EAST TENNESSEE GEOLOGICAL SOCIETY

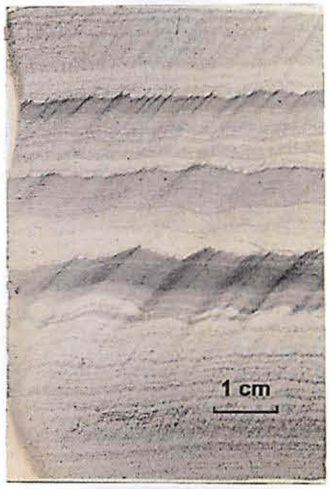
Field Trip Guide
December 7, 2024

Traverse from the Upper Crust to the Lower Middle Crust of the Taconian Orogen (470~440 Ma), Southern Appalachians

Chilhowee sandstone core Ocoee #1 Dam

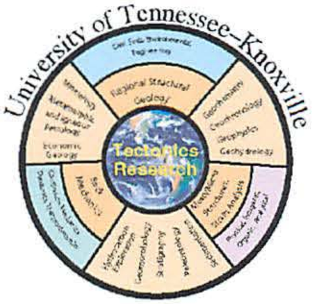
Bob Hatcher*

Extinguished Scientist
& Professor Emeritus



Wilhite Slate graded beds, US 64

Folds on Lake Chatuge, NC



Chunky Gal Mtn cut boomerang fold, US 64

Chunky Gal Mtn cut recumbent fold, US 64

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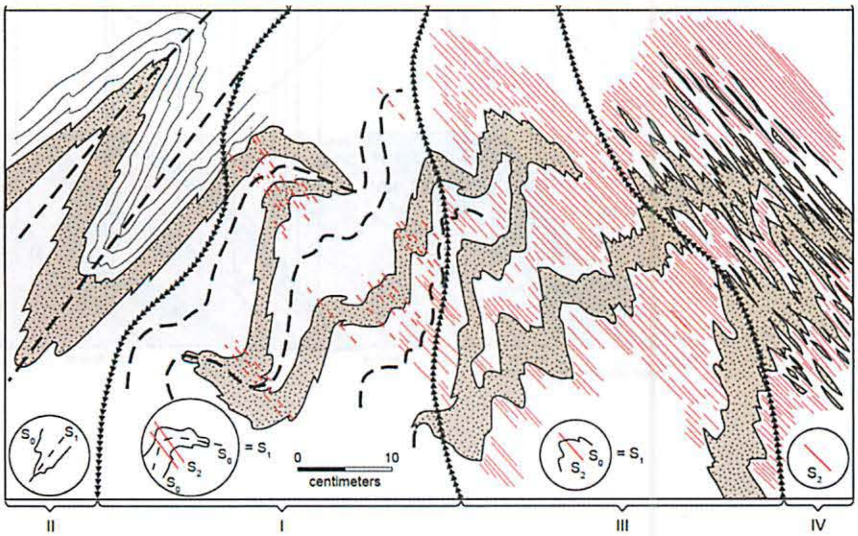


Changes in Intensity of Metamorphism and Deformation Along US 64 from the Great Smoky Fault SE Tennessee to W of Franklin, SW North Carolina:
Traverse from the Upper Crust to the Lower Middle Crust of the Taconian Orogen (470–440 Ma), Southern Appalachian

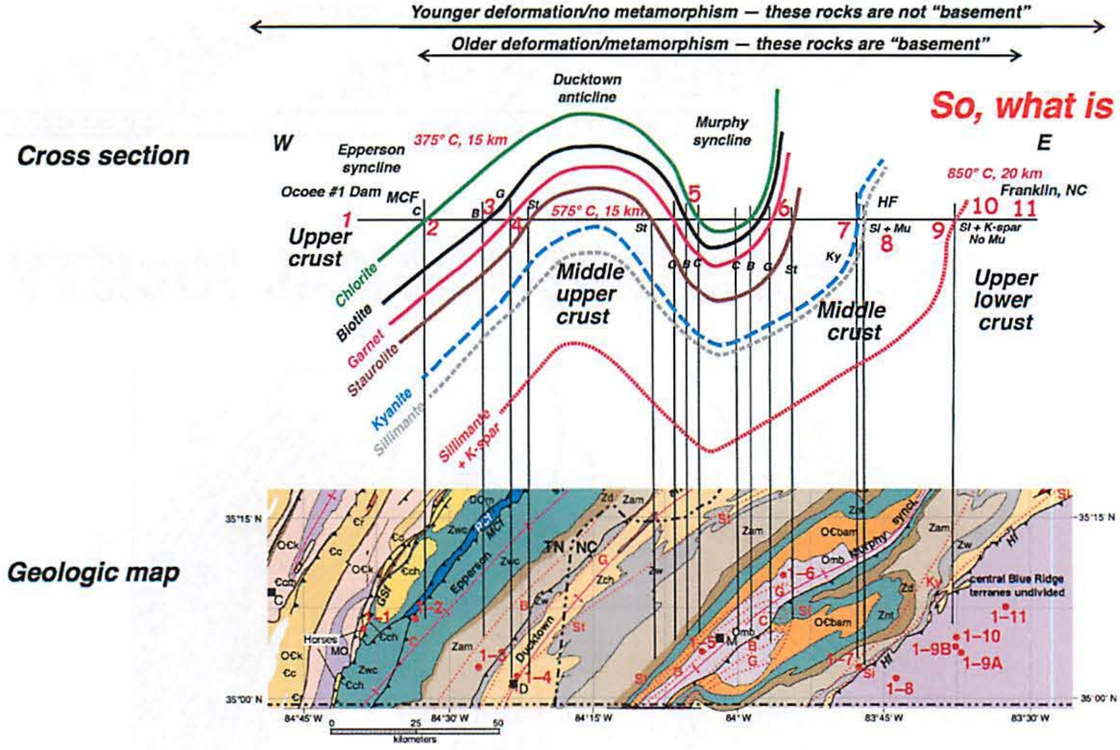
*Bob Hatcher**

Extinguished Scientist
& Professor Emeritus

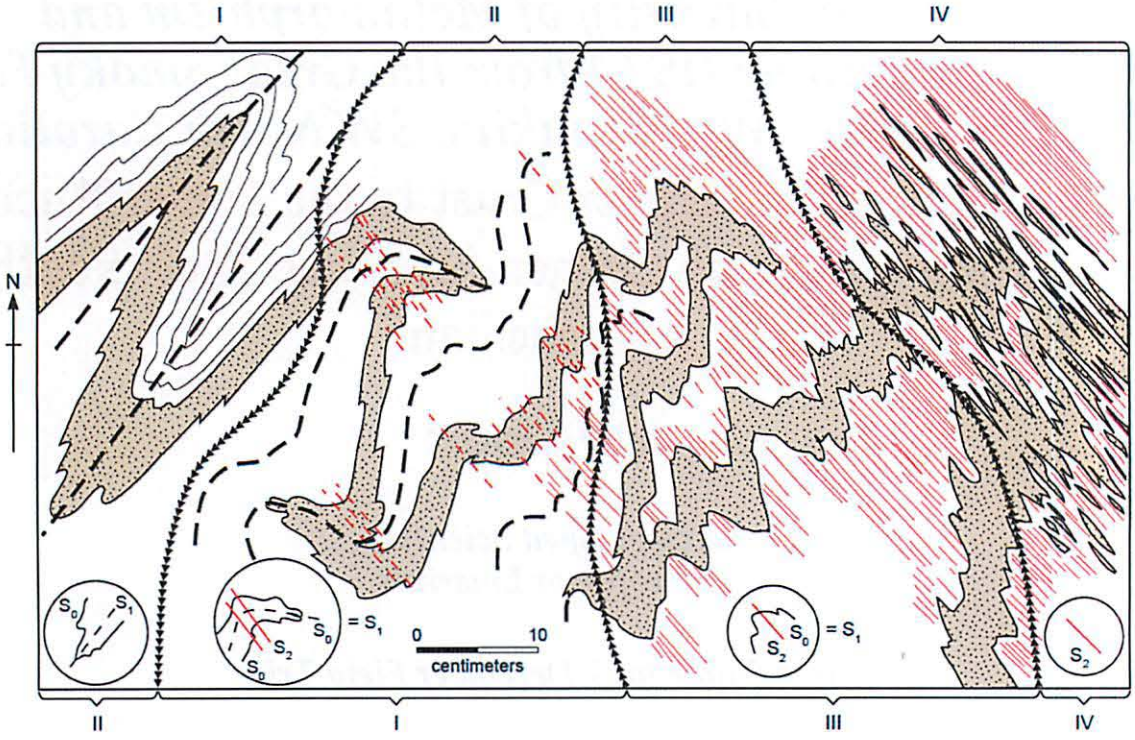
Field Guide for 7 December Field Trip

**Oak Ridge resident*

So, what is "basement"



Concept: **Transposition** Progressive deformation renders all layering parallel



INTRODUCTION

The purpose of this field guide is to introduce a geologic traverse from the very external parts of the internal parts of the southern Appalachians to what was the lower crust of an orogenic belt that formed from 470-440 Ma. While this event is recognized throughout the Appalachians from Alabama to Newfoundland, orogenies occurring at the same time have also been documented worldwide (van Staal and Hatcher, 2010). Most more recent orogens formed more recently like the Himalayas and North American Cordillera, because they are not eroded very deeply, do not have much of their inner workings exposed for geologists to study. In addition to the deeply exposed Taconian orogen in parts of the Appalachians, and in contrast with other major orogenic belts in the world, the Appalachians record two additional major tectonic events of at least equal magnitude that are recognized throughout the chain (Hatcher, 2010). The internal parts of these orogens are also exposed at the present level of erosion, a claim that cannot be made for any other Phanerozoic to modern orogenic belt on Earth.

This field trip route has been followed and taken many forms since it was first run in 1978 (Hatcher et al., 1978), for non-geologists, undergraduate and graduate geology students, and local to world-renowned professionals. The rocks have not changed much during this time, except to become slightly older. Some of the exposures have undergone greater decomposition by weathering or degradation by highway department modifications. This traverse remains a world-class journey from the external to the internal parts of a mountain chain (Figure 1). The emphasis of this field trip is on changes in metamorphic grade and deformation intensity as we go eastward into the Blue Ridge, which correlates with traveling deeper into the crust to near the base of the middle crust, to the point where there are almost no minerals that contain water (or OH^-) and the rocks have begun to melt (Figure 2). We will actually see the first indications of melting in the rocks when we reach STOP 7.

The western Blue Ridge consists of rocks deposited along the rifted margin of North America (Ocoee Supergroup) overlain by the Chilhowee Group (Lower Cambrian), which contains the cleaner sediments of the rift-to-drift transition. The Chilhowee Group is succeeded by the Shady Dolomite, the first Paleozoic carbonate bank deposited facing the open ancient Iapetus ocean (product of the breakup of supercontinent Rodinia ~750 Ma), and the overlying predominantly sandstone-shale Rome Formation (Fig. 5). These rocks were deposited nonconformably on Grenvillian 1.2–1.0 Ga basement. This sequence of Neoproterozoic to Ordovician rocks and events of the western Blue Ridge are analogous to the Triassic to Tertiary sediments deposited in the fault-bounded basins in the Piedmont and Atlantic Coastal Plain during the breakup of supercontinent Pangea.

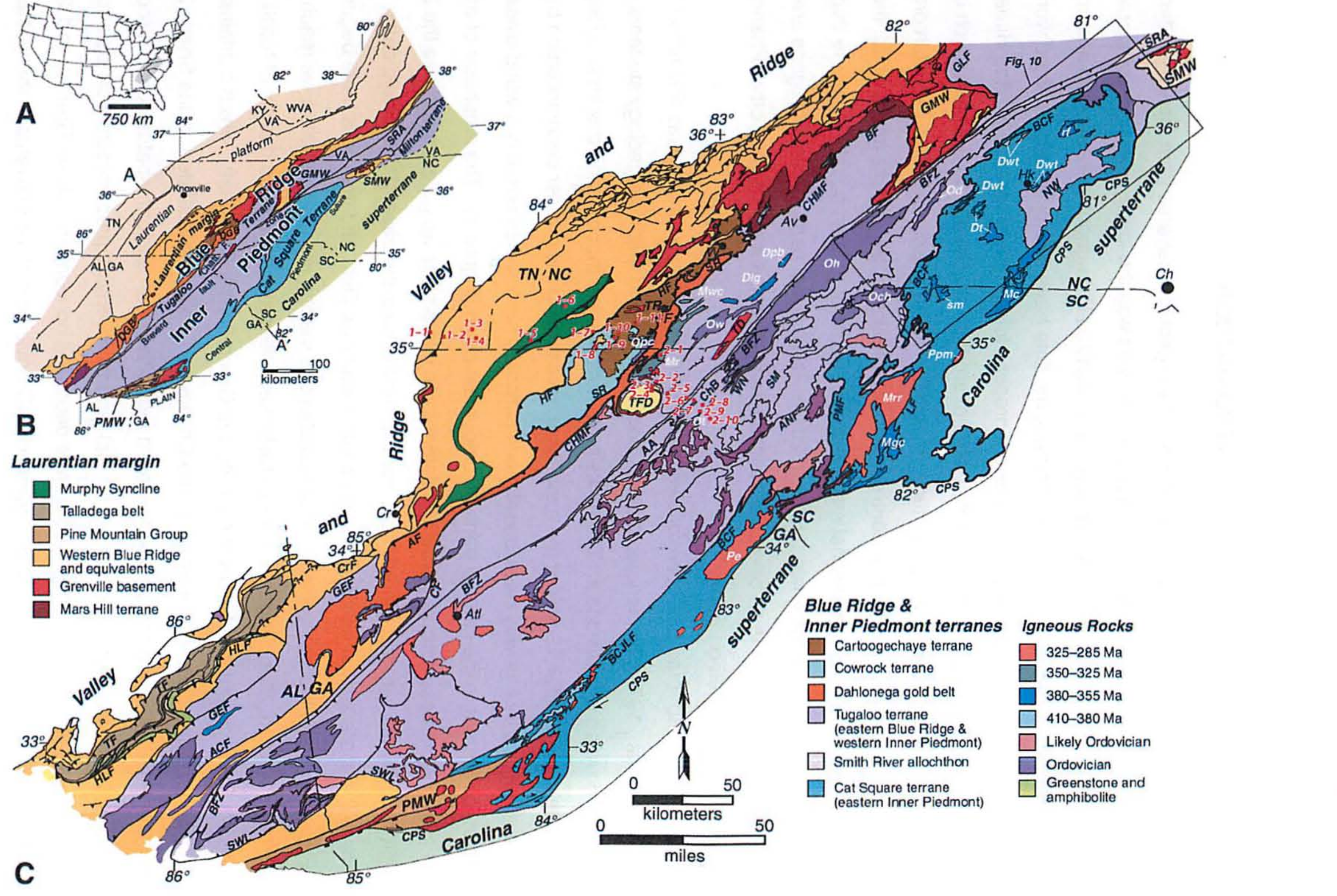

A
750 km
B
C
Laurentian margin
Murphy Syncline
Talladega belt
Pine Mountain Group
Western Blue Ridge and equivalents
Grenville basement
Mars Hill terrane
Blue Ridge & Inner Piedmont terranes
Cartoogechaye terrane
Cowrock terrane
Dahlonega gold belt
Tugaloo terrane (eastern Blue Ridge & western Inner Piedmont)
Smith River allochthon
Cat Square terrane (eastern Inner Piedmont)
Igneous Rocks
325–285 Ma
350–325 Ma
380–355 Ma
410–380 Ma
Likely Ordovician
Ordovician
Greenstone and amphibolite
Valley and Ridge
Blue Ridge
Inner Piedmont
Carolina superterrane
Laurentian margin
platform
Tugaloo
Brevard fault
Cat Square Terrane
Central Piedmont suture
Milton terrane
Knoxville
0 100 kilometers
0 50 kilometers
0 50 miles
N
Fig. 10
TN NC
AL GA
SC GA
NC SC
VA NC
KY VA WVA
TFD
GMW
SMW
PMW
SRA
Atl
Av
Ch
Cr
CPS
BFZ
CHMF
HF
SR
AF
GEF
HLF
TF
BCJLF
SWL
ACF

Figure 1.

Figure 1. (A) Index map of the United States. (B) Simplified tectonic map of the southern Appalachians showing the location of the Blue Ridge, Inner Piedmont, and other major tectonostratigraphic terranes. A–A′ is the approximate location of cross section in Figure 4. Chatt. F.— Chattahoochee fault; DGB—Dahlonega gold belt; GMW— Grandfather Mountain window; PMW—Pine Mountain window; SMW—Sauratown Mountains window; SRA—Smith River alloch-thon. Colors: Dark purple—Elkahatchee pluton (Middle Ordovician); yellow, pink, light orange, and brown—internal Blue Ridge terranes; red—Grenville and pre-Grenville basement. (C) Tectonic map of the Blue Ridge and Inner Piedmont of Alabama, Georgia, North Carolina, South Carolina, and Tennessee with locations of field-trip stops shown in red. Inset box shows approximate location of Figure 10. Map modified from Hatcher et al. (2007a) and Merschat et al. (2010). AA—Alto allochthon; ACF—Alexander City fault; AF—Allatoona fault; ANF—Anderson fault; BCF—Brindle Creek fault; BCJLF—Brindle Creek–Jackson Lake fault; BF—Burnsville fault; BFZ—Brevard fault zone; CF— Chattahoochee fault; ChB—Chauga belt; CHMF—Chattahoochee–Holland Mountain fault; CPS—central Piedmont su-ture; CrF— Cartersville fault; Dlg—Looking Glass granodiorite; Dpb—Pink Beds granodiorite; Dt—Toluca Granite; Dwt—Walker Top Gran-ite; GEF—Goodwater–Enitachopco fault; GLF—Gossan Lead fault; GMW—Grandfather Mountain window; GSF—Great Smoky fault; HF—Hayesville fault; HLF—Hollins Line fault; LF—Laurens fault; Mc—Cherryville Granite; MCF—Miller Cove fault; Mgc—Gray Court granite; Mr—Rabun granodiorite; Mrr—Reedy River granite; Mwc—Walnut Creek granodiorite; NW—Newton window; Obc—Brooks Crossroads granitoid; Och—Caesars Head granite; Od— Dysartsville Tonalite; Oh—Henderson Gneiss; Opc—Persimmon Creek Gneiss; Ot—Toccoa granitoid; Ow—Whiteside Granodiorite; Pe—Elberton Granite; PMF—Paris Mountain fault; PMW—Pine Mountain win-dow; Ppm—Pacolet Mills Granite; rf—Rocky Face pluton; SM—Six Mile–Seneca nappe; SMW—Sauratown Mountains window; SR—Soque River fault; SRA—Smith River allochthon; SWL—Stone Wall Line fault; TD—Toxaway dome; TF—Talladega fault; TFD—Tallulah Falls dome; TR—Trimont Ridge complex; WN—Walhalla nappe. Cit-ies: Atl—Atlanta; Av—Asheville; Ch—Charlotte; Cr—Cartersville; F—Franklin; Hk—Hickory; W—Waynesville. States: AL—Alabama; GA—Georgia; KY—Kentucky; NC—North Carolina; SC—South Carolina; TN—Tennessee; VA—Virginia; WVA—West Virginia.

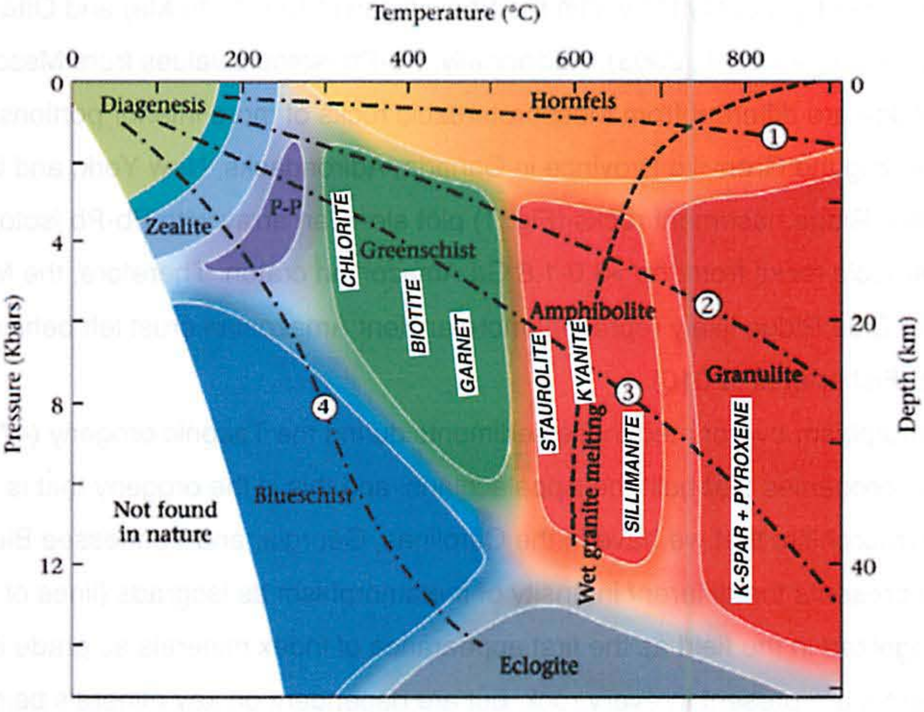


Figure 2. Correlation of T and P (depth) with the minerals we will see that tell us where we are in the crust on our traverse.

Supercontinent Rodinia formed 1.3–1.0 Ga as a product of the Grenvillian orogeny, which generated a significant volume of crust worldwide, evidenced by the distribution of similar age rocks preserved in the ancient cores of most continents. The Grenville orogeny in eastern North America is the product of three tectonic events: the Elzevirian (actually pre-Grenville) from 1.25–1.22 Ga, Shawinigan from 1.2–1.14 Ga, Ottawan from 1.09–1.02 Ga, and Rigolet from 1.01–0.98 Ga (McLelland et al., 2013).

In the southern Appalachians, the western Blue Ridge consists of rocks deposited along the rifted margin of Laurentia (Ocoee Supergroup of impure sediments) overlain by the Chilhowee Group (Lower Cambrian), which contains the cleaner sediments of the rift-to-drift transition. The Chilhowee Group is succeeded by the Shady Dolomite, the first Paleozoic carbonate bank deposited facing the open Iapetus ocean, and the overlying predominantly sandstone-shale Rome Formation. These rocks were deposited nonconformably on Grenvillian 1.2–1.0 Ga basement. This sequence of Neoproterozoic to Ordovician rocks and events of the western Blue Ridge are analogous to the Triassic to Tertiary sediments deposited in the fault-bounded basins in the Piedmont and Atlantic Coastal Plain during the breakup of Pangea. Several smaller massifs occur in the Cartoogechaye (Trimont Ridge) and Tugaloo terranes (Toxaway and Tallulah Falls domes) (Fig. 1). Most of the Mesoproterozoic basement varies from granite to granodiorite gneiss with some biotite gneiss, amphibolite, and granulite gneiss. Sensitive high-resolution ion microprobe (SHRIMP) U-Pb zircon ages of basement generally fall within the Shawinigan (1190–1140 Ma) and Ottawan (1080–1040 Ma) events (Carrigan et al., 2003). Additionally, Pb-Pb isotopic values from Mesoproterozoic rocks of the Blue Ridge are different from Mesoproterozoic rocks of more interior portions of the Lauren-tian craton including the Grenville Province in Canada; Adirondacks, New York; and Llano uplift, Texas. Instead, Blue Ridge basement rocks (Fig. 1) plot along an array with Pb-Pb isotopic values from Mesoproterozoic rocks from the >3.0-1.8 Ga Amazonian craton. Therefore, the Mesoproterozoic rocks of the Blue Ridge likely represent more ancient Amazonian crust left behind after the breakup of Rodinia (Fisher et al., 2010).

Metamorphism overprinted these sediments during the Taconic orogeny (470-448 Ma), the first of the three orogenies that built the Appalachians, and this is the orogeny that is responsible for most of the metamorphism that we have in the Carolinas, Georgia, and Tennessee Blue Ridge (Fig. 3). Figure 3 represents the different intensity of metamorphism as isograds (lines of equal metamorphic grade recognized in the field as the first appearance of index minerals as grade increases). Not all index minerals are present in every rock, but are dependent on key minerals being developed in aluminous shales that become slate then phyllite then schist as grade increases. We are fortunate that all of the index minerals from low grade (chlorite) to very high grade (sillimanite-K-spar without most hydrous minerals) have been recognized along the traverse we will make today.

The cross-section line in Figure 4 is an interpretation of the geology from the surface, where the geology is reasonably known, to a depth of several kilometers, where the structure is known only by geophysical techniques and the rules for constructing rigorous cross sections.

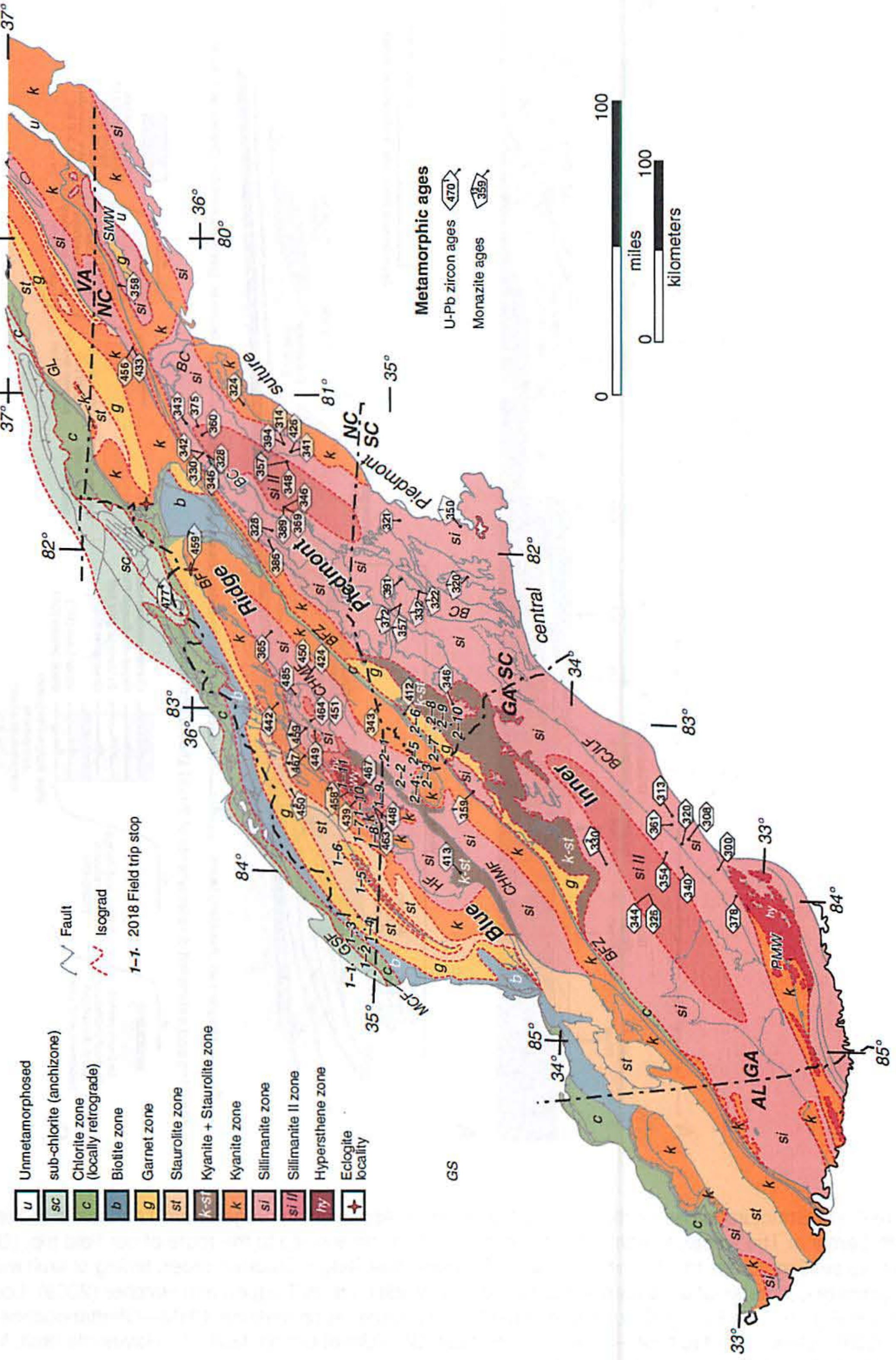


Figure 3. Metamorphic isograd map of the southern Appalachian Blue Ridge and Inner Piedmont, modified from Merschat et al. (2017; see references therein for sources of compilation). Wayah granulite-facies metamorphic core (K-spar-sillimanite + pyroxene) indicated by abbreviation, Wy. Field-trip stops are shown. From Merschat et al. (2018). BCJLF—Brindle Creek–Jackson Lake fault; BF—Burnsville fault; BFZ—Brevard fault zone; CHMF—Chattahoochee-Holland Mountain fault; GLF—Gossan Lead fault; GSF—Great Smoky fault; HF—Hayesville fault; MCF—Miller Cove fault; PMW—Pine Mountain window. States: AL—Alabama; GA—Georgia; NC—North Carolina; SC—South Carolina; VA—Virginia.

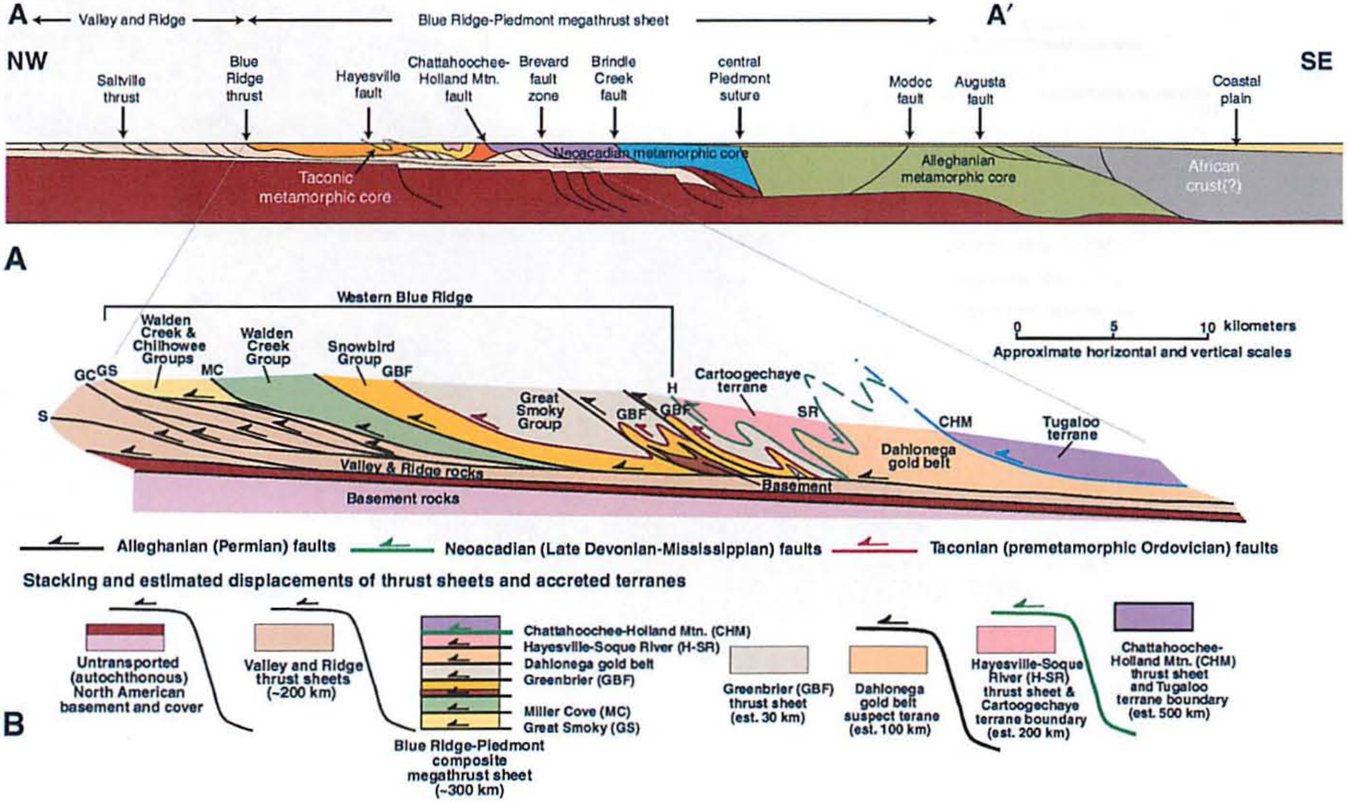


Figure 4. (A) Structural cross section across the southern Appalachian orogen from Tennessee to the Coastal Plain in South Carolina. The western segment of the cross-section line is close to the route of our field trip. (B) Diagrammatic NW-SE cross section across the Tennessee–North Carolina Blue Ridge. Stacking order, timing of fault movement, and approximate estimates of displacement are indicated. Modified from Thigpen and Hatcher (2009). Location of the line is shown in Figure 1, and lies just northeast of the field-trip route. Abbreviations: CHM—Chattahoochee–Holland Mountain fault; GBF—Greenbrier fault; GC—Guess Creek fault; GS—Great Smoky fault; H—Hayesville fault; MC—Miller Cove fault; S—Saltville fault; SR—Soque River fault.

FIELD GUIDE

The route of the field trip is illustrated in Figure 5, which also depicts Blue Ridge topography. Figure 6 also depicts the field trip route superposed on a geologic map of our area of interest.

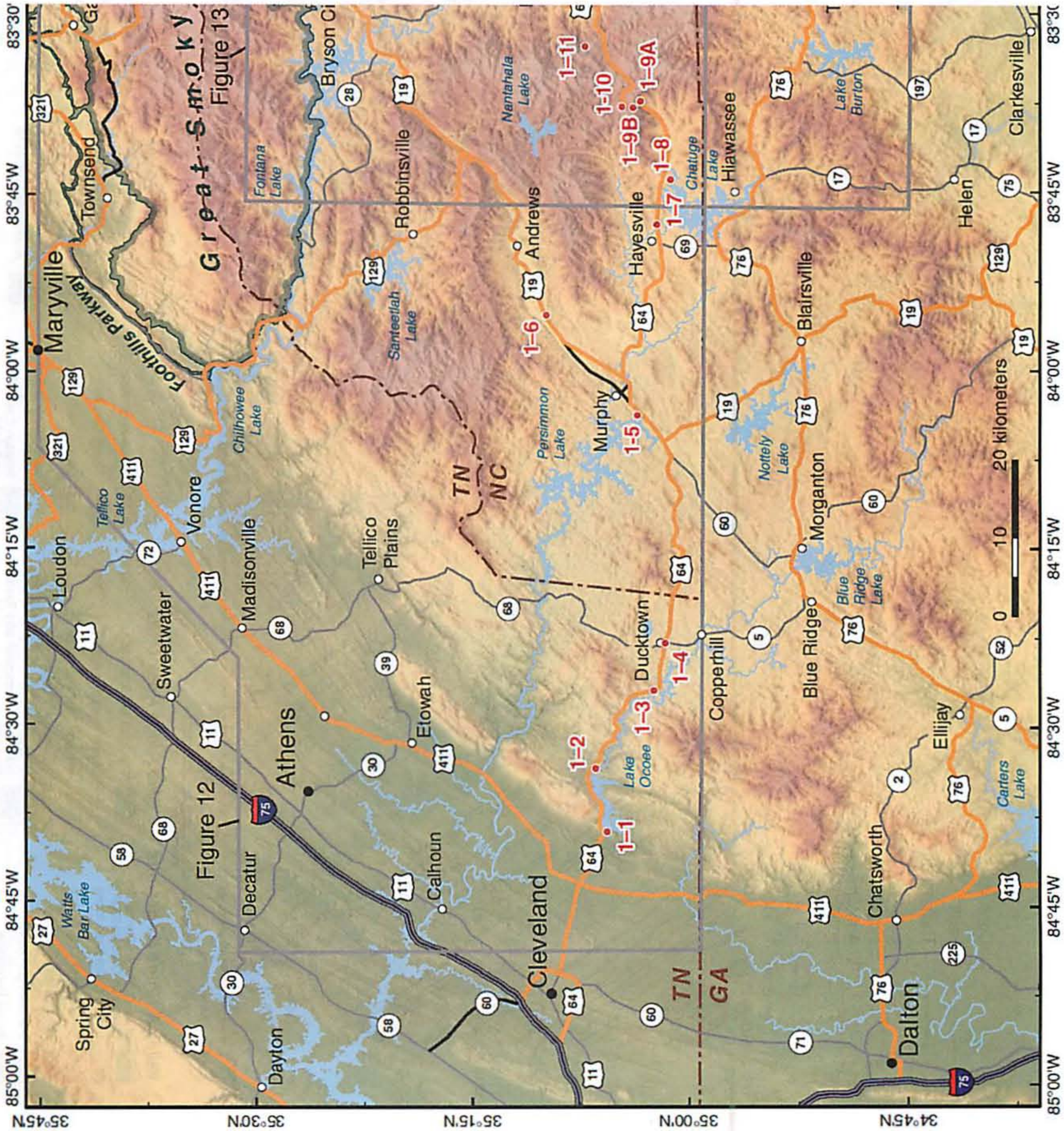


Figure 5. Field-trip route map with stops shown on a shaded relief map of adjoining parts of southeastern Tennessee, southwestern North Carolina, and northeastern Georgia. The map includes part of the Valley and Ridge and Blue Ridge. Map created by Andrew L. Wunderlich (Tennessee Geological Survey). State abbreviations: GA—Georgia; NC—North Carolina; SC—South Carolina; TN—Tennessee.

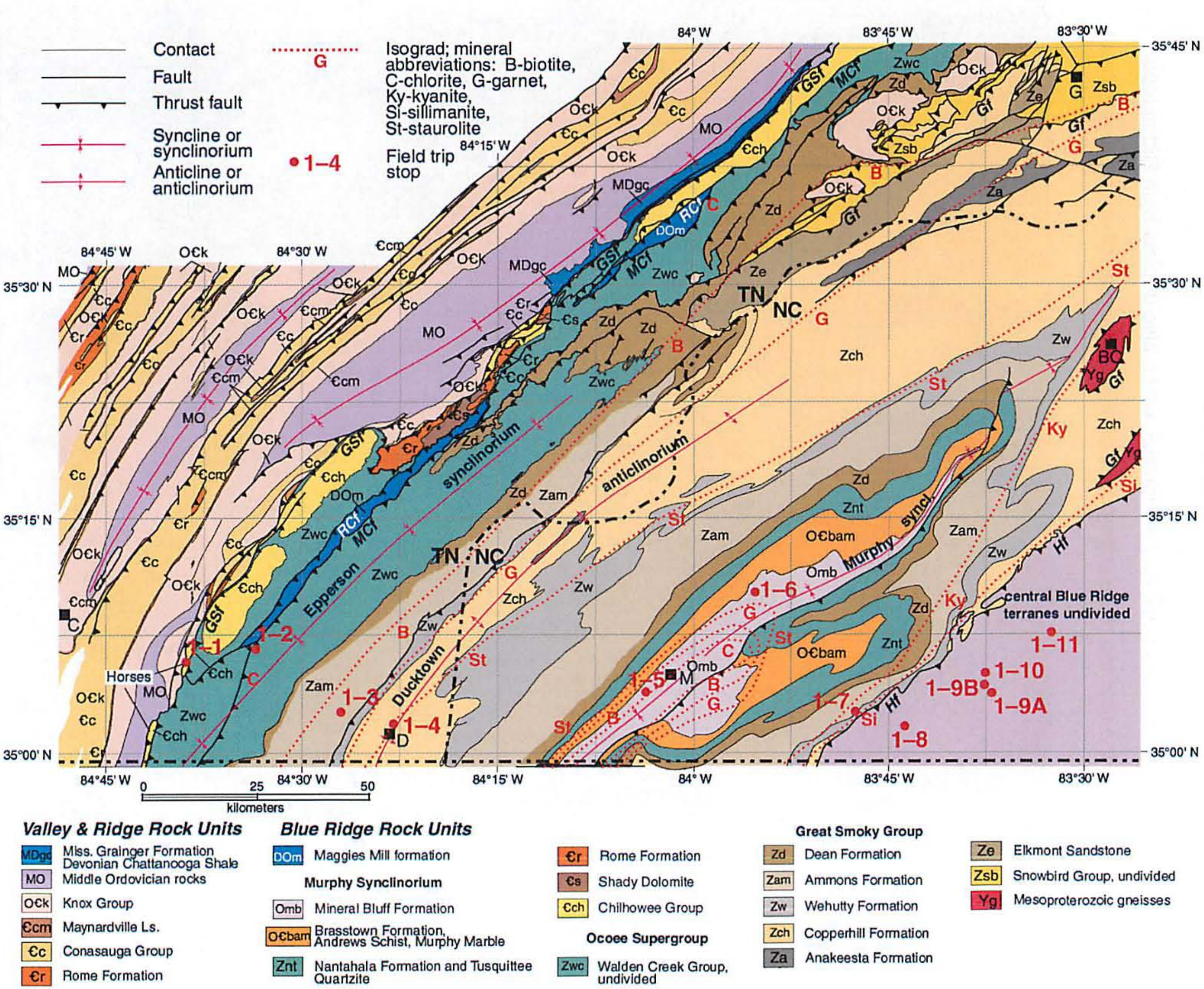


Figure 6. Geologic map of portions of the Valley and Ridge, and Blue Ridge in southeastern Tennessee and southwesternmost North Carolina showing field trip stops 1 through 11. Map compiled from numerous published sources. Gf—Greenbrier fault; GSf—Great Smoky fault; Hf—Hayesville fault; MCf—Miller Cove fault; Murphy syncl.—Murphy syncline; RCf—Rabbit Creek fault. Cities: BC—Bryson City; C—Cleveland; D—Ducktown; G— Gatlinburg; M— Murphy. States: NC—North Carolina; TN—Tennessee.

STOPS 1 and 2 involve very dangerous traffic conditions along US 64. ***PLEASE BE VERY CAREFUL WHEN YOU CROSS THE HIGHWAY.***

STOP 1. Ocoee Dam No. 1 (Parksville Reservoir) (35.0964° N, 84.6478° W)

PLEASE WATCH THE TRAFFIC HERE!!!

Purpose: *To examine a brittlely deformed, very low metamorphic grade Hesse (Chilhowee Group) sandstone block caught up by the fault and the structures within it.*

Ocoee Dam No. 1 is located some 37 km (23 mi.) east of Cleveland in southeastern Tennessee in the transition between the Blue Ridge and Valley and Ridge (Fig. 6). The geology here is complex in that the dam was constructed on a block of Chilhowee Group sandstone along the Great Smoky fault (Fig. 6). In addition, the immediate footwall of the fault consists of another block of Knox Group dolostone. Both blocks are composed of strong rocks, but each is strongly deformed internally. The exposure of part of the Chilhowee block along U.S. 64 at the dam reveals a complex of slickensided (many polished with clear quartz) surfaces in a variety of orientations, but bedding is still locally distinguishable. Highly fractured Knox Group dolostone is present in the woods along the hillslope some 50 m west of the dam on the northeast side of the highway. Additional data have been collected from exposures downstream from the spillway, and core and thin section descriptions are presented below.

The footwall of the Great Smoky fault contains several subsidiary faults above the Saltville fault in the Valley and Ridge to the W..

The geologic section constructed from exposures immediately downstream from Ocoee No. 1 Dam on the southwest side of the Ocoee River (Fig. 7) characterizes the complex deformation also observed in the exposure on U.S. 64 immediately northwest of the dam, and in core recovered from beneath the dam. Most of the Chilhowee Group rocks consist of massive sandstone with minor amounts of thin-bedded sandstone and shale in a large horse emplaced along the Great Smoky fault. The large number of faults that can be observed in the exposures immediately downstream of the spillway demonstrates the large amount of brittle deformation that occurred during the last stages of emplacement of the Great Smoky fault in the horse of Chilhowee Group sandstone and shale that is present at the dam site.

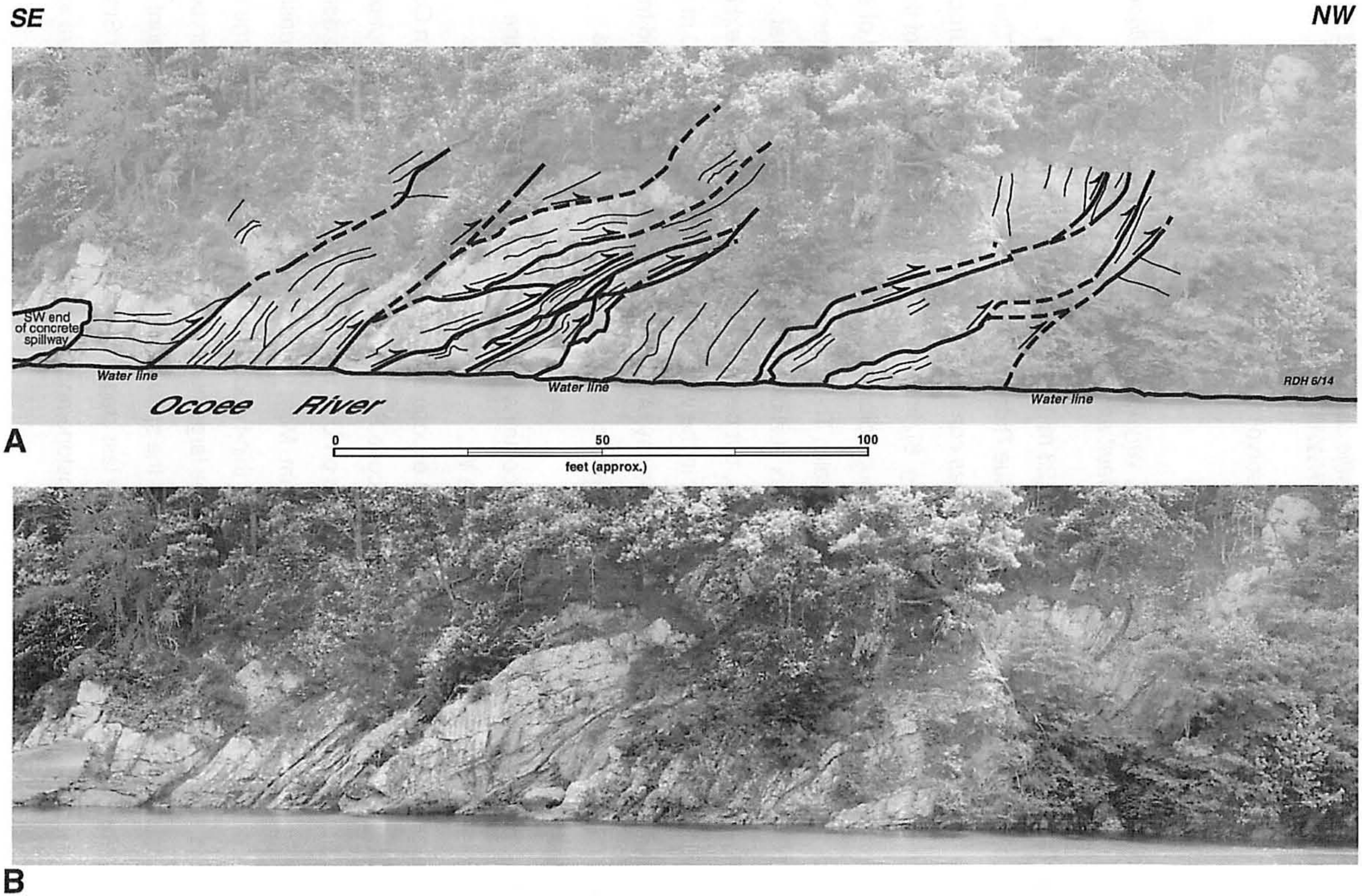


Figure 15. Photograph of the exposure on the southwest side of the Ocoee River from the end of Ocoee Dam No. 1 spillway (on left side of the section and photograph) downstream with interpreted cross section overlain onto the reduced intensity photo (A) and the original photograph (B). Faults are indicated by heavy lines (dashed where inferred); visible bedding is indicated by fine lines.

Five thin sections were cut from core derived from Ocoee #1 holes B0005 (229 ft, 69.8 m) and B006 (165.6 ft, 50.5 m), where coherent rock could be sampled and brittle faults are visible in the core (Fig. 8). Banding in the core material at the hand specimen scale led to the hypothesis there was deformation at sufficiently elevated temperatures during Great Smoky thrust sheet emplacement to initiate ductile flow and recrystallization in the quartz that dominates the sandstone in the most intensely deformed quartzite, but this was not borne out at the microscopic scale (Fig. 8). The layering shown in the photos consists of alternating quartz-rich layers with clay-rich layers. The quartz has not undergone incipient recrystallization that would indicate deformation above 300 °C. Instead, quartz and detrital feldspar (both plagioclase and K-feldspar) grains are still angular, abundant fine-grained clay (probably illite) and detrital muscovite are present, and there are numerous tectonic stylolites present in all five thin sections (Fig. 8). This indicates pressure solution accompanied deformation until the rocks of the block were transported close to the surface along the Great Smoky fault, where the deformation became overwhelmingly brittle, producing numerous large and small faults, and other fractures. The maximum principal stress (σ_1) at the time the rock mass was being deformed is perpendicular to the stylolite layers. The "quartzite" at the surface, however, remains well-cemented sandstone, but the quartzite in the core is "welded" indicating some mobility of quartz and is still not a true metamorphic rock. This is further confirmed by the lack of recrystallization of detrital muscovite and clay minerals, but the stylolites indicate the maximum temperature reached during deformation was ~200 °C, enough to cause pressure disssolution of quartz grains, but not high enough for the rock mass to exhibit any incipient quartz recrystallization structures or ductile flow.

There appear to be at least three kinds of fractures present in the thin sections: tension fractures (Mode I), stylolites produced by compression, and small faults, which are shear fractures (Modes II and III). Tension fractures are characterized by opening perpendicular to the fracture surface, are commonly filled with quartz fragments and clays, and frequently contain coarse-grained carbonate. The carbonate is slightly twinned, indicating it has undergone some deformation after crystallization. Carbonate was not observed in any of the five sections in interpreted stylolites or in Mode II and III fractures. An important geotechnical conclusion that could be drawn from this observation is that, if pervasive in fractures throughout the sandstone, the carbonate would have strain softened the rock mass, and also provided a soluble component that would have weakened the fractured sandstone with minimal weathering. This may be the reason there was such poor

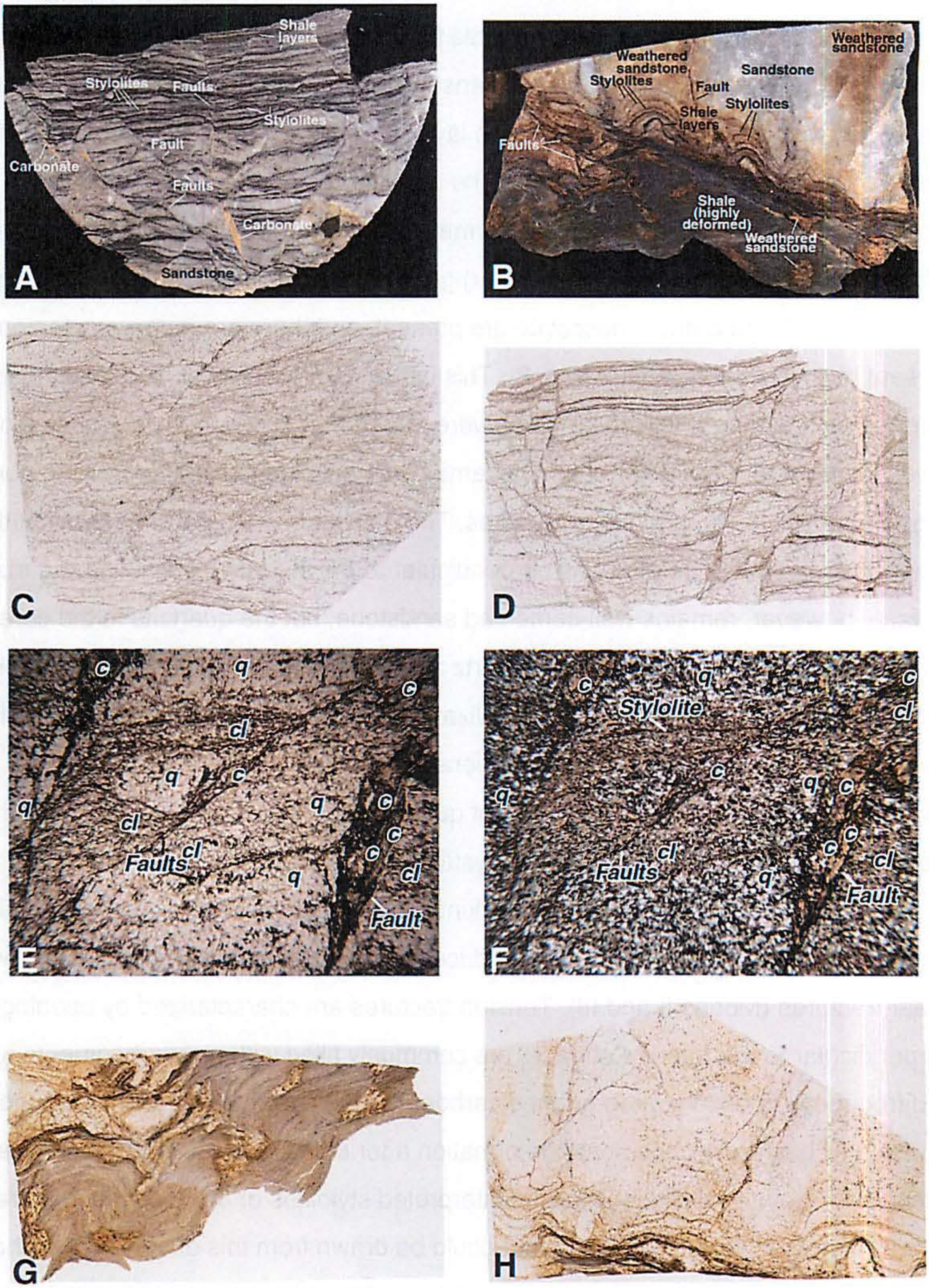


Figure 8. Composite of digital images and scans of Ocoee #1 core from B0005 and B006 that illustrate brittle deformational structures in the quartzites near the Great Smoky fault at Ocoee Dam No. 1. (A) Sawed sandstone surface of core from B0005 at depth 69.8 m (229 ft) from which thin sections were cut (C, D, E, and F). Banding caused by interlayered quartz-rich and clay-rich layers is displaced by small late brittle faults with apparent normal displacement. The difficulty of matching layers across faults probably indicates these are oblique-slip faults with respect to the saw cuts. Carbonate (either dolomite or ankerite, iron-bearing dolomite) was deposited in some of the exten-sion cracks (Mode I fractures) in the sample. Many of the layers have been modified by pressure solution, making them very irregular. Maxi-mum width of specimen in A is ~7.8 cm. (B) Sawed partially weathered shale-sandstone contact in B006 at depth of 50.5 m (165.6 ft) from which thin sections were made (G, H). This sample is composed mostly of sandstone with layers of shale along the dark side. Banding consists of original bedding, stylolites, and curved bands produced by diffusion of iron hydroxide (Liesegang bands) away from the weathered surface. Maximum width of specimen in B is ~8.2 cm. (C and D) Digital scans of thin sections of core samples from Ocoee #1 B0005 at depth of 69.8 m (229 ft). The thin sections are dominated by brittle deformation, and some pressure solution, as indicated by the presence of stylolites. Maximum width of C is 5 cm, maximum width of D is 5.7 cm. (E and F) Photomicrographs of parts of thin sections of core from B0005 that illustrate some of the representative deformation structures and textures present in the rocks at Ocoee #1. Sandstone (q—quartz) with interlayers of clay-rich material (cl) cut by faults, some of which propagated along Mode I extension fractures that had formed earlier and were filled with carbonate (either dolomite or ankerite). The carbonate was fragmented when the faults propagated through these veins. E is in plane light; F is crossed polars. (G and H) Digital scans of thin sections of a sample from B006 at depth of 50.5 m (165.6 ft). (G) Shaly material was deformed into small folds and the stronger quartzite was fractured and cut by faults. (H) The best examples of stylolites of any of the Ocoee Dam No. 1 spillway thin sections.

core recovery in some holes, accompanied by abundant rusty iron (probably limonite) staining, and poor rock quality in much of the core. Similarly, the stylolites introduce additional potentially weak layers in the rock, another possible reason for poor core recovery near the faults that are present in the block of Knox.

Continue E on US 64/74 to a creek called Maddens Branch and park a short distance to the E in a layby.

STOP 2. *Cleavage and Primary Sedimentary Structures in Wilhite Formation (Walden Creek Group) at Madden Branch (35.1096° N, 84.5590° W)*

Because of the obstacles present on the N side ot the highway, we will stop only to have a look at the rocks from the river side of the highway. Even so, **WATCH THE TRAFFIC HERE, EVEN IF YOU ARE NOT CROSSING THE HIGHWAY!!!**

Purpose: *To examine primary and tectonic structures in chlorite-grade (lower greenschist facies) slate, sandstone, and silty carbonate (muscovite + quartzite + chlorite + magnetite).*

Maddens Branch (Fig. 6 and 10) lies ~11 km east of Ocoee Dam No. 1 on U.S. 64, and exposes highly cleaved and folded chlorite-grade rocks of the Miller Cove thrust sheet (Fig. 10) (Thigpen and Hatcher, 2017). The rocks are mapped as Wilhite Formation, Walden

Creek Group. Hurst and Schlee (1962) considered the rocks at Madden Branch to be the youngest rocks in the Neoproterozoic succession in this area. The rocks consist of greenish-gray slate with thin interlayers of fine-grained, tan, carbonate-rich siltstone along with moderate to thick beds of massive- to medium- or coarse-grained gray feldspathic sandstone. The sandstone beds range from thicknesses of a few centimeters to >1 m. Ripple and scour marks are present on some bedding planes (Fig. 18). Part of the section is composed of variegated sand and shale or siltstone layers ranging from greenish to reddish gray or to more buff colors.

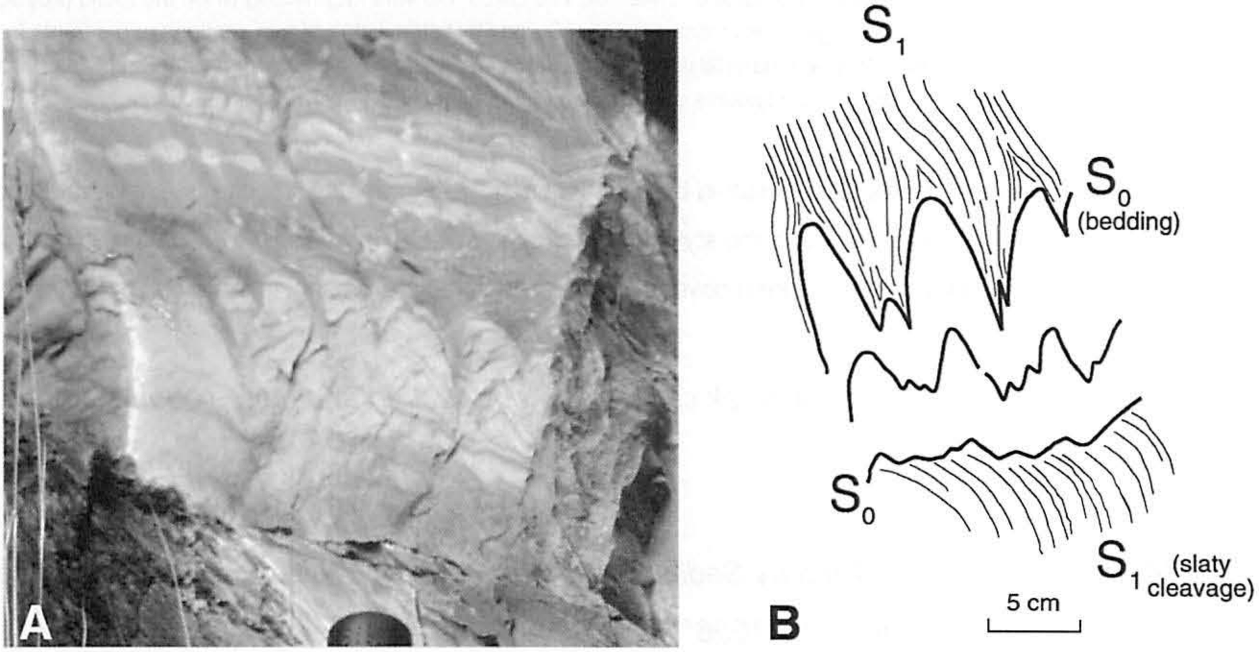
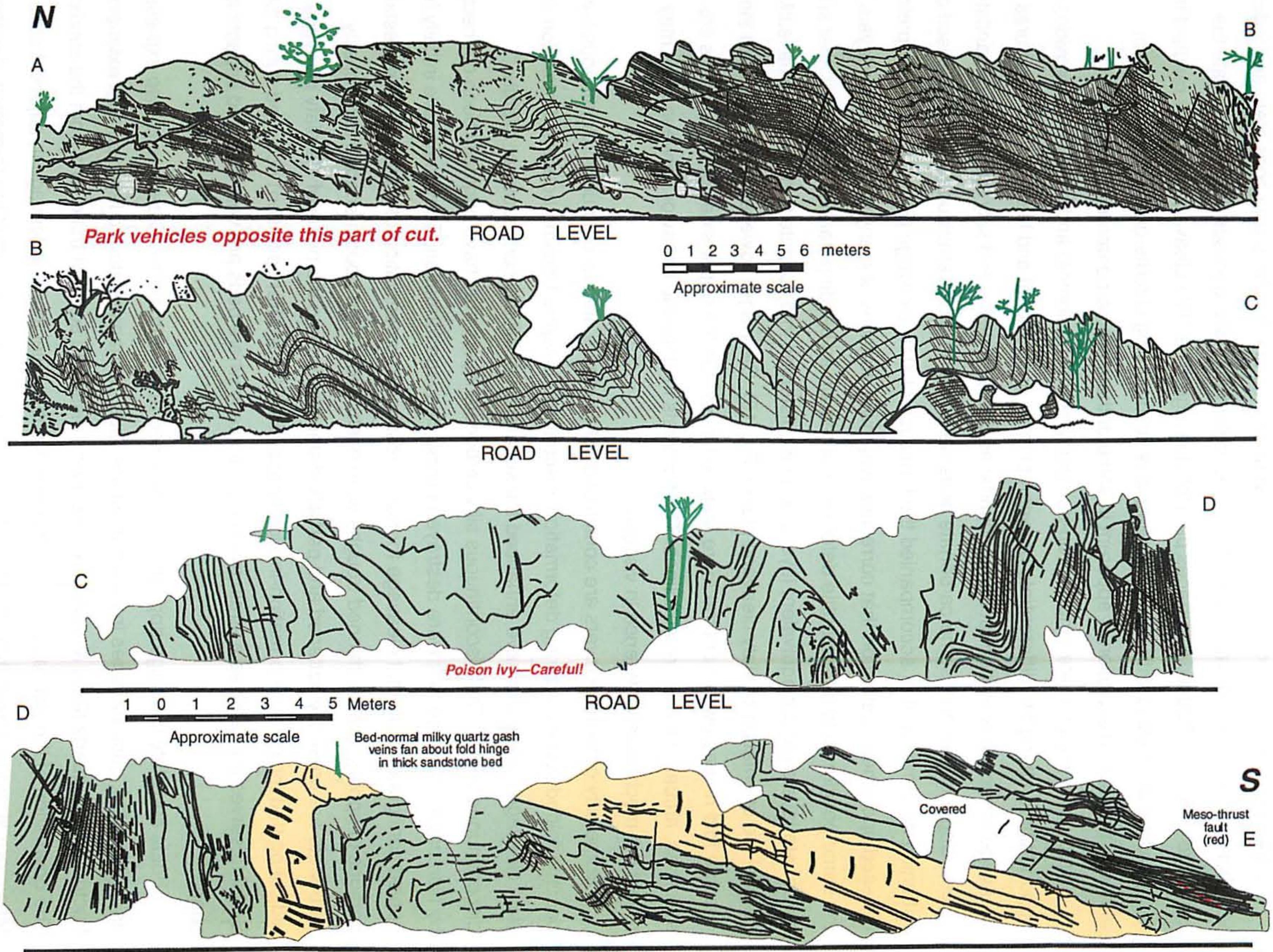


Figure 18. (A) Flattened ripples and refracting cleavage in Wilhite Formation slate (darker color) and interlayered silty carbonate (ankeritic dolomite) and fine-grained sandstone (light colored). (B) Relationships between flattened ripple marks in bedding and slaty cleavage at Madden Branch.

The deformation at Madden Branch is dominated by folds (Fig. 10) with amplitudes ranging from a few centimeters to 25 m. Folds range from cleaved very tight to open buckle folds in the Wilhite Formation slate with some evidence of flexural slip (layering strongly involved in folding) in the more massive sandstones. Vergence of folds is toward the northwest. These folds are probably older than the brittle deformation at Ocoee Dam No. 1, although no absolute ages exist to date the structures at either location. Late, low-amplitude open folds have not been observed.



RDH 1977, 2002, 2004, and D. Borchers 2001

Figure 10. Detailed sketch of roadcut at Madden Branch, Stop 2.

Slaty cleavage is the dominant tectonic structure. Its orientation is very consistent and indicates very little folding after cleavage formed, or other deformational processes that would rotate the cleavage (Fig. 10). Fold axial surfaces parallel cleavage. The slaty cleavage probably resulted from recrystallization of clays with some pressure dissolution during chlorite-grade metamorphism, although pressure dissolution is apparent in some of the more carbonate-rich layers.

Study of silty carbonate (impure iron-bearing (ankeritic) dolomite) and slate layers provides an opportunity to attempt to differentiate between primary depositional and later tectonic structures. Cleavage refraction is evident at some boundaries between pelitic and silty carbonate or sandstone layers. Upper surfaces of some carbonate beds were rippled. Their amplitudes were increased during flattening deformation that accompanied the formation of slaty cleavage (Fig. 10). This interpretation is based upon the observation that corresponding lower surfaces of many silty carbonate layers in the same position in folds are brittle deformed but remain as bedding-parallel surfaces. Other silty carbonate layers exhibit equivalent layer-boundary distortion into cuspate folds whose axial surfaces parallel the orientation of slaty cleavage planes Fig. 10). Cleavage, however, refracts toward the cuspate fold hinges away from the more arcuate hinges. On the upper sides of beds, cusps are synclines, arcuate hinges are anticlines. The contrasts in cleavage behavior between beds may reflect the mechanical difference in viscosity.

Some silty carbonate layers are continuous, while others are discontinuous. Continuous layers become folded surfaces during deformation; discontinuous layers become boudins. Formation of slaty cleavage appears to have enhanced the separation of initially continuous or slightly discontinuous layers. The discontinuous silty carbonate layers may have originally been connected by filamentous laminae that were destroyed during cleavage formation. They may have initially had a rippled configuration so that cleavage formation resulted in preservation of material in the crestal portions of ripples, but the thinned troughs were destroyed. Some boudin-shaped pods of silty carbonate are presently flattened and partially dismembered into the plane of the slaty cleavage, indicating that incipient deformation-induced parallelism (called transposition) occurred during folding. Bedding serves primarily as a strain marker, particularly where beds are very thin, and impacts fold shape.

Folds and slaty cleavage appear to have formed at the same time. Cleavage is also expressed as quartz-filled, gash fractures in metasandstone beds, perhaps related to layer-parallel extension, fracturing, and quartz filling as pressure dissolution dissolved some of the quartz from the sandstone. The orientation of the gashes in the sandstones is subparallel to slaty cleavage in adjacent slate, but fans more about fold axes than the slaty cleavage, indicating perhaps that the formation of extension gashes occurred early and that rotation occurred during progressive deformation. Numerous joints and a few small late brittle faults are also present at Maddens Branch.

A small fault near the west end of the cut dips steeply but irregularly crosses both bedding and cleavage. This structure has a striated movement surface upon which slickensides and fibers indicate dip-slip motion.

A small, early 1.5-m-long thrust is present at the easternmost end of the exposure. It occurs in the slate just above the contact with the sandstone and displays the classic features of a décollement thrust. The fault is in incompetent layers and exhibits drag folds in the zone of maximum displacement. It could have formed early, during the cleavage-forming event, or even earlier during diagenesis.

Metamorphic grade at Madden Branch is in the chlorite zone and marks the beginning of a continuous progression of Barrovian metamorphic zones that climaxes with pyroxene granulite facies in the Cartoogechaye terrane (Figs. 1and 6). Taconic metamorphism (470–448 Ma) is well documented in the amphibolite to granulite core to the east. Although no absolute metamorphic ages exist here, the continuous progression of isograds and continuity of structures from the Taconic Wayah granulite core to here suggest metamorphism at Madden Branch and in the Miller Cove thrust sheet is Taconic (Merschat et al., 2017; Thigpen and Hatcher, 2017). X-ray diffraction study of slate indicates strong orientation of chlorite and muscovite parallel to the slaty cleavage suggesting that recrystallization and metasandstone beds, perhaps related to layer-parallel extension, fracturing, and quartz filling as pressure dissolution dissolved some of the quartz from the sandstone. The orientation of the gashes in the sandstones is subparallel to slaty cleavage in adjacent slate, but fans more about fold axes than the slaty cleavage, indicat-ing perhaps that the formation of extension gashes occurred early on and that rotation occurred during progressive deformation. Numerous joints and a few small late brittle faults are also pres-ent at Madden Branch.

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Continue eastward 15 km on U.S.-64 to Boyd Gap.

STOP 3. *Wehutty Formation at Boyd Gap (35.0432° N, 84.4502° W)*

Purpose: To examine biotite grade graphitic phyllite and metasandstone (muscovite + quartz + biotite + pyrrhotite).

Stop 3 is located at Boyd Gap on U.S. 64 (Fig. 6) and consists of thick-bedded metagraywacke and interbedded sulfidic slate of the Ammons Formation (Fig. 11), Great Smoky Group, folded into west-vergent (leaning) modified concentric buckle folds. The two major rock types of this unit, dark-gray laminated graphitic slate or phyllite and metagraywacke, are well represented and constitute most of the exposed beds. A few of the beds are matrix-rich metagraywacke. The metagraywacke is composed mainly of quartz and feldspar with subsidiary biotite, muscovite, quartz, and feldspar. Some of the large quartz grains have an opalescent blue color (likely related to Ti producing lattice defects, which is annealed at kyanite grade, and sourced from basement rocks; Hadley and Goldsmith, 1963). Most noteworthy of the accessory minerals are graphite and iron sulfides, both indicative of strongly reducing conditions during deposition. Metagraywacke beds contain pyrrhotite, but pyrite rather than pyrrhotite is present in the dark slate and matrix-rich meta-graywackes, the result of nonequilibrium caused by the much higher sulfur content of the slate compared to the metagraywacke. Polished section examination invariably reveals small blebs of chalcopyrite associated with the pyrrhotite. Sphalerite and rare galena may be observed here.

Bedding is still prominent here; less common primary features include graded bedding, slump structures, flame structures, intraformational clasts in some metagraywacke, rare concretionary structures, and a few penecontemporaneous folds. This indicates that deformation has not become intense enough to rearrange the rock mass and obliterate primary structures. So, layering still plays a dominant role in folding this far into the chain.

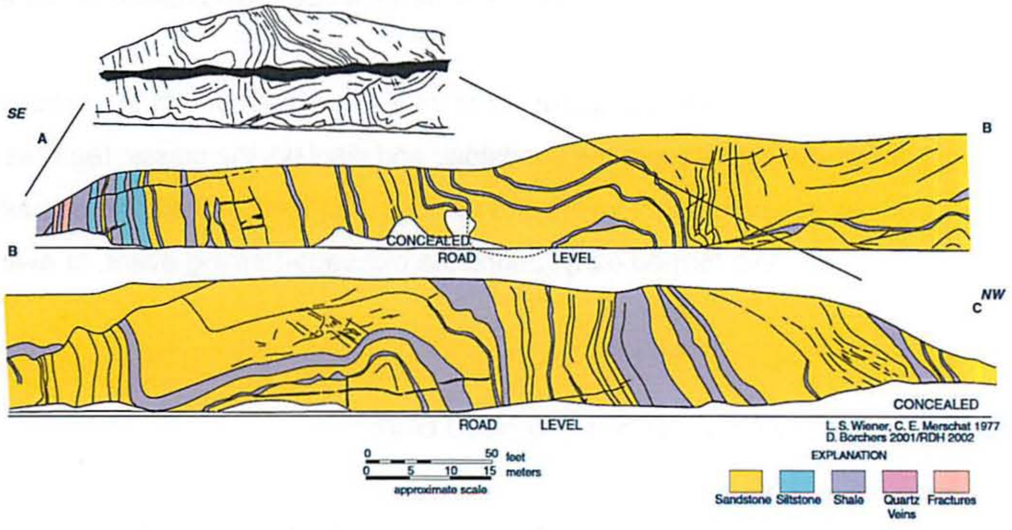

Figure 11. Sketch of the southwest side of the roadcut at Boyd Gap on U.S. 64.

The dominant layered structures are bedding and slaty cleavage. Their geometric relations are most obvious in the fine-grained beds. Bedding is obviously folded and generally strikes ~045. The attitude of slaty cleavage is much more limited, with an average strike of ~030 and dip 65° southeast. A new structure we have not seen before in our traverse, however, is mm-scale crenulation of the slaty present on many foliation surfaces in the slate—indicative of increased deformation from Stop 2. Top-of-bed or facing directions, as determined by bedding-cleavage relations, agree with the sedimentary top-bottom criteria, indicating the rocks here have not been tectonically overturned. The large, almost roadcut-size folds at Boyd Gap (Fig. 11) are asymmetric overturned to the northwest, with nearly horizontal axes. The slaty cleavage is approximately parallel to the axial surfaces of these folds. Differences in layer strength have controlled the behavior of individual beds. The more competent metagraywacke layers maintained fairly uniform thickness from limb to limb, although minor systematic variations indicate that they, too, are deformed by flow to some extent. Fold mechanisms in the least competent beds range between flexural slip (layering dominant) and flexural flow (layering still dominant, but weak layers undergo plastic flow), but the vergence and fold geometry are virtually the same as at Stop 2.

Nearly north-trending, left-lateral strike-slip cross faults are also present. These faults displace all other features and are clearly post-metamorphic brittle structures. Slickensides on the fault surfaces are subhorizontal or plunge very gently (<5°) southward. Displacement along any one of these faults is not large. By matching fold hinges from one wall of the exposure to the other, we estimate the displacement to be ~45 m. Faults with similar genetic relations have been noted in the mines and denuded area of the nearby Copper Basin a few km to the east. The greatest displacement known here is ~100 m.

Continue E on U.S. 64 into Ducktown and turn left at the first traffic light, drive past the Piggly Wiggly grocery to a stop sign at the intersection with TN 68, and turn left, quickly turn left again U-turning onto a grassy area and park beside the highway, then walk back to the S to the exposures beside the road.

STOP 1-4. *Copperhill Formation in historic Ducktown, Tennessee (35.0333° N, 84.3810° W)*
Purpose: To examine garnet-zone Copperhill Formation schist and metasandstone.

Ducktown, Tennessee (Figs. 5 & 6), locally known as the Great Copper Basin, is a copper (>zinc>>>gold>silver)–mining district that was mined from 1847 until the mines closed in the 1970s. The last product produced here was sulfur for making sulfuric acid (primarily from roasting pyrite-pyrrhotite FeS_2) and sintered iron. The Ducktown ore is a massive sulfide deposit within the Copperhill Formation. Production was primarily from eight massive sulfide bodies. The ore bodies are mostly tabular and located parallel to bedding, and contain predominantly pyrrhotite and pyrite, with minor chalcopyrite ($CuFeS_2$) and sphalerite (ZnS), and trace amounts of silver and gold dissolved in pyrite.

The rocks here belong to the Copperhill Formation, near the base of the Great Smoky Group, and are exposed in the Ducktown anticlinorium. The rocks contain garnets, with staurolite and kyanite found at depth in the mines. This is the first place where deformation has produced parallelism (transposition) of original sedimentary bedding and foliation. Features produced by deformation and metamorphism, where the finer-grained, formerly clay-rich tops of beds form coarser metamorphic minerals, muscovite (white mica) and garnet, and produce the appearance of grading. T-P estimates of ~550 °C, ~6 kb have been obtained from Copperhill Formation schist (Nesbitt and Essene, 1982).

Backtrack to U.S.-64 and again drive E. Continue 35.6 km to Murphy, North Carolina, and pull off onto the right shoulder at the exposure; a Ford dealership is across the highway to the west.

STOP 5. *Mineral Bluff Formation along U.S. 64 in Murphy, North Carolina (35.078503° N, –84.040160° W)*

Purpose: To observe chlorite grade (muscovite + quartzite + chlorite + magnetite) phyllite or schist and minor metasandstone of the Mineral Bluff Formation. ***Have we returned to Madden Branch?***

The sinuous Murphy syncline (Figs. 1 and 6). extends from near Bryson City, North Carolina, southwest to east of Cartersville, Georgia. Stop 5, located near Murphy, North Carolina (Fig. 6), is in the core of the Murphy syncline. The Murphy syncline contains a stratigraphic sequence of the quartzite, schist, and carbonate similar to the Chilhowee Group exposed at Stop 1. The rocks stratigraphically overlie the Ocoee Supergroup and are in a continuous sequence from the base of the Copperhill Formation, Great Smoky Group, to the rocks exposed within the syncline. There are no major faults that offset the stratigraphy or metamorphic isograds, but there are likely several unconformities.

Exposed in the core of the syncline are some of the youngest sedimentary rocks in the western Blue Ridge of North Carolina and Tennessee, the Ordovician or younger Mineral Bluff Formation. The Mineral Bluff Formation here consists of green (again revealing the metamorphic grade) phyllite or schist and a few beds of interlayered metasandstone. Metamorphic grade has dropped back to the chlorite zone, but the deformation remains polyphase and complex, owing to later folding tightening the syncline.

Continue through Murphy and take U.S. 19-74 NE toward Andrews. Follow U.S. 19-74 to NC 141 and turn right (SE). Drive ~700 m and park on the right short of a roadcut in solid rock.

STOP 6. Staurolite-Bearing Mineral Bluff Formation South of Marble, North Carolina (35.1683° N, 83.9213° W)

Purpose: To examine the Mineral Bluff Formation at staurolite grade. This is the same rock unit as at the previous stop. Note the immediate differences!

Stop 6 is located within the core of the Murphy syncline near Marble, North Carolina (Fig. 6), ~18 km (11 mi.) northeast of Stop 5 (Fig. 6). The town of Marble got its name from exposures of the Murphy marble just to the northwest, and several small quarries that mined the marble for building stone and talc periodically during the past hundred years. We will not visit the Murphy marble. The gray, coarse-grained porphyroblastic staurolite-(minor garnet)-biotite schist and metasiltstone [muscovite + biotite (+ minor garnet) + staurolite] is part of the Mineral Bluff Formation. This is the same unit that we saw at Stop 5, but at higher grade. Relict bedding is also present. Staurolite crystals may be collected from the saprolite in the roadcut on the northeast side of the road, whereas fresh rock can be observed in the main cuts on both sides of the road. Nesbitt and Essene (1982) obtained estimates of ~540 °C (and ~450 °C on lower-grade assemblages toward Murphy), and pressures of 4–4.5 kb nearby. The staurolite isograd cuts across the Murphy syncline just southwest of this stop and the kyanite and sillimanite isograds, which extend from farther to the northeast, continue on the southeast limb of the syncline in Great Smoky Group rocks (Fig. 6). The kyanite and sillimanite isograds cross the Hayesville fault farther E.

Continue S on NC 141 to the intersection with U.S. 64 at Peachtree. Turn left (E) onto U.S. 64, drive through Hayesville, and pull off (very carefully) onto the right side of the road next to a fresh exposure of biotite metasandstone.

STOP 7. *Migmatitic Metagraywacke (Great Smoky Group) East of Hayesville, North Carolina (35.0406° N, 83.7947° W)*

Purpose: *To examine Great Smoky Group metasandstone at sillimanite grade and compare it to the metasandstone at Stops 3 and 8.*

This exposure along U.S. 64 is located <1 km west of the Hayesville fault (Fig. 6), the Taconic suture that separates rocks of the Laurentian rifted margin from the Cowrock and Cartoogechaye terranes (Stops 9 through 11). In southwestern North Carolina and into Georgia, the Hayesville fault juxtaposes the Cowrock terrane against the Great Smoky Group. These rocks are virtually the same s those in the Copperhill Formation, Great Smoky Group rocks that we saw in Ducktown, Tennessee (Stop 4), but here at much higher metamorphic grade—sillimanite zone in the lower middle crust. The quartzofeldspathic metasandstones of the Copperhill Formation are two-mica, two-feldspar (K-spar &plagioclase) gneisses and schists, as compared with metasandstones of the central and eastern Blue Ridge that contain only plagioclase (An~20). Schists on both sides of the Hayesville fault contain two micas, ± aluminum silicate and other common aluminous minerals, and are therefore less diagnostic of transition from Laurentian margin to distal terranes. Quartz- feldspar veins and layers in the metasandstone suggest minimum-melt conditions have been reached, and several ptygmatic folds of quartz-feldspar veins are present. The regional metamorphic grade increased from staurolite zone at Stop 6 to crossing the tightly compressed kyanite and sillimanite isograds in the immediate footwall of the Hayesville fault at this stop (Fig. 6). Eckert et al. (1989) demonstrated that the kyanite and sillimanite isograds cross the Hayesville fault, further establishing that it is a pre- to syn-metamorphic fault. Northwest of Waynesville, North Carolina, monazite Th-U-Pb chemical ages of 467 ± 11 Ma and 459 ± 6 Ma from the immediate Hayesville fault footwall (Fig. 2) indicate Taconic metamorphism at 470–460 Ma affected the Great Smoky Group rocks (Moecher et al., 2005), and likely is the time of metamorphism experienced in the footwall of the Hayesville fault at this stop.

Continue E on U.S.-64. Approximately 1 km E the soils become a darker red color, because of the increased amount of weathered iron in the rocks—both biotite (in biotite paragneiss) and hornblende (in amphibolite). This marks the Hayesville fault hanging wall where there is no ready bedrock exposure to observe. Continue E to NC 175 and turn right. Drive S ~1.5 km and park immediately before a T-intersection where the road that turns right immediately crosses a bridge. Walk down to the lakeside to the right (W) side of the bridge. High water during the late spring and summer months may prevent access to the exposure, but it is quite accessible during late fall.

STOP 8. *Great Smoky Group Schist and Metasandstone on Lake Chatuge in the Shooting Creek Window (35.0247° N, 83.7314° W)*

Purpose: To observe a sillimanite-grade pelitic schist in Great Smoky Group rocks; compare these rocks with the pelite at Stop 3.

In southwestern North Carolina and northeastern Georgia are two windows through the Hayesville fault, both are cored by Great Smoky Group rocks and framed by the Lake Chatuge mafic-ultramafic complex in the Cowrock terrane (Figs. 1 and 6). The larger Brasstown Bald window occurs in Georgia, whereas the Shooting Creek window is mostly within North Carolina (Fig. 6). The rocks beneath the bridge along the Lake Chatuge shore consist of polydeformed Great Smoky Group metasandstone and pelitic schist (garnet + muscovite + biotite ± sillimanite) exposed in the Shooting Creek window just east of the Hayesville fault (Fig. 6). The Shooting Creek window is arched by a NE-SW– and E-W–trending fold (Fig. 6). The rocks are part of the lower Great Smoky Group, either the Copperhill Formation or possibly some non-graphitic schist of the Wehutty Formation. There are ptygmatically folded veins and crenulation folds here. The muscovite clots probably are pseudomorphs after sillimanite.

Return to U.S.-64 and turn E again. Drive through Shooting Creek, ascend Chunky Gal Mountain, and turn left into the overlook and park. Walk across U.S.-64 to the large roadcut on the east side of the highway.

STOP 9A. *Chunky Gal Mountain (35.0588° N, 83.6203° W)*

STOP 9B. Glade Gap (35.0674° N, 83.6295° W)

Purpose: *To examine rock assemblages and structures, including the Chunky Gal Mountain fault, at two large exposures of central Blue Ridge rocks.*

Stop 9 is separated into two parts: Stop 9A located at a large roadcut east of the overlook on U.S. 64 (Figs. 12 and 13), and Stop 9B at Glade Gap (Fig. 14). Stops 9A and 9B are located in the central Blue Ridge southeast of the Hayesville fault (Figs. 13 and 14), which separates reasonably well-known and divisible high-grade stratigraphic sequences of the Great Smoky Group from biotite paragneiss, pelitic schist, mafic and ultramafic rocks, quartzite, and Grenvillian orthogneiss of the Cowrock and Cartoogechaye terranes. The Cartoogechaye and Cowrock terranes are separated by the Chunky Gal Mountain fault (Figs. 6 and 13). These rocks were metamorphosed to upper amphibolite facies sillimanite II zone assemblages (sillimanite + K-feldspar + muscovite). Sillimanite is present in the pelitic schist in this area. Rutile is present in some of the schist in the area, but has not been observed here. Geothermometry and geobarometry estimates from these rocks and the Lake Chatuge mafic-ultramafic complex framing the Shooting Creek and Brasstown Bald windows range from 650 to 837 °C and 7–11 kb. Small dikes of late trondhjemite(?, a granitic rock composed mostly of quartz, with plagioclase feldspar and biotite) also intrude the rocks at Chunky Gal Mountain and Glade Gap exposures.

The sequence of rocks in this area is correlated with the rocks in the Coweeta Group (Figs. 6, 12, and 13). Pelitic schist overlying metagraywacke-biotite gneiss is similar to the sequence in the Coweeta Group just to the east in the Cowrock terrane, with the pelitic schist possibly equivalent to the Ridgepole Mountain Formation and the metagraywacke-biotite gneiss equivalent to the Coleman River Formation.

Figure 12. Oblique aerial photograph of Stop 9A with the trace of the Chunky Gal Mountain fault shown.

The contact in the Chunky Gal Mountain cut between the amphibolite (part of the Buck Creek complex) and biotite gneiss units is a major fault and is shown on the map as the Chunky Gal Mountain fault (Figs. 33 and 34). This fault may merge into the Hayesville fault toward the north and is joined by the Shope Fork fault to the east, south of Franklin. There is an abrupt change in orientation of foliation across the boundary in the Chunky Gal Mountain cut, and the biotite gneiss is mylonitic for at least 20 m from the contact (Fig. 34). This is the primary criterion for recognition of the fault. For purposes of discussion, the contact between the amphibolite, metagraywacke-biotite gneiss, and pelitic schist units is interpreted as a synmetamorphic folded thrust throughout this area (Figs. 13, 33, and 34). If these rocks are in thrust contact, the amphibolite-ultramafic bodies could be an ophiolite sheet that was emplaced prior to Paleozoic peak metamorphism, then enjoyed the deformational-thermal rigors of the metamorphic event. Some of the relationships between these units could be explained equally if the amphibolite and nearby ultramafic rocks were intrusive; however, a contact metamorphic aureole is absent, suggesting this is not likely. Relationships in this and

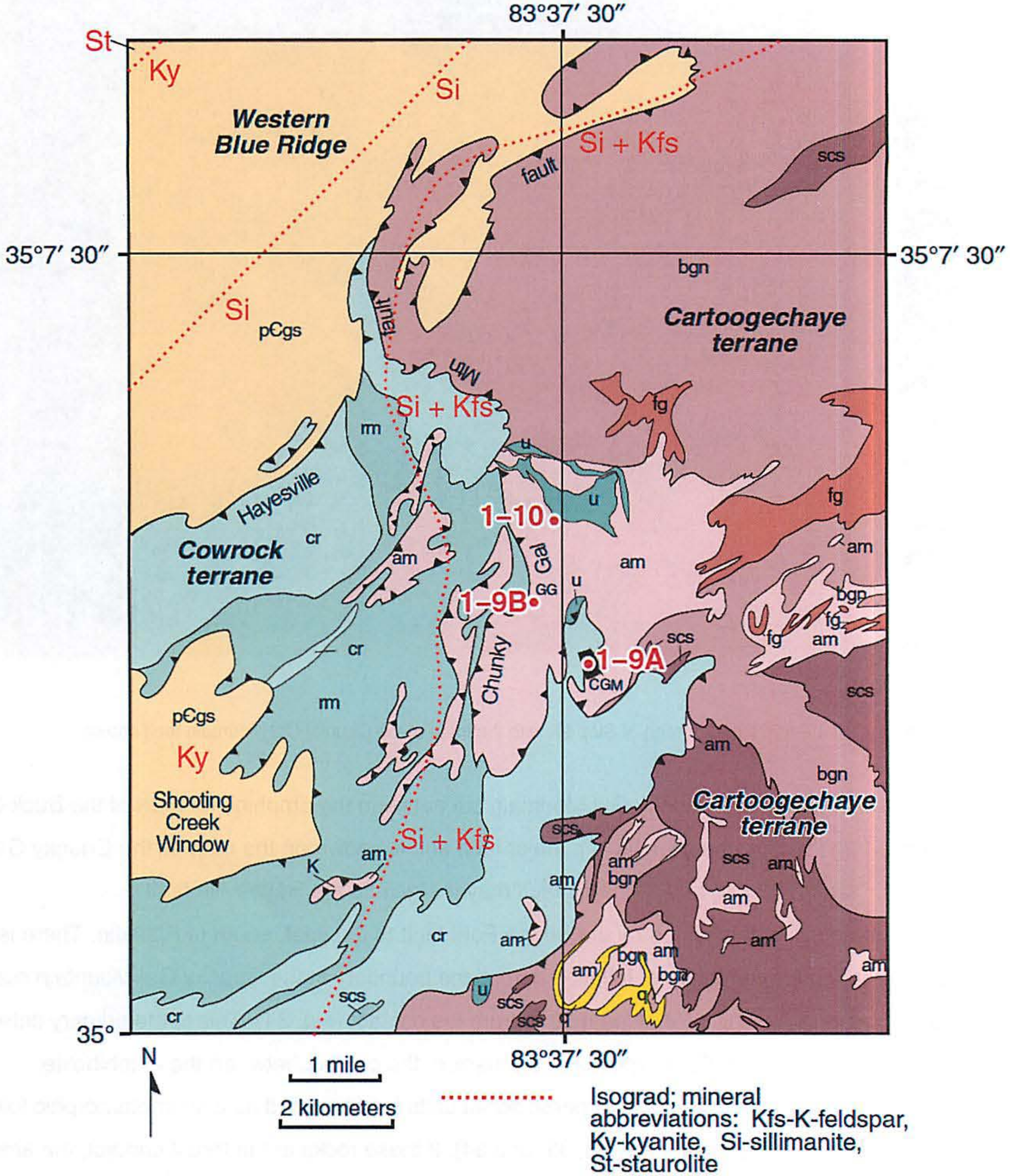

Figure 13. Detailed geologic map of the area near Chunky Gal Mountain (Stop 9A) and Glade Gap (Stop 9B), Shooting Creek and Rainbow Springs quadrangles. am—amphibolite; bgn—quartz-plagioclase-biotite gneiss; CGM—Chunky Gal Mountain; cr—Coleman River Formation, Coweeta Group; fg— felsic gneiss (possible 1.1 Ga basement gneiss); GG—Glade Gap; p Cgs—Great Smoky Group; q— Rainbow Springs quartzite; rm—Ridgepole Mountain Formation, Coweeta Group (mostly biotite and muscovite schist); scs—Shooting Creek schist; u—ultramafic rocks. Geology by RDH, assisted by Gregory Bryan, Stephen C. Godfrey, Louis L. Acker, and Brad Hubbard, 1977–1978.

other well-studied mafic-ultramafic complexes in the area favor these bodies being parts of dismembered ophiolites.

The deformation at Stop 9 is dominated by tan early foliation (note that foliation and compositional layering—original bedding?—are parallel), which contains passive flow isoclinal and isoclinal recumbent folds (layering only a scorekeeper) that have been refolded by more upright passive flow folds (Fig. 12).

Calcsilicate pods (from impure dolomite) and layers in the metasandstone were deformed into boudins during the earliest deformation and meta-morphism. Several of these have associated quartz or quartz-feldspar veins filling pressure shadows and fractures formed parallel to the long axes of the boudins.

Faulting has affected these rocks at two different times, but most faults of both generations have a northeast trend. One event produced faults, and probably took place when the rocks were being metamorphosed but just after the thermal peak (ca. 460 Ma), because very little if any retrogression of minerals occurs in mylonites here (Figs. 13). Classic static recrystallization textures, however, of quartz ribbons and other components are present in thin sections of mylonites. Mylonite zones range up to 10–12 m thick near these faults. Ultramylonite from the Chunky Gal Mountain fault shows a drastic reduction of grain size in the fault zone, but hornblende remained stable, suggesting deformation at near metamorphic peak conditions (Figs. 13). Mylonite from other fault zones in the metasandstones and biotite gneiss contain garnet, K-feldspar, plagioclase, biotite, and muscovite, and undulose and deformation twinned plagioclase porphyroclasts indicate amphibolite-grade deformation associated with the mylonites. Movement sense on these ductile faults and other shears appears to be normal, and down-to-the-west (clockwise facing the cut; Figs. 12 and 14). The trace of the fault is folded (Fig. 12), and the top-down-to-the-west shear sense is interpreted as a folded thrust, not as a normal fault. SHRIMP U-Pb ages of metamorphic zircon and zircon rims from the Coweeta Group marble several meters below the main mylonitic zone of the Chunky Gal Mountain fault range from 466 to 447 Ma and have a weighted average of 463 ± 5 Ma (Merschat et al., 2017). The metamorphic rims and amphibolite-grade mylonites (Figs. 2, 35, and 36) are interpreted to be the result of Taconic metamorphism and deformation, and these rocks are closer to the very high-grade core of Taconic metamorphism in the Wayah Bald area (Figs. 2 and 3).

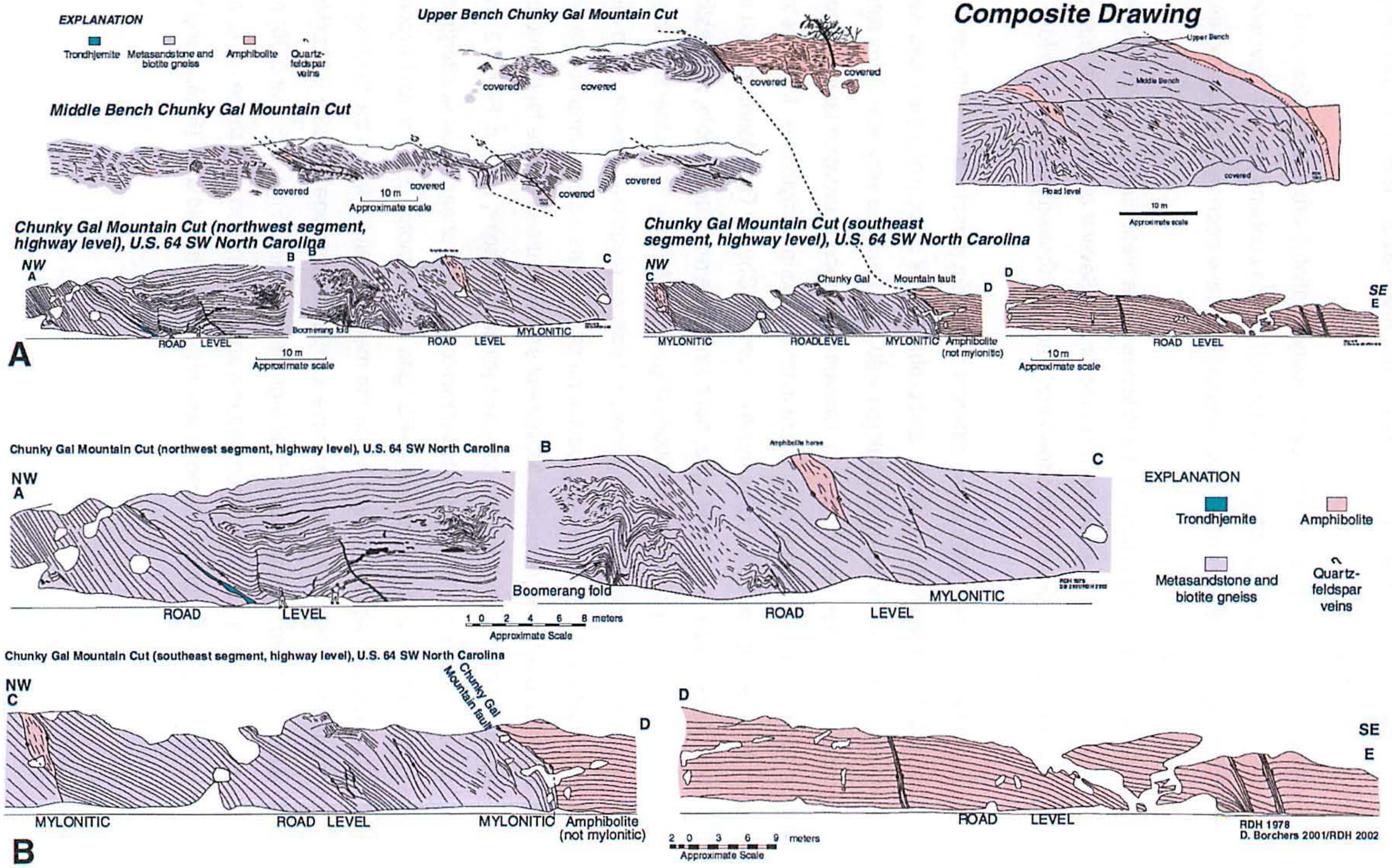

Figure 34. (A) Detailed sketch of the geology of the northwest part of the Chunky Gal Mountain cuts on U.S.-64, near Shooting Creek, North Carolina. (B) Blowup of lower panels showing the geology at road level. Note that the movement sense on all of the subsidiary faults formed at the same time as the main Chunky Gal Mountain fault.

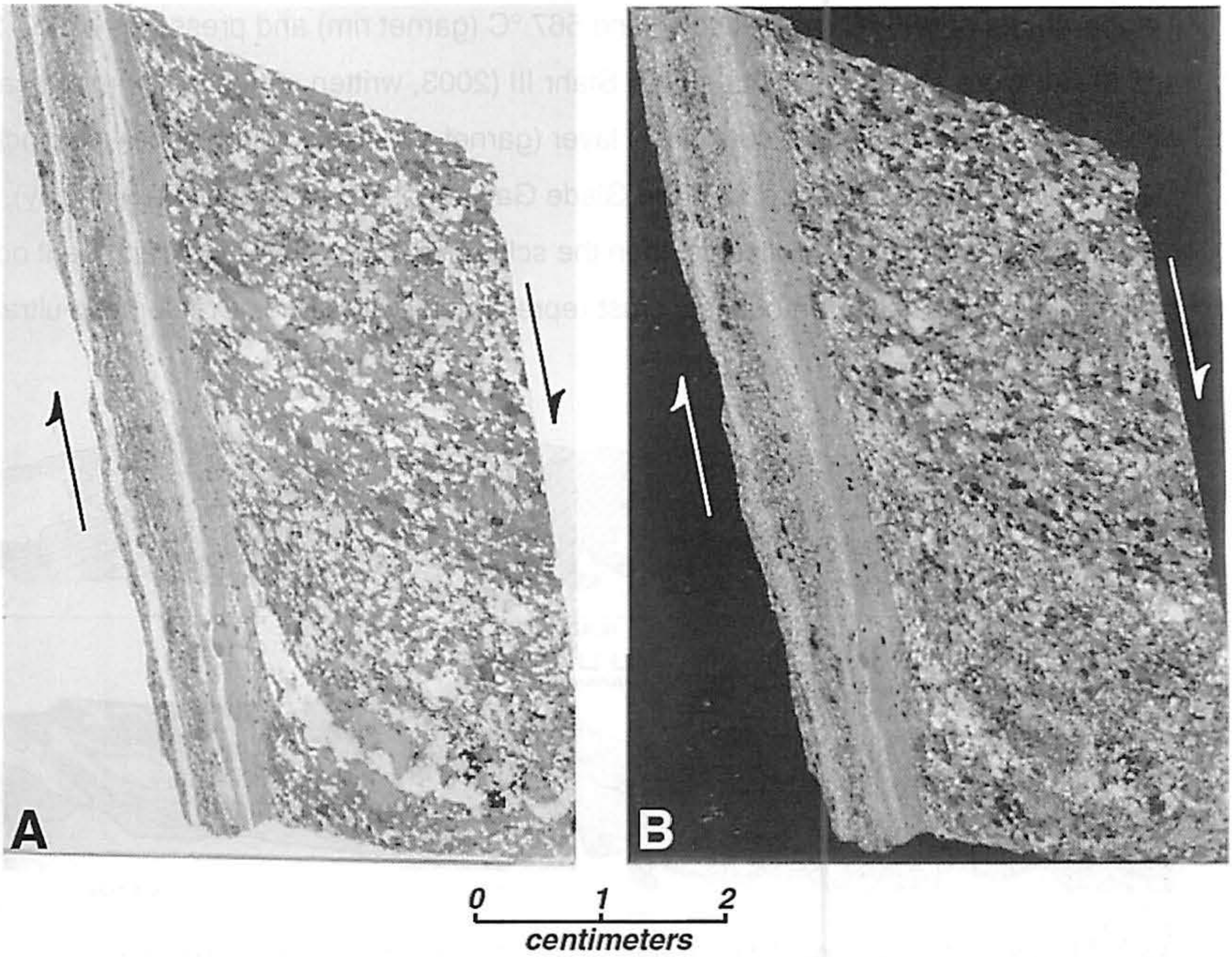

Figure 13. Photomicrographs of a thin section in (A) plane-polarized light and (B) polars crossed from the Chunky Gal Mountain fault in the original orientation of the sample. The fine-grained ultramylonite fault zone, 0.5 cm wide, truncates and partly transposed the earlier foliation in the amphibolite (hanging wall) to the right. Hornblende remained stable in both the amphibolite and ultramylonite, indicating the fault formed at near peak metamorphic conditions.

Later brittle faults having both normal and thrust movement sense may be observed here. These faults have very sharp, well-defined surfaces and truncate veins, boudins, trondhjemite dikes and foliation surfaces. A few have associated drag folds. Some of these faults behave like bedding faults, following incompetent zones (schist or layer boundaries) and crossing thick competent layers at a high angle.

About 3.2–4.0 km (2.0–2.5 mi.) east of Glade Gap (Fig. 14) is a large cut on U.S.-64 (Stop 9B) that was opened in 1978. The roadcut contains amphibolite, metagraywacke, and muscovite-biotite schist that are isoclinally to recumbently folded, by second-generation folds (Fig. 12). The deformation history and metamorphism are similar to Stop 9A: polydeformed very high-grade rocks that are intruded by late trondhjemite dikes and cut by late faults.

Temperatures of 655 °C (garnet core) and 567 °C (garnet rim) and pressures of ~10.3 kb and 8.9 kb were obtained by Donald W. Stahr III (2003, written commun.) from the same garnet core and rim from the coticule(?) layer (garnet + biotite + hornblende+ plagioclase + K-feldspar) at the southwest end of the Glade Gap exposure (S side of the highway). If the garnet-rich layers are true coticules, then the schist and metagraywacke represent ocean-floor sediment deposited on oceanic crust represented by the Buck Creek mafic-ultramafic complex.

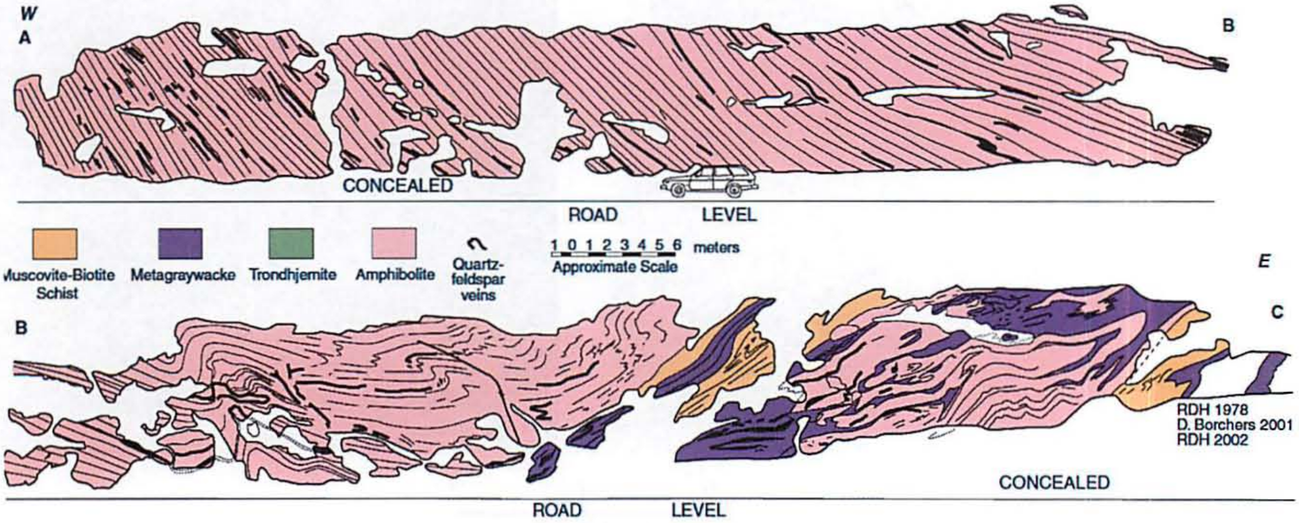

Figure 14. Sketch of the geology of the northwest side of the cut through Glade Gap on U.S.-64.

Return to vehicles and drive up the hill to Glade Gap; stop briefly to look at the garnet-rich layers in the smaller exposure at the SW end of the cut. Drive east 1.9 km on U.S. 64. Turn left on Old U.S. 64, then take an immediate left to the Buck Creek gravel road. Follow road to a place where is rock exposed in the tributary creek to the left. Park on road shoulder and get out to examine the rocks in the creek, slightly weathered Buck Creek dunite (almost pure olivine, Mg_2SiO_4).

STOP 10. *Metadunite of the Buck Creek Complex along Buck Creek (35.07850° N, 84.62805° W)*

Purpose: *To examine the Buck Creek mafic-ultramafic complex.*

The Buck Creek metadunite is part of the Buck Creek mafic-ultramafic complex (Fig. 13), which is one of the larger dunite bodies in the Appalachians (including Newfoundland!). The dunite and associated rocks were mined economically from the early 1900s to the 1940s for corundum and olivine for use as refractory sand (Pratt and Lewis, 1905; Stuckey, 1965). The olivine is 90% Mg_2SiO_4, and alteration minerals talc and serpentine are present, along with primary chromite. During and after World War II, the U.S. Bureau of Mines established and then abandoned a pilot plant to mine corundum and beneficiate the dunite for use as a refractory material. Hadley (1949) made a detailed geologic map of the body. The trenches and pits at Corundum Knob (Fig. 13) have been significantly expanded by mineral collectors looking for corundum and other associated minerals. A detailed description of the locality can be found in Peterson et al. (2006). The Buck Creek mafic-ultramafic complex consists of two ~3-km-long ultramafic bodies surrounded by amphibolite, and is encompassed within migmatitic biotite gneiss (probably rocks of the Coweeta Group) in the Cartoogechaye terrane. Metadunite is ~90% of the body (Peterson et al., 2006). It is a massive medium-grained metadunite composed of olivine + chromite + magnetite and with minimal secondary alteration minerals talc, chlorite, carbonates, and iron oxides. Metatroctolite (olivine-plagioclase igneous rock) occurs with the two metadunite bodies. The metatroctolite is dense, bluish-gray to greenish-gray, strongly foliated schist, weathers with the plagioclase producing a knobby surface, and is the primary ridge former within the ultramafic body. It is composed of calcium-rich plagioclase, orthopyroxene, Mg-rich clinopyroxene, Fe-bearing spinel, ± sapphirine $(Mg,Al)_8(Al,Si)_6O_{20}$ (Peterson et al., 2006).

Green to pale-green edenite-margarite schist occurs on the margins and contains edentitic hornblende + plagioclase ± zoisite ± kyanite ± corundum (Peterson et al., 2006). The summit of Corundum Knob is dominantly metatroctolite and edenite-margarite schist. Prograde metamorphic conditions for the Buck Creek mafic-ultramafic complex are delimited by the sapphirine-bearing metatroctolite assemblages (≤850 °C, 0.9–1.0 GPa), actinolite-chlorite schist (~825 °C, 1.2–1.4 GPa) and dunite (≤800 °C, 1.1–1.2 GPa); conditions which are similar to those reported from Winding Stair Gap (~850 °C, 7–9 kbar).

Return to U.S.-64 and turn left (E). Continue to the highest point on the highway at Winding Stair Gap, where the Appalachian Trail crosses the highway; continue downhill for ~200 m and park.

STOP 1-11. *Winding Stair Gap (35.1224° N, 83.5435° W)*

Purpose: To examine granulite facies metasandstone (quartz + K-feldspar +sillimanite) and mafic rocks.

Metamorphic conditions of 750–850 °C, P ~6.5–8.0 kb were estimated here using various standard geothermometers and barometers (Absher and McSween, 1985; Moecher et al., 2004); and over a wide area (T ~585 °C, P ~5.5 kb at the kyanite-sillimanite isograd; T ~842

°C, P ~9.8 kb or hornblende granulite; T ~669 °C, P ~6.52 kb, XH the sillimanite II isograd) (Eckert et al., 1989).

Rocks exposed at Winding Stair Gap (Fig. 6) are likely part of the Shooting Creek schist and belong to an unnamed mafic/ultramafic unit in the Cartoogechaye terrane (Fig. 6). These are likely of the Shooting Creek schist and belong to a unit in the Cartoogechaye terrane (Fig. 6). These rocks contain abundant prismatic sillimanite, microcline or other K-feldspar, almandine garnet, and clinopyroxene, and orthopyroxene (the latter two in mafic rocks only), along with quartz and plagioclase. Mafic rock types consist of metagabbro to metapyroxenite composed mostly of augite and retrogressive hornblende. The high metamorphic grade of these rocks was first recognized by Force (1976) and prograde assemblages are characteristic of the granulite facies (Hatcher and Butler, 1979). Additional detailed studies of the metamorphic assemblages at Winding Stair Gap have been made by Eckert et al. (1989).

Most previous investigators concluded that the rocks of this area are Grenville basement rocks. Similar sequences may be recognized, however, in both this high-grade zone and lower grade terranes to the west and east. Detrital zircons from the schist in Winding Stair Gap yield ages from 1.0 Ga to 750 Ma, and the zircons had Paleozoic metamorphic rims. Merschat et al. (2010) dated a zircon from quartzite in this terrane to the south of Winding Stair Gap and identified a similar detrital suite, 1.0, 1.1, 1.2, 1.4 Ga, indicating this is not a basement terrane; basement rocks, however, have been identified in this terrane west of Franklin, North Carolina (Hatcher et al., 2004). It is therefore concluded that this is Paleozoic granulite facies metamorphism, and that the rocks belong to the Coweeta Group Coleman River sandstone). Zircon separated from a garnet-bearing leucosome in the schist at Winding Stair Gap yielded U-Pb metamorphic zircon ages of 458 ± 2 Ma (ID-TIMs [isotope dilution-thermal ionization mass spectrometry]) and 460 ± 12 Ma (SHRIMP) (Moecher et al., 2004). Geothermobarometry estimates from the garnet-bearing leuco-some yielded near peak conditions of ~850 °C, 8.0 kbar during the Taconic orogeny (Moecher et al., 2004). The granulite facies metamorphism at Winding Stair Gap and surrounding areas was named the Wayah granulite core by Eckert et al. (1989), which is the Taconic metamorphic core of the southern Appalachians (Fig.6). Although the Chunky Gal Mountain and Hayesvile faults were crossed, this transect has crossed a complete Barrovian sequence of metamorphism related to the Taconic orogeny. The terranes included within this domain—Cowrock, Cartoogechaye, and Dahlonega gold belt—were accreted to the Laurentian margin of the western Blue Ridge during the Taconic orogeny.

Several small post-metamorphic faults here have an east-west to northeast strike. At least one fault is late, and exhibits brittle to low temperature ductile behavior at chlorite-biotite grade. A low temperature biotite- and chlorite-bearing (retrograde) mylonite is present on the opposite side of the road (SE end of the cut) along an E-W–trending fault.

End of field trip. DRIVERS PLEASE READ CAREFULLY! *Retrace steps along US 64 through Murphy to Ranger (1 traffic light) to the intersection of US 64 and NC 294. Turn onto NC 294. Follow NC 294 to intersection with TN 68 (just inside the TN State Line) and turn right (W) onto TN 68. Follow TN 68 through Tellico Plains and Sweetwater to I-75. Take I-75 N to TN 95 exit to Oak Ridge and return to Oak Ridge.*

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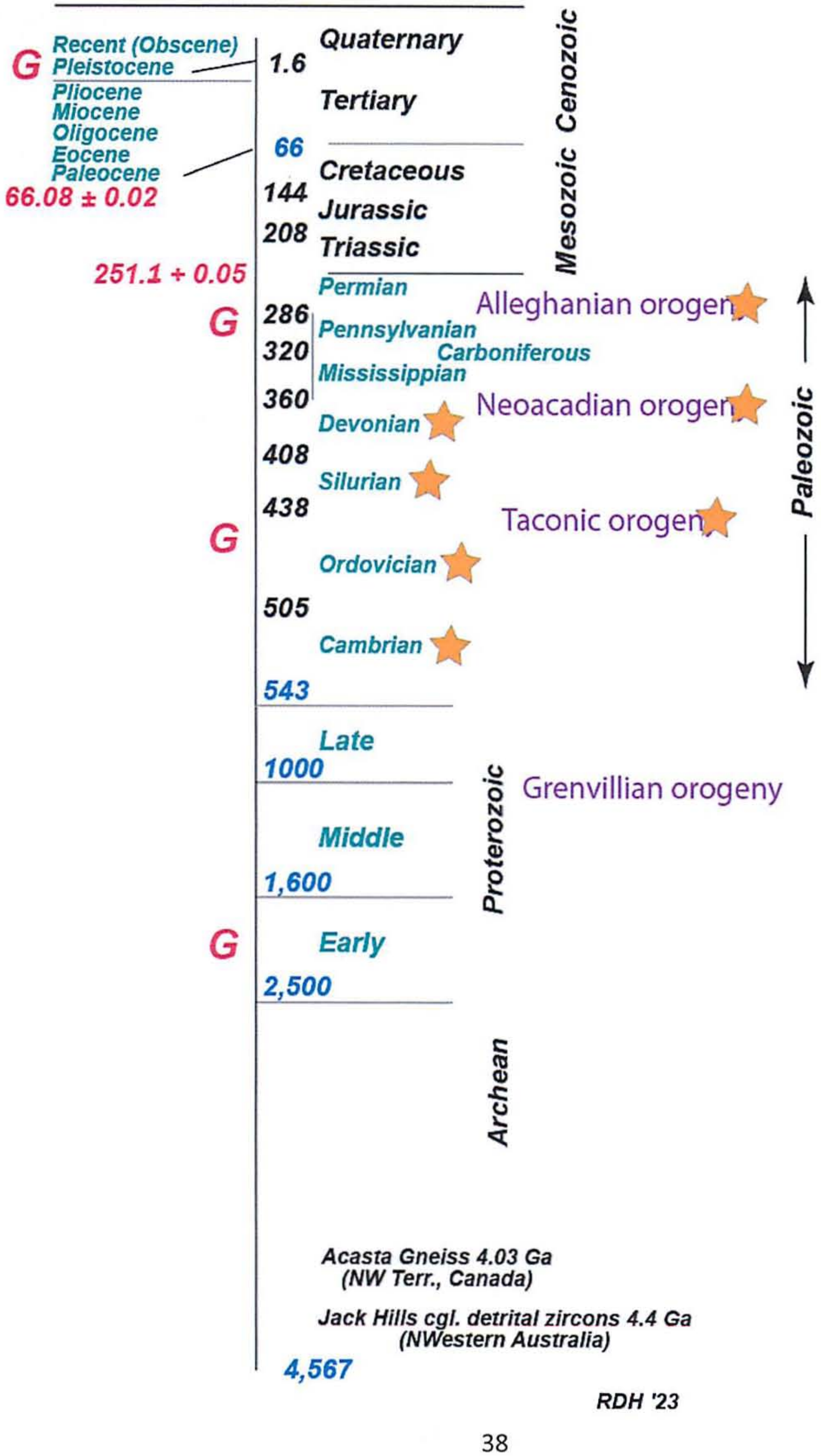
Geologic Time Scale



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