REPORT ON RECOMMENDED LIST OF STRUCTURES FOR SEISMIC INSTRUMENTATION IN SOUTHEASTERN UNITED STATES

U.S. GEOLOGICAL SURVEY
SOUTHEASTERN UNITED STATES INSTRUMENTATION OF STRUCTURES ADVISORY COMMITTEE

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INTRODUCTION

The Southeastern United States is a seismically active region requiring earthquake hazard mitigation programs, including that related to the investigations of strong shaking of structures. As part of its earthquake hazard planning, the United States Geological Survey (USGS) identified the Southeastern United States as one of the regions for the implementation of a structural instrumentation program to further these studies. Selection of structures for strong motion instrumentation is accomplished by establishing advisory committees in the various seismic regions including the Southeastern United States.

This report outlines the efforts of that committee in the Southeastern United States, particularly in Charleston, South Carolina--the location of the 1886 Charleston earthquake.

THE STATUS OF STRUCTURAL INSTRUMENTATION PROGRAMS OF THE USGS

The main objective of any instrumentation program for structural systems is to improve the understanding of the behavior, and potential for damage, of structures under seismic loading. The acquisition of structural response data during earthquakes is essential to confirm and/or further develop methodologies used for analysis and design of earthquake resistant structural systems. This objective can best be realized by selectively instrumenting structural systems to acquire strong ground motion data, and recording of the responses of structural systems (buildings, components, lifeline structures, *etc.*) to the strong ground motion. As a long term result, one may expect design and construction practices to be modified to minimize future earthquake damage [1].

Although various codes in effect in the United States, whether nationwide or local, recommend different quantities and schemes of instrumentation, in the southeastern United States, the Standard Building Code (of the Southern Building Code Congress) does not recommend any instrumentation for buildings. Many municipalities, particularly those in South Carolina must use the Standard Building Code. On the other hand, the Uniform Building Code (UBC) [2] recommends for Seismic Zones 3 and 4, a minimum of three accelerographs be placed in every building over six stories in height with an aggregate floor area of 60,000 square feet or more, and in every building over 10 stories in

A general description of the targeted regions for structural instrumentation is shown in the map in Figure 1 [5]. The general status of the committees is summarized in Figure 2 [5].

SEISMICITY OF THE SOUTHEASTERN UNITED STATES

The studies related to the seismicity of the southeastern United States have always referred to the 1886 Charleston Earthquake as the largest earthquake known to have occurred in the Eastern United States [6]. A summary of the seismicity of the area and a detailed study of seismicity of Charleston, South Carolina by Talwani [6] is provided in Appendix B of this report for further reference. Recent studies on seismicity of the area are also summarized by Talwani in Appendix B.

ADVISORY COMMITTEE FOR STRONG-MOTION INSTRUMENTATION OF STRUCTURES IN THE SOUTHEASTERN UNITED STATES

The initiation of the strong motion instrumentation of structures program in the Southeastern United States is timely, since there are several recent developments related to effective earthquake hazard mitigation in the region. Firstly, the South Carolina Seismic Safety Consortium (SCSSC) has been recently established [7]. The SCSSC is being assisted by the Earthquake Education Center (EEC) at Baptist College of Charleston and the Earthquake Engineering Research Center (EERC) at the Citadel, also in Charleston, South Carolina. The Earthquake Education Center promotes general earthquake education and awareness. More information on EEC is provided in Appendix C. The Earthquake Engineering Research Center aims to develop an earthquake engineering technology base adequate for the establishment and implementation of appropriate seismic building codes and competent community risk assessments within South Carolina and the Southeastern United States. The Earthquake Engineering Research Center administers the Technology Transfer and Development Council (TTDC). The TTDC consists of earthquake engineering specialists located at institutions and engineering companies throughout the southeastern United States. It serves to effectively integrate regional seismic matters and to better represent them in the national and international technical environments

[7]. With these available organizations, therefore, the USGS Advisory Committee for Instrumentation of Structures in the Southeastern United States was formed with TTDC members complemented by USGS personnel.

The advisory committee developed a preliminary list of potential structures which are deemed important, such that, if instrumented, the engineering community would benefit from studying the data acquired during strong earthquakes. Details of the structures were then examined and a prioritization for instrumentation developed among the most important candidates. The top priority strong-motion instrumentation candidate structure is the Charleston Place, a major convention and commercial center being constructed in the historic downtown area of Charleston. Figure 3 shows the location of the Charleston Place and the next five highest priority instrumentation candidates. As a matter of interest, Figure 4 provides these locations, including that of the Charleston Place, superimposed over an illustration of the distribution of damage resulting from the 1886 Charleston earthquake.

The USGS accepted the advisory committee's recommendation and has identified resources to accomplish the strong motion instrumentation of the Charleston Place during 1986. Permission of the owners has been obtained and instrumentation will be installed prior to the Third U.S. National Conference on Earthquake Engineering to be held in Charleston August 25-28, 1986.

Although the advisory committee selected the Charleston Place as the first building in the southeastern United States to be extensively instrumented by the USGS, the overall mission of the committee was not restricted to Charleston. The objectives of the committee have been to consider all regions in the southeastern United States within the scope of objectives defined by TTDC. Other areas and structures other than buildings have been considered. However, for the first building structure to be instrumented, the Committee members concurred on concentrating their efforts in Charleston, South Carolina. As funds become available, the committee will look further into other types of structures in all regions.

STRUCTURES CONSIDERED FOR INSTRUMENTATION

Table 1 summarizes the final list of structures in Charleston, South Carolina in order of priority, as determined by the advisory committee. This list has been condensed from a larger list of structures in Appendix A.

CONCLUSIONS

This report summarizes the efforts of the USGS-Southeastern United States Instrumentation of Structures Advisory Committee. The committee members deliberated over a period of 18 months to select a structure for extensive instrumentation by the USGS.

As a result of these deliberations, the Charleston Place in Charleston, South Carolina, currently under construction, was selected for extensive instrumentation by the committee. At present, this effort is underway.

Other structures not only in Charleston but also in other regions of the southeastern United States, will be considered in the future, pending the availability of funds.

REFERENCES

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[5] Celebi, M., and Maley, R., 1986, Strong motion instrumentation of structures in Charleston, South Carolina and elsewhere: *Proceedings III, U.S. National Conference on Earthquake Engineering*, Charleston, South Carolina, August 1986.

[6] Talwani, P., 1982, Internally consistent pattern of seismicity near Charleston, South Carolina: *Geology*, v. 10, p. 654-658, December 1982.

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TABLE 1

Preliminary List of Structures in Charleston, South Carolina Selected
(in order of ranking as evaluated by committee)

	Structure	Tentative Description
1.	Charleston Place (Convention Center)	8-story tower with 2 4-story wings
2.	Howard Johnson's Hotel	precast, 6-stories, seismic design
3.	Summerall Building	Concrete - 10 floors - not seismically designed. Attached parking garage on fill land.
4.	Dockside Condominiums	20 stories, steel on fill (suitable for wind engineering studies)
5.	"Windswept 5"	Sitting on long piles ~ 90' (piles extended above grade 20-25 ft and 4-story building sits on the piles)
6.	a)* Sheraton	Concrete
	b)* Holiday Inn	12 stories, R.C. on low-prestressed piles
	c)* Marriot (North Charleston)	not on fill land, 12 floors close to presumed epicenter of 1886 earthquake
7.	a)* Navy Credit Union	
	b)* Sheraton (North Charleston)	
8.	a)* Holiday in Summerville (close to fault)	
	b)* Church at Baptist College (close to fault)	

* When more than one structure is listed the instrumentation of only one structure out of the group is recommended.

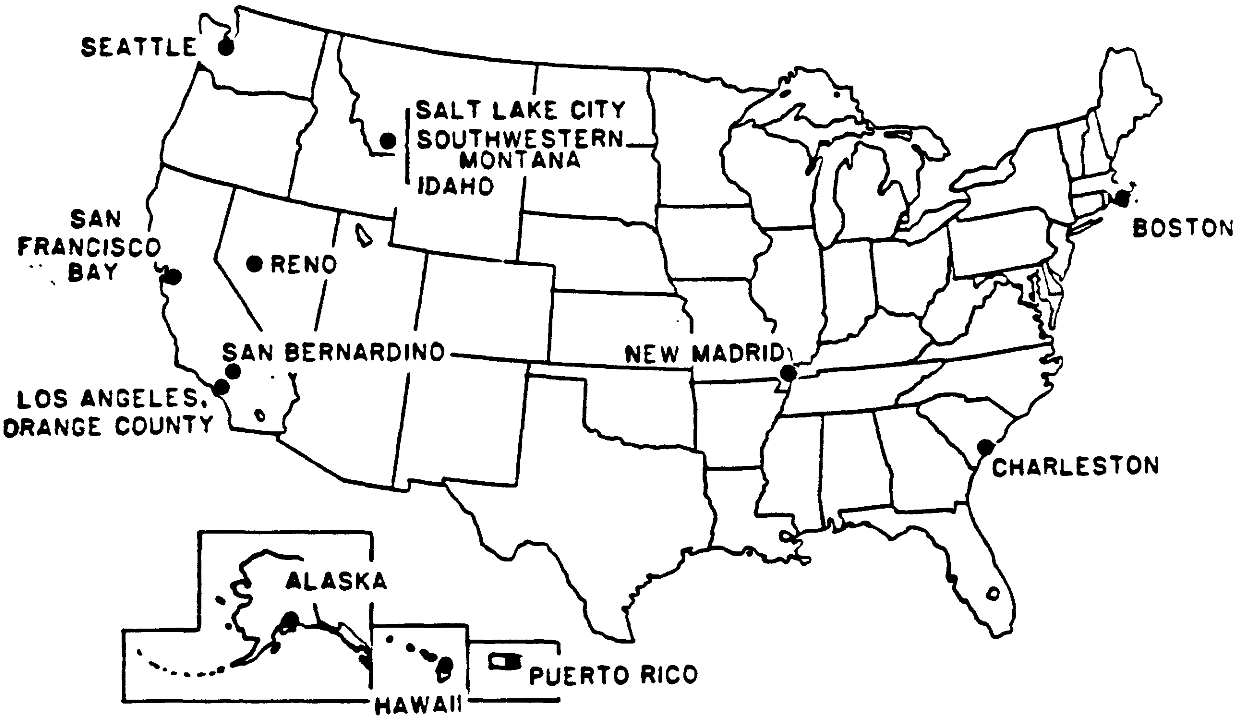

Fig. 1. Target Regions for Instrumentation of Structures Program.

ADVISORY COMMITTEES FOR STRUCTURAL INSTRUMENTATION

COMMITTEE FORMED	REPORT COMPLETED	REGIONS CONSIDERED
X	X	● SAN FRANCISCO AREA
X	X	● SAN BERNARDINO
X		● LOS ANGELES, ORANGE COUNTY
X		● CHARLESTON, SC (SOUTHEAST)
X		● BOSTON,MASS. (NORTHEAST)
X		● NEW MADRID
		● SEATTLE, WASH. (NORTHWEST)
		● UTAH, IDAHO, SW MONTANA (MOUNTAIN REGION)
X		● ALASKA
		● RENO
X		● HAWAII
		● PUERTO RICO

Fig. 2 Current Status of Advisory Committees.

DOWNTOWN AREA

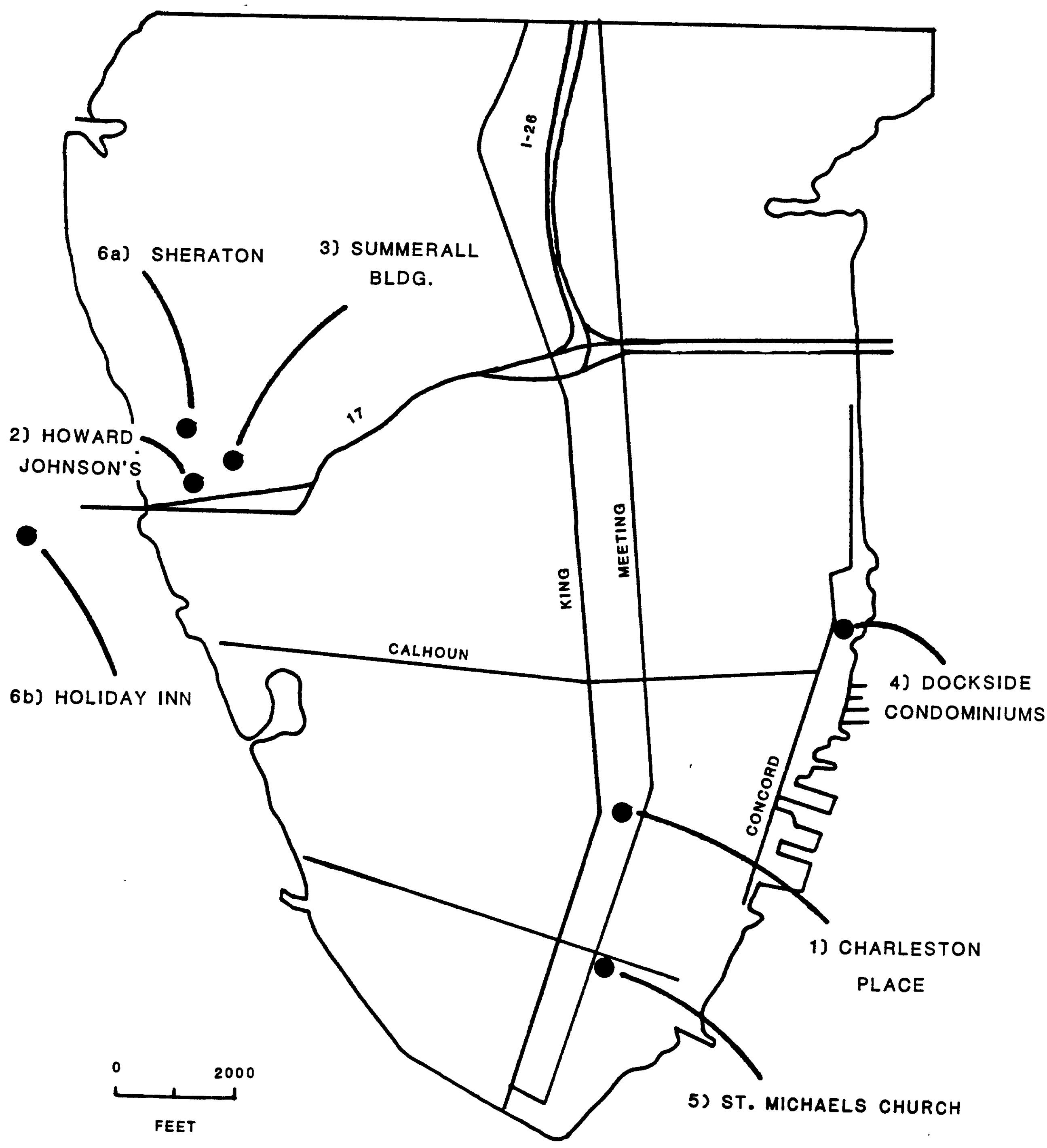

Figure 3. General Map of Downtown Charleston showing the Locations of Structures Selected for Possible Strong-Motion Instrumentation

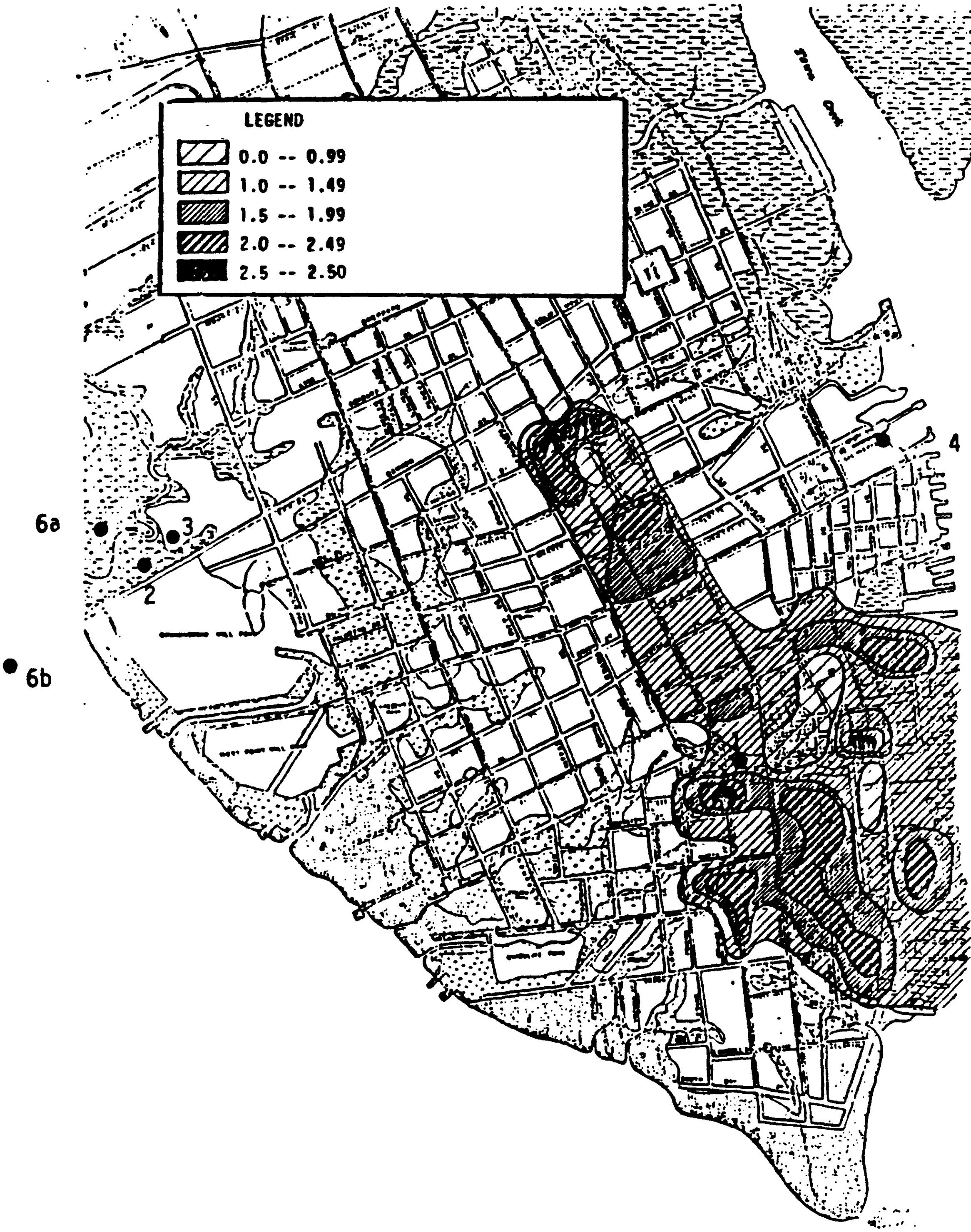

Figure 4. Downtown Charleston (Overall Building Damage Ratings for the 1886 Business District-Unreinforced Masonry)

APPENDIX A

Table A-1
List of Structures in Charleston, South Carolina Considered for Instrumentation

1. "Round" Holiday Inn
   Highway 17
2. St. Francis Xavier Hospital
   Calhoun Street
3. Charleston Place (under construction)
   Market Street
4. City of Charleston Parking Garages:
   A. Cumberland
   B. Concord (under construction)
   C. East Bay (under construction)
   D. Hasell (under construction) (Part of #28)
5. St. Michaels Church
   Meeting Street
6. Summerall Building (Comparison with #25)
   Hagood Avenue
7. Hagood Stadium (Citadel)
   Hagood Avenue
8. Rice Mill Building
   Lockwood Boulevard
9. St. Mary's Church
   Hasell Street
10. Beth Elohim Temple
    Hasell Street
11. Riviera Theatre
    King Street
12. Dockside Condominiums
    Concord Street
13. C.D. Franke Building
    Market @ Church
14. U.S. Customs House
    East Bay @ Market
15. Gaillard Auditorium
    Calhoun Street
16. U.S. Post Office
    Broad @ Meeting
17. St. John the Baptist Cathedral
    Broad Street
18. Massey Coal Terminal
    Off of Meeting Street Exension
19. Bankers Trust
    Calhoun @ Gadsden
20. Circular Church
    Meeting Street
21. Exchange Building
    East Bay Street
22. SCN Bank - Front Building and Annex
    East Bay @ Broad
23. County Hall
    King Street
24. Carroll Building
    East Bay and Meeting
25. Howard Johnson Hotel
    (Comparison with #6)
    Spring Street
26. "Windswept 5" (Planning stage)
    Kiawah Island
27. Seascape (under construction)
    Isle of Palms
28. Meeting Street Renovation (under construction) (Part of #4D)

APPENDIX B

1. Summary by P. Talwani entitled "Results of Recent Studies in Charleston Area".

2. Paper by P. Talwani entitled "Internally Consistent Pattern of Seismicity near Charleston, South Carolina" published in *Geology*, v. 10, p. 654-658, December 1982. (Included in this appendix with permission of the author who is a member of the committee and also with knowledge of GSA. Proper credits related to the paper are shown on the reproduced pages.)

RESULTS OF RECENT STUDIES IN THE CHARLESTON AREA

P. Talwani
University of South Carolina

The existence of the northwest-trending Ashley River fault was confirmed by shallow stratigraphic drilling. The presence of the fault had been suggested by the location of current instrumentally recorded seismicity. Other data suggested that this fault has had an episodic history of activity since about 48 million years ago.

Other field studies at USC suggest that the Charleston area has had at least two large (magnitude ~6) earthquakes prior to 1886, but after about 3700 years before the present. Our preliminary results suggest a recurrence rate of about 1500 years for such large earthquakes. Further research is currently underway.

Internally consistent pattern of seismicity near Charleston, South Carolina

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ABSTRACT

An improved velocity model for the meizoseismal area of the 1886 Charleston earthquake was used to relocate current seismicity, which showed marked separation into clusters. The relocated hypocenters and composite focal plane solutions were compared with available geophysical data to interpret their tectonic significance and possible association with the 1886 earthquakes. There is a distinct velocity discontinuity at a depth of about 10 km, where Vp increases from 5.9 to 6.45 km/s. The relocated hypocenters and composite focal plane solutions delineate two main source zones lying at different depths. The shallower zone, at 4 to 8 km depth and collinear with the Ashley River, is herein named the Ashley River seismogenic zone. The composite focal plane solution suggests reverse faulting on a steeply dipping northwest-striking fault with the southwest side upthrown. This zone is also associated with aeromagnetic and gravity anomalies. The deeper zone, at 9 to 13 km, suggests a right slip on a fault extending N26°E from east of Ravanel to Jedburg, a distance of more than 25 km, and dipping steeply to the west-northwest. Its location and extent are similar to the so-called Woodstock fault. Examination of geomorphic data suggests that there may be some ongoing tectonic uplift and subsidence in the area. The inferred P axes from fault-plane solutions are oriented S60° W. Firsthand accounts of the 1886 earthquakes suggest that two source areas were active in 1886 and the months that followed; I postulate that the two zones of current seismicity are coincident with the 1886 source areas.

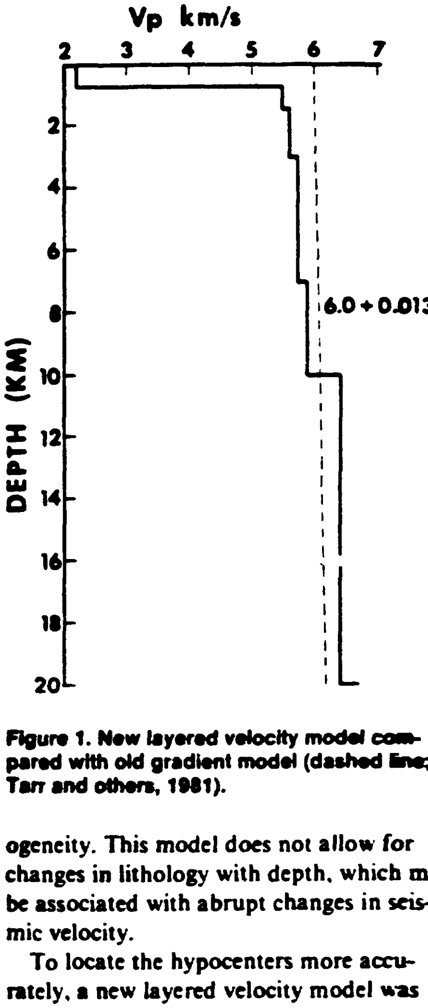

Figure 1. New layered velocity model compared with old gradient model (dashed line; Tarr and others, 1981).

INTRODUCTION

The largest earthquake known to have occurred in the eastern one-third of the United States struck Charleston, South Carolina, in 1886, and smaller earthquakes have occurred in the area from at least 1698 to today (Dutton, 1889; Bollinger, 1977; Bollinger and Visvanathan, 1977; Tarr, 1977; Nuttli and others, 1979; Rhea, 1981). The cause of that intraplate seismicity remains unknown, partly because calculated epicenters and depths of small earthquakes have not defined a spatial pattern clear enough to form the basis of a structural interpretation. I attempt here to define such a pattern of seismicity.

A multidisciplinary study of the tectonics and seismicity in the Charleston area (Rankin, 1977) began with the installation of a seismographic network in 1974. This led to the first instrumental location of earthquakes in the Charleston area. A preliminary result of the seismicity studies was the delineation of three zones of seismicity in the Coastal Plain at Middleton Place, Bowman, and Adams Run (Tarr, 1977; Tarr and others, 1981). Although specific tectonic features responsible for the seismicity were not identified because of an inexact velocity model, the epicentral locations suggested that the current seismicity (1974–1980) was occurring near the location of the 1886 event.

My improved velocity model for the meizoseismal area of the 1886 earthquake (Talwani, in prep.) is a layered model, in which lateral heterogeneity is accounted for in station corrections. I have used it to relocate the current seismicity. The new locations and composite focal plane solutions were analyzed, and the preliminary results are presented here.

VELOCITY MODEL

Following the deployment of the 10-station South Carolina Seismographic Network in 1974, seismic activity was located in the vicinity of Middleton Place, about 20 km northwest of Charleston. In 1977 the number of stations was increased to 16, with a 7-station mininet near Middleton Place (Tarr and others, 1981). Data are recorded on analog tape, which allows for the precise timing of phase arrivals. The hypocenters were located by using a velocity gradient model (Fig. 1). Station corrections were estimated to improve travel-time residuals and to account for lateral heterogeneity. This model does not allow for changes in lithology with depth, which may be associated with abrupt changes in seismic velocity.

To locate the hypocenters more accurately, a new layered velocity model was obtained, with a scheme originally developed by Crosson (1976) and modified by Ellsworth (1978). Phase data for five blasts in the Middleton Place area (Amick, 1979) and 21 well-located earthquakes with the smallest travel-time residuals were used as input. Earthquake phase data were obtained from a catalog by Rhea (1981); only P-wave phase data of Coastal Plain stations were used. The origin times and locations of the blasts were known, and they were used in the modeling. These phase data were simultaneously inverted for hypocentral coordinates, velocity structure, and station delays, using a program called VELEST (Ellsworth, 1978). The program minimizes travel-time residuals by

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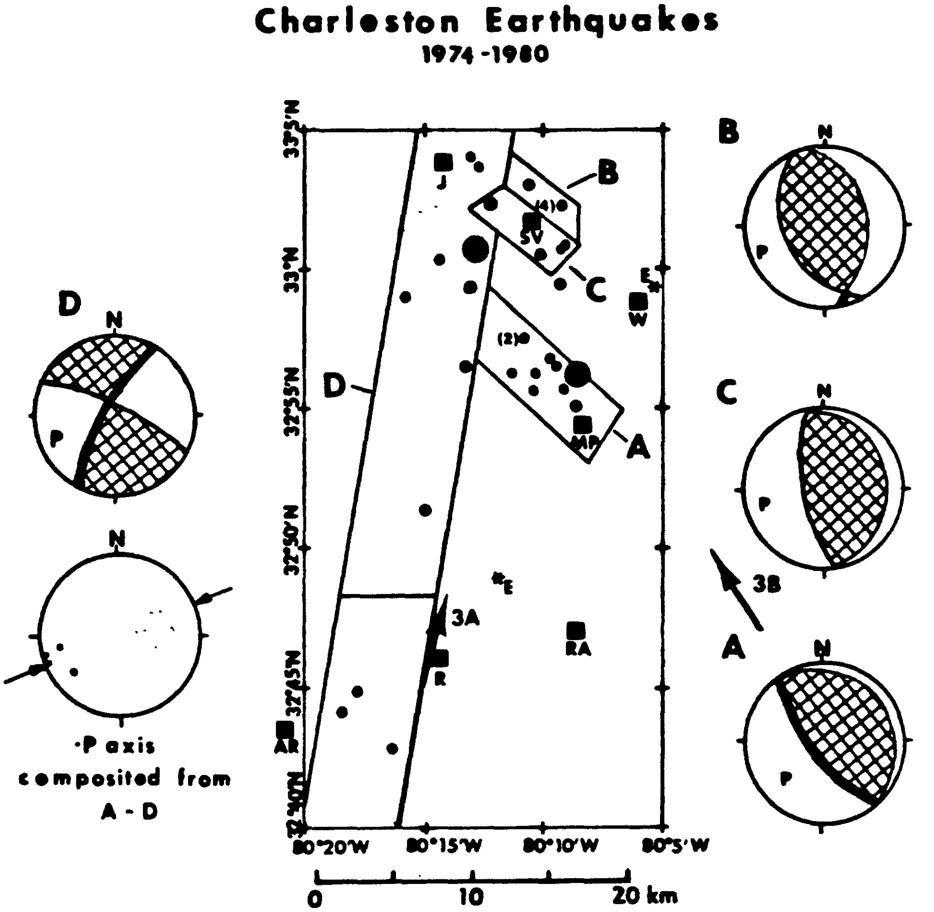

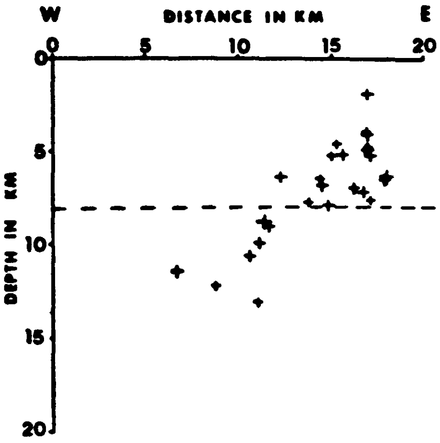

Figure 2. Left: Epicentral locations (solid circles) obtained with new velocity model. Hypocenters in groups A, B, and C are shallower than 8 km; those in D are deeper. Composite focal plane solutions for each group are shown on sides—thrust faulting for shallower events, with right-lateral strike-slip fault for deeper set. Lower focal hemispheres are shown; pattern indicates compressional quadrants; heavy lines indicate preferred modal planes. Inferred P axes for all solutions (solid dots; composited in projection below that for D) are in N60°E–S60°W direction. J = Jedburg, SV = Summerville, W = Woodstock, MP = Middleton Place, AR = Adams Run, R = Ravanel, RA = Rantowles. E* represents Dutton's (1889) epicenters. Two large arrows show view directions for Figure 3, A and B. Above: East-west cross section along lat 33°N at left. Only earthquakes north of lat 32°55'N have been included.

perturbing hypocentral coordinates, station corrections, and velocities of the fixed layers. The starting model was constrained to a depth of about 1 km by velocity log data in Clubhouse Crossroads well (N. W. Higgins, 1977, written commun.) and by a starting model based on refraction surveys (Amick, 1979).

The resulting velocity model is compared (Fig. 1) to that used by Tarr and others (1981). The computed station delays, relative to station SGS (which recorded 30 out of 31 events) varied from -0.64 s to 0.19 s. [A similar pattern was noted by Tarr and others (1981)]. A positive delay implies a slower observed travel path than calculated from the input model.

In Figure 1 the low velocity to a depth of 750 m reflects sediment thickness. The velocity structure in the top 3 to 4 km is controlled by refraction data from the blasts, which were recorded to distances of about 25 km. Below that, the model is controlled by phase data of the 21 earthquakes used in the modeling. One of the interesting features of the velocity model is the abrupt jump in velocity at a depth of 10 km from 5.90 to 6.45 km · s. The earthquake data are inadequate to control the model below a depth of about 20 km.

To test the accuracy of the velocity model, the blasts were relocated using the revised velocity model. For three blasts the relocated epicenters were within 870, 555, and 385 m of the actual sites. For the other two, data were available only along the refraction lines and were inadequate to obtain accurate locations. The suspected Jamestown quarry blast, located more than 60 km away and outside the seismic network, was relocated within 3 km of the quarry.

RESULTS

In addition to the 21 earthquakes used in modeling, an additional 10 events (for which adequate instrumental data were available) were also relocated by using the new velocity model. The local magnitude of the events ranged between 1.1 and 3.8. Four of these events were located outside the Summerville–Middleton Place region, three being in the Adams Run area (near AR in Fig. 2A) and one more than 60 km to the northeast of the area—probably a blast at Jamestown quarry. The results presented below are based mainly on the analysis of the remaining 27 events.

When the new hypocentral locations were compared with those of Rhea (1981) and Tarr and others (1981), a marked clustering of hypocenters became apparent. An example is the location of four events that occurred in less than 2 min on October 30, 1978. The original depths of these events (located in group B) were 6.8, 7.3, 7.1, and 3.0 km. The relocated depths are 4.9, 4.7, 4.9, and 4.1 km, respectively. These data also suggest a relative accuracy in the depths of about 1 km.

DISCUSSION

Grouping of Earthquakes

In order to infer the presence of possible faults that the earthquakes are associated with, they were grouped according to their three-dimensional locations and consistency of their phases with composite focal plane solutions. The data were divided into four groups (Fig. 2), and composite focal plane solutions were obtained for each group.

Group A contains 10 events. They lie in a small (5 km × 3 km) northwest-oriented cluster, at depths between 4.6 and 7.7 km. In group B there are 5 events, of which 4 occurred in a 2-min span. Their depths range from 4.1 to 7.9 km. In group C there are 4 events, at depths between 3.9 and 6.4 km. Group D consists of 8 deeper events (8.8 to 13.1 km) and is more than 25 km long. Thus, the groups to the east (A, B, and C) contain earthquakes shallower than 8 km, with an average depth of 5.9 km; in group D, to the west, the earthquakes are deeper than 8 km, with an average depth of 10.8 km.

COMPOSITE FOCAL PLANE SOLUTIONS

Figure 2 shows the lower-hemisphere projections of the composite focal plane solutions for each group. For all the shallow groups (A, B, and C), these are thrust-fault solutions. Of these, solution A is the most constrained, with 57 phases. The composite focal plane solution is similar to that obtained by Tarr and others (1981) for many of the same events, including the M_L = 3.8 event on November 22, 1974. The solution for group D yields right-lateral strike-slip faulting. On the basis of direction of elongation of the epicentral clusters (see also Fig. 3A), the preferred nodal plane strikes N26°E and dips 76°SW. For group A, both fault planes strike N37°W, and the steeply southwest dipping plane is chosen on the basis of the plane defined by the hypocenters (Fig. 3B) and the suggestion of a fault in the shallow sediments along the Ashley River noted in the COCORP reflection seismic data by Schilt and others (1979). This is at variance with the suggestion of Behrendt and others (1981) and Seeber and Armbruster (1981) that the horizontal plane is the preferred nodal plane; they implied a possible association with an inferred decollement at that depth. Also, these data do not support a composite focal plane solution with reverse faulting along a fault trending N64°E—the suggested Slandsville group of Tarr and others (1981).

A further check on these composite focal plane solutions is provided by the location of the P axes. All four axes plunge shallowly toward about S60°W. This internally consistent pattern is at variance with the poorly constrained Slandsville solution of Tarr and others (1981) which suggested northwest-southeast compression, but in agreement with the two other solutions in that paper.

The composite focal plane solutions for groups A and D have the following properties. The preferred nodal planes are collinear with the long axes of the associated epicentral clusters. The inferred P axes are roughly parallel, although one solution indicated reverse faulting and the other indicated strike-slip movement. The solutions are well constrained (Talwani, in prep.), and the orientations of the fault planes are probably accurate to ±10°. The inferred axis of maximum horizontal compression N60°E does not agree with the northwest orientation obtained from hydraulic fracturing to depths of 344 m in the sedimentary strata in Clubhouse Crossroads well by Zoback and others (1978) or that by Wentworth and Mergner-Keefer (1981) based on the orientation of Cenozoic faulting of Coastal Plain sediments. However, it is consistent with composite focal plane solution data from Monticello Reservoir in central South Carolina and Lake Jocassee in northwest South Carolina. The inferred northeast direction of maximum compressive stress from solutions near Summerville is also consistent with hydraulic fracturing and overcoring data at Bad Creek, about 18 km northwest of Lake Jocassee (Talwani and others, 1981). These observations suggest that the inferred orientations of the maximum horizontal stress at hypocentral depths are different from those in the shallow sediments and that a re-evaluation of inferred in situ stress directions given by Zoback and Zoback (1980) may be in order.

Selection of Fault Planes

In order to choose the fault plane from two nodal planes in a composite focal plane solution and to view them in three

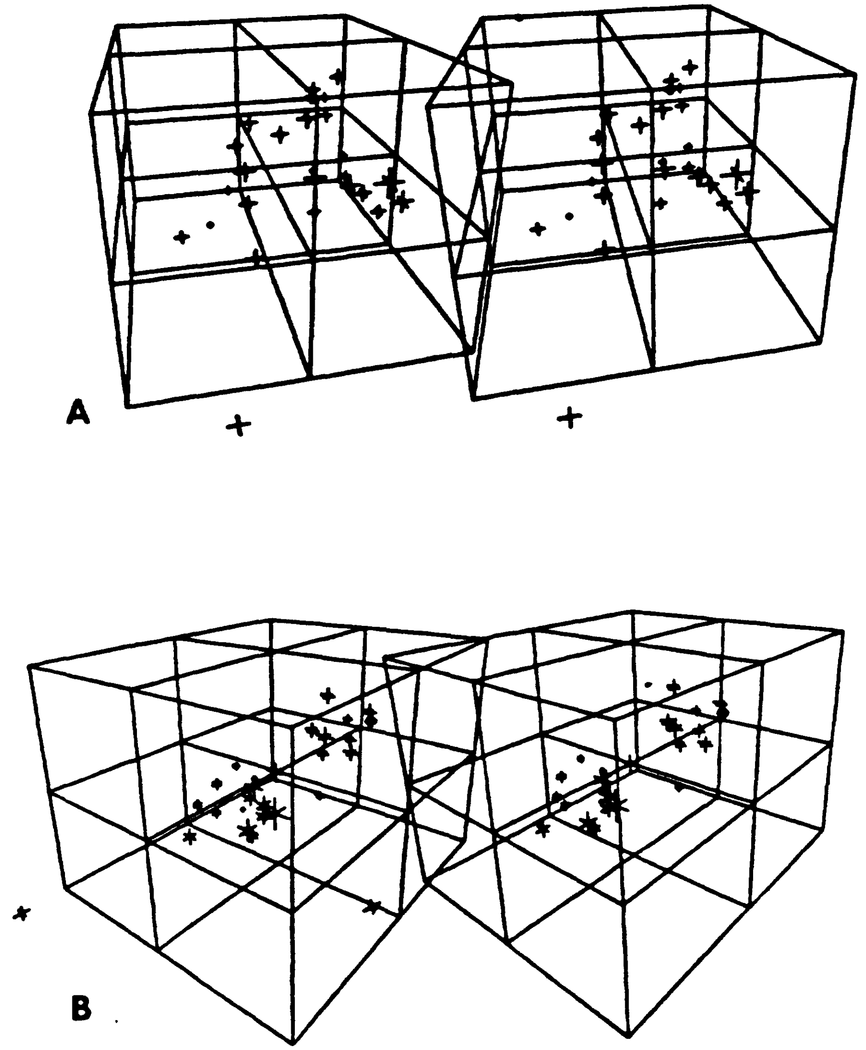

Figure 3. Stereoscopic projection of region between lat 32°54' and 33°06'N and long 80°06' and 80°18'W, extending to depth of 15 km. Views from two points located 5 km above ground and 35 km from center of viewed region along two lines passing through (A) lat 32°45'N, long 80°15'W and (B) lat 32°48'N, and long 80°W. Horizontal plane in middle is at depth of 8 km.

dimensions, the Summerville–Middleton Place earthquakes have been plotted in stereoscopic projection (Fig. 3, A and B). It is apparent that the events of group D (lying below 8 km) define a north-northeast-trending fault that dips steeply to the west. The events in group A clearly define a northwest trend (Fig. 3B). This view indicates a near-vertical plane, trending northwest. When these views are compared with the composite focal plane solutions for groups A and D, we conclude that the steeply dipping fault in solution A and the north-northeast-oriented fault in solution D are the likely fault planes.

Taber (1914) attributed the Charleston earthquake and the seismicity that occurred in the following 30 yr to "readjustments taking place along a plane of faulting, located in the crystalline basement underlying the Coastal Plain sediments, not far from Woodstock, and extending in a general northeast-southwest direction." This came to be known as the Woodstock fault, although its exact location was never defined. The north-northeast-oriented seismic zone defined by events in group D (Figs. 2A, 3A) fits Taber's description, although it is located about 10 km to the west of Woodstock. I have named this the Woodstock fault.

The earthquake epicenters and inferred fault plane from the composite focal plane solution for group A trend N37° W. The epicentral trend is collinear with the Ashley River (Fig. 4A). I have named the source region defined by these earthquakes the Ashley River seismogenic zone. This zone is also associated with pronounced collinear aeromagnetic and gravity anomaly patterns (Talwani and others, in prep.). There are several northwest-oriented dikes and other features on the aeromagnetic map of South Carolina.

Geomorphic Evidence

From the composite focal plane solution we infer that the movement at hypocentral depths (4 to 8 km) along the Ashley River seismogenic zone is such that the southwest side of the fault is thrust over the northeast side. If this movement was to be transmitted to shallow sediments, we would expect an indication of uplift to the southwest of the Ashley River. The deeper Woodstock fault is oriented north-northeast, dips steeply to the west, and is associated with right-lateral strike-slip movement. Earthquakes on this fault would not be expected to produce substantial vertical offsets in the shallow sediments.

In Figure 4A, the epicentral locations and composite focal plane solutions of earthquakes in group A are compared with the trends of nearby rivers. Note how both the Edisto and Stono Rivers abruptly change their courses. These are the only rivers in South Carolina that do so. A study of shallow sediments in the area between the right-angle bend in the Edisto River and the Ashley River indicates that the Edisto flowed toward the Ashley as late as 100,000 to 120,000 yr ago (D. Colquhoun, 1982, personal commun.; R. Weems, 1981, personal commun.). A change in the course of the Edisto River could have been due to the deposition of deltaic material which essentially blocked its path and caused it to flow to the south, or it could have been due to tectonic uplift that occurred in a region southwest of the Ashley River, with the same effect.

The situation in the Middleton Place region is compared with that in the Central Atlantic Coastal Plain (Fig. 4B). Higgins and others (1974) noted that the sharp bends in the Delaware, Susquehanna, and Potomac Rivers define a northeast trend, which was associated with aeromagnetic anomalies—the southeast side high and the northwest side low. Sbar and others (1975) located a magnitude 3.8 earthquake that occurred on February 28, 1973, on the trend defined above, and its fault plane parallel to this northeast axis. The depths of the aftershocks monitored on portable seismographs ranged between 5 and 8 km.

When we compare A and B in Figure 4 we see remarkable similarities. The seismic activity is occurring along faults defined by aligned river trends. The trends defined by the rivers appear to be parallel to those inferred from fault-plane solutions and aeromagnetic data (dashed lines). Reverse faulting is indicated for both areas, and the earthquakes are shallow (4 to 8 km).

Leveling Data

In search of independent corroborative evidence of tectonic uplift, I examined the available information on leveling data. There have been at least three leveling surveys in the area since 1915. Some authors have indicated that subsidence is occurring in the Charleston area; others have suggested uplift. Further work is necessary to resolve the cause of these different conclusions.

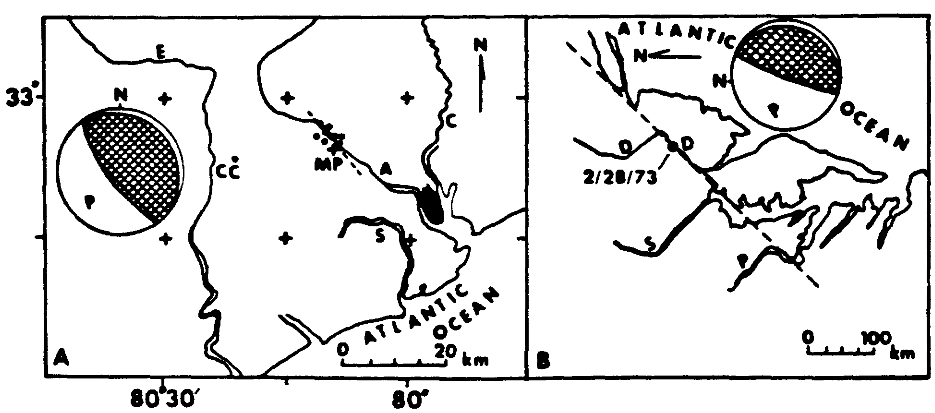

Figure 4. A: Earthquakes in group A compared with location of Edisto (E), Ashley (A), and Stono (S) Rivers, together with composite focal plane solutions for this group. MP = Middleton Place; C = Cooper River; CC = Clubhouse Crossroads well # 1. Inferred fault, shown by dashed line through cluster, strikes N37°W and is along strike of an aeromagnetic gradient. B: Location of earthquake near Delaware (D, 2/28/73) compared with trends in Delaware (D), Susquehanna (S), and Potomac (P) Rivers. Dashed line represents aeromagnetic trend. Focal plane solution of Sbar and others (1975) is also shown. Note that this figure has been rotated in order to compare with A and that scales are different.

Comparison with Isoseismal Data for 1886 Earthquake

The pattern of isoseismals in the meizoseismal area of the 1886 event was compared with the location of current seismicity. Dutton (1889) has presented two sets of isoseismals, those drawn by Sloan who actually traversed the area, and Dutton's own version of Sloan's data. Sloan's isoseismals enclose Dutton's epicenters (Fig. 2A) and extend about 20 km to the northeast and southwest of them. The northeast-southwest trend of isoseismals is offset by a northwest bulge, 10 km wide and 20 km long, that surrounds Jedburg and Summerville. The deeper events (group D) defining the Woodstock fault are oriented parallel to the long axis of Sloan's isoseismals. Groups A, B, and C appear to be associated with the northwest bulge in the isoseismals. This observation suggests, as do firsthand accounts of the

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earthquake and isoseismals of current seismicity, that immediately following the earthquake, both source areas were active.

CONCLUSIONS

An improved seismic velocity model for the meizoseismal area of the 1886 Charleston earthquake shows an abrupt increase in velocity at a depth of about 10 km, leading to the intriguing suggestion that it may be associated with a decollement surface, or a diffraction pattern observed at a depth of 11 km offshore of Charleston by Behrendt and others (1981). A comparison of epicenters with the intensity pattern of the 1886 earthquake suggests that modern earthquakes are occurring at the same locations. Improved hypocentral locations, together with the well-constrained composite focal plane solutions, were used to infer the geometries of the failure surfaces. Consistency of composite focal plane solutions, hypocentral location patterns, and the inferred P axes imply a coherent deformation pattern. This led to the separation of two seismic source zones at different depths, and along differently oriented faults. The earthquakes to the east of about long 80° 12'W define the shallower set, with hypocentral depths between 4 and 8 km. All these earthquakes are associated with high-angle reverse faulting. The preferred nodal plane of the best constrained composite focal plane solution is collinear with the seismicity along a segment of the Ashley River, and it has been named the Ashley River seismogenic zone. Its location is consistent with geomorphic, aeromagnetic, and gravity anomaly patterns. The deeper north-northeast-striking Woodstock fault is associated with right-lateral strike-slip movement. It is longer and a likely candidate for the main shock in 1886.

The data presented here do not support the contention of Behrendt and others (1981) that the Charleston earthquakes are related to the downward extension of the N60° E-trending Cooke fault. No evidence for its existence is seen in the contemporary seismicity. An attempt to obtain composite focal plane solutions using events in that orientation led to an unacceptable number of inconsistencies. These results are also at variance with the conclusions of Wentworth and Mergner-Keefer (1981). No evidence of shallow northeast-trending faults or northwest horizontal compression was detected.

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Reviewer's comment

This paper has used refined techniques and an updated velocity model to resolve the interaction of two possible faults as a cause of the Charleston earthquake, a subject of continuing controversy. In favor of this interpretation is the consistent stress direction that could activate both faults and the determination of possible physical discontinuity between the levels affected by each fault. These two factors make the interpretation more feasible.

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APPENDIX C

Earthquake Education Center

J. Bagwell

The Earthquake Education Center promotes general earthquake education and awareness through training workshops and programs on earthquake history, causes, effects, and preparedness. Institutional changes have resulted from the training workshops and programs presented in the past two and a half years. For example: (1) schools of Charleston, Berkeley, and Dorchester Counties of South Carolina implemented earthquake drills. The efforts of training teachers and administrators in earthquake safety procedures have been multiplied many-fold by the trained teachers teaching their colleagues and students about earthquake preparedness; (2) one utility company designed a brochure on ways to store emergency water supplies. The company mailed the brochures out with their monthly water bills; (3) a local hardware store promoted emergency supplies as special sale items and displayed brochures on what to do before, during, and after an earthquake; (4) a private corporation sponsored an earthquake safety display and puppet show in a local mall; (5) the Charleston District of the Army Corps of Engineers developed a communication and emergency procedures plan with input from the Earthquake Education Center; and (6) special workshops were provided for the media, hospital groups, special needs audiences (senior citizens, youth groups), neighborhood councils, and the S.C. Emergency Preparedeness Division Coordinators.