THE BREVARD FAULT: A SUBSIDIARY THRUST FAULT to the SOUTHERN APPALACHIAN SOLE THRUST

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Seismic reflection profiling has proven to be an important tool for delineating subsurface geologic structures. One of the most spectacular applications of this technique by the Consortium for Continental Reflection Profiling (COCORP) resulted in the discovery of a thin, layered sequence of Paleozoic sedimentary rocks underlying a 6 to 15 km thick layer of the crystalline rocks of the Blue Ridge, Inner Piedmont, and possibly the Charlotte belt and Carolina slate belt in the southern Appalachians (1). These sediments appear remarkably undisturbed, and their configuration, including normal faulting and eastward thickening, implies that the overlying thin crystalline sheet has overthrust the Paleozoic continental margin of the southeastern United States for a distance of perhaps 260 km or more (1).

The existence of these sedimentary layers suggests that the structures which are observed at the surface are spatially controlled either by lithologic variations within the thrust sheet, by occasional inflections in the sedimentary layers, or by both. The Brevard zone is one of the best examples of a feature which, at the surface, appears to be a major crustal feature and yet is probably controlled by lateral lithologic changes within the thrust sheet and an inflection in the underlying sediments. Furthermore, the COCORP data show conclusively that basement rocks beneath the thrust sheet are not directly involved in the Brevard fault.

Many studies have been undertaken in various parts of the Brevard lineament by numerous workers. More than twenty distinct models have been proposed for its origin and significance. These include a syncline (2), a thrust fault (3, 4), a normal fault (5), a strike-slip fault (6), and a paleo-subduction zone (7, 8). As it is beyond the scope of this paper to review in detail each of these models, we will focus our discussion on the characteristics which are well defined by the COCORP profiles. Reviews of the models and geologic characteristics of the Brevard zone may be found in Hatcher (4), Odom and Fullagar (8) and Clark et al (9).

The COCORP data support the interpretation of Hatcher (4) in which the Brevard zone is described as a stratigraphically controlled thrust fault on the west flank of the low grade, synformal Chauga belt. Such models as a paleo-subduction zone (8) or an in situ suture are incompatible with the data. The locations of the COCORP southern Appalachian profiles in Tennessee, North Carolina and Georgia are shown in Fig. 1.

The data are presented in two forms. Fig. 2 and Fig. 4 are displays of the processed sections (Line 1 and Line 2) near the Brevard zone. Fig. 3 and Fig. 5 are interpretive line drawings of seismic events abstracted from the processed seismic data. As this paper will concentrate on the interpretation of data near the Brevard zone, the portion of Line 1 from stations 1 to 890 (Georgia) and Line 2 are shown in Figs. 2 through 5. The Brevard zone is located between stations 260 and 340 on Line 1.

<u>Layered Sediments</u>. The most significant finding of the COCORP southern Appalachian traverse is an extensive sequence of relatively flat lying, layered seismic events between 2.0 and 5.0 seconds (6 to 15 km for an average velocity of 6.0 km/sec) which underlie the crystalline rocks of the southern Appalachians (1). This layering is visible on Figs. 2 through 5 and is denoted as 'SED'. A layered reflection appearance such as this may result from layered sediments, layered plutonic rocks, layered volcanic rocks, or layered metamorphic rocks. However, several lines of evidence indicate these events are reflections from Paleozoic sediments.

Exotic fragments of carbonates are found within the Brevard zone of South Carolina and northeast Georgia and have been interpreted to represent sedimentary material transported to the surface during the latest stages of thrusting (4). Minor element analyses indicate these carbonates are from the Cambrian-Ordovician Knox Group (10). These findings are significant in that they establish the presence of sedimentary rocks at depth and provide evidence that these rocks are not highly metamorphosed (10). The low metamorphic grade of these carbonates also implies that the sediments at depth are likewise only slightly metamorphosed and thus the possibility of hydrocarbon potential cannot be ruled out.

Platform sediments are observed within the Grandfather Mountain window in North Carolina and demonstrate that the Blue Ridge is

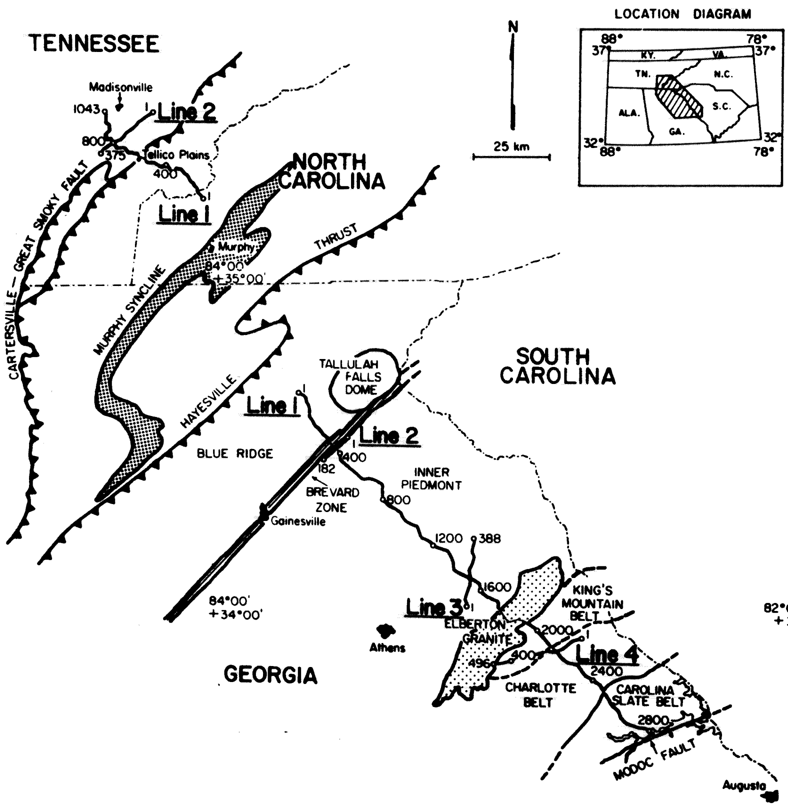
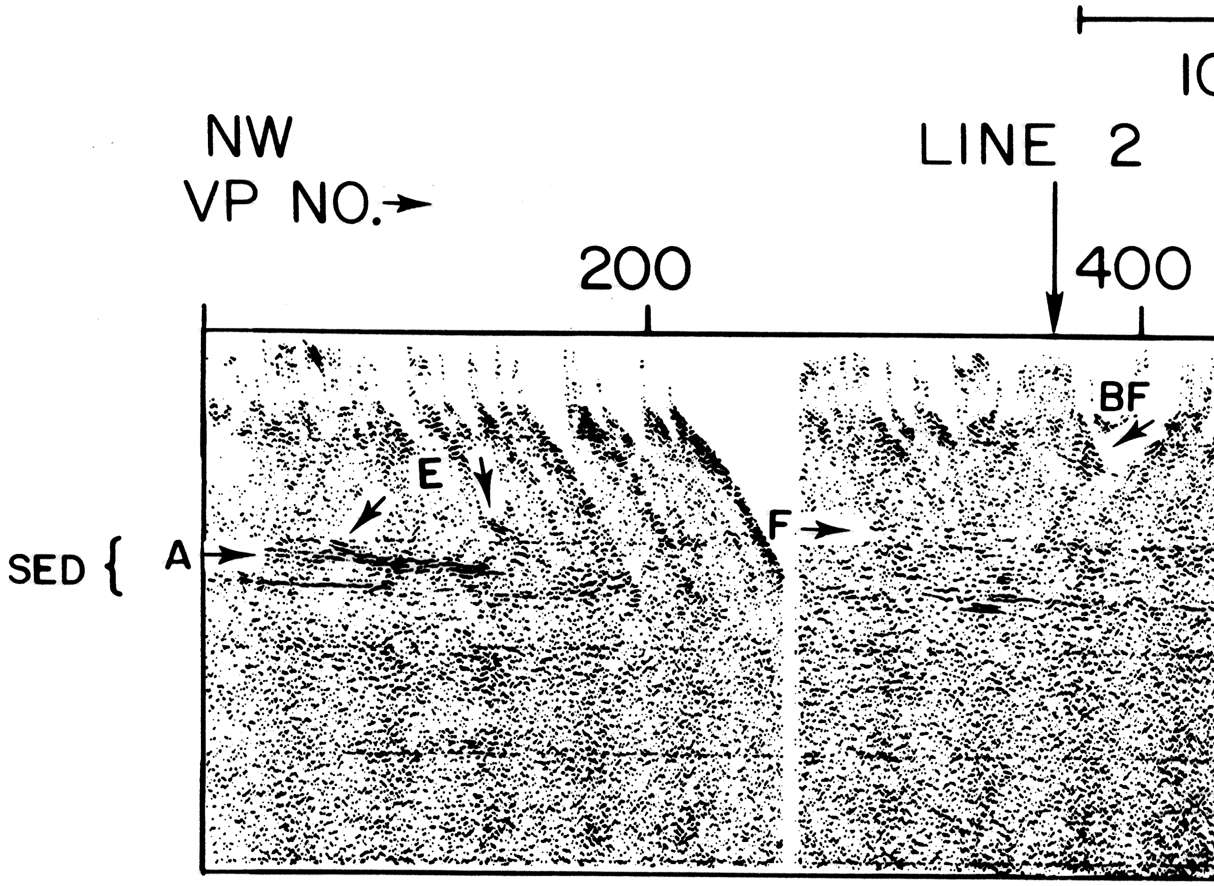


Fig. 1. Location map for the COCORP southern Appalachian traverse. Some major geologic features are indicated by the various patterns.

COCORP SOUTHERN AP

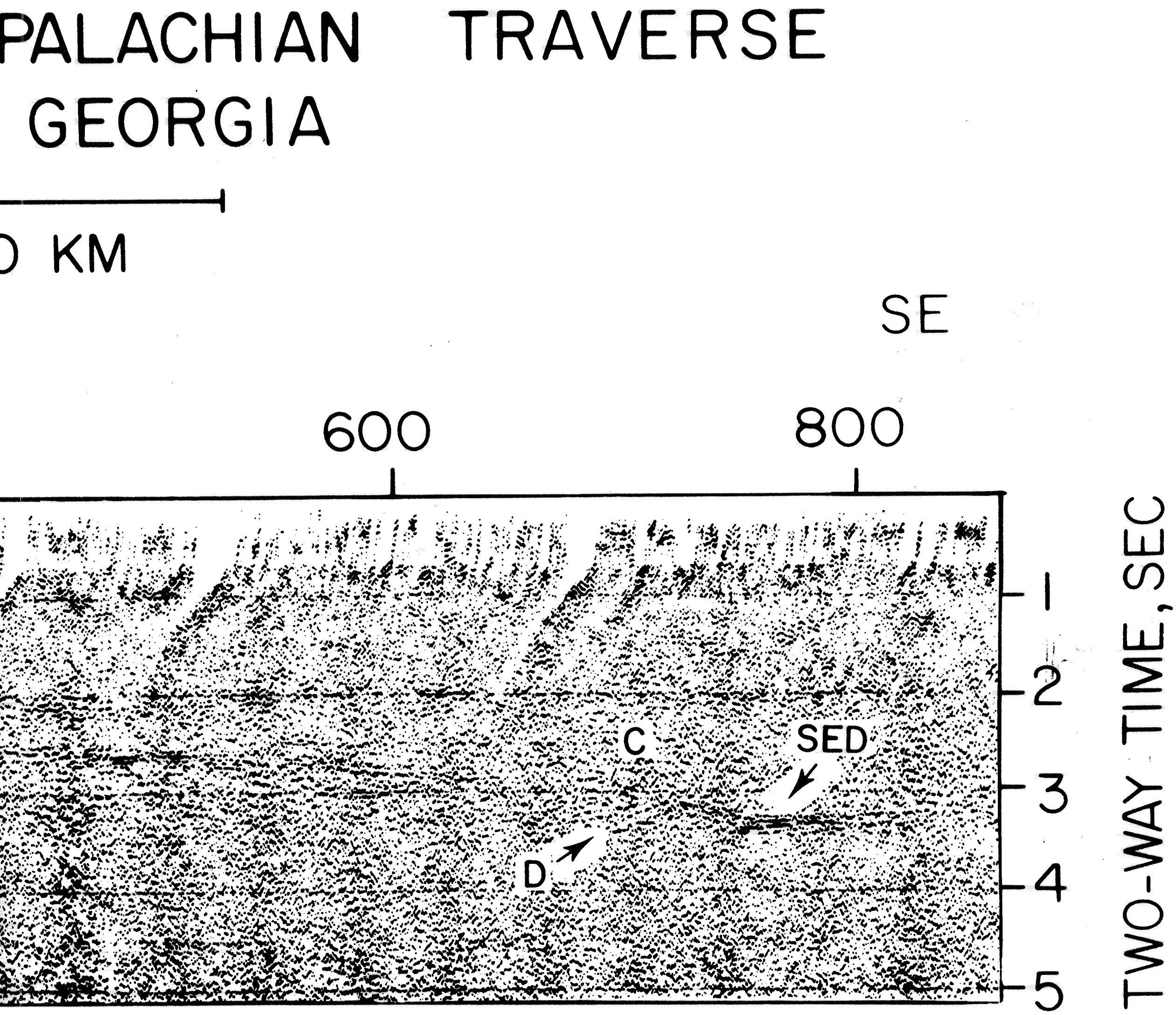
LINE 1 -



STACK VEL.
STA. 550

TIME	VEL($^M/_S$)
0.0	4572
0.1	4877
2.5	5791
2.8	6096
3.1	6400
5.0	7010

Fig. 2. Line 1 (Georgia) is perpendicular to the Brevard Zo
axis is in surface distance, denoted by vibrator point (VP) n
'SED' indicates the layered events which are interpreted a
stacking velocity functions for two locations: VP 550 and VP
by the letters, are discussed in the text.



STACK VEL.
STA. 780

TIME	VEL ($^M/s$)
0.0	4572
0.1	4877
2.7	5791
3.3	6400
3.4	6416
5.0	7010

Zone, extending from northwest to southeast. The horizontal
number. 'BF' marks the location of the Brevard fault, and
as Paleozoic sediments. At the bottom of the figure are
P 780. These and other features, such as the events denoted

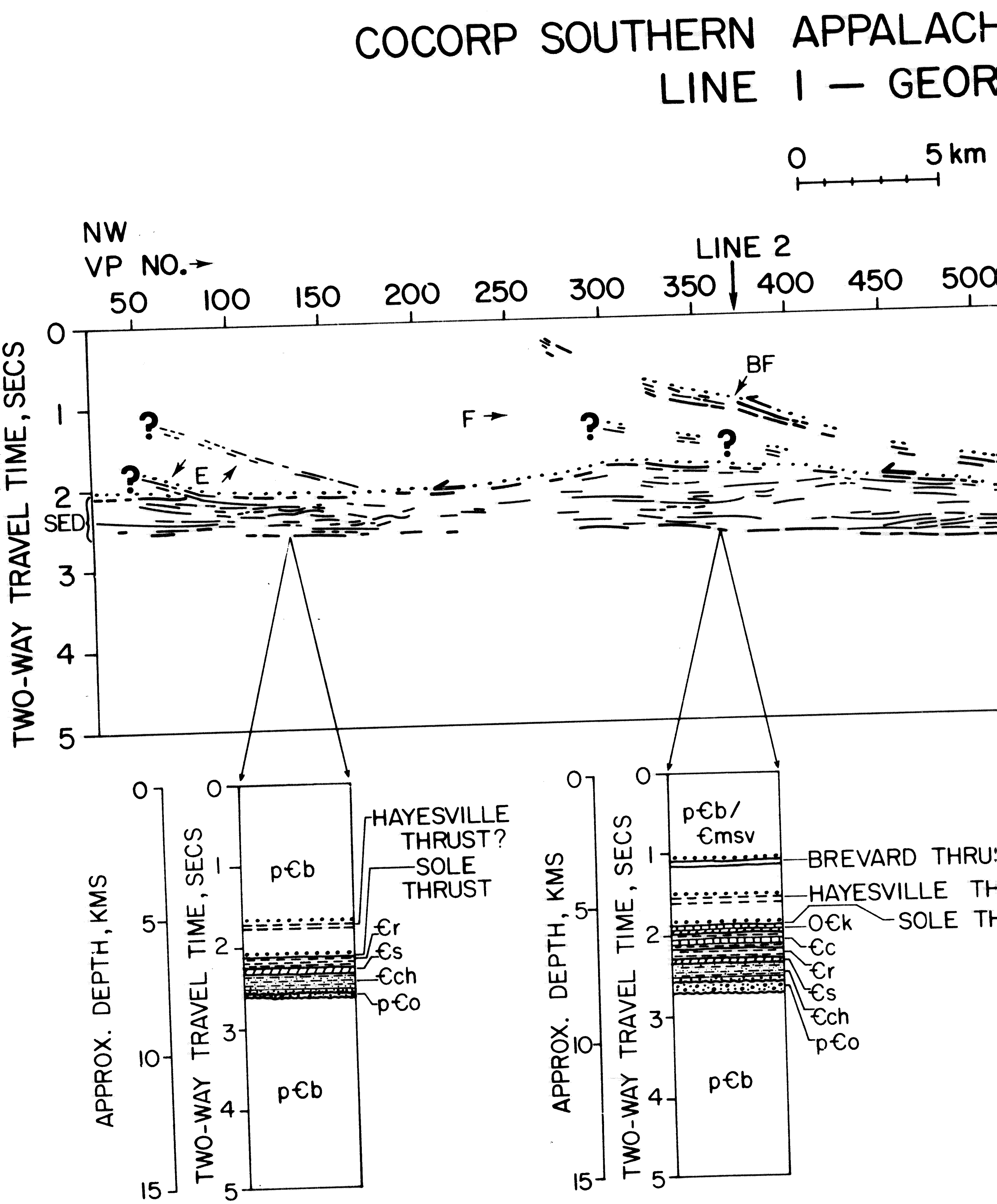
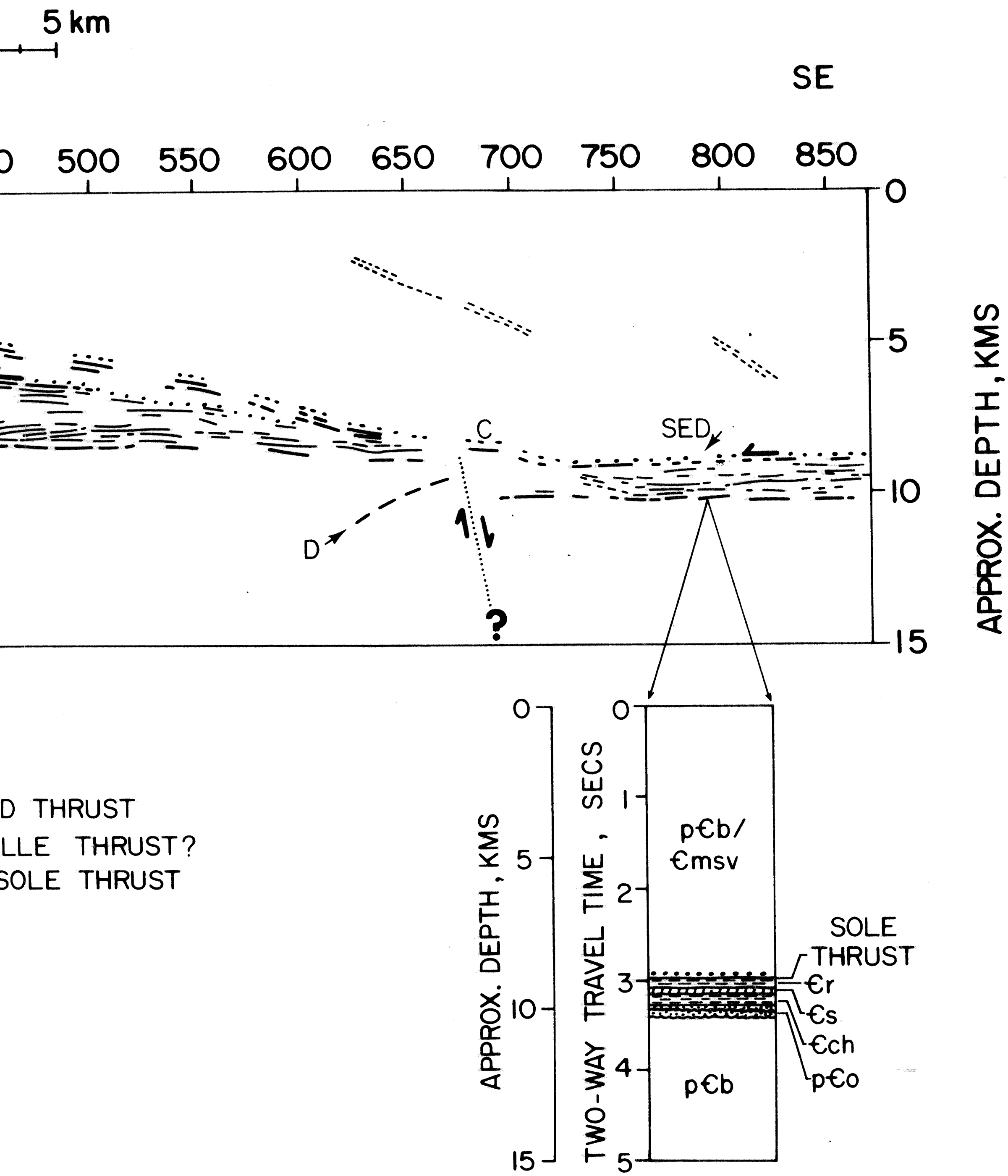


Fig. 3. Line drawing of events abstracted from the seismic data
illustrated to display the similarity between the seismic section
Ridge. The stratigraphic thicknesses are after Harris and Milici (18
symbols.

ALACHIAN TRAVERSE
GEORGIA



ic data (Line 1). Hypothetical stratigraphic columns are
section and the Paleozoic stratigraphy of the Valley and
ici (18). See Fig. 5 for an explanation of the formation

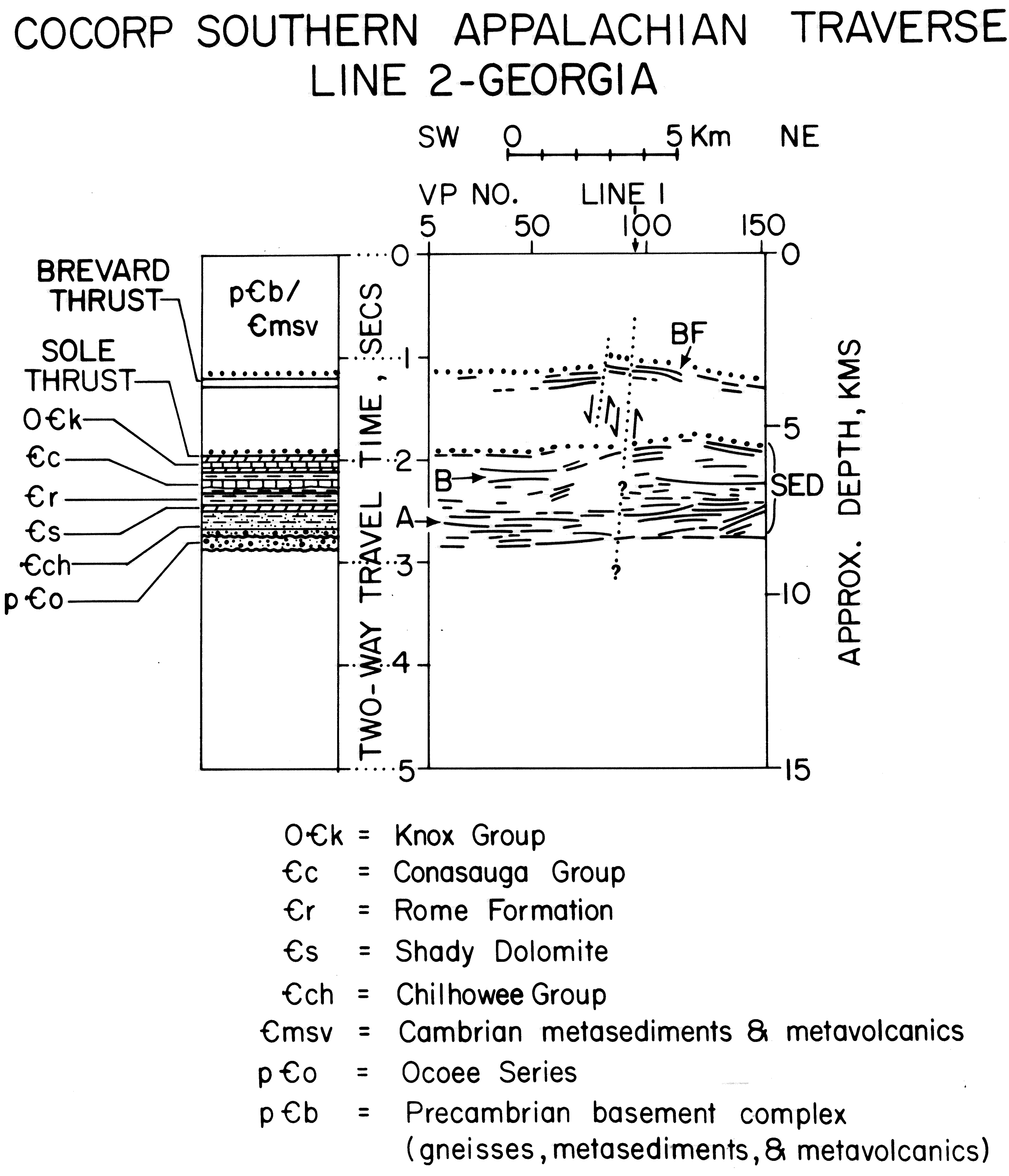


Fig. 5. Line drawing of seismic events abstracted from Line 2. A hypothetical stratigraphic section (with thicknesses after Harris and Milici (18)) is shown on the left side.

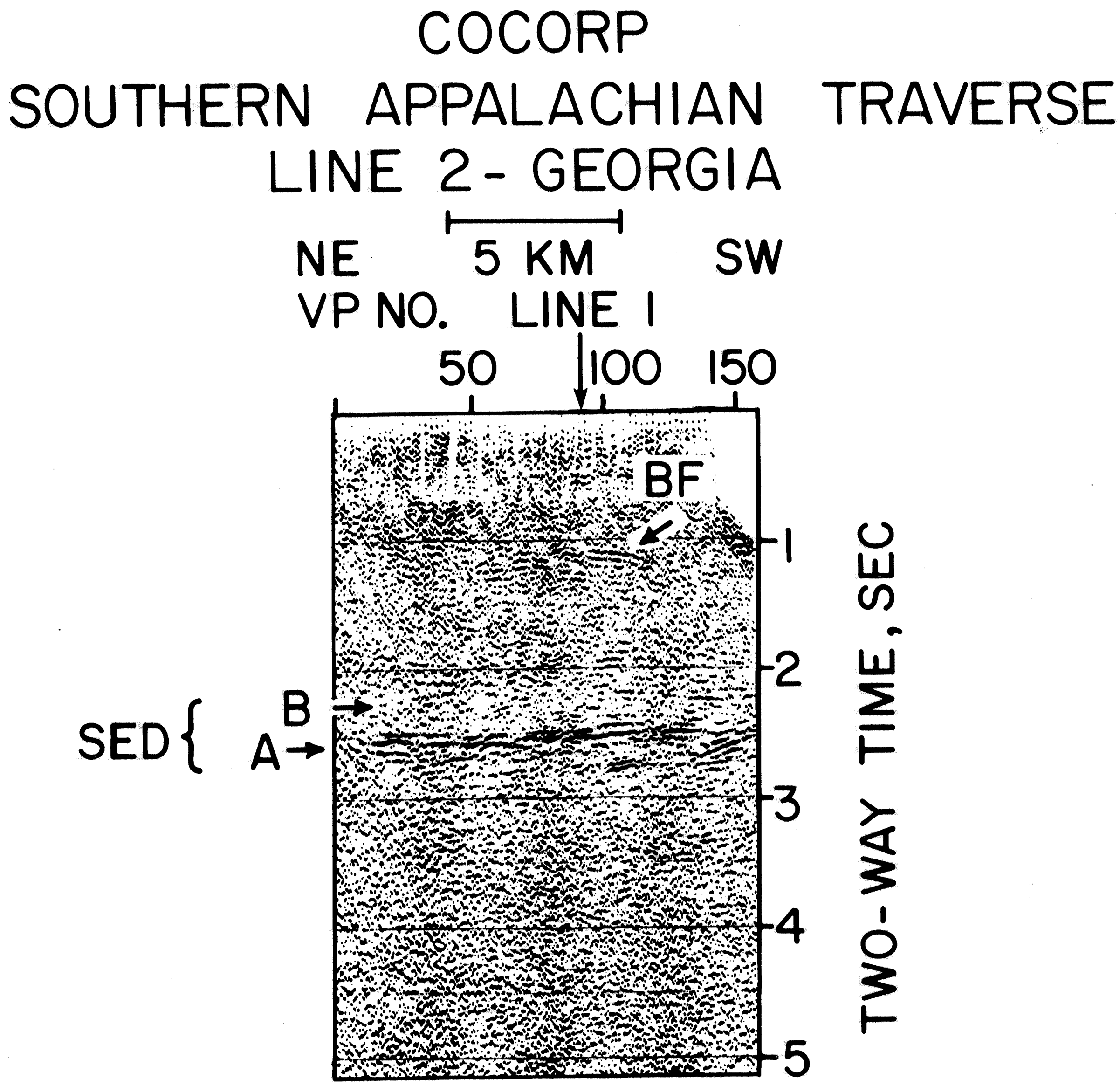


Fig. 4. COCORP Line 2 perpendicular to Line 1. 'BF' denotes the Brevard fault, and 'SED' denotes the layered sediments. 'A' and 'B' are discussed in the text.

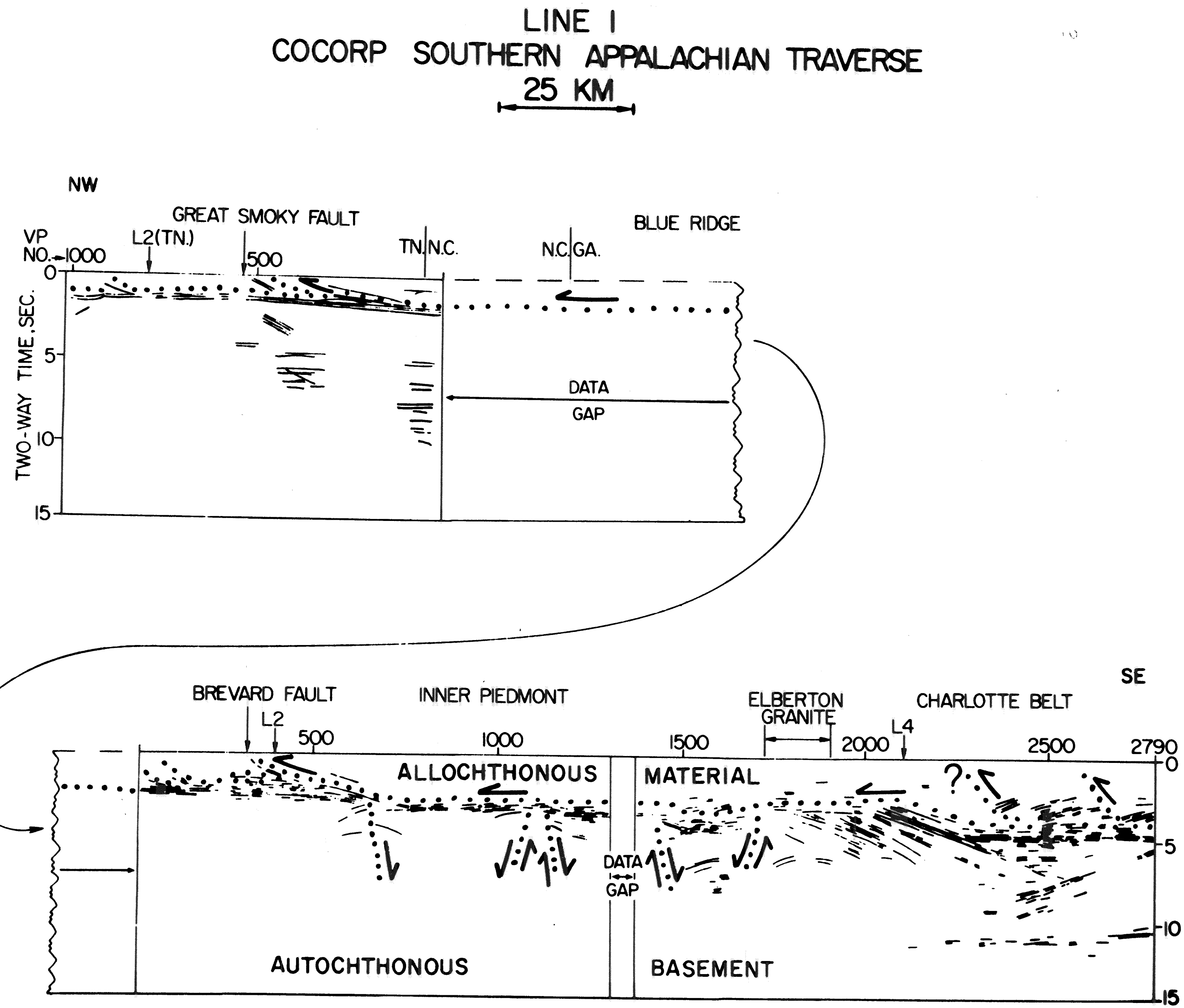


Fig. 7. Line drawing of seismic events abstracted from the entire northwest-southeast COCORP traverse across the southern Appalachians (from Cook et al (1)). The dotted lines indicate the locations of faults. Normal faults are interpreted to be present beneath the Inner Piedmont and suggest that this area marks the location of the Paleozoic continental shelf (1).

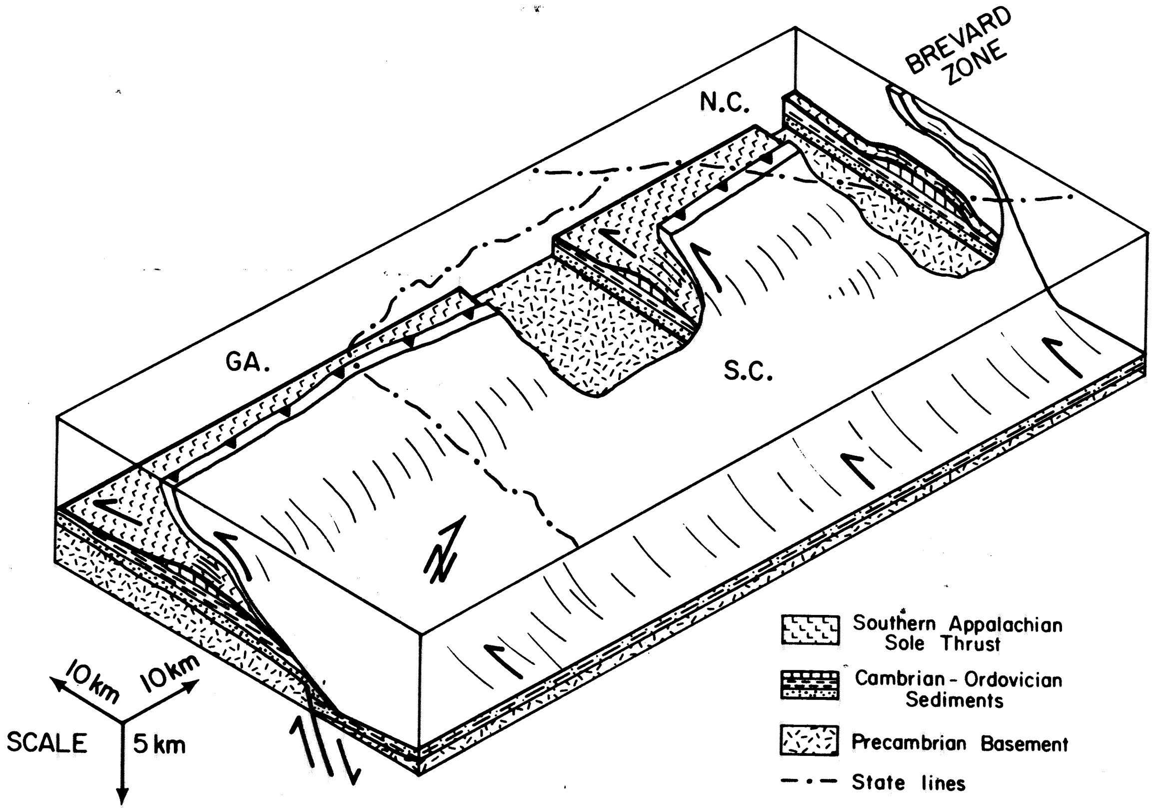


Fig. 6. Block diagram illustrating a three dimensional view of the Brevard fault and the underlying sediments. The lower edge of the block is drawn from the COCORP data and the cutaway near the upper edge is drawn from the interpretation of Clark et al (9). An intermediate cutaway is drawn to illustrate the similarity of the underlying sediments and the Brevard fault along strike.

allochthonous there (11). By analogy, layered sediments may also be present beneath the Blue Ridge in Georgia.

The seismic character and thickness of the 2.0-3.5 sec reflection events in Figs. 2 through 5 are similar to reflections from Cambrian-Ordovician sediments in the Valley and Ridge. For example, the high amplitude events at 2.2-2.4 sec on Line 1, stations 30-100 (Figs. 2 and 3, A) and on Line 2 (Figs. 4 and 5, A) have a thickness of about 0.6 km (for a velocity of 6.0 km/sec). Tegland (12, p. 49) shows similar events from the Cambrian section which has a thickness of 2000 ft (about 0.6 km). Tegland (12, p. 49) also indicates that the top of the Knox Group (Ordovician) is marked by a low amplitude reflection about 5000 ft (about .525 sec) above the base of the Rome formation (Cambrian). Line 2 (Figs. 4 and 5) has a similar event at about 2.2 sec (Figs. 4 and 5, B). This similarity in seismic character suggests the events from beneath the Brevard zone in Georgia are reflections from the Cambrian-Ordovician sequence. To illustrate the inferred correlation of the layered seismic events with the lower Paleozoic sequence, Figs. 3 and 5 include hypothetical stratigraphic columns at various locations.

Finally, the portion of the COCORP traverse in the Valley and Ridge of Tennessee exhibits layered events which are similar to the Cambrian-Ordovician sequence of Tegland (12) and identified from well data. These events appear to correlate with the layered events in Georgia, strongly suggesting the sediments extend beneath the Blue Ridge and Piedmont.

The Brevard Fault Reflection. Event 'BF' in Figs. 2 through 5 dips eastward with an average, unmigrated dip of about 16 - 18 degrees east and projects to the surface outcrop of the Brevard fault. This event is interpreted as a reflection from the fault zone. Line 2 (Figs. 4 and 5) crosses Line 1 at station 373 and indicates that the fault plane is a relatively planar feature.

Structural complexities caused by faulting or folding of the Brevard fault are visible on both Line 1 and Line 2. The dip section (Line 1) shows an apparent flexure in the fault plane near station 360, though such an appearance may also result from a pre-existing ramp within the Chauga belt. In contrast, the strike section (Line 2) appears to show offset by faulting. Although this is the first time faulting of the Brevard at depth has been inferred perpendicular to strike, the flexure interpretation of the Brevard fault zone on the dip section is similar to the interpretation presented for reflection data near Rosman, North Carolina (9). This similarity suggests the Brevard fault plane is folded along much of its length. Based on this information, Fig. 6 is a block diagram of the Brevard fault zone from northern Georgia to North Carolina. The southwestern edge of the block is based on the COCORP data, and the cutaway at the northeastern end of the block is based on the interpretation of Clark et al (9). Also shown is an intermediate section removed to illustrate the proposed similarity and continuity of the underlying sediments and the Brevard fault along strike.

The Brevard fault reflection projects at depth to an offset in the sedimentary layers near stations 600 to 700 on Line 1 (Figs. 2 and 3, C). The sedimentary reflections east of this offset arrive about 0.8 sec later in the time domain than those to the west. To account for such a configuration, either the sediments are deeper east of station 700, or the average velocity decreases laterally, thus causing the events east of station 700 to arrive later in time.

Stacking velocities (Fig. 2) calculated from these data suggest that about 0.1 sec of the offset may be accounted for by a lateral average velocity decrease to the east. Nearly 0.7 sec (about 2.1 km) must be accounted for by vertical offset in the depth domain. Furthermore, the presence of diffracted energy (Figs. 2 and 3, D) indicates that the offset results from faulting. The sense of offset (down to the southeast) implies this feature is a normal fault.

The observation that the Brevard fault event terminates at this offset implies that the normal fault and the development of the Brevard fault may be intimately related. If the normal fault existed prior to westward directed motion of the southern Appalachian thrust sheet, the fault may have acted as a tectonic buttress. Similar lithologies are present along much of the length of the Brevard zone and the northwest boundary of the Brevard zone is generally located within the fissile, incompetent phyllites of the Chauga belt (4). The faulting on the Brevard fault thus appears to be stratigraphically controlled by the weak layers in the Chauga belt and structurally controlled by the normal fault. As Hatcher (4) suggests, the abutment of the weak, low rank Chauga belt rocks against such an inflection could have provided "transference of movement on the Blue Ridge thrust into beds above the inflection zone in the pre-existing" Chauga belt synclinorium (4, p. 195). Minimum offsets on the Brevard fault are thus calculated to be 30 km heave and 8 km throw.

Another interpretation of the normal fault is that it post dates the thrusting along the main sole thrust and is thus related to the Triassic rifting episode. As there is no surface evidence for 2 km of normal faulting near the Brevard fault, and as it would be fortuitous for the Brevard fault and the normal fault to coincide at depth, the pre-thrusting model for the latter feature is preferred.

Similar normal faults are interpreted to be present in the sediments and basement underlying the Inner Piedmont (1). These faults indicate that the Paleozoic North American continental shelf was probably extensionally faulted in a manner similar to present Atlantic-type rifted margins (13). It thus appears that these shelf sediments were then overthrust by the southern

Appalachian thrust sheet during perhaps three stages of major deformation correlating with the Taconian (Ordovician), the Acadian (Devonian), and the Alleghanian (Mississippian-Permian) orogenies (14).

In Fig. 6, the basement normal fault (or a monoclinal flexure) is postulated to exist along the strike of the Brevard zone and probably structurally controlled the thrusting during the late Paleozoic deformation. It is thus likely that this major inflection extends over much of the length of the Brevard zone and, in conjunction with stratigraphic control imposed by the Chauga belt, was an important factor in determining its linearity and surface position.

Other Features of the Reflection Data. Several events which diverge upwards from the sediments are visible west of the Brevard fault (Figs. 2 and 3, E). Projection of these events to the surface off of the west end of Line 1 implies that one or more of them correlate with the Hayesville fault (14). Another event (Figs. 2 and 3, F) is visible which extends from the basement normal fault westward and also projects to the vicinity of the Hayesville fault. It is not clear at this time which, if any, of these is in fact a reflection from the Hayesville fault.

The COCORP traverse crosses the Alto allochthon as discussed by Hatcher (15) from stations 360 to 480 (Line 1, Figs. 2 and 3) but exhibits no obvious reflection events which might be attributed to it. As the field parameters are designed to enhance the deep crustal information, it is possible that the base of the allochthon is too shallow to be visible on these records. Alternatively, the reflective contrasts near the base of the allochthon may be too small to return sufficient observable energy.

Few events are visible at record times greater than 4.0 sec. In contrast, many deep crustal reflection profiles exhibit numerous events which have been interpreted to represent small scale complexity within the lower crust (16, 17). The paucity of deep crustal events on the southern Appalachian traverse near the Brevard zone also contrasts with numerous deep events on reflection data in the area of the Charlotte belt and Carolina slate belt (1). The homogeneous appearance of the reflection data at depth beneath the Brevard zone thus implies that either the lower crust in this area has few reflecting horizons, or the signal strength has been strongly attenuated near the surface.

The Brevard Zone and Southern Appalachian Thrusting. Fig. 7 is a line drawing of the major seismic events on the COCORP southern Appalachian traverse (from Cook et al (1)). The dotted lines are faults which are either seen as reflection events or are inferred from diffraction patterns and offsets in the sedimentary layering. The role of the Brevard fault as a splay of the southern Appalachian sole thrust is emphasized here, thus relating it to the tectonic evolution of the Paleozoic North American plate margin.

After late Precambrian rifting, a passive Atlantic-type margin developed on the eastern coast (as referenced to present coordinates) of the proto-North American continent. The Chauga belt sediments were likely deposited in an epicontinental sea which covered the proto-North American continental shelf and the submerged Piedmont microcontinent (14). The closure of an intervening basin resulted in the collision of the Piedmont microcontinent with the proto-North American continent and the initiation of thrusting over the North American shelf in the Ordovician (Taconian). Further tectonism and continent directed motion during the Devonian (Acadian) and later during the Mississippian (Alleghanian) resulted in the development of the southern Appalachian thrust sheet. During the Alleghanian, the impingement of the low rank schists and phyllites of the Chauga belt on to the normal fault (which appears to have substantially more displacement than other normal faults in the Inner Piedmont) caused it to act as a tectonic ramp and transmit motion along the sole thrust to the surface via Brevard faulting.

Discussion. The subsurface configuration of the Brevard fault as seen on COCORP seismic reflection data, in conjunction with previous seismic data and surface geologic mapping, demonstrate that the Brevard fault is a shallowly dipping thrust related to the southern Appalachian thrust system. Exotic sediments found within the Brevard zone provide important evidence that sediments are present beneath the Brevard zone and Inner Piedmont. The layered seismic character and thicknesses calculated on the basis of the two-way travel time as compared with Valley and Ridge seismic data support this conclusion.

The Brevard fault reflection extends at depth to an inflection in the underlying sediments. This inflection is interpreted as a pre-thrusting normal fault which developed during rifting in the late Precambrian. The data thus support the model of Hatcher (4) in which westward movement of the southern Appalachian thrust sheet during the Paleozoic brought the Chauga belt synclinorium in contact with this tectonc ramp. Continued westward motion caused a transfer of movement from the basal sole thrust into the Chauga belt and resulted in thrusting on the Brevard fault.

In the southern Appalachians it thus appears that the early Paleozoic shelf morphology, in particular normal faulting, was significant in controlling the development of a major structure (the Brevard zone) within the overthrust crystalline sheet. The implication of this finding for similar overthrust terrains such as the Himalayas or perhaps the western cordillera is that shelf morphology, structures and bathymetry all exert major constraints on the evolution of structures which develop in the overriding sheet.

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