New COCORP profiling in the southeastern United States. Part I: Late Paleozoic suture and Mesozoic rift basin

K. D. Nelson, J. A. Arnow,*, J. H. McBride,* J. H. Willemin,
J. Huang, L. Zheng, J. E. Oliver,* L. D. Brown,* S. Kaufman*
Institute for the Study of the Continents (INSTOC), Snee Hall, Cornell University, Ithaca, New York 14853

ABSTRACT

New COCORP profiling in the southeastern United States has revealed a broad zone of dipping reflections that extends downward through the crust beneath the coastal plain in western Georgia. The zone is over 50 km wide, and most of the reflections dip moderately steeply toward the south. Regional considerations suggest that this feature marks the late Paleozoic suture between North America and Africa. Where crossed by the COCORP survey, the suture occurs beneath the north flank of the Triassic-Early Jurassic south Georgia basin. The main depocenter of the south Georgia basin occurs about 90 km to the south and is formed by a large half graben containing more than 5 km of rift basin fill. Farther south, the Paleozoic Suwannee basin sequence beneath northern Florida is poorly imaged on the COCORP profiles. However, weak reflections suggest that these strata (including basal felsic volcanics) may have an aggregate thickness of about 6 km in north-central Florida. At the northwest end of the COCORP traverse, a prominent horizon imaged in the upper crust beneath the inner Piedmont probably marks the southern Appalachian detachment. The detachment appears to be cut off by the Towaliga fault, implying that the Towaliga fault is in part a down-to-the-north normal fault. Intermittent Moho reflections occur at 11-12-s two-way time along the length of the COCORP survey, indicating that the crust in the region has a roughly uniform thickness of about 33-36 km (assuming an average crustal velocity of 6 km/s).

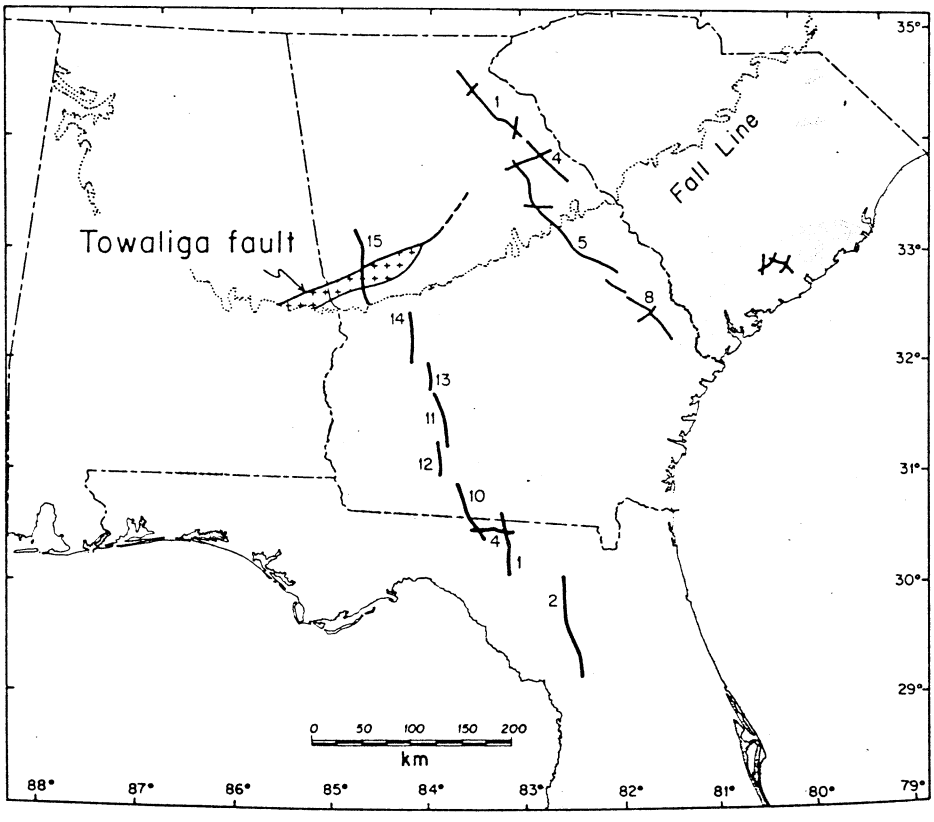

Figure 1. Map showing location of COCORP lines in southeastern United States. Florida lines 1, 2, and 4 and Georgia lines 10–15 are new lines described in this paper. Georgia lines 1–9 and short lines near Charleston, South Carolina, have been described previously (Cook et al., 1979, 1981; Schilt et al., 1983). Stipple = area of Triassic–Early Jurassic subcrop beneath coastal plain (south Georgia basin, after Chowns and Williams, 1983); cross pattern = Pine Mountain belt.

INTRODUCTION

In 1966 Tuzo Wilson made the then-speculative suggestion that northern Florida was underlain by a fragment of African continental crust sutured to North America in late Paleozoic time. Wilson's hypothesis was based on the recognition that early to middle Paleozoic strata encountered in wells drilled through the coastal plain in northern Florida are faunally and lithologically distinct from strata of equivalent age in the Appalachian foreland, yet are faunally and lithologically similar to Paleozoic strata exposed in West Africa (e.g., Whittington and Hughes, 1972; Cramer, 1971, 1973; Pojeta et al., 1976). Although Wilson's hypothesis is now generally accepted (e.g., Pindell and Dewey, 1982; Williams and Hatcher, 1983), the precise location and character of the late Paleozoic suture beneath the coastal plain have remained enigmatic. Scattered well penetrations through the coastal plain in northern Florida and southern Georgia serve to outline the northern subcrop limit of the African (Suwannee basin) Paleozoic sequence (Chowns and Williams, 1983; Smith, 1982). However, to the north Triassic–Early Jurassic red beds and associated mafic igneous rocks subcrop in a broad northeast-trending belt (south Georgia basin), obscuring the location of the Paleozoic suture (Fig. 1). Although some attempts have been made to interpret crustal structure in this region on the basis of aeromagnetic data (e.g., Popenoe and Zietz, 1977; Higgins and Zietz, 1983; Daniels et al., 1983), in general, little detailed information has been available concerning the internal structure of the Mesozoic rift basin in southern Georgia, or the nature of the crust beneath it. Recently, the COCORP project recorded a series of deep seismic reflection profiles, which together compose a deep seismic reflection traverse across this region (Fig. 2). Although processing of the data is still at an interim stage, the main features are already apparent. In particular, it appears that both the Paleozoic suture and Mesozoic rift basin have been imaged on the profiles.

*And Department of Geological Sciences, Cornell University, Ithaca, New York 14853.

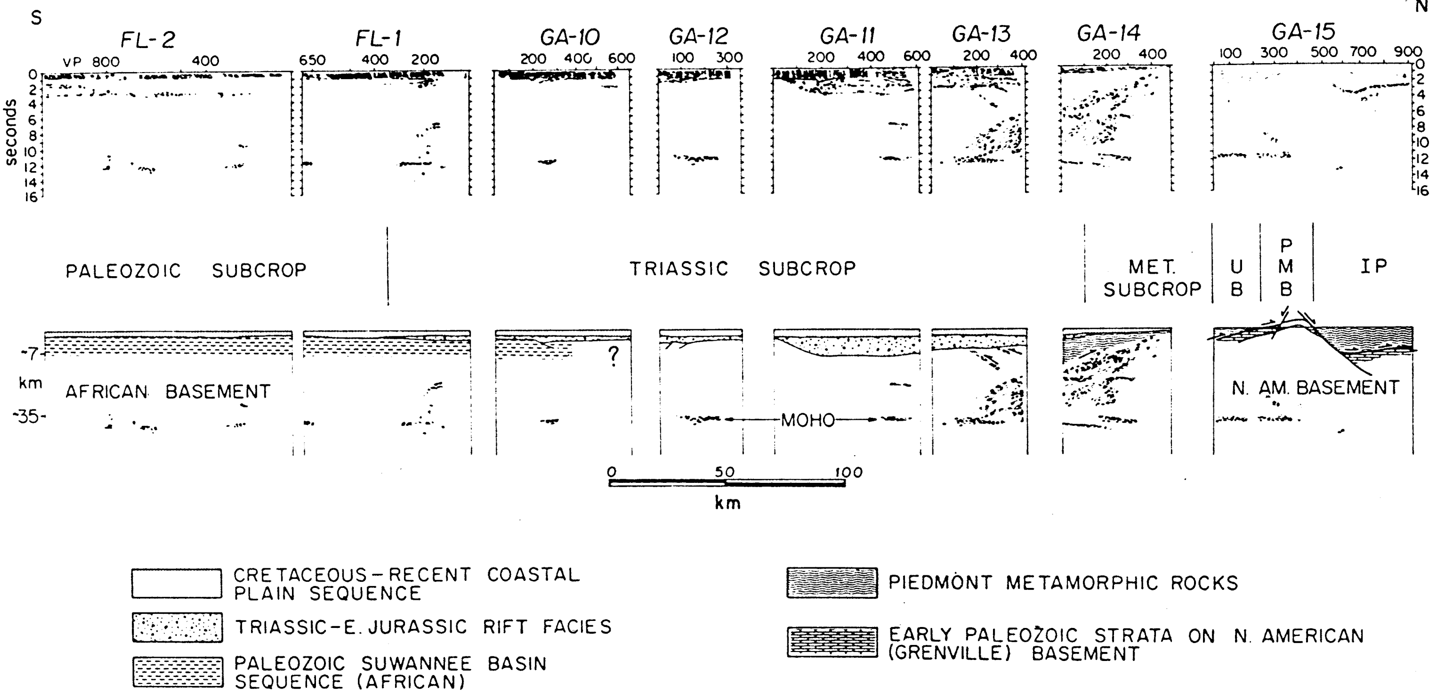

Figure 2. Top: Summary line drawing of new COCORP seismic reflection profiles in southeastern United States (unmigrated). These are conventional Vibroseis 48-fold CDP stacked sections with a record length of 16 s (14 s shown). Bottom: Preliminary geologic interpretation incorporating well data for region covered by coastal plain (primarily from Chowns and Williams, 1983), and surface geologic information for southernmost exposed Appalachians (Schamel et al., 1980). UB = Uchee belt; PMB = Pine Mountain belt; IPB = inner Piedmont. Scale = 1:1 assuming average crustal velocity of 6 km/s.

COCORP RESULTS

Coastal Plain

The most prominent feature visible on the COCORP profiles is a zone of bright subhorizontal reflections, visible in the upper 0- to about 1-s two-way time on all but the northernmost profile (Figs. 2, 3). These reflections undoubtedly originate from the Cretaceous to Holocene coastal plain sequence. Well data indicate that these strata are flat lying and have a thickness of about 1 km in the vicinity of Florida line 2, thickening to about 1.5 km in the vicinity of Georgia line 11, and then thinning to a feather edge at the fall line, which occurs in the gap between Georgia lines 14 and 15 (Barnett, 1975; Popenoe and Zietz, 1977). The regional thickness variation and undeformed character of the coastal plain sequence are clearly apparent on the COCORP profiles and serve to distinguish it from older strata beneath.

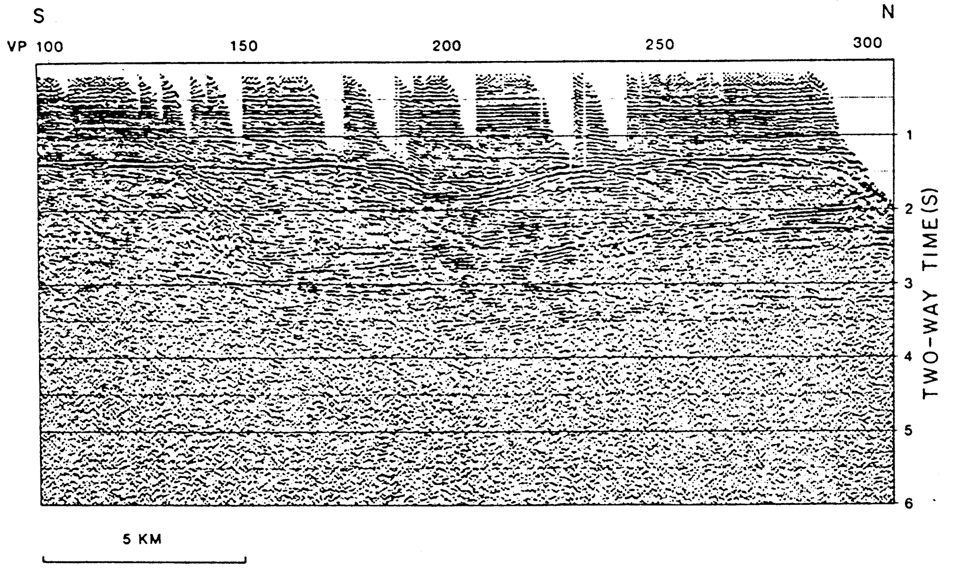

Figure 3. Part of Georgia line 11 (unmigrated CDP stacked section). Horizontal reflections from 0 to about 1.0 s = Cretaceous to Holocene coastal plain sequence. Prominent two-cycle reflection at 1.2 s = Lower Jurassic(?) basalt. South-dipping reflections from 1.2 to about 3 s = Triassic–Early Jurassic rift-basin assemblage. Note small half graben within larger basin assemblage (VP-180–VP-240).

Moho

Discontinuous "patches" of subhorizontal or gently dipping reflections at 11- to 12-s two-way time are also common to each of the COCORP sections. These are the deepest reflections seen on the survey, and on the basis of their apparent depth and laminated character, they are interpreted as Moho (see Oliver et al., 1983). Although these patches of reflections do not define a continuous horizon on the COCORP profiles, their apparent uniformity of travel time implies that the Moho is approximately flat along the length of the survey and occurs at a depth of about 33 to 36 km (assuming 6 km/s average crustal velocity). The discontinuous nature of these deep reflections is probably due to varying signal-to-noise ratio along the survey. Unfortunately, refraction determinations for depth to Moho do not exist in the immediate vicinity of the COCORP lines.

Suwannee Basin

Well data indicate that the coastal plain sequence, south of approximately VP-300 on Florida line 2, lies directly on Paleozoic Suwannee basin sedimentary strata (Chowns and Williams, 1983; Smith, 1982). Reflections from the Paleozoic strata in this region are sparse. This may be due in part to the lithologically monotonous nature of the Suwannee basin sequence and in part to the difficulty of getting coherent seismic signals through the cavernous coastal plain sequence in northern Florida. Where reflections do occur in the Paleozoic sequence, they tend to be flat lying or gently dipping, suggesting only minor deformation. Unfortunately, the data quality does not allow us to define the internal structure of the Suwannee basin sequence in any detail. On Florida line 2 a relatively continuous zone of reflections at 2.5 to 3.0 s can be traced most of the length of the profile. This zone appears to mark the base of layered (sedimentary?) reflections on the profile and is thus tentatively interpreted as marking the top of crystalline basement. This interpretation would imply that the Suwannee basin sequence (probably including basal felsic volcanics) is about 6 km thick in the vicinity of Florida line 2. Farther north we are unable to define the base of these strata.

South Georgia Basin

North of approximately VP-300 on Florida line 1 Triassic–Early Jurassic red beds and associated mafic flows and/or sills are encountered in wells drilled through the coastal plain sequence (Chowns and Williams, 1983). The northern subcrop limit of these strata occurs on the southern half of Georgia line 14. The COCORP data suggest that this rift sequence is relatively thin beneath the north end of Florida line 1 and Georgia lines 10 and 12 (less than 0.5 s thick) but thickens dramatically in a large half graben centered beneath VP-200 on Georgia line 11. From there it appears to thin toward the north.

In southern Georgia the base of the rift sequence is marked by a prominent two-cycle reflection. This reflection is particularly well displayed on Georgia line 12, where it occurs at about 1.2 s across the length of the section (1.7–2.0 km depth). Correlation of the reflection data with a well occurring immediately adjacent to VP-310 on Georgia line 12 indicates that the two-cycle reflection originates from a sequence of early Jurassic(?) basalts intercalated with clastic sedimentary strata.[1] Although this well did not penetrate through these basalts, the reflection data suggest that they lie at or near the base of the Mesozoic rift sequence. Two-cycle reflections similar to those on Georgia line 12 occur intermittently southward on Georgia line 10, Florida line 4, and the north end of Florida line 1. On Florida line 1 the two-cycle reflection merges with the base of the coastal plain sequence at the position where regional well data indicate that the Mesozoic rift sequence pinches out in the subsurface (about VP-300). On all of these lines reflections from immediately beneath the two-cycle reflection are scattered and weak, analogous to the reflections from the Paleozoic Suwannee basin sequence to the south. This character is not due to a lack of signal penetration, for prominent Moho reflections are observed on Georgia line 12 and locally on Georgia line 10 and Florida lines 4 and 1.

The bright two-cycle reflection on Georgia line 12 can also be traced northward on Georgia line 11. North of VP-25 on line 11, prominent generally south-dipping reflections are observed beneath this horizon (Fig. 3). These reflections are clearly distinct in terms of amplitude and geometry from the very weak "Paleozoic" reflections to the south. They define a large half graben, the base of which lies at about 3 s (6 km depth) beneath VP-200 on line 11. This deep graben appears to mark the depositional axis of the south Georgia basin in the region crossed by the COCORP profiles. The geometry of the graben fill suggests that the main basin-bounding fault occurs on the south side of the graben and is listric, dipping toward the north. A distinctive smaller half graben occurs within the fill of the larger basin between VP-180 and VP-240 on line 11. In general, the floor of the main graben shallows northward on Georgia lines 11 and 13. However, the internal structure of the basin is complicated in this region, and it is possible that some prerift strata are included within what is interpreted as rift fill in this area on Figure 2.

[1]Houston Oil and Minerals, Horace Parker #1, Colquitt County, Georgia; Georgia Geological Survey Open-File Report.

Alleghenian Suture

A broad internally complex zone of dipping reflections and probable diffractions extends through the entire thickness of the crust on Georgia line 14 and the north end of line 13 (Fig. 4). This feature is more than 50 km wide and is grossly wedge-shaped in appearance, tapering toward the south. Regional relations suggest that this feature marks the late Paleozoic suture between Africa and North America. This interpretation is based on the following considerations: (1) The zone of dipping reflections/diffractions on Georgia lines 13 and 14 is the only major crustal-penetrating feature imaged on the COCORP survey between known African basement, underlying the Suwannee basin Paleozoic sequence of north Florida, and known North American basement (Grenville), exposed in the Pine Mountain window of west-central Georgia. (2) The position and dominant orientation of reflections defining this feature are appropriate for it to represent the root zone for the inner Piedmont nappes. (3) The zone lies distinctly north of the depositional axis of the Triassic–Early Jurassic south Georgia basin and is thus not obviously related to post-Paleozoic rifting. (4) It coincides with a promi-

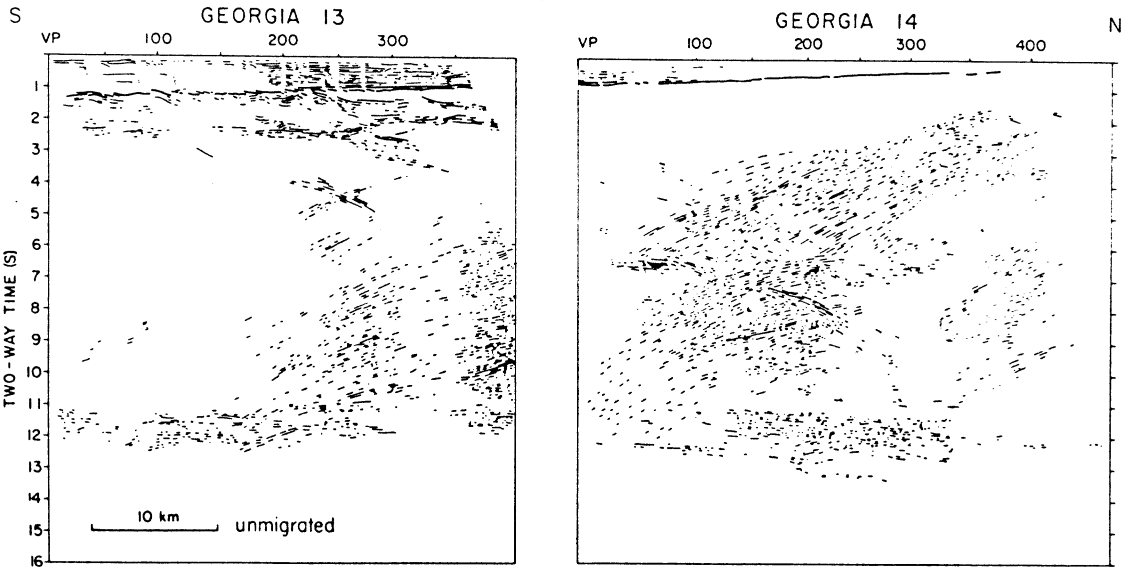

Figure 4. Summary line drawing of Georgia lines 13 and 14 (unmigrated CDP stacked sections). Subhorizontal reflections at 11 to 12 s probably represent Moho. Complex dipping reflections and diffractions, extending through crust, are suggested to represent crustal fabric associated with Paleozoic suture zone.

nent aeromagnetic anomaly (Brunswick anomaly) that extends across Alabama and Georgia and that previously has been recognized as separating two distinct regional magnetic terranes (Daniels et al., 1983). (5) A well drilled on this anomaly in Alabama encountered serpentinite beneath the coastal plain.[2]

Most of the reflections defining the inferred suture zone dip moderately steeply toward the south, though several discrete, apparently crosscutting features dip in the opposite direction. At least one of these north-dipping reflections extends into the upper crust on Georgia line 13 and appears to offset the top of basement(?) in a south-vergent thrust sense. The predominant south-dipping reflections project upward into the southernmost exposed Appalachians (Uchee belt, Pine Mountain belt). Toward the south these reflections intersect subhorizontal Moho reflections, visible on both Georgia lines 13 and 14, at a moderate angle (unmigrated sections). This geometry is particularly well displayed beneath the northern one-third of Georgia line 13 (Fig. 5). Although migration of these lines has not been completed, preliminary analysis indicates that the south-dipping reflections in the lower crust on Georgia line 13 have a migrated dip of 20° to 25°, and project downward toward the Moho at an acute angle. This geometry implies that the dipping crustal fabric defining the inferred suture zone is crosscut by, and thus predates, the subhorizontal Moho fabric defining the base of the crust. This inference is also supported by the fact that the Moho reflections are themselves essentially flat (i.e., undeformed) across the suture zone. Annealing of the base of the crust in this region might reasonably be related to crustal extension and/or igneous activity associated with Mesozoic rifting.

The actual origins of both the Moho and suture-zone reflections remain unclear. In a general sense, the suture-zone reflections appear to originate from within the down-dip extension of the highly deformed and metamorphosed eugeoclinal assemblage exposed in the southernmost Piedmont. However, whether these reflections are caused by primary lithologic boundaries, ductile high strain zones, or some other type of geologic feature within this assemblage is unknown. COCORP is planning more work in the vicinity of Georgia lines 13 and 14 in order to better define the internal geometry of these reflections and, we hope, trace some directly to outcrop.

Pine Mountain Belt

Georgia line 15 extends from the fall line northward across the Uchee belt, the Pine Mountain belt, and part of the inner Piedmont. Crustal reflections beneath the Uchee belt and Pine Mountain belt are limited to scattered, weak, south-dipping reflections that probably represent the northward continuation of the more prominent south-dipping reflections occurring on Georgia line 14. North of the Pine Mountain belt a prominent horizon of laminated reflections, about 0.5 s thick, occurs in the upper crust beneath the inner Piedmont. The southern termination of this horizon occurs at 2.4 s (7-km depth) beneath VP-600 on Georgia line 15. Toward the north this horizon describes a gentle synform and then continues off the north end of the section, shallowing gently toward the north.

Although more profiling is needed to trace out this horizon, its character and position strongly suggest that it marks the southern Appalachian detachment, previously recognized on COCORP profiles in Tennessee and northern Georgia (Cook et al., 1979, 1981). The reflections that define the southern Appalachian detachment on those profiles are thought to originate from early Paleozoic miogeoclinal strata in the lower plate of the detachment, which in turn overlie Grenville basement (Cook et al., 1981). A critical feature of the proposed detachment reflections on Georgia line 15 is that they do not continue southward beneath the Pine Mountain belt. Rather, they terminate abruptly on the north side of the Pine Mountain belt, against the down-dip projection of the Towaliga fault. Grenville basement and overlying metamorphosed cover are exposed in the Pine Mountain belt (Schamel et al., 1980), implying at least 7 km of structural relief on basement across the Towaliga fault. This relief might be due to thrust imbrication of basement during Appalachian orogenesis, post-thrusting down-to-the-north normal fault motion on the Towaliga fault, or some combination of both. Surface mapping indicates that both processes were probably involved. The basement and cover in the Pine Mountain belt are imbricated in several north-vergent sheets; in addition the Towaliga fault, which bounds the north side of the Pine Mountain belt, dips steeply north and appears to have been reactivated as a brittle normal fault subsequent to Appalachian thrusting (Schamel et al., 1980). The COCORP data

[2] Getty Oil Corp., #1 Rufus Garrett, Monroe County, Alabama (Neathery and Thomas, 1975).

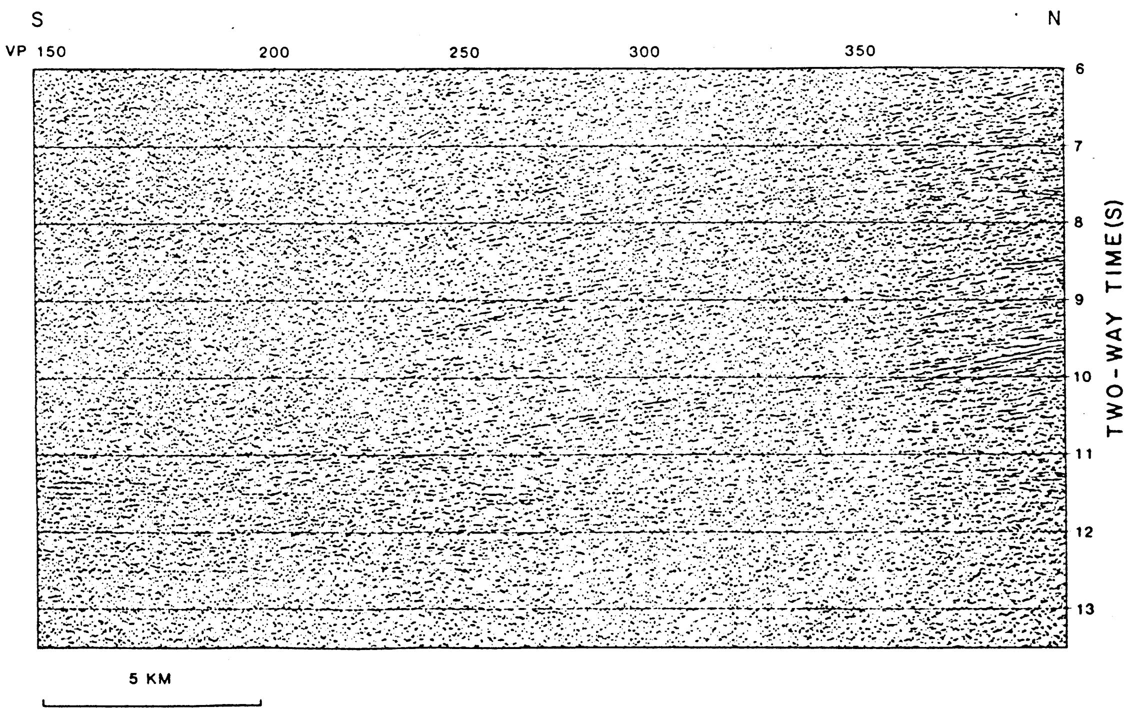

Figure 5. Part of Georgia line 13 showing south-dipping reflections in deep crust (unmigrated CDP stacked section). Diffuse subhorizontal reflections between 11 and 12 s probably represent Moho. Note that south-dipping reflections project downward toward Moho at moderate angle. Migration accentuates this angular discordance.

suggest that this normal fault actually cuts the southern Appalachian detachment. More profiling is needed to determine what the actual offset on this fault is and what role it played in creating the large basement relief evident across the north flank of the Pine Mountain belt. Resolution of these questions will have important implications for how interior basement massifs in the Appalachians formed and will also shed light on the extent to which Mesozoic extension has affected the southern Appalachian Piedmont.

REFERENCES CITED

Barnett, R., 1975, Basement structure of Florida and its tectonic implications: Gulf Coast Association of Geological Societies Transactions, v. 25, p. 122–142.

Chowns, T., and Williams, C., 1983, Pre-Cretaceous rocks beneath the Georgia coastal plain—Regional implications, *in* Gohn, G., ed., Studies related to the Charleston, South Carolina earthquake of 1886—Tectonics and seismicity: U.S. Geological Survey Professional Paper 1313, p. L1–L42.

Cook, F., Albaugh, D., Brown, L., Kaufman, S., Oliver, J., and Hatcher, R., 1979, Thin-skinned tectonics in the crystalline southern Appalachians; COCORP seismic-reflection profiling of the Blue Ridge and Piedmont: Geology, v. 7, p. 563–567.

Cook, F., Brown, L., Kaufman, S., Oliver, J., and Petersen, T., 1981, COCORP seismic profiling of the Appalachian orogen beneath the coastal plain of Georgia: Geological Society of America Bulletin, v. 92, p. 738–748.

Cramer, F., 1971, Position of the north Florida lower Paleozoic block in Silurian time—Phytoplankton evidence: Journal of Geophysical Research, v. 76, no. 20, p. 4754–4757.

—— 1973, Middle and Upper Silurian chitinozoan succession in the Florida subsurface: Journal of Paleontology, v. 47, p. 279–288.

Daniels, D., Zietz, I., and Popenoe, P., 1983, Distribution of subsurface lower Mesozoic rocks in the southeastern United States, as interpreted from regional aeromagnetic and gravity maps, *in* Gohn, G., ed., Studies related to the Charleston, South Carolina earthquake of 1886—Tectonics and seismicity: U.S. Geological Survey Professional Paper 1313, p. K1–K24.

Higgins, M., and Zietz, I., 1983, Geologic interpretation of geophysical maps of the pre-Cretaceous "basement" beneath the coastal plain of the southeastern United States, *in* Hatcher, R., Williams, H., and Zietz, I., eds., Contributions to the tectonics and geophysics of mountain chains: Geological Society of America Memoir 158, p. 125–130.

Neathery, T., and Thomas, W., 1975, Pre-Mesozoic basement rocks of the Alabama coastal plain: Gulf Coast Association of Geological Societies Transactions, v. 25, p. 86–99.

Oliver, J., Cook, F., and Brown, L., 1983, COCORP and the continental crust: Journal of Geophysical Research, v. 88, p. 3329–3347.

Pindell, J., and Dewey, J., 1982, Permo-Triassic reconstruction of western Pangea and the evolution of the Gulf of Mexico/Caribbean region: Tectonics, v. 1, p. 179–212.

Pojeta, J., Jiri, K., and Berdan, J., 1976, Silurian-Devonian pelecypods and Paleozoic stratigraphy of subsurface rocks in Florida and Georgia and related Silurian pelecypods from Bolivia and Turkey: U.S. Geological Survey Professional Paper 879, 32 p.

Popenoe, P., and Zietz, I., 1977, The nature of the geophysical basement beneath the coastal plain of South Carolina and northeastern Georgia: U.S. Geological Survey Professional Paper 1028-I, p. 119–137.

Schamel, S., Hanley, T., and Sears, J., 1980, Geology of the Pine Mountain window and adjacent terranes in the Piedmont province of Alabama and Georgia: Geological Society of America Southeastern Section, 29th Annual Meeting, Guidebook, 69 p.

Schilt, S., Brown, L., Oliver, J., and Kaufman, S., 1983, Subsurface structure near Charleston, South Carolina: Results of COCORP reflection profiling in the Atlantic coastal plain, *in* Gohn, G., ed., Studies related to the Charleston, South Carolina earthquake of 1886—Tectonics and seismicity: U.S. Geological Survey Professional Paper 1313, p. H1–H19.

Smith, D., 1982, Review of the tectonic history of the Florida basement: Tectonophysics, v. 88, p. 1–22.

Whittington, H., and Hughes, C., 1972, Ordovician geography and faunal provinces deduced from trilobite distribution: Royal Society of London Philosophical Transactions, ser. B, v. 263, p. 235–278.

Williams, H., and Hatcher, R., 1983, Appalachian suspect terranes, *in* Hatcher, R., Williams, H., and Zietz, I., eds., Contributions to the tectonics and geophysics of mountain chains: Geological Society of America Memoir 158, p. 33–54.

Wilson, J.T., 1966, Did the Atlantic close and then reopen?: Nature, v. 211, p. 676–681.

ACKNOWLEDGMENTS

We are grateful for the advice and assistance of numerous individuals in the Georgia Geologic Survey and Florida Bureau of Geology. We also benefited from conversations with Dan Arden, Fred Cook, Tim Chowns, Bob Hatcher, Roy Roundtree, Steve Schamel, Doug Smith, and Bill Thomas. Data collection for this survey was carried out by Petty-Ray (Division of Geosource Inc.) crew #6834. The COCORP project is funded by National Science Foundation Grants EAR-82-12445 and EAR-83-13378. Institute for the Study of the Continents Contribution No. 2.

Manuscript received February 12, 1985
Revised manuscript received June 24, 1985
Manuscript accepted July 10, 1985

Printed in U.S.A.