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THE LATE PRECAMBRIAN-EARLY PALEOZOIC CONTINENTAL EDGE IN THE APPALACHIAN OROGEN

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ABSTRACT. Integration of geological and geophysical data indicates that the eastern edge of the Late Precambrian-Early Paleozoic North American continent is buried beneath the crystalline rocks of the southern Appalachian orogen. The transition appears to be essentially coincident with the strong gravity gradient that is continuous throughout much of the length of the orogen. COCORP seismic-reflection data in the southern Appalachians indicate that most of the near-surface crystalline rocks of the Blue Ridge and Inner Piedmont are allochthonous and that reflection character in the crust changes near the Inner Piedmont-Charlotte belt boundary. Layered reflectors beneath the Kings Mountain belt, Charlotte belt, and Carolina slate belt in Georgia are interpreted as sedimentary (or metasedimentary) strata, and the associated gravity change is interpreted as an edge effect corresponding to the boundary between continental and former oceanic or attenuated continental crust. In this interpretation some or all of the carbonate bank that extended over the shelf and had its edge near this transition was likely transported westward above a décollement, whereas the lower crustal and upper mantle rocks that were located at the transition are still in place below the allochthon.

INTRODUCTION

Although it has been suggested for several years that Valley and Ridge shelf strata extend beneath the Blue Ridge (Bryant and Reed, 1970; Hatcher, 1971) and Inner Piedmont (Hatcher, 1971; Clark, Costain, and Glover, 1978; Hatcher and Zietz, 1978; Cook and others, 1979), the nature and extent of this shelf sequence have been largely unknown. Detailed subsurface data from the crystalline Appalachians, in particular seismic reflection profiles, have provided such information (Clark, Costain, and Glover, 1978; Cook and others, 1979). Interpretation of these data strongly favors the notion that the Blue Ridge and Inner Piedmont constitute an allochthonous sheet overlying sedimentary strata of the Late Precambrian-Early Paleozoic shelf, at least as far east as the east edge of the Inner Piedmont.

In some areas of the crystalline southern Appalachians, Cambrian-Ordovician carbonates similar to the carbonate bank discussed by Rodgers (1968) are found at the surface in thrust faults and imply that these carbonates are present at depth (Hatcher, 1971). In other areas, as in New England, Pennsylvania, and Virginia, these carbonates have been transported westward above the décollement surface and are now found in allochthonous packages west of the crystalline terrain (Rodgers, 1968).

The shelf upon which the carbonates were deposited was a passive Atlantic-type shelf (Rodgers, 1968; Wise, 1970; Williams and Stevens, 1974). Evidence for miogeoclinal assemblages is seen as far east as the Grandfather Mountain window in North Carolina (Bryant and Reed, 1970). Because this was a passive margin, and because the surface evidence indicates that the sedimentation was similar to modern passive margins, we might expect it to have had a deep crustal structure somewhat similar to that of a present Atlantic-type margin; that is, during the Late Precambrian and Early Paleozoic, this margin was likely characterized by thinning of the crust from continental crust to oceanic crust and coincident thickening of the surface sedimentary rocks from miogeoclinal to ocean basin assemblages.

We present here an interpretation integrating data from gravity, seismic reflection, seismic refraction, magnetics, and surface geology suggesting that this major crustal change from thick continental crust to thin oceanic or attenuated continental crust is still present beneath the crystalline rocks of the southern Appalachians. Although shelf strata, such as the Cambrian-Ordovician carbonate sequence, have in large part been translated westward, some of the lower sequences of these strata and the lower crust of this shelf constitute the autochthon over which the Blue Ridge-Inner Piedmont allochthon has been thrust.

We interpret the ubiquitous Appalachian gravity gradient as marking this crustal transition, for it may reflect a lower crustal and/or upper mantle transition. Along a modern Atlantic type margin, the shelf edge is generally characterized by a gravity high which results from variations in depth to basement (Rabinowitz, 1974) and crustal thickness. For comparative purposes in the ensuing discussion, we take the line of the Appalachian Bouguer gravity change to be values greater than +10 mgal (fig. 1); local highs may reach as much as +50 mgal (Woollard and Joesting, 1964).

GEOLOGICAL RECONSTRUCTION OF THE EARLY PALEOZOIC MARGIN

Rodgers (1968) interpreted a major facies change in the Cambrian-Ordovician rocks of New England and Pennsylvania as the transition from a shallow-water carbonate-bank sequence on the west to a deeper water clastic sequence on the east. In the Taconic mountains, these masses of carbonates have probably been transported westward (though less than the Taconic allochthons made of upper rise sediments—Zen, 1967), indicating that the original position of the shelf edge was east of the present location of the facies change. Rodgers (1968) projected the original depositional location of the carbonate bank edge to the east side of the rocks making up the present Green Mountains (1 on fig. 1), although Williams and Stevens (1974) suggested the edge of continental crust may have been farther east. Rodgers (1968) also interpreted a similar facies change from platform carbonates to deep water limestones in allochthons in Lancaster County, Pa. (2 on fig. 1) as the southward extension of the bank edge. The restored depositional position of the edge in this location is shown in figure 1.

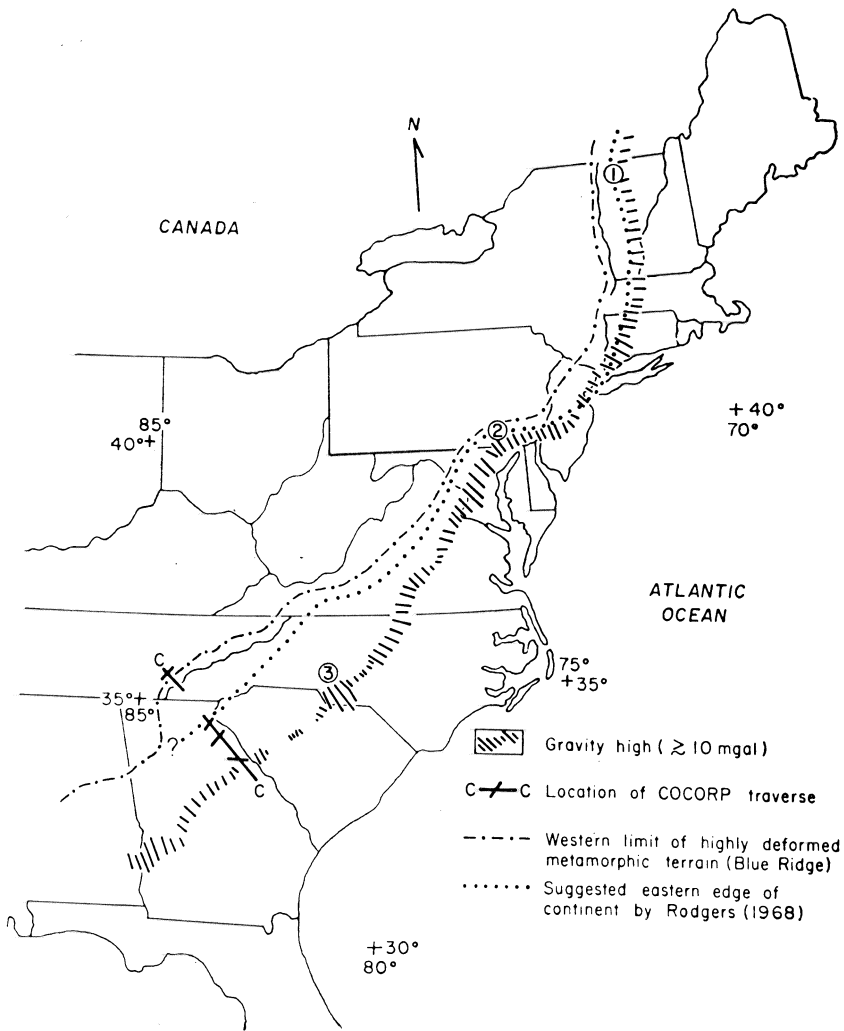


Fig. 1. Map of the eastern United States showing the gravity high (lined area) and its relation to the reconstructed shelf edge, the COCORP traverse, and the structural front of the Blue Ridge. The lined pattern indicates the portion of the Bouguer gravity greater than 10 mgal and thus indicates the trend of the gravity high (from Woollard and Joesting, 1964). (1) and (2) are locations of stratigraphic control for the carbonate bank edge (Rodgers, 1968) in northern Vermont (1) and Lancaster County, Pa. (2). (3) in North Carolina is the easternmost extent for the restored location of the Early Ordovician-Cambrian carbonates in the Pulaski thrust family of the Valley and Ridge (Harris and Bayer, 1979a). The carbonate bank edge was at least as far east as this position.

Palinspastic reconstructions of the folds and thrusts in the Valley and Ridge and Blue Ridge suggest that the Valley and Ridge deformed Cambrian and Ordovician carbonate rocks have been transported 100 to 130 km from the east (Roeder, Gilbert, and Witherspoon, 1978; Harris and Bayer, 1979a). The reconstruction of Harris and Bayer (1979a, their fig. 3) places the depositional location of the Ordovician carbonates in the Pulaski thrust family at a position corresponding to the location of the gravity change (3 on fig. 1). Although the lithologic transitions discussed by Rodgers (1968) have not apparently been observed in this part of the Appalachians, the carbonates exposed in the Pulaski thrust family are of platform type and of Cambrian-Ordovician age (Rodgers, 1970). The bank edge was therefore at least as far east as the reconstructed position of these rocks (fig. 1).

These geologic data thus indicate that the eastern limit of the Early Paleozoic carbonates may, in at least three locations, be restored to an

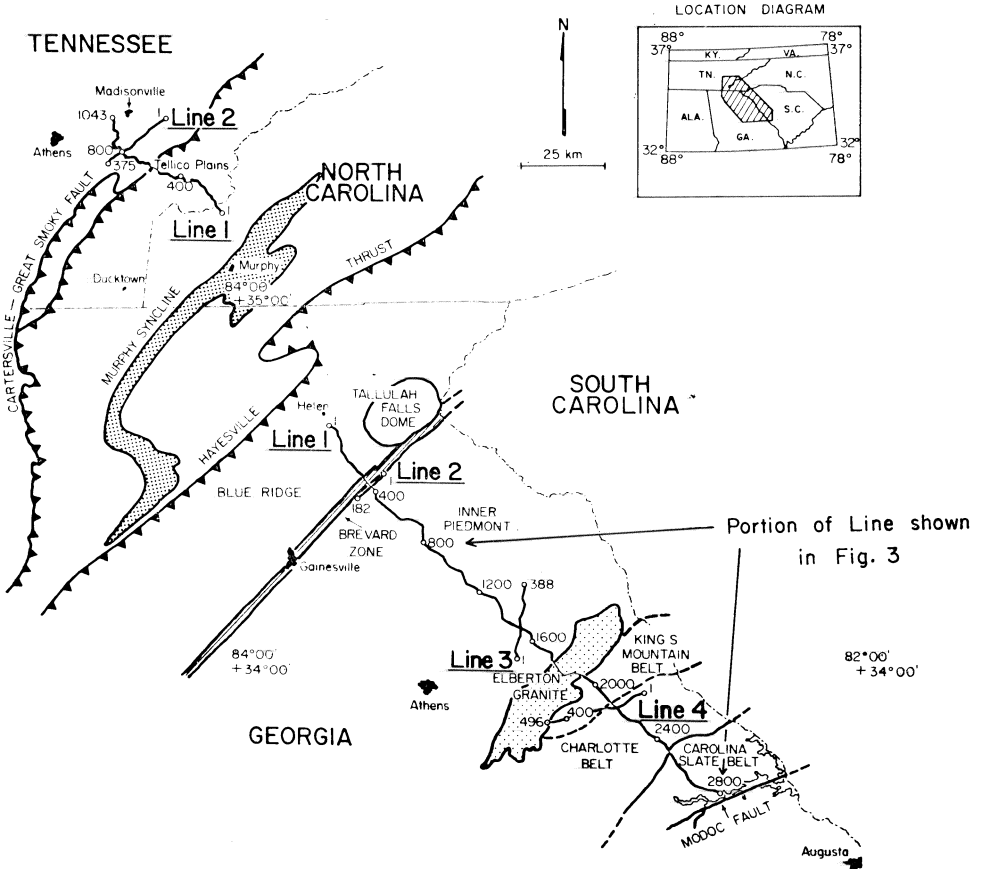


Fig. 2. Location map for the COCORP seismic reflection traverse in Georgia, North Carolina, and Tennessee. The portion of line 1 shown in figure 3 is indicated.

original depositional position coinciding with the gravity high and hence is characterized by a major change in crustal density. If these reconstructions are accurate representations of the original position of the carbonate bank edge, the trend of these three locations may be an indication of the position of the edge of the continental shelf during the time of deposition and thus the approximate position of the change from thick continental crust on the west to thinner oceanic crust on the east.

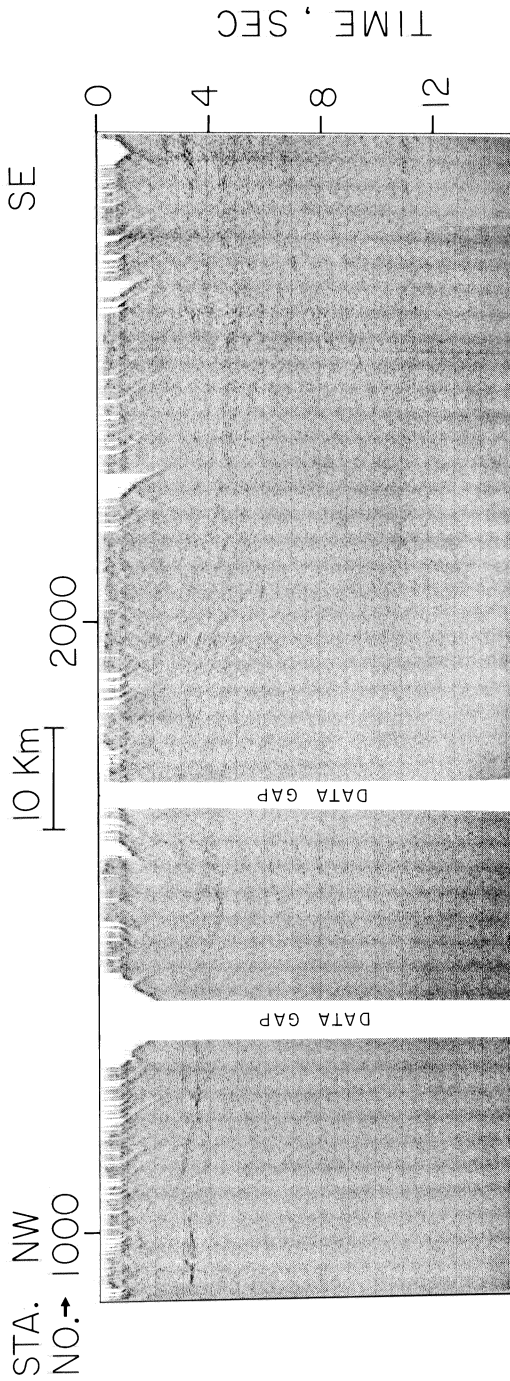
GEOPHYSICAL DATA

Figures 1 and 2 illustrate the location of the COCORP traverse in Tennessee, North Carolina, and Georgia. As the present discussion focuses on the area southeast of the Brevard zone, the portion of line 1 shown in figure 3 is the part of the traverse from the Inner Piedmont to near the Modoc fault in Georgia. A normal sequence of processing has been applied, without migration, to these data (Schilt and others, 1979).

Generally subhorizontal, layered reflections exist on data from beneath the Inner Piedmont. These reflections appear to be from an extension of Valley and Ridge sedimentary strata beneath the Blue Ridge and into the Inner Piedmont (Clark, Costain, and Glover, 1978; Cook and others, 1979; Harris and Bayer, 1979b). Near the Inner Piedmont-Charlotte belt boundary, however, the reflections change in character (fig. 3). The layered reflections beneath the Inner Piedmont typically have a thickness of about 0.5 to 1.0 sec (about 1.5-3.0 km for a velocity of 6 km/sec) or less and are generally sub-horizontal, whereas east of the Inner Piedmont, the sequence dips east, and its thickness increases substantially (fig. 3). Beneath the Charlotte belt and Carolina slate belt, these reflections become horizontal between 4.0 and 6.0 sec (12 and 18 km). Black, Ferguson, and Stewart (1975) and W. Black (written commun., 1979) have seen similar flat, layered reflections on seismic data about 400 km northeast of the COCORP line (but along strike) in the Carolina slate belt of North Carolina, indicating that these flat layers extend under a wide area of the southern Appalachians.

In conjunction with the change in reflection character from the Inner Piedmont to the Charlotte belt, the reflection stacking velocity in the upper 4.0 sec (about 12 km) decreases eastward. For example, the stacking velocity at 3.5 sec beneath the Inner Piedmont (fig. 4) is typically 6.2 km/sec, whereas beneath the Charlotte belt (fig. 4) it is typically 5.8 km/sec at 3.5 sec. The lower velocities in the upper 12 km beneath the Charlotte belt indicate that these rocks are on average less dense than the rocks in the upper 12 km beneath the Inner Piedmont. The densities used in the gravity modeling are chosen to be consistent with these velocity changes.

Any continuously layered, horizontal rock sequence with large enough reflectivity contrasts could produce a similar layered reflection appearance to that from beneath the Kings Mountain belt, Charlotte belt, and Carolina slate belt. However, the combination of low near surface velocities determined from the reflection data (fig. 4) and re-



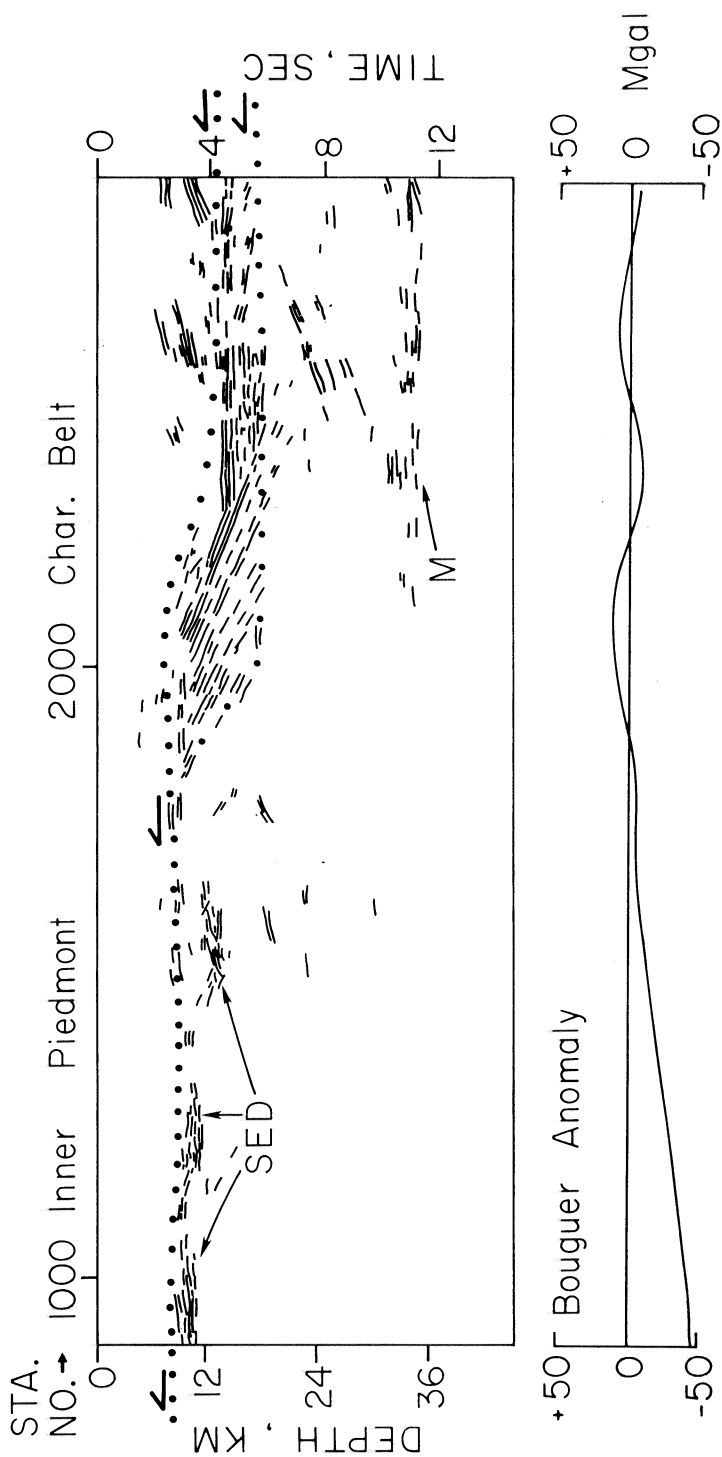
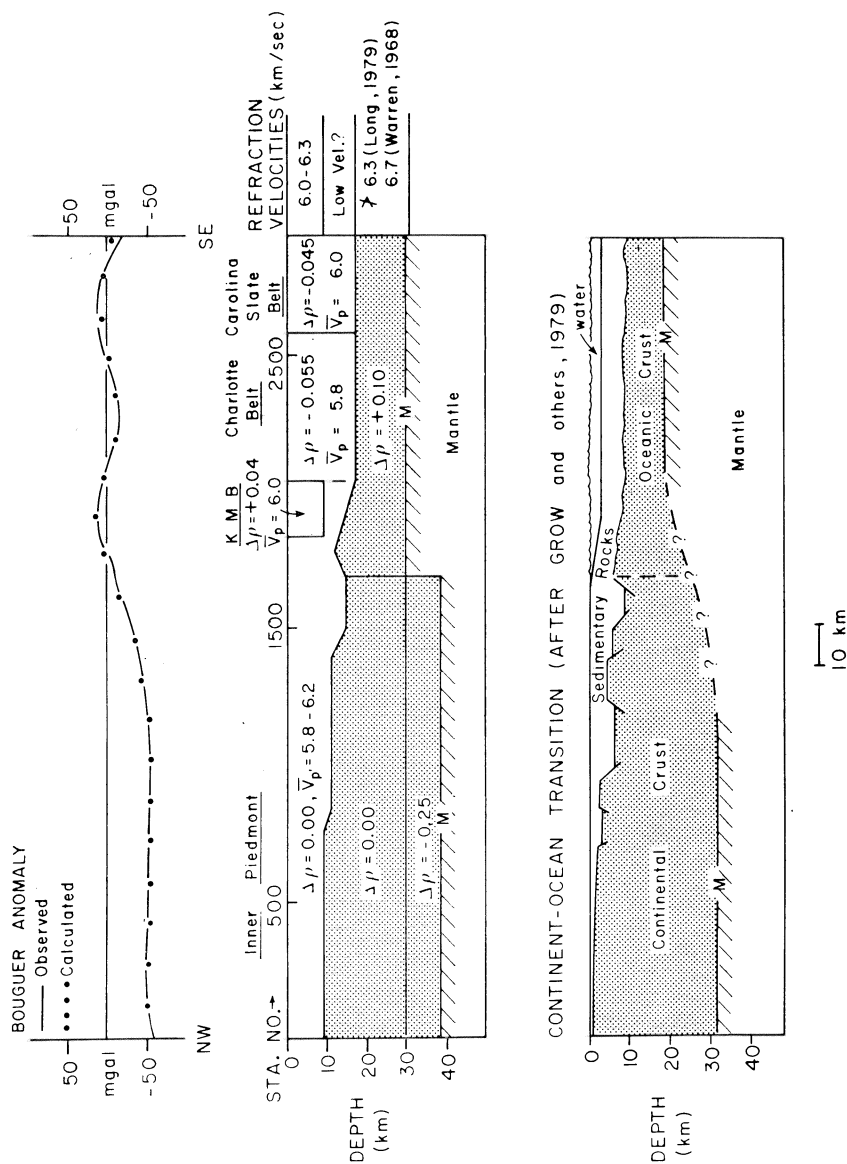


Fig. 3. Bouguer gravity profile, unmigrated COCORP seismic reflection data, and companion line drawing of reflection events from the western Inner Piedmont to the Carolina slate belt in Georgia. The Charlotte belt-Carolina slate belt boundary is located near station 2500. The dotted lines denote the approximate position of possible thrust faults. The dipping reflectors beneath station 2000 may also be characterized by many faults that are parallel to the layering. Significant features include the sub-horizontal layered reflections (denoted as SED) in the Inner Piedmont, which are interpreted as sedimentary reflections (Cook and others, 1979), the change in character of the seismic data near the Inner Piedmont-Charlotte belt boundary (near station 1800), and the deep crustal reflections beneath the Charlotte belt and Carolina slate belt. A cross line located near station 2160 confirms the presence of the dipping events near stations 1800 to 2100.



fraction data (Long, 1979), a possible low velocity zone below 10 km (Long, 1979), the continuous layered character of the reflections (fig. 3), and their position in relation to the reconstructed location of the carbonate bank lead us to interpret these layered reflections as sedimentary (by now metamorphosed) strata of the Late Precambrian-Early Paleozoic ocean basin assemblage. In this scenario, the dipping reflections at the boundary (fig. 3) may be from sediments that are depositively thick or from sediments that are thickened by imbricate, bedding-plane thrusting.

An unusual west-dipping event is visible on the reflection data between 6.0 and 10.0 sec beneath stations 2400 to 2800 (fig. 3). Such a feature is not generally observed on seismic reflection profiles across a modern shelf (see, for example, Grow, Mattick, and Schlee, 1979), and its significance is uncertain.

Reflections are visible near 10.0 to 11.0 sec (about 30 to 33 km) beneath the Charlotte belt and Carolina slate belt (fig. 3). As seismic refraction data and gravity data indicate the Moho is at a depth near 30 km in this area (Long, 1979), these may be reflections returned from it or its vicinity. West of this area, the Moho is likely much deeper, perhaps near 40 km (Warren, 1968; Long, 1979), though no events on the reflection data can be attributed to it. The contrast in lower crust (and Moho) reflecting character from the Inner Piedmont to the Charlotte belt is further evidence that a major crustal boundary is present near the east edge of the Inner Piedmont in this area.

Gravity and magnetics.—The Bouguer gravity field of the eastern United States is characterized by a major gradient extending from Alabama to New England and continuing northeast into Canada. A similar gravity gradient is present in the Ouachita Mountains of Arkansas and Oklahoma (Woollard and Joesting, 1964), but it is unknown at this time if this feature is correlative with the Appalachian gradient. The Appalachian gradient marks the change from low values on the west to high values on the east (Woollard and Joesting, 1964). Thus, the crust and/or upper mantle are of substantially lower density west than east of the gradient. In North Carolina, the steepest part of the gravity gradient and its associated high coincide with the Charlotte belt-Carolina slate belt boundary (eastern edge of the Charlotte belt—Best, Geddes, and Watkins, 1973), whereas in South Carolina and Georgia, the gradient and high generally coincide with the Kings Mountain belt or the western

← Fig. 4. (A) Density model for a Bouguer gravity profile along the COCORP line in Georgia. The observed gravity is from Long, Bridges, and Dorman (1972), although short wavelength variations are eliminated. The Bouguer density of 2.67 g/cc is assumed to 30 km. (M) is the Moho, and (KMB) is the southward projected location of the Kings Mountain belt. The stippled pattern indicates the basement below the sediment layers. For modeling purposes the sediment layer is included with the overlying rocks. Density contrasts are in g/cc and average velocities are in km/sec. Also shown are crustal refraction velocities from Warren (1968) and Long (1979).

(B) A typical model for a modern continent-ocean transition from the Atlantic coast is shown here (from Grow, Mattick, and Schlee, 1979) to illustrate the similarity with (A).

edge of the Charlotte belt (fig. 5). Significantly, the gravity contours appear to transect the strike of major surface belts in this area. Farther north, in Virginia, the gravity high diverges northwest and again does not show a simple one to one correspondence with surface geology. In the northern Appalachians, the high coincides with the Green Mountains and adjacent ultramafic rocks (fig. 1).

A density model has been constructed and gravity computed for a profile across the gravity change in the vicinity of the COCORP line in northeast Georgia. The geometry of the section includes constraints imposed by the seismic reflection data. Thus the densities chosen are consistent with the average velocity trends derived from the seismic data (fig. 4) in the upper 15 km. The observed values for the profile are taken from the Bouguer gravity map of Georgia (Long, Bridges, and Dorman, 1972). Minor, short-wavelength variations have been eliminated, however, as we are primarily interested in large-scale changes in structure.

Best, Geddes, and Watkins (1973) modeled the gradient in North Carolina, where it is considerably steeper than in Georgia. Their "best fit" calculations determined that the source for much of the gravity change is probably located within the upper 10 km in their area. The gradient is not as steep in Georgia, suggesting, though not requiring, that the source for the change is correspondingly deeper. The low seismic velocities near the surface (fig. 4; Warren, 1968; Long, 1979) imply that the upper crust southeast of station 2000 is relatively silicic and low density. In conjunction with the average velocity decrease in the near-surface rocks from the Inner Piedmont to the Charlotte belt, a corresponding decrease in average density in the upper 10 km from 2.67 g/cc to 2.62 g/cc is used in the gravity model. Refraction data (Warren, 1968; Long, 1979) indicate that the top of the mantle under the Charlotte belt and Carolina slate belt is at a depth near 30 km. A mass deficiency with a density contrast of about -0.25 g/cc to the west of the Charlotte belt is thus modeled between 30 and 37 km. The nature of the transition between the Inner Piedmont and the Charlotte belt at Moho depth is not well constrained; it is shown here (fig. 4) as a step. The non-uniqueness of gravity modeling could easily allow the transition to be represented by a ramp function.

The gravity high in the Charlotte belt-Carolina slate belt area (fig. 4) requires that the crust and/or mantle are, on average, very dense. As the shallow mantle is insufficient to account for the steepness of the gradient, a substantial portion of the dense material is in the crust. Magnetic data (discussed below) and the low (5.5 km/sec-6.0 km/sec) velocities east of the Inner Piedmont near the surface imply that the amount of mafic material in the upper 10 km of the Charlotte belt-Carolina slate belt of this area is not very great. These observations lead to the conclusion that the crust between 15 and 30 km has a mass excess relative to the middle crust beneath the Inner Piedmont to account for the gravity high. The density contrast used here (about 0.10 g/cc) suggests a density of about 2.77 g/cc for the lower crust of the Charlotte belt, if a Bouguer density of

2.67 g/cc is assumed for the lower crust of the Inner Piedmont. If a higher density (say 2.80 g/cc) is assumed for the Inner Piedmont crust, the density contrast of 0.10 g/cc would give a density more like oceanic basalt for the lower crust of the Charlotte belt.

Long (1979) observes that refraction-determined velocities do not appear to exceed 6.3 km/sec in the lower crust of this area. However, Warren (1968) models the lower crust in the Carolina slate belt of North Carolina with a velocity of 6.7 km/sec and a thickness of about 14 km. Until the velocities of the lower crust in this area are known more conclusively, it will be difficult to distinguish between attenuated continental crust (as suggested by a velocity of 6.3 km/sec and a density of 2.77 g/cc) and oceanic material (as suggested by a velocity of 6.7 km/sec and a density of 2.90 g/cc). The gravity model thickness of 10 to 15 km for the crust beneath the interpreted sediment layers (fig. 3) is thicker

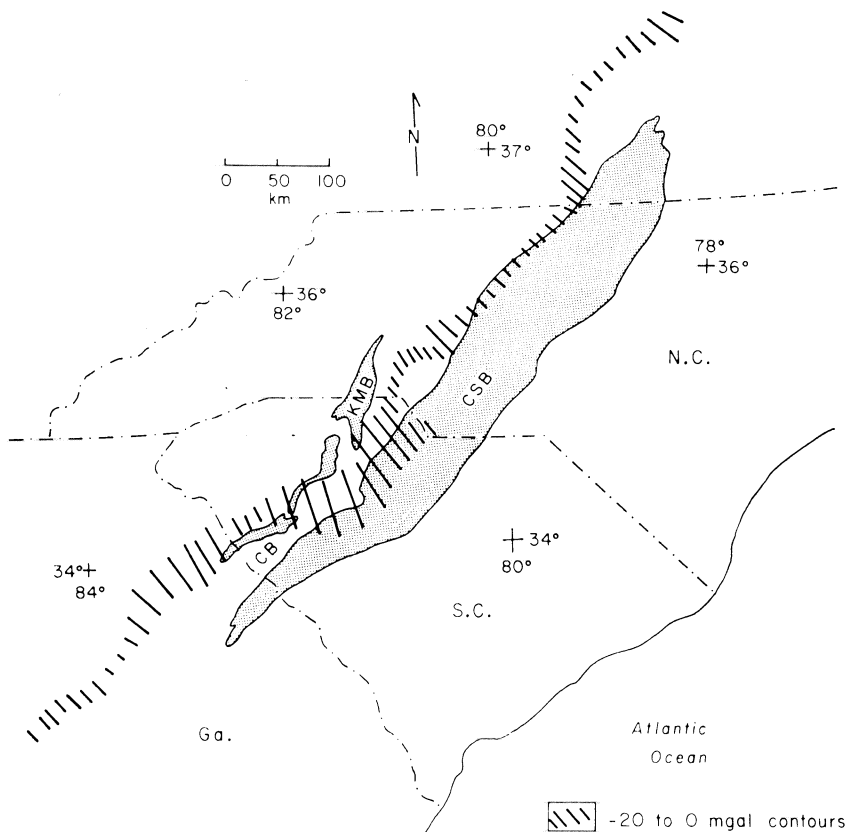


Fig. 5. The gravity change (-20 mgal on the west to 0 mgal on the east—from Woollard and Joesting, 1964) is shown here superimposed on the location of surface belts in the southeastern United States. The crossing of surface belts (the Kings Mountain belt (KMB), Charlotte belt (CB), and Carolina slate belts (CSB)) by the gravity contours suggests that the source for the gravity high is located at depth and bears no direct relation to the surface features.

than normal ocean crust but may be appropriate for small-ocean-basin crust (Menard, 1967) or attenuated continental crust. For comparison with a modern continent to ocean transition, figure 4 also shows an interpretive cross section from Grow, Mattick, and Schlee (1979). The significant features include a decrease in Moho depth and a coincident oceanward thickening of the sedimentary wedge near the transition.

The magnetic data provide another important clue that an unusual crustal transition occurs in this area. In the Charlotte belt there are high-amplitude, short-wavelength anomalies indicating that some mafic material is present near the surface. No broad-wavelength magnetic highs are seen in the Charlotte belt, however, suggesting that the crust in this part of Georgia and South Carolina is on average non-magnetic (Hatcher and Zietz, 1980). As the low near surface seismic refraction and reflection velocities indicate that even non-magnetic mafic rocks do not comprise a significant proportion of the upper crust east of the Inner Piedmont in Georgia, the magnetic and seismic velocity data are mutually consistent if the upper 10 to 15 km of the crust in this area contain primarily silicic material. On the other hand, the gravity high east of the Inner Piedmont implies that the crust as a whole is dense relative to the crust of the Inner Piedmont. The only other position for the mass excess to be located is in the lower and middle crust as modeled in figure 4. Such a model is consistent with refraction data farther north which show a high (6.7 km/sec) velocity in the lower crust of the Carolina slate belt (Warren, 1968).

Other areas characterized by large scale thrust faulting over continental margins frequently show similar linear gravity trends. An interpretation much like the one presented here has been suggested for gravity data near Timor in the southwest Pacific (Chamalaun, Lockwood, and White, 1976). These authors model a strong and continuous gravity gradient as representing the transition from the Australian continental shelf to oceanic crust. An ancient continental edge transition may also be present beneath the allochthonous Purcell anticlinorium (Price, in press). The palinspastically reconstructed position of the shelf edge in that area coincides with a large Bouguer gravity change and an associated shallowing of the Moho.

SYNTHESIS

A crustal-scale transition occurs from the Inner Piedmont to the Charlotte belt in Georgia. The exact nature of this transition has been interpreted in several different ways. Long (1979) suggested that the Carolina slate belt may be a continental rift zone or back-arc basin and thus that the Inner Piedmont-Charlotte belt transition represents a bounding master fault of the rift. Hatcher and Zietz (1978, 1980) suggest that the nappes of the Inner Piedmont are rooted in the Kings Mountain belt and that the boundary between the Kings Mountain belt and the Charlotte belt is a cryptic suture (termed by them the Central Piedmont suture). Our interpretation incorporates some facets from each of these models, but it also has some significant differences.

Of particular importance is the observation that reflectors beneath the Kings Mountain belt, Charlotte belt, and Carolina slate belt (as it is represented on the COCORP line) at 12 to 15 km depth are parallel, nearly continuous, and subhorizontal. As the surface rocks of this area display several stages of folding (Whitney and others, 1978), there is likely a decollement surface between the deformed surface rocks and the underlying horizontal layers. Furthermore, the existence of these continuous (or nearly so) layers beneath the Kings Mountain belt, Charlotte belt, and Carolina slate belt in Georgia (fig. 4) do not favor the interpretation of a major throughgoing crustal suture east of the Kings Mountain belt (Hatcher and Zietz, 1980). The Kings Mountain belt may be a root zone, and perhaps the east edge of it is a suture zone, but we prefer the notion that this zone has been transported over the underlying, continuous, subhorizontal layers. Supporting evidence for this idea derives from the trend of the gravity gradient in Georgia and South Carolina, which transects the surface trace of the Kings Mountain belt (fig. 5).

There are at least three major differences between our interpretation and the notion that the Carolina slate belt (in its present position) is a continental rift. First, the restored position of the carbonate bank edge coincides with the gravity high in at least three locations (fig. 1). Such a carbonate bank is not a common feature of continental rift zones since the deposition of carbonates requires ocean environments. Second, the volcanic rocks of the Carolina slate belt show strong similarities to those of present day volcanic arcs (Whitney and others, 1978). Third, as we mentioned previously, the surface rocks of the Charlotte belt display several major folding (compressional) episodes. These northeast striking, near-vertical folds, which require a substantial amount of shortening, overlie nearly horizontal layers (fig. 3). Various interpretations of these layered reflections are possible; for example, they may be mylonites or recumbently folded layered gneisses. However, we interpret these layers as ocean basin sedimentary (or by now metasedimentary) rocks for three reasons: (1) they show nearly continuous, parallel layering for more than 50 km, (2) the velocities determined from both the reflection and the refraction data are low and thus do not favor the notion of a substantial amount of high velocity (mafic) material at the level in the crust corresponding to these layers, and (3) they occur east (oceanward) of the reconstructed location of the carbonate bank edge, where thick, layered sedimentary rocks were likely deposited.

Surface mapping and high-amplitude, short-wavelength magnetic anomalies demonstrate that mafic material is present at and near the surface east of the Inner Piedmont in Georgia and South Carolina. These features may be small-scale features and may not be representative of the entire upper crust; the low seismic velocities in the upper 15 km along the COCORP line in northeast Georgia indicate that the upper 15 km is not composed of much mafic material. In North Carolina, on the other hand, the gravity gradient is much steeper (Best, Geddes, and Watkins, 1973), and magnetic data indicate that more mafic material is near the surface.

We thus interpret the crustal transition from the Inner Piedmont to the Charlotte belt in Georgia as representing the autochthonous Late Precambrian-Early Paleozoic continental edge. The carbonate bank was deposited on the shelf to the west of this edge, and, as the Inner Piedmont-Blue Ridge thrust sheet rode westward over the shelf, much of the carbonate was transported with it or in front of it, while the rocks that cause the gravity high were left in place. The thick sequence of reflectors beneath the Kings Mountain belt, Charlotte belt, and Carolina slate belt are here interpreted as sedimentary (now metamorphosed) layers that were deposited basin-ward of this shelf edge. Below these reflectors are 10 to 15 km of thin crust which may be oceanic crust or attenuated continental crust. Below this layer, the mantle of the Charlotte belt and Carolina slate belt in this area is nearly 10 km shallower than the mantle beneath the Inner Piedmont. Furthermore, since Black, Ferguson, and Stewart (1975) and W. Black (written commun., 1979) have detected similar layered rocks beneath the Carolina slate belt in North Carolina and the reconstructed position of the carbonate bank edge throughout the Appalachians appears to correspond to the present gravity high, we suggest (as did Griscom in Zeitz and Zen, 1973) that the interpretation of the gravity change as delineating the location of a former continental edge may be applicable to other parts of the orogen.

IMPLICATIONS FOR THE TECTONIC HISTORY OF THE SOUTHERN APPALACHIANS

A model proposed by Hatcher (1978) for the development of the southern Appalachians includes Precambrian rifting of a super continent to produce the proto-North American (Laurentia) and proto-African/South American (Gondwana) continents. In this model, a continental fragment, the Inner Piedmont-Blue Ridge fragment, was also rifted off the North American block and thus was separated by a small basin. If this model is valid, the transition seen on the COCORP data beneath the Inner Piedmont and Charlotte belt might mark the transition from the proto-North American continent to the basin that separated the Piedmont fragment. The lower crust beneath the Charlotte belt and Carolina slate belt might then be characterized as the crust of a small ocean basin crust. Alternatively, the basin east of the ancient edge of North America may have separated the slate belt arc, and the transition delineated by the geophysical changes could be from North American continental crust to oceanic or intermediate crust. The Piedmont and slate belt arc may have been accreted during the continent-directed thrusting of the Early Paleozoic. Final closure of the proto-Atlantic (Iapetus) resulted in the Carboniferous (Alleghanian) collision of North America with proto-Africa/South America (Hatcher, 1978).

Significantly, the closure of the first basin in the Ordovician (Taconian) likely occurred with eastward-dipping subduction. The continuity of sediments on the COCORP profile across the Inner Piedmont preclude the existence of a westward-dipping subduction zone beneath the North American continent at that time; the sedimentary rocks would likely have been destroyed by subduction related volcanism or plutonism. If the interpretation presented here of the sub-horizontal reflections from

beneath the Charlotte belt and Carolina slate belt as representing (meta-) sedimentary layers is correct, a substantial amount of the Early Paleozoic North American-Inner Piedmont basin, as well as the continental shelf, appears to have been overthrust by the allochthon. The acquisition of more seismic reflection data from the coastal plain in Georgia may provide important constraints on the extent and nature of the thrusting and thus the tectonic history of this area.

The interpretation presented here implies that the major structures of the continental shelf, including the transition to ocean basin or marginal basin, remained intact during the multiple deformations of the Paleozoic. The major modification of this shelf appears to be that it is now overlain by several kilometers of highly deformed and metamorphosed material. Following the Paleozoic overthrusting, another rifting episode formed a new passive margin along the present Atlantic shelf which bears a striking resemblance to the Early Paleozoic version, both in morphology and in geophysical characteristics. As it seems unlikely that the Appalachians are unique, linear gravity anomalies in other fold and thrust belts should be reexamined to determine if they might also reflect buried continental margins.

The acquisition of more subsurface data throughout the Appalachians will help to determine the validity of our interpretation and will likely produce modifications of it. However, stacking by overthrusting appears to be the method by which the southern Appalachian orogen evolved during the Paleozoic. Unless a very unusual situation exists here, it seems likely that other orogenic belts, of which Australia and the western cordillera may be examples, have formed by similar continental-margin shuffling.

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