AN INTERPRETATION OF SEISMIC CROSS SECTIONS IN THE VALLEY AND RIDGE OF EASTERN TENNESSEE

By

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INTRODUCTION

The Tennessee Division of Geology, under contract No. EY-76-C-05-5196 with the U.S. Department of Energy and with grants from the U.S. Geological Survey, initiated a project in July 1976 to study the stratigraphic sequence and structural framework within parts of the Valley and Ridge of eastern Tennessee. Basic data generated through this study will be used to assess the hydrocarbon potential of the area. Because the success of the project is dependent on the projection of mapped geologic formations into the subsurface, two seismic profiles spaced about 20 miles (32 km) apart were made roughly at right angles to the strike of the structural grain of the Valley and Ridge (fig. 1). Although the individual profiles do not traverse the entire Valley and Ridge, in combination they form a composite cross section across the Valley and Ridge from the Powell Valley anticline on the northwest to the Blue Ridge on the southeast.

The geophysical aspects of the program are discussed in a report by Tegland (1978). Basic geophysical data in the Tegland report are available from the Tennessee Division of Geology, the U.S. Department of Energy, Morgantown Energy Technology Center, and the U.S. Geological Survey. Both time and depth sections at scales of 1:24,000 or 1:48,000 may be obtained from the Tennessee Division of Geology. The purpose of this report is to provide a more detailed geologic interpretation of the geophysical data.

Depth sections were evaluated in this report because they permit the use of known stratigraphic thicknesses in making the interpretation. Tegland (1978) described in detail his attempts at time-depth conversions, but his conversions are hindered by a lack of velocity data from wells. Locally, inaccurate assumptions of velocity have apparently thinned the seismic cross sections, especially along segment K-1 (south) (fig. 2). Where stratigraphic thicknesses are in reasonable accord with the seismic depth sections, the profiles can be interpreted with some measure of confidence. However, in the eastern part of the Valley and Ridge (TC-2), seismic data are poor, and the interpretation is more equivocal. The reader must be aware that the interpretation presented herein is limited by the quality of the seismic data.

STRATIGRAPHY

Paleozoic rocks in eastern Tennessee can be divided into three major depositional sequences separated by regional unconformities (table 1 and fig. 2). These sequences include a Cambrian through Lower Ordovician unit, a Middle Ordovician through Silurian unit, and an Upper Devonian through Pennsylvanian unit. Formations below the Rome Formation (Lower Cambrian) on the eastern side of the Valley and Ridge are not evident on the seismic cross sections and are, therefore, not shown on the regional facies diagram (fig. 2).

In general, the earliest sequence of Paleozoic sedimentation in the southern Appalachian Valley and Ridge began with the deposition of the Rome Formation (Cambrian), together with the formations of Conasauga (Cambrian) and Knox (Cambrian and Ordovician) Groups. Rome sediments accumulated during the regional submergence of the North American craton. Clastic rocks of the Rome and the Conasauga grade upward and eastward into carbonate rocks and are ultimately capped by nearly 3000 feet (915 m) of carbonate strata of the Knox Group or its equivalents.

The Rome Formation (€r) consists of as much as 1600 feet (490 m) of shale, siltstone, sandstone, and limestone on the hanging walls of the Appalachian thrusts in the western part of the Valley and Ridge (Englund, 1964; Harris and Mixon, 1970; Mixon and Harris, 1971). The Rome is everywhere bottomed by a thrust fault in this area; therefore, the thickness of the formation exposed varies with the stratigraphic position of the thrust. In general, the thicker sections of the Rome (lower stratigraphic position of decollement) are to the west, and the thinner sections are to the east (Harris and Milici, 1977). The full thickness of the Rome is unknown from surface exposures, but the seismic cross sections indicate that it may be as much as 2000 feet (610 m).

The Conasauga Group (€c) changes facies markedly from northwest to southeast across the Valley and Ridge (table 1). In the northwest in the Pine Mountain thrust sheet, it is mostly a shale overlain by a thin carbonate unit, the Maynardville Formation. To the southeast, carbonate rocks gradually replace shale in the section, and, in the middle thrust belts, the Conasauga consists of six interbedded shale and carbonate units, including the Maynardville at the top. In the easternmost thrust sheet (Pulaski), the Conasauga is represented mainly by the Honaker Dolomite, which has the thin Nolichucky Shale in its upper part.

Thickness of the Conasauga ranges from 1500 feet (460 m) in the subsurface of the Pine Mountain thrust sheet to 1900 feet (580 m) in the Hunter Valley, Clinchport, and Copper Creek thrust sheets, to 2000-2700 feet (610-820 m) in the Pulaski thrust sheet. Because the Maynardville Formation at the top of the Conasauga is entirely carbonate rock, it cannot be distinguished in seismic sections from the overlying carbonate rocks of the Knox Group. Therefore, thickness given for the Knox Group includes the Maynardville (O€km).

The Knox Group is dominantly siliceous, cherty dolomite in the western half of the Valley and Ridge. However, the proportion of limestone to dolomite gradually increases eastward, and, in the Pulaski thrust sheet, limestone makes up about 80 percent of the total section (Harris, 1973). The combined thickness of the Knox Group and Maynardville Formation (O€km on cross sections) ranges from 2500 to 2700 feet (760 to 820 m) in the Pine Mountain block to 2700 to 3100 feet (820 to 950 m) in the Saltville thrust block. The Knox apparently thins a short distance eastward to slightly less than 2700 feet (820 m) thick in the Mosheim anticline (TC-2), where the oldest beds exposed are the upper hundred feet of the Maynardville (Brokaw and others, 1966). On the hanging wall of the Pulaski thrust, the Knox and Maynardville are represented by limestone about 3300 feet (1000 m) thick (Byerly, 1969; French, 1966). Total thickness of the carbonate rocks of the Conasauga and Knox Groups in the Pulaski thrust block is about 6000 feet (1830 m), including about 200 feet (60 m) of Nolichucky Shale between them. In Tennessee, the top of the Knox Group is almost everywhere delineated by a regional unconformity on which local relief ranges generally from a few feet to a few tens of feet, although in places it may be much greater.

The second depositional sequence began in Middle Ordovician time upon submergence of the post-Knox Group unconformity. A deep basin lay to the east in what is now the Saltville and Pulaski thrust sheets. It was bordered on the west by a slowly subsiding but relatively stable carbonate shelf. Thickness of limestone in the carbonate shelf ranges from 1850-2050 feet (560-625 m) in the Pine Mountain thrust sheets to 2250 feet (690 m) in the Copper Creek thrust sheet. East of the Saltville fault, the Middle Ordovician sequence thickens and is replaced by shale and siltstone (Sevier Shale, Osv), sandstone (Bays Formation, Ob) and shale (part of the Martinsburg Shale, Omb). Surface estimates of the thickness of the eastern clastic facies of the Middle Ordovician in this area range from 1000 to 2500 feet (300 to 760 m) for the Sevier, from 600 to 870 feet (180 to 265 m) for the Bays, and about 400 feet (120 m) for the erosional remnant of the Martinsburg (Cummings, 1962; Byerly, 1969). However, a drill hole in the Sevier southeast of Knoxville suggests that in places the Sevier may be more than 4000 feet (1200 m) thick.

The lower Paleozoic carbonate shelf began to subside toward the end of the Middle Ordovician, and Middle Ordovician through Silurian clastic rocks prograded westward across the Valley and Ridge. The Silurian rocks deposited in the culmination of this sedimentary sequence change from shallow-water Clinch Sandstone (Sc, 300-550 feet, 90-165 m) in the east to shale and siltstone of the Rockwood Formation (Sr, 500 feet, 155 m) and carbonate rocks of the Hancock Dolomite (included in Sr or Scc, about 115 feet, 35 m) in the west. The second sequence was terminated by uplift and by development of an erosion surface prior to the deposition of the Chattanooga Shale (MDc).

The final sequence of Paleozoic sedimentation began with regional submergence and deposition of the Chattanooga Shale (Devonian and Mississippian). A carbonate platform was reestablished west of the Valley and Ridge during Early Mississippian time, as clastic rocks of the Grainger Formation (Mg, Mississippian) were deposited to the east. After deposition of the Grainger, Mississippian carbonate rocks spread eastward into the northern Tennessee Valley and Ridge, where they are collectively known as the Newman Limestone (Mn). Deposition of Mississippian carbonate rocks terminated when clastic rocks from an eastern source prograded generally westward over the carbonate rocks. Because these clastic rocks are of limited areal extent in the Tennessee Valley and Ridge, they are not shown on figure 2.

The Chattanooga Shale, which is both a potential source and a potential reservoir for hydrocarbons, ranges in thickness from 200 to 400 feet (60 to 120 m) on the Pine Mountain and Wallen Valley thrust blocks and from 400 to 1800 or more feet (120 to 550 m) from southwest to northeast along Clinch Mountain (Swingle and others, 1967; Dennison and Boucot, 1974).

Strata younger than the Chattanooga Shale do not appear on the cross sections in the western part of the seismic lines. However, east of Clinch Mountain the Grainger Formation and Newman Limestone are in the footwall of the Saltville thrust (fig. 1).

The Grainger Formation ranges in thickness from about 300 to 770 feet (90 to 240 m) in the study area, thickening generally northeastward into the geosyncline. The formation consists primarily of shale and siltstone, but contains two sandstone members that range in thickness from 50 to 200 feet (15 to 60 m) (Sanders, 1952).

The youngest formation exposed along a line of traverse is the Newman Limestone (fig. 1, TC-2), which is crossed in the core of the Greendale syncline southeast of Clinch Mountain. The Newman is 2100 to 3000 feet (640 to 900 m) thick and consists mostly of shaly and silty limestone and small amounts of shale, siltstone, and sandstone (Sanders, 1952). Like the Chattanooga and the Grainger, the Newman thins markedly to the west, to about 800 feet (240 m) on Newman Ridge and about 700 feet (210 m) on the Pine Mountain block.

SEISMIC STRATIGRAPHY

Stratigraphic sequences are grouped into seismic units, which have similar signature characteristics (table 1, fig. 3). In the seismic profiles, the contact between Paleozoic strata and older basement appears to be defined by a conspicuous subhorizontal basal reflector, below which basement rocks show little, if any, organized pattern. The basal reflector extends northwestward along K-1, the proprietary line of Geophysical Service, Inc., into a region where the depth to basement is known from well control.

Seismic-stratigraphic units above the basement include the Rome Formation, the Conasauga Group, the Maynardville Formation and the Knox Group, the Middle Ordovician limestone sequence (Ols), the Martinsburg Shale and Sequatchie Formation (Ombs), and the Sevier Shale (including the overlying Bays Formation and Martinsburg Shale).

Silurian, Devonian, and Mississippian formations generally lie too near the surface to show recognizable seismic patterns. Consequently, these formations are projected into the subsurface on the assumption that they maintain uniform thicknesses.

Strong reflectors near the base of the Paleozoic section apparently represent velocity contrasts between beds of sandstone, shale, and carbonate rocks in the Rome Formation and the Conasauga Group. Facies changes in the Conasauga Group, from shale on the west to interbedded shale and carbonate rock to the east, show clearly on seismic section K-1 (south) - TC-1. Conasauga Shale beneath the Powell Valley anticline has a characteristic, fine pattern. To the east in each succeeding thrust sheet, strong and nearly continuous reflectors intervene within the shale pattern, marking the increase of limestone beds eastward within the Conasauga (fig. 4, TC-1, CDP 400-800, fig. 4, TC-2, CDP 700-800). The Rome and the Conasauga (€rc) are combined in the eastern part of line TC-2, where the seismic record is poor. The Knox Group, including carbonate rocks of the Maynardville Formation at its base, generally shows an open pattern with a locally developed basal reflector. Reflectors within the Knox are stronger to the west than to the east and may represent velocity contrasts between interbedded relatively pure and impure dolomite (fig. 3).

Facies changes within Middle Ordovician strata, from the carbonate platform on the west (Powell Valley anticline to the Copper Creek thrust sheet) to the deep-basin shale sequence on the east (Saltville thrust sheet), are discernible in both seismic profiles (figs. 4, 5). Middle Ordovician limestone shows little internal pattern on the west (fig. 4, TC-1, depth points 101-450), but, near the edge of the carbonate platform in the Copper Creek thrust sheet (fig. 4, TC-1, depth points 900-990), strong reflectors mark the top and bottom of the unit. This change in seismic signature records the appearance of a shale wedge in the middle part of the carbonate sequence. East of the Copper Creek thrust sheet on the Saltville and Pulaski sheets (fig. 5, TC-2), the equivalent Middle Ordovician shale shows a fine texture with few internal reflectors.

STRUCTURE

The seismic cross sections (figs. 4, 5) clearly illustrate the thin-skinned nature of southern Appalachian structure, where east-dipping thrust faults rise from lower level décollements in the Cambrian strata. The faults cut diagonally across the Paleozoic carbonate rocks to form ramps and flatten as upper level, nearly horizontal thrust sheets in the bedding of Middle Ordovician to Missisippian shales. This basic structural pattern was described in detail by Harris and Milici (1977).

The contact of Paleozoic strata with the Precambrian(?) crystalline basement dips gently eastward at a rate of less than 2° per mile (1.6 km). Consequently, in a distance of 60 miles (96 km) from the Appalachian Plateau eastward to the Blue Ridge, the depth to the top of the basement increases from 13,000 feet (4000 m) to 23,000 feet (7000 m) below sea level. Locally, the basement appears to have a relief of as much as 2000 feet (610 m), but most of this relief is spurious and is attributed to velocity pull-ups that formed below areas where high-velocity carbonate rocks were duplicated by thrusting. For example, apparent basement relief of about 1000 feet (305m) in the areas east of the Mosheim anticline (TC-2, CDP 1850-2240) and east of the Bays Mountain synclinorium (TC-2, CDP 1500-1630) is very likely the result of erroneous velocity estimations caused by structural duplication of the overlying Cambrian and Ordovician carbonate sequence. Similarly, much of the relief and the west-dipping basement near the western end of TC-2 (fig. 5) probably results from a combination of basement push-down beneath the zone of imbricate thrusting (fig. 5, TC-2, CDP 101-260), where the Cambrian shale and sandstone sequence is inclined and duplicated, and pull-up to the east (fig. 5, TC-2, CDP 260-440), where Cambrian and Ordovician carbonate rocks are also inclined and duplicated by faulting.

The seismic cross sections transect three structural provinces of the southern Appalachians, the Foreland Thrust, Imbricate Thrust, and the Eastern Low Angle Thrust provinces (Milici, in press). The Foreland Thrust structural province is represented by the Powell Valley anticline (fig. 4). The general form of the structure, which resulted from the Pine Mountain fault cutting acutely upward from décollement in Cambrian shale along a ramp of Paleozoic carbonate rocks and then refracting into bedding of overlying Silurian and Devonian shales, is illustrated by the seismic cross section. In detail, the structure is much more complicated because the Pine Mountain fault formed at different stratigraphic levels along, as well as across, strike (Harris and Milici, 1977, p. 31-35).

The Imbricate Thrust structural province consists of closely spaced tectonic ramps and inclined décollements, including the Wallen Valley, Hunter Valley, Clinchport, and Copper Creek thrusts. In general, these faults rise from the basal décollement, cut across the massive carbonate unit of the Knox and the Maynardville, and then flatten into bedding of the overlying Middle Ordovician limestone. Hanging-wall strata above the Knox on the Wallen Valley thrust sheet closely resemble those on the Pine Mountain block, but differ both in thickness and in facies from strata on the thrust sheets to the east. These data suggest that a greater amount of shortening and telescoping of formations has taken place along the Copper Creek and Clinchport faults than along the Wallen Valley fault.

The Eastern Low Angle Thrust province is characterized by thrust sheets that ride westward over footwalls dominated by shale. In outcrop from the south end of Clinch Mountain northeastward into Virginia, the Saltville thrust plate lies on a footwall composed of Mississippian formations. Southwest of Clinch Mountain, the Saltville thrust cuts downward from Mississippian into Ordovician footwall beds. This marked change in the stratigraphic position of the footwall suggests that a cross fault may be buried beneath the Saltville thrust block from near the south end of Clinch Mountain southeastward toward the nose of the Cherokee Lake anticline (fig. 1).

In cross section, along TC-1 (fig. 4), the Saltville fault appears to transect a gently undulating footwall of Silurian to Mississippian clastic rocks as it dips to the southeast. Similarly, the Saltville fault dips gradually eastward along TC-2 (fig. 5), truncating footwall folds along its length from its outcrop to beneath the Bays Mountain synclinorium.

The Pulaski fault appears to ride westward on Ordovician shale in a complexly deformed footwall on the eastern side of TC-2 (fig. 5). The poor quality of the seismic record makes any interpretation in this area tenuous. However, because seismic line TC-2 extends about 4 miles beyond the Valley and Ridge into the Blue Ridge, it clearly illustrates the structural relation of the metamorphic rocks of the Blue Ridge to the sedimentay rocks of the Valley and Ridge and to the Precambrian basement complex. Paleozoic strata, probably ranging in age from Early Cambrian to Middle Ordovician, have an aggregate thickness of about 20,000 feet (6100 m) and appear to project eastward beneath a Blue Ridge thrust sheet 3000 to 4000 feet (900 to 1200 m) thick.

Minimum shortening measured along the lines of section are: Pine Mountain fault - 12 miles (19.3 km); Wallen Valley fault - 6 miles (9.6 km); Hunter Valley-Clinchport faults - 11 miles (17.7 km); Copper Creek fault - 15 miles (24.2 km); and Saltville fault - 22 miles (35.4 km), for a total of 66 miles (106.3 km). In addition, the Pulaski fault has a minimum of 12 miles (19.3 km) of thrusting in Tennessee.

OIL AND GAS POTENTIAL

The thermal maturity of Paleozoic strata in eastern Tennessee has been determined by color changes in conodonts (Epstein and others, 1977; Harris and Milici, 1977). These irreversible color changes are related to an increase in temperature produced mainly by an increase in depth and duration of burial. Five distinct conodont color alteration indices (CAI) have been recognized. In general, potential commercial oil is limited to areas that have a CAI of 2 or less, whereas potential commercial gas is limited to areas that have a CAI index less than 4.5.

The conodont alteration indices plotted on surface maps in this study area (Harris and Milici, 1977, pl. 1; Epstein and others, 1977, figs. 15, 17) suggest that Ordovician strata are a potential source for natural gas production across the region of study to, and possibly beneath, the Blue Ridge (fig. 5). Oil production would be restricted to the western part of the area in the subsurface projection of the Appalachian Plateau rocks beneath the Powell Valley anticline and Wallen Valley thrust sheet. Mississippian age strata appear to be a potential source for production of both oil and gas wherever they occur beneath the southern Appalachian thrust sheets in Tennessee.

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Figure 1. Geologic map of northeastern Tennessee, showing location of seismic lines K-1 (south), TC-1 and TC-2 (see Hardeman and others, 1966, for detailed explanation).

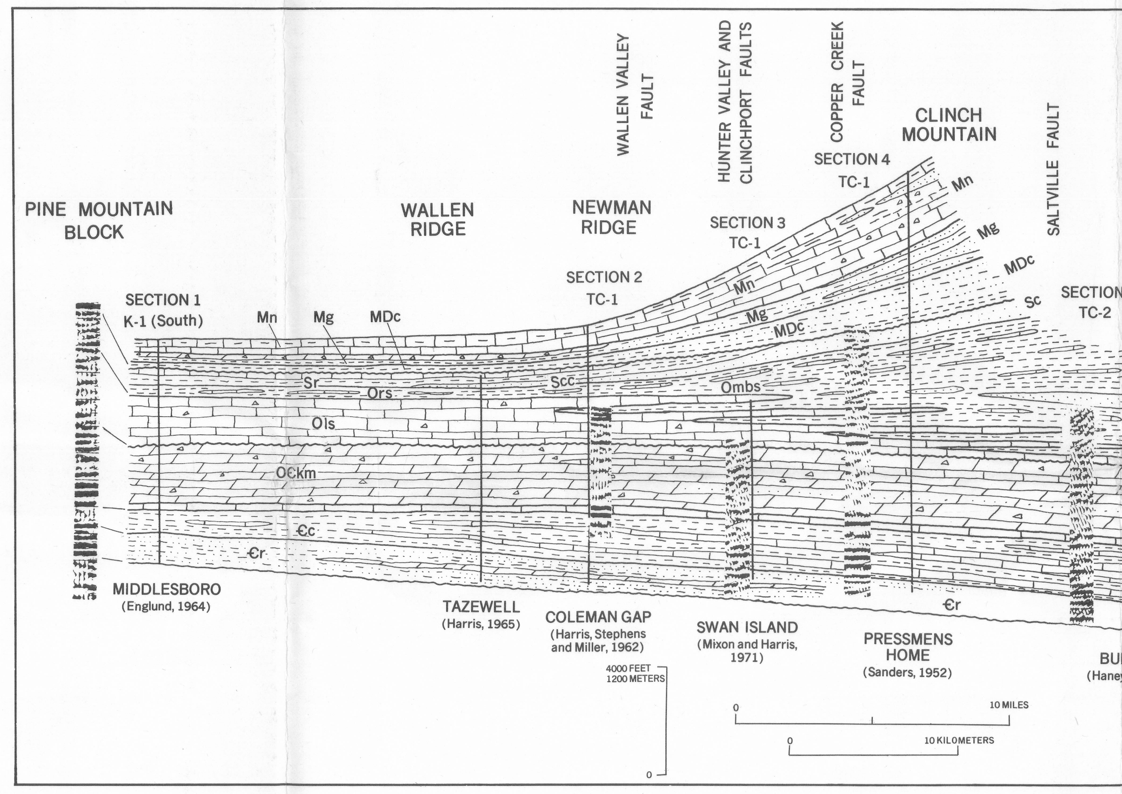

Figure 2. Generalized stratigraphic diagram across the Valley and Ridge of northeastern Tennessee. €r - Rome Formation; €c - Conasauga Group, less the Maynardville Formation; O€km - Maynardville Formation and Knox Group; Ols - Middle Ordovician limestones; Ors - Reedsville and Sequatchie Formations; Osv - Sevier Shale; Ob - Bays Formation; Omb - Martinsburg Formation; Ombs - Martinsburg and Sequatchie Formations; Sr - Rockwood Formation; Scc - Clinch and Clinton Formations; Sc - Clinch Sandstone; MDc - Chattanooga Shale- Mg - Grainger Formation; Mn - Newman Limestone. See figures 4 and 5 for locations of seismic columnar sections.

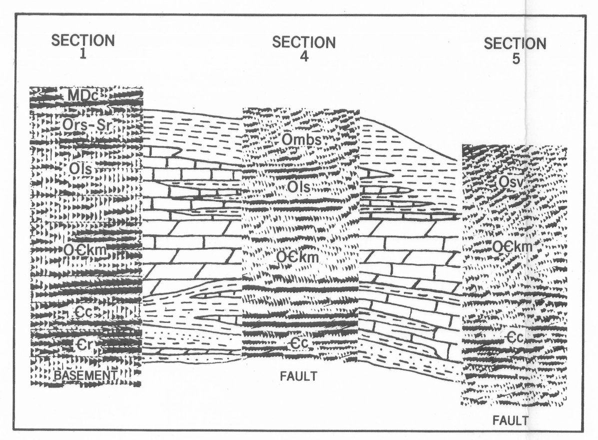

Figure 3. Relationship of seismic signatures to regional facies. See figures 4 and 5 for locations of seismic columnar sections.

SYSTEM	SERIES	DEPOSITIONAL SEQUENCE	FORELAND THRUST PROVINCE	SYMBOL	THICKNESS FEET (METERS)	IMBRICATE THRUST PROVINCE	SYMBOL	THICKNESS FEET (METERS)	EASTERN LOW ANGLE THRUST PROVINCE	SYMBOL	THICKNESS FEET (METERS)
MISSISSIPPIAN	Upper Mississippian	III				Newman Limestone	Mn	700-3000 (210-900)			
MISSISSIPPIAN	Lower Mississippian	III				Grainger Formation	Mg	300-770 (92-240)			
DEVONIAN	Upper Devonian and Lower Mississippian	III	Chattanooga Shale	MDc	200 (60)	Chattanooga Shale	MDc	400-1800 (120-550)			
			Unconformity			Unconformity					
SILURIAN	Lower, Middle and Upper Silurian	II	Hancock Dolomite	Sr	550 (165)	Hancock Dolomite; Clinton Formation	Sc	400 (120)			
SILURIAN	Lower, Middle and Upper Silurian	II	Rockwood Formation	Sr	550 (165)	Clinch Sandstone; Clinch Sandstone	Sc	260-550 (79-165)			
ORDOVICIAN	Upper Ordovician	II	Sequatchie Formation	Ors	260-300 (79-92)	Sequatchie Formation	Ombs	290-375 (90-115)			
ORDOVICIAN	Upper Ordovician	II	Reedsville Shale	Ors	275-375 (84-115)	Martinsburg Shale	Ombs	1600 (490)			
ORDOVICIAN	Middle Ordovician	II	Middle Ordovician Limestone Sequence	Ols	1850-2050 (560-630)	Middle Ordovician Limestone Sequence	Ols	2250 (690)	Martinsburg Shale	Omb	400 (120)
ORDOVICIAN	Middle Ordovician	II							Bays Formation	Ob	600-870 (180-270)
ORDOVICIAN	Middle Ordovician	II							Sevier Shale	Osv	1000-2500 (300-760)
			Unconformity			Unconformity			Unconformity		
ORDOVICIAN	Lower Ordovician	I	Knox Group	O€km	2500-2700 (770-820)	Knox Group	O€km	2700-3100 (830-950)	Jonesboro Limestone	O€km	3300 (1000)
CAMBRIAN	Upper Cambrian	I	Knox Group	O€km	2500-2700 (770-820)	Knox Group	O€km	2700-3100 (830-950)	Conococheague Limestone	O€km	3300 (1000)
CAMBRIAN	Upper Cambrian	I	Maynardville Formation	O€km	2500-2700 (770-820)	Maynardville Formation	O€km	2700-3100 (830-950)	Maynardville Formation	O€km	3300 (1000)
CAMBRIAN	Upper Cambrian	I	Conasauga Shale	€c	1500 (450)	Conasauga Group: Nolichucky Shale	€c	1900-2300 (580-710)	Nolichucky Shale	€rc	4000-5000 (1200-1550)
CAMBRIAN	Middle Cambrian	I	Conasauga Shale	€c	1500 (450)	Conasauga Group: Maryville Limestone; Rogersville Shale; Rutledge Limestone; Pumpkin Valley Shale	€c	1900-2300 (580-710)	Honaker Dolomite	€rc	4000-5000 (1200-1550)
CAMBRIAN	Lower Cambrian	I	Rome Formation	€r	2000 (610)	Rome Formation	€r	2000 (610)	Rome Formation	€rc	4000-5000 (1200-1550)
CAMBRIAN	Lower Cambrian	I							Shady Dolomite	€s	
CAMBRIAN	Lower Cambrian	I							Chilhowee Group	€ch	
			Unconformity			Unconformity			Unconformity		
PRECAMBRIAN									Ocoee Group	p€o	
									Unconformity		
PRECAMBRIAN			Basement			Basement			Basement		

Table 1. Seismic-stratigraphic units in northeastern Tennessee.