STRUCTURE OF THE RIDDLEVILLE BASIN FROM COCORP SEISMIC DATA AND IMPLICATIONS FOR REACTIVATION TECTONICS[1]

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ABSTRACT

Seismic reflection data collected during COCORP's traverse of the southern Appalachians reveal that the Triassic Riddleville basin is a half-graben defined by strong, north-dipping basal reflections truncated on the north by a major south-dipping normal fault. Lithologies observed in similar basins suggest that these high amplitude, continuous reflections may be from lacustrine sediments or basaltic layers. The high-angle border fault soles into the Augusta fault, a major south-dipping, low-angle Paleozoic thrust. Geometric relations suggest that formation of the Riddleville basin reactivated this older Appalachian fault.

INTRODUCTION

Seismic reflection profiling across the southern Appalachian Orogen in 1978, 1979, and 1980 by the Consortium for Continental Reflection Profiling (COCORP) transected part of eastern Tennessee, westernmost North Carolina, and eastern Georgia (fig. 1). The initial survey demonstrated that a major detachment extends from the Blue Ridge thrust beneath the Blue Ridge and Inner Piedmont (Cook et al. 1979). Subsequent profiling indicated, among other possibilities, that this or a series of related detachments may extend eastward beneath the Coastal Plain as far as 400 km from the western Valley and Ridge (Cook et al. 1981).

The southern part of the COCORP traverse crossed a linear aeromagnetic low in the Coastal Plain, which has been interpreted as a Triassic basin by Daniels et al. (1983). As this survey provided some of the first nonproprietary seismic data over an onshore east coast Triassic basin, reprocessing of the original COCORP data was carried out to better define the basin and its relationship to older structure. The seismic results define a half-graben with a bounding fault that appears to merge into a pre-existing Paleozoic detachment. The bounding fault is similar in geometry to other features on the reflection data which can be interpreted as thrust faults that splay off deeper detachments. We suggest that this fault and perhaps other Triassic normal faults associated with continental rifting may be reactivated thrust faults which were formed originally in earlier collisional episodes of the Appalachian orogeny.

TECTONIC HISTORY AND GEOLOGIC BACKGROUND

Late Triassic to Early Jurassic rift basins are common along the entire North American Atlantic coast (e.g., Rodgers 1970; Marine and Siple 1974; Klitgord and Behrendt 1979). They are exposed onshore in the Appalachian Piedmont province from North Carolina to Nova Scotia and buried beneath Coastal Plain and continental shelf sediments along the North American continental margin. The basins on the continental shelf, remnant features along the edge of the main Atlantic rift, are buried beneath 7–14 km of sediments making them relatively inaccessible for study (Sheridan 1974). Those basins buried beneath the Coastal Plain and exposed in the Piedmont province (fig. 1, inset) are adjacent to the main rift zone and have been labelled "peripheral" basins by Daniels et al. (1983). Because of their accessibility, the peripheral basins exposed in the Piedmont are better studied than those buried beneath the Coastal Plain. The exposed basins are generally linear features, usually tens of kilometers long and several kilometers wide, although size varies considerably (Marine and Siple 1974). The stratigraphic column in the largest of the exposed peripheral basins (the Newark-Gettysburg basin) has been estimated to be in excess of 10 km (e.g., Olsen 1980). A com-

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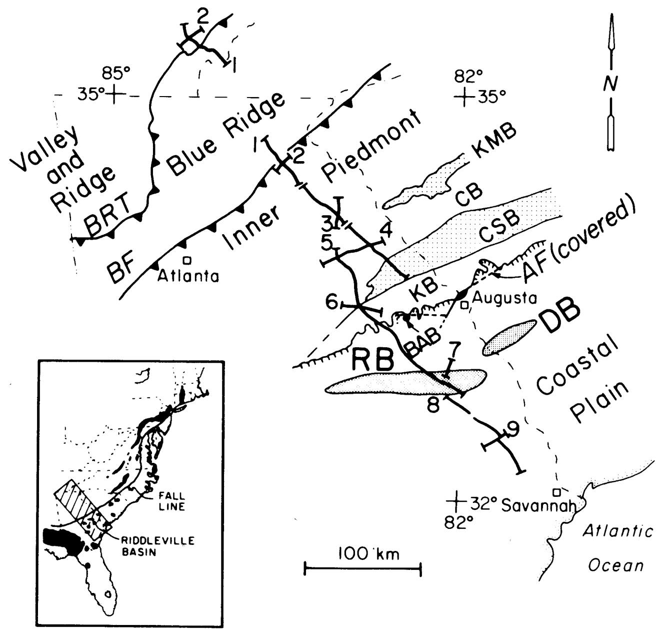

FIG. 1.—Location diagram for COCORP lines in the southern Appalachians. Geologic contacts and faults after Pickering (1976), Williams (1978), and Snoke et al. (1980). BRT = Blue Ridge thrust, BF = Brevard fault, AF = Augusta fault, RB = Riddleville basin, DB = Dunbarton basin, KMB = Kings Mountain belt, CB = Charlotte belt, CSB = Carolina Slate belt, KB = Kiokee belt, BAB = Belair belt. Location of Riddleville and Dunbarton basins after Zietz et al. (1980), Marine and Siple (1974) and Daniels et al. (1983). Inset: Map of Triassic basins along the U.S. Atlantic Coast (adapted from McKee et al. 1959, Marine and Siple 1974).

monly inferred geometry for peripheral basins is that of a half-graben perhaps formed by fault block rotation (Rodgers 1970; Lindholm 1978), with basin strike generally following the grain of the Appalachians (Odom and Hatcher 1980). The bounding fault with the largest offset is here termed the border fault. Approximately half of these peripheral basins have east-tilted basin fill, bounded on the eastern side by a major normal fault, while the other half are generally west-dipping with the border fault on the western edge (Lindholm 1978).

Triassic basins appear to be controlled, in part, by pre-existing structures. Some border faults of Triassic basins along the U.S. Atlantic margin have reactivated preexisting weaknesses. For example, Ratcliffe (1971) has suggested that the normal faults of the Ramapo system in New York and New Jersey, which form the border for the Newark graben, reactivated strike-slip and normal faults as old as Precambrian and Early Paleozoic. Lindholm's (1978) demonstration that the border fault of the Culpeper basin in Virginia is parallel to an earlier foliation in the crystalline country rock raises the question as to whether pre-existing trends influenced that Triassic fault's geometry. His reconnaissance of other exposed basins found that parallelism between country rock foliation and border fault orientation is common.

The Dunbarton Triassic basin, one of the better studied buried basins in the southeast, is located in the southern third of the Savannah River Plant near Dunbarton, South Carolina (fig. 1). Its western end is only about 20 km from the eastern end of the Riddleville basin, of which it may be a northest extension. Siple (1967) originally identified the Dunbarton basin using aeromagnetic and well data. A subsequent seismic reflection survey and additional well coverage have been described by Marine (1974) and Marine and Siple (1974). As a result, the Dunbarton basin's structure has been interpreted as an asymmetric graben with possible normal faults on both its northwest and southeast sides.

The Riddleville Triassic basin of east central Georgia is buried beneath Coastal Plain sediments of Cretaceous and Tertiary age (Herrick and Vorhis 1963). It was originally identified on the basis of an aeromagnetic survey of the southeastern United States by Daniels et al. (1983) who correlated a large number of elongated, featureless aeromagnetic lows beneath Coastal plain cover with Triassic age sedimentary basins. The depth to crystalline basement derived from magnetic data is a minimum of 2.1 km for the Riddleville basin with a slight shallowing to the south (Daniels et al. 1983). A well drilled just north of the town of Riddleville penetrated red bed sediments (Daniels et al. 1983). No age was determined for these rocks, but on the basis of lithologic similarities with Newark Supergroup sediments the basin was inferred to be Triassic-Jurassic.

COCORP RESULTS

The second part of the COCORP southern Appalachian survey extended across the exposed Charlotte and Kiokee Belts and into the Coastal Plain to within 30 km of Savannah, Georgia (fig. 1). As described by Cook et al. (1981) these data allow several interpretations, one of which is that a major Appalachian detachment, or series of detachments, extends from beneath the Blue Ridge and Piedmont provinces to the southeast beneath the Coastal Plain (fig. 2). The most prominent feature on the seismic section beneath the Coastal Plain is an east-dipping, low-angle zone of reflections (AF in fig. 2) interpreted by Cook et al. (1981) as the subsurface extension of the Augusta fault. Above the Augusta fault between vibration points (VPs) 1520 and 1800 is a pronounced east-dipping reflection

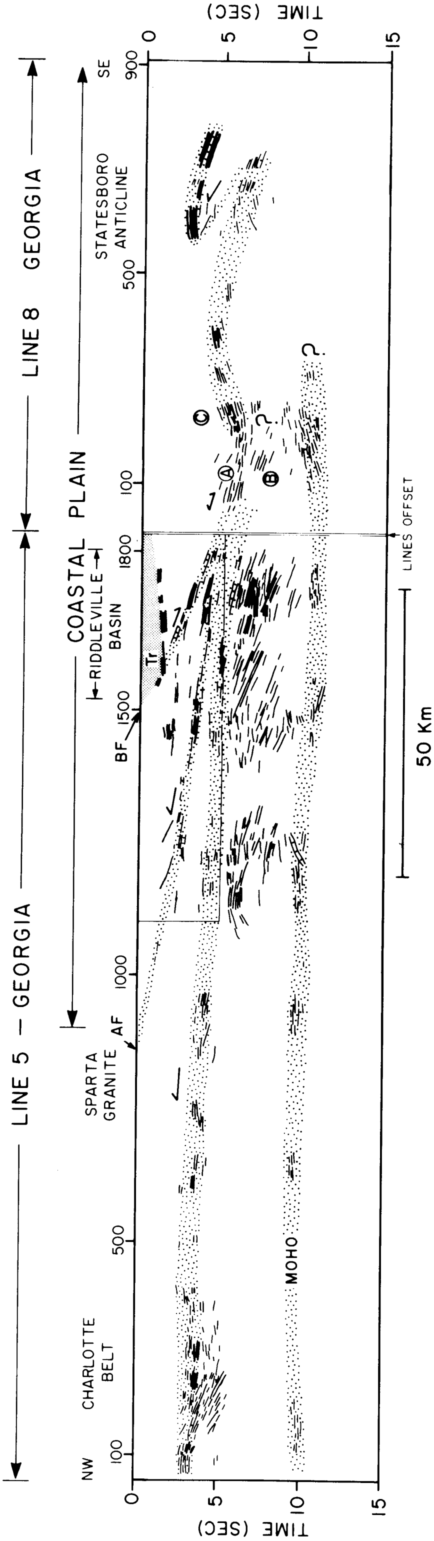

FIG. 2.—Line drawing of seismic events seen on the COCORP profile from the Eastern Piedmont to near Savannah. The box surrounding the Riddleville Basin (shaded) indicates the reprocessed upper section shown in figure 3. The letters refer to significant reflections discussed in text. Dotted pattern emphasizes interpreted continuity of structures. AF = Augusta Fault, BF = Border Fault, Tr = Triassic reflections.

(BF) which truncates a gently north-dipping layered sequence (Tr) inferred by Cook et al. (1981) to correspond to the Riddleville basin.

Reprocessing of the upper 5 sec. of the seismic data (shown in the box on fig. 2) for the Riddleville basin has been carried out to better define its structure and stratigraphy, and its relationship to the underlying Augusta fault. Because COCORP field operations and initial processing are optimized to image deep structures, less effort was originally devoted to analyzing the shallow structure. In this case, a significant improvement in the shallow section was obtained from detailed velocity analyses and migration. Frequency filtering and deconvolution were tried but contributed little to improving the section. For this reason such processing is not included in the sections shown here. Trace mixing was employed to help remove effects of spatial aliasing.

Structure.—The dominant feature on the reprocessed data is the southeast-dipping set of reflections which project to the vicinity of the surface position of the Augusta fault (AF in figs. 2 and 3; Cook et al. 1981). This fault is exposed as a mylonitic zone separating phyllite and greenstone of the Belair belt from granite gneiss of the Kiokee belt and has been interpreted as a major Alleghanian thrust fault (Maher 1978; Snoke et al. 1980; Snoke and Secor 1981). The band of reflections extends at least as deep as 4.0 seconds two-way travel time (10–12 km) near the end of line 5, some 60 km south of its surface position. While not completely continuous, this reflection feature has a fairly strong, layered character over most of its extent, similar in some respects to Wong et al.'s (1982) seismic model for a mylonitic fault zone. Recently, Iverson and Smithson (1983) have questioned both the existence of this reflecting zone and its correspondence to the Augusta fault. Although the problem of correlation may always be subject to some uncertainty until more detailed seismic or well data becomes available, the arguments marshalled by Iverson and Smithson (1983) against associating this reflecting band with the Augusta fault are weak at best (see Cook 1984). As to the existence of the reflecting horizon itself, Iverson and Smithson (1983) fail to show the reprocessed section from which they have drawn their conclusions; thus it is impossible to evaluate the validity of their criticism on this point. However, we believe that both the original seismic sections as published in Cook et al. (1983) and the reprocessed sections in figure 3 convincingly support the identification of a distinct reflecting horizon extending at low-angle beneath much of the Coastal Plain.

Careful inspection of large-scale versions (e.g., Cook et al. 1983) of the seismic sections for line 5 suggests that a number of generally weak, dipping reflectors overlie but do not cross the Augusta fault. These reflectors appear to dip consistently toward the southeast on the seismic sections; however, cross-line seismic control, with the exceptions noted below, is lacking so that true 3-D geometry cannot be ascertained. The most prominent of the southeast-dipping events, obvious even on the reduced sections in figure 3, is beneath the Riddleville basin (MF, fig. 3). This reflector projects to the pre-Cretaceous surface at station 1520, near the aeromagnetically inferred northern border of the Riddleville basin (Zietz et al. 1980, Daniels et al. 1983) and is thus interpreted to be the border fault for the basin. Event MF may be traced to depth on the reflection section at least as far as VP 1800 at about 4 sec. where it converges with the locally steepening Augusta fault near the edge of the data. For convenience, this geophysically inferred fault is referred to in this paper as the Magruder fault, after the nearest town along the seismic line.

It is unclear what happens to the Augusta fault and its related structures south of the end of line 5. Line 8, which is a nearly parallel continuation of line 5 but offset by 24 km along structural strike (fig. 1), has a series of southeast-dipping reflections between 5 and 8 sec. in the first 200 stations (A and B, fig. 2). The Augusta fault and the Magruder fault appear to merge with these southeast-dipping reflections at about 5 sec. (15 km) at the junction of these two lines. These reflections may represent a continuation of the Augusta fault into the deeper crust, truncating a set of northwest-dipping events (C, fig. 2) in the process. Although the deeper set of dipping reflections, B in figure 2, seems to be aligned with the Magruder fault reflections, this alignment is illusory. Consideration of the geometrical relationships among reflections in three dimensions, as discussed below, requires the

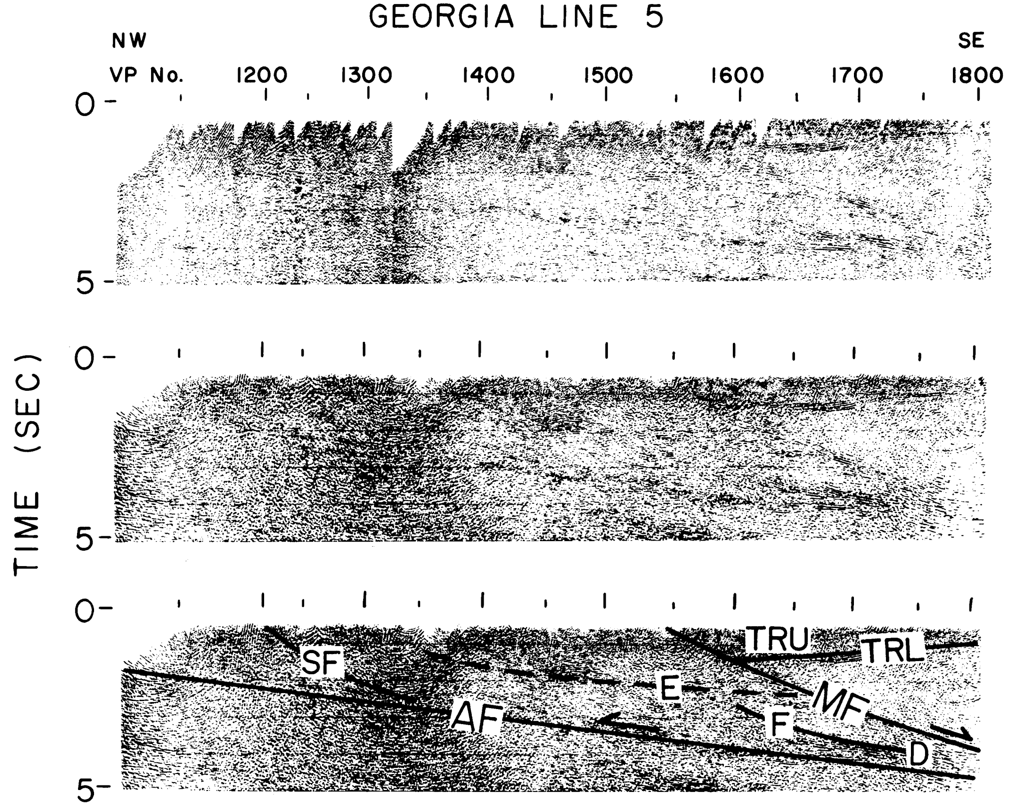

FIG. 3.—(1) Portion of seismic data from line 5. (2) Equivalent migrated section. (3) Interpreted version of migration. The letters refer to significant reflections discussed in the text.

Magruder fault to intersect the Augusta fault farther to the northwest than is suggested in figure 2.

Line 5 is the only COCORP reflection survey across the Riddleville basin. Although line 7 (fig. 1) has no CDP reflection coverage over the basin, refraction information was gleaned from common source recordings across the northern border. Offsets and slope changes in refracted arrivals between VPs 1510 and 1530 on line 5 (fig. 4*a*) and slope changes between VPs 85 and 90 on line 7 (fig. 4*b*) are interpreted to mark the change from basement to Triassic material. These features indicate an east to east-northeast trend for the border fault which is more-or-less consistent with the easterly aeromagnetic trends (Zietz et al. 1980; Daniels et al. 1983). Therefore, line 5 is interpreted to obliquely transect the basin at about 30° to strike.

Although the Riddleville border fault appears on the seismic section to dip about 21° (migrated), correction for the oblique traverse suggests that it actually dips at approximately 50°. Repositioning the Triassic border fault on the seismic section to its true apparent dip indicates that it should intersect the Augusta fault along a broader zone of reflections between VPs 1670 and 1700 at 10–12 km depth (D, fig. 3). Because of the oblique crossing and migration effects, the junction of these two faults is not clearly delineated. The Triassic border fault is fairly steep to a depth of about 8 km; below this it may flatten out and sole into the underlying detachment in the area of thickened reflections, or it may continue fairly steeply and be truncated by them. There is, however, no evidence that the border fault offsets the underlying Augusta fault.

Beneath the Riddleville basin are subhorizontal events which parallel the underlying Augusta fault. Some of these events (e.g., E, fig. 3) are horizontally continuous and may be

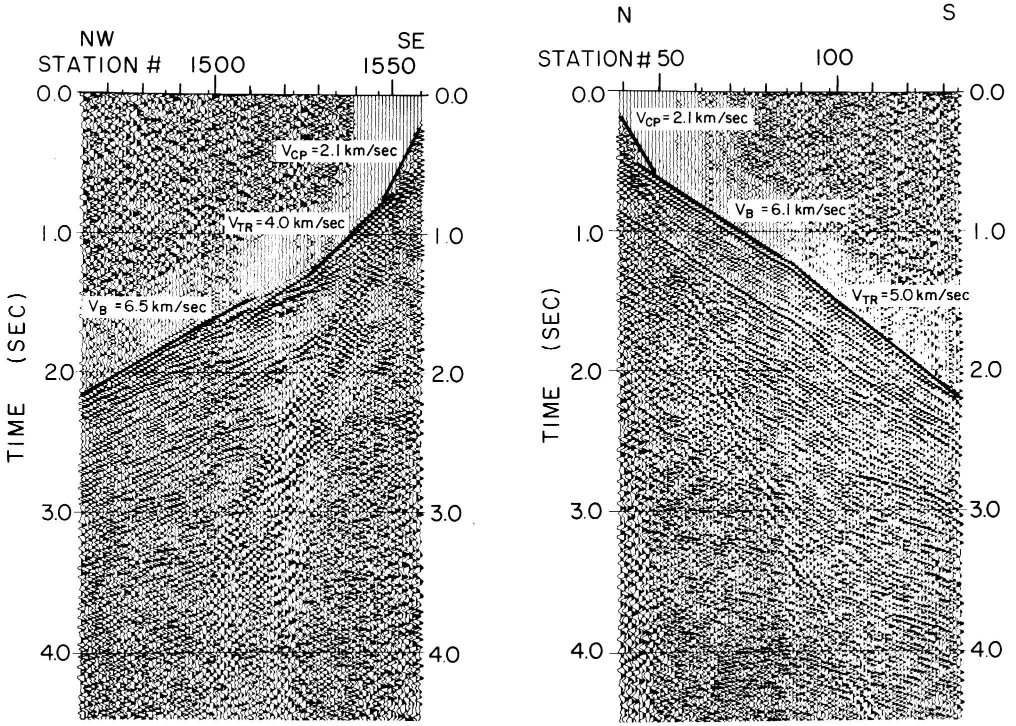

FIG. 4.—(A) COCORP field file from line 5 showing refraction breaks across the Triassic border fault. Note the slope change and offset in the refraction breaks between stations 1510 and 1530 which indicates the fault zone location. (B) COCORP field file from line 7 across the Triassic border fault. The slope change between stations 85 and 90 indicates the fault zone location.

from thrust faults subsidiary to the underlying decollement, or they may be from lithologic contacts within the allochthonous sheet. The border fault appears to truncate these events.

Another set of southeast dipping reflections is observed between station 1550 and 1650 from 3.0 to 4.0 sec. (F, fig. 3). These reflections project to the surface somewhere between stations 1450 and 1500, although continuity above 3.0 sec. is extremely poor. Because they project toward the surface near the inferred border of the Riddleville basin, it is possible that they also correspond to Triassic faults. These events are just north of the interpreted Magruder fault and dip slightly more steeply (about 55 to 60°).

Stratigraphy.—The Riddleville basin has a distinctly layered reflection character. A series of high amplitude, laterally correlative reflections extending from VPs 1560 to 1800 between 1.0 and 1.5 sec. is interpreted to be from the basal section of the Riddleville basin (TRL, fig. 3). These reflections contrast with the more limited lateral continuity of events imaged in the upper basin section above them (TRU, fig. 3) and that observed below them. The basin is buried by approximately 500 m (0.5 sec.) of Coastal Plain sediments which are too shallow to be imaged on the seismic sections shown here. However, the effects of the Coastal Plain sediments have been accounted for in the processing and subsequent depth calculations for the features beneath it.

The upper part of the Riddleville basin has a number of relatively high amplitude horizontal reflections which are laterally discontinuous and interspersed with locally transparent zones (TRU, fig. 3). Limited well control, which penetrates about 500 m into the upper section, indicates that this basin fill is similar to that found in other east coast Triassic grabens (Daniels et al. 1983). The rocks in these basins are typically of nonmarine fluvial origin and have very poor lateral continuity (e.g., Bain and Harvey 1977). Small sandstone lenses, basalt flows, or diabase intrusions encased in shales and coals may account for locally significant velocity contrasts, causing the relatively strong, though laterally limited, reflections seen on the seismic section above the layered sequence (Sangree and Widmier 1977). The layered reflection sequence between 1.0 and 1.5 sec. (fig. 3, TRL) is interpreted to be from the lower Triassic section of the Riddleville basin because it is near the depth to basement of approximately 2.1 km estimated from aeromagnetic data (Daniels et al. 1983). The much greater lateral continuity of the basal events indicates that they have a different origin than the overlying basin fill. The reflections may be from fairly continuous lake or marsh sediments, which are common in other Triassic basins (Olsen 1980) or from interlayered sediments and basalt flows. Similarly continuous reflections mapped beneath the Coastal Plain near Charleston, South Carolina, have been correlated with a basalt layer in wells (Schilt et al. 1983). The Charleston basalt and others in the exposed Triassic grabens have been dated as Late Triassic-Early Jurassic and were emplaced over a large section of sedimentary basin fill (e.g., Eardley 1962; Gohn et al. 1978). There is no evidence of a substantial clastic section underlying the layered events on line 5, but deeper sedimentary rocks cannot be ruled out on the basis of the seismic sections alone if they are poorly reflecting.

The basal Triassic reflections have an average apparent north dip of 6 to 10°. Velocities derived from the reflection data indicate that these events vary from 2.5 to 3.0 km depth in the northern and central portions of the basin and that they shallow to about 1.7 km between VPs 1750 and 1800. The reflection character is variable over these basal events. Two strong reflection peaks are visible in most parts of the basin, with an abrupt thickening between VPs 1640 and 1690 where 5 reflection peaks are more characteristic. This thicker zone appears to form the deepest part of the basin. To the north some of these events appear to be truncated near VP 1640, perhaps as a result of normal faulting, while to the south they shallow gently along a north-dipping flexure near VP 1700. Minor offsets and truncations within this sequence may be due to internal faulting.

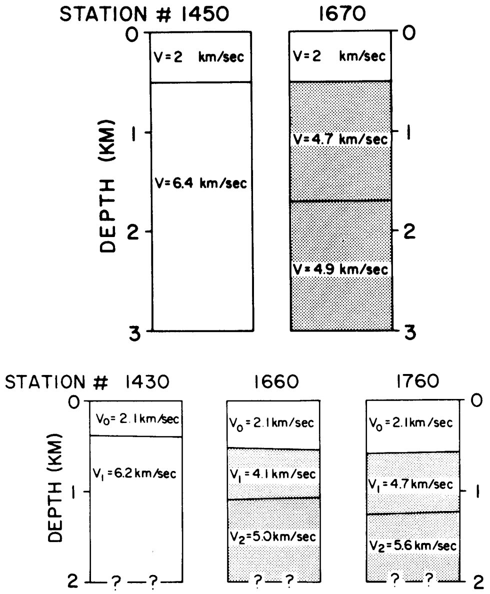

FIG. 5.—(A) Interval velocities from stacking parameters, north of the Riddleville basin (left) and with the Triassic sedimentary section (right). (B) Layered velocity models from COCORP reversed refraction profiles north of the Riddleville basin (left), and within the Triassic Riddleville basin (center and right).

Interval velocities corresponding to the lower layered Riddleville sequence are determined from the reflection data to be about 4.8 to 4.9 km/sec. (fig. 5). While such velocities are high enough to suggest a substantial percentage of basaltic rocks, sonic logs from wells in the nearby Dunbarton Basin indicate rock velocities for Triassic sedimentary rocks (with no volcanic component) may be as high as 6.7 km/sec. The range of velocities observed in this well, from 2.8 to 6.7 km/sec. with the majority between 4.6 and 5.6 km/sec. (Marine 1974), suggests that seismic velocity is an ambiguous indicator of volcanic versus sedimentary lithology in such basins. Although shallow refraction velocities have been determined from reversed profiles constructed from COCORP data, they sample velocities no deeper than about 1.5 km, not deep enough to reach the layered events. Refraction velocities of 4.1 to 5.6 km/sec. characterize the shallow Triassic sedimentary rocks (fig. 5).

Gravity models, in which a constant density of 2.56 gm/cc (which could correspond to a sandstone/siltstone lithology with a velocity of 4.8 to 4.9 km/sec., Gardner et al. 1974) is assigned to the seismically defined basin

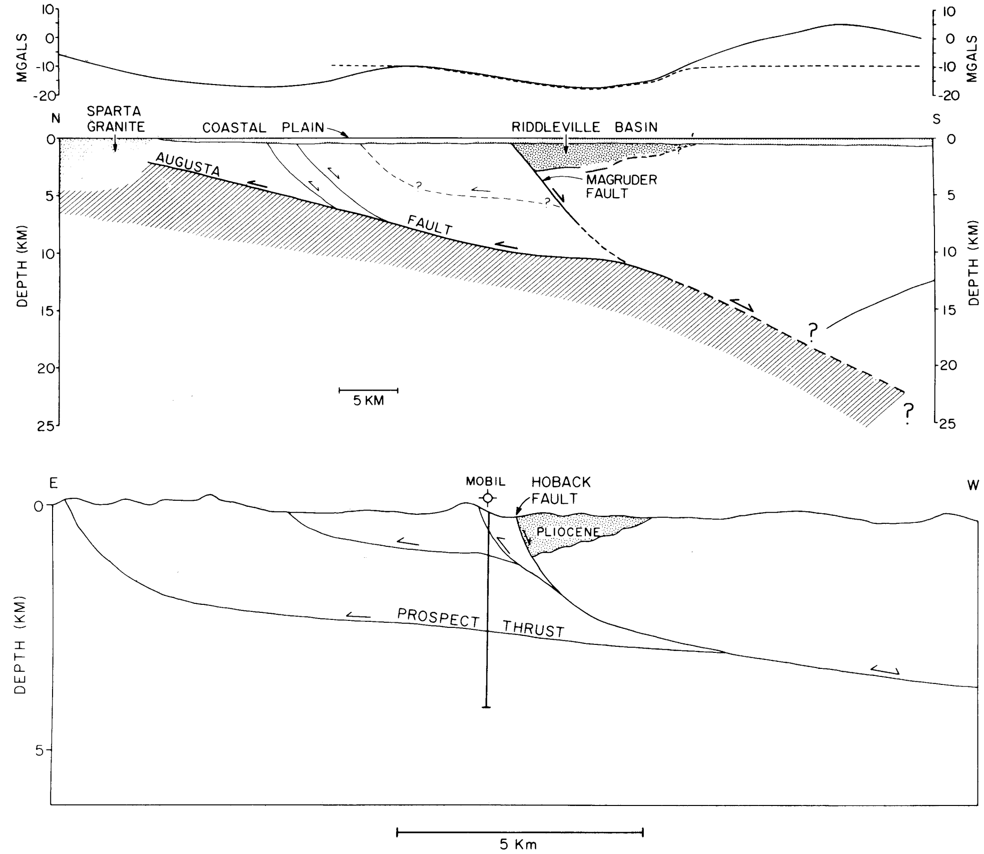

FIG. 6.—(A) Cross section of the Riddleville basin perpendicular to strike, based on the COCORP data with its associated observed Bouguer gravity profile (solid line) and gravity computed from simple density models (dashed line; see text). Gravity data from Long et al. 1972. (B) Comparative cross section from the eastern Basin and Range after Royse et al. (1975).

match the locally observed gravity reasonably well (fig. 6*a*). As with most gravity models, this one is nonunique. An equally good fit can be made by assuming two densities, an upper basin unit of 2.52 gm/cc, corresponding to a clastic sequence, and a lower basin unit of 2.72 gm/cc, corresponding to a layered basalt and sediment sequence.

DISCUSSION

COCORP seismic reflection profiling has shown that Mesozoic extensional faulting in the Riddleville basin has been concentrated along one principal border fault, here termed the Magruder fault. Block rotation along this fault of 6 to 10° seems to have resulted in the formation of an asymmetric graben (fig. 6*a*). The Magruder fault dips approximately 50° south to a depth of at least 8 km and appears to intersect the low-angle Augusta fault at 10–12 km depth. Whether this Triassic fault is truncated by the Augusta fault or shallows and merges into it is not clear. The seismic line crosses the basin at an oblique angle and three-dimensional geometrical complications obscure the intersection of these faults. In any case, however, normal fault motion on the Magruder fault must have been taken up along at least a portion of the underlying Augusta fault since the latter is not significantly offset where the Magruder fault is expected to intersect.

Corroborative evidence for Mesozoic reactivation of Paleozoic features in this area is scanty at best. The strike of Triassic-Jurassic features in eastern Georgia and western South Carolina appears to follow the older Paleozoic trends in some cases. For example, the Paleozoic Augusta fault and local aeromagnetic lineaments from Paleozoic rock buried beneath the Coastal Plain have an easterly trend north of the Riddleville basin and a northeasterly trend northwest of the Dunbarton Basin, subparallel to the orientation of these respective Mesozoic basins (fig. 1; Snoke et al. 1980; Zietz et al. 1980; Popenoe and Zietz 1977). The Magruder fault has a geometry on the seismic section that is similar to weaker events farther northwest along line 5 (e.g., SF, fig. 3, and Cook et al. 1983). Cook et al. (1981) have pointed out the geometrical similarity of these subsidiary structures to splay thrusts off decollements in the Valley and Ridge sedimentary province (Harris and Milici 1977). Thus the Triassic border fault may have formed along a pre-Triassic thrust splaying off the Augusta fault. It has been suggested (e.g., Ratcliffe 1971; Seeber and Armbruster 1981) that reactivation of ancient Appalachian structures may even be important in contemporary tectonics, although the validity of such speculations awaits more definitive evidence.

A possible analog for the Riddleville situation may be found in the Idaho-Utah-Wyoming thrust belt. Both regions formed as a result of extensional stresses that overprinted an older thrust belt. Seismic sections from western Wyoming, for example (fig. 6*b*), indicate that Tertiary normal faults sole into decollements which originally formed as thrust faults (Royse et al. 1975; Conrad 1977). The major normal faults appear to follow ramp structures along thrusts which splay off lower detachments. In the section shown here (fig. 6*b*), the Hoback fault has followed a step in an imbricate thrust to reactivate the Prospect thrust at depth. The resulting rotation has formed a half-graben very similar to the Riddleville basin. The relationship of the Hoback and Prospect faults is very similar to that proposed here for the Magruder and Augusta faults.

The Riddleville Basin has two seismically distinct zones. A well-layered lower section, which dips toward the Magruder fault, is overlain by a poorly-layered upper section, which accounts for most of the basin fill. The layers in the lower section dip 6 to 10° north, while the limited continuity in the upper section suggests a more horizontal bedding. A similarly bimodal seismic stratigraphy has been noted by COCORP surveys in other rifts: for example, in the Keweenawan rift beneath Kansas and Michigan and in the Rio Grande rift in New Mexico (Serpa et al. 1984). The lower, layered unit has been interpreted as interlayered basalt and sediments with the overlying nonlayered sequence attributed to poorly bedded clastic sediments (e.g., Brown et al. 1982). Layered reflections also occur in similar basins in Utah. There, however, they extend throughout the basin and have been interpreted as lacustrine sediments, since well cores in the area indicate a very limited igneous component (McDonald 1976). The lower, layered sequence in the Riddleville basin may also be lacustrine, as basalt flows in exposed east coast Triassic basins are generally restricted to the upper sedimentary section (Eardley 1962; Gohn et al. 1978).

The asymmetric half-graben geometry of the Riddleville Basin is not only common in other Mesozoic basins along the east coast of the U.S. (e.g., Sanders 1963; Rodgers 1970) but has been noted in other rifts, the Bay of Biscay (de Charpal et al. 1978) and the Keweenawan rift in Kansas (Serpa et al. 1983) being two examples. Asymmetric grabens are also prevalent in the Basin and Range Province (Wernicke and Burchfiel 1982; McDonald 1976). Thus, predominantly one-sided faulting and block rotation appears to be common to many rifts.

SUMMARY AND CONCLUSIONS

Analysis of reprocessed COCORP data from eastern Georgia delineates the Riddleville basin as an asymmetric half-graben with a maximum depth of 3 km. Reflections from the lower basin section are much more continuous than those in the upper section. This observation, along with the nonmarine nature of these Triassic basins, suggests that the lower basin fill is either lacustrine in nature or a sequence of interlayered basalt and clastics. The inferred border fault is on the basin's northern side and appears to merge into a major Paleozoic thrust, the Augusta fault, at depth. We believe that these data suggest strong Paleozoic structural control of and reactivation by subsequent Triassic-Jurassic faulting.

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