East Tennessee Geological Society

Blue Ridge Foothills Field Trip

December 3, 2022

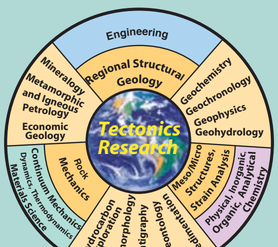
Prof. Bob Hatcher

Tectonics and Structural Geology Research
University of Tennessee–Knoxville

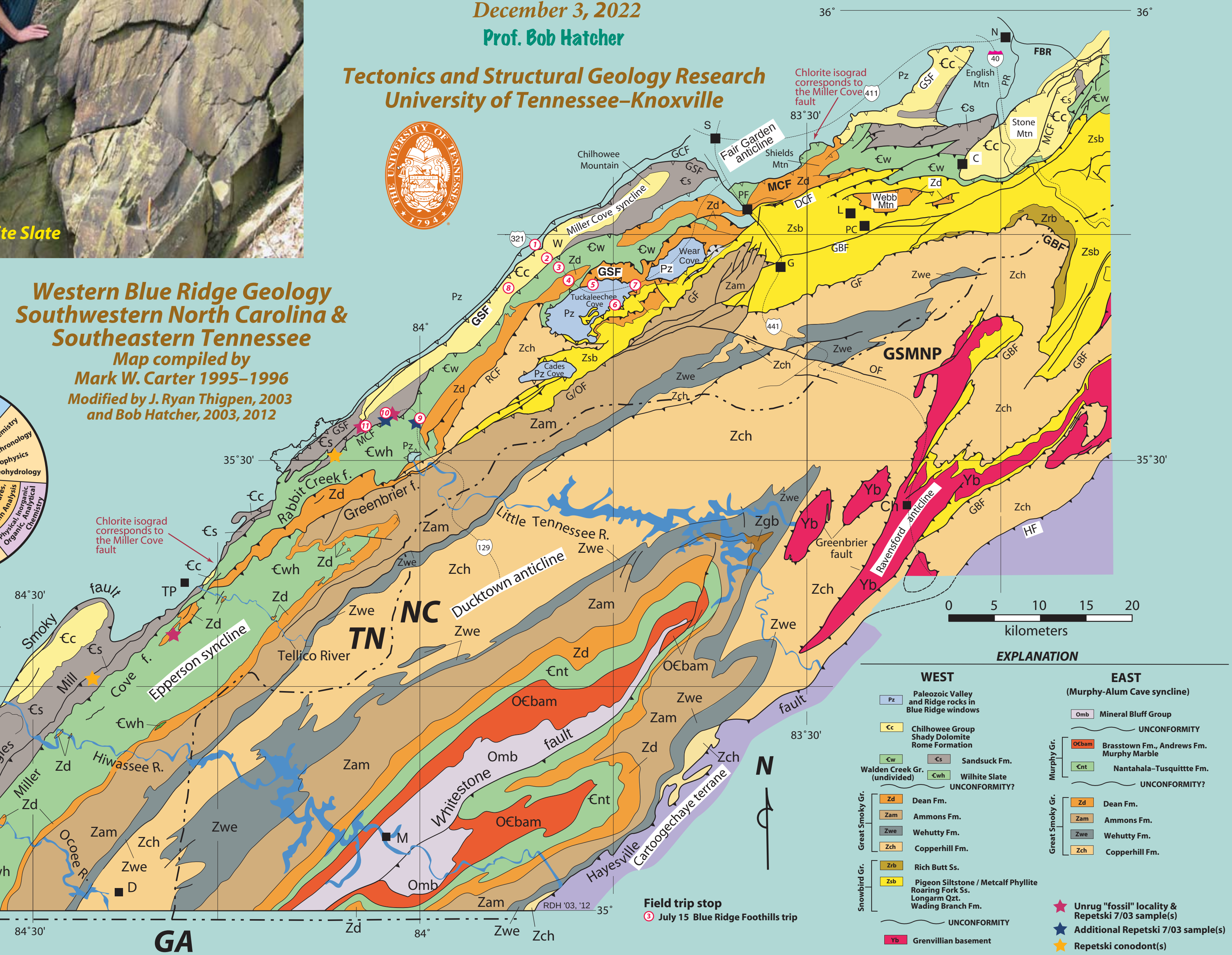
Western Blue Ridge Geology Southwestern North Carolina & Southeastern Tennessee

Map compiled by Mark W. Carter 1995–1996

Modified by J. Ryan Thigpen, 2003 and Bob Hatcher, 2003, 2012



Science Alliance
Center of Excellence



Map compiled (and modified) from:

M. P. Ausburn et al. (1998) Topton quad., NC Geol Survey
King et al. USGS Professional Paper 349
D. W. Mohr (1975) Noland Creek quad., NC Geol Survey
Univ. of South Carolina unpublished Ph. D. dissertation
J. O. Costello (1993)
Univ. of Tennessee unpublished M.S. theses:
M. W. Carter (1994)
D. J. Geddes (1995)
S. L. Martin (1997)
H. E. Phillips (1952)
R. J. Rackley (1951)
L. S. Wiener, unpublished map
L. S. Wiener and C. E. Merschat (1992) SW NC, SE TN, & N GA Geologic Map, NC Geol Survey

Additional explanation inside front cover.

Faults

GBF—Greenbrier
G/OF—Greenbrier/Oconaluftee
OF—Oconaluftee
MCF—Miller Cove
GF—Gatlinburg
DCF—Dunn Creek
GCF—Guess Creek
GSF—Great Smoky
RCF—Rabbit Creek
WF—Whitestone
HF—Hayesville

Towns

Tennessee

D—Ducktown
TP—Tellico Plains
W—Walland
G—Gatlinburg
PF—Pigeon Forge
S—Sevierville
S—Sevierville
PC—Pittman Center
L—Laurel
C—Cosby
N—Newport

North Carolina

M—Murphy
Ch—Cherokee

PREAMBLE

This field trip guide is one that I have used for undergraduate structural geology, graduate structural geology, Appalachian structure, and graduate tectonics field trips, as well as slightly in modified form for field trips for non-geologists and Earth science teachers. It was used most recently for a group of University of Tennessee graduate students in a tectonics class in spring 2022, and has been revised again for this trip.

The guide contains an introductory section that provides some fundamental background followed by a section containing the discussion of each field trip stop. You will see that I try to bring out particular points at each stop and also to bring in concepts as well. It also will be clear that, while I am primarily a structural geologist, I consider it essential to bring out aspects from any subdiscipline of geology on any scale that may be present in the rocks or the scenery at any of the field trip stops. This reflects my basic approach to teaching both in the field and to a degree in the classroom, as well as my approach to research. The primary goal in interacting with students at any level is to increase their ability to think critically.

There are boxes scattered throughout the guide containing notes about aspects of learning that I try to bring out at some of the stops that may not be obvious from the stop descriptions.

INTRODUCTION

The purpose of this trip is to observe structures in the field that we have discussed in class, along with some of the concepts and ideas that we have discussed in class this term. We will be looking at the transition from the external parts of the Appalachians into the internal parts. Similar—but not identical—transitions exist in most other mountain chains in the world regardless of whether or not they are the products of continent-continent collision, like the Urals, Alps, and Himalayas, or if they are part of the Cordilleran chain that extends from Alaska to southern Chile.

For us to accomplish these goals, we will be looking at rocks and structures ranging from an exposure in the Valley and Ridge to exposures in the westernmost parts of the western Blue Ridge. The rocks here range from Ordovician shales and limestones of the Appalachian Valley and Ridge to Neoproterozoic to Cambrian sandstone, shale, and other rock types in the western Blue Ridge that have a totally different appearance and history from the Valley and Ridge rocks (Fig. 1). The principal difference in terms of their origins is the Valley and Ridge rocks were deposited well up onto the ancient North American continental shelf, whereas the older sedimentary rocks were deposited at water depths from very shallow to very deep along the ancient margin in a rifting environment following the breakup of supercontinent Rodinia beginning ~750 Ma or even earlier. The Ordovician shale and sandstone at the first stop on the field trip were also deposited in deep water, but in a basin that formed in front of the Taconic mountains, which formed by volcanic arc and related crust being shoved onto the outer continental margin, causing the region to the west (in front) of the overthrust arc material to subside and form a basin to the west. These clastic sedimentary rocks undergo a facies change to shallow-water limestone to the northwest, confirming that the source of the clastic material was to the southeast.

Once we cross the Great Smoky fault and enter Blue Ridge topography we will still be in sandstone, shale, and carbonate rocks that have not been deformed any more extensively than rocks in the Valley and Ridge, despite the fact that these rocks and those to the southeast have been transported some 400 km from the southeast to where they reside today (Fig. 2). We will stop to look at some of the carbonate rocks in the first block of Blue Ridge topography. These rocks are dolomite [$CaMg(CO_3)_2$]—limestone is composed mostly of calcite, $CaCO_3$—and are very similar to dolomite that we find in the Valley and Ridge, except that this dolomite unit (called Shady Dolomite) is older than the oldest rock unit of any kind exposed across the Tennessee Valley and Ridge. This rock unit comprises the first carbonate deposited in the Appalachians (from Alabama to Newfoundland) along the North American rifted margin following breakup of the supercontinent, indicating that the margin faced open ocean in the Early Cambrian.

From the vantage point of these carbonate rocks, we can look across a small creek located just down the hill and see that there is a somewhat different topography than that in the valley where we are standing. The creek follows an ancient fault, southeast of which are rocks that are markedly different from any of those to the west. The fault block to the northwest should really be considered a piece of the Valley and Ridge that happens to be located in Blue Ridge topography, so the Great Smoky fault simply brings up a suite of older rocks that do

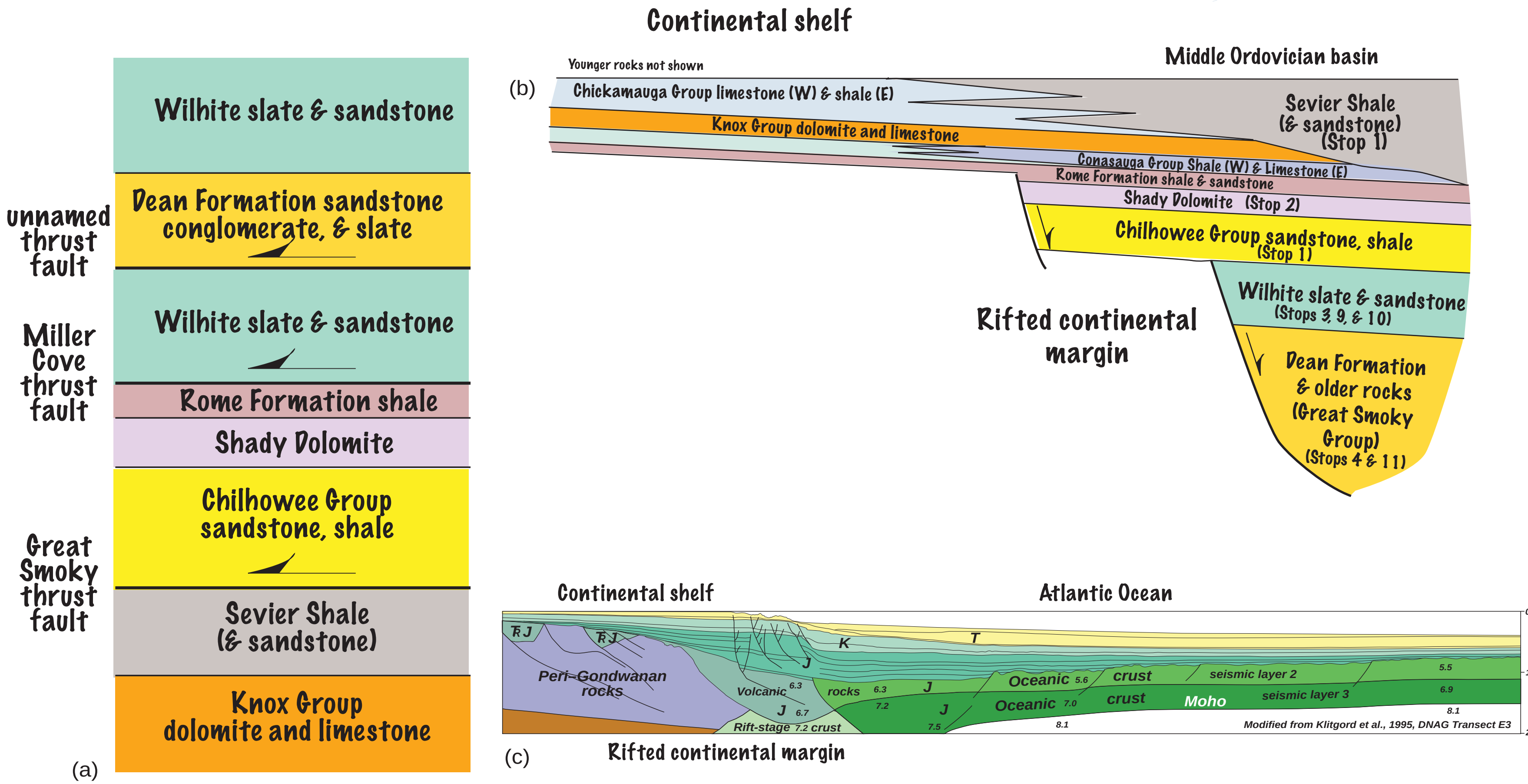


Figure 1. Three perspectives of continental margins. (a) Deformed margin as seen on the field trip simplified into a column. (b) Ancient North American margin in eastern Tennessee (was actually facing south, rather than east, located in the southern hemisphere with the equator passing just north [west] of here). (c) Modern Atlantic margin off North Carolina.

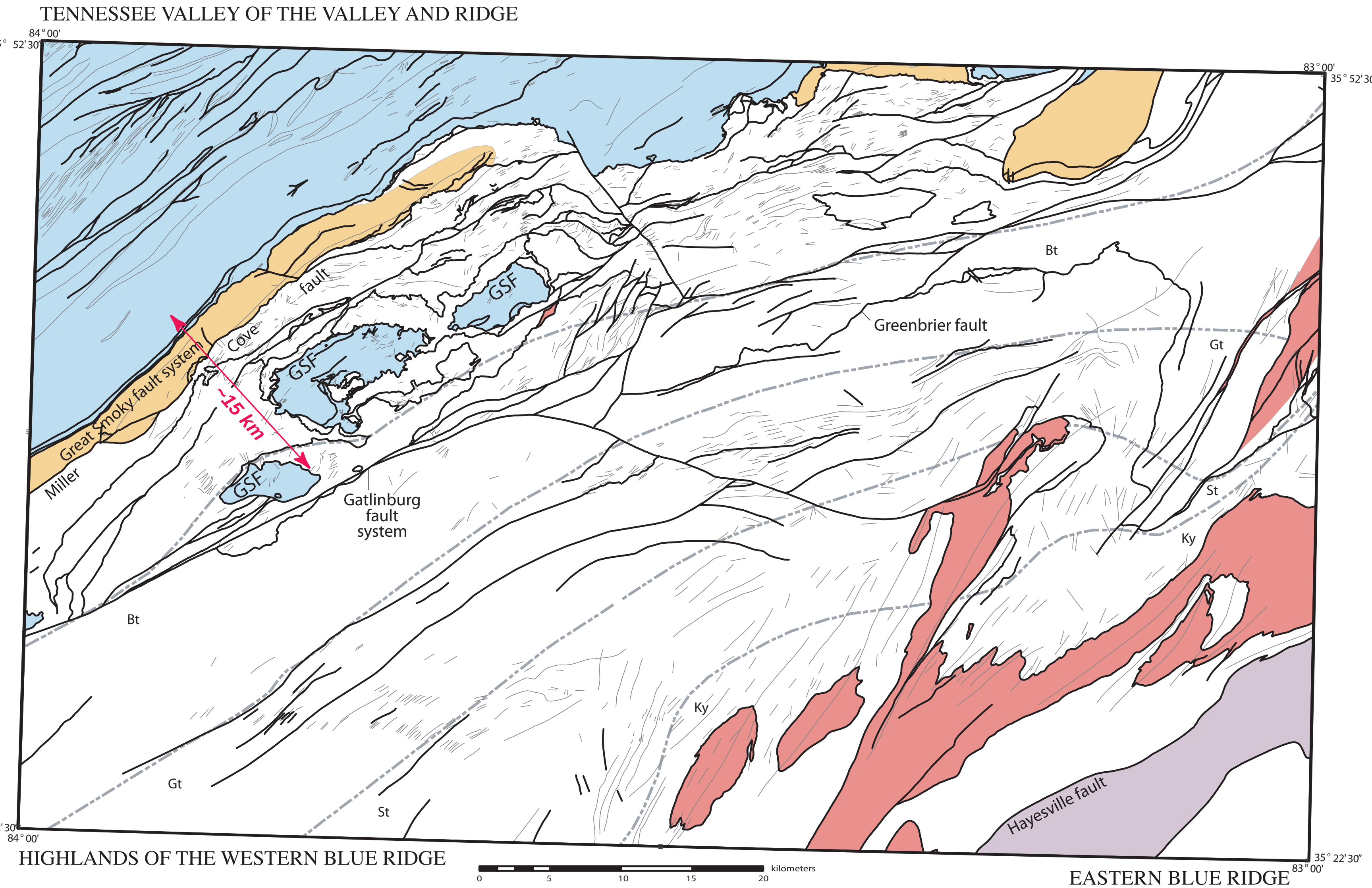


Figure 2. (a) Simplified geologic map of the Great Smoky Mountains National Park showing the simple windows (Tuckaleechee Cove, TC; Cades Cove, CC; and Wear Cove, WC) and the minimum displacement (some 15 km) estimated on the Great Smoky fault (GSF) measured from southeast of Cades Cove to the trace of the fault on the edge of the Valley and Ridge to the northwest (red arrow). Gray dashed lines are metamorphic isograds: Bt–biotite. Gt–garnet. St–Staurolite. Ky–kyanite. (Modified by RDH from Southworth et al., 2005).

not occur in the Valley and Ridge. The mechanics of formation of this part of the Great Smoky fault, however, is identical to the mechanics of formation of Valley and Ridge faults: the fault propagated along a weak rock unit, e.g., shale, in the sedimentary sequence just below the Chilhowee Group rocks that underlie Chilhowee Mountain and the less erosionally resistant, overlying Shady Dolomite that underlies the linear valley making up Miller Cove. The fault then refracted across strong layers in the Chilhowee Group and Shady Dolomite (e.g., sandstone, limestone, or dolomite) to a higher weakness zone: probably the Rome Formation that overlies the Shady Dolomite and rests directly on the Precambrian basement rocks beneath the Valley and Ridge. The Miller Cove fault, located along and southeast of the creek, however, brought up rocks that contain structures and metamorphism that were produced ~460 Ma, so what we are seeing here is an earlier crust—that we could call basement—that has been through an earlier tectonic event and was transported northwestward by a much younger fault, the Great Smoky fault. The expansive but thin mass of crust that comprises the Great Smoky (-Miller Cove-Blue Ridge) Blue Ridge-Piedmont megathrust sheet pushed the Valley and Ridge rocks in front of it like a snowplow: as it moved forward, thrusts propagated northwestward in front of it as snow piles up in front of the snowplow.

We will make several stops in these earlier deformed and metamorphosed rocks, and then arrive in an open, elliptical valley surrounded by high mountains. This valley is underlain by Valley and Ridge limestone and shale of the kinds exposed just west of the Great Smoky fault. This elliptical valley was produced by erosion through the great slab of the Blue Ridge (Great Smoky) thrust sheet to expose the rocks in Tuckaleechee Cove window and in the adjacent smaller but identical windows, Wear Cove (NE) and Cades Cove (SW). Measurement on the map from the southeast margin of Tuckaleechee Cove directly northwest to the trace of the Great Smoky fault where we first saw it provides a minimum displacement of ~10 km, but seismic reflection and other geologic data permit us to conclude that the Great Smoky fault has a minimum displacement of >400 km (Hatcher et al., 2007). For a window or series of windows to form, as we have here, the rocks of the hanging wall of the thrust sheet are arched into an antiform (upfold having the shape of an anticline) that was probably intensely fractured along its crest and permitted erosion to breach the thrust sheet and expose the rocks beneath the sheet. We will make three stops at exposures of the Great Smoky fault (counting the one at the boundary between the Valley and Ridge and Blue Ridge) and a fourth on the southeast side of Tuckaleechee Cove where we can see some structures beneath the sheet that enable us to formulate a model to explain the structure beneath Tuckaleechee Cove. We will then return to the frontal block of the Blue Ridge and turn southwestward onto the Foothills Parkway. Once we are on the Parkway we will make several stops to look southeastward into the Blue Ridge and northwestward across the Valley and Ridge. If the weather is clear, we will be able to see the high mountains along the crest of the Blue Ridge on the Tennessee-North Carolina line to the southeast and the Cumberland Plateau to the northwest of Oak Ridge. Our lunch stop will be at a convenient and scenic place along the Parkway, then we will continue southwestward to its southwest end on US 129 at Chilhowee Lake on the Little Tennessee River. We will then drive along US 129 to look at several interesting exposures of rifted margin sedimentary rocks, which were metamorphosed during the early Paleozoic.

Tuckaleechee Cove

Unmetamorphosed Ordovician carbonate and clastic rocks in the “coves” or valleys of the western Great Smoky Mountains surrounded by cleaved and metamorphosed Precambrian clastic rocks were first noted by Keith (1895) and he (Keith, 1927), along with Jonas (1932), recognized the significance of the low-angle character of the Great Smoky thrust fault. Keith correctly interpreted the Paleozoic rocks in the coves as windows. The windows were later studied by Wilson (1935), who first recognized the significance of later folding. King (1964), and Neuman and Nelson (1965), mapped the simple windows of the western Great Smoky Mountains, recognizing three large (Wear Cove, Tuckaleechee Cove, and Cades Cove) and several smaller windows (Whiteoak Sink, Calderwood, and Big Spring). They also demonstrated that the Great Smoky thrust sheet is folded along a broad antiform that appears to be terminated to the east by the Gatlinburg fault. We now recognize that the antiform continues eastward into the Valley and Ridge as the Fair Garden anticline and that the existence of the antiformal fold in the Great Smoky thrust sheet was produced by arching of the thrust sheet by construction of a footwall duplex in the platform rocks beneath the thrust sheet (Hatcher et al., 1989; Hatcher, 1991) (Figs. 3, 4, and 5).

The Great Smoky thrust sheet comprises the frontal portion of the Blue Ridge-Piedmont composite megathrust sheet. The portion we will examine here is also composite, consisting of an unmetamorphosed Miller Cove syncline frontal block composed of the Neoproterozoic–Cambrian Ocoee Supergroup rocks overlain

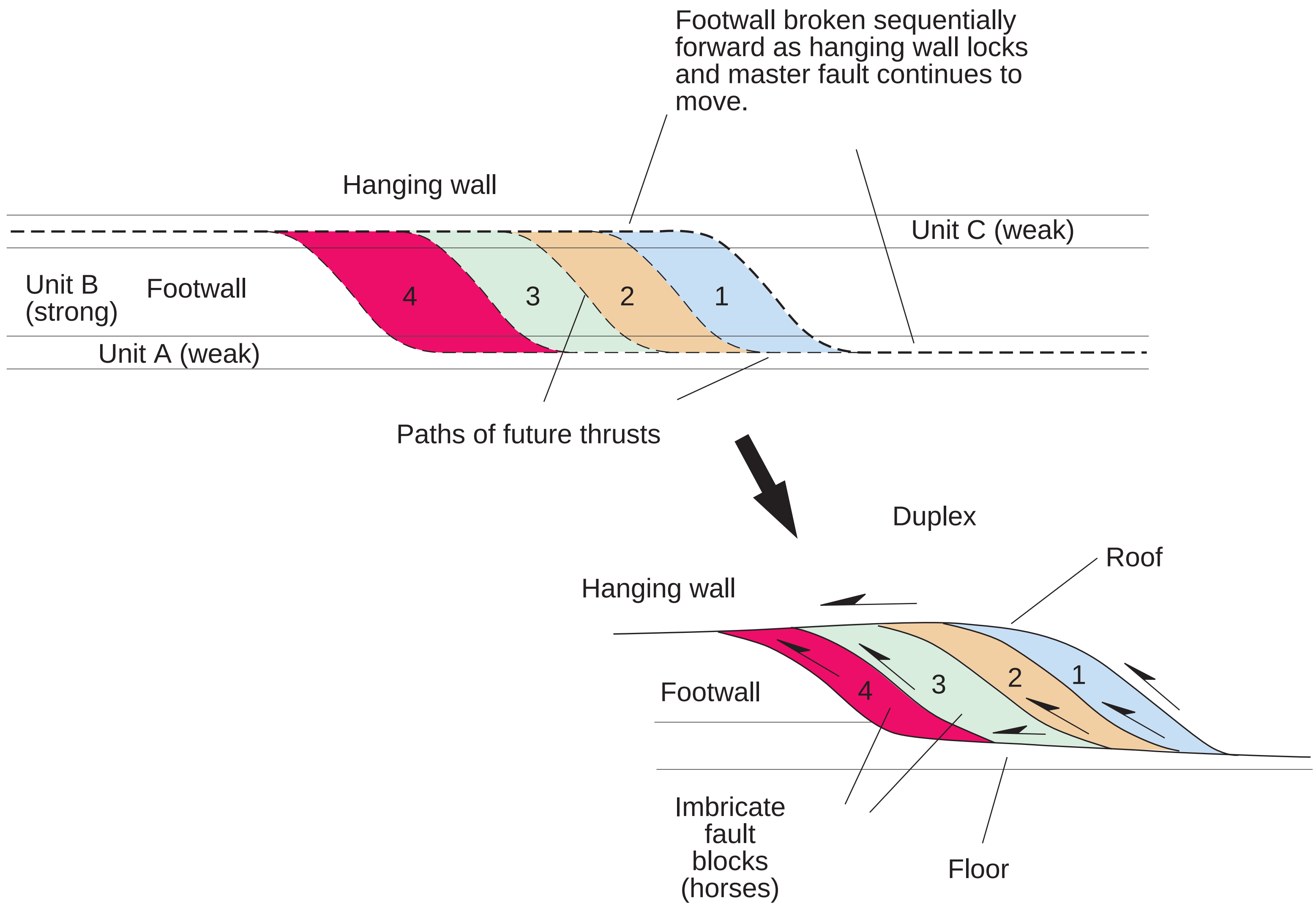


Figure 3. Formation of a duplex thrust system from originally horizontal sedimentary rocks. The numbers indicate the sequence of formation of the blocks (horses) within the duplex in sequence of anternating weak and strong sedimentary rocks, with the hanging wall locking and breaking the footwall to form block 1. The hanging wall plus block 1 locks again and the footwall is broken to form block 2, etc.

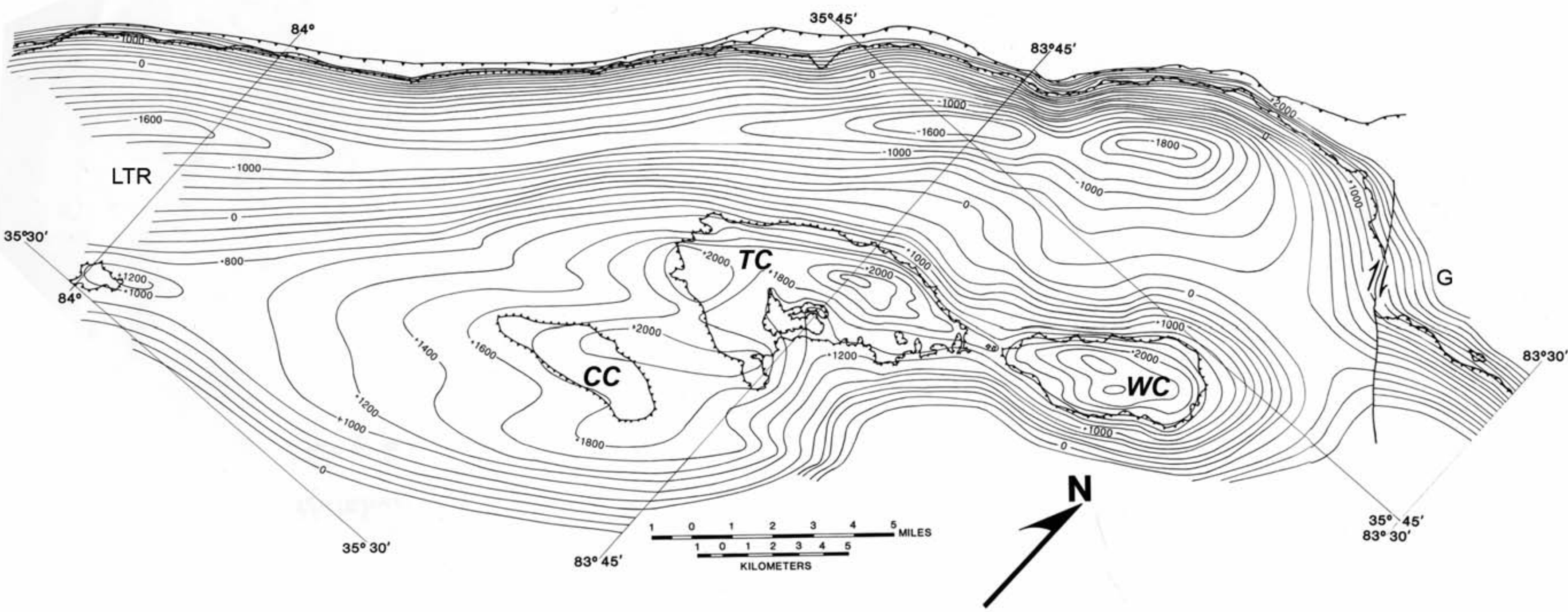


Figure 4. Structure contour map of the Great Smoky fault from near Gatlinburg (G) to the Little Tennessee River (LTR). After King (1964) and Neuman and Nelson (1965). Major windows: TC–Tuckaleechee Cove. CC–Cades Cove. WC–Wear Cove.

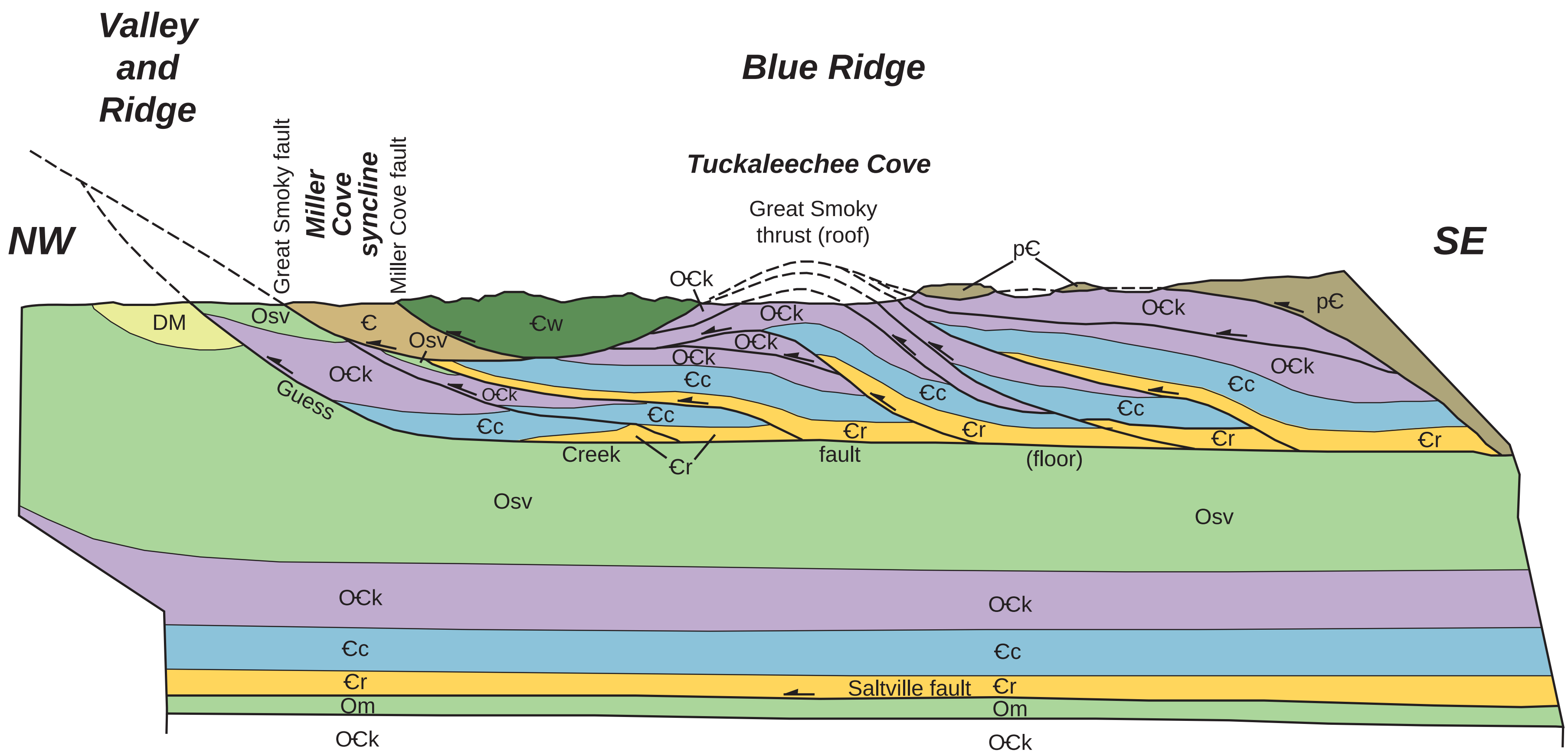


Figure 5. Cross section from the Valley and Ridge (NW) through the front part of the Blue Ridge in southeastern TN. The section crosses Tuckaleechee Cove and illustrates the model, based on the smaller-scale structure observed at Cedar Bluff, to explain the antiformal nature of the faults beneath and within Tuckaleechee Cove window and synclinal nature of the rocks northwest of the window. pЄ– Older rocks southeast of Tuckaleechee Cove thrust up along the Great Smoky fault. Єw – Wilhite Slate and related rocks. Є– Cambrian(?) to Cambrian (Chilhowee Group and younger) rocks of the Miller Cove syncline. Єr – Rome Formation. Єc – Conasauga Group. OЄk – Knox Group. Osv–Sevier Shale. Om–Middle Ordovician rocks. DM – Devonian and Mississippian rocks. See Figure 1 for more information about the nature of these rocks.

by a complete section of rift- and post-rift-to-drift sequence of Lower Cambrian Chilhowee Group rocks, then the Shady Dolomite, and a partial section of Rome Formation. The Rome Formation is the oldest rock unit exposed in the Valley and Ridge (recall the rocks at Moores Gap Church, if you have been on an RDH field trip in the Oak Ridge-Clinton area). The southeast flank of the Miller Cove syncline is cut off by the Miller Cove fault, which brings up green chlorite-grade slate and sandstone of the Neoproterozoic to Lower Cambrian(?) Walden Creek Group (Wilhite Slate and related rocks). The slate is called slate because it breaks more easily along a structure called slaty cleavage than along bedding (see the left photo on the cover of the guidebook); it has been mined locally for roofing slate. A significant attribute of the Chilhowee Mountain block is it establishes stratigraphic (sequential) continuity between the Blue Ridge and Valley and Ridge, and the rocks comprising this block represent a stratigraphic position where the master Great Smoky fault ramped (refracted) upward from a rift-drift continental margin sequence into the Rome Formation beneath the platform succession (Fig. 1b). This relationship can be observed in the U.S. Appalachians from Alabama to Vermont in the transition zone between more external Valley and Ridge structures and more internal structures of the Blue Ridge. The formation names change, but this transition remains the same throughout the U.S. Appalachians.

Southeast of the three large windows are other large thrust faults, including the pre- to late- metamorphic Greenbrier thrust (Fig. 2a), which transported Great Smoky Group rocks over Walden Creek and older rocks, including the 1.1 Ga basement rocks shown in pink in Figure 2(a). Metamorphic grade increases uniformly eastward from chlorite west of the windows to biotite and garnet east of the windows, further demonstrating the late Paleozoic time of emplacement of the Blue Ridge-Piedmont megathrust sheet. This metamorphic sequence continues uninterrupted southeastward to very high grade lower crustal (granulite-facies) assemblages in the central and eastern Blue Ridge located west of Franklin, NC.

The exposure at Cedar Bluff inside Tuckaleechee Cove window (Stop 6) provided a key to formulation of a hypothesis to explain the structure beneath the windows (Figs. 1, 3, 4, and 5). Here several imbricate faults visible in Knox Group dolomite and limestone appear to merge upward into the Great Smoky thrust (Fig. 6). If so, it is likely the Cedar Bluff exposure is a mesoscopic-scale duplex immediately beneath the Great Smoky roof thrust. This has led to the hypothesis that the antiform that arched the Great Smoky thrust sheet and produced the Fair Garden anticline (to the NE) was produced by deformation of the platform sedimentary rocks beneath the Great Smoky sheet and formation of a large duplex—called the Smokies Foothills duplex—during emplacement of the Great Smoky fault as the floor of the Blue Ridge-Piedmont megathrust sheet (Hatcher et al., 1989). The roof of the duplex is the Great Smoky thrust sheet and the floor is the Guess Creek thrust that outcrops immediately west of the trace of the Great Smoky thrust (Fig. 5). Thrust faults that have been mapped in the Ordovician rocks inside Tuckaleechee Cove window and Fair Garden anticline are probably horses in the duplex. If this interpretation is correct, it demonstrates again the mechanism of arching of a large thrust sheet by formation of a footwall duplex (Boyer and Elliott, 1982) (Figs. 3, 4, and 5). Hatcher et al. (1989) and Hatcher (1991) further explored this interactive property between thrust sheets and footwall rocks.

Figure 6. Panoramic view looking E toward Cedar Bluff in Tuckaleechee Cove window. Rocks exposed here all belong to the upper part of the Knox Group (here called Jonesboro Limestone). The Great Smoky fault that overlies these rocks would be present along the highest part of the ridge toward the SE. Several SE-dipping imbricate thrust faults are visible in the bluff that produced “rollover” anticlines or “snakehead” structures in the hanging wall. Photos taken in December 2011 then composited and edited in Photoshop 6™ July 2012.

FIELD GUIDE

Drive east from Knoxville on U.S. 129 (Alcoa Highway) to Maryville, Tennessee, then southeast on U.S. 321/TN 73 toward the Great Smoky Mountains National Park. Stop at the large cut on the right immediately northwest of Chilhowee Mountain.

STOP 1. Sevier Shale (Middle Ordovician), Guess Creek Block, and Blue Ridge contact (Great Smoky fault), Little River Gap, near Walland, Tennessee. Location: 35.7363° N, 83.8243° W.

PURPOSE: To examine a well-exposed section of eastern clastic assemblage of Middle Ordovician rocks (equivalents of the limestones located above the Knox at the corner of Edgemoor Road and Melton Lake Drive in Oak Ridge) containing a wide variety of rock types and structures, and the Great Smoky fault.

Are the rocks here right-side-up or overturned?
What is a noncylindrical fold? Have you seen any before coming here?
What kind(s) of folds are here?
What is a tubidite?
What kind of contact is present at the base of Chilhowee Mountain (SE end of exposure)? Evidence?

The exposure of Sevier Shale at Little River Gap immediately west of the Great Smoky fault and about 1 km west of Walland, Tennessee (Fig. 7), provides an opportunity to look at a well-exposed section of rocks presumably in the same fault block as the Sevier Shale in Tuckaleechee Cove window (Figs. 1 and 2).

At least three distinct shales are exposed in the main roadcut. At the southeastern end of the continuous part of the cut is fine-grained sandstone and shale containing cm-scale graded beds (indicative of deep water rapid deposition), shale, and scour-and-fill structures grade upward into mostly shale with some sandstone and mudstone. Much of the shale is calcareous. A second unit to the northwest is composed of medium to dark blue-gray calcareous shale, possibly correlative with the Blockhouse Shale (Neuman, 1955). The third unit exposed at the northwest end of the cut is composed of blue-gray calcareous shale similar to that present in the other units. In addition, graded and massive beds of calcareous sandstone and sandy limestone also occur here, along with scour-and-fill structures on the bases of several sandstone beds. Bed thickness ranges from 5 to 50 cm. Calcite-filled fractures are abundant. Graded conglomerate containing clasts of limestone, dolostone, chert, and clastic rock fragments occurs in this unit, but is hard to find today, because the rocks in the cut have weathered since the cut was constructed in 1987.

Graptolites (*Glyptograptus teretiusculus, Dicellograptus sp., Reteograptus qeinitizianus, Pseudoclimacograptus sp., Didymograptus sp., Glyptogaptus sp., and Pseudoclimacograptus angulatus* identified by Prof. S. C. Finney, Cal State–Long Beach, and belong to the *Nemagraptus gracillis* Zone or the uppermost *Glyptograptus teretiusculus* Zone: Middle Ordovician, ~470 Ma), and possible fish scales, occur in shale and sandstone near the east and west ends of the cut. Primary structures are mostly upward facing where they occur in the exposure, but a few face downward. Obviously overturned beds occur here on the inverted limbs of folds where we can see the fold hinges.

Several complexly folded zones occur in the exposure. Folds range from open to tight and from limb-dominated kink folds to folds with broadly curved hinges. Most probably formed by layer-parallel slip and buckling. Some of the very tight folds toward the southeast end of the exposure have curved axes.

Weak slaty cleavage occurs in shale in the east half of the exposure (Fig. 7). The cleavage here dips moderately southeast.

The small exposure of the Great Smoky fault at the northwest end of the cut southeast of the large concrete retaining wall is initially not very obvious, but the contact between Middle Ordovician shale and medium- to coarse-grained Lower Cambrian sandstone (Cochran Formation, basal Chilhowee Group) is evident at the northwest edge of the exposure. Careful observation also reveals a small horse of (Knox?) carbonate along the fault (now removed, but still lying in the ditch). Hanging wall rocks here were transported some 400 km from the southeast to rest atop the Middle Ordovician foreland basin clastic sedimentary rocks of the footwall. Few realize the significance of this exposure or the fault exposed here.

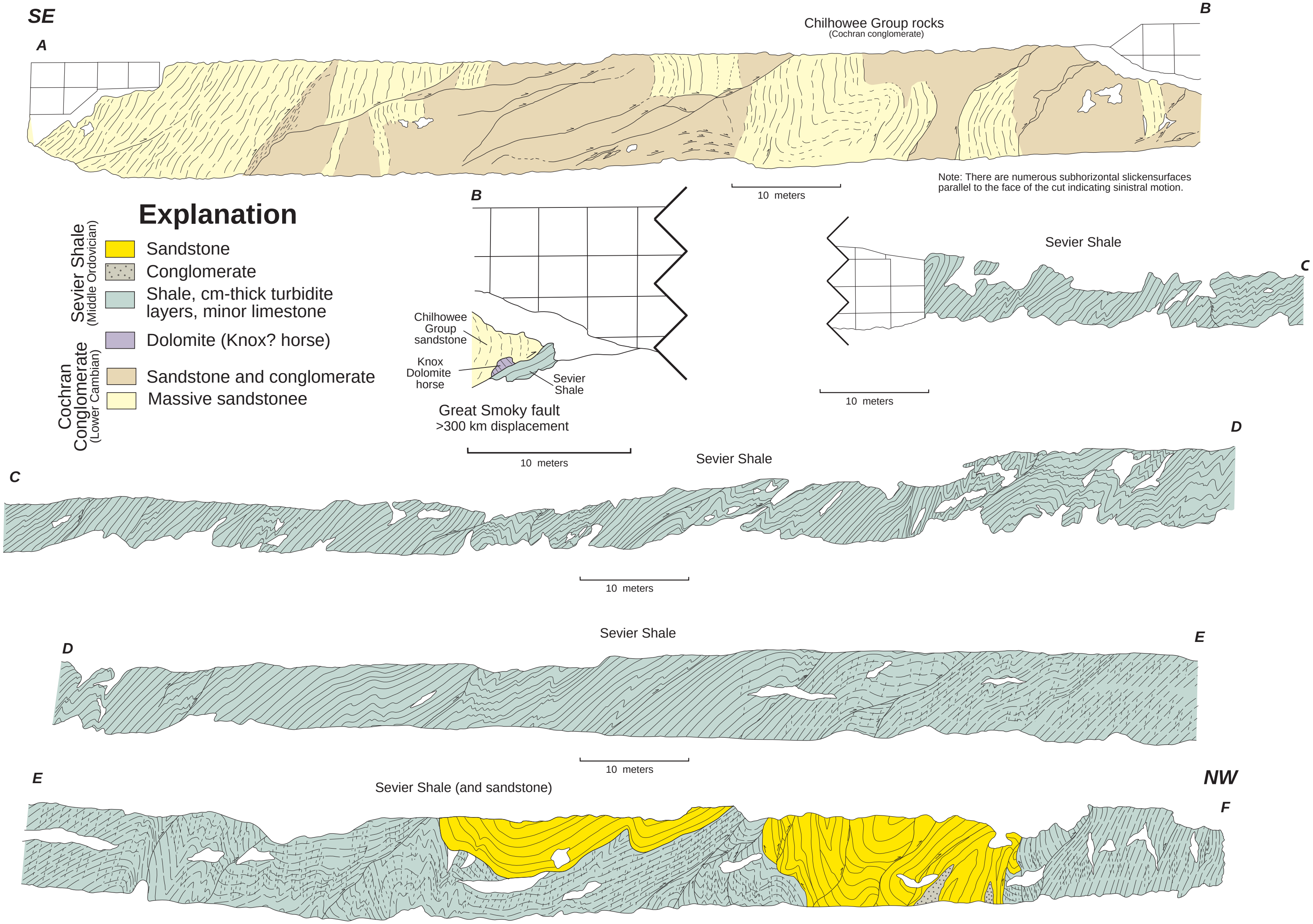


Figure 7. Sketch of the roadcut at Stop 1. Sketch was constructed in the field from detailed photographs of the exposure in 1992 by Mark W. Carter, G. Landon Davidson, and James A. Heller as part of a term problem in a UTK graduate structural geology course (other data they collected are not included). The diagram is detailed enough that you should be able to locate yourself in this diagram as you walk along and look at the exposure.

Subhorizontal Fe-oxide-coated slickenline (movement) surfaces on Chilhowee Group sandstone are probably a local manifestation of the strike-slip fault that localized the Little River water gap, consistent with a mapped fault in the gap (Neuman and Nelson, 1965). Despite this, the net displacement here is dominated by the several kilometers of vertical displacement in the Great Smoky fault hanging wall and >400 km of horizontal displacement, all dip-slip, from the southeast. The strike-slip fault has only ~200 m of displacement.

[***NOTE:*** Many of the data on Middle Ordovician rocks from this exposure were collected by Dartmouth College undergraduate Kurt S. Larson in 1988 as part of a University of Tennessee Science Alliance Summer Undergraduate Research Fellowship directed by Prof. Hatcher. Additional structural data were collected and the sketches included here were made by Mark W. Carter, G. Landon Davidson, and James A. Heller as part of an advanced structural geology course problem in 1992 at the University of Tennessee–Knoxville.]

NOTE: *This is a stop where undergraduates are instructed in measuring planar structures and the different components of folds, as well as accurately recording structural data in a field book (perhaps on an iPad today) and bringing in the importance of making accurate sketches of structures and other features. We commonly spend up to an hour here so the undergrads can be split into small groups (commonly <5) and any grad students doing field-oriented research projects and I can demonstrate measurement techniques and get them started with measurements. They are also encouraged to measure, sketch, and describe structures at other stops on this trip. With undergraduates, earlier in the semester we spend a day (first trip of the semester) going to a couple of stops in the Valley and Ridge W of Knoxville, one fault-dominated and the other fold-dominated where they are introduced to measuring planar structures and folds with a Brunton compass (or equivalent, although I have not found one), actually collect data and calculate the dip of a fault in an abandoned quarry, measure/determine the elements to characterize a fold in space, and make sketches of structures they see in the field. They are also encouraged to take photographs, but emphasizing the value of accurate sketching to improve observations, with photographs used to augment sketches.*

Continue southeastward on U.S. 321 past Chilhowee Mountain. Stop at cut on right in carbonate rocks in Miller Cove.

STOP 2. Miller Cove Syncline. Location: 35.7234° N, 83.8189° W.

PURPOSE: To demonstrate the lack of internal deformation and metamorphism in the first block within the Blue Ridge thrust sheet.

We are in the Blue Ridge here. Conventional wisdom states that these rocks are metamorphosed, but they are not, and neither are the rocks of the Chilhowee Group below the Shady Dolomite in this exposure or the Rome Formation above it. Why aren't the rocks metamorphosed?

The exposure here is in the Shady Dolomite that overlies the Chilhowee Group in the Miller Cove syncline. The rocks here consist of Lower Cambrian Shady Dolomite, compositionally an almost theoretical dolomite, $CaMg(CO_3)_2$ (Hatcher et al., 1973). Chilhowee Group sandstones underlying Chilhowee Mountain to the northwest are increasingly silicified during weathering to form resistant units. The carbonate and shales of the overlying Shady Dolomite and Rome Formation are topographically recessive and form the floor of the linear Miller Cove valley. The Miller Cove fault is located along the creek at the bottom of the hill to the southeast. Immediately southeast of the fault are greenschist facies slate and sandstone of the Wilhite Slate interbedded with sandstones and conglomerates that appear to have little internal deformation (but see STOP 3).

One of the characteristics of the Miller Cove fault footwall is the lack of obvious metamorphism of either the Chilhowee Group clastic rocks or the overlying Shady and Rome. Internal deformation within these rocks is also lacking here in this frontal Blue Ridge block, except for a locally developed weak cleavage. The Great Smoky fault beneath us that surfaces at the previous exposure is a bedding thrust. So, while we are in the topographic Blue Ridge until we cross the Miller Cove fault (located in the creek just down the hill), I suggest that we are still in the Valley and Ridge fold-thrust belt, contrary to conventional wisdom. Consequenty, the Great Smoky fault here is the highest Valley and Ridge thrust sheet.

> ***NOTE:*** *I commonly do not spend a lot of time here with students, but try to show them some of the map relationships and encourage them to take a look at the exposed dolomite to confirm the lack of deformation and metamorphism.*

Continue southeastward along U.S. 321/TN 73. Note the sudden appearance of darker-colored, more highly deformed rocks in cuts immediately southeast of Miller Cove Creek. We have now crossed the Miller Cove fault and are in more highly deformed and metamorphosed (chlorite grade—note the greenish color, some due to moss!) Wilhite Slate and related sandstone.

STOP 3. Tightly Folded and Cleaved Wilhite Formation (Walden Creek Group). Location: 35.6981° N, 83.8091° W.

PURPOSE: To contrast the deformation style and rocks here with those at the previous exposure.

What fold mechanisms are present?
Are the rocks right side-up or overturned here?
What causes the green color in these rocks?
What is the metamorphic grade here?
What are the different kinds of planar structures present here?

This exposure consists of fine-grained greenish-gray slate and siltstone of the Lower Cambrian(?) Wilhite Formation. Several folds with a prominent slaty cleavage, and amplitudes as large as the cut are exposed here (Figs. 8 and 9, and guidebook cover). A small fold located west of the larger folds contains a fanned axial-planar slaty cleavage and slickenfibers on bedding surfaces, indicating a composite mechanism formed the fold (buckle folding and cleavage formation followed by flexural slip during the last stages of folding, drag of cleavage along bedding, and fanning of the cleavage).

Measurements of moderately SE-dipping cleavage and fold axial surfaces in the rocks exposed here and to the NW and SE all plot as a bullseye in the NW quadrant of a fabric diagram; fold axes plot near the primitive circle in the NE and SW quadrants of the fabric diagram; and bedding measurements are distributed along a great circle (Fig. 10). The pole to the great circle plots in the NE quadrant in the array of cleavage-bedding measurements. Cleavage-bedding intersection lineations plot in the NE and SW quadrants, and superpose the fold axis array.

These rocks could be considered part of the basement (older crust) formed during the early Paleozoic Taconic orogeny. It was deformed and metamorphosed during the Ordovician long before the late Paleozoic Alleghanian event(s) that formed the Blue Ridge thrust sheet.

> ***NOTE:*** *Here, traffic permitting (occasionally breaking the group into two or even three smaller groups to be able to hear and appreciate the explanation of the relationships described above), I take the opportunity to explain the relationships in the small mesoscopic fold exposed here. This is one of the places in the world where real structures behave perfectly when plotted on a fabric diagram.*

Continue southeastward on U. S. 321/TN 73.

Figure 8. Folds at Stop 3. Note the shape of the folds compared with any you might have seen before in the Valley and Ridge, along with the presence of slaty cleavage. Also see the photo on the left on the front cover of the guidebook for another fold located ~25 m to the NW. Former Clemson University undergrad Charlie Seijo for scale. A comparison of the lack of trees at the time this photo was made with the trees present today dates this photo.

(a)

(b)

Figure 9. (a) Overturned fold in Wilhite Slate following reworking of the roadcut along US 321 in 2012 by the Tennessee Department of Transportation (compare with the fold on the cover of the guidebook as it appeared before the slightly weathered material was removed). The asymmetry of the fold and the thickening in the antiformal hinge are still quite evident, and the bedding surface to the left still exposes slickenfibers of chlorite and Fe oxides (not visible in the photo), attesting to the multiple mechanism of folding. The light-colored nearly vertical material in the fresh rock to the upper left are thin zones of recrystallized quartz oriented parallel to cleavage, not visible in the old exposure. (b) Primary sedimentary structures exposed by the reworking of the roadcut. These features were not visible before, and serve as way-up indicators.

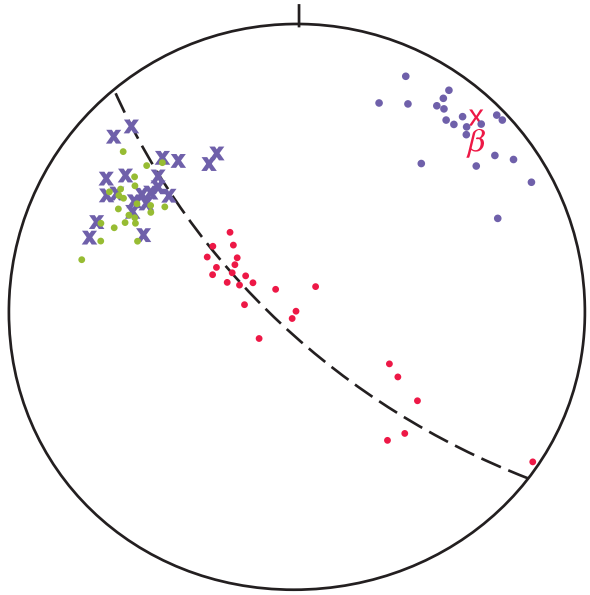


Figure 10. Equal-area plot of structural measurements in Wilhite Slate from Maddens Branch locality on US 64 in SE Tennessee (From Hatcher et al., 1978, their Fig. 15). Red dots—25 poles to bedding (S_0). x—location of the pole to the great circle (dashed line) best fit for the bedding data (β). Purple dots—21 fold axes. Purple xs—poles to the same 21 fold axial surfaces. Green dots—23 poles to cleavage (S_1). Compare this small dataset with the plots of a larger dataset from the same rock unit distributed over a large area in SE Tennessee in Hatcher (1995, his Fig. 18–13).

STOP 4. Graded Beds in Channels in Upper Dean Formation (Great Smoky Group beneath Wilhite Slate). Location: 35.6900° N, 83.7978° W.

PURPOSE: To examine graded bedded sequences and channels in the upper Dean Formation.

What primary structures are present?
Is there evidence of large sedimentary processes going on here?
These rocks appear undeformed on first inspection—do you see evidence of deformation in these rocks, other than the small fault in the cut?

Sandstone, feldspar-bearing sandstone (arkose), conglomerate containing many rock types (dominated by rounded milky quartz pebbles, but with lesser amounts of limestone and shale pebbles), and dark slate are present. The rocks here appear less deformed than those at the previous stop, probably related to the dominance of mechanically strong, coarse, massively bedded sandstone and conglomerate (note that the shale pebbles are cleaved and are now slate). Graded beds are easy to see in the large cliff face. This sequence may have formed as part of a submarine channel-fan complex.

> ***NOTE:*** *This is a great place to introduce the concept of strain partitioning, especially when students get out of the vans expecting to look at sedimentological features, which are rather spectacular here.*

Continue southeastward on U.S. 321/TN 73 and turn left (northeast) onto the new bridge over the Little River, then immediately turn right and drive ~1 mi (1.6 km) to a small exposure of dolostone on the left side of the road. Parking is very difficult here, making it hard to have a large group be able to see the rocks with cars going by, but all traffic moves very slowly here and is generally light.

STOP 5. Great Smoky Fault at the Northwest Side of Tuckaleechee Cove. Location: 35.6923° N, 83.7710° W.

PURPOSE: To examine the fault inside Tuckaleechee Cove window demonstrating that cleaved and metamorphosed (low grade) Wilhite Slate is in direct contact with a horse of unmetamorphosed Knox Dolomite.

What evidence of faulting can you see here?
What rock units are present?

Exposures of the Great Smoky fault are relatively rare in accessible locations. This exposure involves cleaved, banded Lower Cambrian(?) Wilhite Slate thrust over a horse of Ordovician Knox Dolomite (Fig. 11). The slate appears little deformed by emplacement of the thrust, with only a few carbonate-filled veins cutting the older deformation. The Knox Dolomite here, however, is intensely fractured, and carbonate veins are cut by younger carbonate-filled fractures, indicating a history of recurrent movement on the fault. The horse of Knox Dolomite rests on Middle Ordovician Sevier Shale in the flat area (the pasture) immediately to the southeast. Rocks on either side of this fault were deposited at least 400 km apart from each other, and the highly deformed Knox records a complex history of movement as a horse (disconnected block) that was derived from the footwall and carried along the fault.

This stop provides an excellent vista of Tuckaleechee Cove window and the Great Smoky Mountains to the southeast (the high mountain nearby to the southeast is Rich Mountain, ~900 m). The lower foothills immediately southeast of the window are underlain by Walden Creek and Snowbird Group rocks; the high mountains in the distance (elevations to >2000 m) are underlain by Great Smoky Group (meta-) sedimentary rocks. Think about the now-eroded Great Smoky fault extending up into the air above us toward the SE from the exposure here, and realize that it comes back down at the next stop.

Return to U.S. 321/TN 73; continue eastward on TN 73 beyond the left turn of US 321 and stop in a parking area to view a vertical cliff to the northeast.

STOP 6. Cedar Bluff inside Tuckaleechee Cove. Location: 35.6775° N, 83.7204° W.

PURPOSE: To look at the exposure that serves as the model for the map-scale Smokies Foothills duplex.

What rock units are involved here?
What are the elements of a duplex, and what components can be seen here?

Cedar Bluff, located ~150 m from the roadside viewpoint, consists of a near-vertical exposure of massive upper Knox Group dolomite and limestone above the Little River, with Snowbird Group rocks at the top of the hill (covered by vegetation; Figs. 5, 6, and 12). Faults in this exposure were first noted by Neuman and Nelson (1965, *their* Fig. 11). Folding and bedding truncations along thrust faults are obvious here. Hatcher et al. (1986) reinterpreted the structure as a mesoscopic duplex with the Great Smoky fault as the roof. Cedar Bluff serves as the model for interpretation of the footwall duplex that formed the culmination that was eroded to expose the Great Smoky fault around the windows (see Fig. 5).

> ***NOTE:*** *In addition to pointing out the sketch in the guidebook, I commonly sketch the relationships here on a whiteboard. Cedar trees grow thicker each year regardless of the season and it is difficult to otherwise point out the relationships in the bluff.*

Return to U.S. 321/TN 73 stoplight. Turn right and continue eastward on US 321 toward Pigeon Forge. Turn left into subdivision and park so that other cars can pass.

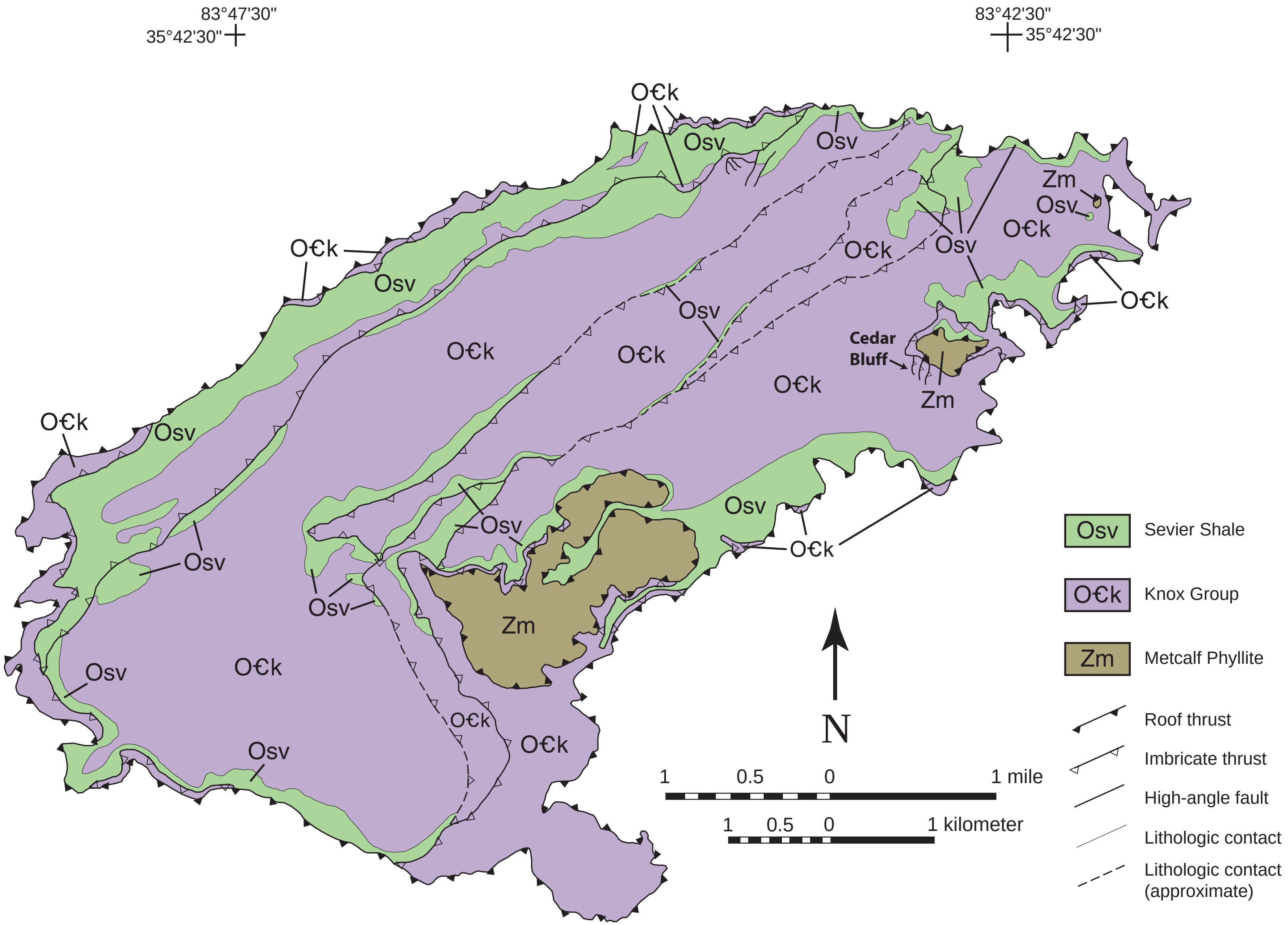


Figure 11. Detailed geologic map of the interior of Tuckaleechee Cove window (by RDH and J. O. Costello, 1986, originally published in Hatcher et al., 1989, and modifying a geologic map by Neuman and Nelson, 1965). Dashed faults crossing the window were mapped by tracing zones of shale chips of Sevier Shale separating the faults in the Knox Dolomite (called Jonesboro Limestone by the USGS). Electronic graphic by J. Ryan Thigpen, 2004.

STOP 7. Great Smoky fault at east end of Tuckaleechee Cove.

PURPOSE: To examine another exposure of the Great Smoky fault.

What evidence that you can see here suggests the contact might be a fault?
Are there fault rocks present along the contact?
How does this exposure of the Great Smoky fault resemble the other two you have seen today?
How is it different?

The Great Smoky fault exposed at this locality is again a sharp contact between Knox Group dolomite in the footwall and Walden Creek Group or older rocks in the hanging wall (Fig. 13).

Return to U.S. 321/TN 73 stoplight. Turn right and continue westward on US 321 toward Walland. Turn left onto the Foothills Parkway and drive to the first good overlook into the Smokies and pull in.

STOP 8. Views from Foothills Parkway

PURPOSE: To relate rocks and structure to the landscape visible to the SE and NW.

What are you seeing from here? Looking SE? NW?

> ***NOTE:*** *I answer the questions posed here so that the students can see the relationships between rock type, structure, and topography. My common practice here is to place the geologic map on the ground along the shoulder of the road and try to point out the rock/tectonic units on the map and then in the field.*

Continue SW on the Foothills Parkway to U.S. 129 and turn left (SE). Drive to the boat ramp and turn around; drive ~0.4 mi NW and pull off next to the large fold in the road cut.

STOP 9. Fold on Chilhowee Lake

PURPOSE: To examine a large fold and the associated structures.

What is the fold mechanism here?
What are the rocks here and how have they been deformed?
Is there a relationship between rock type and the structures you can see developed in them?
What are the different structures you can identify here?
Make structural measurements here to fill in the data sheet.

Exposed here is Wilhite Slate (Walden Creek Group) that has been folded, cleaved, and later overprinted by brittle structures (Fig. 14). Details of the geology of the nearby area may be found in Neuman and Nelson (1965), because the highway is located immediately outside the southwestern boundary of the Great Smoky Mountains National Park. The early folds are flexural-flow-modified buckle folds with a strong axial planar slaty cleavage. A limestone layer in the sequence pinches in the cut by primary sedimentary thinning and has been thickened tectonically in the hinge of the fold during folding and cleavage formation. Some pressure dissolution is evident parallel to cleavage in the limestone layer, but the cleavage in the slate formed by recrystallization and growth of layers of very fine-grained micas parallel to the cleavage. Despite this, a series of apparently offset layers parallel to cleavage was observed here some time ago, suggesting the controversial passive-slip fold mechanism might have occurred here (Fig. 15).

Brown (1971) studied several of the folds in the Wilhite Formation along U.S. Highway 129 next to Chilhowee Lake and concluded that there may be as much as 30 percent flattening in the folds.

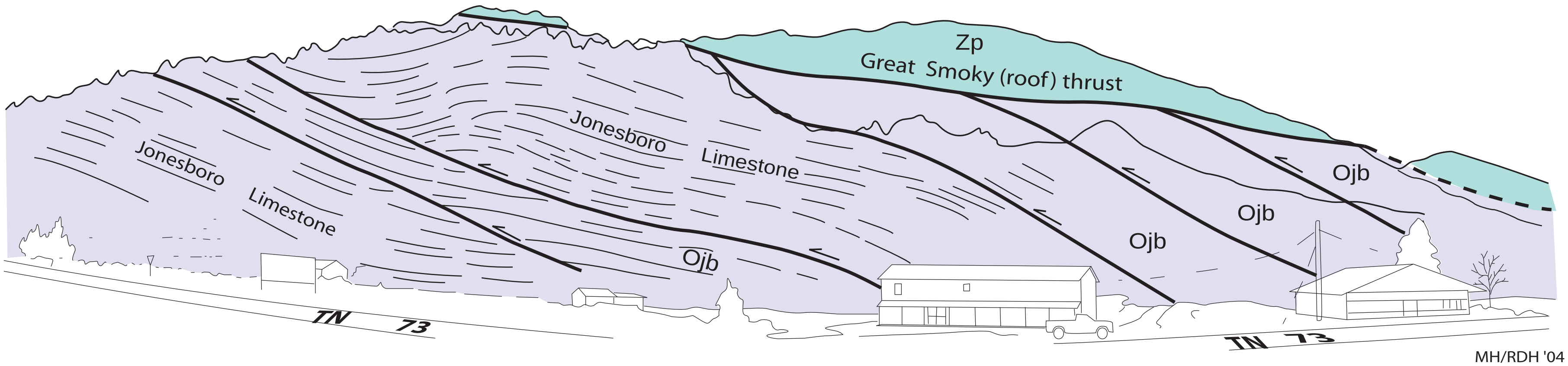


Figure 12. Sketch of Cedar Bluff made from photographs (see Fig. 6). Ojb—Jonesboro Limestone (upper Knox Group). Zp—Pigeon siltstone. Compare this sketch with the photo in Figure 5. Original drawing by Libby Martin, 1986; electronic graphic by Mark Hunter and RDH, 2004.

Figure 13. Exposure of the Great Smoky fault on US 321 at the east end of Tuckaleechee Cove window. The light-colored footwall rocks belong to the Knnox Group (here called Jonesboro Limestone), while the hanging wall rocks are clastic rocks belonging to one of the Precambrian or older Cambrian clastic units. The ffault zone is rather thin and the rocks beneath relatively undeformed for a fault with 400 km of displacement. The planar fabric in the hanging wall rocks is also an older foliation.

Several white calcite-healed extension fractures cut the limestone and probably record the folding history of this structure. One set is fanned by the fold, while others cut obliquely through the layer. Later extensional and contractional brittle faults envelop the fold and appear in an intersecting and anastomosinig pattern throughout the cut. Sense of motion of these faults ranges from thrust to normal.

An important thing to note here is the planar nature of the carbonate layer, and that it pinches to zero thickness in this exposure. It is unlikely that termination of the layer occurred because of tectonic processes, or that the carbonate is a fragment (even a deformed one).

There also are some very small, ptygmatically folded quartz veins in the exposure ~100 m to the SE.

NOTE: *I frequently ask the students as a group to name as many tectonic structures as they can observe here.*

Continue W on U.S. 129 past the end of the Foothills Parkway and pull over on the right at exposures just past the boat ramp.

STOP 10. Chilhowee Lake W of Foothills Parkway

PURPOSE: To examine an ancient submarine landslide and associated rocks.

What kinds of rocks are present?
What kinds of tectonic structures can you identify?
What is a mullion?
Are the rocks right side up or overturned here? How can you tell?

The outcrop contains a thick unit of carbonate breccia enclosed in a sequence of interbedded carbonate and shale that grades up-section into sandstone.

The objective of this stop is to show the sedimentological relationship between the carbonate breccia, the interbedded limestone and calcareous shale, and the overlying mechanically derived sedimentary rocks. These relationships also play an important role in developing a basin model for the Walden Creek Group. Microfossils determining the age of the Walden Creek Group have been reported from this outcrop (Unrug et al., 2000), but these data have never been replicated.

The outcrop consists of an overturned sequence of interbedded carbonates and siliciclastic sediments, with a thick debris-flow breccia bed near the base of the measured interval. Here, overturning has been determined by graded beds in the upper part of the section, and by cleavage-bedding relationships. They form an integral part of the Walden Creek Group sequence and date the deposition of the Walden Creek Group. Above the lime sandstone beds are shale, siltstone, and graded sandstone beds 10-20 cm thick, representing deposition in a deep marine basin.

The breccia bed is attributed to submarine landslide and consists of angular carbonate fragments 2-20 cm long. The breccia represents several different rock types that rest in a matrix of limey mud and quartz sand. Some of these fragments have been derived from thinly bedded limestone 1-2 cm thick, while others contain quartz sand. Other fragments present in this fossil landslide are composed of shale up to 80 cm across. This landslide breccia forms a planar bed 3.5 m thick of considerable lateral extent. The breccia bed is interpreted as a landslide that carried carbonate fragments of shallow water origin into a deep-water basin in which predominantly silica-rich sediments accumulated. The preceding two paragraphs are from Unrug et al. (2000).

The tectonic structures present here are also intriguing. Cleavage dips less than bedding and parasitic folds confirm the overturned nature of this section (Fig. 16). Mullions formed at shale-siltstone bed contacts demonstrate the relationship between the higher and lower viscosity layers, with the mullion cusps pointing into the siltstone. Large slickenline surfaces are also present.

Continue W on U.S. 129 to Chilhowee Dam and park on the left just beyond the dam.

Figure 14. Recumbent fold in Wilhite Slate on U.S. 129 ALONG Chilhowee Lake. (a) View from perpendicular to the roadcut. (b) View parallel to the hinge of the fold.

Figure 15. Folds of bedding developed parallel to slaty cleavage—passive slip folds? U.S. 129 on Chilhowee Lake.

Figure 16. Interbedded fine sandstone and slate with a carbonate debris flow at the right side of the photo. The small fold, and other structures not visible in this view, provide hints that these rocks may be overturned.

STOP 11. Conglomerate at Chilhowee Dam

PURPOSE: To examine some complex sedimentary deposits that probably formed during the Neoproterozoic.

What is an armored mudball?
How were these rocks deposited?
What rock types can you identify in the clasts?

This stop description is modified from Unrug et al. (2000).

Outcrops adjacent to the Chilhowee Dam expose Wilhite Formation channelized conglomerate and sandstone. The outcrop is on the north side of the road. Ample parking is available on the south side of the road west of Chilhowee Dam.

The objective of this stop is to illustrate sedimentological relationships between channelized sandstone, conglomerate, and landslide breccia beds in the Wilhite Formation at STOP 10. In addition, the presence of carbonate clasts in conglomerate composed of many carbonate textural types has important implications for developing age relationships and a model for the Wilhite basin and the pre-Walden Creek carbonate basin.

This outcrop contains abundant channelized deposits of conglomerate made up of numerous rock types, interbedded with landslide breccia and sandstone. The conglomerate contains mostly quartz pebbles, with lesser amounts of carbonate pebbles, eroded carbonate breccia pebbles, and armored mud balls, particularly in the western portion of the outcrop (Fig. 17). Armored mud balls are lined with 4-8 cm quartz pebbles. Conglomerate beds are locally graded, and may be up to several meters thick. Landslide breccia beds (up to 2 m thick), consisting of quartz pebbles and shale fragments in a matrix of quartz sand are interbedded with and truncated by the conglomerate. Channelized quartz sandstones have also been truncated by these landslide breccias. These sandstones are coarse- to fine-grained, and consist of immature silica-rich sediments. In the eastern portion of this outcrop, quartz sandstones and quartz pebble conglomerate commonly exhibit well-developed and repetitive graded bedding.

The multiple truncations of different lithologies indicate an environment characterized by intense submarine erosion. The strata exposed in the roadcut are interpreted as deposits within a fan delta.

End of Trip. Return to Maryville and Knoxville.

REFERENCES CITED

Boyer, S. E., and Elliott, D., 1982, Thrust systems: American Association of Petroleum Geologists Bulletin, v. 66, p. 1196-1230.

Brown, A., 1971, Deformation in the Wilhite Formation between the Capshaw Branch and Miller Cove faults: Geological Society of America Abstracts with Programs, v. 3, no. 5, p. 298–299.

Hatcher, R. D., Jr., 1991, Interactive property of large thrust sheets with footwall rocks—the subthrust interactive duplex hypothesis: A mechanism of dome formation in thrust sheets: Tectonophysics, v. 191, p. 237–242.

Hatcher, R. D., Jr., 1991, Structural Geology: Principles, Concepts and Problems, 2nd ed.: Upper Saddle River, New Jersey, Prentice Hall Inc. (Pearson), 525 p.

Hatcher, R. D., Jr., Price, V., Jr., and Snipes, D. S., 1973, Analysis of chemical and paleotemperature data from selected carbonate rocks of the southern Appalachians: Southeastern Geology, v. 15, p. 55-70.

Hatcher, R. D., Jr., Costello, J. O., and Edelman, S. H., 1986, The Smokies Foothills duplex and possible significance of the Guess Creek fault: A corollary to the mapping of King and Neuman: Geological Society of America Abstracts with Programs, v. 18, p. 226.

Hatcher, R. D., Jr., Lemiszki, P. J., and Whisner, J. B., 2007, Boundaries and internal deformation in the curved southern Appalachian foreland fold-thrust belt *in* Sears, J. W., Harms, T., and Evenchick, C. eds., Whence the Mountains? Inquiries into the Evolution of Orogenic Systems: A Volume in Honor of Raymond A. Price: Geological Society of America Special Paper 433, p. 243–276. Doi: 10-1730/2007.2433(12).

(a)

(b)

Figure 17. Sedimentological and structural features in roadcut across US 129 from Chilhowee Dam. (a) Slate pebbles with vein quartz pebbles stuck to them providing the appearance that the slate pebbles were mudballs when they were deposited and accreted pebbles suggesting they may have become armored (sometimes called armored mudballs). Orange-weathering clasts are dolostone. (b) Slate and gray limestone cobbles in a matrix dominated by white vein quartz pebbles. Small dark objects in the limestone cobble are quartz grains, most of which are composed of clear quartz and may be frosted. The dark gray cobbles that today are slate were likely mud when they were deposited. Pocketknife is 8.5 cm long.

Hatcher, R. D., Jr., Merschat, C. E., Milici, R. C., and Wiener, L. S., 1978, A structural transect of the southern Appalachians, Tennessee: 1978 Guidebook, Tennessee Division of Geology, Report of Investigations 37, p. 5–52.

Hatcher, R. D., Jr., Thomas, W. A., Geiser, P. A., Snoke, A. W., Mosher, S., and D. V. Wiltschko, 1989, Alleghanian orogen, Chapter 5 *in* Hatcher, R. D., Jr., Thomas, W. A., and Viele, G. W., eds., The Appalachian–Ouachita orogen in the United States: Boulder, Colorado, Geological Society of America, The Geology of North America, v. F–2, p. 233–318.

Jonas, A. I., 1932, Structure of the metamorphic belt of the Southern Appalachians: American Journal of Science, 5th Series, v. 24, p. 228-243.

Keith, A., 1895, Description of the Knoxville sheet (Tennessee-North Carolina): U.S. Geological Survey Geologic Atlas, Folio 16, 6 p.

Keith, A., 1927, Great Smoky overthrust [abs.]: Geological Society of America Bulletin, v. 38, p. 154-155.

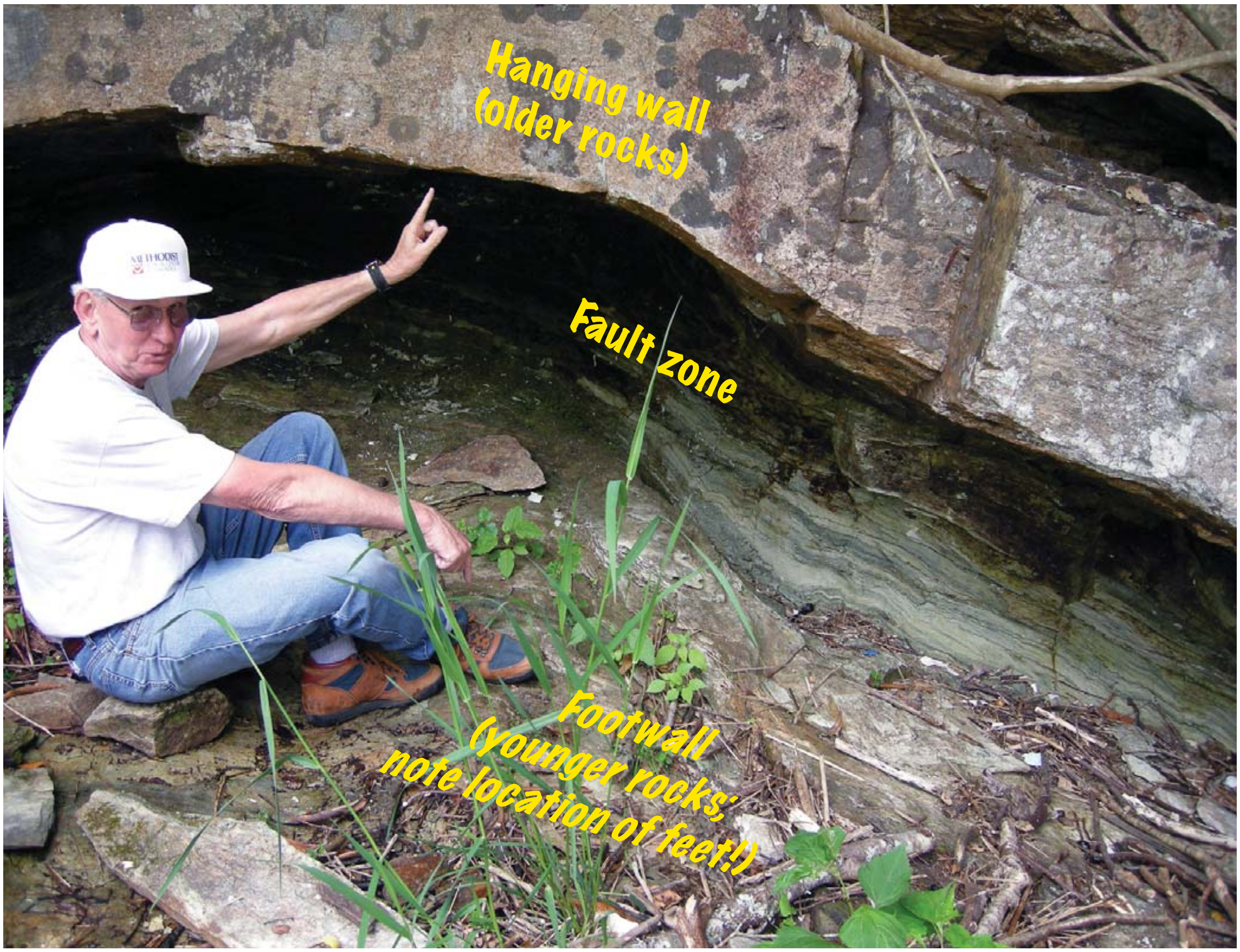
King, P. B., 1964, Geology of the central Great Smoky Mountains, Tennessee: U.S. Geological Survey Professional Paper 349-C, 148 p.

Neuman, R. B., 1955, Middle Ordovician rocks of the Tellico-Sevier belt, eastern Tennessee: U.S. Geological Survey Professional Paper 274-F, p. 141-177.

Neuman, R. B., and Nelson, W. H., 1965, Geology of the western Great Smoky Mountains, Tennessee: U.S. Geological Survey Professional Paper 349-D, 81 p.

Unrug, R., Ausich, W. I., Bednarczyk, Cuffey, R. J., Mamet, B. L., Palmes, S. L., and Unrug, S., 2000, Paleozoic age of the Walden Creek Group, Ocoee Supergroup, in the western Blue Ridge, southern Appalachians: Implications for evolution of the Appalachian margin of Laurentia: Geological Society of America Bulletin, v. 112, p. 982-996.

Wilson, C. W., Jr., 1935, The Great Smoky thrust fault in the vicinity of Tuckaleechee, Wear, and Cades Coves, Blount and Sevier Counties, Tennessee: Journal of the Tennessee Academy of Science, v. 10, p. 57-68.



Fault components (at Linville Falls fault in NC, demonstrated by scholarly nuclear engineer.