

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

add

Date: 2/15/78

Project Title: A Geophysical Investigation of the Seismicity of the Clark Hill Reservoir Vicinity

Project No: G-35-633 (Follow-on to G-35-622 & G-35-616)

Gr Cd

Project Director: Dr. Leland T. Long

Sponsor: U.S. Nuclear Regulatory Commission

Agreement Period: From 9/1/74 Until 11/30/78

Type Agreement: Contract No. NRC-04-77-210 (Formerly AT(49-24)-0210 and AT(40-1)-4822); Mod. No. 5

Amount: \$41,086 Mod. 5 funds (\$140,433/NRC & \$14,000/GIT Contrib. for the total contract)

Reports Required: Quarterly Progress Reports; Annual Progress Reports; Final Report; Publications Preprints; Publications Reprints

Sponsor Contact Person (s):

Technical Matters

Contractual Matters
(thru OCA)

Kellogg V. Morton, Chief
Research Contracts Branch
Division of Contracts
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Defense Priority Rating: None

Assigned to: Geophysical Sciences (School/Laboratory)

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- Other _____

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT TERMINATION

Date: October 18, 1979

Project Title: A Geophysical Investigation of the Seismicity of the Clark Hill Reservoir Vicinity

Project No: G-35-633

Project Director: Dr. L. T. Long

Sponsor: U. S. Nuclear Regulatory Commission

Effective Termination Date: 4/30/79

Clearance of Accounting Charges: 4/30/79

Grant/Contract Closeout Actions Remaining:

- Final Invoice and Closing Documents
- Final Fiscal Report
- Final Report of Inventions
- Govt. Property Inventory & Related Certificate
- Classified Material Certificate
- Other Certified Statement of Costs

NOTE: CONTINUATION OF G-35-622 and G-35-616
CONTINUED BY G-35-662

Assigned to: Geophysical Sciences (School/Laboratory)

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Project Code (GTRI)
Other _____

G-35-63

(G-35-622)

NUREG-0013
G35-622

A GEOPHYSICAL INVESTIGATION OF THE
SEISMICITY OF THE CLARK HILL RESERVOIR VICINITY

Annual Progress Report No. 3

September 1, 1976 - November 30, 1977

Leland Timothy Long
School of Geophysical Sciences
Georgia Institute of Technology
Atlanta, Georgia 30332

Report Date - November 1977
Manuscript Submitted - June 1978

PREPARED FOR THE U. S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REGULATORY RESEARCH UNDER
CONTRACT NO. AT-(49-24) 0210 now (NRC-04-77-210)

A Geophysical Investigation of the Seismicity of the
Clark Hill Reservoir Vicinity

Annual Progress Report No. 3

Abstract

Seismic monitoring has continued at stations CH5 and CH6 in the Clark Hill Reservoir area and ETG in the Lake Sinclair area. Stations BEL near the Belair fault and 8 RF telemetry stations in the Clark Hill Reservoir area were monitored for shorter time periods (1 mo. to 5 mo.). The preliminary Bouguer Anomaly map of the Belair fault vicinity shows a large positive anomaly, interpreted as a mafic intrusion, southeast of the Belair fault. The analysis of micro-earthquake spectra, earthquake focal mechanisms, seismic refraction data, microearthquake locations and microearthquake activity variations with water level indicate that the earthquakes occur in a tensional environment in the Clark Hill Reservoir area and the earthquakes occur along prelubricated shallow joint surfaces or foliation planes. The causative stresses are low-level and could be derived from stress amplification or strength modification of coherent near-surface geologic units.

Scope of Investigation

To use gravity, seismic-refraction, and other available geophysical data to study the structures of the crust in the Clark Hill Reservoir area and to relate the structures to earthquake activity as recorded by a telemetered seismic array or by portable microearthquake recorders. To initiate seismic monitoring of the Belair Fault and of seismic activity near Lake Sinclair for similar studies of crustal structure and seismicity.

Results of Investigation During Year

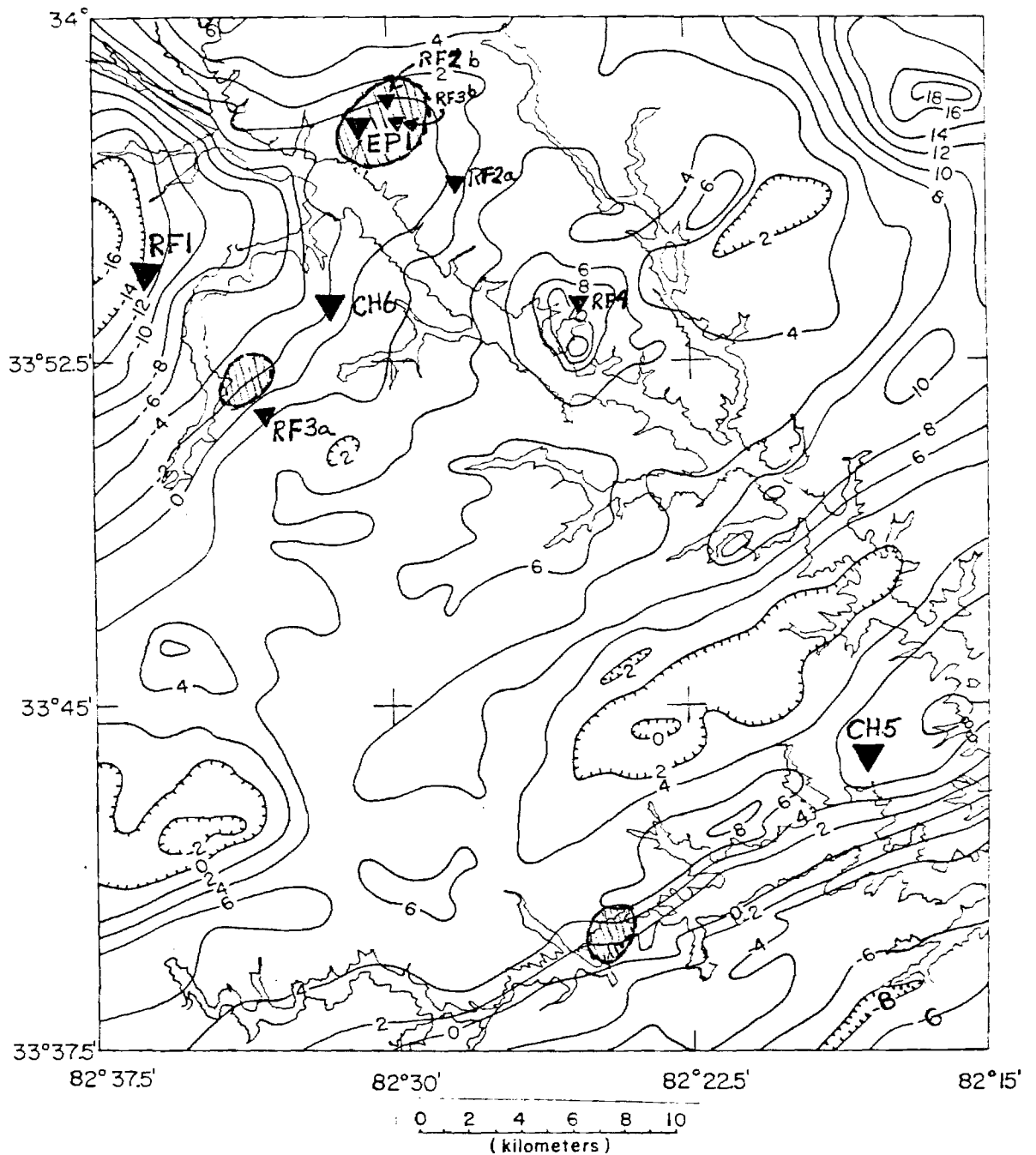
Recording Summary: Seismic monitoring continued without major interruption at CH5 (Double Branches in the southern part of the reservoir) and at CH6 (near Goshen in the northern part of the reservoir). Power was supplied to station CH6 to enable it to be used as a RF receiving station. Stations RF1, RF2a, RF3a and RF4 were established (see figure 1 for locations) and operated sporradically for about two months. Because of transmission difficulties or vandalism, stations RF3a, RF2a and RF4 were removed and stations RF2b and RF3b were established in the eepicentral area. RF2b and RF3b were removed in July 1977 and were replaced in October by a three-component system located at station EP1 (originally designated GEO).

A log of the activity has been maintained for the aftershock zone of the August 4, 1974 earthquake. Figure 2 shows the number of events recorded at CH6 (or its equivalent) versus water level. Two significant swarms occurred. The first occurred in September 1976 following a decrease in water level. The second occurred in November 1977 following a more rapid decrease in water level.


All regional data recorded at stations operated out of Georgia Tech have been made available for publication in the Southeast United States Seismic Network Bulletins. We will continue to cooperate fully with Gil Bollinger's efforts to make the Bulletin a significant document.

Station ETG has been recording in the Lake Sinclair area (see Figure 3 for location) in cooperation with the Wallace dam seismic net funded by Georgia Power. Events located by ETG and the Wallace Dam net are shown on Figure 3. The Lake Sinclair area is proving to be as active as the Clark Hill area.

Station BEL in the immediate vicinity of the Belair fault was operated from May 2, 1977 to July 14, 1977. It was a three-component, 4.5 Hertz system. No local earthquakes were identified. Because of the high noise environment of the area a good recording site could not be found and only larger Quarry Blasts were recorded.



**SIMPLE BOUGUER ANOMALY MAP OF THE
CLARK HILL RESERVOIR AREA**

▼ Seismic Stations
 Epicentral Zones

by
 Leland Timothy Long
 Harry Edward Denman
 Helmut Yung-An Hsiao
 George Eugene Marion
 (1976)

GEORGIA INSTITUTE OF TECHNOLOGY
research supported by
 Nuclear Regulatory Commission,
 Office of Nuclear Regulatory Research

Figure 1. Recording station locations September 1, 1976 to November 30, 1977

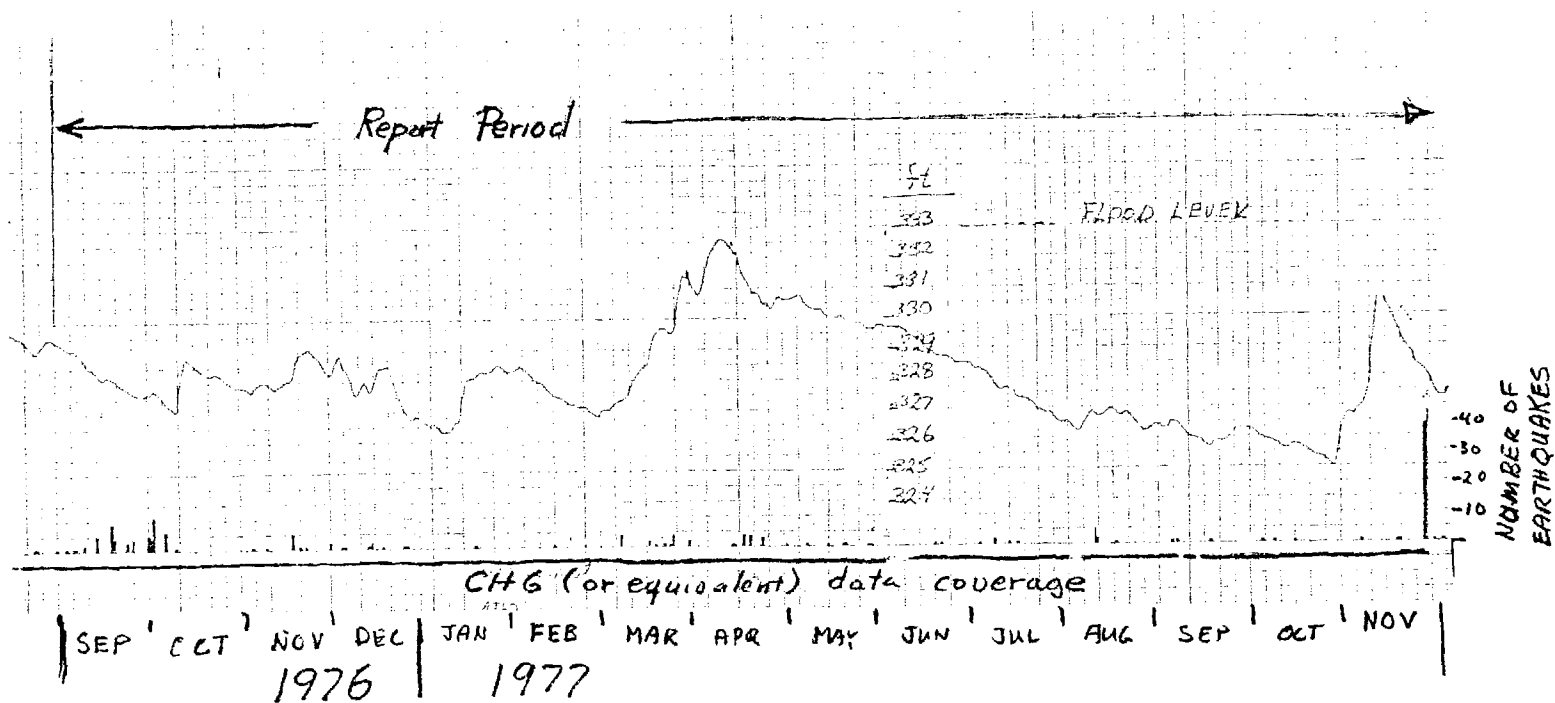


Figure 2. Water levels and seismic activity in the Clark Hill Reservoir area, during period of September 1, 1976 to November 30, 1977

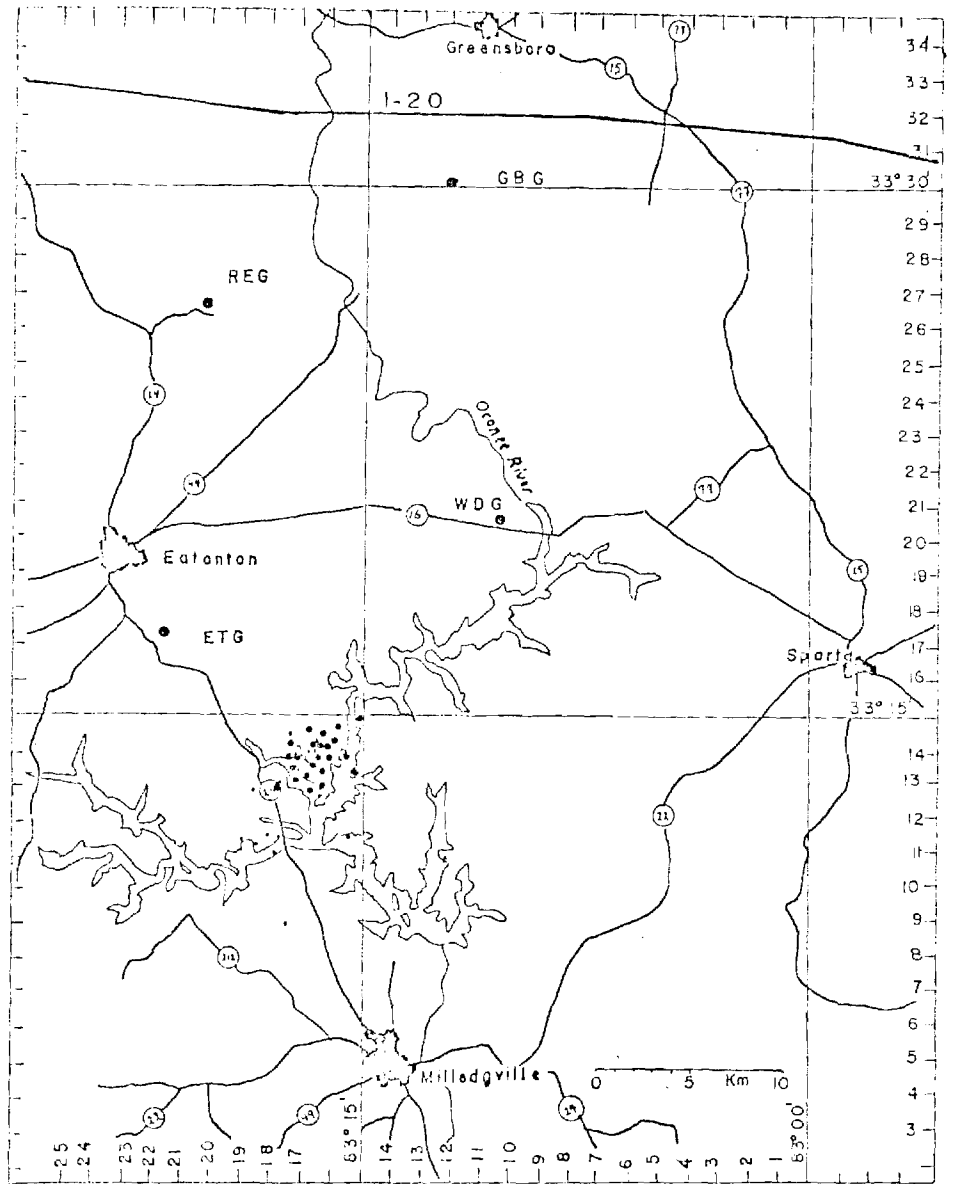


Figure 3. Earthquake locations and recording stations of the Wallace Dam seismic net

Belair Gravity Study: A preliminary Bouguer gravity map of the vicinity of the Belair fault zone, Georgia, is complete (See Figure 4). The gravity data revealed the existence of a mafic intrusion in the crust located southeast of the Belair fault. The edge of the mafic intrusion parallels the Belair fault and is probably related. However, the age of the mafic is probably late Precambrian or early Cambrian.

Spectral Studies: The significant results of the spectral analysis of the local seismic data is developed in a masters theses by George E. Marion. Of particular interest is the high frequency trend of the CHRA and Jocussee Reservoir spectra (W-3) which differs significantly from the W-2 slope for the Maryville, Tennessee, earthquakes. The ratio of P-wave to S-wave corner frequency for the Jocussee area were typically greater than unity, for CHRA events the ratio was near unity and for Maryville, Tennessee events less than unity. These observations imply transonic rupture velocities for CHRA and Jocussee events, probably along existing surfaces, whereas the Maryville events would be of subsonic rupture. The differences observed may prove to be fundamental differences between reservoir induced earthquakes (Jocussee and in part CHRA) and tectonic events (Maryville, Tennessee and in part CHRA).

Software was developed to utalize a graphical to digital on line digitizer for future spectral studies.

Focal Mechanisms: A general investigation of focal mechanisms in the southeast United States was the topic of the masters theses of Stewart Guinn. The CHRA portion of his analysis indicates two predominant mechanisms. The August 2, 1974 main event showed possible movement on a near vertical plane striking $N80^{\circ}+20E$ with the north side moving down. Aftershocks showed both the mechanism of the main event and movement on a near-vertical fault plane striking $N60^{\circ}+20W$ with the northeast side moving up. The main event focal mechanism corresponds to the general direction of the regional foliation of the rocks. The second mechanism corresponds to a prominent joint set in the epicentral area.

The technique developed by Stewart Guinn in his theses solves for the domain of valid solutions using a complete search of the focal sphere. The method and associated computer program will be published in Earthquake Notes.

Seismic Refraction: The seismic refraction data for the CHRA was developed into a masters theses by David Dunbar. His results were used to revise the epicenters of the shallow focus CHRA events in the aftershock zone of the August 2, 1974 earthquake. The method required development of a table of travel times versus depth and distance to allow reliable depth estimates. The new location revealed two sets of planes compatible with the focal mechanism solutions mentioned above.

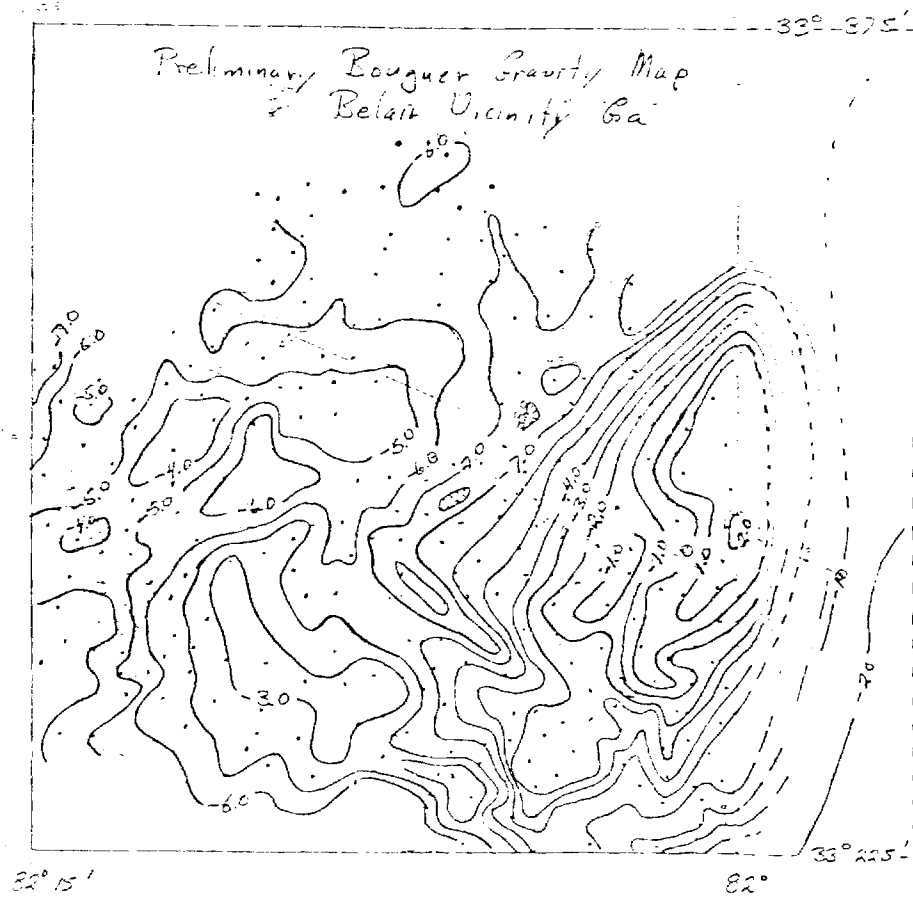


Figure 4. Preliminary version of Bouguer Anomaly map of the Belair fault vicinity, Georgia

Earthquake Mechanism: The studies of Seismic spectra, focal mechanism and relocated events indicate the earthquake mechanism for the CHRA events and perhaps Piedmont Province earthquakes in general is one of movement along prelubricated shallow joint surfaces or foliation planes. The stress is generally tensional, the causative stresses are low-level and could be derived from stress amplification or strength modification of coherent near-surface geologic units. This mechanism allows a restriction on the size of the maximum plausible earthquake by placing practical limits on the size of the fault plane and magnitude of the stress drop. The upper limit in size for the fault plane is the 40 Km² implied by microearthquake activity near Jocussee lake. CHRA microearthquakes and geologic units indicate about 10 Km². The stress drop estimates for these events is consistently about 6 bars. Using 6 bars and a fault plane of 40 Km² in the relation of Randal (1973) a magnitude 5.6 event is the maximum plausible induced earthquake.

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- Dunbar, David Malcolm (1977). A seismic model of the Clark Hill Reservoir Area, Master's thesis, Georgia Institute of Technology 59pp.
- Hsiao, Helmut Yung-An (1977). The "stress amplification" mechanism for intraplate earthquakes applied to the southeast United States, Master's thesis, Georgia Institute of Technology 84pp.
- Marion, George Eugene (1977). A spectral analysis of microearthquakes that occur in the Southeastern United States, Master's thesis, Georgia Institute of Technology 154 pp.

Publications and Reports

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- Long, Leland Timothy (1977) Maximum "induced" earthquake, Clark Hill Reservoir Area, Appendix 1, section B in Geological and Seismological evaluation of earthquake hazards at the Richard B. Russell Project. U. S. Army Engineer District, Savannah, Corp. of Engineers, Savannah, Georgia.

Talks

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- Marion, George E. and L. T. Long (1977). Spectral analysis of Southeastern United States Microearthquakes, paper presented at Southeastern Section Geological Society of America meeting March 24, 1972.
- Long, Leland Timothy (1977). Regionization of the South Carolina Seismic Zone, paper presented at American Geophysical Union meeting, June, 1977.

Guinn, S. A. and L. T. Long (1977). A computer method for determination of valid focal mechanism solutions using P-wave first motions applied to Southeastern United States earthquakes, paper presented at Eastern Section Seismological Society meeting October 13, 1977.

Long, L. T. and Yang-An Hsiao, (1977). Some seismic implications of stress amplification in rigid structures of the crust. Paper presented at Southeastern Section, Seismological Society of America, October 13, 1977.

6-35-633

NUREG-0014
G35-633

A GEOPHYSICAL INVESTIGATION OF THE
SEISMICITY OF THE CLARK HILL RESERVOIR VICINITY

Quarterly Progress Report No. 11

December 1, 1977 - February 28, 1978

Leland Timothy Long
School of Geophysical Sciences
Georgia Institute of Technology
Atlanta, Georgia 30332

Report Date - August, 1978

PREPARED FOR THE U.S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REGULATORY RESEARCH UNDER
CONTRACT NRC-04-77-210

A Geophysical Investigation of the Seismicity of the
Clark Hill Reservoir Vicinity

Quarterly Progress Report No. 11

Abstract

Seismic monitoring has continued at stations CH5 and CH6 in the Clark Hill Reservoir Area and at Station ETG in the Lake Sinclair area. Focal mechanism studies which were part of Stewart Guinn's thesis imply stress directions which migrate with time or which give fault planes which are in agreement with near vertical foliation or near vertical joint set directions.

Scope of Investigation

The objective of this work is to determine the relation between geology and seismicity and to delineate the tectonic environment that is responsible for the earthquakes in the Clark Hill Reservoir vicinity. Seismic activity rates and water levels in the Clark Hill Reservoir will be monitored. Microearthquakes will be recorded with portable equipment and used to obtain spectral signatures, focal mechanisms and locations. Continuous seismic coverage will be maintained in the area of the August 2, 1974 (Magnitude 4.3) earthquake. One station will be used to monitor activity near Lake Sinclair.

Four areas where past seismic activity has been high will be surveyed using direct current electrical resistivity soundings to depths of 0.5 to 1.0 km to determine whether the water content in hypocentral areas is significantly higher than normal.

Results of Investigation During Quarter

Recording Summary: Seismic monitoring continued without major interruption at CH5 (Double Branches in the southern part of the reservoir) and at CH6 (near Goshen in the northern part of the reservoir). However EP1 (formally GEO) did not operate from December to March 1978 because the radio receivers at CH6 were vandalized.

A log of the seismic activity was maintained for the aftershock zone of the August 4, 1974 earthquake. Figure 1. shows the number of events recorded at CH6 (or its equivalent) versus water level. The overall activity level was low during the quarter.

All regional data recorded at stations operated out of Georgia Tech have been made available for publication in the Southeast United States Seismic Network Bulletins.

Station ETG has been recording in the Lake Sinclair area (See Figure 2 for location) in cooperation with the Wallace Dam seismic net funded by Georgia Power Company. Events located by ETG and the Wallace Dam net are shown on Figure 2. The Lake Sinclair area is as active as the Clark Hill Reservoir Area.

Focal Mechanisms: During the period, the general investigation of focal mechanisms in the southeast United States was completed as a Masters Thesis by Stewart Guinn. A copy is attached to this report since it represents a significant amount of work and analysis. The first portion of the thesis was a development of a computer program to map the domain of valid focal mechanisms. The program was then used to study in detail the focal mechanisms at nine locations in the Southeastern United States. The results are summarized in figure 3. In almost all cases the "B" or null axis is near or at horizontal. Also the "P" and "T" axes were typically at angles close to 45° indicating near vertical planes of movement for most earthquakes. Except for the three epicenters in the folded Appalachians which indicate possible horizontal compression oriented North-South, the indicated horizontal stress field is of low magnitude or tensional.

A significant portion of Stewart Guinn's thesis concerned the Clark Hill Reservoir area. The focal mechanism determined for the August 2, 1974 main earthquake indicates a tension axis directed north and plunging 45° . Two possible positions for the P axis are indicated. The first is toward the east and nearly horizontal. The second plunges at 45° toward the south. The first implies reverse movement on northwest or northeast striking planes dipping respectively to the southwest and southeast. The second focal mechanism implies normal or high-angle reverse type movement on an eastwest near-vertical fault plane. The second solution is the preferred solution since it corresponds to focal mechanism from a number of aftershocks. The aftershock data indicate that a second type of focal mechanism is active in the aftershock zone. The second type of mechanism is normal movement on northwest striking plane which is near to vertical or dipping southwest.

The conclusions based on focal mechanism studies and other data are as follows: (1) the stress directions inferred are not fixed but rather migrate with time, (2) the possible fault plane orientations in most cases are in good agreement with foliations or joint set directions, (3) the focal mechanisms appear to be dominated by nearly vertical faults with no uniform preference for normal or reverse type movement, and (4) the CHRA activity occurs along multiple planes rather than on a single dominant shear zone.

Resistivity Study: Instrumentation for the resistivity field work was designed during the Quarter.

Progress During Quarter: The project progressed at the scheduled rate during the quarter.

Efforts Expended During Quarter: The principle investigator expended an average of 20% time on the project during the quarter. One electronics technician was employed at approximately 30% time and one graduate student at one half time.

BIBLIOGRAPHY

Thesis

Guinn, Stewart Allen (1977), Earthquake focal mechanisms in the Southeastern United States, M.S. Thesis, Georgia Institute of Technology, Atlanta, Georgia, 150 pp.

Publications

Guinn, Stewart and Long, L.T. (1977). A Computer Method for determination of valid focal mechanisms using P-wave first motions, Earthquake Notes Vol. 48, No. 4, p. 21-33.

Guinn, S.A. and Long, L.T. (1977). A gravity survey of the Dalton, Georgia area. (in Press) Georgia Geological Survey Bulletin.

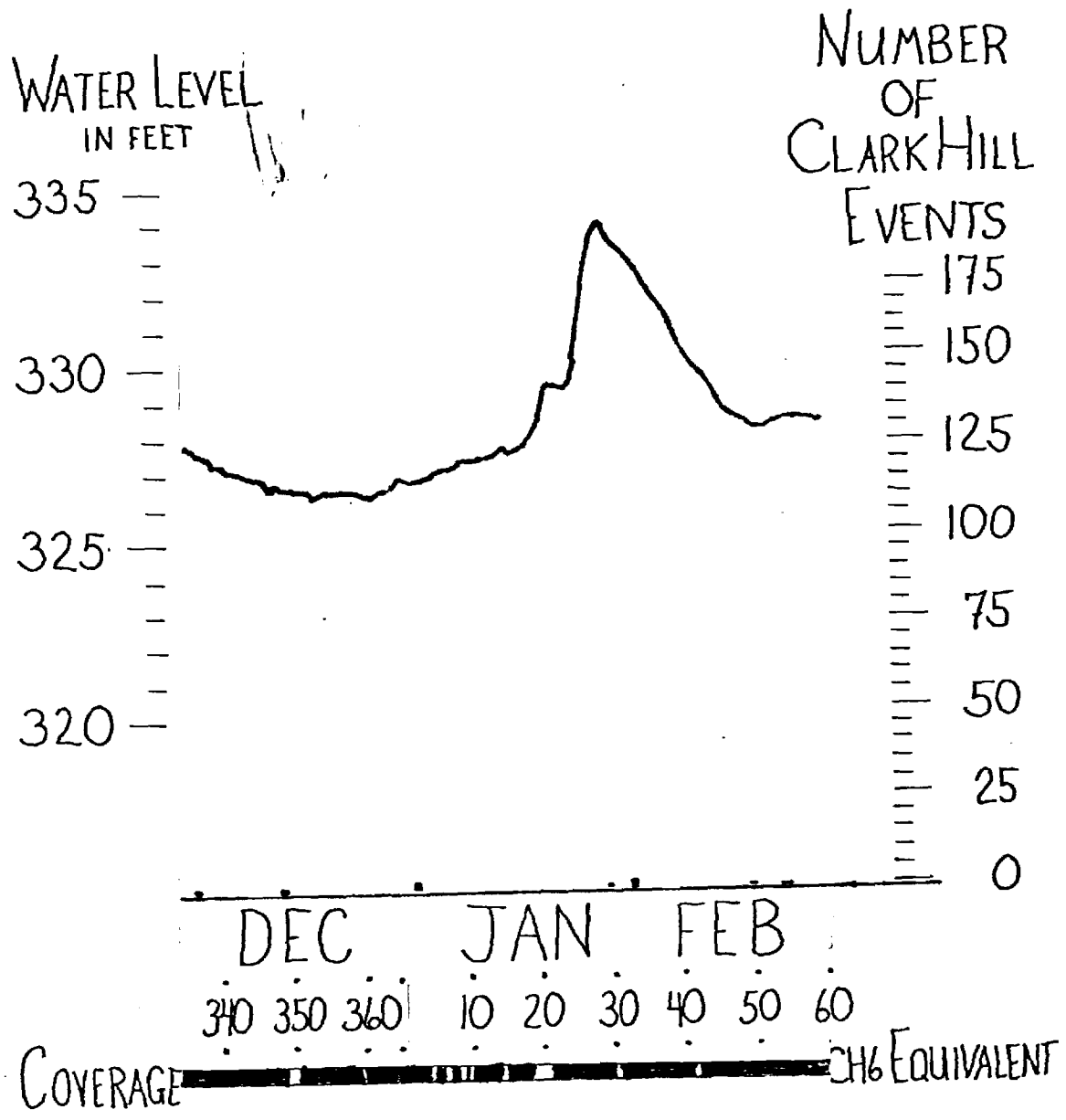


Figure 1. Seismic activity and water levels in the Clark Hill Reservoir vicinity. All epicenters are in the aftershock zone of the August 4, 1974 earthquake.

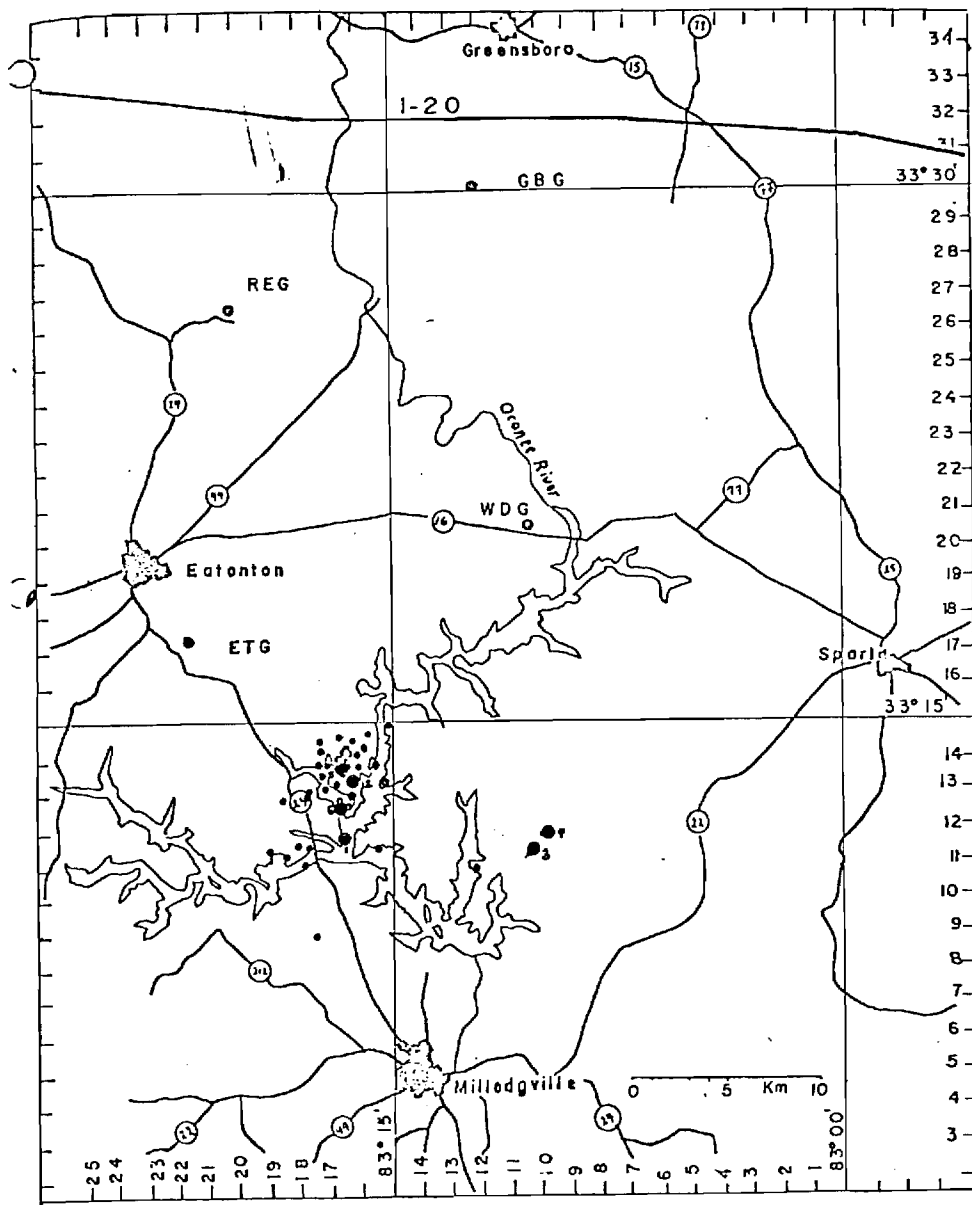


Figure 2. Epicenters located in the Lake Sinclair area. Large dots are epicenters for earthquakes occurring during the period. Small dots are previously located earthquakes.

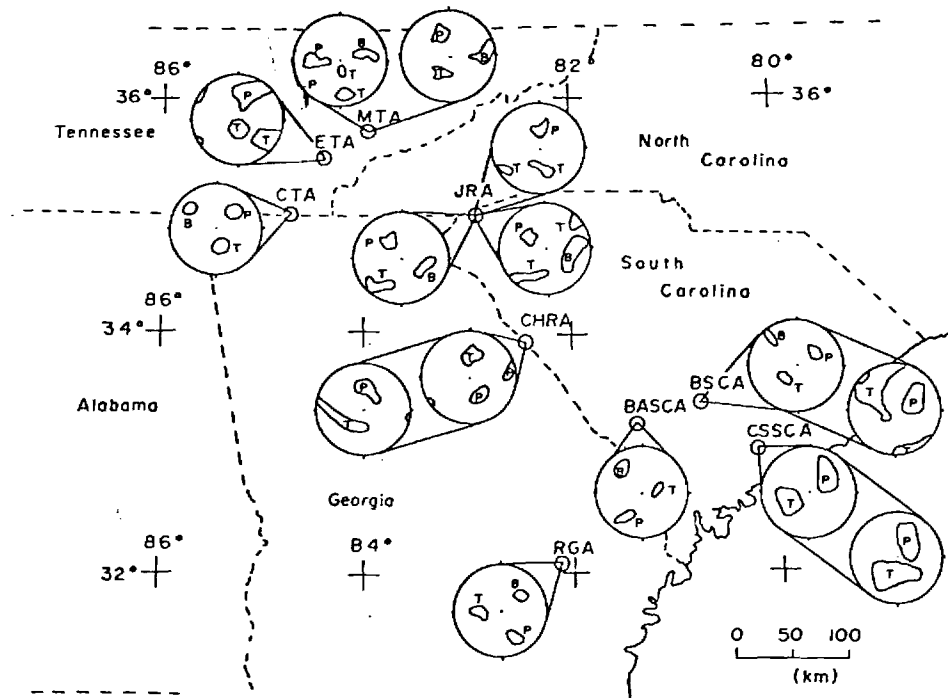


Figure 3. Domains of valid focal mechanisms for southeastern United States earthquakes (taken from Stewart Guinn's Masters Thesis).

NUREG-0015
G35-633

A GEOPHYSICAL INVESTIGATION OF THE
SEISMICITY OF THE CLARK HILL RESERVOIR VICINITY

Quarterly Progress Report No. 12

March 1, 1978 to May 31, 1978

Leland Timothy Long
School of Geophysical Sciences
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Atlanta, Georgia 30332

Report Date - December, 1978

PREPARED FOR THE U. S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REGULATORY RESEARCH UNDER
CONTRACT NRC-04-77-210

A Geophysical Investigation of the Seismicity of the
Clark Hill Reservoir Vicinity

Quarterly Progress Report No. 12

Abstract

Seismic monitoring has continued at stations CH5, CH6 and EP1 in the Clark Hill Reservoir area and at station ETG in the Lake Sinclair area. An investigation of the geologic literature and geophysical data inspired a model for the central Piedmont as a late Precambrian to Cambrian continental rift zone with the Carolina Slate belt as its axis. The current stress condition in the Clark Hill Reservoir area based on aftershock data and focal mechanisms appears to be tensional.

Scope of Investigation

The objective of this work is to determine the relation between geology and seismicity and to delineate the tectonic environment that is responsible for the earthquakes in the Clark Hill Reservoir vicinity. Seismic activity rates and water levels in the Clark Hill Reservoir will be monitored. Microearthquakes will be recorded with portable equipment and used to obtain spectral signatures, focal mechanisms and locations. Continuous seismic coverage will be maintained in the area of the August 2, 1974 (Magnitude 4.3) earthquake. One station will be used to monitor activity near Lake Sinclair.

Four areas where past seismic activity has been high will be surveyed using direct current electrical resistivity soundings to depths of 0.5 to 1.0 km to determine whether the water content in hypocentral areas is significantly higher than normal.

Results of Investigation During Quarter

Recording Summary: Seismic monitoring continued without major interruption at CH5 (Double Branches in the southern part of the reservoir) and at CH6 (near Goshen in the northern part of the reservoir). Station EP1 (formerly GEO) was reestablished as a three component system on March 23, 1978.

A log of the seismic activity was maintained for the aftershock zone of the August 2, 1974 earthquake. Figure 1 shows the number of events recorded at CH6 (or its equivalent) versus water level. The overall activity level was low during the quarter. All of the local and regional data recorded at stations operated out of Georgia Tech have been made available for publication in the Southeast United States Seismic Network Bulletins.

Station ETG has been recording in the Lake Sinclair area (see Figure 2) in cooperation with the Wallace Dam seismic net funded by Georgia Power Company. Events located by ETG and the Wallace Dam net are shown in figure 2.

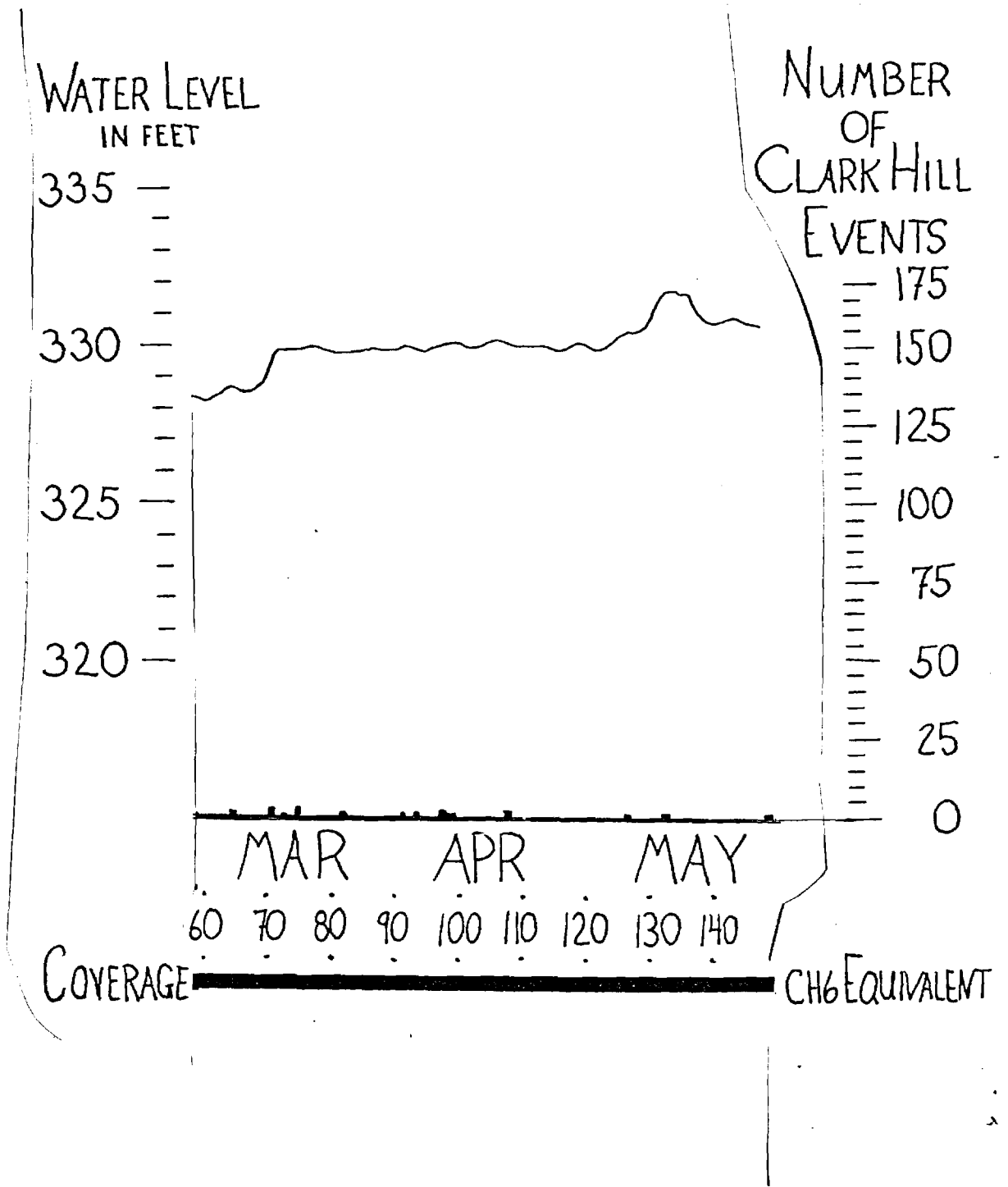


Figure 1. Log of activity versus water level for Clark Hill Reservoir area.

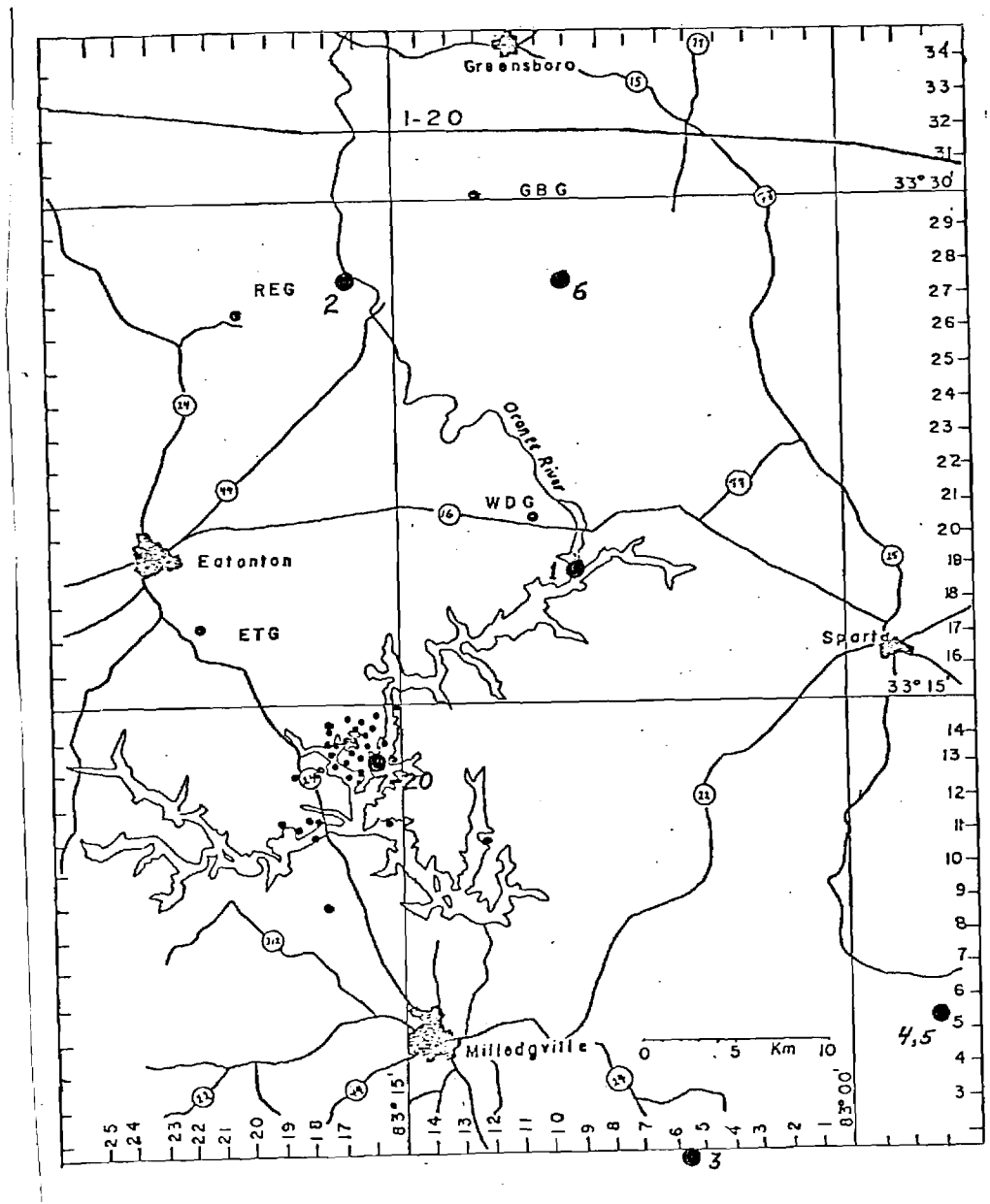


Figure 2. Earthquakes located in the Lake Sinclair region with the help of station ETG. Large dots are events occurring during the three month reporting period.

Geological Data: During the quarter an effort was initiated to summarize available geologic data and relate that data to the geophysical data obtained on the project. Most concepts of the tectonic history of the Central Piedmont were found to be inconsistent with the geophysical data for shallow crustal structure in the Clark Hill Reservoir area and also inconsistent with crustal thickness models based on gravity data in the Central Piedmont. As a consequence, the geological summary developed into a more extensive analysis than was originally planned. The analysis suggests that the Carolina Slate belt rocks in the Clark Hill Reservoir area may delineate the axis of a late Precambrian to Cambrian crustal rift zone and represent remnants of rift-derived volcanic and sedimentary rocks. The negative Bouguer anomalies southeast of the Clark Hill Reservoir area near Augusta may represent evidence for a detached fragment of continental crust. The pattern of the magnetic and gravity anomaly contours for the northwestern edge of this fragment is similar to the pattern of magnetic anomaly contours and the Piedmont gravity gradient in central Georgia, northwest of the Clark Hill Reservoir area. The zone of rifting or crustal extension is nearly 160 km wide and can be traced into Virginia. Gravity profiles across the edges of the hypothesized rift indicate the existence of anomalies due to high-density rocks in the upper 5 km of the crust in the proposed rift and anomalies due to low-density rocks at the base of the adjacent continental crust. Seismic data indicate a typical rift-zone velocity structure which consists of a high-velocity (6.3 km/sec) discontinuous surface layer which is 0.0 to 5.0 km thick over a low-velocity (6.0 km/sec) crustal layer which extends to depths of at least 30 km.

The above conclusions have been submitted to Geology and a preprint of the manuscript is attached.

Spectral Studies: The results of the spectral study which was George Marion's thesis were presented at the Seismological Society of America annual meeting. The results were extended to hypothesize that areas that exhibit frequency cubed amplitude decay in their displacement spectra are more susceptible to reservoir induced seismic activity than areas that exhibit displacement amplitude spectral decay rates less than or equal to frequency squared. An abstract of the talk is attached.

Focal Mechanisms and Stress: The results of David Dunbar (M.S. thesis) concerning the relocation of aftershocks using a revised velocity model and the results of Stewart Guinn (M.S. thesis) concerning focal mechanisms were compared. The aftershocks were found to locate on planes consistent with the focal mechanisms. The planes indicated are generally near vertical. If the alignment of epicenters are used to constrain the focal mechanisms, then the earthquakes are occurring in response to horizontal extension. These results were presented at the Southeastern Section of the Geological Society of America meeting. An abstract of the talk is attached.

Resistivity Study: Instrumentations for the resistivity field work was assembled during the Quarter. Preliminary plans to attempt resistivity analysis with the EM technique were abandoned because of the unavailability or cost of equipment and questionable availability of appropriate personnel. The decision was made to use the Schlumberger depth sounding method.

Progress During Quarter: The project progressed at the scheduled rate during the quarter.

Efforts Expended During Quarter: The principle investigator expended an average of 20% time on the project during the quarter. One electronics technician was employed at approximately 30% time and one graduate student at one half time.

The Carolina Slate Belt-Evidence
of a Continental Rift Zone

Leland Timothy Long
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ABSTRACT

Near the South Carolina and Georgia border, the southeastern portions of the Charlotte and Carolina Slate Belt near the Coastal Plain overlap are coincident with the northwestern edge of an isolated negative Bouguer gravity anomaly. This anomaly is interpreted as evidence for a detached fragment of continental crust. The pattern of the magnetic and gravity anomaly contours for the northwestern edge of this fragment is similar to the pattern of magnetic anomaly contours and the Piedmont gravity gradient in central Georgia. This geometrical similarity suggests the fragment may have been separated from a larger continental block by a rift zone nearly 160 km wide. The Carolina Slate Belt in Georgia and South Carolina may delineate the axis of this continental rift or rift system and represent remnants of rift-derived volcanic and sedimentary rocks. Gravity profiles across the edges of the hypothesized rift indicate the existence of anomalous high-density rocks in the upper 5 km of the crust in the proposed rift and low-density rocks at the base of the adjacent continental crust. Seismic data in Georgia indicate a typical rift-zone velocity structure which consists of a high-velocity (6.3 km/sec) discontinuous surface layer which is 0.0 to 5.0 km thick over a low-velocity (6.0 km/sec) crustal layer which extends to depths of at least 30 km. Magnetic lineations provide evidence for the faults and/or depositional layering of the rift and outline the structures and margins of the rift. The rift developed from late Precambrian through Cambrian time (650 to 520 m.y.) as determined from radiometric age determinations of Carolina Slate Belt rocks. In North Carolina the rift was reactivated during the Triassic,

but in Georgia and South Carolina, Triassic extension was restricted to the southeastern edges of the detached crustal fragment.

INTRODUCTION

Speculation on the tectonic history of the southern Piedmont including the Inner Piedmont, the Charlotte Belt, and the Carolina Slate Belt are numerous and diverse. Recently, Hatcher and others (1977) have pointed out the remarkable continuity of the system of magnetic anomalies which could be interpreted as faults or continuous lithologic units extending from the Piedmont Province of Alabama into Virginia. They observed a mirror-image geometrical similarity to the San Andreas shear zone but note also the existence of low- and high-angle segments and a complex history involving multiple periods of activity. The more conventional contemporary speculations explain the existence of the Carolina Slate Belt by island arc-continental collision(s) or meganappes (Bentley and others, 1974; Butler and Ragland, 1969; Rankin, 1975). The traditional interpretation of formation in a geosyncline with subsequent orogeny and uplift (Rodgers, 1970) implies a stratigraphy (Overstreet and Bell, 1965; Hatcher, 1972) that identifies the Inner Piedmont and Charlotte Belt rocks as an older basement on which the Carolina Slate Belt rocks were deposited. The Carolina Slate Belt rocks now form the axis of a synclinorium. In this paper, a tectonic history is proposed that explains the zone of crust represented by Charlotte and Carolina Slate Belt rocks as a continental rift zone which developed in late Precambrian through Cambrian time.

The proposed rift zone (Fig 1) is interpreted mainly from crustal thicknesses and velocities obtained from gravity and seismic data. The Charlotte and Carolina Slate Belt rocks are interpreted as the remnants of a rift zone which separates a detached fragment of continental crust from the main portion of the continent. The extensive apparent fault systems interpreted from aeromagnetic data by Hatcher and others (1977)

can now be explained as an alignment of crustal block-edge faults or parallel lithologic units within the rift.

PROPOSED STRUCTURAL MODEL

The Piedmont gravity gradient in Georgia, South Carolina and North Carolina generally corresponds to the -10 mGal contour line on the Bouguer gravity map (Fig. 2). The more negative anomalies to the northwest correspond generally to the Inner Piedmont. These more negative Bouguer gravity anomalies (Fig. 2) and their free-air counterparts (Long, 1974) imply overcompensation at the base of the crust by low-density continental crustal rocks. Hence, the Piedmont gravity gradient marks the boundary between crustal blocks which differ in thickness and/or composition. A significant feature of the Piedmont gravity gradient in Georgia is its non-linearity. Near 83.5°W the strike shifts from northeast to north and at 34°N it shifts back to northeast. In addition, near 81.5°W and 33.5°N an area 75 by 200 km of negative free-air (Long, 1974) and Bouguer (Fig. 2) gravity anomalies exist to the southeast of the Piedmont gravity gradient. The negative anomalies suggest the interpretation of the zone delineated approximately by the -10 mGal contour line as a fragment of continental type crust (Fig. 1). The negative free-air anomalies would be caused by overcompensation at the base of the crust. The geometrical similarity of this proposed fragment might have been originally closer to the continental crust to the northwest. In contrast the Bouguer anomalies between the crustal fragment and the Piedmont gravity gradient average near zero and show strong localized positive and negative anomalies. The axis of the zone of near-zero Bouguer anomalies corresponds generally to the Carolina Slate Belt in Georgia, South Carolina and North Carolina. The free-air anomalies (Long, 1974) in this zone are +10 to +20 mGal implying a thinner undercompensated crust.

The simple geometrical relation presented above suggests an oceanic type rift with continuous separation of the two sides from a single fracture. The relative direction of separation of the displaced crustal fragment is east-south east. However, because an abrupt change to oceanic crust is not observed, the edges of the proposed rift are more like those of a continental rift where crustal extension is accomplished through normal faulting on numerous faults within the zone of extension. To the northeast the edges of the rift become more diffuse and hence the zone of extension is gradational across the width of the rift. The actual character may be one of transition from a partially oceanic rift to a typically continental rift from southwest to northeast. The transition may in part have been brought about by different apparent rates of separation since toward the southwest in Georgia the indicated separation was normal to the edges of the displaced crustal fragment, but toward the northeast in central South Carolina, separation required a significant strike-slip movement. In North Carolina and possibly into Virginia the rift separation appears to be more normal to the Piedmont gravity gradient.

Radiometric age determinations of the rocks in the Carolina Slate Belt indicate that the rift could have developed during the late Precambrian to Cambrian time, 650 to 525 m.y. (Butler and Ragland, 1969; Whitney and others, 1978). The extensional Triassic basins (Fig. 1) developed to the southeast of the displaced crustal fragment in South Carolina and Georgia. In North Carolina the Triassic extension developed within the proposed rift zone. This indicates that the axis of Precambrian-Cambrian rifting differed from the axis of Triassic rifting. In North Carolina the Raleigh Belt is also generally delineated by a -10 mGal contour line. This zone, centered near $78^{\circ}W$

and 36°N , could represent another displaced fragment of continental crust. If displaced continental crust existed between the Raleigh Belt and the displaced block on the Georgia-South Carolina border, it has probably been thinned and distorted by Triassic extension or masked by the Coastal Plain overlap.

GEOPHYSICAL EVIDENCE FOR RIFT ZONE

Two crustal structure profiles across the Piedmont gravity gradient in Georgia (see Fig. 1 for location) were constructed from gravity data to facilitate discussion of the rift zone. The first extends southeast across central Georgia and the second extends parallel to the Savannah River near the Georgia-South Carolina border. Best and others (1973) from the interpretations of gravity profiles across the Piedmont gravity gradient in North Carolina, have shown that the gradient is caused by a vertical or steeply dipping interface within the upper crust.

Central Georgia Profile: The central Georgia profile (line AA' on Fig. 1) is a southward extension of a line of gravity data presented by Long (1974). Near 230 km, the profile (Fig. 3) is distinguished by a large positive Bouguer anomaly interpreted as being caused by an extensive mafic intrusive in the crust. High density material is also indicated near the surface in order to satisfy the sharpness of the Piedmont gravity gradient and the observed occurrence of dense metamorphic rocks such as hornblende gneiss. These dense metamorphic rocks are separated from the granite gneiss to the northwest by the Towaliga Fault. As indicated in Fig. 3, the Towaliga Fault may be the major structure separating the two zones of different crustal structure.

Savannah River Profile: The Savannah River profile (line BB' in Fig. 1) extends southeast across the Piedmont gravity gradient in northeast Georgia to the Belair and Augusta Faults in central Georgia (Fig. 4).

The central portion of the profile is presented in more detail by Long and others (1976). The metadacities, rhyolitic tuffs or schists, and mafic intrusions between the Modoc fault zone and the westward extension of the Kings Mountain Belt (Towaliga fault in Georgia) comprise an extensive zone of late Precambrian-Cambrian activity. The near-surface materials near 150 and 180 km are generally more mafic than the adjacent crust and hence typically exhibit a positive gravity anomaly. The seismic velocity near the surface at 180 km is about 6.3 km/sec (Dunbar, 1977) and, hence, faster than expected for a granitic crust. Below about 10 km however, the seismic data imply a velocity decrease. Recent seismic refraction data (Kean, 1978) confirm a 30 km thick 6.0 km/sec crustal layer and provide no evidence for velocities above 6.3 km/sec deeper in the crust. Below about 10 km however, the seismic data imply a velocity decrease. The velocity decrease may be evidence for the remnants of the continental crust which once existed in the rift. The granite plutons such as the Danburg granite developed during a later (300 m.y.) event. In the rift, high-density mafic rocks occur near the surface. Hence, the lower density granites are gravitationally unstable and the granites would develop as concentrated plutons which were mobilized from the lower crust during the event at 300 m.y. The depth to the Moho on the basis of gravity data appears to increase on both sides of the rift. Hence, as indicated in Fig. 4, the extensions of the Kings Mountain Belt or the Towaliga Fault zone and the Modoc fault zone may represent near-surface evidence of some of the edge faults of the Precambrian-Paleozoic rift zone.

In North Carolina, studies (Best and others, 1973) of the depth to the source of the Piedmont gravity gradient also indicate a high-density shallow (0-10 km) source with a nearly vertical contact coincident with the boundary between the Charlotte Belt and the Carolina Slate Belt.

The negative Bouguer anomalies of the Rayleigh Belt indicate that it may also represent a continental crustal fragment which has separated from the main crustal block. Hence, the rift zone may extend through North Carolina into Virginia.

Magnetic Data: The 1:250,000 scale aeromagnetic data (Petty and others, 1965; U.S. Geological Survey 1976 open file maps) have generated considerable speculation, perhaps because faults, contact zones between lithologic units, and magnetized zones are difficult to distinguish without extensive detailed surface investigations. However, in the magnetic maps of the Piedmont Province, the edges and central part of the proposed rift are characterized by relatively strong linear magnetic anomalies. In the central Georgia Piedmont many of the linear anomalies (Fig. 5) are coincident with known faults such as the Towaliga, the Goat Rock and the Modoc. The shorter linear anomalies are probably caused by lithologic units or splays from some of the larger faults. The faults and the lithologic units could be in part genetically related to the rift and major intrusives within the rift. The mafic crustal intrusive interpreted along the gravity profile AA' at 220 km (33.2°N, 83.7W in Fig. 5) is associated with perturbations of the linear magnetic anomalies. In contrast, the bordering continental blocks which are identified with the inner Piedmont generally lack the pronounced linear magnetic anomalies.

DISCUSSION

The rift model presented above as an explanation for the crustal structure and major faults in the central Piedmont Province represents a major departure from many current tectonic models in that the major faults are interpreted as being initially normal or extensional faults rather than as thrust faults. Reactivation as thrust faults during a

later compressional phase is indicated by cataclastic fabrics. However, subsequent compressional deformation did not obliterate the gross structure of the rift.

The zone of Charlotte and Carolina Slate Belt rocks and their associated faults extending from Georgia into Virginia demonstrate many geophysical features typical of intracontinental rift valley systems (see McConnell, 1972) such as the Rhine Graben and Baikal Rift Systems, although these examples are more recent tectonic features. The width of the proposed central Piedmont rift system is on the order of 50 to 150 km and it extends for over 600 km. The development of oceanic crust may have been inhibited by the slower spreading rate typical of continental rifts and the displacement which is limited to about 150 km. However, some of the amphibolites and hornblende gneisses may be remnants of incipient oceanic crust. The Charlotte and Carolina Slate Belt lies between crustal blocks containing older Precambrian rocks which are typical of the Inner Piedmont. In a rift zone the crust at Moho depths is penetrated by intrusives from the mantle so that the effective depth to the Moho is reduced. However, recent seismic refraction data (Kean, 1978) show no evidence for a higher velocity crustal layer above the Moho and limit its thickness to a few kilometers. Typically, a rift zone shows a low-velocity zone between 10 and 20 km depth. This is indicative of the presence of granitic crustal rocks on which the more-dense extrusives of the rift floor were deposited. The variety and distribution of the Carolina Slate Belt volcanics is comparable to observed volcanics in the more active portions of well developed rift valleys such as the East African rift. However, most geochemical arguments (Whitney and others, 1978) prefer comparisons to primitive oceanic island arcs. The geochemical arguments might be satisfied if the rift represents back-arc spreading perhaps related to a southeast

dipping subduction zone which intersects the surface to the northwest (Slaymaker and Watkins, 1978).

Recognition of the Carolina Slate Belt as denoting the axis of a rift provides an explanation for the large systems of faults identified by Hatcher and others (1977) without requiring large strikeslip or thrust movements. The Towaliga fault, and Kings Mountain Belt, generally denote the approximate western edge of the rift. The southeastern edge would be generally denoted by the Goat Rock (?) and Modoc, or Augusta Fault. The Goat Rock Fault may not be continuous with the Modoc Fault since the southeastern edge of the proposed rift may instead extend southwest under coastal plain sediments. The southeastern edge of the proposed rift may extend to the Augusta Fault near Augusta, Georgia. However, the extension of the Augusta Fault into North Carolina (Hatcher and others, 1977) probably denotes the eastern boundary of the rifted blocks of Precambrian crust. Near Augusta, the southeastern boundary of the rifted block is probably coincident with the Dunbarton Triassic basin.

Since the system of faults can be interpreted as crustal block edge-faults developed through extension, individual faults would not necessarily be expected to be continuous over the entire length of the proposed rift. In general, rift zones are characterized by a complex system of splays and associated faults. The possible existence of extensional tectonics during the late Precambrian to Cambrian time has been proposed also in the interpretation of geophysical data pertaining to the Rome trough (Ammerman and Keller, 1976) in Kentucky and Tennessee and in the interpretation of geological data (Rankin, 1975) in the Southern Appalachians. The evidence presented above for extension as late as 550 m.y. ago and the evidence for the Triassic spreading initiating about 200 m.y. ago leaves about 350 m.y. for the development

and closing of the proto-Atlantic if its suture is located in the Piedmont Province. The geophysical data and this resulting model do not require (or exclude) the development of a significant expanse of oceanic crust or the transition through two complete reversals of the dominant tectonic stress. However, in the opinion of the author the character of the rift would have been largely destroyed by the collision of an island arc and continent and the suture for the proto-Atlantic ocean must occur elsewhere.

ACKNOWLEDGMENTS

Reviewed by Robert H. Carpenter and Charles O. Pollard. Research was supported by the U.S. Nuclear Regulating Commission.

LIST OF FIGURES

- Figure 1. Location and geometry of the proposed central Piedmont rift system and crustal fragments. Triassic basins are taken from Marine and Siple (1974).
- Figure 2. Regional Bouguer gravity anomalies. Anomalies less than -10 mGal are hatched; anomalies greater than +10 mGal are shaded. (Contours after Long and others 1974; Long and others 1976; and Mann, 1962).
- Figure 3. Bouguer gravity profile and interpreted density structure of line AA' (see Fig. 1) in Central Georgia. The model from 0 to 160 km is from Long (1974). The dashed line at 15 km is a reference line for the interpreted surface of the intermediate crustal layer.
- Figure 4. Bouguer gravity profile and interpreted density structure for line BB' (see Fig. 1) in eastern Georgia. The model from 160 to 200 km is abstracted from Long and others (1976).
- Figure 5. Interpretation of the prominent linear magnetic anomalies in the Georgia Piedmont. Quiet areas interpreted as the edge of the rift are indicated by cross hatches.

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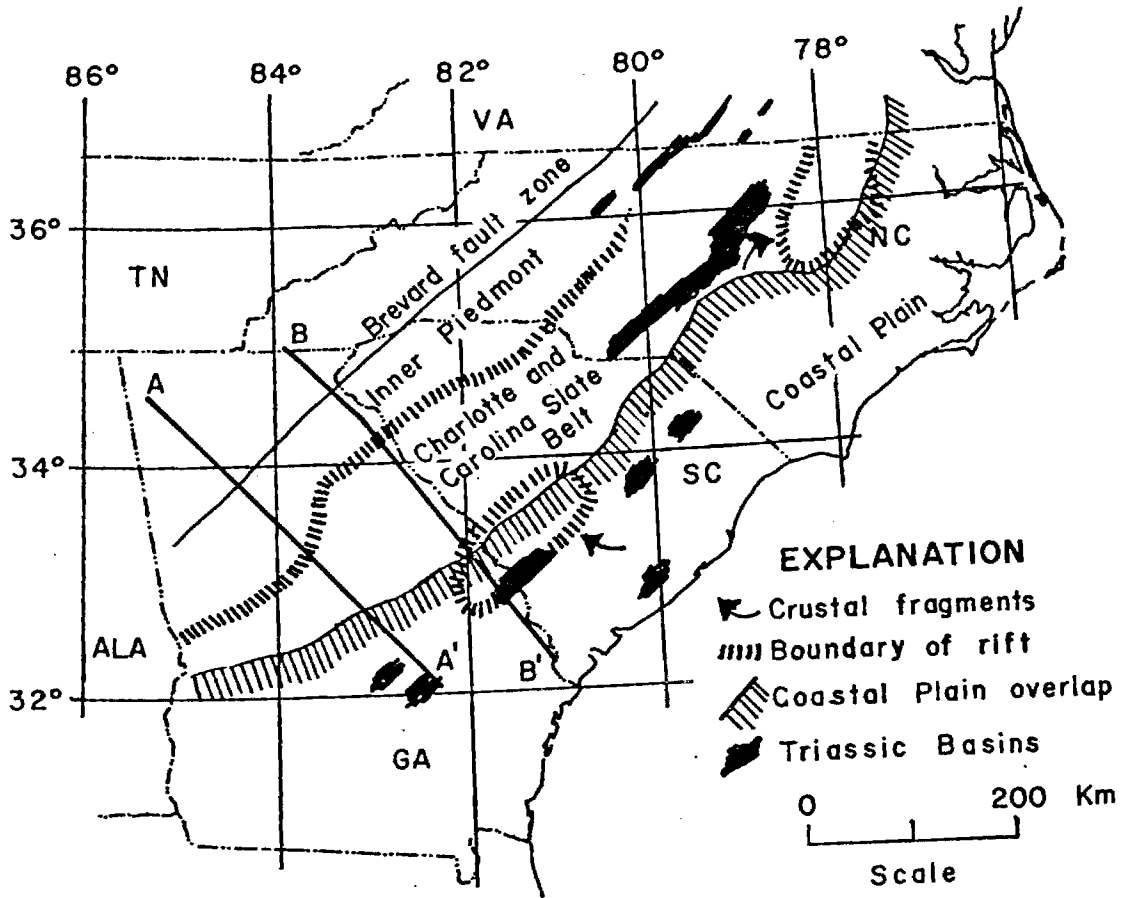
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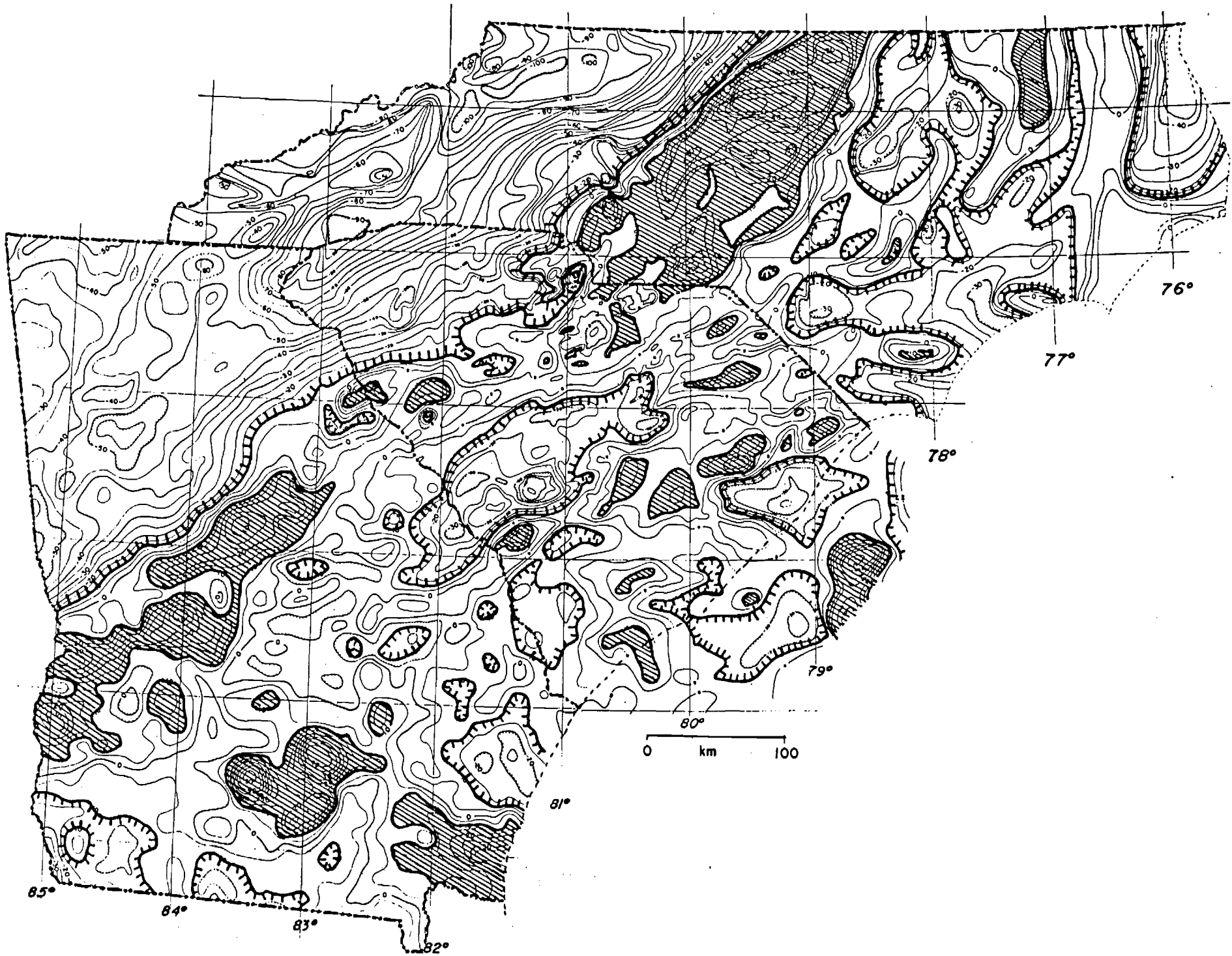
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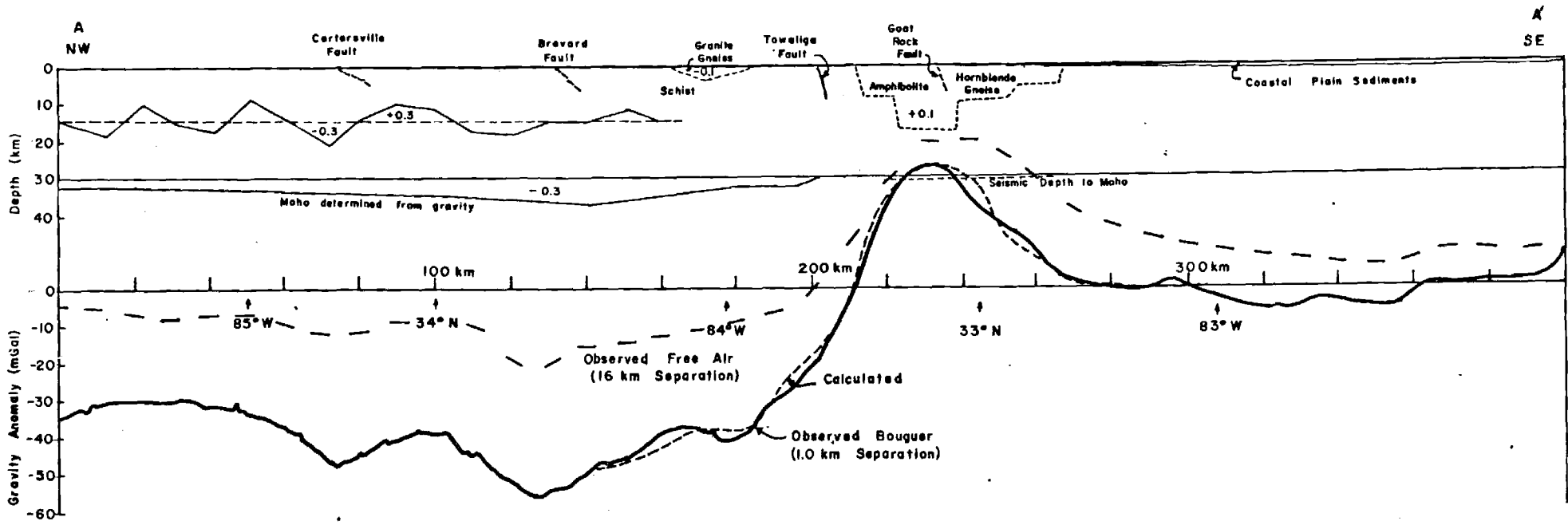
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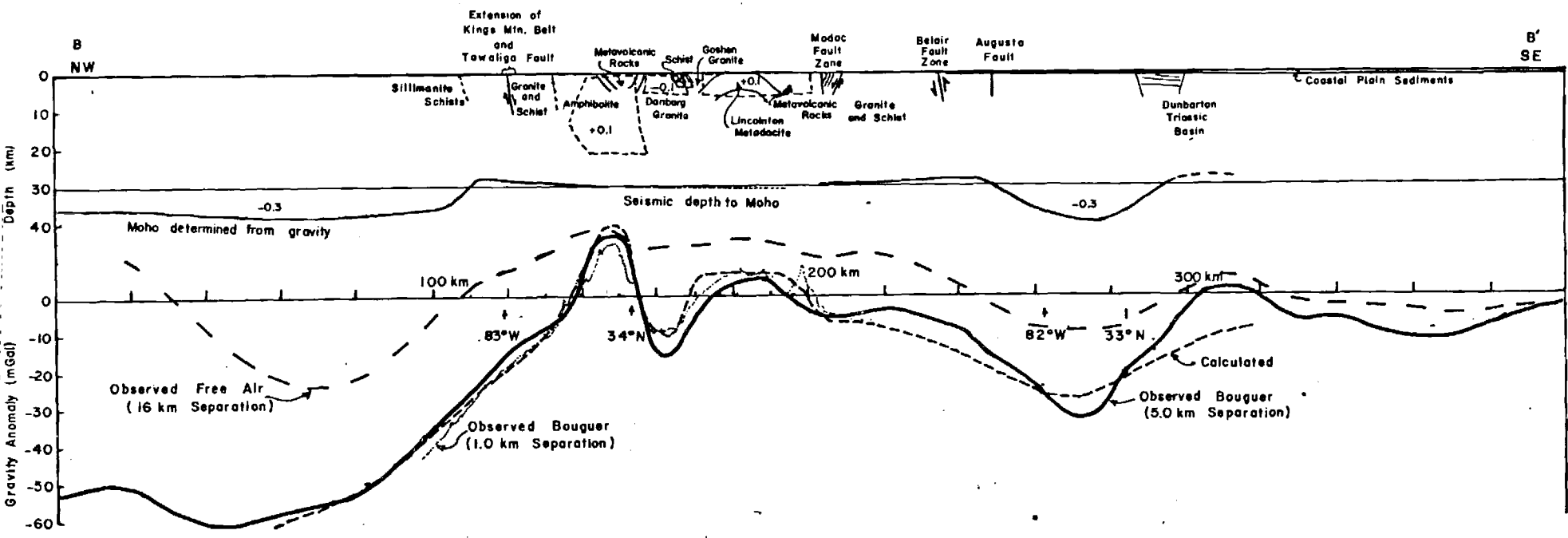


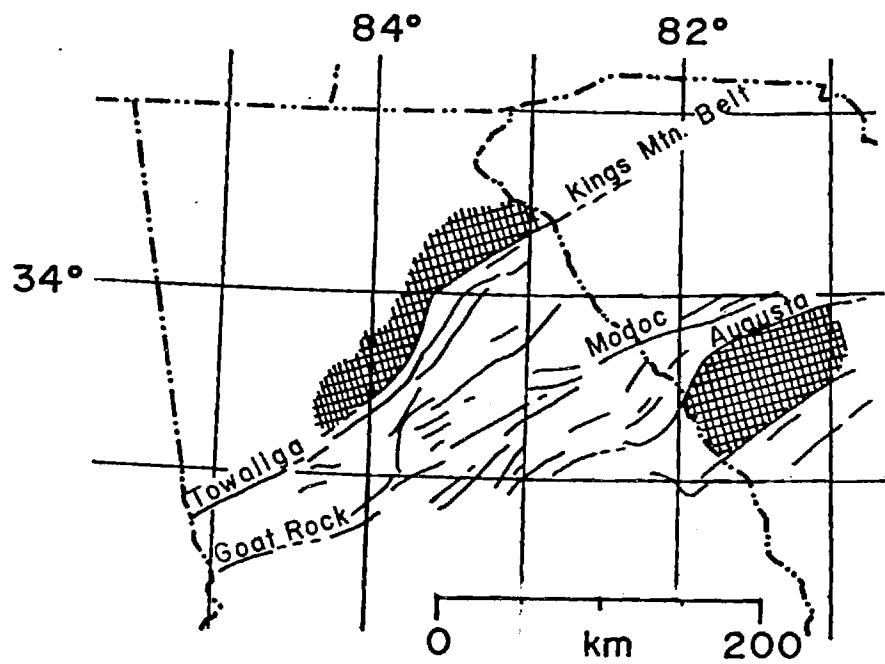


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Affiliation

MICROEARTHQUAKE SPECTRA IN THE SOUTHEASTERN UNITED STATES
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CLASSIFICATION
(underline one):

Body of Abstract

Magnetic tape records of the vertical component of 93 Southeastern United States microearthquakes were used to calculate 165 body wave displacement spectra. The microearthquakes were recorded at hypocentral distances of 0.4 to 21.0 km. The spectra for events near Clark Hill Reservoir, Georgia, and the Jocassee Reservoir, South Carolina, typically showed w^{-3} amplitude decay, well defined spectral corners and ratios of P-wave to S-wave corner frequencies greater than unity. In contrast, microearthquake spectra for events near Maryville, Tennessee, typically showed w^{-2} amplitude decay, rounded spectral corners and ratios of P-wave to S-wave corner frequencies less than unity. We believe the Clark Hill and Jocassee spectra are best explained by an equidimensional fault which nucleates rupture at a point of high resistance to slip and ruptures transonically along an existing fracture. The Maryville spectra are best explained by subsonic rupture along faults which may show premature stick. Because events near the Clark Hill and Jocassee Reservoirs are influenced by reservoir loading and the Maryville events are unrelated to a reservoir, the observed differences in seismic spectra may be useful in identifying areas susceptible to induced seismic activity.

Recent Earthquake
Seismic Source
Functions
Wave Propagation
Seismicity
Seismic Risk
Engineering Seis.
Strain Seis.
Microseismicity
Instrumentation
Array Processing
Mantle-Core Struc
Gen. Seismology &
Geophysics
Other _____

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Crustal Structure, Earthquake Locations and Focal Mechanisms
in the Clark Hill Reservoir Area

by

L.T. Long
D.M. Dunbar
S.A. Guinn

Abstract

CRUSTAL STRUCTURE, EARTHQUAKE LOCATIONS AND FOCAL MECHANISMS IN THE
CLARK HILL RESERVOIR AREA

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Excavation blasts at the Richard B. Russell project were used to develop a travelttime curve for the Clark Hill Reservoir Area. The interpreted velocity structure shows a gradient from 4.5km/sec near the surface to 6.0km/sec at about 0.8km. Below 0.8km, the velocity increases gradually to 6.3km/sec at 5km. A low velocity zone may exist in the 6 to 15km depth range. The velocity structure was then used to relocate events in the epicentral zone of the August 2, 1974, earthquake. A reduction in scatter was achieved and two general alinements of epicenters were observed. The first is a plane which strikes N 50°E and dips 70°NW. The second corresponds to two planes which strike N 20°W and dip 70°SW. The first corresponds generally to the focal mechanism of the August 2, 1974, earthquake and selected aftershocks. The second corresponds to the focal mechanisms of other individual aftershocks. The aftershocks generally indicate near vertical planes. If the alinement of epicenters are used to constrain the focal mechanisms, then the earthquakes are occuring in response to horizontal extension.

A talk presented at the Southeastern Section of the Geological Society of America meeting in Chattanooga, Tennessee, April 7, 1978

6-35-633

NUREG-0016
G35-633

A GEOPHYSICAL INVESTIGATION OF THE
SEISMICITY OF THE CLARK HILL RESERVOIR VICINITY

Quarterly Progress Report No. 13

June 1, 1978 to August 31, 1978

Leland Timothy Long
School of Geophysical Sciences
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Report Date January 1979

PREPARED FOR THE U. S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REGULATORY RESEARCH UNDER
CONTRACT NRC-04-77-210

A Geophysical Investigation of the Seismicity of the
Clark Hill Reservoir Vicinity

Quarterly Progress Report No. 13

Abstract

Seismic monitoring continued at stations CH5, CH6, and EP1 in the CHRA and at station ETG in the Lake Sinclair area. The gravity data near the Belair fault indicates the existence of a mafic intrusive which shows a possible indirect relation to the Belair fault. Spectral studies indicate a Q_p of 900 for the Piedmont. Seismic refraction data indicate a crustal thickness of 33 km.

Scope of Investigation

The objective of this work is to determine the relation between geology and seismicity and to delineate the tectonic environment that is responsible for the earthquakes in the Clark Hill Reservoir vicinity. Seismic activity rates and water levels in the Clark Hill Reservoir will be monitored. Microearthquakes will be recorded with portable equipment and used to obtain spectral signatures, focal mechanisms and locations. Continuous seismic coverage will be maintained in the area of the August 2, 1974 (magnitude 4.3) earthquake. One station will be used to monitor activity near Lake Sinclair.

Four areas where past seismic activity has been high will be surveyed using direct current electrical resistivity soundings to depths of 0.5 to 1.0 km to determine whether the water content in hypocentral areas is significantly higher than normal.

Results of Investigation During Quarter

Recording Summary: Seismic monitoring continued without major interruption at CH5 (double branches in the southern part of the reservoir) and at CH6 (near Goshen in the northern part of the reservoir). Station EP1 operated in the epicenter area as a three component system through July 29, 1978.

A log of the seismic activity was maintained for the aftershock zone of the August 2, 1974 earthquake. Figure 1 shows the number of events recorded at CH6 (or its equivalent) versus water level. For the period of June through August. A significant swarm of events occurred during this time period. The swarm actually consisted of three swarms separated in time by about 20 days. The swarms coincided with a gradual slight decrease in reservoir water level.

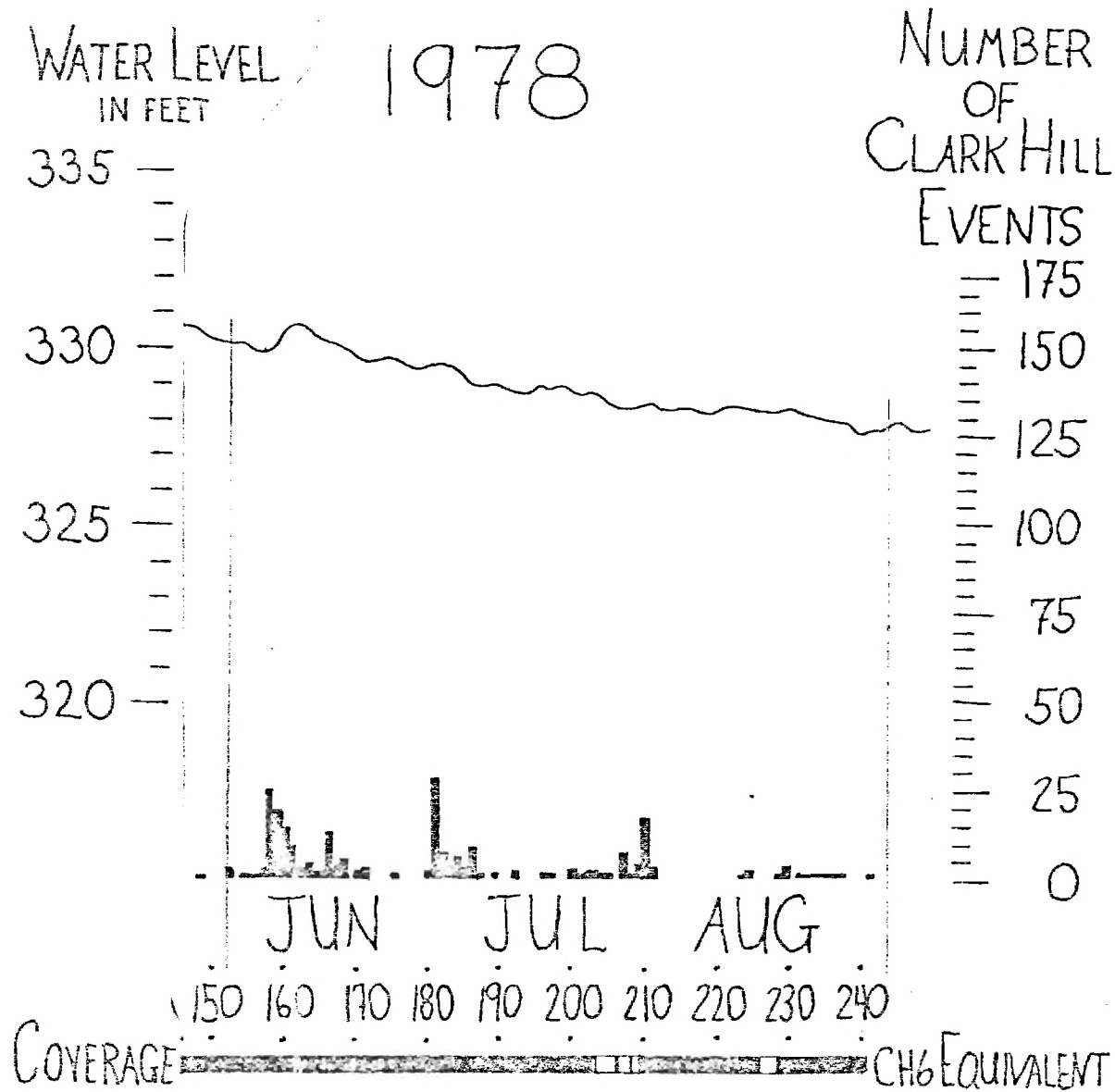


Figure 1. Log of activity versus water level for the Clark Hill Reservoir area.

Station ETG has been recording in the Lake Sinclair area. Events located by ETG and the Wallace Dam net funded by Georgia Power Company are shown in Figure 2.

All of the local and regional data recorded at stations operated out of Georgia Tech have been made available for publication in the Southeast United States Seismic Network Bulletins.

Geological Data: During July and August the gravity data obtained in the vicinity of the Belair fault was interpreted in conjunction with available aeromagnetic data. A preliminary report was prepared and is under revision for possible submission for publication. The fault zone proper does not have an appreciable effect on the Bouguer gravity anomaly since its displacements are small and it does not separate rocks of appreciable density contrasts. However, the Belair fault does parallel a contact with a mafic unit located about 6 km southeast of the fault. This mafic unit has a significant anomaly of more than positive 10 mGal. An anomaly of this size is compatible with the interpretation of this zone as representing a source area for the volcanics of late Precambrian-Cambrian age believed to exist southeast of the Belair fault. The zone of mafic rocks is terminated about 15 km further southeast in the region of a very steep negative gradient to the southeast. This gradient marks the southeast edge of the intrusive and the northwest edge of a thicker fragment of continental type crust. The parallelism of the contacts might be interpreted as indicative of a causal relation. However, the direction of recent movement implies a northwest thrust and is not consistent with the rift mechanism proposed for the central Piedmont at the age of formation of the rock units identified. Instead, a hypothesis is being considered which explains the Belair as the concentration of stress on the northwest edge of the thicker fragment of continental type crust. The stresses are presumed to be derived from the downward bending of the coastal plain.

Spectral Studies: Many of the events occurring during the June swarm were recorded on magnetic tape. The event of 12 June 1978 was of sufficient magnitude ($M_L = 1.5$) to be recorded also on the Wallace Dam net as well as at stations CH5, CH6 and EP1. EP1 recording was obviously saturated but the other stations could be used for P-wave spectra. The analysis of CH6 and CH5 data (10 and 30 km respectively) showed the corner frequency to exceed the highest frequencies reliably recorded with the typical telemetry system (about 40 Hz). The spectra was virtually flat from 1.0 Hz to 40 Hz at CH6. At stations CH5 and REG the change in the spectra could be explained by attenuation with a Q_p of 900 ± 200 . This value for the Piedmont province is relatively high. Apart from the evaluation of Q_p it is

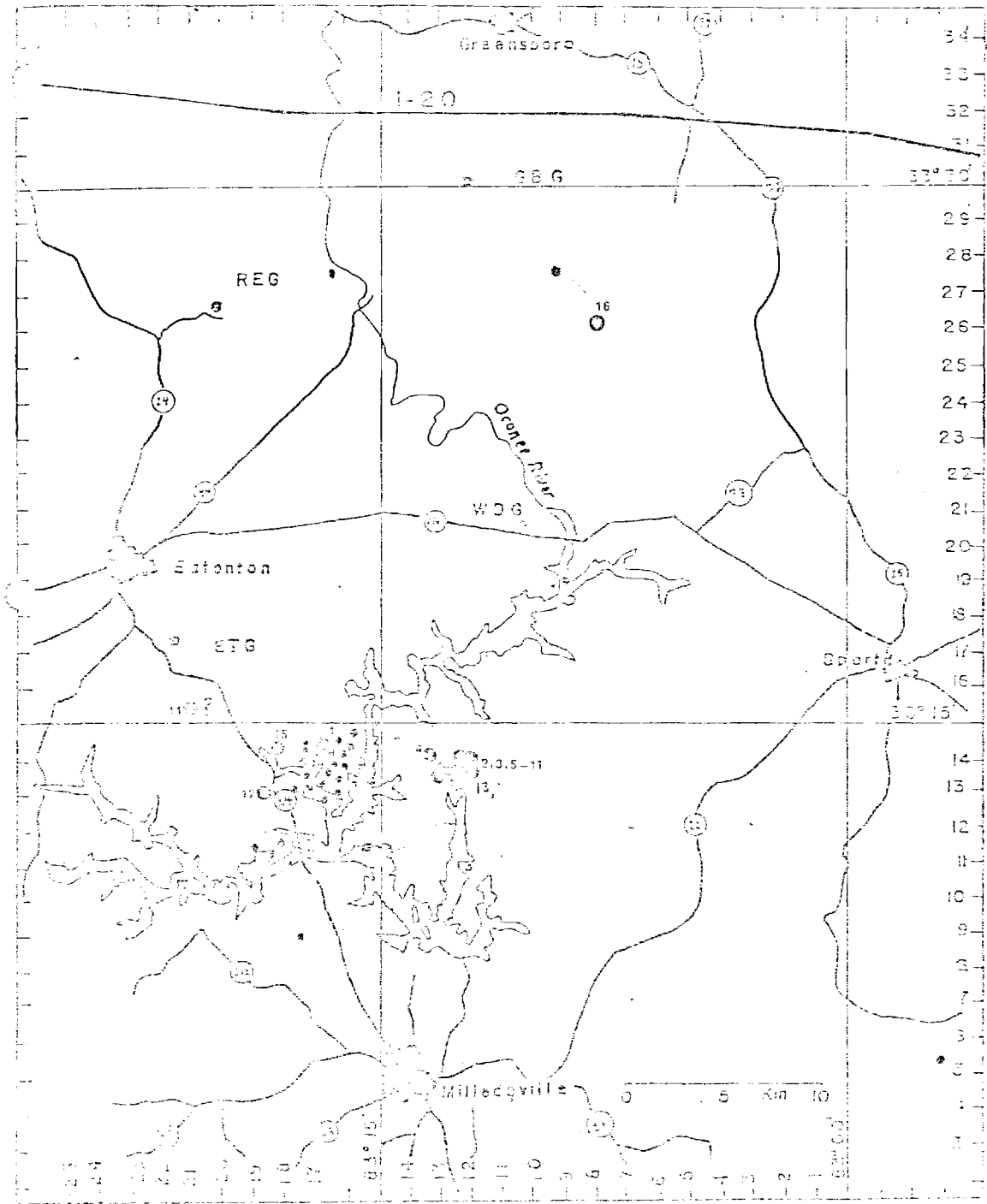


Figure 2. Earthquakes located in the Lake Sinclair region with the help of station ETG. Large dots are events occurring during the three month reporting period.

evident that the traditional telemetry system can not be used to study high-frequency spectral slope or corner frequencies for these events.

Seismic Refraction Data: During the quarter, as part of his master's thesis, Allan Kean assembled and analyzed traveltimes from earthquakes and explosions in the Southeastern United States. His study was carried out in three phases. The first phase consisted of assembling existing data from the EDR reports. When plotted, these data implied P-wave velocities of 5.75, 6.3 and 8.12 km/sec at depths of 0, 7 and 37 km respectively. The second phase was a detailed refraction line extending northeast from Georgia into South Carolina in the central portion of the Piedmont. The detailed refraction line used data recorded simultaneously on the CHRA net the Wallace Dam net and selected stations from the South Carolina net. The data indicate velocities of 5.5, 6.05 and 8.2 km/sec at depths of 0, 2.6, and 33 km respectively. The gravity data indicate that the crustal thickness is uniform along the refraction line. The existence of an intermediate velocity layer could not be verified. The third phase was to use selected events to determine crustal thickness outside the area of the detailed refraction line.

Resistivity Study: No progress was made on the acquisition of resistivity data because of a lack of appropriate personnel.

Progress During Quarter

No significant progress in the proposed resistivity study was achieved during the quarter. However, during the quarter, progress was made in the gravity data interpretation and seismic refraction data.

Efforts Expended During Quarter

The principle investigator expended an average of 20 percent time on the project during the quarter. One electronics technician was employed at approximately 15 percent time and two graduate students at one half time.

NUREG-0017
G35-633

A GEOPHYSICAL INVESTIGATION OF THE
SEISMICITY OF THE CLARK HILL RESERVOIR VICINITY

Quarterly Progress Report No. 14

September 1, 1978 to November 31, 1978

Leland Timothy Long
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Atlanta, Georgia 30332

Report Date February , 1979

PREPARED FOR THE U. S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REGULATORY RESEARCH UNDER
CONTRACT NRC-04-77-210

A Geophysical Investigation of the Seismicity of the
Clark Hill Reservoir Vicinity

Quarterly Progress Report No. 14

Abstract

Seismic monitoring continued at CH5, CH6 and ETG. A thermal mechanism for some reservoir seismic activity was examined. Resistivity data were obtained in the field and indicate a resistivity structure consisting of a thin low-resistivity layer over a high-resistivity half space.

Scope of Investigation

The objective of this work is to determine the relation between geology and seismicity and to delineate the tectonic environment that is responsible for the earthquakes in the Clark Hill Reservoir vicinity. Seismic activity rates and water levels in the Clark Hill Reservoir will be monitored. Microearthquakes will be recorded with portable equipment and used to obtain spectral signatures, focal mechanisms and locations. Continuous seismic coverage will be maintained in the area of the August 2, 1974 (magnitude 4.3) earthquake. One station will be used to monitor activity near Lake Sinclair.

Four areas where past seismic activity has been high will be surveyed using direct current electrical resistivity soundings to depths of 0.5 to 1.0 km to determine whether the water content in hypocentral areas is significantly higher than normal.

Results of Investigation During Quarter

Recording Summary: Seismic monitoring continued without major interruption at CH5 (Double branches in the southern part of the CHRA) and at CH6 (near Goshen in the northern part of the CHRA). Station EP1 was returned to the lab for modifications and repair.

A log of the seismic activity was maintained for the aftershock zone of the August 2, 1974 earthquake. Figure 1 shows the number of events recorded at station CH6 or its equivalent versus water level during the period of September through November. The activity level was slight and averaged about two events per week. The level decreased during the report period indicating that the activity was part of the aftershock sequence of the swarms in June and July. Station ETG has been recording in the Lake Sinclair area. Events located by ETG and the Wallace Dam net funded by Georgia Power Company are shown in Figure 2.

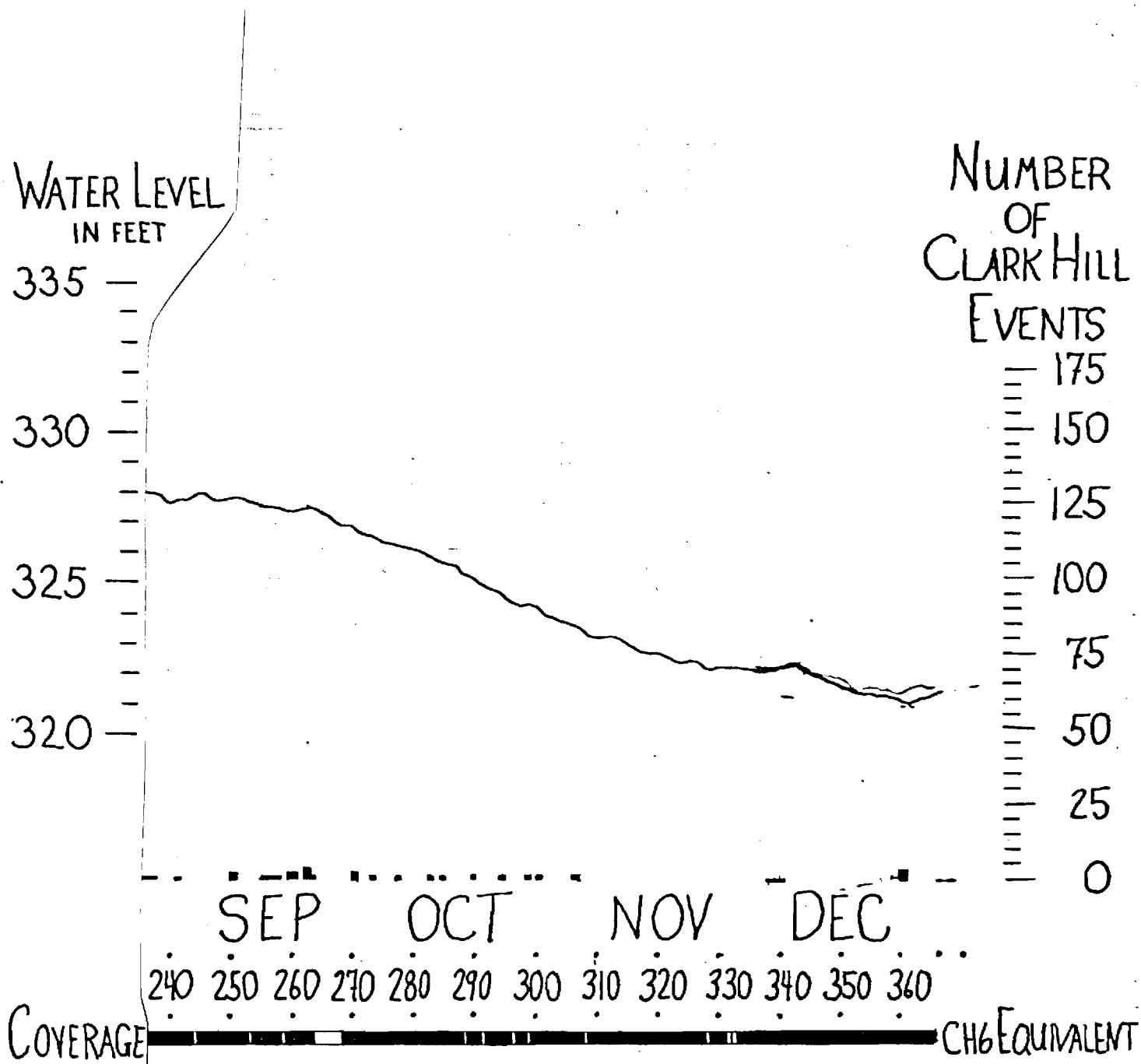


Figure 1. Seismic activity in the CHRA versus water level.

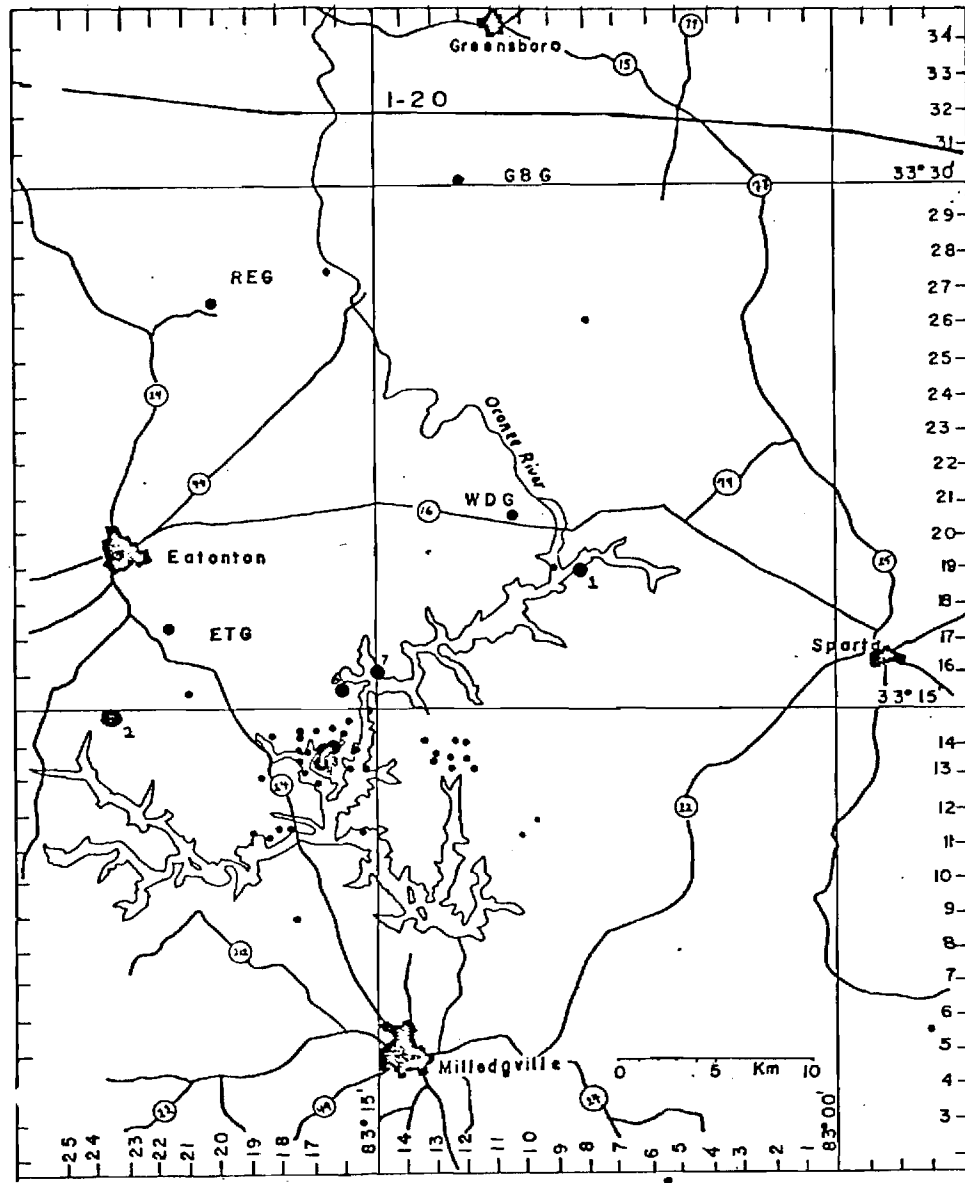


Figure 2. Seismic activity in the Lake Sinclair area. Event locations were computed from arrivals at station ETG and the Wallace Dam net.

All of the local and regional data recorded at stations operated out of Georgia Tech have been made available for publication in the southeast United States Seismic Network Bulletins.

Refraction Studies: The analysis of the seismic refraction line in the central Piedmont Province was completed during the quarter by Allen Kean as his Master's theses. The results of the study were presented at the Eastern Sections, Seismological Society of America meeting in October. An abstract for the talk is attached. The thesis has also been rewritten for submission to Earthquake Notes. A preprint of the publication sent to Earthquake Notes will be sent. The most significant aspect of the study was the implication that the Moho might someday be mapped and that with knowledge of the effective depth to the Moho the depths of local earthquakes can be computed to ± 5 km.

Studies of the Mechanism: During the quarter, a master thesis by Lee Brown was essentially completed. While this study was only partially funded, the results apply to the CHRA. The topic was the influence of temperature changes on the stress distribution near the surface and the possible role of temperature changes induced by ground water on the generation of earthquake stresses. The model studied is a vertical crack with an initial fixed crack width that extends into a semi-infinite medium with properties of competent basement rock. Fluid is allowed to flow down the crack with driving pressures compatible with reservoir water levels and the colder reservoir water perturbs the initial temperature field. Stresses are accumulated in the medium if a non-uniform temperature is established due to the fluid flow. The feasibility of the mechanism can be shown by a one-dimensional relation between Hook's law and change in temperature such that 1.0 degree centegrade develops approximately 3.2 bars of stress. The model developed shows that cracks of width 0.04 to 0.06 cm or greater develop stresses which migrate down the crack and increase in magnitude with time. Crack widths of 0.04 cm or less only develop stresses near the surface with time. The stresses developed are primarily tensional and the tension axis is parallel to the crack.

Resistivity Study: During the period two Schlumberger vertical depth soundings were obtained in the CHRA. A report on the analysis of these data is attached. The data indicate that the surface layer is both shallow (less than 50 meters) and low resistivity (less than 400 ohm-m). The hard rock has a typical resistivity of 5000 ohm-m.

Progress During Quarter

The project progressed at the scheduled rate during the quarter.

Efforts Expended During Quarter

The principle investigator expended an average of 20 percent time on the project during the quarter. One electronics technician expended about 5% time during the quarter. Two graduate assistants worked at about one-third time each during the quarter.

A CRUSTAL SEISMIC REFRACTION STUDY OF THE SOUTHEASTERN UNITED STATES

Allan E. Kean and Leland Timothy Long, School of Geophysical Sciences, Georgia Institute of Technology, Atlanta, Georgia 30332

The U. S. Geological Survey E. D. R. data for southeastern United States earthquakes occurring from July 1970 to June 1977 were combined to establish an average traveltime curve for the southeastern United States. The P-wave traveltimes are described by the equations; $T_0 = 0.2 + 0.05X/5.75 + 0.05$ km/sec, $T_1 = 1.0 + 0.1X/6.32 + 0.2$ km/sec, and $T_2 = 7.6 + 0.4X/8.12 + 0.8$ km/sec, with a scatter of ± 2.0 seconds. S-wave velocities corresponding to T_1 to T_2 were 3.66 ± 0.3 km/sec and 4.65 ± 0.5 km/sec respectively. The scatter was interpreted as being caused largely by variations in crustal thickness.

The central part of the Piedmont Province extending northeast from central Georgia and across South Carolina was then chosen for a detailed seismic refraction study. Gravity data indicate that this zone has a uniform crustal structure. Traveltimes from accurately located recent earthquakes and explosions occurring and recorded within the zone were then used to define the traveltime curves. The P-wave traveltime curves are described by; $T_0 = X/5.50 + 0.2$ km/sec, $T_1 = 0.4 + 0.2X/6.05 + 0.05$ km/sec, and $T_2 = 7.6 + 0.3X/8.20 + 0.25$ km/sec with a scatter of ± 0.5 seconds. The S-wave velocities corresponding to T_1 and T_2 were 3.5 ± 0.2 km/sec and 4.73 ± 0.3 km/sec respectively. The implied crustal structure consists of a 2.6 km thick surface layer over a 30.4 km thick crust. No evidence for an intermediate "Conrad" crustal layer was found.

Using the resulting central Piedmont crustal structure as a reference and using events either recorded outside and occurring within the zone or occurring outside and recorded within the zone, an apparent crustal thickness (depth of crust minus depth of focus) can be obtained for the southeast United States from the difference between the observed and theoretical P_n arrival times.

A GEOPHYSICAL INVESTIGATION OF THE SEISMICITY OF
THE CLARK HILL RESERVOIR VICINITY

Report on:

VERTICAL ELECTRIC SOUNDING
WITH SCHLUMBERGER ELECTRODE ARRANGEMENT
NEAR CLARK HILL RESERVOIR

for Project G35-633

School of Geophysical Sciences
Georgia Institute of Technology
Atlanta, Georgia 30332

by

Heroel Hernandez-Cortes

VERTICAL ELECTRIC SOUNDING WITH THE SCHLUMBERGER
ELECTRODE ARRANGEMENT NEAR THE CLARK HILL RESERVOIR

Introduction

The field instrumentation and wires for the Schlumberger vertical sounding electrode arrangement have been assembled and tested in the field. Two depth probes have been completed in the CHRA and the objective of this report is to present the interpretation of this initial data. Standard interpretation methods were employed involving the plotting of apparent resistivity versus array spacing and comparing the observed curves with theoretical curves for known models.

Procedure

Two vertical electric soundings were carried out in the Clark Hill area near the border between Georgia and South Carolina in the neighborhood of station EP1 (Figure 1). These vertical electric soundings were performed with the Schlumberger arrangement along dirt roads that run along ridges (Figure 1) in a fairly straight and flat fashion. The center of the spread for profile No. 1 was located at approx. 420 ft. above sea level and for profile No. 2 was located at 470 ft. above sea level. The water level at the Clark Hill reservoir was located at approx. 322 ft. above sea level. The power for the vertical electric sounding was supplied from a set of eight - 12 volt batteries connected in series. The current I and voltage V were measured with a potentiometer assembled at the geophysics lab. This potentiometer provides three different scales with an accuracy of 1 mV, 0.1 mV and 0.01 mV respectively (or 1 mA, 0.1 mA and 0.01 mA).

To the input for the potentiometer a balancing bridge was added in order to provide the operation with a quick way to balance residual potential occasionally found in the ground.

Stainless-steel bars were used as electrodes. A single-conductor copper wire (gauge 14) was used for the terminals A and B. A double-conductor copper wire (tin coated, gauge 20) was used for M and N.

Interpretation

Profile number 1 shows a two-layer structure (see Figure 2). The upper layer has a resistivity of 160 ohm-m and a thickness of about 40 m.

The profile number 2 indicates a three layer structure (see Figure 3). The upper layer has a resistivity of 490 ohm-m and a thickness of 14 m, the middle layer shows a resistivity of 40 ohm-m and is 4.7 m thick. The deeper layer has a resistivity of 5000 ohm-m.

The graph provided by the data of vertical electric sounding number 1 (Figure 2) was interpreted by comparing the graph with a master curve for a two-layer case in which the underlying material bears an infinite resistivity. A close fitting was achieved for the lower portion of the data graph, but not so for the upper-right portion. The slope of this part of the graph was greater than 45° , which is the maximum slope theoretically attainable (Master curve from Mooney and Wotzell (1956) two layer curves).

Vertical electric sounding number 1 was carried out on a fairly narrow ridge (Figure 7). This means that neither the upper layer nor the lower layer have a lateral extension to infinity. This will imply that, as we increase the spread, there will be less conducting material available than in the theoretical case (laterally-infinite layers). Therefore, the apparent resistivity measured as AB is increased will go faster to higher values. Ultimately this will cause the higher slope in the plotted curve.

The center of spread for V.E.S. No. 1 was located at approximately 30 m above the water level of the Clark Hill Reservoir. The boundary between the two layers was found to be 40 m below the surface. Considering that the top layer is weathered rock and soil, the location of the boundary with the sound rock will allow a good saturation of water through the top layer which would account for the low resistivity. The graph from V.E.S. No. 2 (Figure 3) data was compared with master curves for a three-layer situation (Standard Graphs for Resistivity Prospecting, prepared by Rijkswaterstaat, The Netherlands). The upper portion fitted closely while the left-lower portion was somewhat approximated due to the fact that data points didn't show a completely clear trend for low values of AB/2. While the survey was being carried out, strong fluctuations in the galvanometer's needle were observed (telluric current's) which could have affected the quality of the values. When the AB spread was increased above 100 meters this fluctuation disappeared.

The lower layer observed, which has a high resistivity (5000 ohm-m) is considered to be the sound rock Adamellite gneiss (after Georgia Geological Survey).

The upper layer was considered to be weathered rock and soil, while the middle layer can be just a saturation of water within part of the weathered rock, that is, a watertable resting on top of the sound rock (Figure 5). The material interpreted as weathered rock has a different resistivity at both profiles (160 m at V.E.S. No. 1 and, 490 m and 49 m at V.E.S. No. 2).

The location of the upper boundary of the sound rock at V.E.S. number 2 (above reservoir's water level) favors the formation of a localized watertable. While, at V.E.S. number 1, where upper boundary of sound rock is below reservoir's water level favors a more uniform saturation of water throughout weathered profile.

The difference in resistivity between what is considered water-saturated in both profiles (160 ohm-m at V.E.S. number 1 and 49 ohm-m at V.E.S. number 2) can be due to a different ion population. This, is a result of the different parental material and a different ion exchange rate between the two watertables and the water of the reservoir.

The higher elevation at V.E.S. number 2 favors the formation of a dryer layer on top of the watertable, which doesn't show at V.E.S. number 1, at which the low elevation can eventually allow permanent, near to the surface of the ground saturation with water from the lakes.

Future Plans

Four more V.E.S. are being planned. Three of them will be carried out in a straight line and slightly overlapping each other. The direction of this proposed resistivity survey line is N30°W and at about 3 km N.E. from the place where V.E.S. #1 and #2 were carried out (see Figure 6). The fourth is to be carried out at about 7 km south of V.E.S. #1 and #2 near station CH6. The direction this resistivity line will have is to be determined by the field conditioned to accessibility of the various places where the electrodes are to be set.

The maximum AB/2 spread is going to be increased to 800 meters which will allow a probable survey depth of 400-600 m limited mainly by the resistivity of the basement or by changes in resistivity inside the basement.

The three overlapping lines (V.E.S. #3, #4 and #5) will be located at the zone where a high percentage of epicenters have been located. V.E.S. #6 will be located at a non-seismic zone.

Following these V.E.S.'s a horizontal profiling will be attempted in the epicenter area.

TABLE OF FIGURES

- Figure 1. Topographic map showing location of V.E.S. number 1 and 2.
- Figure 2. Resistivity curve at V.E.S. number 1 and its interpretation (curve was compared with Mooney and Wetzel (1956) master curves for two layers situation).
- Figure 3. Resistivity curve at V.E.S. number 2 and its interpretation (compared with Standard Graphs for Resistivity Prospecting, prepared by RIJKS-WATERSTAAT, 1969, Netherlands, which is the Agency of public services of Holland).
- Figure 4. Interpreted profile at the center of spread for V.E.S. number 1. The profile is perpendicular to direction of spread (Vertical scale exaggerated).
- Figure 5. Interpreted profile at center of spread for V.E.S. number 2. Profile is perpendicular to direction of spread (Vertical Scale exaggerated).
- Figure 6. Geologic map showing the locations of V.E.S. number 1 and 2.

BIBLIOGRAPHY

- Bhattacharya, P. K., and Patra, H. P. (1968). Direct current geoelectric sounding. Elsevier, Amsterdam.
- Dobrin, M. B. (1976). Introduction to geophysical prospecting. Third edition, McGraw-Hill, New York, New York.
- Mooney, H. M. and Wetzel, W. W. (1956). The potentials about a point electrode and apparent resistivity curves for a two-, three-, and four-layer earth. Minneapolis, University of Minneapolis press.
- Rijkswaterstaat (1969). Standard graphs for resistivity prospecting. Netherlands.

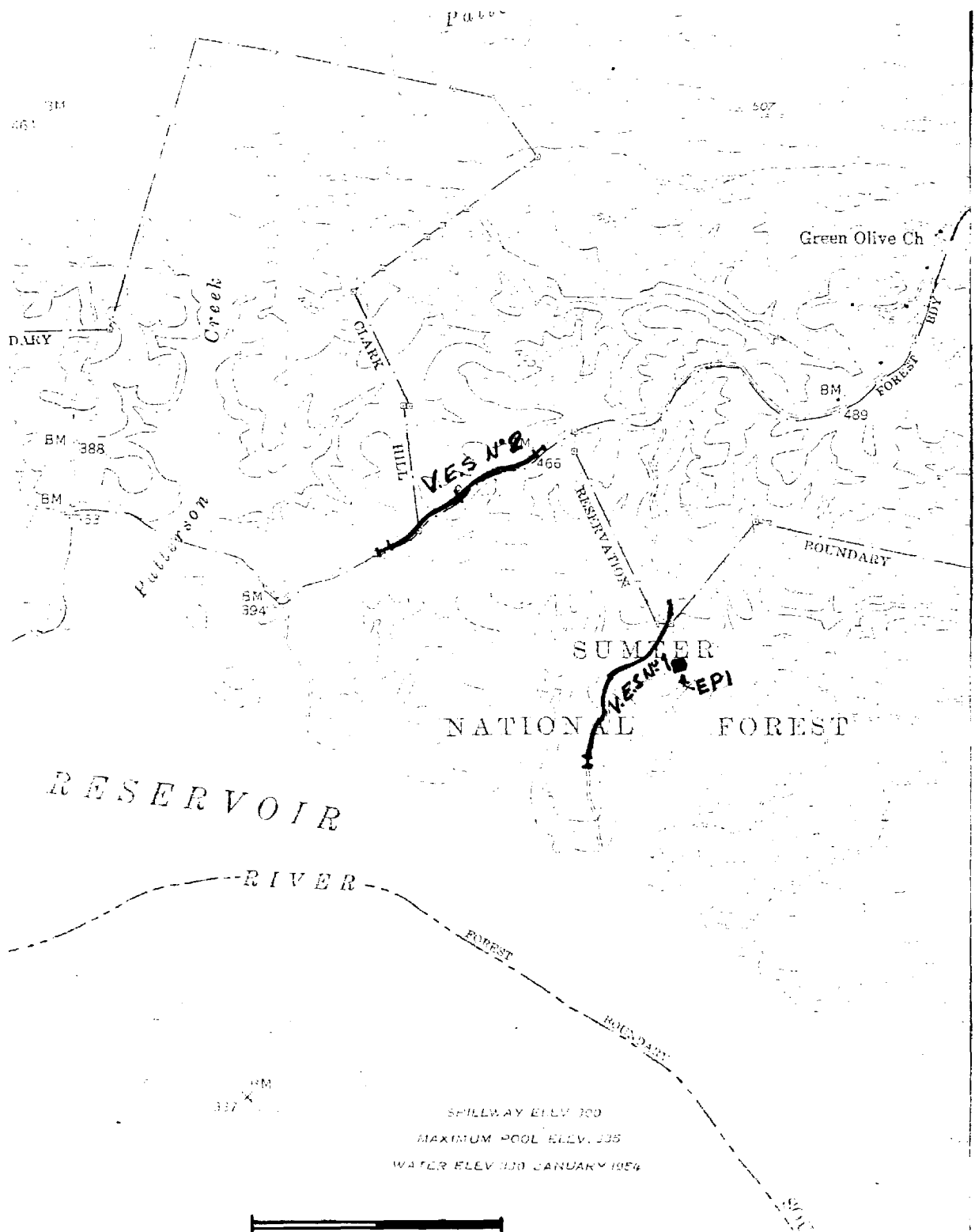


Fig 1

V.E.S. (PROFILE No 1)

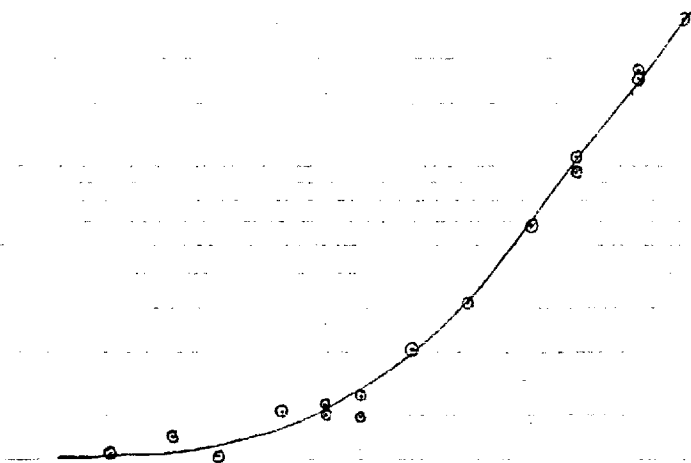
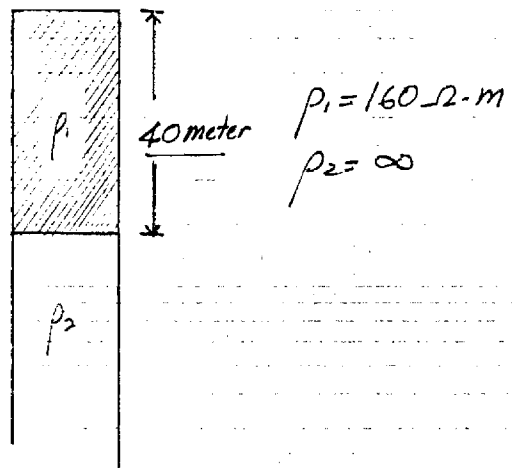


FIG 2

RESISTIVITY - DATA FORM

E.S. No.: 1 Date: Dec 12 '78 Operator: H. J. M. DE E. G. SMITH
 AB Direction: N 21° E Notes: _____
 Location: CLARK HILL
LATITUDE 23° 57'
LONGITUDE 82° 30' - 50"

(mV) (mA) (Ω·m)											
AB/2	MN	K	AV	i	ρ	AB/2	MN	K	AV	i	ρ
3	2	1.26				200	80	150.8	14.8	22.5	957
5	2	3.77				300	20	1412	1.3	10	1836
7	2	7.54				300	80	347	5.1	10	1770
10	2	15.55				400	20	2510	4.5	46	2455
10	5	5.89	39.4	32	154	400	80	622	12.9	46	2552
15	2	35.2	26.7	21.5	171	400	200	236			
15	5	13.75				500	20	3925			
20	5	24.75	5.2	8.5	151	500	80	975			
30	5	56.2	12	33	204	500	200	377			
40	5	100.1	4.7	22	214	200 300		754			
40	20	23.6	15.24	18	200	750	200	368			
50	5	156.7	3.7	29.5	197	1000	200	155			
50	20	37.7	16.4	31	225	1000	500	589			
70	20	75.4	13.07	32.5	303	1500	200	3520			
100	20	155.5	17.42	65.4	415	1500	500	1375			
150	20	352	3.7	45.3	673	2000	200	6270			
150	80	82.1	24.7	42.5	670	2000	500	2475			
200	20	627	3.8	22.5	1059	3000	500	5615			

FIG 2 DATA

V.E.S (PROFILE N°1) $\rho_1 = 160 \Omega\cdot m$, $h_1 = 40$ meters.

The following table shows the estimated $AB/2$ spread required to detect the existence of a hypothetical third layer. Different situations are considered for the resistivity of this third layer as well as for the thickness of the second layer. Third layer's thickness is considered infinite.

ρ_2	second layer's thickness	ρ_3	$AB/2$ Spread
$25\rho_1$	from 20m to 160 m	∞	1,000 m (minimum)
"	from 320m to 1,000 m	∞	1,500 m (")
"	" 20m " 1,000 m	$100\rho_1$	10,000 m (")
"	" 640m " 1,000m	$10\rho_1$	3,000 m (")
"	" 300m " 800 m	$5\rho_1$	2,000 m (")
"	" 800m " 1,200 m	$5\rho_1$	3,000 m (")
"	" 800m " 1,200 m	$3\rho_1$	2,000 m (")
"	" 800m " 1,200 m	$2\rho_1$	2,000 m (")
"	" 800m " 1,200 m	ρ_1	2,000 m (")
"	" 1,000m " 1,200 m	$\rho/2$	2,000 m (")
"	" 1,000m " 1,200 m	$\rho/4$	2,000 m (")
"	" 1,000m " 1,200 m	$\rho/10$	2,000 m (")
"	" 800m " 1,200 m	0	2,000 m (")
$15\rho_1$	" 20m " 1,200 m	∞	1,000 m (")
$15\rho_1$	" 20m " 1,200 m	$45\rho_1$	3,000 m (")

FIG 2 DEPTH PENETRATION

V.E.S. (PROFILE N°2)

$$\rho_1 = 490 \Omega\text{-m}$$

$$\rho_2 = 49 \Omega\text{-m}$$

$$\rho_3 = 4900 \Omega\text{-m}$$

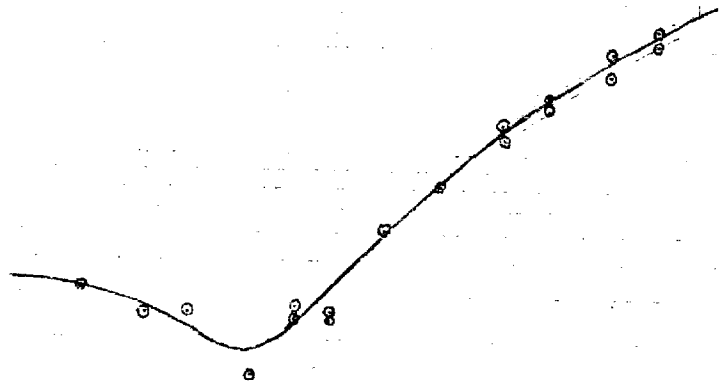
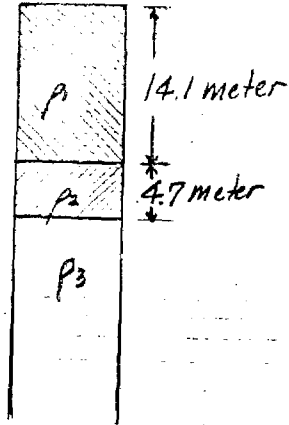


FIG. 4

FIG 3

RESISTIVITY - DATA SHEET

E.S. No.: 2 Date: 2001 Operator: ...
 Dip direction: 137E Notes: _____
 Location: ...
...
21-20"

AB/2	MN	K	(mv) (mA) (-2 m)			AB/2	MN	K	AV	i	c
			AV	i	c						
3	2	1.26				200	80	150.8	62.2	1826	1428.
5	2	3.77				300	20	1412	15	12.5	1694.
7	2	7.54				300	80	347	7.1	12.5	1971.
10	2	15.55				400	20	2510	2.3	27.5	209.7.
10	5	5.89	87.9	12.5	414.	400	80	622	10	27.5	226.2.
15	2	35.2				400	200	236			
15	5	13.75	24.5	10	33.7.	500	20	3925			
20	5	24.75	14.28	10.5	32.7.	500	80	975			
30	5	36.2	3.6	8.5	23.80.	500	200	377			
40	5	100.1	2.0	10.5	32.13	700	200	754			
40	20	23.6	15.3	10.5	34.4.	750	200	868			
50	5	136.7	3.1	14	34.7.	1000	200	1555.0			
50	20	37.7	13.3	14	35.7.	1000	500	589			
70	20	75.4	12.2	15	61.5.3	1500	200	3520			
100	20	155.5	26.5	26.1	808.0	1500	500	1375			
150	20	352	15.81	49	111.3.0	2000	200	6270			
200	20	32.1	72.42	49	121.3.0	2000	500	2475			
300	20	147	14.3	13.26	125.0.	3000	500	3615			

FIG 3 DATA

V.E.S (PROFILE N°2):

$$\begin{array}{l} \rho_1 = 490 \Omega \cdot m \\ \rho_2 = 49 \Omega \cdot m \\ \rho_3 = 4900 \Omega \cdot m \end{array} \quad \begin{array}{l} h_1 = 14.1 m. \\ h_2 = 4.7 m. \end{array}$$

If estimates are to be done about the spread required in order to detect a deeper layer with low resistivity, the top two layers can be reduced to an equivalent layer. Thus, the profile can be treated as a two layer one and the problem reduces to that of V.E.S. Profile N° 1.

— Reduction from a three layer system to a two layer one:

Since in this case we are dealing with a H type curve with ρ_3 large compared with ρ_2 then

$$h_E = h_1 + h_2 = 18.8 m$$

and

$$\rho_E = \frac{h_1 + h_2}{S_1 + S_2} = \frac{(h_1 + h_2)}{\left(\frac{h_1}{\rho_1} + \frac{h_2}{\rho_2}\right)}$$

$$\rho_E = 150 \Omega \cdot m$$

FIG 3 DEPTH
PENETRATION

D_3	Third layer's thickness	D_4	$AB/2$ spread required
25PE	160 m to 600 m	10PE	1,500 m (minimum)
"	from 300 m to 600 m	5PE	1,500 m (")
"	" 300 m " 600 m	3PE	1,000 m (")
"	" 300 m to 600 m	2PE	1,000 m (")
"	" 300 m " 600 m	PE	1,500 m (")
"	" 300 m " 400 m	PE/2	900 m (")
"	" 500 m " 600 m	PE/2	1,500 m (")
"	" 300 m " 500 m	PE/4	1,000 m (")
"	" 250 m " 300 m	PE/4	1,000 m (")
"	" 400 m " 600 m	PE/10	1,300 m (")
"	" 250 m " 300 m	PE/10	1,000 m (")
"	" 300 m " 600 m	0	1,500 m (")
15PE	" 250 m " 600 m	0	5,000 m (")
15PE	" 400 m " 600 m	5PE	1,500 m (")
15PE	" 400 m " 600 m	PE	1,500 m (")

FIG 3 DEPTH PENETRATION

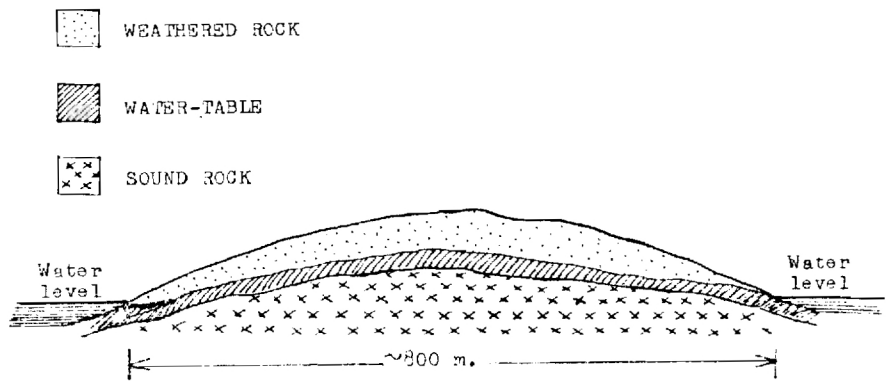


FIG 5

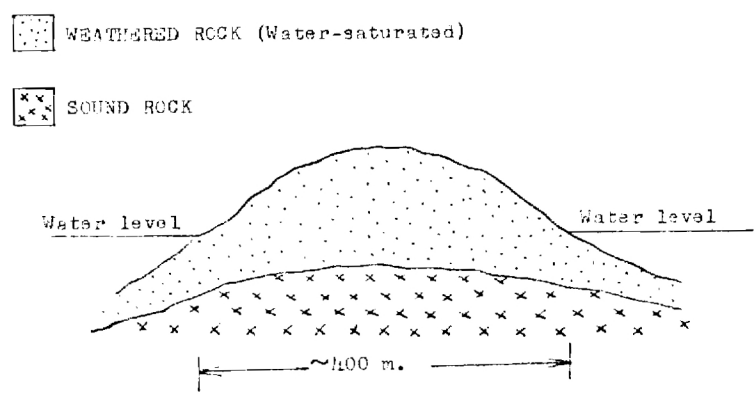


FIG 4

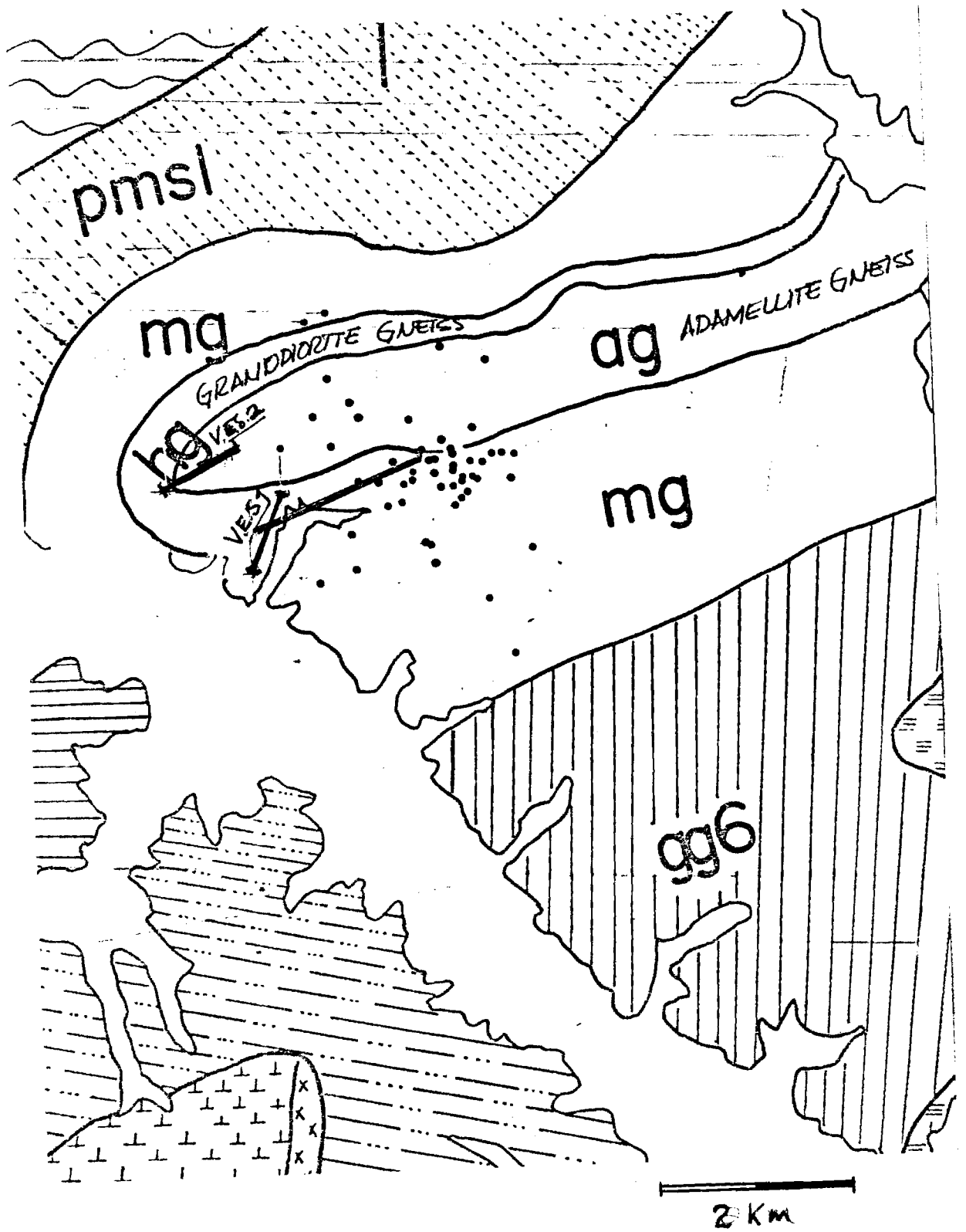


FIG 6

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

OFFICE OF
THE
COMPTROLLER

May 28, 1980

Kellogg V. Morton, Chief
Research Contracts Branch
Division of Contracts
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Morton:

Enclosed is the Statement of Costs and Final Voucher for Contract Number NRC-04-77-210 covering the period December 1, 1977 through April 30, 1979.

If you have any questions or desire additional information, please let us know.

Sincerely,

David V. Welch, Manager
Grants and Contracts Accounting

DVW/GHS/jb
Enclosures

cc: Dr. L. T. Long
Dr. C. E. Weaver
Mr. E. E. Renfro
Mr. O. H. Rogers ✓
File G-35-633

DISTRIBUTED ON 7/6/80

GEORGIA INSTITUTE OF TECHNOLOGY, ATLANTA, GEORGIA
U. S. Department of Energy
Statement of Costs

1. Name and Address of Contractor: Georgia Institute of Technology
Atlanta, Georgia 30332
2. Contract Number: NRC-04-77-210
3. Beginning and ending date of pertinent contract period: December 1, 1977
through April 30, 1979
4. Costs incurred during the pertinent contract period:
 - a. Salaries and wages \$ 18,830.53
 - b. Equipment -0-
 - c. Travel (all domestic) 1,523.31
 - d. Other direct costs 6,777.75
 - e. Total direct expenditures \$ 27,131.59
 - f. Indirect charges 13,950.62
5. Total costs for items under Article A-II(a) for the pertinent contract period \$ 41,082.21
6. Support Cost \$ 41,082.21
7. Cumulative support cost \$ 138,997.97
8. Accumulated support ceiling 140,433.00
9. The difference between lines 7 and 8 \$ 1,435.03

I hereby certify that this report is true and correct to the best of my knowledge and belief and that the costs listed herein were incurred in connection with the performance of the research provided for under this contract and in accordance with the terms and conditions set forth therein.

David V. Welch, Manager, Grants & Contracts Accounting
Name and Title of Business Officer

Signature

Date

5/28/80

U.S. DEPARTMENT, BUREAU, OR ESTABLISHMENT AND LOCATION
Office of the Controller
Attn: Mr. J. Lincoln, Director
Division of Accounting
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

DATE VOUCHER PREPARED
May 21, 1980

CONTRACT NUMBER AND DATE
NRC-04-77-210

REQUISITION NUMBER AND DATE

SCHEDULE NO.

PAYED BY

PAYEE'S NAME AND ADDRESS
Georgia Institute of Technology
Atlanta, Georgia 30033

RF-41656

DATE INVOICE RECEIVED

DISCOUNT TERMS

PAYEE'S ACCOUNT NUMBER
G-35-633

SHIPPED FROM TO WEIGHT GOVERNMENT B/L NUMBER

NUMBER AND DATE OF ORDER	DATE OF DELIVERY OR SERVICE	ARTICLES OR SERVICES <i>(Enter description, item number of contract or Federal supply schedule, and other information deemed necessary)</i>	QUANTITY	UNIT PRICE		AMOUNT (¹)
				COST	PER	
	12/1/77 to 4/30/79	Final Payment 10% of \$ 41,086.00				\$ 4,108.60

(Use continuation sheet(s) if necessary) (Payee must NOT use the space below) TOTAL \$ 4,108.60

PAYMENT: <input type="checkbox"/> COMPLETE <input type="checkbox"/> PARTIAL <input type="checkbox"/> FINAL <input type="checkbox"/> PROGRESS <input type="checkbox"/> ADVANCE	APPROVED FOR	EXCHANGE RATE	DIFFERENCES
	= \$	= \$1.00	
	BY ²		
	TITLE	Amount verified; correct for <i>(Signature or initials)</i>	

Pursuant to authority vested in me, I certify that this voucher is correct and proper for payment.

(Date) (Authorized Certifying Officer)³ (Title)

ACCOUNTING CLASSIFICATION

PAID BY	CHECK NUMBER ON TREASURER OF THE UNITED STATES	CHECK NUMBER ON (Name of bank)
	CASH DATE	PAYEE ⁴ Georgia Institute of Technology

¹ When stated in foreign currency, insert name of currency.
² If the ability to certify and authority to approve are combined in one person, one signature only is necessary; otherwise the approving officer will sign in the space provided, over his official title.
³ When a voucher is received in the name of a company or corporation, the name of the person writing the company or corporate name, as well as the capacity in which he signs, must appear. For example: "John Doe Company, per John Smith, Secretary", or "Treasurer", as the case may be.

PEP
 TITLE David V. Welch, Manager
 Grants & Contracts, Accto.