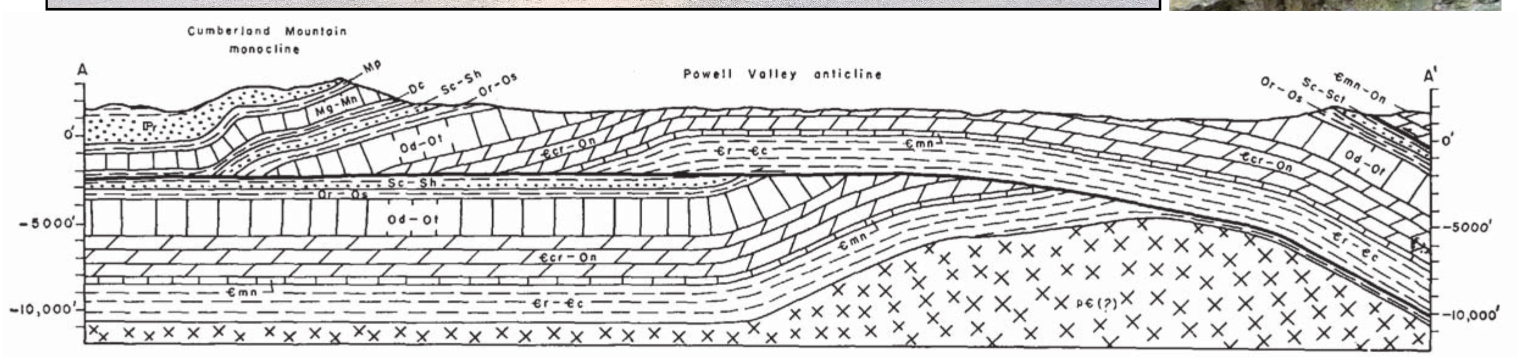
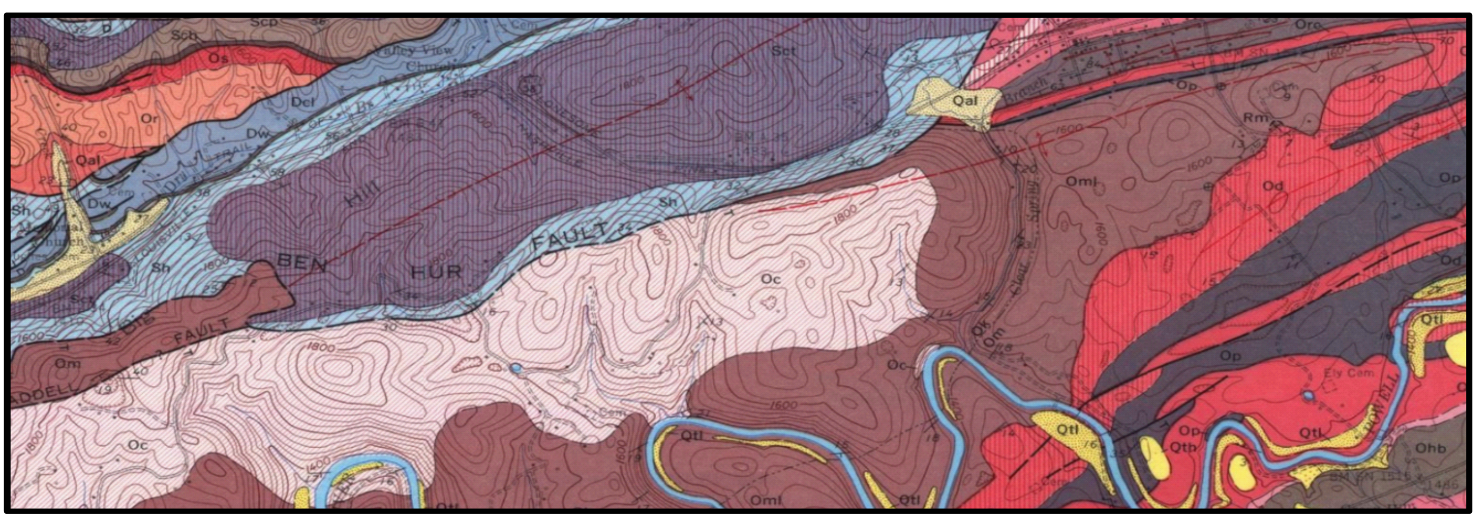
Geological Society of Kentucky
2018 Fall Field Trip October 12 and 13

A GEOTRAVERSE FROM BREAKS INTERSTATE PARK TO NATURAL TUNNEL STATE PARK

Tuscarora Sandstone “pipe rock”





GEOLOGICAL SOCIETY OF KENTUCKY – FALL FIELD TRIP 2018
A GEOTRAVERSE FROM BREAKS INTERSTATE PARK, KENTUCKY TO NATURAL TUNNEL STATE PARK, VIRGINIA

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October 12-13th, 2018

Introduction

The southwestern part of the Appalachian Plateau and Virginia Valley and Ridge provides a unique opportunity to review Neoproterozoic through Paleozoic sedimentary rocks, Alleghanian compressional structures, and Cenozoic geomorphic features derived from the underlying fold and thrust belt geometry. The purpose of this field trip is to provide an anatomical review of the Pine Mountain thrust sheet, the western-most thrust sheet in the Appalachian Valley and Ridge, from its leading margin at the base of Pine Mountain to its tailing margin southeast of Duffield, Virginia (Figure 1). We will finish the field trip observing Natural Tunnel State Park, a natural tunnel developed in the Hunter Valley thrust sheet. Previous field trips have reviewed the stratigraphy of the Pound Gap U.S. Highway 23 road cut in its entirety; however, this trip will review the Paleozoic stratigraphy in the context of the regional structures developed in southeast Kentucky and southwest Virginia during the assembly of the supercontinent Pangea.

Tectonic and Depositional History

Appalachian Basin sedimentary rocks contain the stratigraphic record of three (or more) orogenies and a complete Wilson Cycle (Hatcher, 2007). The depositional history of the central Appalachian Basin initiated with Neoproterozoic rifting of Grenville aged (1.0-1.2 Ga) metamorphic rocks along the periphery of the Rodinian Supercontinent about 750 Ma ago. Failed rifting in the U.S. Midcontinent region created the Reelfoot Rift and similar failed rifting created the Rome Trough that trends through eastern Kentucky, western West Virginia, and southwest Pennsylvania. Successful rifting along the periphery of the Laurentian margin created a series of promontories/salients and reentrants/recesses along the newly formed passive margin (Thomas, 1977). Sedimentary rocks in the Pine Mountain thrust sheet that will be observed on this field trip were deposited in the newly formed basins. The Conasauga Depocenter trends from northeast Georgia through eastern Tennessee and into southwestern Virginia where it laps onto the northwest to southeast trending Virginia Arch, which separated the Pennsylvania Depocenter that trends from northern Virginia into eastern Pennsylvania (Figure 2). The Catoctin Formation that occurs in near Mt. Rogers in central Virginia contains metamorphosed continental flood basalts and metarhyolites that produced zircon U-Pb age dates that suggest rifting occurred between 570-550 million years ago and maybe as early as 820 Ma (Aleinikoff et al., 1995; Southworth et al., 2009).

The Paleozoic sedimentary succession in the Virginia Valley and Ridge, as well as the Cumberland Plateau, can be generically defined as a passive margin succession followed by several foreland basin successions (Figure 3 and 4; Ettensohn, 1994). Rifting began in the Neoproterozoic and persisted through the early Cambrian which resulted in the deposition of Chilhowee Group conglomerates, feldspathic arenites, and bi-modal volcanic rocks (Figure 5). The passive margin phase that began in the Early Cambrian saw an increase in carbonate deposition beginning with the Shady Dolomite. Passive margin sedimentation terminated around 465 Ma (Ettensohn, 2004) in the late Middle Ordovician when island arc-collision marked the inception of the Taconic Orogeny (Figure 6). Middle Ordovician loading along the outer shelf created a peripheral bulge that resulted in the basin-wide Knox unconformity. This unconformity marks the transition from passive margin to foreland basin style sedimentation whereby the long-standing Laurentian carbonate platform gave way to a facies mosaic of argillaceous carbonates, shales, and wedges of coarse clastic sediments (Ettensohn, 2004). The Blount tectophase (Figure 7) focused around the Virginia Promontory and possibly the Alabama Promontory where clastic sediments from the Blount deltaic complex filled the earlier formed depocenters. Much of this deltaic complex is destroyed by later tectonism. The Taconic phase of during the Late Ordovician involved subduction and collision with island arc terranes that resulted in widening of the basin and deposition of the Queenston Delta during the Late Ordovician. The Queenston Delta is thickest near the New York Promontory; however it extends well into the Michigan Basin and almost 1060 mi (1700 km), along strike, from southern Canada into northeastern Tennessee. The deposition of the Blount and Queenston deltaic complexes laid the foundation for future decollements during the upcoming Alleghanian Orogeny. The Queenston deltaic complex is truncated by a major unconformity at the Ordovician-Silurian transition that marks the

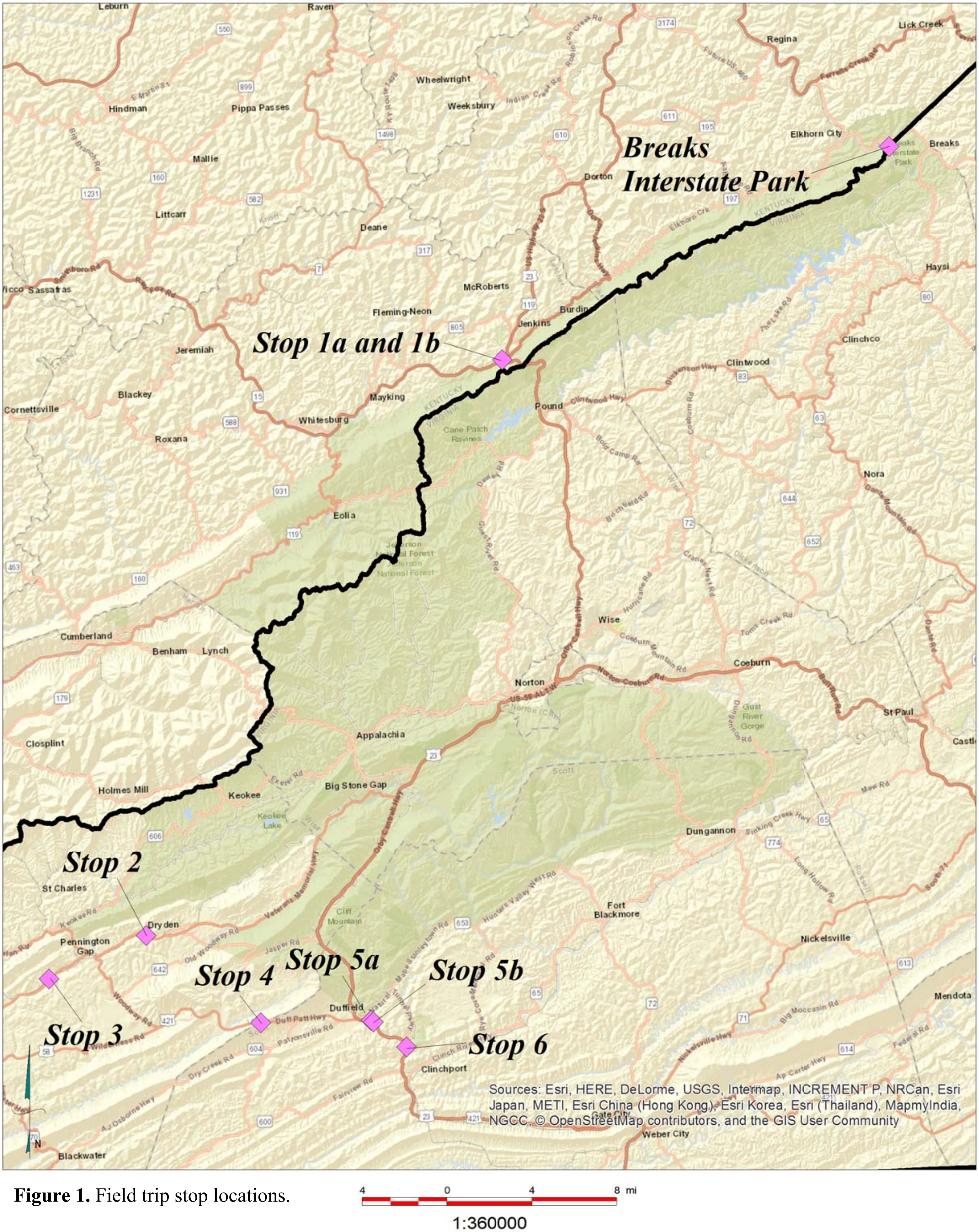

Figure 1. Field trip stop locations.

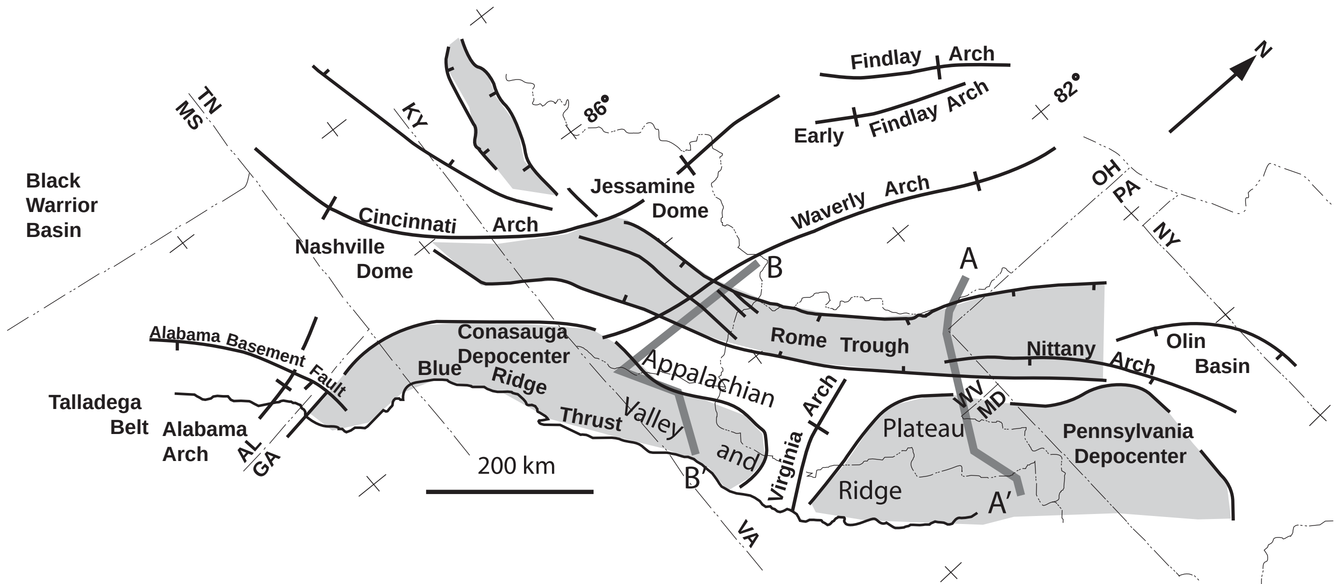

Figure 2. Structural base map of central and southern Appalachia Valley and Ridge, showing depocenters and Rome Trough (shaded) and arches (modified from Read, 1989a). Base map is not palinspastically restored. Location of schematic cross sections A-A' and B-B' shown.

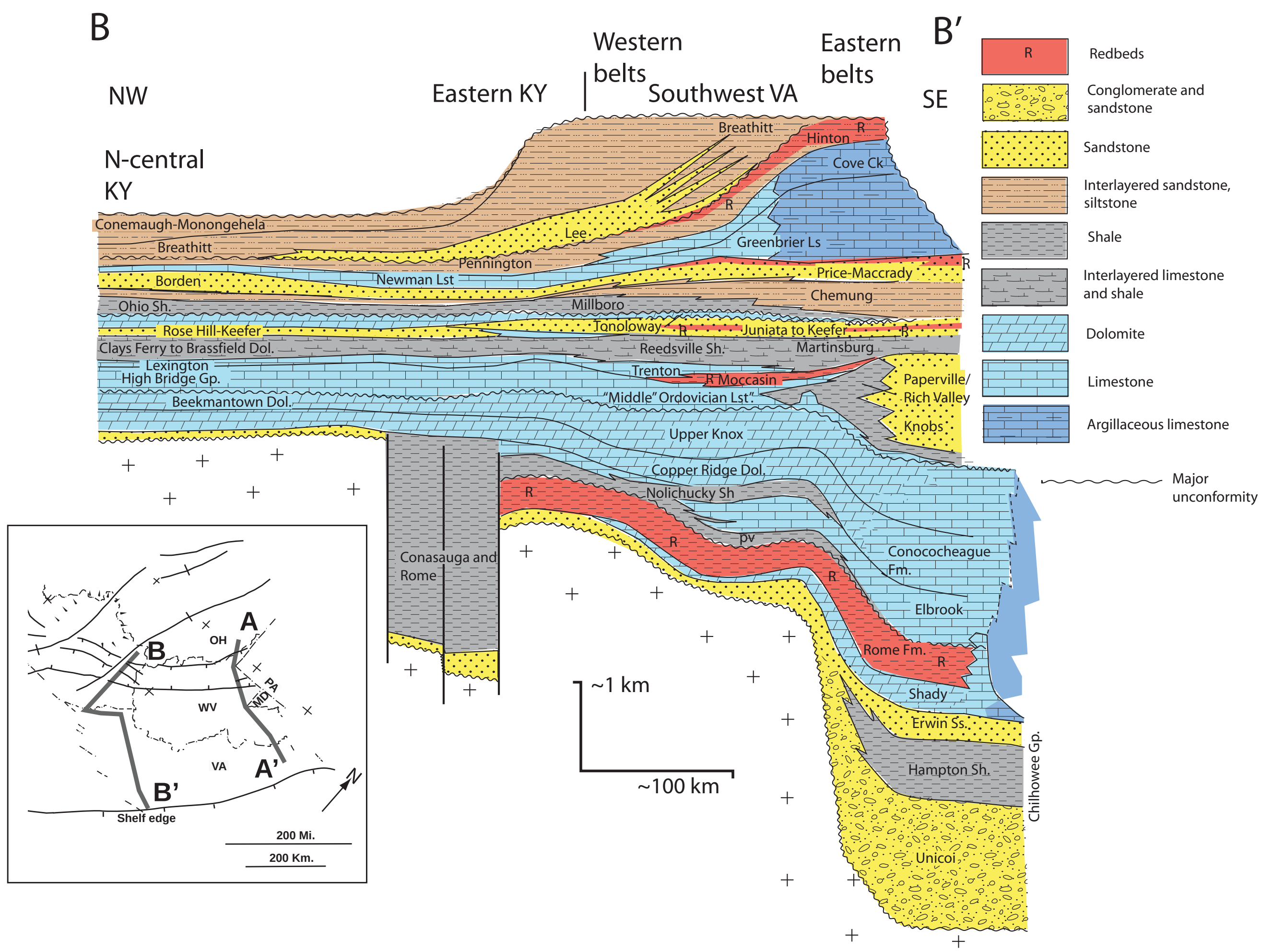

Figure 3. Schematic cross sections of the Paleozoic succession, Virginia showing general relations of units. Thicknesses and horizontal scale approximate; horizontal distances in fold-thrust belt are palinspastically restored. Top: Northern Virginia-Ohio cross section A-A' and Bottom: Southwestern Virginia-Kentucky cross section B-B'. Cross sections compiled from schematic sections of E. Rader in Cosuna Chart (Patchen et al. 1984; Ryder et al. 2009; and Read 1989a).

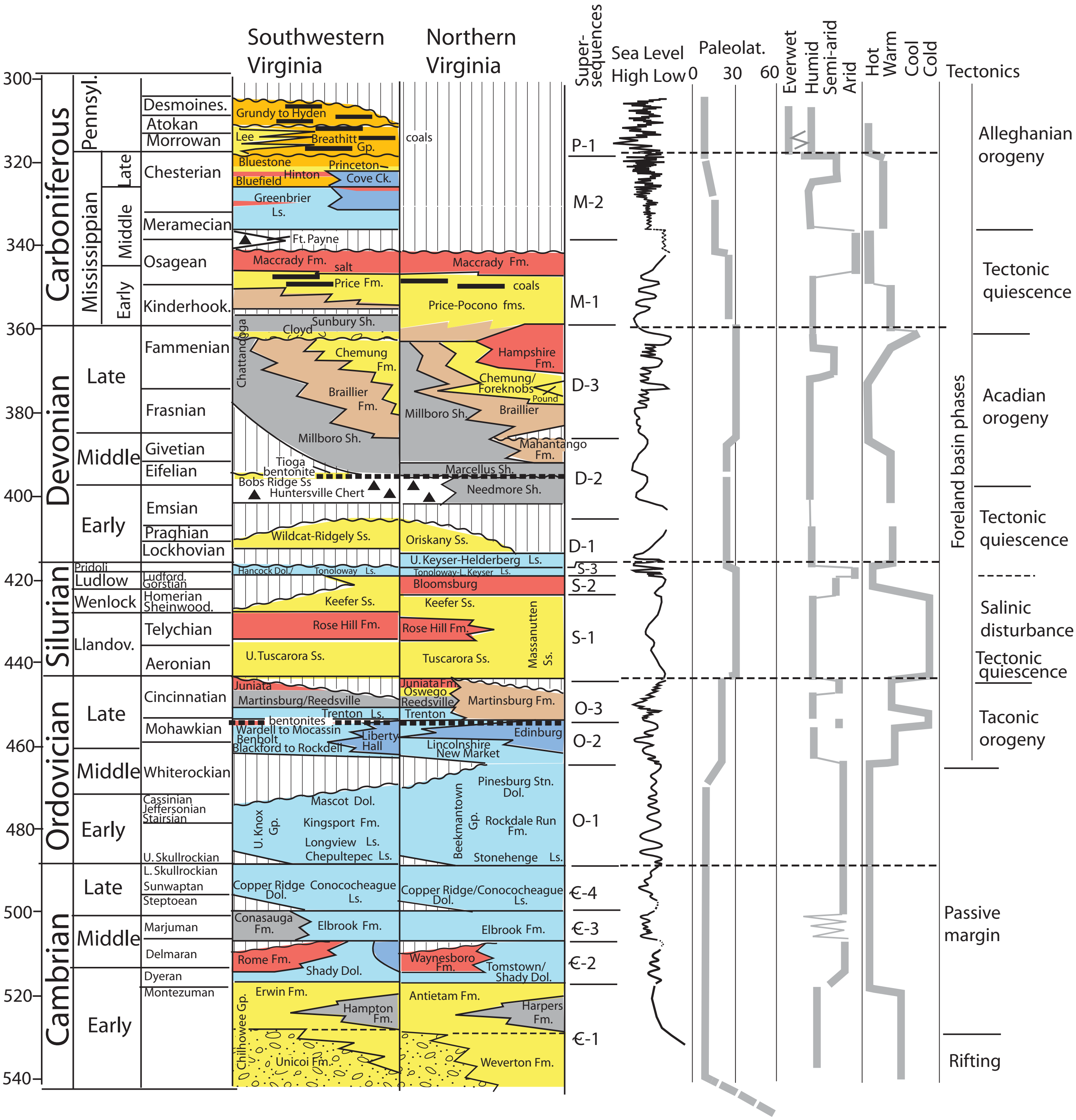

Figure 4. Summary chronostratigraphic diagram showing stratigraphic units and nomenclature in northern and southwestern Virginia, the accommodation (relative sea level) history, paleolatitude, paleorainfall (in terms of everwet to arid), paleotemperature (hot to cold) and and tectonics. Paleolatitudes and paleoclimate from Scotese 2001; other references given in discussion in text. Red-beds (red), conglomerate (yellow, open ellipses and dots), sandstone (yellow), mixed siliciclastics (orange), coal (heavy black lines), prodelta or turbidite clastics (pale brown), shale (gray), chert (solid triangles), carbonates (light blue), offshelf carbonates (dark blue), volcanic ash (heavy dashed lines), unconformities (vertical lines).

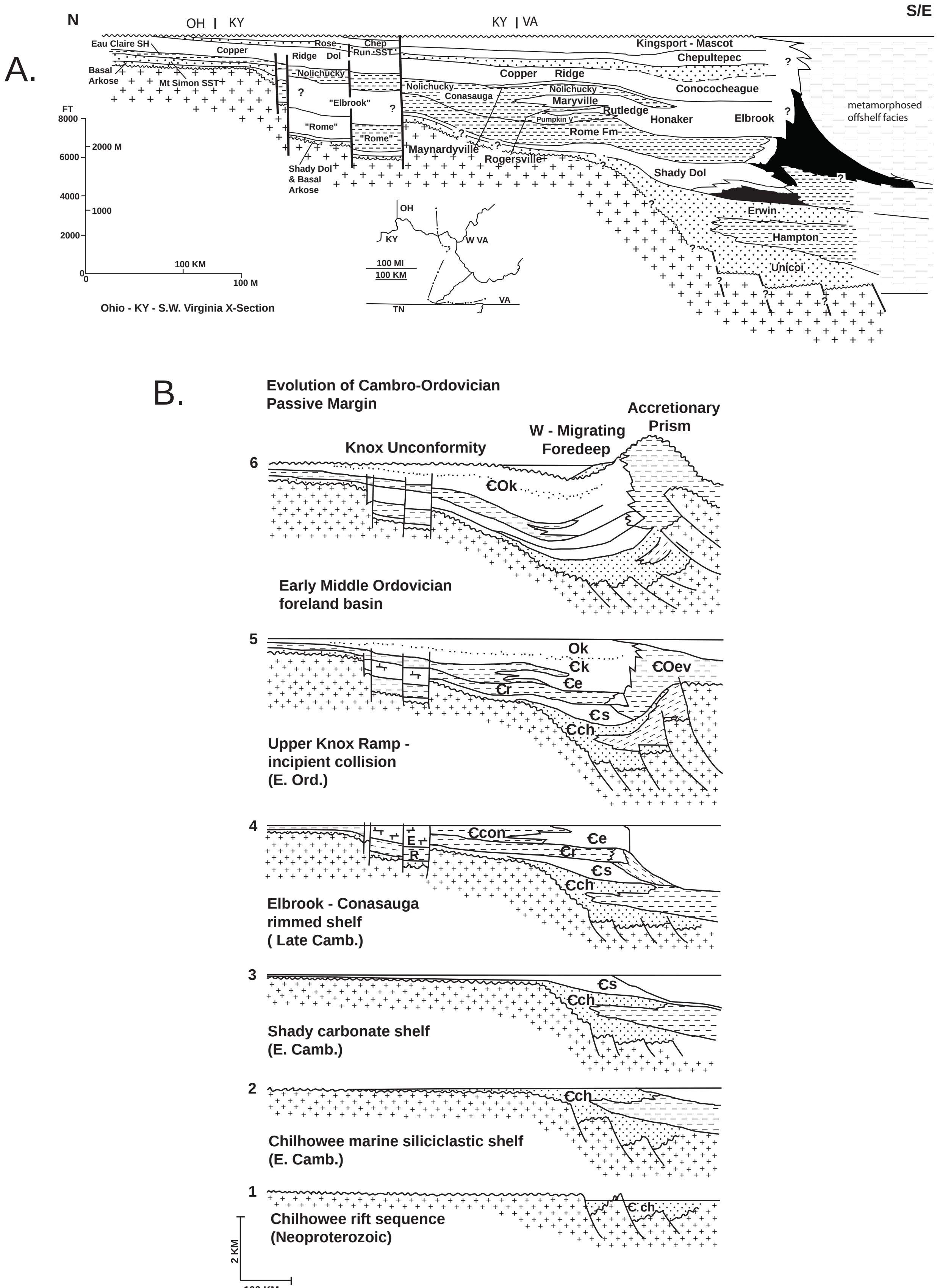

Figure 5 A. Regional cross section of Cambro-Ordovician passive margin succession (based on Koerschner and Read 1989). B. Evolution and destruction of Cambro-Ordovician passive margin sequence. Єc h is Chilhowee Group, Єs is Shady Dolomite, Єr is Rome-Waynesboro formations, Єe and Єc on are Elbrook and Conasauga formations, Єk is Lower Knox Group, Ok is Upper Knox/Beekmantown carbonates, ЄOk is lower and upper Knox Group combined, and ЄOev is Evington Group (modified from Read, 1989b).

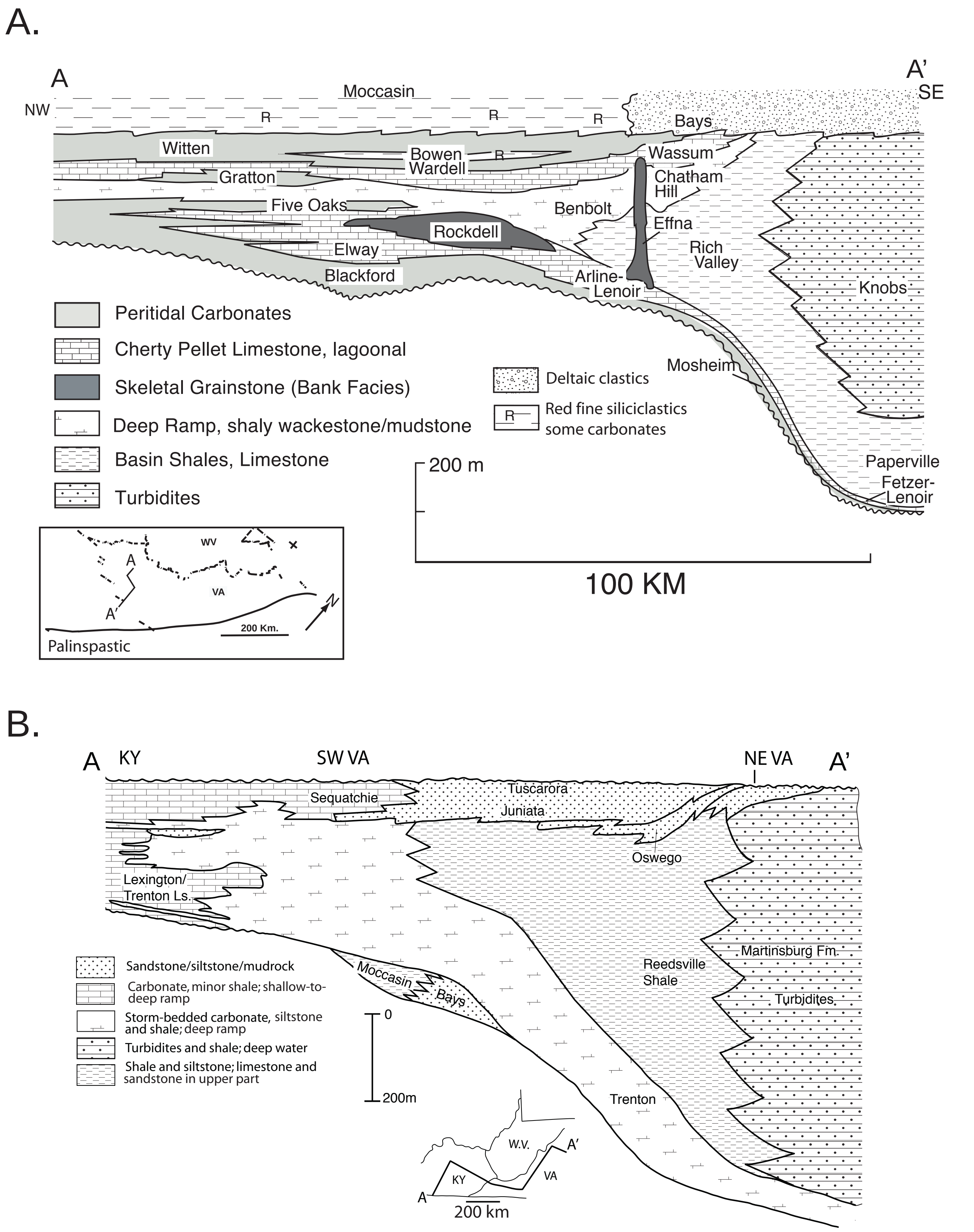

Figure 6. Regional cross sections of Middle and Late Ordovician supersequences. A. "Middle" Ordovician Limestone supersequence (modified from Read, 1980). B. Late Ordovician supersequence (Martinsburg Formation/Trenton-Reedsville formations) (modified from data in Kreisa, 1981 and Diecchio, 1985a).

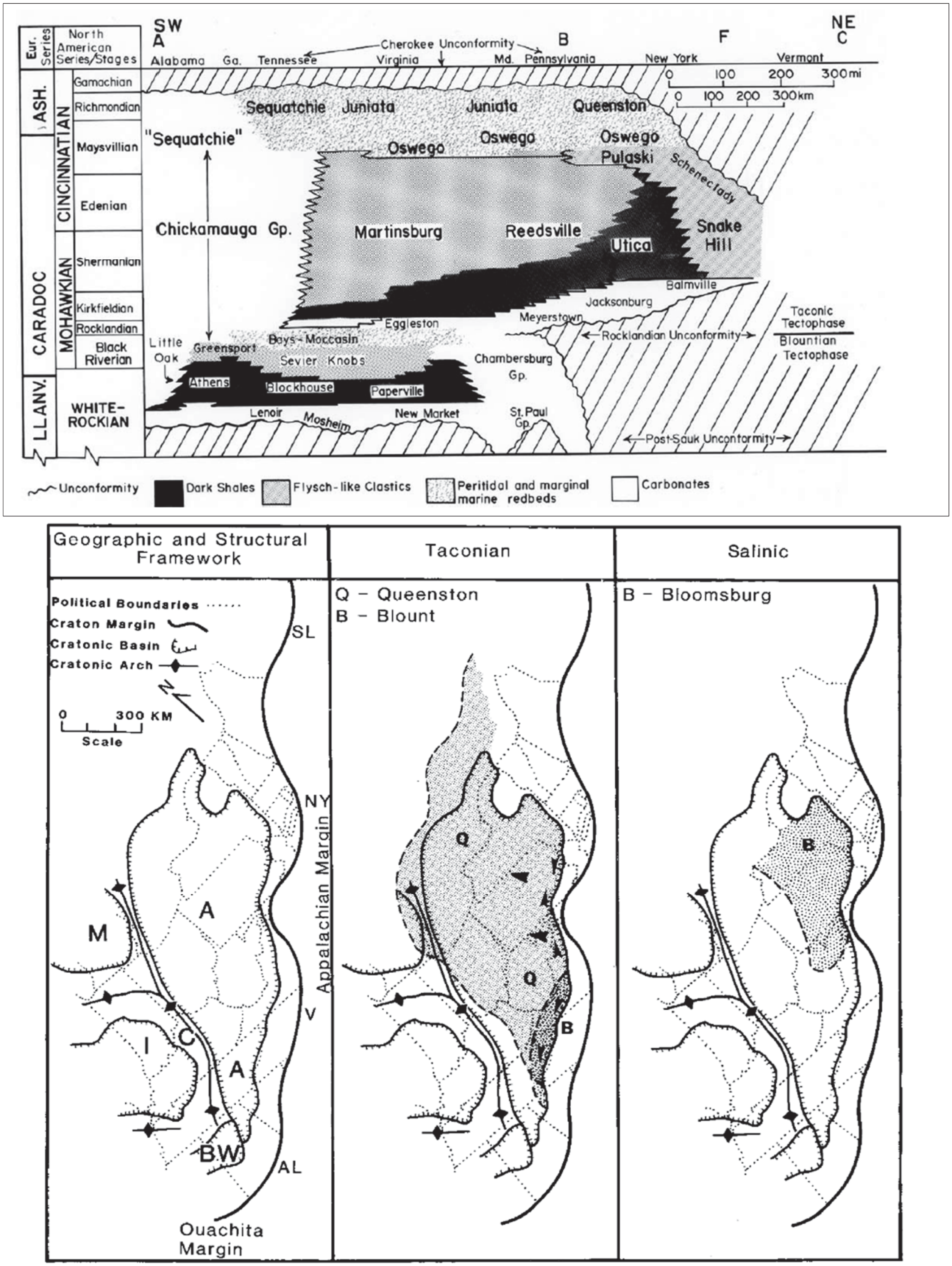

Figure 7. a) Schematic Middle-Upper Ordovician section paralleling the strike of the Appalachian Basin and showing the repetition and migration of the delta-complex sequences that represent the Blountian and Taconic tectophases. b) Distribution of major Taconian and Salinic clastic wedges or delta complexes on southern Laurentia (Ettensohn, 2004).

end of the Taconic orogeny and clastic sedimentation. Overlying the unconformity is the mixed carbonate-clastic sequence known as the Helderberg Group (Silurian-Early Devonian) which consists of small transgressive and regressive cycles with small clastic wedges in western Virginia and southeast West Virginia nearest the Virginia Promontory. The Salinic Disturbance was primarily focused around the New York Promontory.

The Acadian Orogeny in the Central Appalachian Basin possibly began as early as the Late Silurian time when dark shales first appear in the Central Appalachian Basin (Figure 8; Ettensohn, 2004). During this time Laurussia and one or more of the Avalon terranes were on a collision course with their convergence marking the inception of the Acadian Orogeny. Convergence along the eastern Laurussian margin was transpressional as evidenced by lineations developed in Blue Ridge and Inner Piedmont crystalline rocks (Merschat and Hatcher, 2012). Protracted transpressional collision worked to develop a series of deltaic complexes that originated nearest the New York Promontory and migrated southwestward during the zippered closure of the Iapetus Ocean that transgressed a period of time from the early Late Silurian to Early Mississippian. Ettensohn (2004) describes four tectophases during the Acadian-Neoacadian event with the first tectophase originating near the St. Lawrence Promontory during the Early and Middle Devonian clastic wedges were produced the subsequently destroyed by later tectonism. The second tectophase begins in the Middle Devonian near the New York Promontory and the third tectophase represents the southward migration of deformation towards the Virginia Promontory due to direct collision along the continental margin. The fourth tectophase occurred during the Early Mississippian and represents collision with the Virginia Promontory and the southward migration of the orogeny (Ettensohn, 2004). This tectophase encapsulates a long duration, estimated at 45 million years, from the Mississippian – Early Pennsylvanian and is the successive development of two distinct clastic wedges that are separated by a thick carbonate unit. The earliest clastic wedge is known as the Price-Pocono, Grainger, or Borden deltaic complex. This deltaic complex has a wide foot print that extends 500 mi (800 km) along the length of the Appalachian Basin and 375 mi (600 km) to the west, where it extends beyond the Cincinnati Arch and into the Illinois Basin. The widespread extent of shale associated with the Acadian-Neoacadian deltaic complexes assisted with the development of later folds and faults during the Alleghanian Orogeny and creates the master decollement that bounds the Pine Mountain thrust sheet at the western margin of the foreland fold and thrust belt.

The Alleghanian Orogeny began in the Early Pennsylvanian with the transpressional collision between Gondwana and Laurussia and ultimately persisted until Permian. The Alleghanian Orogeny differs from previous events because it represents continent-continent style collision instead of continent-arc collision like previous orogenies. The Allegheny clastic wedge that formed on the cratonward side of the orogen extends more than 690 mi (1,100 km) to the west and 810 mi (1,300 km) along strike with the Black Warrior Basin-Appalachian Basin. The clastic wedge is composed primarily of terrestrial and marginal marine origin with deep water marine sediments similar to the dark shale present in Taconic and Acadian-Neoacadian deltaic complexes.

The stratigraphic framework derived from the multiple episodes of Appalachian mountain building coupled with intervening episodes of carbonate deposition that correlate tectonic quiescence (Fig. 9) created a mechanical stratigraphy that allowed thrust faults to propagate through the orogenically derived, marine shales or the passive margin shales. The oblique-collision aided the wide-spread lateral distribution of structurally weak shale units across the basin allowed the thick successions of indurated carbonates and sandstones work to deflect horizontal compressive stress propagation from deeper to more shallow decollements.

Structural Framework

Harris and Milici (1977) described the Appalachian Valley and Ridge as “rootless folds and gently to steeply dipping thrust faults, which, at depth, join a master décollement near the sedimentary rock-basement contact.” Wentworth (1921) described the Cumberland Overthrust block (Pine Mountain thrust sheet) as a remarkable quadrilateral block about 125 miles (200 km) long and 25 miles (40 km) wide that is bound to the southwest by the Jacksboro tear fault near Jacksboro, Tennessee, to the northwest by the Russell Fork tear fault near Haysi, Virginia, to the southeast by the Hunter Valley fault, near Duffield, Virginia and to the northwest by the Cumberland Plateau along the Kentucky-Virginia border (Figure 10). Displacement along the Pine Mountain thrust sheet is roughly 1.9 mi (3 km) near the Russell Fork tear fault and increases to 13 (21 km) near the Jacksboro tear fault. The southern extent of the Pine Mountain thrust sheet appears to be controlled by the thinning of the Upper Devonian-Lower Mississippian Chattanooga Shale in the Wartburg Basin that occurs southwest, along strike, with the Pine Mountain thrust sheet (Rich, 1934; Mitra, 1988), near Oliver Springs, Tennessee.

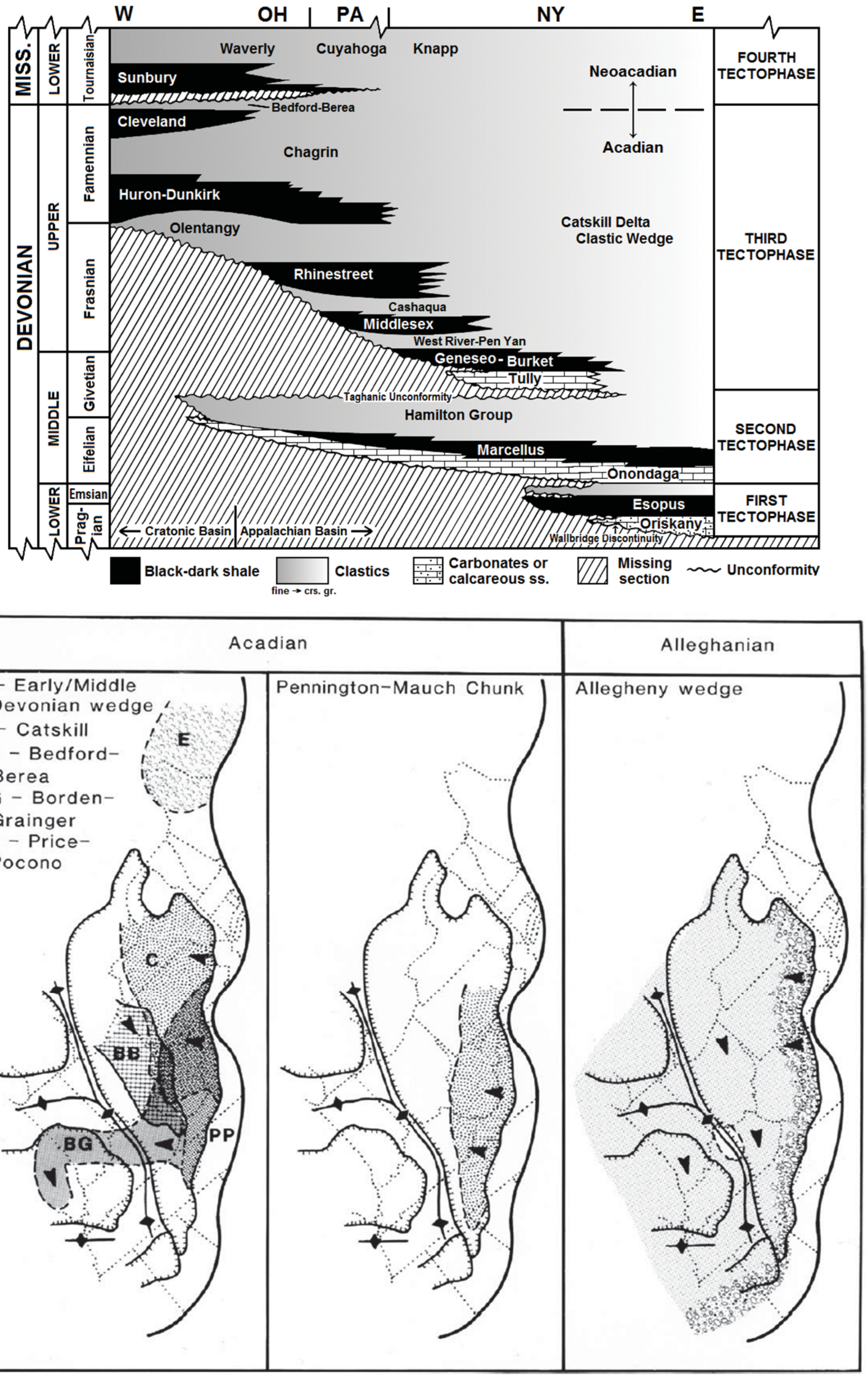

Figure 8. a) Schematic W-E cross section from north central Ohio to east-central New York showing the makeup of the Catskill delta complex. b) Distribution of major Acadian/Neoacadian and Alleghanian clastic wedges or delta complexes on southern Laurentia (Ettensohn, 2004).

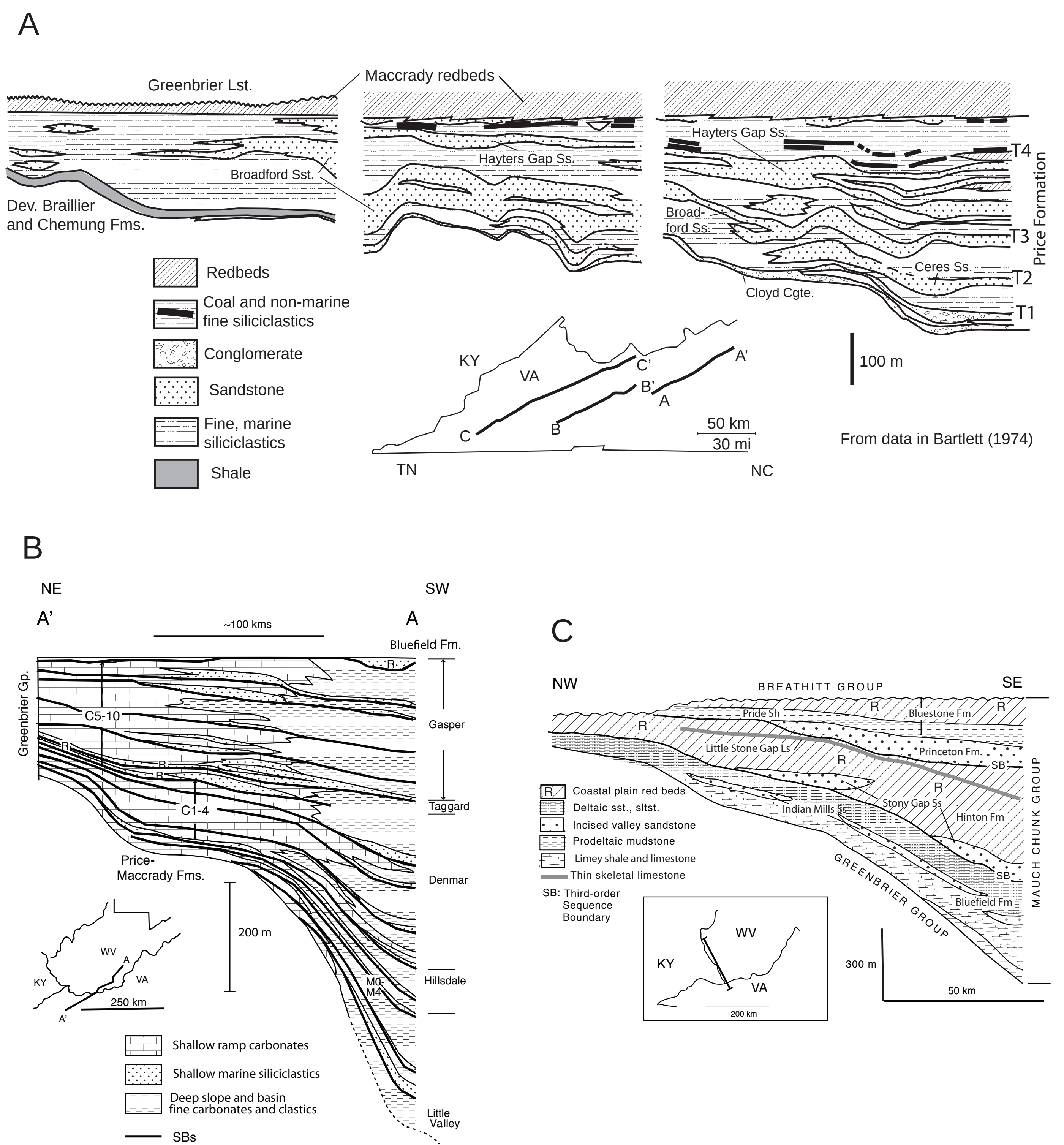

Figure 9. Regional cross sections of Mississippian supersequences. A. Lower Mississippian Price-Maccrady formations (drawn mainly from data in Bartlett 1974, and from Kreisa and Bambach, 1973; Bjerstedt, 1986; Bjerstedt and Kammer 1988;). B. Greenbrier Limestone (modified from Al-Tawil et al., 2003; Huggins, 1983). C. Mauch Chunk Group (modified from Miller and Eriksson, 2000).

Rich (1934) was the first to suggest that major structures in southwestern Virginia were related to thrusting that did not bring basement (crystalline) rocks to the surface. Rich (1934) further suggested that these structures are confined to sedimentary rocks whereby the propagation and movement of thrust sheets to the northwest produced anticlines and synclines (Figure 11). Rodgers (1949) defined this particular style of deformation as "thin-skinned" because sedimentary thrust sheets did not include crystalline basement rocks. The location of thrust ramps in the Appalachian Valley and Ridge are influenced by pre-existing, rift related normal faults that occur as steps in the basement surface. Basement normal faulting that resulted from Late-Proterozoic rifting of the eastern Laurentian margin.

Mitra (1988) indicates that some areas of the Pine Mountain thrust sheet are folded by sub-thrust horses and duplexes that produced erosional fensters within the thrust sheet. The Powell Valley anticline is a classical ramp-anticline (Figure 12) where displacement along the Pine Mountain thrust fault cut up section from the Rome Shale into base of the Knox Group, then into the Upper Devonian-Lower Mississippian Chattanooga Shale then to the surface, likely due to effective stress and thrust efficiency decreasing as the sheet moved to the west. Two smaller local folds, known as the Chestnut Ridge and Sandy Ridge anticline are separated by the intervening Cedars syncline and are related to two sub-thrust faults, the Chestnut Ridge and Sandy Ridge thrust which climb from a decollement at the base of the Knox Group to the base of the Chattanooga Shale (Figures 13). The two anticlines constitute a hinterland sloping duplex and the Pine Mountain thrust sheet overlaps this duplex in the field trip area. Mitra (1988) calculated between 45,000 ft (13,720 m) to 47,000 ft (14,325 m) of shortening (Figures 14 and 15) in the Pine Mountain thrust system in cross sections drafted through the field trip area. Protracted transpression during the Alleghanian Orogeny created regional folds such as the Middlesboro syncline and Powell Valley anticline (Figure 16). Both are major regional folds that overprint the Cambrian through Pennsylvanian rocks and thrust faults in southeastern Kentucky and southwestern Virginia.

Physiography and Topography

The Pine Mountain Thrust sheet is located within the Cumberland Plateau Physiographic Region, a subregion of the greater Appalachian Mountains. The Cumberland Plateau is defined by the presence of gently dipping, resistant, and narrow bedrock ridges composed of sandstone and siltstone, and intervening deep, steeply incised stream valleys eroded in less resistant bedrock including shale and coal beds. Virtually all land area is in slope except for the ridge tops and valley bottom areas. Local topographic relief is commonly on the order of 1,000 ft (305 m) or more and up to 2,000 ft (610m) at the highest ridges. Black Mountain (4,145 ft/1,265 m elevation), Harlan County, is the highest point in Kentucky, and capped by the Four Corners Formation (Middle Pennsylvanian). The lowest elevation is 1,000 ft (305 m) along the Cumberland River near Pineville, Bell County, Kentucky where the Rocky Face Fault terminates at the Pine Mountain Fault.

A well-developed dendritic drainage pattern is established in most of the region. The primary exception is along and south of Pine Mountain where the southwest flowing Poor Fork of the Cumberland River has a 19 mile (31 km) long straight pattern from Cumberland to Harlan, Kentucky. Immediately north of Pine Mountain, segments of several streams, including Cowan Creek and Straight Creek, follow the trend of Pine Mountain. Most streams in the Kentucky part of the fault block drain to the Cumberland River, and most streams in the Virginia portion drain to the Powell River. Both of these rivers drain westward to their confluence with the Tennessee River.

Land Use and Cultural Development

As a result of the rugged topography, land use and cultural development in the region is primarily restricted to bottom lands along major and minor stream valleys. Land values of bottom areas are at a premium; hence the highest and best use for stream bottoms is for homes or commercial structures. Agricultural and manufacturing land uses are virtually non-existent. Floods are common events and can occur year round, and the larger towns have constructed flood walls and berms. Wise, Virginia (2016 population 3,083), Harlan, Kentucky (2016 population 1,606), and Pineville, Kentucky (2016 population 1,756) are the largest towns in the region. The U.S. Army Corp of Engineers operates dams and maintains recreation lake reservoir levels at North Fork Pond Lake, Wise County, Virginia (154 surface acres) and Martins Fork Lake, Harlan County, Kentucky (340 surface acres). Ridge and slope areas support a mixed deciduous forest, and land use in these areas is characterized as recreational. A small part of the George Washington and Jefferson National Forest designated land is located in Letcher County, Kentucky and a larger contiguous area is located in Dickenson and Wise Counties, Virginia adjacent to the Kentucky state line.

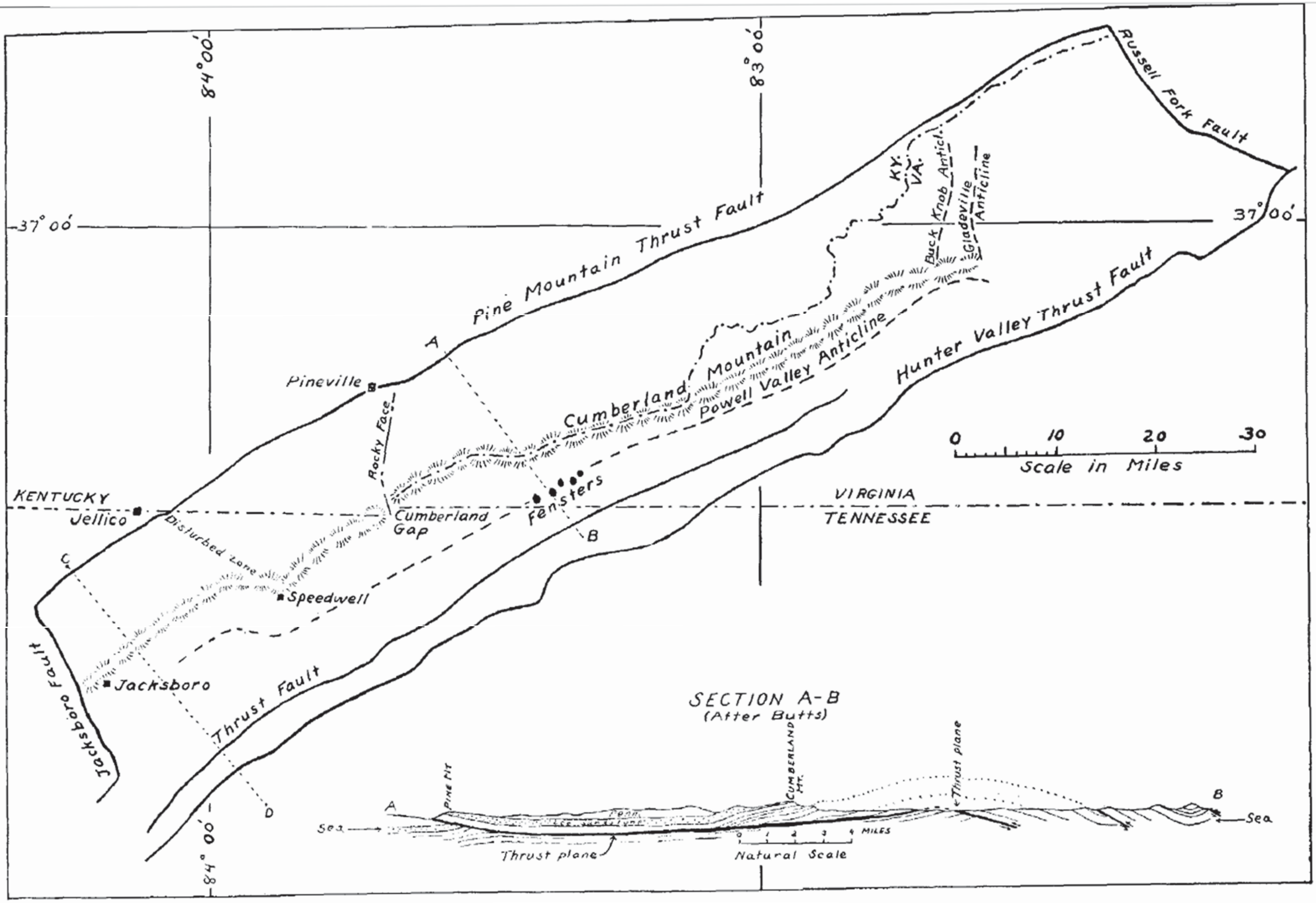

Figure 10. Original map from Rich (1934) of the Pine Mountain thrust sheet and Hunter Valley fault.

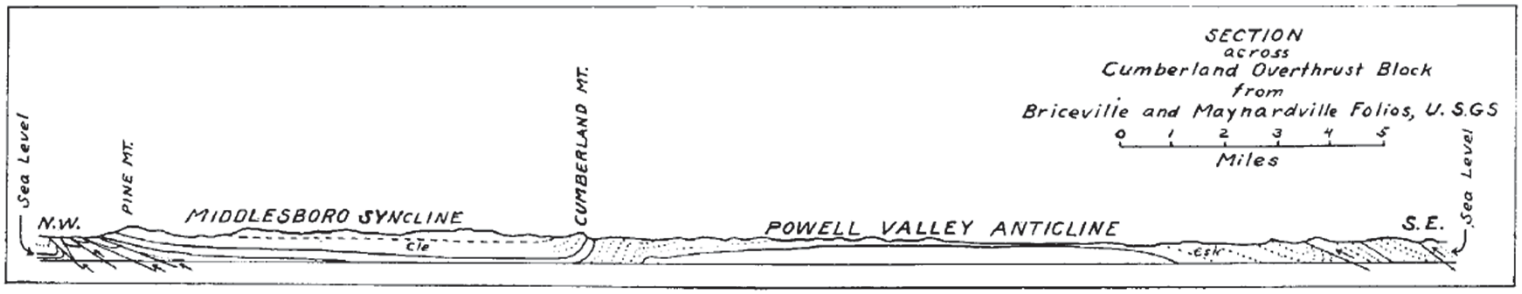

FIG. 2.—Topographic and geologic cross section of western part of Cumberland overthrust block along line *CD* (Fig. 1), showing flat-topped Powell Valley anticline and flat-bottomed Middlesboro syncline; also showing earlier, now disproved, conception of relations of Pine Mountain thrust fault. From Briceville and Maynardville folios, United States Geological Survey.

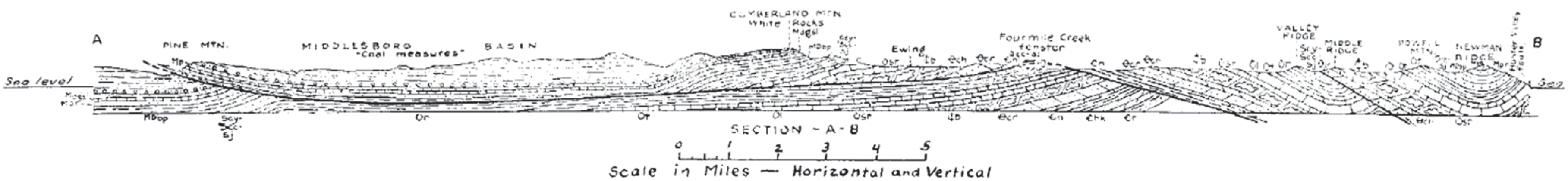

FIG. 3.—Cross section of Cumberland overthrust block showing fensters and newer conception of relations of Pine Mountain fault. Courtesy of Charles Butts and Virginia Geological Survey.

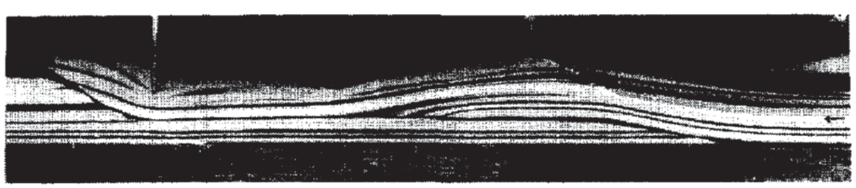

FIG. 6.—Model made by piling paper sheets as in Figure 4 and thrusting toward left. Note similarity to structure of Cumberland block.

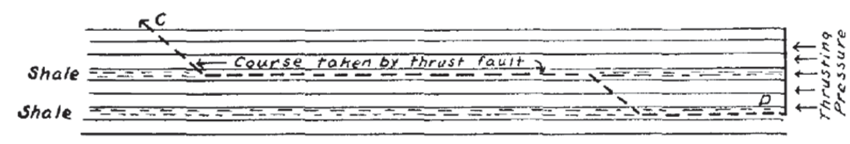

FIG. 4.—Diagram representing course of incipient thrust plane in series of sedimentary rocks. Plane follows beds of easy gliding, such as shales, and breaks diagonally across more brittle beds from one shale to another, and, finally, up to surface.

Figure 11. Original cross section from Rich (1934) and diagrams depicting the propagation of the Pine Mountain thrust sheet through the Devonain Shale.

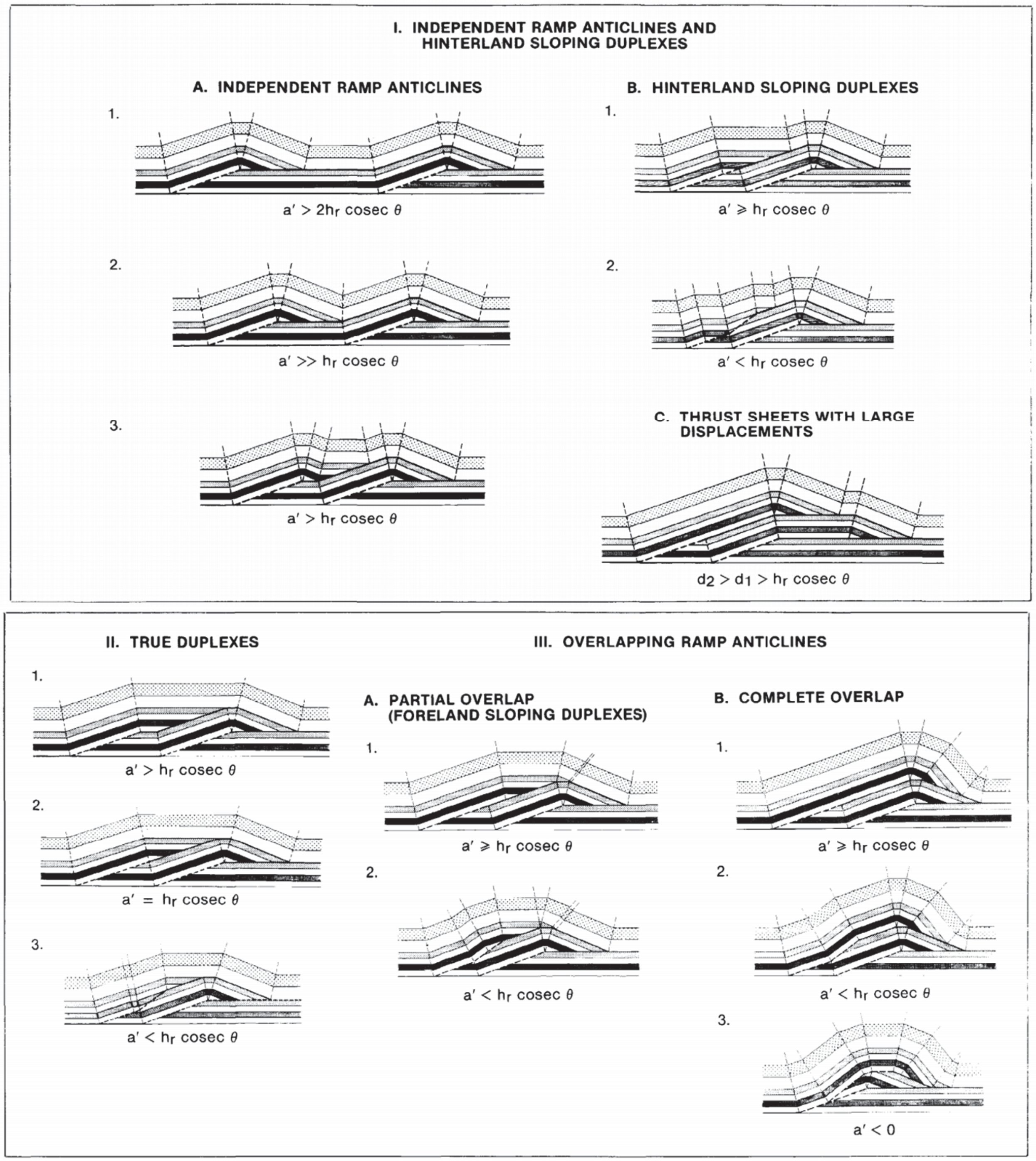

Figure 12. A geometrical classification of duplexes by Mitra (1986) showing the systems of ramp anticlines. The classification is based upon relative displacement on adjacent thrusts (d_1-d_2), final spacing between ramps (a'), and ramp length ($h_r$cosecθ). Duplexes are divided into three main classes (I, II, III) on the basis of the degree of overleap between adjacent horses. Models are created for two thrusts, but general principles can be applied to multiple thrusts. Modified from Mitra (2006).

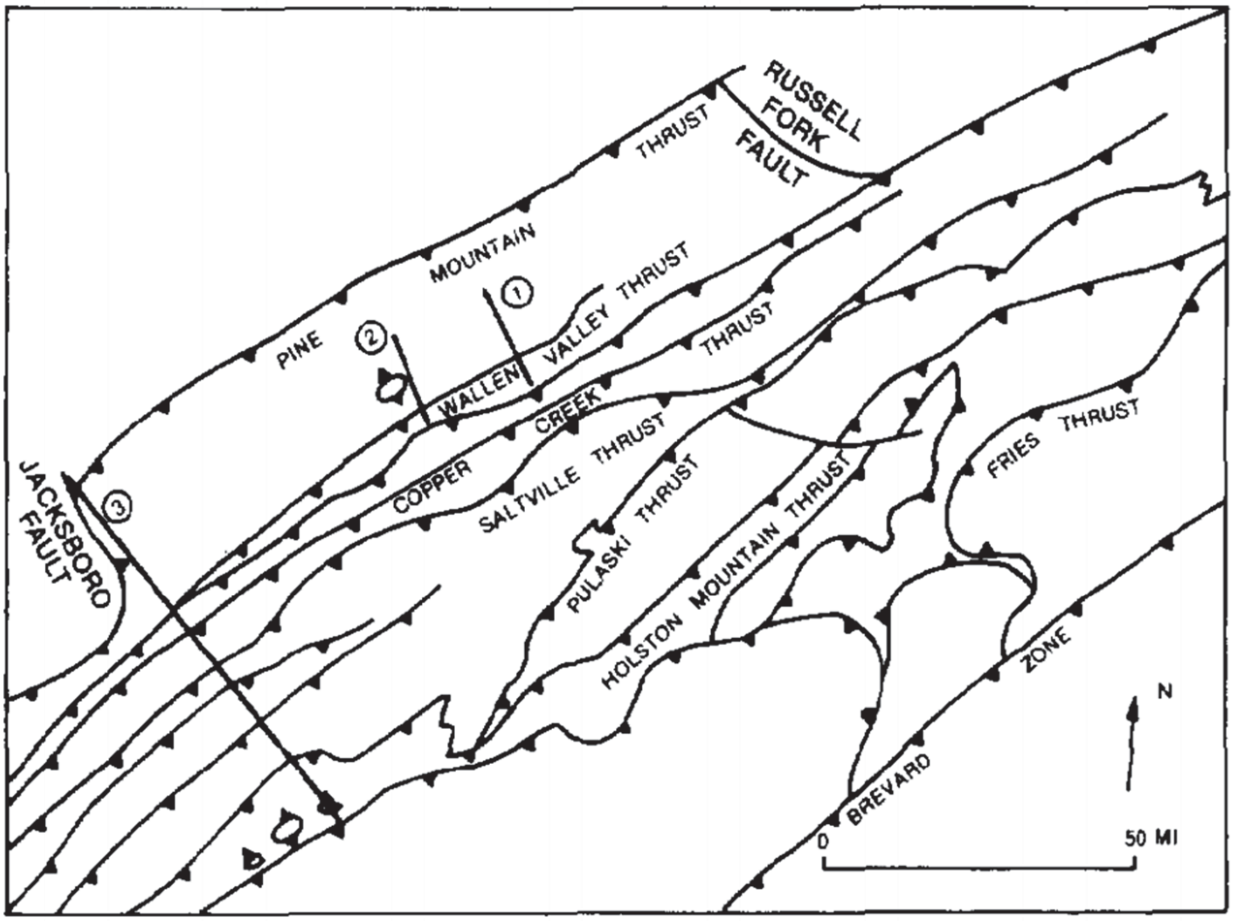

Figure 13. Generalized map of southern Appalachian fold and thrust belt in Virginia, Kentucky, and Tennessee showing locations of strctural cross sections. 1 = Figure 14; 2 = Figure 15; 3 =Figure 16.

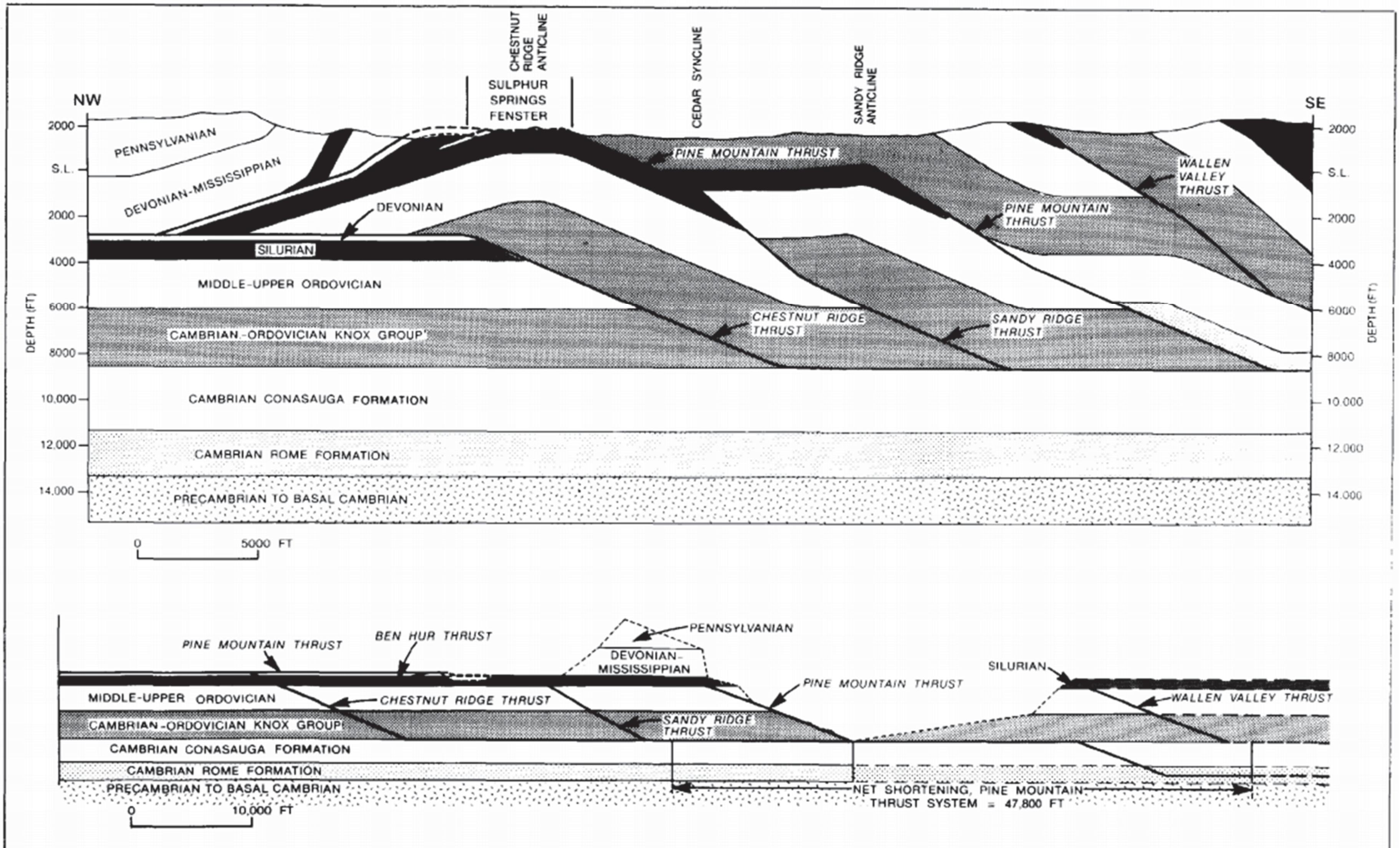

Figure 14. Balanced structural cross section and its restored counterpart through Sulphur Springs fenster. Pine Mountian thrust sheet overlaps a hinterland sloping duplex consisting of Chestnut Ridge and Sandy Ridge anticlines. Ben Hur oil field is located on the crest of the Chestnut Ridge anticline.

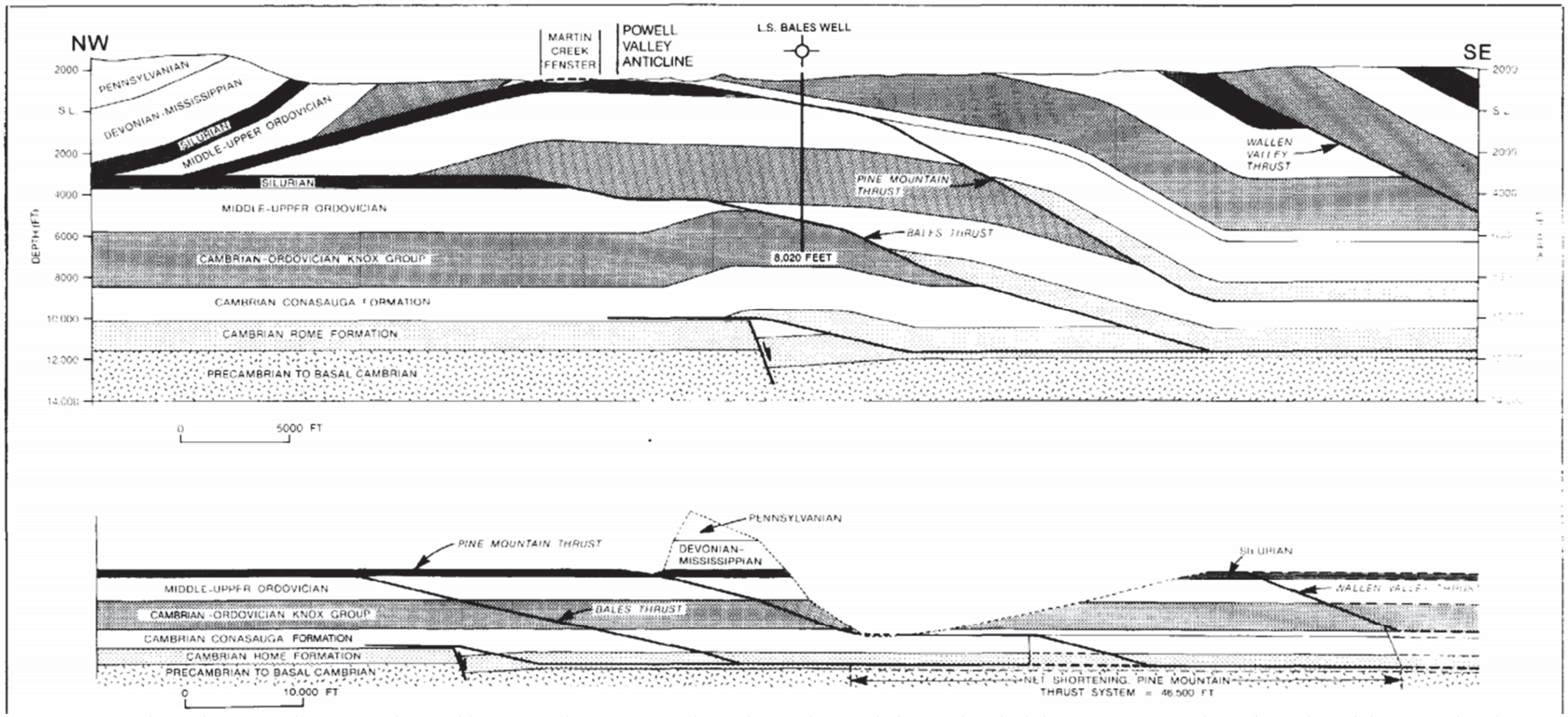

Figure 15. Balanced structural cross section and its restored counterpart through Martin Creek fenster in Virginia. Structure consists of a series of three overlapping ramp anticlines. Rose Hill oil field is located on crest of Bales sheet, whereas lowermost sheet penetrated by Bales well is nonproductive. Location of section is shown

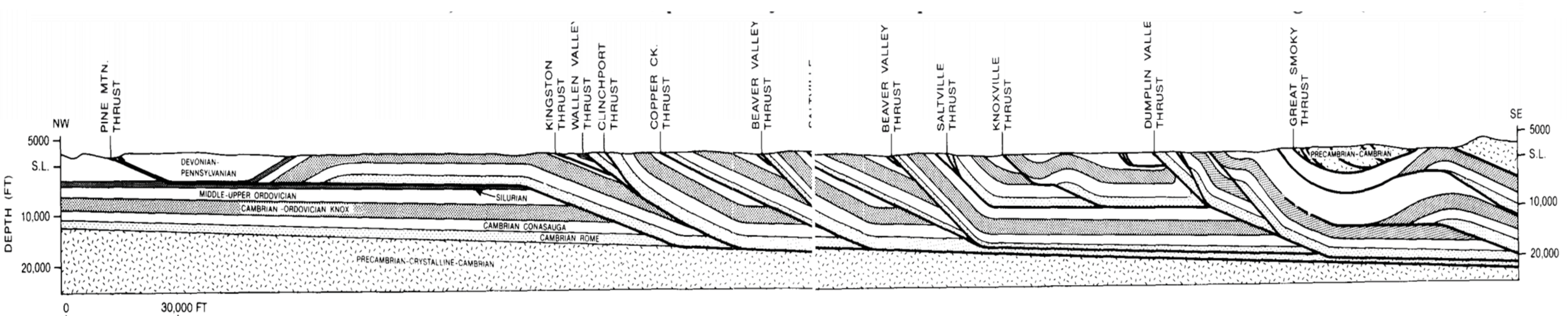

Figure 16. Interpretive cross section through southern Appalachian Valley and Ridge province, Tennessee.

Public roads and railroads are largely restricted to stream valleys. The principal highways of the region skirt the perimeter of the thrust sheet, such as U.S. Highways 23, 25E, and 119. From northeast to southwest, narrow water gaps at Pound Gap, Big Stone Gap, Pennington Gap, Cumberland Gap, and Pineville funnel vehicle and some railroad traffic. The four-lane Cumberland Gap Tunnel which carries U.S. 25E was completed in 1996, and provides a marked improvement for enhancing regional economic development. U.S. Highway 421 from Harlan, Kentucky to Pennington Gap, Virginia remains the only major regional highway to traverse the mountainous central part of the thrust block.

Economic Geology

Significant coal production from the Pine Mountain Thrust Sheet has occurred continuously since the late 19th Century and developed with the introduction of railroads. Drift mining from outcrops along the base of stream valleys has yielded the great majority of coal in the region, and historically was enabled by former large towns or “coal camps” such as at Benham, Cumberland, Elkhorn City, Harlan, Jenkins, Lynch, and Middlesboro, Kentucky, and at Appalachia, Dante, and Trammel, Virginia. Contour strip mining and augering has also yielded a substantial amount of coal since the 1950’s. To a lesser extent, mountain top removal (MTR) operations commenced on parts of Black Mountain in the late 1980’s until opposition from organized citizen groups effected sweeping environmental permitting restrictions in the late 1990’s. In 2011, Virginia based A&G Coal Company received a permit for MTR in the area, but other than blasting, little or no coal production has been recorded.

Approximately 300 producing gas wells and 25 producing oil wells are located on the Kentucky portion of the thrust sheet, and numerous oil and gas wells are located on the Virginia portion. The number and density of exploration drill holes and historic production on the thrust sheet is significantly less than that north of Pine Mountain. The distribution of the producing wells, all of which are spudded in Middle Pennsylvanian strata, are mostly concentrated along the upper limbs of the Middlesboro Syncline and within one mile north of the master fault.

Approximately 50 named oil pools are located on the thrust sheet, however, nearly all of these have fewer than 10 wells and most have fewer than 5 wells. Named production pools of significance are located at Highsplint, Harlan County (12 oil wells), Holmes Mills, Harlan County (45 gas wells). In Virginia, the principal oil fields are Rose Hill and Ben Hur fields, Lee County, and the principal gas field is Roaring Fork, Wise County. Natural gas production is primarily from the Chattanooga Shale (Upper Devonian-Lower Mississippian) source rock/reservoir rock and the Berea Sandstone (Upper Devonian).

Prior to about 2008, all commercial exploration drilling was vertical and primarily targeted structural traps from several producing carbonate and mixed clastic horizons. These horizons include the Pennington Formation (Upper Mississippian) down to the Hardy Creek Limestone (Middle Ordovician; Harris and Milici, 1977). The established source rock for the region is the Chattanooga Shale (Upper Devonian-Lower Mississippian) which is also an established reservoir rock.

Interpretations of seismic reflection profiles indicate a 10-mile (16 km) wide, north-south trending basement bounded graben of mostly shale fill that is connected with the larger Rome Trough of east central Kentucky and West Virginia is mapped in easternmost Harlan County and adjacent Letcher County. This feature connects with the Rome Trough in Floyd County, Kentucky, and is so referred to as the Floyd Embayment. Discoveries of organic rich shale of the Rogersville Shale, a clastic tongue of the Conasauga Shale (Upper Cambrian) in parts the eastern part of the Rome Trough from three deep drilling tests during the early 2010’s revitalized interest of a deep play in the region, and subsequently the Rogersville Shale was mapped throughout much of southeastern Kentucky and southwestern Virginia based on the seismic profiles. The Rogersville Shale varies in thickness from 200 feet to greater than 1,200 feet (365 m) in eastern Kentucky and West Virginia but only 200 to 400 feet (60 to 120 m) in the Pine Mountain thrust block. Drilling depths are from 3,000 to 5,000 feet (915 to 1525 m). However, there are no exploration tests that penetrate below the Copper Ridge Dolomite of the Knox Group (Upper Cambrian) along and south of the Pine Mountain Fault, and the Rogersville Shale play is speculative in this area.

Limestone is produced from several surface quarries on the margins of the Pine Mountain thrust sheet where thick Upper Mississippian and Upper Ordovician limestones are exposed. Pine Mountain Stone Company, Inc. operates a surface quarry in the "Big Lime" (Upper Mississippian) that is exposed along the north side of Pine Mountain near Jenkins, Kentucky and at Bledsoe, Kentucky. South of and along Stone Mountain, quarries are present in the Greenbriar Limestone near Big Stone Gap, and in the Woodway Limestone (Upper Ordovician) near Woodway and along Cumberland Mountain at Ewing, Virginia.

Pennsylvanian Strata and Coal Geology of the Pine Mountain Thrust Sheet

Pennsylvanian strata crop out throughout the Pine Mountain Thrust Sheet and have been extensively explored during the prolonged course of coal, oil and gas exploration. Owing to the structure of the Middlesboro Syncline and subsequent differential erosion of stream valleys, the thickness of the Pennsylvanian rocks as reviewed from published geologic quadrangles varies from approximately 1,500 ft (460 m) near Pineville, Bell County, Kentucky up to 4,500 ft (1,370 m) near Little Black Mountain, Harlan County, Kentucky. The gross succession of Pennsylvanian rock types, from base to top, is conglomeratic sandstone, sandstone, siltstone, shale, and coal, and sandstone, siltstone, shale, coal and limestone.

The correlation and dating of Pennsylvanian strata in the greater Appalachian Basin has been greatly refined in the latter part of the 20^{th} Century by detailed palynological studies of coal beds and identification of fossil species in marine zones. A composite correlation chart of the greater Appalachian Basin lists the Pennsylvanian Series, Stages, time scales, floral zones, and principal rock Groups (Figure 17; Greb et al., 2008).

As many as 30 commercial coal beds have been identified and mapped on the published geologic quadrangles for the region. Most coal beds have a dual nomenclature north and south of the Pine Mountain Fault as a result of differences of historic prospecting and mining activities, and the earlier lack of understanding of the structural offset, lithologic contrasts, and faunal assemblages of marker beds. A stratigraphic correlation chart of major coal beds located north and also south of and along the Pine Mountain Fault (Rice, 1979) is included for reference (Figure 17).

Pre-Field Trip Discussion, Breaks Interstate Park

This presentation seeks to familiarize the Geological Society of Kentucky members with a two geoscience apps that we commonly use in the field, FieldClino from Midland Valley and Rock'd. Rock'd is provided by the University of Wisconsin Macrostrat Lab in collaboration with the NSF and UW Geoscience. Both apps have overlapping features and both have specific features which set them apart from one another. The FieldClino app allows the user to collect field data using the app and records the station using the phones GPS coordinates. FieldClino allows the user to take strike and dip measurements using the phones compass and inclinometer. Data can be compiled and displayed in the various stereonet projections or exported as a .csv file that can be readily imported into a variety of mapping software. The Rock'd app is of particular interest in that it can provide access to more than 155 geologic maps using the Macrostrat map database. The Rock'd app also provides access to the Scotese tectonic maps of geologic time, which are handy when instructing in the field. One feature that sets Rock'd apart from FieldClino is the ability to identify the elevation, geologic age, gross lithology, and rock formation at your phones GPS coordinates. Both apps are just a small segment of what is out there but useful in the field.

Field Trip

*******The Field Trip will begin at the Pine Mountain Park-N-Ride south of the US-23/US-119 Intersection*******

Stop 1a – Foot wall of Pine Mountain fault zone, Pound Gap, Jenkins, Kentucky

Stop 1a begins with an outcrop of Pine Mountain fault zone footwall that is comprised of highly fractured and in some places overturned Pennsylvanian Breathitt Sandstone, siltstone, shale, and coal. This stop also marks the contact between the Cumberland Plateau to the west and the Valley and Ridge Province to the east. The strongly fractured rocks are due to proximity to the Pine Mountain thrust fault.

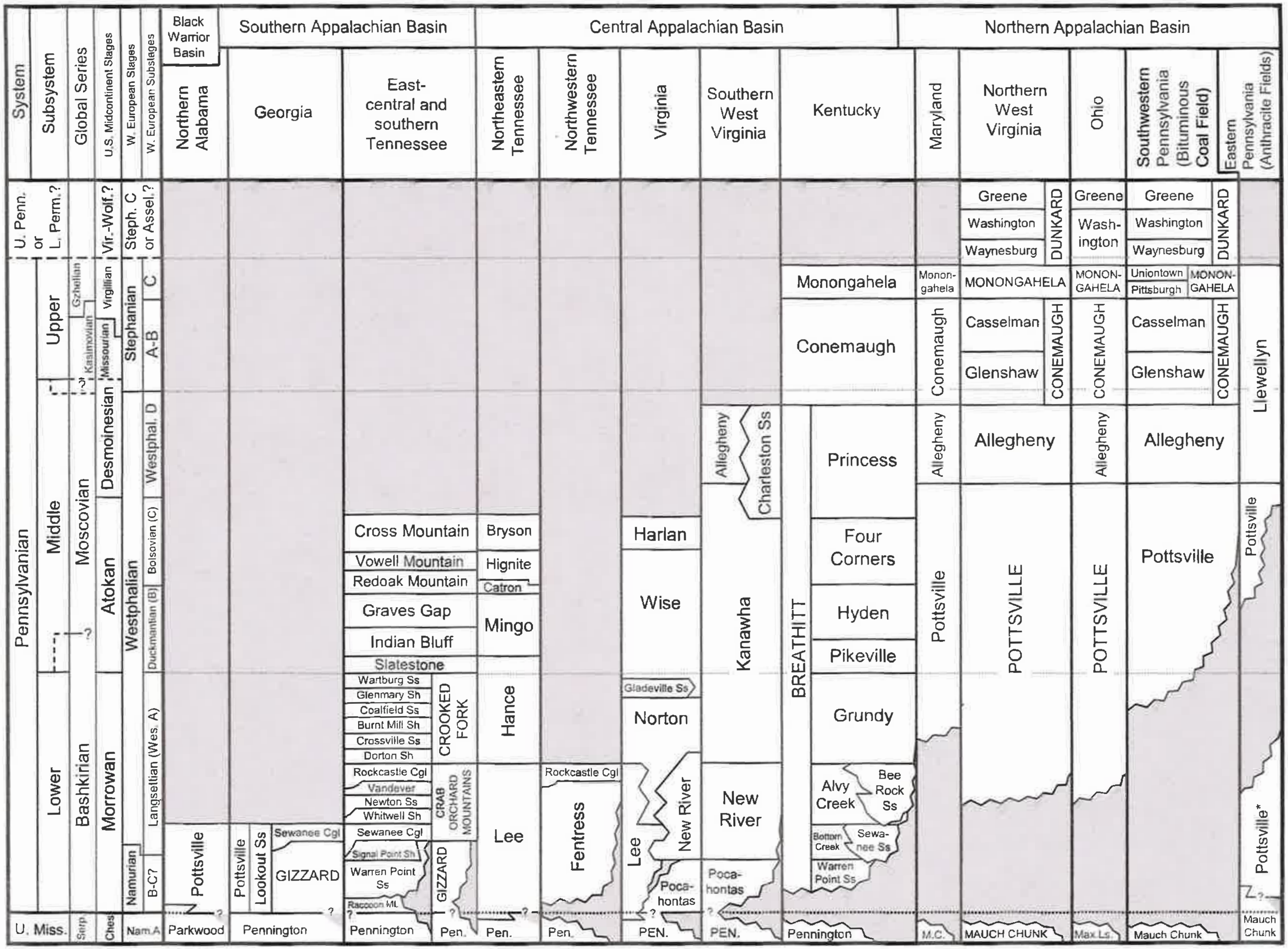

Figure 17. Correlation chart of principal coal beds of the Pennsylvanian Series of eastern Kentucky (Rice, 1979).

Stop 1b – Hanging wall of Pine Mountain fault zone, Pound Gap, Jenkins, Kentucky

As we drove from Stop 1a to Stop 1b we crossed the Pine Mountain fault zone. As we pull to the base of the next outcrop we will enter the hanging wall, where we will see the Devonian through Pennsylvanian section exposed along U.S. Highway 23 as it crosses Pound Gap. The decollement is developed in the Lower Huron member of the Ohio Shale.

Lunch Stop: Mi Monterrey

Travel Note: We'll get off U.S. Highway 23 and head towards Big Stone Gap to access U.S. Highway 58. Traveling southwest from Big Stone Gap we'll pass overturned beds of Clinch/Tuscarora Sandstone near the Williams Cove fault. The Ben Hur thrust fault will cross U.S. Highway 58 before we arrive at our next stop south of Dryden, Virginia.

Stop 2 – Silurian Hagan Shale, Dryden, Virginia

Stop 2 is south of Dryden, Virginia along the westbound lane of U.S. Highway 58 (Figure 18) where the highway exposes footwall rocks that show pervasive deformation below the low-angle Ben Hur thrust fault (Figure 19). The Silurian Hagan Shale at this stop contains numerous folds and slaty to pencil cleavage that is often truncated against small thrust faults (Figure 20). Footwall rocks trend across to the southeast side of the road, where a large outcrop exposes highly fractured, medium-to-dark gray Hancock Dolomite. The Ben Hur occurs southeast of this outcrop. This thrust fault is unique in that it shows strong deformation several hundred feet above and below the fault plane. This is due to the presence of shaley interbedded limestone in the hanging wall and thick accumulation of siltstone and shale in the footwall. The Ben Hur thrust fault is one of the sub-thrust imbricate faults that creates a ramp that

Travel Note: Traveling Route 58 towards Pennington Gap we'll see vertical beds of Middle Ordovician carbonates in the highly deformed zone of the Ben Hur thrust fault.

Stop 3 – Ordovician Ben Hur Limestone, Pennington Gap, Virginia

At Stop 3 we'll observe folded Ordovician Ben Hur Limestone in the footwall of the Ben Hur thrust fault. The west verging, open anticline at this location consists of thin-to-medium bedded light-brown to light-gray, fine-grained, limestone with thin interbeds of shale (Figure 21). The N 35° E fold axial trend can be traced along the "co-axial" sidewalk along US-58. Due to the mix of thin-to-medium carbonates and shale interbeds this locality provides a look at both bedding-plane slip surfaces and wedge thrusts that are developed where shale beds terminate. Additionally, the fold hinge shows a wedge thrust developed in medium bedded limestone. Several hinge wedges are developed in the fold core in the medium-bedded limestone where flexural slip occurs when shale interbeds are thickest and terminate when shale beds truncate. Thin to medium bedded Ordovician carbonates with intervening shale layers are pervasive in this portion of the basin which resulted in a mechanical contrast that allowed minor faults to transfer slip between bedding planes.

Travel Note: As we travel southeast from Pennington Gap on U.S. Highway 421 we'll cross into Ordovician Chepultepec Dolomite in the hanging wall rocks of the Ben Hur fault. We'll pass through the town of Woodway, which is the type locality for the Woodway Limestone before passing through a broad valley underpinned by flat beds of Hurricane Bridge Limestone (lower Middle Ordovician). We'll take a left at the intersection of U.S. Highway 421 and U.S. Highway 58 and travel towards the north slope of Powell Mountain where we we'll climb up stratigraphic section through the Eggleston Limestone, Trenton Limestone, Reedsville Shale, and Sequatchie Shale where we will access Stop 4 at the crest of Powell Mountain.

Stop 4 – Upper Ordovician Sequatchie and Silurian Hagan Shale, Clinchport River overlook

This location is on the crest of Powell Mountain and on the eastern limb of the southwest-to-northeast trending Powell Valley anticline. As we walk across the road we'll see grayish-red beds of calcareous mudstone that compose the Upper Ordovician Sequatchie Formation (Figure 22). A disconformity between the grayish-red Sequatchie Shale and the Silurian Hagan Shale is less pronounced at this outcrop than other parts of the basin. The

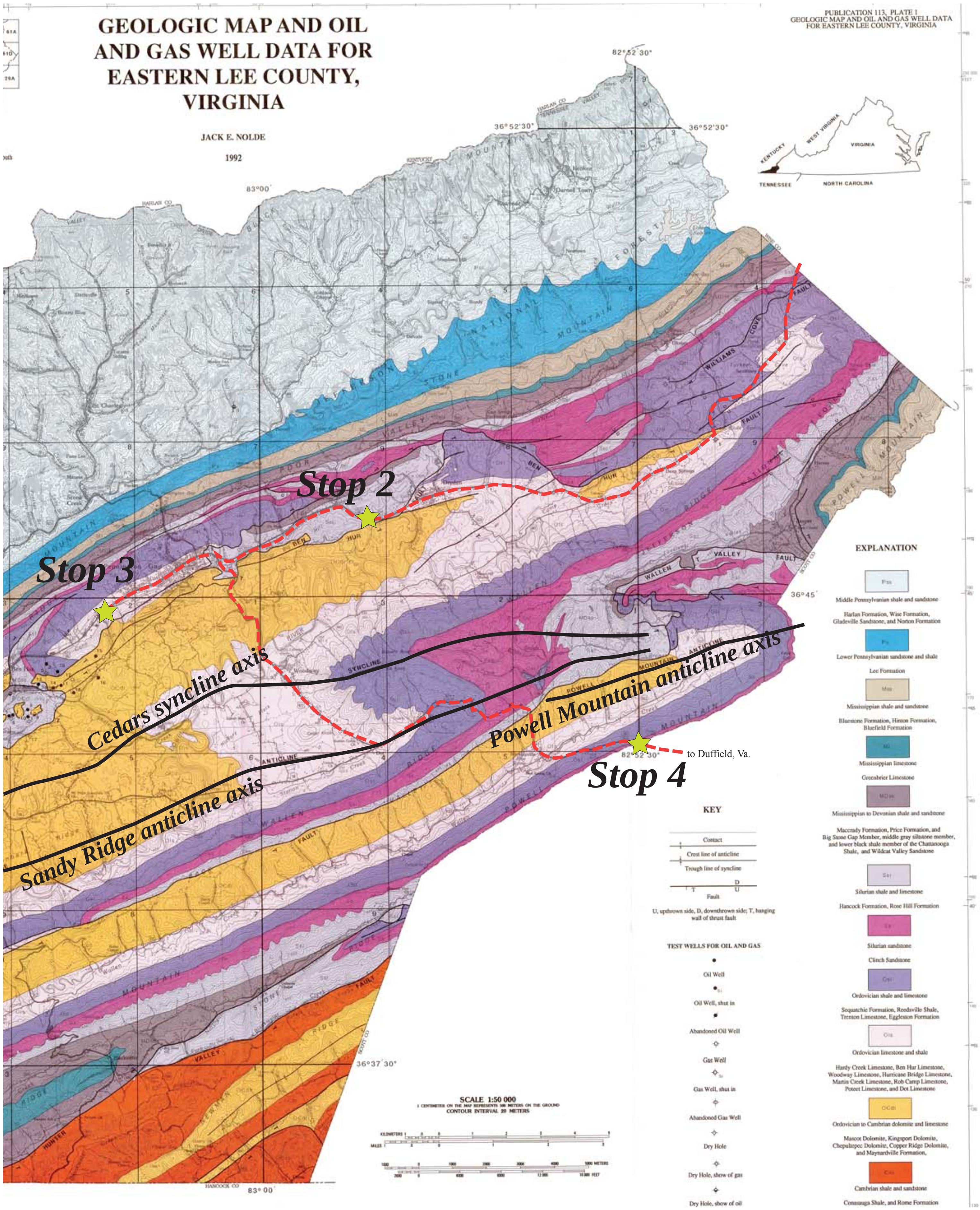

Figure 18. Geologic Map of Lee County, Virginia modified from Noble (1992) to include the locations of stops 2, 3, and 4 in relation to the major faults and folds in the region.

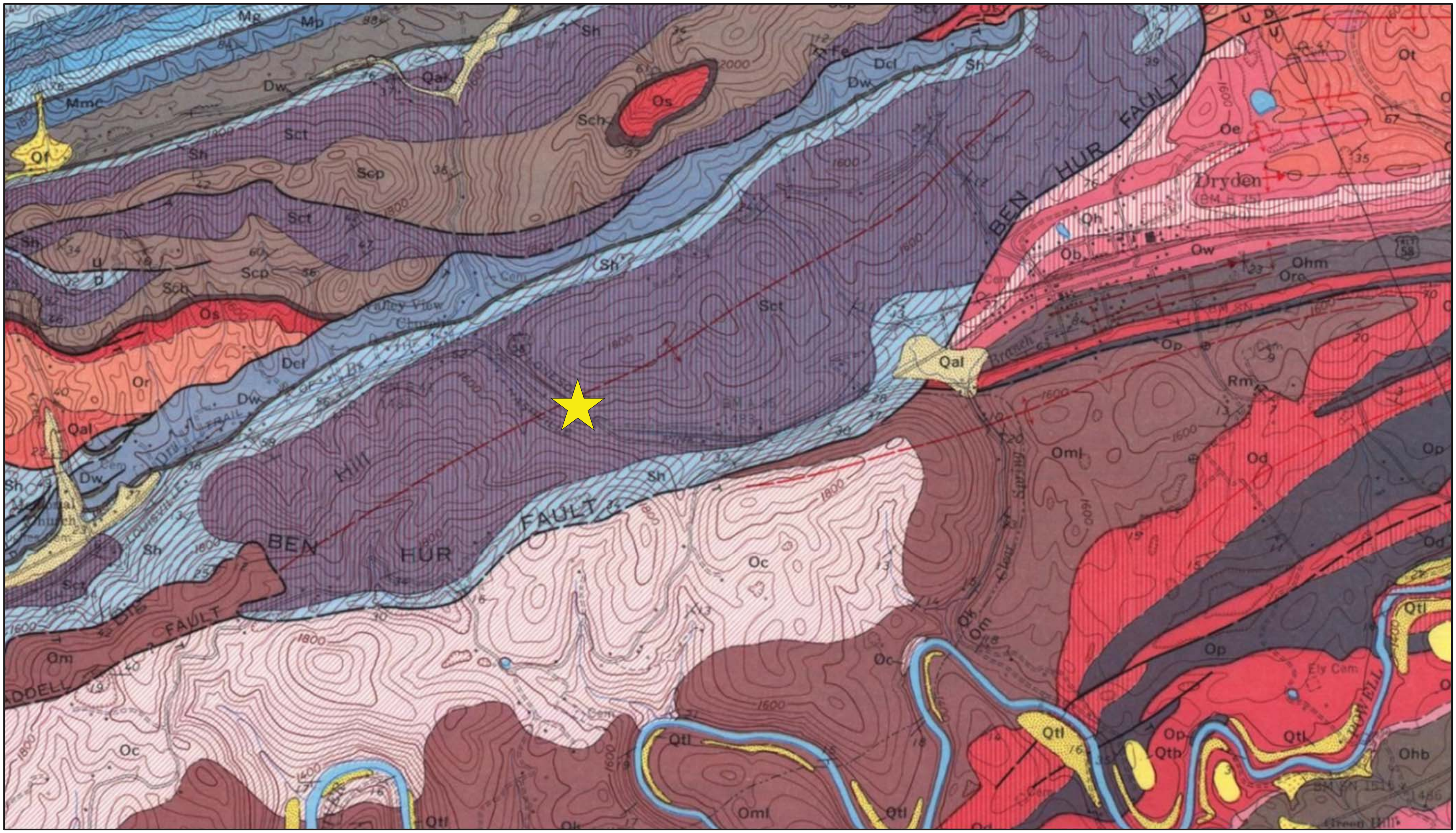

Figure 19. Geologic Map around Stop 2 showing the outcrop location in relation to the Ben Hur thrust fault.

Figure 20. Folded Silurian Hagan Shale in the footwall of the Ben Hur fault at Stop 2.

Figure 21. Cross-sectional photo of an asymetric, west-verging fold in thin-to-medium bedded Ordovician Ben Hur Limestone near Pennington Gap, Virginia. Several limb and hinge wedge thrusts are developed across the outcrop.

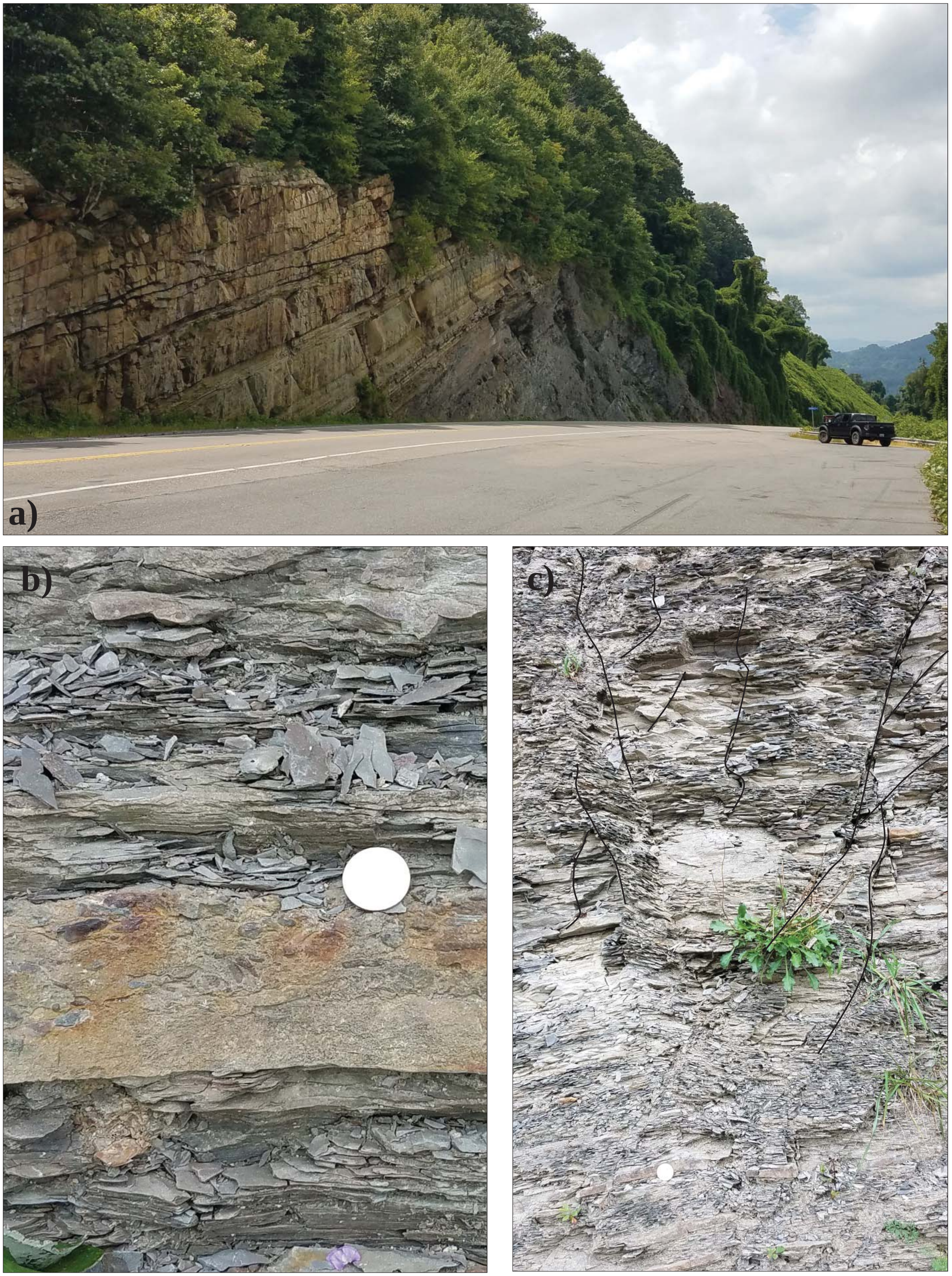

Figure 22. a) Stop 4 outcrop showing the transition from the Ordovician Sequatchie Shale, Silurian Hagan Shale, and Tuscarora Sandstone. b) Lag deposit in the Hagan Shale. C) Small wedge faults in Ordovician Sequatchie Shale.

significance of this outcrop is that it shows the transition from sediments deposited during the waning Taconic orogeny into a short period of tectonic quiescence marked by the deposition of the vertically burrowed Clinch/Tuscarora Sandstone. The basal Hagan Shale is marked by a very fine grained, tan sandstone bed that is 14" thick and forms a prominent ledge at this stop. The Hagan Shale here is greenish-gray, soft, laminated, with several pebble lags before transitioning into shallow water Clinch/Tuscarora Sandstone. The Clinch/Tuscarora Sandstone here is composed of thin tan-to-brown beds of vertically burrowed fine-grained sandstone (Figure 23). As we drive towards Duffield, Virginia along the eastern limb of the Powell Valley Anticline, you will see a linear valley that is underpinned by Upper Devonian-Lower Mississippian Chattanooga Shale. The prominent linear ridge southeast of the valley is held up by Rutledge Limestone in the hanging wall of the Hunter Valley thrust fault.

Travel Note: As we descend down the southeast limb of the Powell Valley anticline towards the town of Duffield we will enter a broad, flat valley that is underpinned by Chattanooga Shale and cut by the nearly flat Red Hill fault.

Stop 5a – Hunter Valley Fault, Duffield, Virginia

The roadcut that we will observe at Stop 5 shows the Devonian-Mississippian Chattanooga Shale below the Cambrian Rutledge Limestone. Here the Chattanooga Shale comprises the tailing edge of the Pine Mountain thrust sheet and has been truncated by the low-angle, Hunter Valley thrust fault. The Hunter Valley thrust sheet extends along strike more than 100 mi (160 km) from northeastern Tennessee into southwest Virginia, to the southeast, the thrust sheet becomes footwall to the Clinchport thrust sheet. The Hunter Valley thrust fault cuts more than 7,500 ft (2,290 m) of sedimentary rock from the Rutledge Limestone up to the Chattanooga Shale. The fractured and weathered Chattanooga Shale at this outcrop has a strong pencil cleavage and abundant crenulations. Small folds and small displacement faults are pervasive throughout the exposure (Figure 24).

Travel Note: We'll drive a very short distance to the next outcrop of Rogersville Shale.

Stop 5b – Rogersville Shale, Devils Race Path, Virginia

The Rogersville Shale has become a formation of interest for oil and gas operators in a portion of the Rome Trough that trends through Johnson, Lawrence, Magoffin, and Morgan Counties, Kentucky and Cabell, Putnam, and Wayne Counties, West Virginia. In Wayne County, West Virginia a core from the Exxon #1-Smith a series of organic-rich intervals with total organic carbon (TOC) as high a 4.4%, the organic-rich interval corresponds to methane, ethane, and propane formation gas peaks on the mud log gas curves.

The Rogersville Shale is 110 ft (34 m) thick in this portion of the Hunter Valley thrust sheet, as you move further to the west the Rutledge-Rogersville-Maryville sequence becomes more shaley and is commonly referred to as the Conasauga Shale, to the east these formations grade into carbonates and dolomitic rocks referred to as the Honaker Formation.

Travel Note: As we leave the Devil's Racepath locality we'll turn right and travel south on U.S. Highway 23, along the way we'll drive past outcrops of faulted Maryville Limestone, Nolichucky Shale, and Upper Cambrian Maynardville Limestone. Several small recognizable faults are present in the Maryville Limestone outcrop along with ribbon texturing. We'll all pass the Copper Ridge Dolomite and Chepultepec Dolomite (lower part of Knox Group) before turning left onto State Route 871 towards Natural Tunnel State Park. Along the way to Natural Tunnel State Park on State Route 871 we will pass the abandoned Natural Tunnel Stone Company quarry in the highly fractured and faulted Lower Ordovician Chepultepec Dolomite. The Chepultepec is differentiated from the underlying Copper Ridge Dolomite by the sandy beds and lenses at the top and base of the formation, in addition the Chepultepec is typically light-colored and absent of chert.

Stop 6 – Natural Tunnel State Park

Natural Tunnel lends it's origin to Stock Creek as it trends from north to south across the Hunter Valley thrust sheet, where it enters the Clinch River west of Clinchport, Virginia. Natural Tunnel is developed in Ordovician Chepultepec Dolomite in the hanging wall of the Hunter Valley thrust fault. Stock Creek was a large underground stream that pursued a channel for more than 2 mi (3.2 km) from a higher level on the north to the Clinch River on the south. A large portion of the roof of the subterranean channel has collapsed and eroded away except for in the vicinity of Purchase Ridge, where the overlying bedrock above the cavern was hundreds of feet thick. A steep walled valley resulted both upstream and downstream from the natural tunnel. The tunnel is 900 ft (275 m) long and the roof averages 75 ft (23 m) above stream level. A vertical walled amphitheater is developed above the south portal of the tunnel and may be viewed from the Park Headquarters. The walls of the amphitheater are formed by Chepultepec Dolomite (Lower Ordovician). Sandstone float is derived from solution of the sandy dolomite near the top of the Chepultepec.

The Norfolk Southern Railroad utilizes Natural Tunnel for a water level route from Horton's Summit to Clinchport on the Clinch River. Although the tunnel is straight, one bend in the tunnel was too sharp for trains to negotiate, so a corner was blasted off in constructing the railway through the tunnel. Elsewhere the tunnel roof and walls are unaltered by man.

Stop 7 – (Optional) Moccasin Limestone

The grayish-red Middle Ordovician Moccasin Limestone is easily distinguishable by its abundant mud cracks. In this area the Moccasin is 435' thick of which 360' is red calcareous mudstone (Cooper, 1945)

This will conclude our field trip. We'll return you back to your vehicles. We hope everyone enjoyed the rocks and have a safe drive home!

Figure 23. a) Outcrop of Tuscarora Sandstone showing vertically burrowed thin beds. Beds here dip to the southeast towards the Hunter Valley fault that occurs across the Clinch River to the southeast. c) Vertical burrows in Tuscarora Sandstone.

Figure 24. Hunter Valley thrust fault showing the Cambrian Rutledge thrust over Devonian Chattanooga Shale. Small sub-thrusts are developed both in the hanging wall and footwall.

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