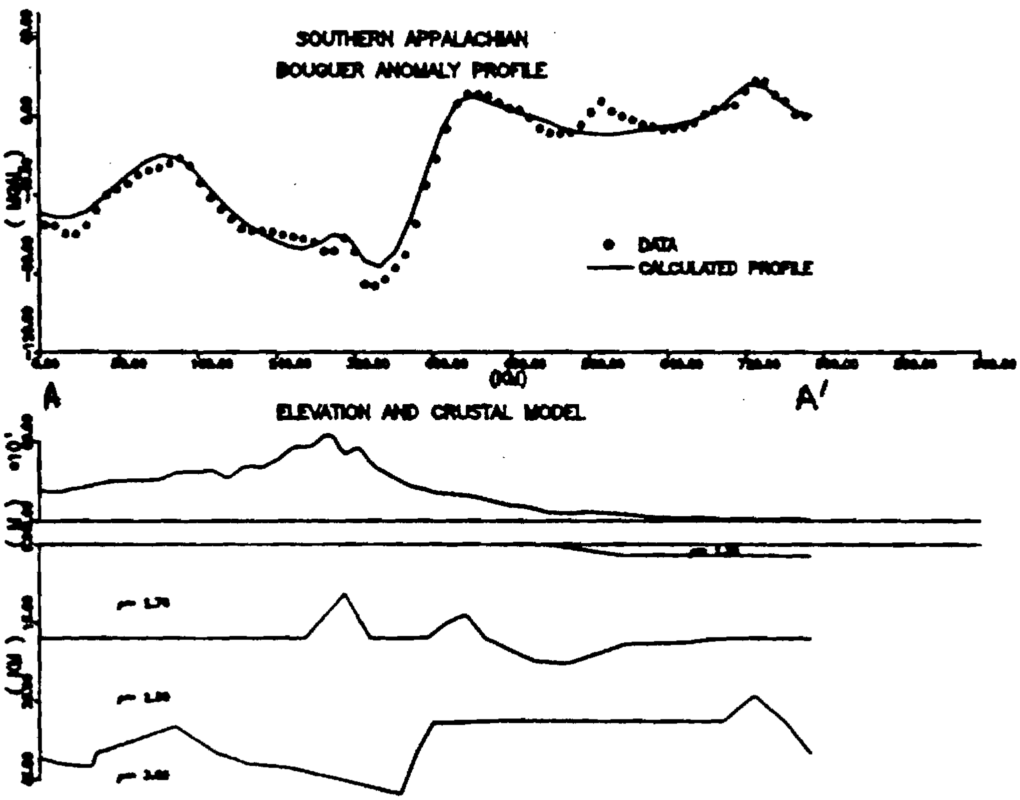

SOUTHERN APPALACHIAN
BOUGUER ANOMALY PROFILE
DATA
CALCULATED PROFILE
A
A′
ELEVATION AND CRUSTAL MODEL

Figure 6.

LITHOSPHERE MODEL APPALACHIAN 4

LITHOSPHERIC THICKNESS = 100KM

$\rho 1$ = 2.7 G/CM**3

$\mu 1$ = 10.**11 PA

G*ρ1*L/2/μ1 =0.0150

VERTICAL EXAGERATION 1

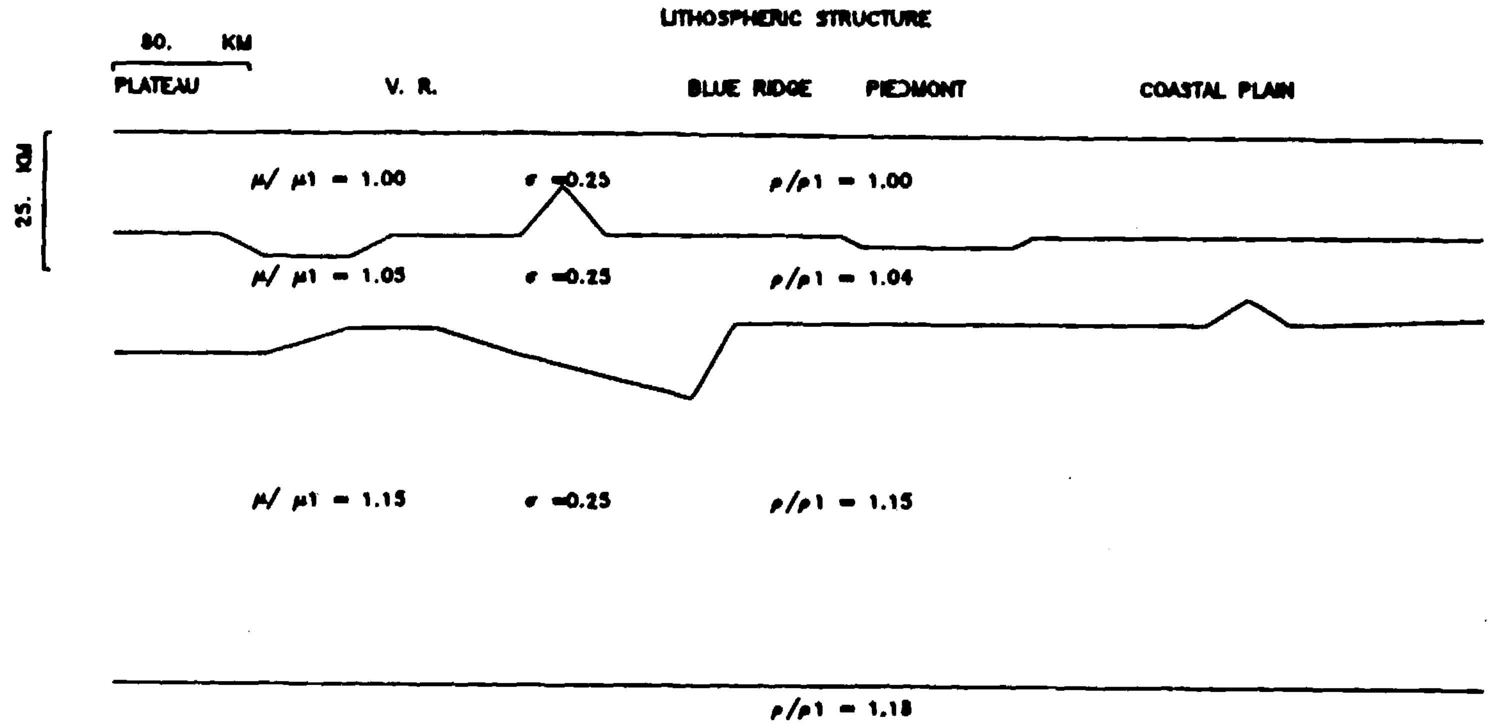


Figure 7a.

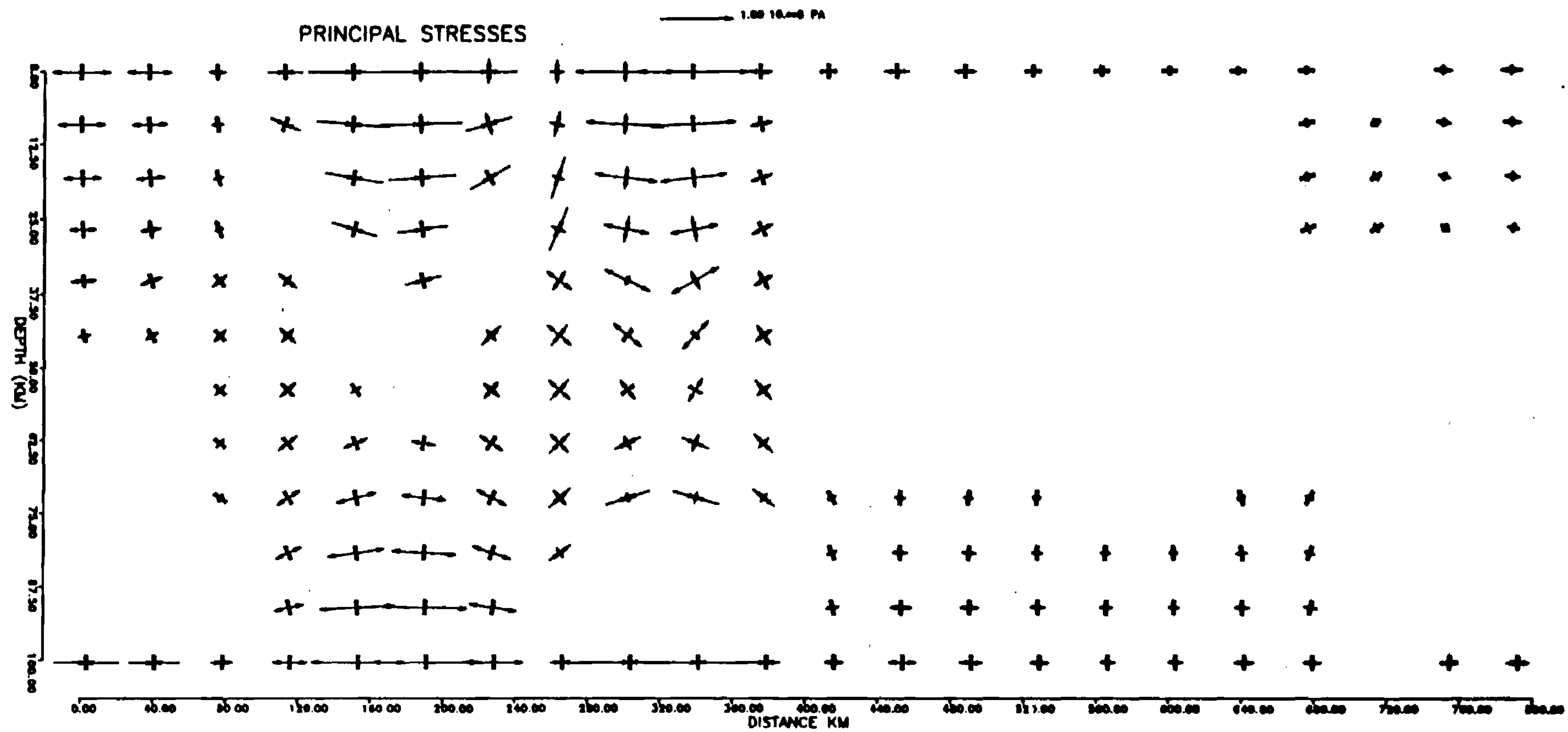


Figure 7b.

B STRESS DIFF. LITHOSPHERE MODEL APPALACHIAN 4

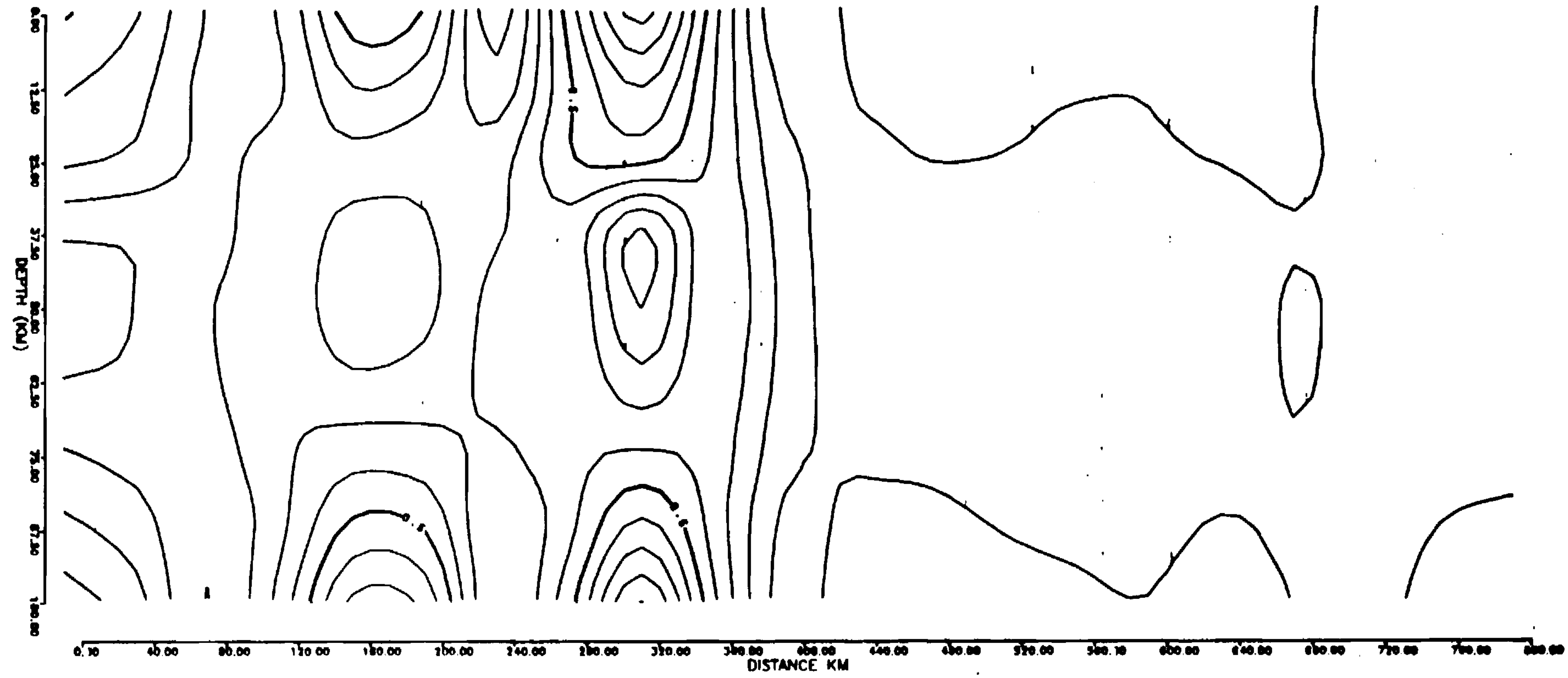


Figure 7c.

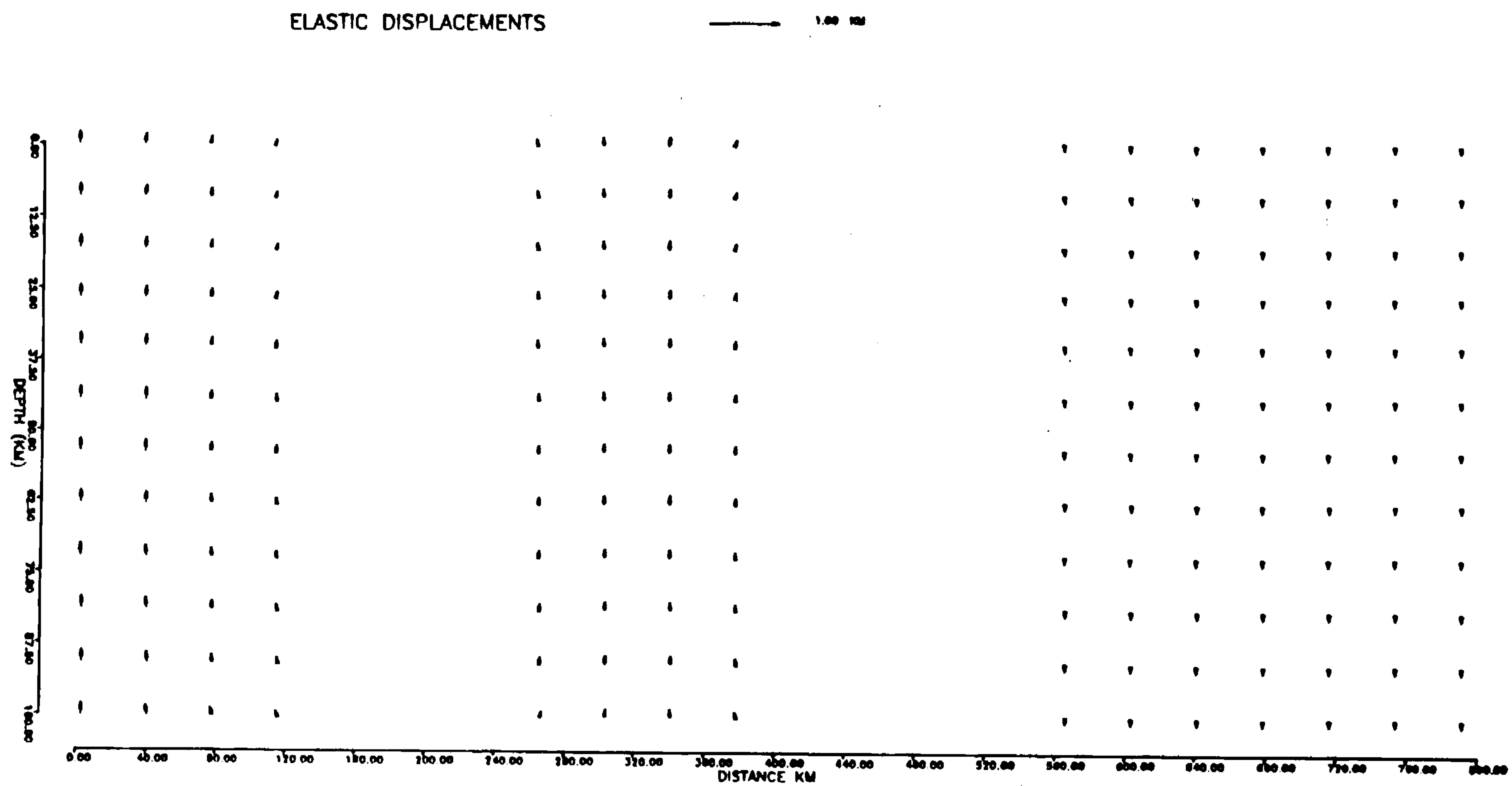


Figure 7d.

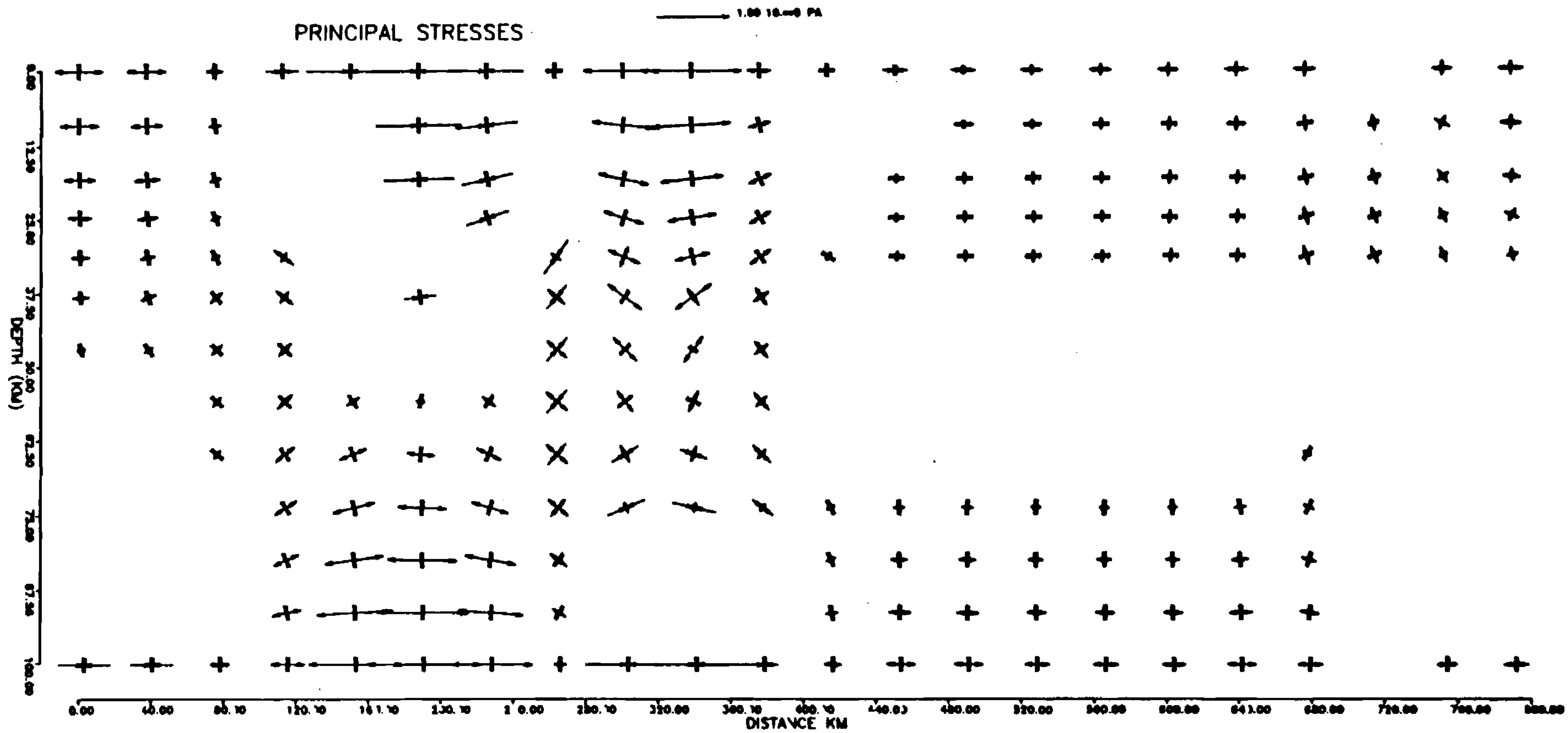
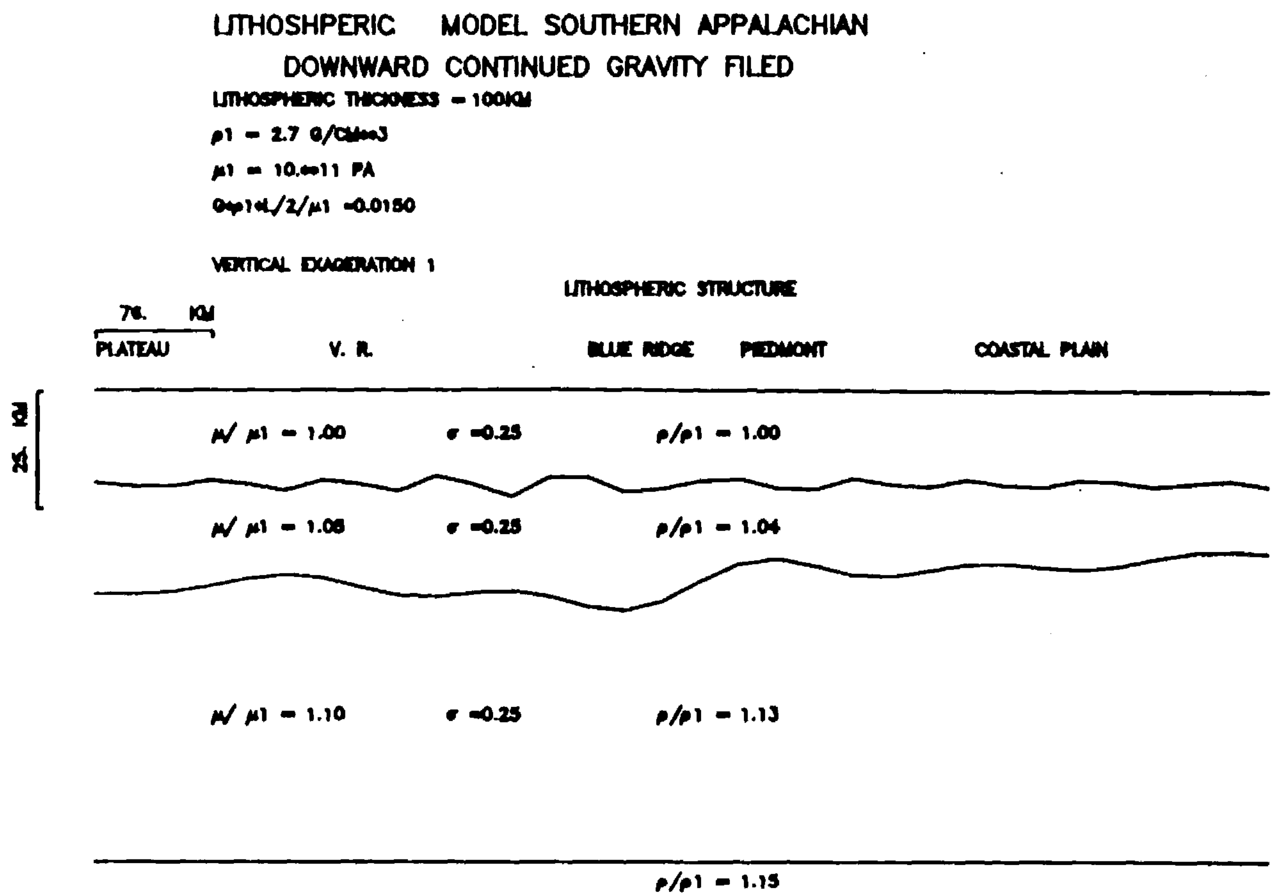


Figure 8.



LITHOSHPERIC MODEL SOUTHERN APPALACHIAN
DOWNWARD CONTINUED GRAVITY FILED
LITHOSPHERIC THICKNESS = 100KM
ρ1 = 2.7 G/CM**3
μ1 = 10.**11 PA
G*ρ1*L/2/μ1 =0.0150
VERTICAL EXAGERATION 1
LITHOSPHERIC STRUCTURE
76. KM
PLATEAU
V. R.
BLUE RIDGE
PIEDMONT
COASTAL PLAIN
25. KM
μ/ μ1 = 1.00
σ =0.25
ρ/ρ1 = 1.00
μ/ μ1 = 1.05
σ =0.25
ρ/ρ1 = 1.04
μ/ μ1 = 1.10
σ =0.25
ρ/ρ1 = 1.13
ρ/ρ1 = 1.15

Figure 9a.

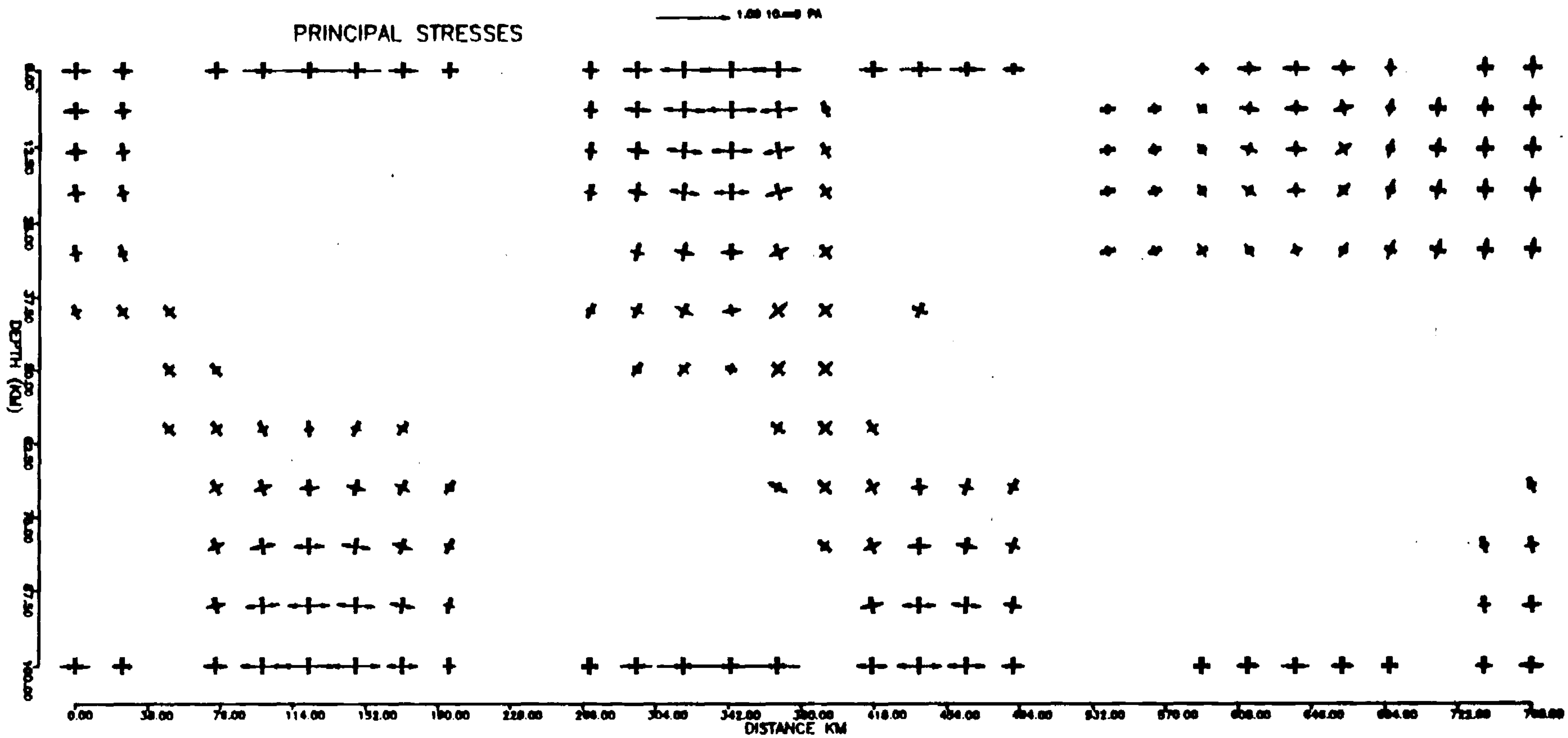


Figure 9b.

CONCLUSIONS AND RECOMMENDATIONS

The reported study shows convincingly that the internal sources (i.e., topography, crustal thickness heterogeneities) play a dominant role in generating the stresses that are observed in the lithospheric plate. Further studies need to be done along the same line to confirm the present report. In addition, there is a need to expand the model and include in it several effects that have not been taken into account yet.

1) The non-elastic behaviour of some parts of the lithosphere.

2) The three-dimensional effects. This is necessary because the surface and the deep structures do not always strike along the same direction (for instance, the buried rift and the Appalachian Mountains make a 45° angle). Also, three-dimensional calculations would permit the inclusion of the plate tectonic forces.

The undertaking of such studies is warranted by the success of this study in explaining intraplate seismicity.

APPENDIX I. Data on Scientific Collaborators.

J I A N   K U A N G

R E S U M E

Born: September 4, 1957, Shanghai (People's Republic of China)
Citizenship: China

<u>Education</u>

Georgia Institute of Technology, Atlanta, Georgia
Major: Geophysics   Minor: Math
Expected Degree: Ph.D. (June 1986)

Columbia University, New York
Major: Applied Geophysics   Minor: Math and Physics
Degree: M.S. (May 1983)

Chang Chen Geological College, China
Major: Geology   Degree: B.S. (January 1980)

<u>Work Experience</u>

Date: September 1983 - Present
Position: Research Assistant
Employer: School of Geophysical Sciences, Georgia Institute of Technology
Duties: Work for a project which is funded by the National Science Foundation

Date: September 1981 - May 1983
Position: Research Assistant
Employer: Lamont-Doherty Geological Observatory, Columbia University (in the Aldridge Lab of Applied Geophysics)
Duties: Work for oil company projects, programming

Date: February 1980 - August 1981
Employer: The Hydraulic Power Station Designing Company of Eastern China, Shanghai, China
Duties: Geological survey in southeast of China

<u>Organizations</u>

Society of Exploration Geophysicists, member since 1982
American Geophysical Union, member since March 1985

APPENDIX II: PUBLICATIONS AND COMMUNICATIONS

The results of the study have been reported at different conferences and meetings:

- Chapman Conference on Vertical Crustal Movement
- Southeastern Geological Society of America Meeting
- Seismological Society of America Meeting
- Geodynamics Research Symposium
- American Geophysical Union Meeting

They have been submitted for publication in the *Journal of Geophysical Research*.