STUDIES RELATED TO THE CHARLESTON, SOUTH CAROLINA, EARTHQUAKE OF 1886 -- TECTONICS AND SEISMICITY (COLLECTED ABSTRACTS)

Edited by Gregory S. Gohn

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Introduction

Since 1973, the U.S. Geological Survey (USGS) has conducted extensive investigations of the tectonic and seismic history of the Charleston, S.C., earthquake zone. The goals of these investigations have been to discover the source of the large intraplate Charleston earthquake of 1886 and to establish its tectonic setting. These goals are being pursued to evaluate the potential for future seismicity in the Charleston region and to determine whether that region differs in any tectonically significant fashion from other parts of the Southeastern United States. The seismic history of the Southeast is dominated by the 1886 event, and an understanding of its specific source and the uniqueness (or nonuniqueness) of its tectonic setting is essential to correct assessment of seismic hazards in this region.

Investigations by the USGS began with the installation of a temporary seismographic network in March 1973, followed by the installation of the permanent South Carolina seismographic network in May 1974. Geological and geophysical field investigations began in 1975 with the drilling of the first of three deep stratigraphic test holes northwest of Charleston at Clubhouse Crossroads in Dorchester County. Preliminary results of these earlier studies were reported in USGS Professional Paper 1028 (Rankin, 1977) and in many other abstracts and reports in the geological literature.

Seismological, geophysical, and geological investigations by USGS scientists and by affiliated and nonaffiliated scientists in other institutions are continuing in the Charleston area and throughout the Southeast. Conspicuous among the recent investigations have been multidisciplinary studies of the materials recovered from the Clubhouse Crossroads test holes; seismic-reflection and refraction surveys in the Charleston area and offshore; regional studies of aeromagnetic, gravity, and deep-well data; and continued monitoring and analysis of the seismicity near Charleston. This report presents, as abstracts, principal conclusions and working hypotheses of some ongoing investigations. Deep drilling, the seismographic network, seismic surveys, and related investigations conducted in the Charleston area by USGS scientists are supported by the U.S. Nuclear Regulatory Commission, Office of Nuclear Research, under Agreement No. AT-(49-25)-1000.

GEOCHEMISTRY AND TECTONIC SIGNIFICANCE OF SUBSURFACE BASALTS NEAR CHARLESTON, SOUTH CAROLINA -- CLUBHOUSE CROSSROADS TEST HOLES #2 AND #3

By David Gottfried, C.S. Annell, and G.R. Byerly

Major-, minor-, and trace-element compositions of lower Mesozoic basalts from three deep test holes near Charleston, S.C., are used to characterize magma type and to determine the tectonic setting of these volcanic rocks at the time of their eruption. Chemical and petrographic evidence indicates that slight to extreme oxidation and hydration in nearly all samples has caused widespread mobility of K, Na, and related trace elements. The minor elements P and Ti, the trace elements Th, Nb, Ta, Zr, and Hf, and the rare-earth elements (REE) show little or no variation regardless of the degree of alteration. The contents of these stable elements and the patterns of light REE enrichment in basalts from the deepest of the test holes show the presence of two chemical types that are strikingly similar to lower Mesozoic high-Ti, quartz-normative tholeiites and lower Mesozoic olivine-normative tholeiites exposed in eastern North America.

The olivine-normative basalt is stratigraphically intercalated within a sequence of quartz-normative tholeiitic basalts. Quartz-normative basalts above and below the olivine-normative basalt have nearly identical contents of most of the stable minor and trace elements, but the lower basalts have significantly more Cu and Ni and higher Ni/Co ratios. These differences are ascribed to pre-eruption separation of an immiscible sulfide melt into which Cu and Ni were strongly partitioned.

The new chemical data clearly show that the olivine tholeiitic magma type does not necessarily represent the earliest stage of volcanism in the eastern North American, early Mesozoic tholeiite province and that the spatial distribution of olivine-normative magma types in this province is not related to any significant change in tectonic environment.

$^{40}Ar/^{39}Ar$ AGES OF BASALT FROM CLUBHOUSE CROSSROADS TEST HOLE #2, NEAR CHARLESTON, SOUTH CAROLINA

By Marvin A. Lanphere

$^{40}Ar/^{39}Ar$ total-fusion ages of three samples of basalt from Clubhouse Crossroads test hole #2, near Charleston, S.C., range from 182 to 236 m.y.; only one of the total-fusion ages agrees within analytical uncertainty with conventional K-Ar ages of the same samples. Data from $^{40}Ar/^{39}Ar$ incremental heating experiments indicate that only one sample meets the criteria for a reliable crystallization age. The $^{40}Ar/^{36}Ar$ versus $^{39}Ar/^{36}Ar$ isochron age for this basalt is 184 ± 3.3 m.y. This age is in good agreement with reliable ages of tectonically related lower Mesozoic diabase intrusions in eastern North America and Liberia. The ages of all these intrusions are consistent with their emplacement shortly after initiation of central Atlantic rifting about 190 m.y. ago.

PALEOMAGNETIC INVESTIGATIONS OF THE CLUBHOUSE CROSSROADS BASALT

By Jeffrey D. Phillips

Paleomagnetic investigations have been undertaken on partially oriented basalt samples recovered from three USGS deep test holes at Clubhouse Crossroads near Charleston, S.C. The basalt unit lies at the base of the Coastal Plain sedimentary section; it is 256 m thick in test hole #3. It overlies and is partially interbedded with a sedimentary red-bed unit of probable Triassic or Early Jurassic age. On the basis of the paleomagnetic evidence and the geologic descriptions of the cores, 23 flows can be identified. Six of the flows have negative magnetic inclinations, which are interpreted as indicating periods of reversed polarity; one test hole contains a definite sequence of five reversed-polarity intervals separated by four normal-polarity intervals. The mean thermal remanent-magnetization (TRM) inclination for the 23 flows after magnetic cleaning is $35.4 \pm 3.2^{\circ}$. Comparison of this value with a paleoinclination curve for the Charleston area reveals that the age of the basalt has a 95-percent chance of being in the range 110-196 m.y. Comparison of the Clubhouse Crossroads basalt with other eastern North American basalts and diabases suggests that the true age is more likely to be in the older part of this range.

GEOLOGY OF THE LOWER MESOZOIC(?) SEDIMENTARY ROCKS IN CLUBHOUSE CROSSROADS TEST HOLE #3 NEAR CHARLESTON, SOUTH CAROLINA

By Gregory S. Gohn, Brenda B. Houser, and Ray R. Schneider

In Clubhouse Crossroads drill hole #3 near Charleston, S.C., a minimum of 121 m of well-consolidated sedimentary red beds underlies 256 m of subaerial basalt flows. The basalt flows are of Early Jurassic age and underlie 775 m of Cretaceous and Cenozoic Coastal Plain deposits. The red beds are of probable Late Triassic and(or) Early Jurassic age, on the basis of the age of the basalt and the lithologic similarity of the red beds to lower Mesozoic red beds exposed elsewhere in the Eastern United States.

The red-bed section is divided into an upper fine-grained facies (39 m) consisting of mudstones, siltstones, and argillaceous sandstones and a lower coarse-grained facies (82 m) consisting of mudstones and conglomeratic sandstones. Sandstones in the fine-grained facies show several types of low-amplitude cross-stratification, whereas conglomeratic beds in the coarse-grained facies are inversely and normally graded. The predominant sandstones in both facies are arkosic wackes that contain abundant quartz-feldspar lithic fragments as well as abundant feldspar. Detrital lithic fragments and heavy minerals indicate that the red beds' provenance consisted primarily of granitic rocks. Microbrecciated granitic rock, basalt, and mylonite are additional types of detrital rock fragments found in the deposit.

Comparison of the red-bed section with exposed Triassic-Jurassic red beds and modern continental sediments suggests that the Clubhouse Crossroads rocks were deposited in fluvial and alluvial-fan environments.

GEOLOGY OF THE BASEMENT ROCKS NEAR CHARLESTON, SOUTH CAROLINA -- DATA FROM DETRITAL ROCK FRAGMENTS IN LOWER MESOZOIC(?) ROCKS, CLUBHOUSE CROSSROADS TEST HOLE #3

By Gregory S. Gohn

Detrital rock fragments in conglomeratic lower Mesozoic(?) sedimentary rocks in Clubhouse Crossroads drill hole #3 are the only material available for direct geologic study of the pre-Mesozoic crystalline basement in the Charleston, S.C., area. No other drill holes in the area have penetrated the pre-Mesozoic section. Many lines of evidence from the core (textures, mineralogy, sedimentary structures) and from local geophysical surveys (basement-surface configuration) suggest that the source area for these compositionally immature, poorly sorted conglomeratic sediments was proximal to their site of deposition.

Four types of basement rocks occur as detrital clasts; in decreasing order of abundance, these types are granodiorite and similar plutonic rocks, microbreccia, basalt, and mylonite. Plutonic igneous-rock fragments grouped as granodiorite have apparent compositions ranging from tonalite or granodiorite to granite. Alteration of the granodiorite has occurred, and the present mineralogy is typically saussuritized plagioclase, perthite, quartz, chlorite, opaque minerals, epidote, and sphene. Microbreccia clasts have a protolith that closely resembles the granodiorite clasts, but the microbreccia shows considerable comminution of grains, fracturing, and secondary epidote, chlorite, quartz, and zeolite(?) mineralization in veinlets. Basalt clasts in the deposit have also been mineralogically altered to saussuritized plagioclase, chlorite, epidote, and other secondary minerals, but they do not show obvious effects of penetrative deformation. Mylonite clasts have a mineralogy similar to that of the granodiorite clasts, but the mylonite clasts have been strongly deformed, and their texture is dominated by fluxion structure and porphyroclasts.

Inferences about the geologic history represented by these detrital rock fragments can be made from the petrologic data. However, the lack of data on the larger geometries of the rock units involved and on their relative and absolute ages limits these interpretations. At least one episode of granodiorite intrusion into an unknown sequence of host rocks has been documented, as has an episode of basaltic volcanism or shallow plutonism. The basalt cannot be temporally related to the younger lower Mesozoic basalt encountered higher in the drill hole. The mylonite and microbreccia may represent relatively ductile and relatively brittle deformation, respectively, within a single fault zone, or they may represent contrasting styles of deformation in different fault zones of different age. Deformation textures are restricted to the interiors of the detrital mylonite and microbreccia clasts and do not extend into the enclosing sedimentary matrix. Therefore, on the basis of the probable age of the sedimentary section, the minimum age of the faulting is established as early Mesozoic. The mylonite and microbreccia are direct evidence of ancient faulting in basement rocks of the Charleston area.

SEISMIC-REFRACTION STUDY IN THE AREA OF THE CHARLESTON, SOUTH CAROLINA, 1886 EARTHQUAKE

By Hans D. Ackermann

Thirty-five seismic-refraction spreads were recorded in an area near Summerville, S.C., that encloses the zone of intensity-X effects of the Charleston 1886 earthquake. Penetration was to a 6.0- to 6.4 km/s layer at depths ranging from 700 to 2,400 m; this layer is interpreted as representing the pre-Mesozoic crystalline basement complex. The surface of this layer consists of a northeast-trending ridgelike feature, which the coincident magnetic anomalies suggest contains both mafic and silicic rocks. The ridge is bounded on the northwest by an abrupt 900-m drop in altitude of the basement surface, inferred to represent a Triassic basin border fault. Recent earthquake epicenters appear to cluster on both sides of this fault; however, fault-plane determinations indicate high-angle faults both parallel and perpendicular to the ridge-boundary fault. Thus, the combined results indicate that the basement complex in the earthquake area contains orthogonal northeast- and northwest-trending faults and rocks of highly contrasting types.

Refraction arrivals were also recorded from a shallower, gently seaward-sloping horizon marking the base of the Cretaceous section. Clubhouse Crossroads #3, a test hole about 18 km southwest of Summerville, encountered this horizon at 775 m depth and then penetrated

256 m of the lower Mesozoic basalt flows before encountering sedimentary red beds. The seismic interpretations suggest that the flows thin and become increasingly intercalated with sediments away from the test hole.

A REFLECTION SEISMIC STUDY NEAR CHARLESTON, SOUTH CAROLINA

By B.R. Yantis, J.K. Costain, and Hans D. Ackermann

Three reflection-seismic lines were recorded approximately 40 km northwest of Charleston, S.C., by the U.S. Geological Survey. Lines designated Clubhouse Crossroads, Interstate, and Middleton Place are 1.7, 1.0, and 4.3 km long, respectively, and their minimum separation is approximately 20 km. The three lines cover an area of approximately 200 km^2 in the meizoseismal region of the 1886 earthquake. Fourfold and sixfold common-depth-point data were obtained.

The largest amplitude reflection on any of the seismic lines is from the top of a basalt layer at a depth of 750 m in Clubhouse Crossroads test hole #1 (CC#1). Wave shape, amplitude, and arrival time of reflections on individual unprocessed traces indicate that the basalt is present at all three sites. If we assume a planar reflector, the strike and dip of the basalt are approximately N. 55° E. and 0.5° SE. Velocity analyses of some individual seismograms indicate a reflection from the bottom of the basalt layer. From the seismic data, the basalt appears to range from 150 to 230 m in thickness; it may be thinnest at the Interstate line and thickest at the Middleton Place line.

Four reflections above the basalt can be correlated with changes in lithology and(or) degree of induration of the core from CC#1. A reflection from near the top of the Peedee Formation (Upper Cretaceous) can be correlated on all three lines. If we assume a planar structure, the strike and dip of this reflector are N. 45° E. and less than 0.1° SE. No faults were detected on any of the three reflection lines; these lines are not near the Cooke fault, a structural feature defined by other reflection surveys.

SUBSURFACE STRUCTURE NEAR CHARLESTON, SOUTH CAROLINA -- RESULTS OF COCORP REFLECTION PROFILING IN THE ATLANTIC COASTAL PLAIN

By F. Steve Schilt, Larry D. Brown, Jack E. Oliver, and Sidney Kaufman

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In May and June of 1978, the Consortium for Continental Reflection Profiling (COCORP) surveyed four lines totalling 72 km in length in the Charleston-Summerville area of South Carolina. The objective was to map the structure of the entire crust in that area. Some particularly interesting near-surface structures were detected in addition to deeper features. A strong event at 0.7 s is present on all profiles and corresponds to the lower Mesozoic basalt layer penetrated at about 750 m in USGS drill holes. The top of an older basement having as much as 1 km of relief can be seen at about 1.0 s (~1600 m). The Coastal Plain sediments, basalt layer, and basement can all be traced with good continuity over much of the lines; they are cut by a reverse fault and possibly by a small fault-bounded graben, each having an offset of a few tens of meters. A line that crosses a zone of recent seismicity shows noticeable differences in shallow structure on either side, although the shallow section across part of the seismic zone itself was not observed on this line, owing to a gap in the data on either side of the Ashley River. Beneath the Mesozoic and younger strata, the upper crust appears generally transparent to seismic energy down to 6.0 s (~18 km). From about 6.0 to 11.0 s, many short scattered reflections having a laminated appearance suggest a transition from relatively homogeneous igneous rocks to a more anisotropic and metamorphosed lower crust. The crust-

mantle transition appears to be represented by a distinct band of short reflection segments to 10.5-11.0 s, whose depth (~32-34 km) agrees with data from a refraction study in the central Appalachian Piedmont. If the gently dipping Appalachian overthrust discovered in Georgia by a COCORP survey extends beneath the Charleston area, it is conceivable (but speculative) that some of the reflections below 6.0 s are metasedimentary layers beneath imbricate thrusts.

LAND MULTICHANNEL SEISMIC-REFLECTION EVIDENCE FOR TECTONIC FEATURES NEAR CHARLESTON, SOUTH CAROLINA

By Robert M. Hamilton, John C. Behrendt, and Hans D Ackermann

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In 1979, 140 km of multichannel seismic-reflection profiles was acquired in the vicinity of the 1886 Charleston earthquake. The strongest reflection is from the pre-Late Cretaceous unconformity, which is generally smooth (local relief less than 50 m) and dips southeast. The smoothness shows that vertical faulting within a kilometer of the surface has not been substantial since at least the Late Cretaceous. Nevertheless, the few places of deformation appear to have tectonic significance. On one profile, a zone of flexure in the Upper Cretaceous and Cenozoic sediments overlies an apparent offset in older rocks, which indicates the presence of a fault zone. Similar deformation on another profile indicates that the strike of the fault zone may be northeast, but, because the line crosses the fault zone at a low angle, the evidence for the strike direction is not strong. The fault zone, named the Cooke fault, has about 50 m vertical displacement (southeast side down) on a Jurassic-age basalt layer at 750 m depth. Overlying Upper Cretaceous and Cenozoic beds have decreasing displacement with decreasing depth. The nature of these offsets coupled with the large displacement (190 m) of a reflector below the basalt suggests continuing Cenozoic movement of a postbasalt-flow, pre-Late Cretaceous fault, which may have been formed during Triassic rifting. The fault extends into a cluster of 1973-1978 epicenters, possibly indicating that the fault may

be the cause of the seismicity; however, this relationship is uncertain because focal depths are 3-13 km, and the deep structure of the fault and its relation to deeper faults are unknown.

Two other zones of unknown strike that indicate Cenozoic faulting are seen. Also seen is a northeast-striking fault zone named the Drayton fault (southeast side down); it offsets only the basalt and immediately overlying sediments, an indication of Late Cretaceous movement. In the northern part of the study area, layered reflections are interpreted as Triassic red beds a few kilometers thick that are bounded on the southeast by a Triassic(?) normal fault. The shallow minor deformation seen on the profiles is interpreted as a second-order manifestation of deep faulting, possibly caused by reactivation of ancient thrust faults. Future corroboration of the existence of the Cooke fault, the association of the Cooke fault or other faults with seismicity, and determination of the primary mode of current tectonic deformation will be important in assessing the earthquake risk in many areas of similar tectonic setting outside the Charleston region in the Atlantic coastal and continental margin areas.

MARINE MULTICHANNEL SEISMIC REFLECTION EVIDENCE FOR CENOZOIC FAULTING AND DEEP CRUSTAL STRUCTURE NEAR CHARLESTON, SOUTH CAROLINA

By John C. Behrendt, Robert M. Hamilton, Hans D. Ackermann, V. James Henry, and Kenneth C. Bayer

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Multichannel seismic-reflection data combined with single-channel, high-resolution reflection profiles collected offshore from Charleston in 1979 have allowed us to define the following geologic features.

1) The Helena Banks fault, a northeast-striking, high-angle, west-dipping reverse fault at least 30 and possibly 70 km long, is about 12 km offshore and extends upward to about 10 m from the sea bottom. This fault was probably reactivated in the Cenozoic from a Triassic-age structure; the most recent movement is at least as young as Miocene or Pliocene. Other shallow Cenozoic faults were also found.

2) A subhorizontal surface is defined by diffractions at about 11.4 ± 1.5 km depth. The depth range of hypocenters calculated for Charleston-area seismicity during 1973-1978 is 3 to 13 km. We interpret the subhorizontal surface as a décollement and suggest a causal relationship to seismicity.

3) Reflections at 9-11 s, corresponding to a depth of about 29-35 km, are interpreted to be from the Mohorovicic discontinuity (Moho); this depth is in agreement with a crustal-refraction determination for the Moho of 29.9 km.

4) A series of west-dipping, north-striking reflecting surfaces(?) or diffracting "edges" lies beneath the surface defined by diffractions.

5) A Jurassic-age basalt layer extending onshore and offshore for about 100,000 km^2 deepens seaward from about 1.0 to 1.4 km in the Charleston region. This surface, as defined by a strong reflection, is largely undisturbed except by the Helena Banks and a few other faults showing small vertical displacement.

6) Several Triassic-age or older faults exist; within resolution of the seismic-reflection data, these faults do not show evidence of reactivation since the basalt was extruded.

We suggest that the Charleston seismicity is primarily caused by movement along the décollement and that movement on the high-angle reverse faults, although it is a second-order effect, also may cause earthquakes. Future corroboration of these causal relationships will be important in assessing the earthquake risk in many areas of similar tectonic setting outside the Charleston region in the Atlantic coastal and continental margin areas.

DISTRIBUTION OF SUBSURFACE LOWER MESOZOIC ROCKS IN THE SOUTHEASTERN UNITED STATES, AS INTERPRETED FROM REGIONAL AEROMAGNETIC AND GRAVITY MAPS

By David L. Daniels, Isidore Zietz, and Peter Popenoe

Aeromagnetic data, in conjunction with data from deep wells, are used to interpret the nature of the pre-Cretaceous "basement" beneath the Coastal Plain in Georgia and South Carolina. These data reveal some of the complexity of the broad early Mesozoic rift basin, which appears to extend at least from the Gulf of Mexico to the Atlantic Ocean. Along the northern edge of this rift, in the Savannah River region, depth-to-magnetic-source calculations delineate two interconnected basins, which are separated from the main rift by a broad horst of crystalline basement. The Riddleville (Ga.) basin appears to contain at least a 2.2-km thickness of basin fill; it is deeper than the Dunbarton (S.C.) basin, which has at least a thickness of 1.0 km of fill. A maximum thickness of 3.5 km near Statesboro, Ga., is indicated for the main basin, called here the South Georgia rift.

Abundant lower Mesozoic diabase dikes in the South Carolina Coastal Plain are revealed on the magnetic map by narrow anomalies that have two dominant trends, northwest and north. One set of several north-trending anomalies can be traced continuously across the Coastal Plain, Piedmont, and Blue Ridge for 480 km. The two sets, which may represent two episodes of intrusion, have characteristic distributions: northwesterly

trends are to the southwest and northerly trends to the northeast in the study area. A broad area of overlap extends from 80° W., in South Carolina, to northern Virginia. Several lower Mesozoic diabase sills within the rift are indicated by circular low-amplitude magnetic anomalies.

Intense magnetic highs and corresponding gravity highs indicate the presence of abundant large bodies of mafic rocks in the pre-Cretaceous "basement" in addition to the dikes and sills; two groups of mafic rocks are distinguished. Circular or oval anomalies are interpreted as largely gabbroic plutons, which may be as young as early Mesozoic and which are present both within and outside the rift. Elongate anomalies, which form a northeast-trending belt across Georgia and South Carolina, may reflect deformed pre-Mesozoic mafic rocks.

The largest and least understood magnetic feature of the region is the Brunswick anomaly, a long-wavelength anomaly system 1,100 km long, which is mostly offshore but which also bisects the Georgia Coastal Plain. The anomaly divides two regions of differing magnetic character and magnetic trend, which suggests that it is closely related to a Paleozoic suture between a Florida-South Georgia microcontinent and the North American craton.

PRE-CRETACEOUS ROCKS BENEATH THE GEORGIA COASTAL PLAIN -- REGIONAL IMPLICATIONS

By T.M. Chowns and C.T. Williams

The records of 78 wells that have penetrated pre-Cretaceous rocks beneath the Georgia Coastal Plain have been analyzed and used as the basis for a regional interpretation of the "basement" of the southern Atlantic and eastern Gulf Coastal Plains. Four major terranes are recognized. The first consists of medium- to high-grade metamorphic rocks and granitic plutons immediately south of the Fall Line and represents the subsurface continuation of the Piedmont province. In south Georgia, the "basement" is quite different and comprises a terrane of mildly deformed Paleozoic sedimentary rocks underlain by a terrane of felsic volcanic rocks. The Paleozoic sedimentary sequence totals at least 9,750 m and consists of Lower Ordovician quartz arenites overlain by fossiliferous shales and sandstones of Middle Ordovician to Middle Devonian age. The felsic volcanic-rock terrane is probably Proterozoic Z to Cambrian in age and consists of porphyritic rhyolites, vitric crystal tuffs, and tuffaceous arkoses intruded by granitic plutons. These two anomalous terranes are separated from the buried Piedmont by a fourth terrane of lower Mesozoic continental red beds correlated with the Newark Group. The red beds are known to be at least 3,500 m thick and occupy a complex graben, the South Georgia basin. The red beds contain dikes and sills of tholeiitic diabase belonging to the lower Mesozoic eastern North American suite. Basalt flows possibly related

to the diabase occur outside the South Georgia basin. Where the composition of the red beds is appropriate, well-developed metamorphic aureoles indicative of zeolite-facies alteration are present. The zeolite-facies minerals are also disseminated regionally in small amounts through the Triassic terrane, which suggests very low grade regional metamorphism.

These results are compared with those of similar studies in Florida, Alabama, and South Carolina and, with the aid of regional aeromagnetic data, they provide a paleogeologic map of the Fall Line unconformity beneath the southeastern Coastal Plain. The Proterozoic Z to Paleozoic rocks in south Georgia and Florida represent a disjunct fragment of the African craton that was sutured to North America probably during the Permian. The position of the suture is uncertain, but the boundary between Piedmont rocks of the Appalachian orogen and African platform deposits, possibly a northwest-dipping thrust fault, may be traced in the subsurface from Alabama to South Carolina. Before the opening of the Atlantic Ocean, this boundary was continuous with the overthrust on the east side of the African Mauritanide orogenic belt. The South Georgia basin formed during the early Mesozoic in response to the initiation of the North Atlantic Ocean; its existence may indicate that incipient spreading centers in the Gulf of Mexico and the North Atlantic were originally connected on the north side of the Florida peninsula.

POTASSIUM-ARGON RELATIONS IN DIABASE DIKES OF GEORGIA -- THE INFLUENCE OF EXCESS ^{40}Ar ON THE GEOCHRONOLOGY OF EARLY MESOZOIC IGNEOUS AND TECTONIC EVENTS

By Robert E. Dooley and J.M. Wampler

Conventional K-Ar ages for 20 diabase dikes from the Piedmont and Blue Ridge provinces of Georgia are highly variable (190-1,628 m.y.) and discordant, in a pattern similar to the K-Ar ages in Liberian diabase dikes. We interpret the large range in conventional K-Ar ages of diabase dikes in Georgia as having been caused by the presence of excess ^{40}Ar in most, if not all, the dikes. The dikes in Georgia are probably not more than 195 m.y. old and may be contemporaneous with structurally similar dikes in the Northeastern United States that are about 180 m.y. old. Structural relationships indicate that these dikes are part of a system of dikes that formed in the continents around the central Atlantic Ocean as the ocean began to open. The amounts of excess ^{40}Ar in the diabase samples have been calculated by assuming a 180-m.y. age for the dikes in Georgia. Most diabase dikes in the northern part of the Piedmont and in the Blue Ridge contain large and variable amounts of excess ^{40}Ar (as much as 36 STP nl/g). Samples from diabase dikes in the southern part of the Piedmont of Georgia contain small amounts of ^{40}Ar (less than 1.0 STP nl/g). This distinct regional variation in excess ^{40}Ar content of diabase does not appear to be related to the argon content of the country rocks at the sampling sites. Locally, the pattern of discordance in K-Ar ages within dikes suggests that excess

^{40}Ar is concentrated in the later crystallizing parts of a dike. This concept is supported by evidence that some of the excess ^{40}Ar is concentrated in microstructural irregularities in the rock. The evidence indicates that the excess ^{40}Ar in the diabase is argon that arrived at the site of emplacement as part of the magma. Some of the argon in the magma must have originated at the site of partial melting in the asthenosphere, but the regional pattern of excess ^{40}Ar in the diabase dikes appears to have been influenced by the thickness of the crust through which the magma ascended. Where the crust is thicker, most of the crust is presumably Precambrian basement. Rocks at intermediate or lower levels of the crust are probably the most important source of the excess ^{40}Ar found in the diabase dikes of the northern part of the Piedmont and Blue Ridge. Samples from the southern part of the Piedmont have little excess ^{40}Ar, either because the magma was not contaminated with argon from the crust or because these samples formed close enough to the surface for argon to escape from the magma.

MESOZOIC DEVELOPMENT AND STRUCTURE OF THE CONTINENTAL MARGIN OFF SOUTH CAROLINA

By William P. Dillon, Kim D. Klitgord, and Charles K. Paull

A nearly undeformed wedge of Mesozoic and Cenozoic strata forms the Continental Shelf and Blake Plateau off South Carolina. The wedge is built on an unconformity, known as the postrift unconformity, at the top of beveled Triassic and Lower Jurassic sedimentary deposits, Paleozoic crystalline basement rocks, Paleozoic sedimentary rocks of various stages of metamorphism, and Mesozoic volcanic and plutonic mafic igneous rocks. The postrift unconformity generally forms both seismic basement and magnetic basement. This unconformity is marked by two zones of major subsidence off South Carolina, separated by the apparent landward continuation of the deep-sea Blake Spur fracture zone. South of that fracture zone, beneath the Blake Plateau, is the broad Blake Plateau basin, reaching depths of 14 km. North of the fracture zone and parallel to the continental margin is the narrow Carolina trough, which is as much as 11 km deep. The postrift unconformity is formed by a strongly reflecting layer beneath the Continental Shelf off South Carolina that probably represents a seaward extension of the lower Mesozoic volcanic flows penetrated by drilling near Charleston. During Jurassic time, the Blake Plateau basin and Carolina trough subsided rapidly and were filled with sediment to a depth of more than 7 km. In contrast, Cretaceous subsidence of the continental margin was widespread and relatively uniform and resulted in the accumulation of a blanket of sediment 1 to 4 km thick.

BASEMENT STRUCTURE INDICATED BY SEISMIC-REFRACTION MEASUREMENTS OFFSHORE SOUTH CAROLINA AND ADJACENT AREAS

By William P. Dillon and Lyle D. McGinnis

Seismic-refraction profiling data collected by the U.S. Geological Survey (USGS) and other researchers have been projected to two lines extending parallel to the strike of regional structure on the continental margin of the Southeastern United States. One line extends along the Continental Shelf from northern Florida to southern North Carolina; the other is parallel to it along the inner Blake Plateau. Data from the shelf show a very strong refracting horizon having compressional wave velocities of about 5.8-6.3 km/s. This horizon dips gently away from the Cape Fear arch and appears to terminate near the Georgia-Florida boundary. This seismic horizon is inferred to represent basalt layers comparable with the basalt drilled by the USGS near Charleston. High refraction velocities south of the Georgia-Florida boundary probably represent Paleozoic basement. The set of refraction profiles on the Blake Plateau show only one compressional wave value that probably is related to basement. Other very high refraction velocities (about 7 km/s) beneath the western Blake Plateau might result from mafic or ultramafic plutons.

MESOZOIC TECTONICS OF THE SOUTHEASTERN UNITED STATES COASTAL PLAIN AND CONTINENTAL MARGIN

By Kim D. Klitgord, William P. Dillon, and Peter Popenoe

Many of the major structures associated with Paleozoic and Mesozoic tectonic events along the Southeastern United States Coastal Plain and continental margin have distinctive geophysical and geological properties. Several studies have integrated magnetic and gravity data with seismic-reflection and drill-hole data to map these structures. In particular, these data have been used to identify three major tectonic boundaries that separate terranes of Paleozoic, Triassic, and Jurassic tectonic activity and to map sedimentary basins that formed as a result of Triassic and Jurassic rifting events. The major tectonic boundaries are: 1) Near the continental margin, a hinge zone in basement that separates Jurassic-age marginal basins from Triassic and older structures to the west; 2) a line of narrow grabens, associated with the Brunswick negative magnetic anomaly, that separates a Paleozoic basin underlying northeastern Florida, which was not greatly affected by Triassic tectonic activity, from a broad zone of considerable Triassic tectonic activity and sediment accumulation in the Charleston, S.C., region; and 3) a narrow east-west zone near 33° N. that separates the geophysically distinctive Piedmont to the north from the Charleston region. The Triassic sedimentary basins include narrow basins or grabens within the Piedmont and along the major tectonic boundaries; they also include broad zones of sediment accumulation over a blockfaulted Paleozoic basin in northwestern Florida and in areas delineated by low-gradient magnetic and gravity fields in parts of the Charleston region. Deep marginal basins, containing sedimentary rock as much as 14 km thick, formed at sites of Jurassic rifting seaward of the basement hinge zone. Reconstructions of the positions of the North American, South American, and African continents during the Early Jurassic provide a framework for relating the Mesozoic tectonic events and structures to major Paleozoic orogenic events and tectonic units.

RELOCATION OF INSTRUMENTALLY RECORDED PRE-1974 EARTHQUAKES IN THE SOUTH CAROLINA REGION

By James W. Dewey

Regionally and teleseismically recorded earthquakes from South Carolina and vicinity have been relocated by using a regional velocity model and station traveltime adjustments determined by the method of Joint Epicenter Determination. The revised hypocenters are accompanied by confidence ellipsoids so that a user can evaluate the likelihood that an earthquake took place on a particular tectonic structure defined by geological or geophysical methods. The revised hypocenters of all nine pre-1974 earthquakes within 100 km of Charleston are consistent with the occurrence of these earthquakes in the Middleton Place-Summerville zone or the Bowman cluster, two source regions identified on the basis of microearthquakes recorded by the South Carolina network since 1974. The confidence ellipsoid on one of the hypocenters indicates that the shock could also have taken place at the Adams Run cluster, a microearthquake source 20 km south of the Middleton Place-Summerville zone. The previously determined epicenters of several earthquakes had been mislocated by 50 km or more. In the Piedmont of South Carolina and northeast Georgia, shocks tend to take place in the vicinity of several manmade reservoirs. However, the earthquake of July 26, 1945, previously thought to be at Lake Murray, has been relocated away from the lake. The region of Lake Jocassee experienced a regionally recorded earthquake in 1969 prior to the filling of the reservoir.

SEISMICITY NEAR CHARLESTON, SOUTH CAROLINA, MARCH 1973 TO DECEMBER 1979

By Arthur C. Tarr and Susan Rhea

Newly completed seismological studies provide additional insight into the source area of the Charleston, S.C., earthquake of August 31, 1886, its relationship to other seismically active areas nearby, and differences between the patterns of Charleston-area activity and seismicity in the Piedmont province of South Carolina. These studies include refinements to the South Carolina earthquake catalog, relocation of earthquakes recorded instrumentally prior to installation of the South Carolina seismic network, improved hypocenter determinations from 7 years (1973-1979) of seismic-network data, and composite focal mechanisms.

We suggest that current activity in the Middleton Place-Summerville seismic zone is in the fault zone of the August 31, 1886, main shock. The newly determined hypocenters define a three-segmented seismic zone composed of two en echelon segments that strike northwest and dip about 80° to 90° southwest, and a third segment that strikes east-northeast. A composite focal mechanism of 16 earthquakes suggests reverse dip-slip motion, on a northwesterly trending plane, in response to a generally northeasterly trending greatest principal compressive stress.

Two other important clusters of epicenters were located instrumentally near Bowman and Adams Run. They are spatially distinct from the Middleton Place-Summerville seismic zone. No earthquakes have been located in the gap between the Bowman cluster and the Middleton Place-Summerville zone in the 9 years since the Bowman cluster became active in 1971.

All three active areas near Charleston are on the flanks of positive gravity and aeromagnetic anomalies from which other geologists have inferred the presence of relatively dense magnetic bodies that are probably mafic or ultramafic intrusions. In broad areas of flat or negative gravity and aeromagnetic anomalies, seismicity seems to be lacking. Positive traveltime anomalies suggest that these broad areas may be deep basins filled with low-velocity sediments.

Although earthquakes in the Piedmont tend to be scattered, those in the Coastal Plain tend to cluster. We interpret this clustering pattern to result from many localized stressed regions on or near intersecting faults or in zones of weakness between blocklike crustal units, originating from early Mesozoic tectonic processes. We postulate that the broad flat gravity and magnetic lows in the area between Bowman and Summerville may be aseismic either because no major crustal fractures or zones of weakness cross this area or because strain is being released aseismically.

REGENERATE FAULTS OF SMALL CENOZOIC OFFSET -- PROBABLE EARTHQUAKE SOURCES IN THE SOUTHEASTERN UNITED STATES

By Carl M. Wentworth and Marcia Mergner-Keefer

The principal style of Cenozoic faults and earthquake focal-mechanism solutions known along the eastern seaboard suggests that a domain undergoing northwest-southeast compression extends along the eastern seaboard between the continental margin and the front of the Appalachian Mountains. In the Southeast, several mapped northeast-trending zones of high-angle reverse faults and many faults in isolated exposures offset Coastal Plain deposits as much as 100 m; the youngest recognized offset is 0.35 m in probable Pliocene or Pleistocene surficial gravels in the Stafford fault zone in Virginia. Movement has been progressive from at least late Early Cretaceous into the Cenozoic, average offset rates being about 1 m/m.y. Northeast-striking reverse source mechanisms of various recent earthquakes indicate that reverse faulting is still active and that such faults can be seismogenic.

The extent of the domain is inferred from (1) reverse faults known in South Carolina and along the Fall Line from Georgia to New Jersey; (2) earthquake source mechanisms, particularly in coastal New England; and (3) the broad distribution of early Mesozoic normal faults in the exposed Piedmont terrain and beneath the Coastal Plain and offshore. We suggest that, to a large extent, the reverse faults reuse parts of these early Mesozoic faults. We characterize the domain from the known fault histories, the existence of geometrically compatible earthquakes, and our expectation that seismogenic reverse faults are scattered essentially throughout the region no more than a few tens of kilometers apart. If correct, this expectation implies that the historic seismic pattern is not stationary over the long term.

The intensity-X Charleston earthquake of 1886 took place in the best documented part of the Atlantic Coast domain, close to a Cretaceous-Cenozoic reverse fault and an inferred early Mesozoic fault zone, both trending east-northeast. Some recent small aftershocks near these faults indicate similar reverse faulting, and the 1886 intensity pattern suggests a northeast strike for the main-shock source. We thus conclude that northeast-trending reverse faulting produced the 1886 earthquake. Many of the recent aftershocks seem to be on northwest-trending structure, however, probably in response to temporary changes in the local stress field resulting from the strain release of the 1886 main shock. If this conclusion and our concept of the Atlantic Coast domain are correct, then earthquakes at least as large as 1886 Charleston should be possible in most parts of the domain.

The Atlantic margin was placed in compression approximately normal to its length sometime after successful rifting, certainly by latest Early Cretaceous, probably in the Jurassic, and possibly soon after extrusion of the 184-m.y.-basalt at Charleston. The compression is presumed to be causally related to the continental margin and, on the basis of declining rates of reverse faulting, may be inversely related to the duration of Atlantic spreading.

SPECULATIONS ON THE NATURE OF CHARLESTON, SOUTH CAROLINA, SEISMICITY

By G.A. Bollinger

The data base for the Charleston, S.C., seismicity consists of Dutton's study (1889) of the 1886 earthquake, information on historical and recent earthquakes from many sources, and the results of 6 years of instrumental monitoring by a Statewide network. These data are considered in conjunction with results from seismic studies in other areas in an attempt to infer source information for the 1886 shock.

The Charleston area is an unusual locale in the Southeastern United States. What is known concerning pre-1886 South Carolina seismicity suggests that most of the activity may have been concentrated in the Charleston vicinity. The post-1886 activity does show a concentration there. Additionally, this area is the only such seismically active locale in the Atlantic Coastal Plain province. The temporal characteristics of the post-1886 seismicity suggest that the aftershock process is probably not over. Focal-mechanism studies of recent events show steeply dipping nodal planes that have a northwest strike. Statewide, the seismicity changes from a clustering habit in nonmetamorphic "basement" terrane to a diffuse habit in metamorphic basement terrane.

Given a body-wave magnitude (m_b) estimate of 6.7 for the 1886 earthquake (derived from intensity studies), published scaling relations allow order-of-magnitude estimation of the parameters for the event:

fault length = 25 km, fault width = 12 km, average slip = 1 m. (A surface-wave magnitude of 7 and a stress-drop of 100 bars are assumed in the above estimates.)

Relationships between the strike of surface ruptures and(or) focal-mechanism nodal planes and the trend of the innermost isoseismal contour for selected earthquakes are interpreted to favor, although not conclusively, a northeast-trending causal fault for the 1886 shock. The strong vertical motions reported in the 1886 meizoseismal area indicate dip-slip fault movement.

A single source zone localized by intersecting structures is suggested as the cause of both the current Charleston area seismicity and the 1886 earthquake. The faulting in 1886 was probably on a northeast-trending structure, whereas the current activity is on a northwest-trending structure. The geological-geophysical data base to date gives evidence for structures along both trends but does not allow selection between them.

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