

To the Graduate Council:

I am submitting herewith a thesis written by Neil E. Whitmer entitled "Structural and Stratigraphic Investigations of the Bays Mountain Synclinorium, Parrottsville and a Portion of Cedar Creek 7.5-Minute Quadrangles, East Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geology.

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STRUCTURAL AND STRATIGRAPHIC INVESTIGATIONS OF THE BAYS
MOUNTAIN SYNCLINORIUM, PARROTTSVILLE AND A PORTION OF CEDAR
CREEK 7.5-MINUTE QUADRANGLES, EAST TENNESSEE

A Thesis
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Neil E. Whitmer
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Dedication

This thesis is dedicated to my parents, Larry and Debbie Whitmer, great role models and friends. I can never thank you enough for always believing in me, inspiring me, and encouraging me to reach higher in order to achieve my goals.

Acknowledgements

I wish to express my gratitude to Dr. R.D. Hatcher, Jr. for his guidance and patience during the past three years. I wish to thank my committee members, Dr. Don Byerly, Dr. Linda Kah, and Dr. Peter J. Lemiszki for their help in preparing the final draft. Additional appreciation is extended to Dr. Peter Lemiszki for his assistance and guidance in the field. I would also like to thank Bob Ratliff and Peter Geiser for supplying and assisting with LithoTect 2D during the restoration of cross-sections. Special thanks are directed to the fellow graduate students who have helped me in various areas, especially Matt Gatewood for being my partner in crime. Most importantly, I would like to thank my mom and dad, whose guidance and unwavering support has given me the confidence to pursue my life's path.

Abstract

The southern Valley and Ridge foreland fold-thrust belt is comprised of a wedge of Lower Cambrian through Pennsylvanian sedimentary rocks that were folded and faulted during the late stages of the Alleghanian orogeny. Within one of the eastern thrust sheets lies the Bays Mountain synclinorium. Rocks as young as Middle Ordovician are preserved in the core of the synclinorium and record the evolution of a Taconian (Blountian) Sevier tectonic basin.

The Parrottsville and Cedar Creek 7.5-minute quadrangles are located on the southeastern flank of the Bays Mountain synclinorium of East Tennessee and contain rocks belonging to the Conasauga, Knox, and Chickamauga Groups. In the southeastern part of this region, the Pulaski thrust sheet overrode the Sevier basin and exposes rock as old as Middle Cambrian along its trace. Post-emplacement folding of the Pulaski fault created a sinuous fault trace that juxtaposes the southeastern and northwestern phases of the Knox and Conasauga Groups.

Until recently, Sevier basin rocks in the Parrottsville and Cedar Creek 7.5-minute quadrangles have been divided into two units: Lenoir Limestone and Sevier Shale. Previous studies concluded divisions proposed elsewhere for the Sevier basin sediment were not applicable in the vicinity. Geologic mapping during this study, however, has identified one subdivision that has been traced along and across strike some 50 km to the northeast.

The conventional model for Sevier basin formation has been that of a foredeep basin that formed in response to crustal loading during the Taconic orogeny. Petrologic

analyses of Sevier basin sedimentary rocks combined with recent detrital zircon data indicate new tectonic models for the basin need consideration. Unit thicknesses acquired in this study suggest a recently proposed back-bulge model that requires a peripheral bulge preventing sediment from the interior of the mountain belt from reaching the Sevier basin to be rheologically infeasible. Rather, data supports a complex development basin model in which basement thrusting sufficient to isolate the Sevier basin from potential sediment sources in the interior portion of the mountain belt occurred during its development.

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Chapter 1

Introduction

Geologic Setting

The Appalachian Valley and Ridge province is composed of a package of Lower Cambrian through Lower Pennsylvanian strata deposited on the Laurentian margin. Alleghanian continent-continent collision of Laurentia and Gondwana deformed these rocks into a foreland fold-thrust belt that extends from Alabama to New York (Hatcher et al., 1989). Thrust faults with large displacement account for much of the deformation within the southern Valley and Ridge, and in East Tennessee, the structurally weak siltstone and shale of the Lower Cambrian Rome Formation are utilized as the master décollement. The Dumplin Valley thrust sheet was emplaced by one of these faults and contains the Bays Mountain synclinorium of East Tennessee (Hardeman, 1966). The Bays Mountain synclinorium at the latitude of the Parrottsville and Cedar Creek quadrangles is flanked by the Dumplin Valley fault to the northwest, and the Pulaski fault to the southeast, and is cored by Middle Ordovician Chickamauga Group rocks. A portion of the Chickamauga Group was deposited in the Sevier tectonic basin and represents the evolution of the Sevier basin from a stable carbonate bank to a rapidly subsiding basin produced by crustal loading during the Taconic orogeny (Drake et al., 1989).

Study Area

Geologically, the Parrottsville and Cedar Creek quadrangles are located on the southeastern flank of the Bays Mountain synclinorium (Fig. 1-1). In addition to Chickamauga Group strata, the area contains rocks belonging to the Knox and Conasauga Groups. The mapped area is located 16 km (10 mi) northeast of Newport, TN, near the North Carolina border, and includes portions of Cocke and Greene Counties, TN.

Purpose

Several studies of the Sevier basin have focused on its stratigraphic and structural characteristics (Benedict and Walker, 1978; Shanmugam and Walker, 1978, 1980, 1983; Shanmugam and Lash, 1982). These investigations, however, were either conducted at a small scale and exclude detailed information or at outcrop scale and consist of isolated but detailed investigations. Although these studies have proven invaluable for providing a broad overview of the basin, more detailed studies that areally connect its parts are needed to better understand the 3D framework of the basin and complex depositional history.

The purpose of this study is to (1) produce a detailed (1:24,000-scale) geologic map of an area in the interior of the Middle Ordovician Sevier basin, (2) to conduct structural and stratigraphic analysis to connect new data with regional interpretations, and (3) to consider the depositional and tectonic history of the Sevier basin, taking into account Sevier Shale thickness estimates from this study. To achieve these objectives, structural data including dip-strike measurements of bedding planes, cleavage, fractures,

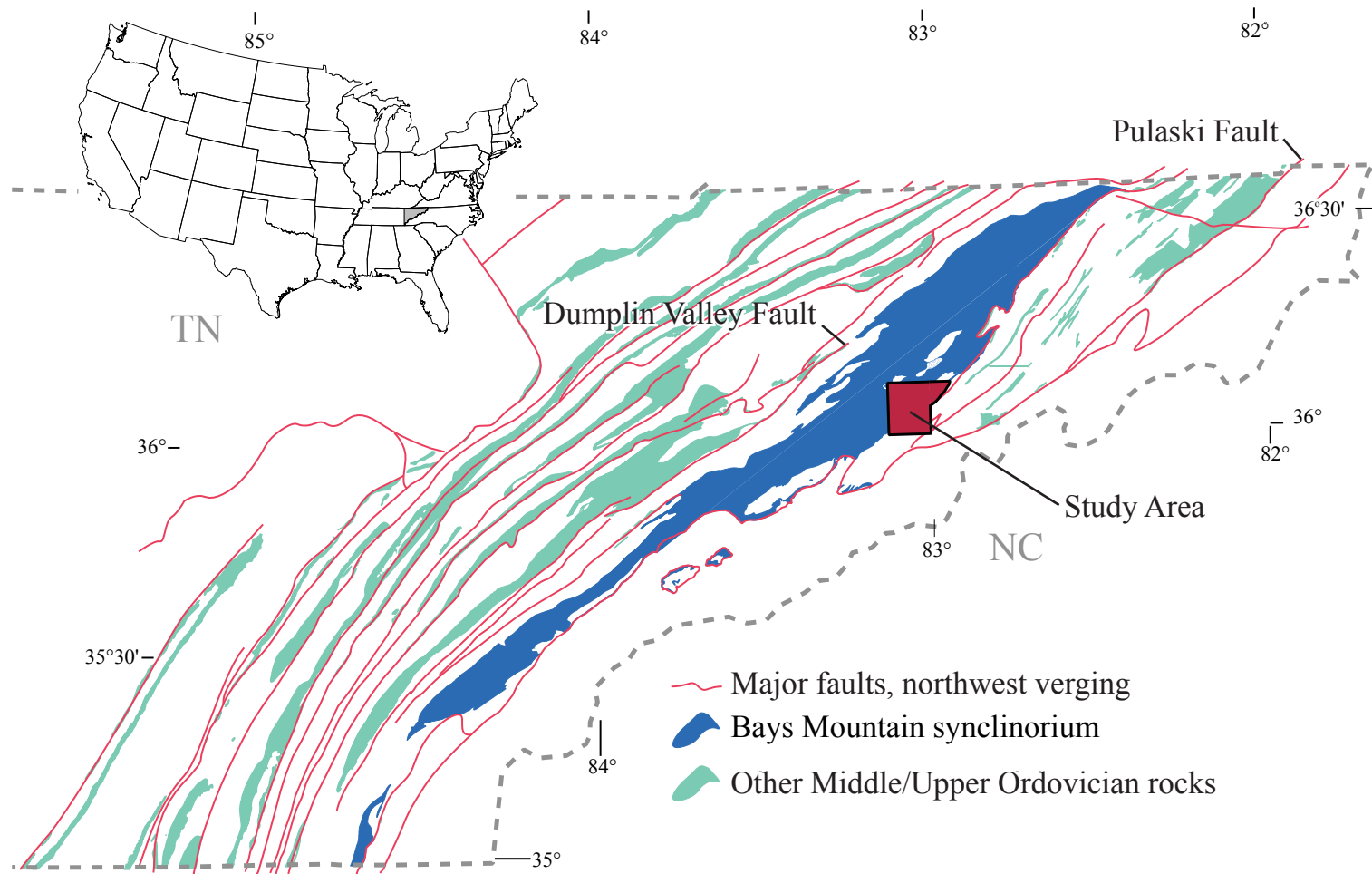


Figure 1-1. Extent of the Bays Mountain synclinorium in relation to the study area.
(Modified from Hatcher et al., 1990.)

and meso-scale folds were collected with the aid of a Brunton compass at approximately 1200 stations in the mapped area. Mapping was conducted at 1:24,000 scale on a 7.5-minute topographic quadrangle base, and at 1:12,000 scale where needed. Stratigraphic contacts and faults were located based on lithologic changes encountered along and across strike. The structural data and stratigraphic contacts were compiled using Adobe Illustrator™ software at 1:24,000 scale on digital raster graphic maps and geo-referenced using MAPublisher™ software. Geologic cross sections were constructed using Adobe Illustrator by accurately transferring contacts and structural information to the section lines. Industry seismic reflection data were also used to project geometries of rock units to depth. Cross sections were then retrodeformed using LithoTect™ 2D software. The field work conducted in the study area, combined with that of Lemiszki (2003), Kohl and Lemiszki, (2004) and Bultman (*in progress*), has resulted in a more 3D view of facies and thickness changes of a portion of the Sevier basin than had previously been resolved.

Previous Work

Several previously published regional geologic maps that contain portions of the study area, including maps by Keith (1895, 1905a, 1905b), Rodgers (1953a), Brokaw et al. (1966), and Hardeman (1966). Keith's folios were an incredibly ambitious attempt to document the structure and stratigraphy of a large area, however the work suffered from poor resolution and an incomplete understanding of regional stratigraphy. Although many of Keith's stratigraphic problems were corrected by Rodgers' (1953a) map, the resulting 1:125,000 map was not much of an improvement in detail for the Parrottsville and Cedar Creek region.

Rodgers (1953a), Shanmugam and Walker (1978, 1980, 1983), and Finney et al. (1996) constructed stratigraphic and paleontologic reconstructions of the Sevier basin strata (Fig. 1-2, Figs. 1-3a and 1-3b). Their depositional analysis (Shanmugam and Walker, 1978, 1980) concluded: (1) that sediment thicknesses in the Sevier basin may be as great as 3,000 m (10,000 feet), and that (2) depositional environments of the Sevier Shale began at bathyal depths (> 700 m) and then shallowed via infilling of the basin by deposition of sediment gravity flows. (3) They suggested that three components of subsidence were critical to developing Sevier basin stratigraphic architecture: (1) subsidence initiated with coequal tectonic and sediment loading; (2) subsidence resulting from tectonic loading; and (3) and sediment loading compaction-related subsidence. (4) Combined, these interpretations suggest development of the Sevier basin as a Taconic foredeep basin.

In a more recent work, Finney et al. (1996) estimated basin subsidence rates and foreland migration based on graphic correlation of graptolites. Twenty-two samples were analyzed and compiled into a composite standard reference section. Graptolites collected from strata representing initiation of subsidence (Middle Ordovician Lenoir-Sevier contact) became progressively younger to the northwest, indicating a northwestward migration of the basin hinge. Subsidence rates at this contact were calculated to be 6 cm/kyr (Finney et al., 1996), similar to the Shanmugam and Walker (1980) estimate of 4 cm/kyr.

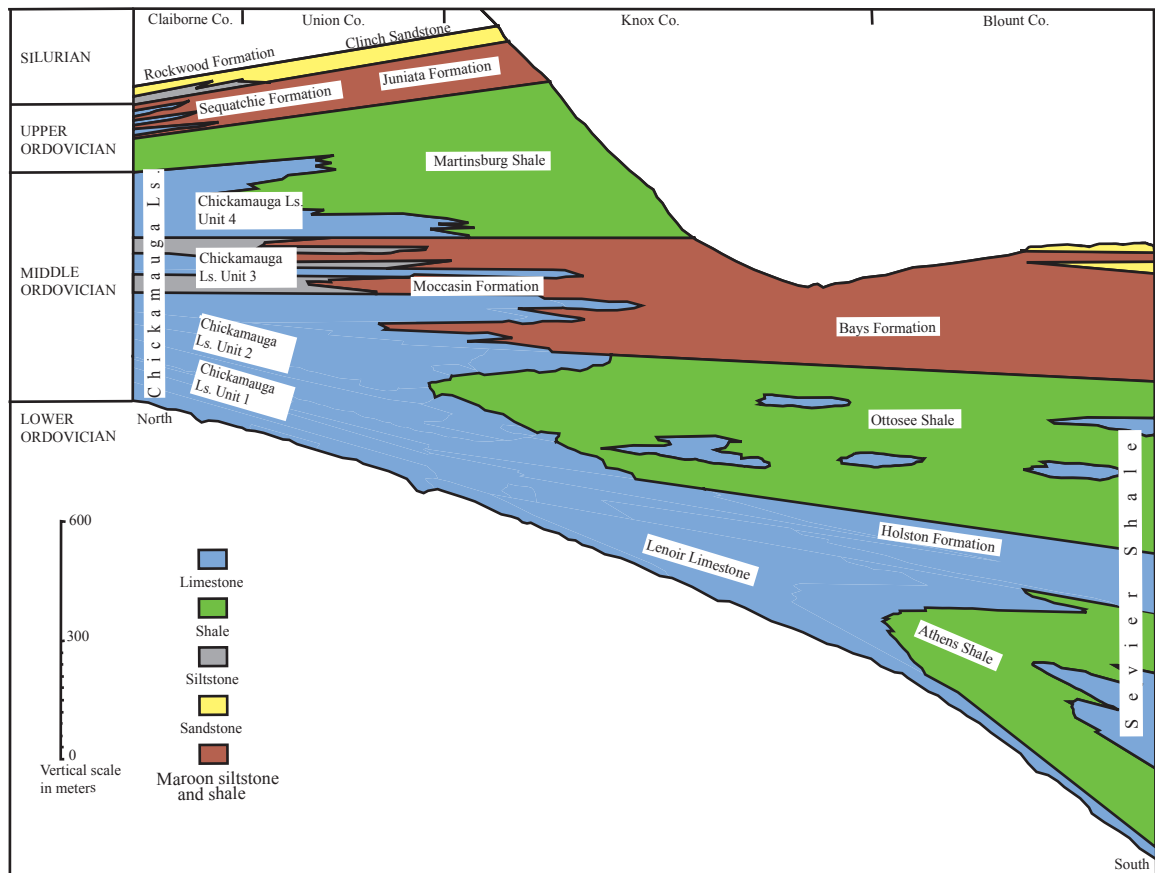


Figure 1-2. Facies relationships in Middle and Upper Ordovician rocks of East Tennessee (modified from Rodgers, 1953b).

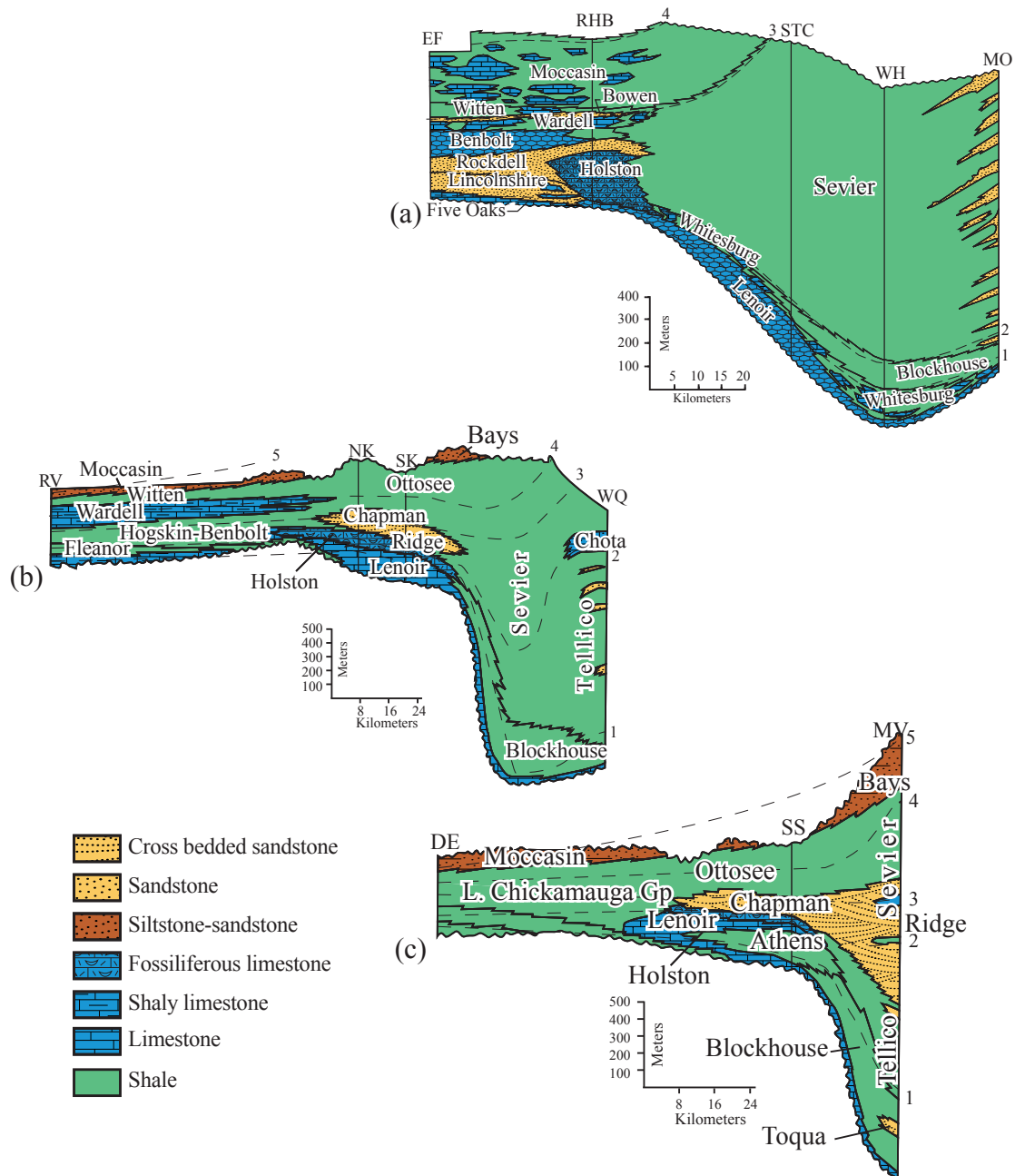


Figure 1-3. Chickamauga Group stratigraphy (modified from Walker et al., 1983). (a) Cross section from Evan's Ferry (EF) through Red House Branch (RHB), St. Clair (STC), Whitesburg (WH), to Mosheim (MO). (b) Cross section from Raccoon Valley (RV) on northwest, through Knoxville (NK and SK) in center, to Wildwood quadrangle (WQ) to southeast. Section location in Figure 1-4. (b) Chickamauga Group stratigraphy farther south from that in Figure 1-3a (modified from Walker et al., 1983). Cross section from Decatur (DE) on northwest through Sweetwater (SS) in center, to Mount Vernon quadrangle (MV) to the southeast. Dashed lines 1 to 5 are time lines. Section locations in Figure 1-4.

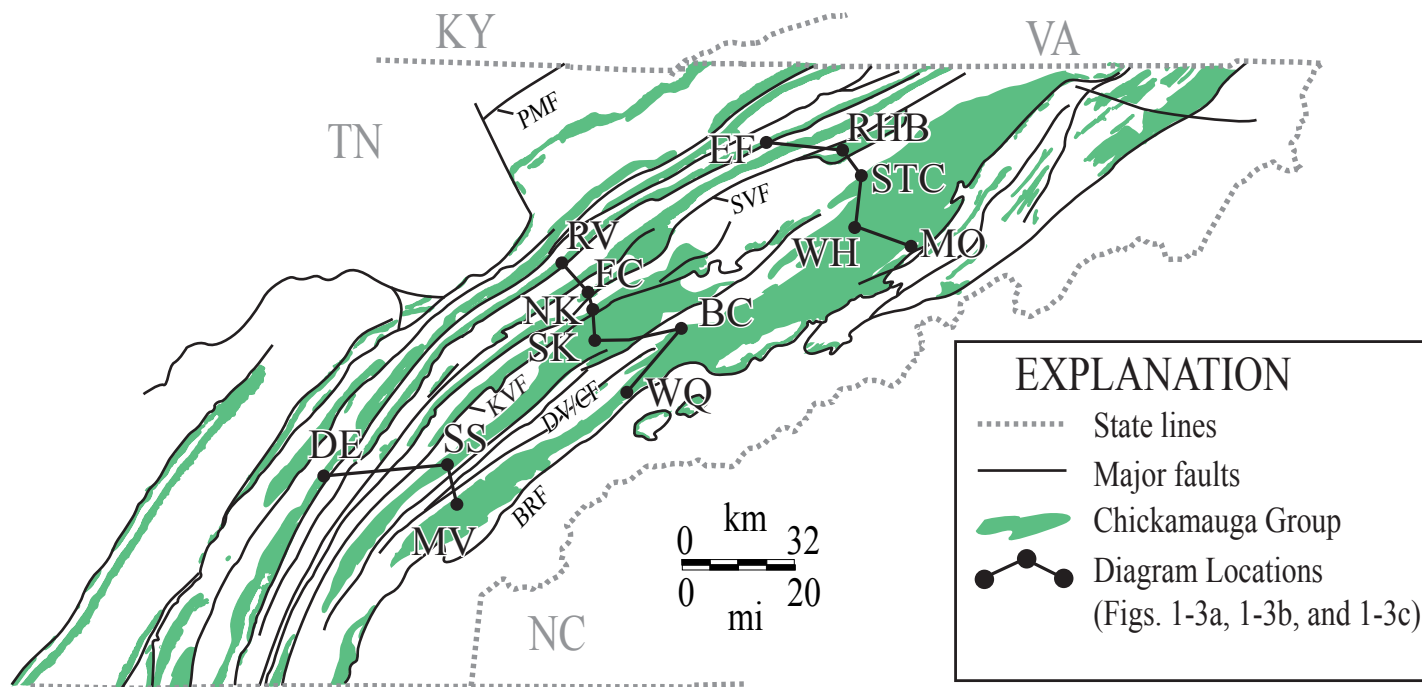


Figure 1-4. Locations of the Walker and Shanmugam diagrams from Walker et al. (1983). Geographic locations: BC (Boyds Creek Quadrangle); DE (Decatur); EF (Evan's Ferry); FC (Fountain City); MO (Mosheim); MV (Mount Vernon); NK (North Knoxville); RHB (Red House Branch); RV (Raccoon Valley); SK (South Knoxville); SS (Sweetwater); STC (St. Clair); WH (Whitesburg); and WQ (Wildwood quadrangle). Geologic features are: BRF—Blue Ridge fault; DV/CF—Dumplin Valley/Chestuee faults; PMF—Pine Mountain fault; and SVF—Saltville fault. (Base map modified from Hatcher et al., 1990.)

Chapter 2

Stratigraphy and Lithologic Descriptions

Regional Overview

The rocks in the study area range in age from Middle Cambrian to Middle Ordovician and include units from the Conasauga Group (fms), Knox Group (fms), and Chickamauga Group (fms). Sedimentary strata record an upward evolution from an immature to mature passive margin followed by development of a tectonic (Sevier) basin which was sourced from the southeast during the Blountian phase of the Taconic orogeny (Drake et al., 1989).

Geologic mapping was based on several parameters. Where available, bedrock exposure was used to identify and divide the Conasauga and Chickamauga Groups. The Knox Group was identified and divided primarily by character of chert, sandstone float, soil type, and topography. Stratigraphic issues resolved by mapping include (1) revision of thickness estimates, (2) subdivision of stratigraphic units based on previously developed and newly recognized relationships, and (3) improved interpretation of depositional environments.

The study area (Fig. 2-1, 2-2) is of stratigraphic interest in that a portion of the Pulaski fault, which juxtaposes contrasting Conasauga and Knox facies, has been traced across the southeast corner of the map area. The central phase of the Conasauga Group and the northwestern phase of the Knox Group are exposed in the footwall of the Pulaski fault, whereas the hanging wall exposes the southeastern phase of the Conasauga Group (Honaker Dolomite, Nolichucky Shale, and Maynardville Limestone) and the

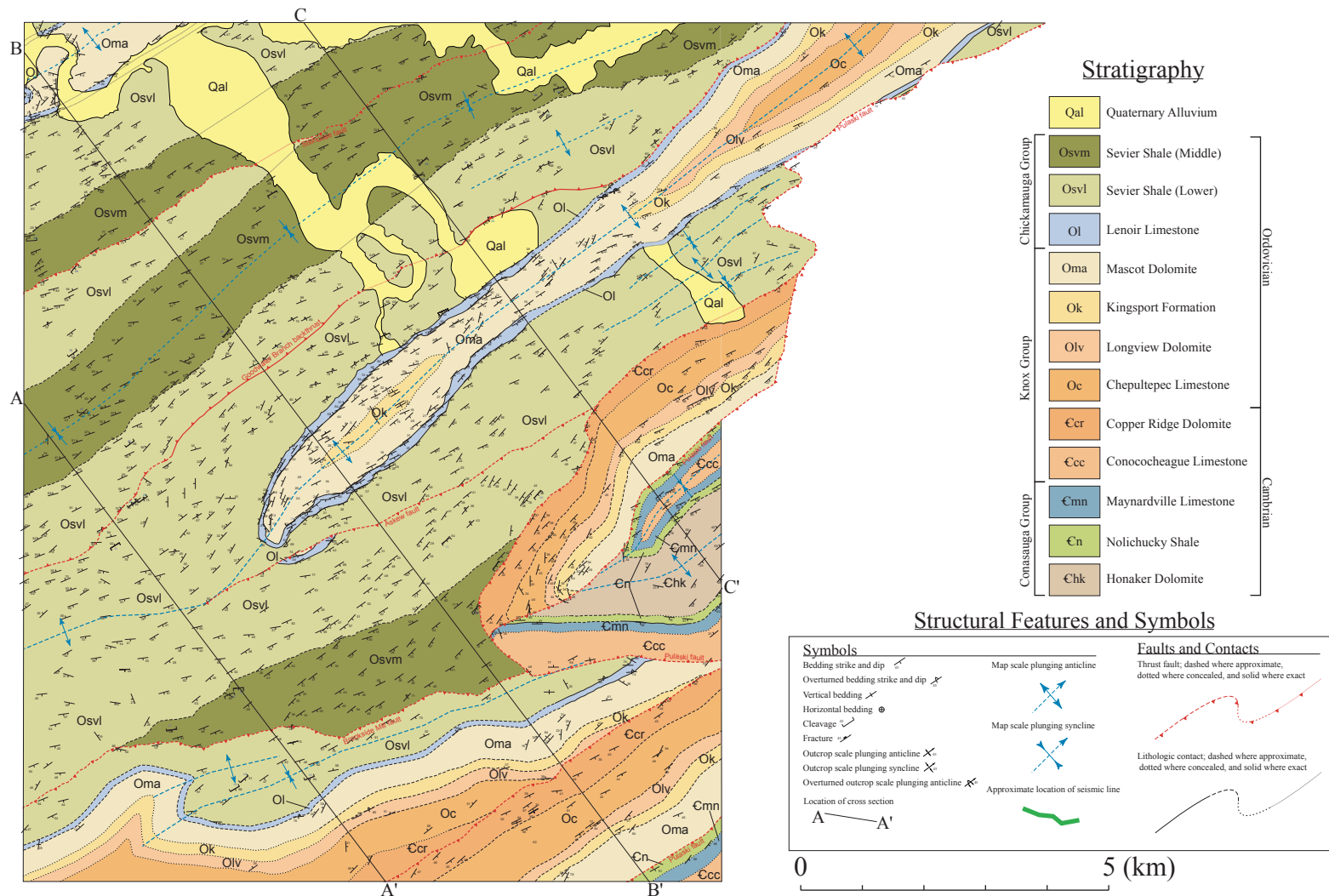


Figure 2-1. Geologic map of the field area with location of cross-section lines and seismic reflection data.

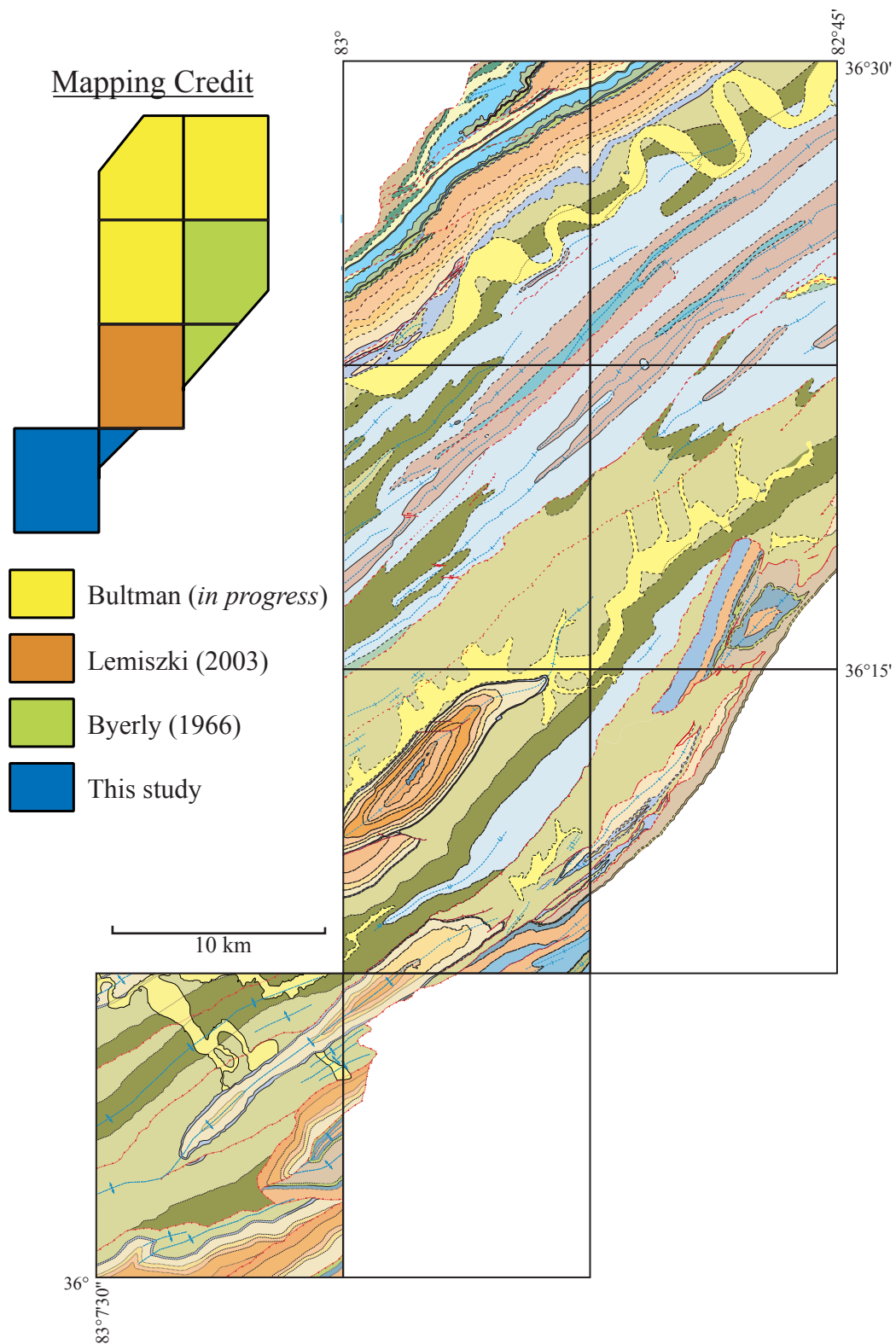


Figure 2-2. Generalized compiled geologic map at 1:300,000 scale. For explanation, see Plate I.

southeastern phase of the Knox Group (Jonesboro Limestone and Conococheague Limestone) (Rodgers, 1953a).

Conasauga Group

Rodgers (1953a) divided the Middle to Late Cambrian Conasauga Group into southeastern, central, and northwestern phases (Fig. 2-3). The southeastern phase of the Conasauga Group is approximately 610 m thick here and in the study area, crop out in the hanging wall of the Pulaski fault. The group is divisible into the Honaker Dolomite, Nolichucky Shale, and Maynardville Limestone.

Honaker Dolomite. Butts (1940) was the first to use the name Honaker Dolomite as the equivalent of the Rutledge Limestone, Rogersville Shale, and Maryville Limestone. Total thickness of the Honaker Dolomite is nearly 457 m (1500 ft) (Byerly, 1966; Hardeman, 1966). The unit is located at the base of the Conasauga Group. Honaker Dolomite outcrop (Fig. 2-4a, 2-4b) is rare in the study area. Where present, fresh surfaces consist of thin- to thick-bedded, fine- to medium-grained, medium- to dark-gray dolomite. Weathered surfaces of the Honaker have a ribboned, light-gray appearance with slightly raised surfaces of silty dolomite. Some beds have a fetid odor when broken. Rare medium-grained quartz sandstone observed in float rock is also present. The lower portion of the Honaker contains black to dark gray, microbial masses and pods of chert. The contact at the base of the Honaker is not exposed in the study area, but according to Rodgers (1953a) the unit grades into shale and siltstone of the underlying Pumpkin Valley Shale. Soils are clay rich and generally tan to light orange.

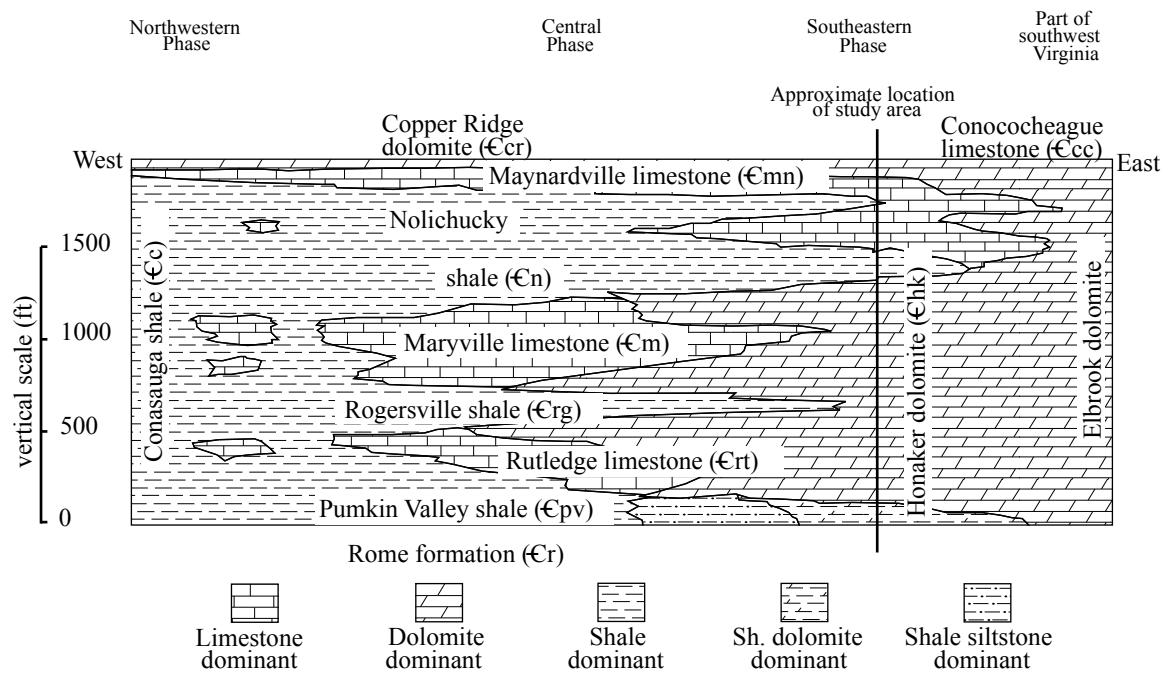


Figure 2-3. Facies changes of the Conasauga Group across the Valley and Ridge. (Modified from Rodgers, 1953b.)



(a)



(b)

Figure 2-4. Honaker Dolomite exposure. (a) Stromatolite bed in Honaker Dolomite outcrop. Outcrop is located along State Route 35, near Ottinger Shelton Chapel. Hammer is resting on top of bedding plane (Dipping toward camera). (Hammer is ~ 12 in. long.) (b) Typical outcrop of Honaker Dolomite. Outcrop is located along State Route 35, near Ottinger Shelton Chapel. Hammer head is parallel to bedding plane (dipping into slope). (Hammer is ~ 12 in. long.)

Nolichucky Shale. The Nolichucky Shale was named by Campbell (1894). Total thickness of this unit is approximately 61 m (200 ft). It is tan-green to olive-green, fine-grained, fissile, non- to weakly calcareous shale (Fig. 2-5). Fragments of trilobites and rare brachiopods have been observed in the field. Despite similar lithologies, the Nolichucky Shale can readily be distinguished from the Sevier Shale by color and fossil assemblage. Thin siltstone beds are present near the upper and lower contacts. Bedrock exposures are rare, with shale chips being more common. The unit is the key lithologic break that permits the underlying Honaker Dolomite to be separated from the Maynardville Limestone. Nolichucky soil contrasts with that of the Maynardville Limestone and Honaker Dolomite in that it is medium-brown and less consolidated with abundant shale chips.

Maynardville Limestone. The Maynardville Limestone (Fig. 2-6) was named by Oder (1934) for exposures near Maynardville, TN. Total thickness of the Maynardville Limestone is approximately 91 m (300 ft). Outcrops of Maynardville Limestone are very rare in the study area. Where present, outcrop is typically medium- to light-gray, thin- to massive-bedded, fine- to medium-grained, thrombotic limestone and interbedded silty limestone and ribbon dolomite. Dolomite becomes more abundant near the contact with the overlying Conococheague Limestone. The upper boundary of the Maynardville Limestone is defined by medium-grained quartz sandstone in the base of the Conococheague Limestone. Maynardville Limestone soil is clay rich and typically tan to light orange.



Figure 2-5. Penciled, non-calcareous, fissile Nolichucky Shale. Orientation of pencils is 021° , 17° NE. Located northeast of Ottinger Shelton Chapel. (Hammer is ~ 12 in long.)



Figure 2-6. Typical outcrop of Maynardville Limestone silty limestone facies. Located along Shelton Branch Creek and State Route 35. (Hammer is ~ 12 in long)

Knox Group

Safford (1869) originally named the Knox Dolomite. He noted that the dominant lithology of the Knox Group was not the same in different parts of the Valley and Ridge province. The change to which Safford referred is almost certainly the contrast between the northwest and southeast phases described by Rodgers (1953a). The study area contains portions of both phases of the Knox Group. The northwest phase of the Knox Group can be subdivided into five units: Copper Ridge Dolomite (Upper Cambrian), and Lower Ordovician Chepultepec Dolomite, Longview Dolomite, Kingsport Formation, and Mascot Dolomite (Fig. 2-7). The southeast phase is divided into the Upper Cambrian Conococheague and Lower Ordovician Jonesboro Limestones. The Upper Cambrian to Lower Ordovician Knox Group is 700–1000 m thick in East Tennessee (Hardeman, 1966), and 900 m thick in the Parrottsville and Cedar Creek 7.5-minute quadrangles.

Copper Ridge Dolomite. The type locality for the Copper Ridge Dolomite (Fig. 2-8) occurs at Thorn Hill in Grainger County, TN (Ulrich, 1911). Because the base of the Copper Ridge Dolomite is not exposed in the mapped area, the Rodgers (1953a) thickness estimate of approximately 274 m (900 ft) is used. Of the portion of the unit exposed in the mapped area, the bottom is light-gray, medium-grained, well-bedded dolomite with occasional quartz sandstone beds. The overlying 228 m (750 ft) is dark gray, crystalline dolomite with interbedded, blue-gray fine-grained dolomite. Freshly broken surfaces occasionally possess a fetid (asphaltic) odor. Beds average 30 cm (1 ft) thick, but vary between 1.5 m (5 ft) to a few centimeters. The top ~15 m (50 ft) are light-

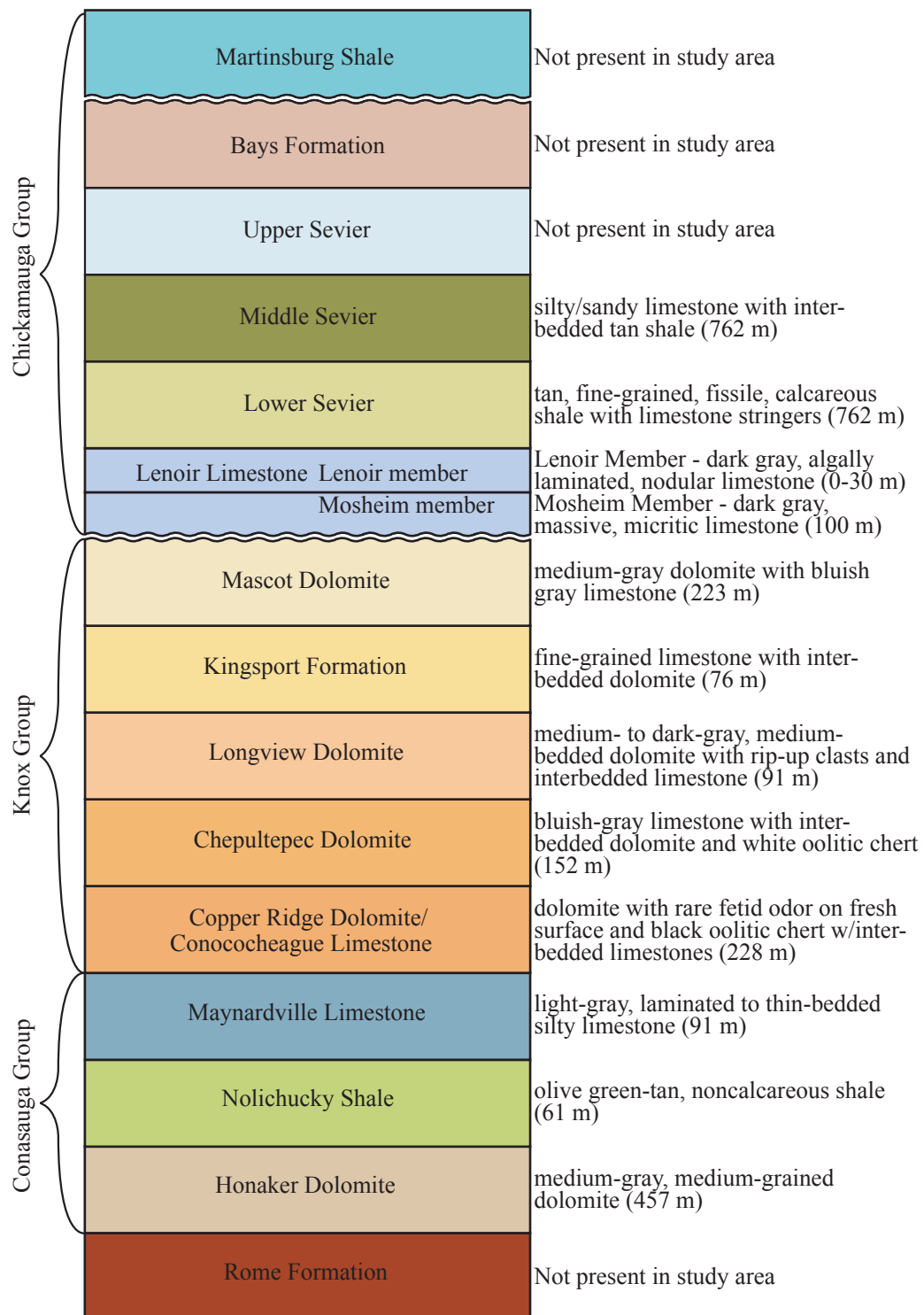


Figure 2-7. Generalized stratigraphic column and relationships between units in the study area. Column is not to scale.



Figure 2-8. Microbial lamination in Cambrian Copper Ridge Dolomite. Light gray microbial layers contain coarser silt-size grains. Exposure is located along Ottinger Creek near Ottinger, TN. (Hammer is ~ 12 in long.)

gray, well-bedded dolomite with rare interbeds of microbially laminated limestone. Soil formed from the Copper Ridge is clay rich and generally light- to reddish-orange. Black, thrombolitic chert and concentrically banded gray and black fine-grained oolitic chert can be found in float in the middle portion of the unit. Large (>10 cm diameter), black, thrombolitic chert spheres are also found near the basal contact.

Conococheague Limestone. Stose (1908) was the first to correlate the Conococheague Limestone (Fig. 2-9) with the type locality at Conococheague Creek, Franklin County, Pennsylvania. The thickness of the Conococheague Limestone is approximately 274 m (900 ft). This unit is considered the southeastern phase Knox Group equivalent of the Copper Ridge Dolomite (Rodgers, 1953a). The unit consists of thin- to medium-bedded, bluish-gray limestone ribboned with occasional silty dolomite beds. Dolomite is more abundant in the lower part of the unit. The bottom portion 18 m (60 ft) of the unit contains several thin beds of medium-grained, moderately well-sorted white, quartz sandstone. The base of the Conococheague Limestone is located below the lowest sandstone. Rare dark-gray thrombolitic chert can be found throughout, and gray chert cemented oolites occur near the middle of the unit.

Chepultepec Dolomite. The Chepultepec Dolomite conformably overlies the Copper Ridge Dolomite (Fig. 2-10). The type locality is located in Chepultepec (now Allgood), Alabama and was described by Ulrich (1911). This unit can be subdivided into two subunits: The lower subunit is about 91 m (300 ft) of bluish-gray, fine-grained limestone



Figure 2-9. Typical exposure of Conococheague Limestone. The more resistant layers are silty dolomite. Exposure is located along U.S. Route 411, near Shelton Chapel. (Hammer is ~ 12 in long.)



Figure 2-10. Typical exposure of Chepultepec Limestone. Limestone bed possesses a dolomitic microbial texture. The outcrop is located along Ottinger Creek, near Ottinger, TN. (Hammer is ~ 12 in long.)

with interbedded medium-gray, medium- to fine-grained dolomite and carbonate-cemented quartz sandstone. The lowest sandstone marks the boundary between the Chepultepec Dolomite and the underlying Copper Ridge Dolomite. Tan ooids in white chert cement are found near the middle of the unit, typically as float. The upper subunit is 152 m (500 ft) thick and composed of bluish-gray, fine-grained limestone beds averaging 30 cm (1 ft) in thickness with medium-gray, fine-grained dolomite. Soil formed from the Chepultepec Dolomite is clay rich and generally tan to light orange.

Longview Dolomite. The type locality of the Longview Dolomite (Fig. 2-11) is located near Longview, Alabama (Butts, 1926). Total thickness of the Longview Dolomite is approximately 91 m (300 ft). The Longview Dolomite is predominantly dolomite that varies from light- to medium-gray, fine- to coarse-grained, and medium- to thick-bedded. The light-gray beds are fine-grained and yield silty texture on weathered surfaces, whereas the medium-gray beds are generally coarser. The upper third of the Longview contains occasional matrix-supported dolomite rip-up clasts. The contact with the underlying Chepultepec is marked by the transition from predominantly dolomite in the Longview to predominantly limestone in the Chepultepec. The gastropod *Lecanospira* has been observed in the unit in the field area (Byerly, 1966). Longview soil is clay rich and generally light- to reddish-orange.

Kingsport Formation. The name Kingsport Formation was first applied by Oder and Miller (1945) to a group of rocks near Kingsport, TN. Thickness of the Kingsport Formation is approximately 76 m (250 ft). The Kingsport Formation (Fig. 2-12) is



Figure 2-11. Dolomite rip-up-clast breccia in dolomite of upper portion of Ordovician Longview Dolomite. Exposure is located along Ottinger Creek, near Ottinger, TN. (Hammer is ~ 12 in long.)



Figure 2-12. Typical outcrop of Kingsport Formation limestone. The outcrop is located near Luther Memorial Church, TN. Hammer head is parallel to bedding plane. (Hammer is ~ 12 in. long.)

light-gray, fine-grained, thin- to medium-bedded, silty limestone and dolomite. The lower portion of the unit grades into bluish-gray, fine-grained, thin- to medium-bedded limestone that lacks interbedded dolomite. Chert nodules are found throughout the unit. Gastropods have been observed in the limestone beds of the unit. The Kingsport Formation-Longview Dolomite boundary is based primarily on the first downward appearance of appreciable dolomite. Soil is clay rich and generally medium brown to light orange.

Mascot Dolomite. Oder and Miller (1945) named the Mascot Dolomite (Fig. 2-13) from exposures near Mascot, TN. Total thickness of the Mascot Dolomite is approximately 223 m (730 ft). The unit is light- to medium-gray, fine-grained dolomite interbedded with medium- to blue-gray, fine-grained limestone. Weathered exposures of the Mascot Dolomite are light-gray to white with occasional red hues on weathered surfaces and silty laminae stand out in relief. Light-gray nodular chert beds are sporadic to rare throughout the unit. Thin, medium-grained, well-sorted sandstone beds are present in the lower half of the unit and are typically observed as float. One or more medium-grained, quartz sandstone layers with chert matrix mark the boundary with the underlying Kingsport. Gastropods have been observed in the medium- to blue-gray limestone beds. Mascot Dolomite soil is clay rich and generally light to reddish orange.



Figure 2-13. Typical outcrop of Mascot Dolomite with "stitching wax" texture. The outcrop is located near Harned Chapel, TN. Hammer is resting on bedding plane. (Hammer is ~ 12 in. long.)

Knox Group Discussion

Geographically, the suite of Knox Group in my map area is one of the most southeastern exposures of northwestern phase of Knox Group. Although the Knox Group here possesses many of the characteristics of “typical” northwestern phase Knox Group, it also possesses lithologic qualities similar to the Jonesboro and Conococheague Limestones. The Knox here contains much more limestone and less chert than more northwesterly exposures. This is believed to be a result of the proximity of this area to southeastern phase of Knox Group, and may indicate the Pulaski fault at this latitude has much less displacement than segments farther north. Rodgers (1953b), Byerly (1966), and Lemiszki (2003) observed the same phenomenon in the Mosheim anticline (Fig. 2-2) where rocks identified as Copper Ridge Dolomite coexist with and lie stratigraphically below Conococheague Limestone.

Knox (Middle Ordovician) Unconformity

The Knox unconformity is a major stratigraphic boundary that separates the Knox Group from the overlying Chickamauga Group. In East Tennessee, it marks the transition from a passive-margin (Knox Group carbonates) to convergent margin (Chickamauga Group) sedimentation (Neuman, 1976; Read, 1980; Shanmugam and Walker, 1978, 1980; Mussman and Read, 1986). The thickness of rock removed by erosion along the unconformity increases from 0 m in parts of Pennsylvania, Maryland, and northern Virginia (Lowry, 1957; Suter and Tillman, 1973; Tillman, 1976; Read and Tillman, 1977) to greater than 140 m in Virginia and Tennessee (Webb, 1959). Although the vast extent

of the unconformity suggests eustatic sea level change as a cause, tectonics also seem to have locally influenced its development. Mussman and Read (1986) reported angular discordance as much as 12° in parts of western Virginia. Jacobi (1981) and Quinlan and Beaumont (1984) speculated that the unconformity may have formed as a result of the shelf (Knox Group) passing over a peripheral bulge with uplift as great as 180 m. The fact that the unconformity extends as far west as the Franklin Mountains in West Texas and the subsurface in western Kansas and Oklahoma, however, suggests a dominantly eustatic origin. Following erosion, the sea again transgressed over the platform and carbonate deposition resumed for a time before clastic sediments derived from the east buried the carbonate bank (Walker et al., 1983).

Chickamauga Group

The Chickamauga Group was previously referred to as the Chickamauga Limestone until Swingle (1964) elevated it to group status. The Chickamauga is an assemblage of Middle to Late Ordovician strata that grade from predominantly carbonate in the western Appalachian basin to a thick detrital wedge in the east (Figs. 1-2 and 1-3a, 1-3b). The Chickamauga Group in the vicinity of the study area is composed of Lenoir Limestone, Sevier Shale, Bays Formation, and Martinsburg Formation (Fig. 2-7). The dynamic nature of the basin's history is expressed as numerous facies and thickness changes. Several attempts have been made to subdivide and correlate Chickamauga Group rocks (Rodgers, 1953b; Walker et al., 1983) (Figs. 1-2 and 1-3a, 1-3b). The discontinuous facies, thickness changes, and lack of exposure have led to several distinct

interpretations of Chickamauga stratigraphy, illustrated in Figure 2-14. Rodgers (1953a) stated that probably more controversy has raged over the stratigraphy of the Chickamauga Group and equivalent units in the southern Appalachians than over that of any other unit except the Ocoee Series.

Lenoir Limestone. Safford and Killebrew (1876) were the first to use the name “Lenoir Limestone” to refer to the basal limestone of the Chickamauga Group. The unit was previously named “Maclurea Limestone” (Safford, 1869). The Lenoir Limestone represents the stable carbonate bank of the Middle Ordovician Sevier basin (Drake et al., 1989). In the study area, the unit is divisible into the Mosheim (Fig. 2-15) and Lenoir (Fig. 2-16) facies. The Mosheim Member is approximately 31 m (100 ft) of very dark gray, massive-bedded, very fine-grained limestone that weathers light gray. The Mosheim Member forms very smooth, “pavement-style” exposures in which it is very difficult to observe bedding and obtain accurate dip-strike measurements. Based on the presence of bird’s-eye structures, this unit has been interpreted as upper intertidal to supratidal in origin (Benedict and Walker, 1978). Rip-up clasts of Mascot chert and dolomite from the Middle Ordovician erosion surface (Knox unconformity) have been observed in the basal (5 cm) Mosheim. The Lenoir Member is between 0 and 10 m thick and conformably overlies the Mosheim. It consists of dark-gray, nodular limestone with clay seams. The Lenoir facies has been interpreted to have been deposited between 10-20 m water depth (Benedict and Walker, 1978). The gastropod *Maclurites magnus* has been observed in the field in both the Mosheim and Lenoir facies (Neuman, 1955). Total



29



Figure 2-15. Typical outcrop of the Mosheim Member of the Lenoir Limestone. Outcrop is located along Sinking Creek, near Luther Memorial Church. Hammer head is parallel to bedding plane. (Hammer is ~ 12 in. long.)



Figure 2-16. Typical outcrop of the Lenoir Member of the Lenoir Limestone. Outcrop is located along Oven Creek, near Harned Chapel. Hammer head is parallel to bedding plane. (Hammer is ~ 12 in. long.)

thickness of the Lenoir Limestone is highly variable partly related to the irregular surface of the Knox unconformity, but is typically 31 m (100 ft) thick in this area.

Sevier Shale. The study area contains part of the Chickamauga Group Sevier basin stratigraphy that had previously been divided into Lenoir Limestone and the very broad subdivision Sevier Shale. The name “Sevier Shale” first appeared in Campbell (1894) to describe the shale underlying the Bays Sandstone and overlying the Shenandoah Limestone (obsolete terminology for Lower Cambrian to Middle Ordovician Conasauga and Knox Groups) near Greeneville, TN, as a single, undivided unit. Rodgers (1953a, 1953b) and Byerly (1966) adopted this classification for sediments in the Sevier basin in the belief that the mass of shale forms a single mappable unit, although locally it may be possible to recognize different members. Keith (1895) subdivided the Sevier basin sediments to the southwest in the Tellico-Sevier syncline area into the Athens Shale, Tellico Sandstone, and Sevier Shale, but attempts to apply the same divisions near the study area resulted in very little of the Chickamauga Group rocks mapped as Sevier Shale.

Adopting divisions of Sevier basin sediments that will lead to additional stratigraphic subdivisions is not my goal, although the Sevier Shale has been subdivided here for the first time by Lemszki (2003), Bultman (*in progress*), and this study. These subdivisions are valid across the entire basin at this latitude. Lemiszki (2003) divided the Sevier Shale in the Mosheim 7.5-minute quadrangle into three sub-units: lower, middle, and upper Sevier. Despite the geographical and stratigraphic thickness

differences, Keith's (1895) recognition of a lower shale (Athens Shale), a middle sandy unit (Tellico Sandstone), and an overlying shale (Sevier Shale) in the Sevier basin farther south are similar to the tripartite division proposed in the Mosheim 7.5-minute quadrangle (Lemiszki, 2003) and the study area.

The divisions proposed by Lemiszki (2003) have also been traced into fellow graduate student John Bultman's field area (Fig. 2-2). Fence diagrams that depict thickness changes in the lower, middle, and upper Sevier have been created that incorporate the area shown in Figure 2-2 (Fig. 2-17). Since the upper Sevier Shale and top of the middle Sevier Shale are not present in the Parrottsville and Cedar Creek 7.5-minute quadrangles, thickness estimates were used from the adjacent Mosheim 7.5-minute quadrangle (Lemiszki, 2003). The total thickness of the Sevier Shale increases from a minimum of 790 m in the Stony Point 7.5-minute quadrangle (Bultman, *in progress*) to a maximum of approximately 2,133 m (7,000 ft) in the Parrottsville and Cedar Creek 7.5 minute quadrangles (this study).

Lower Sevier. The lower Sevier Shale (Fig. 2-18) consists primarily of calcareous shale, but also contains silty shale, silty limestone, and shaly limestone. The basal 31 m (100 ft) of the unit is tan and gray, fine-grained, fissile, thin-bedded, graptolite-rich shale. Above the 31 m of gray shale, the unit is still a fine-grained, fissile, calcareous, graptolite-rich shale; the color, however, is primarily tan to light gray. Graptolites collected from the lower Sevier Shale in the vicinity of the study area (Fig. 2-2) were sent to Dr. Stan Finney at Long Beach State University for analysis. Graphic correlation places the

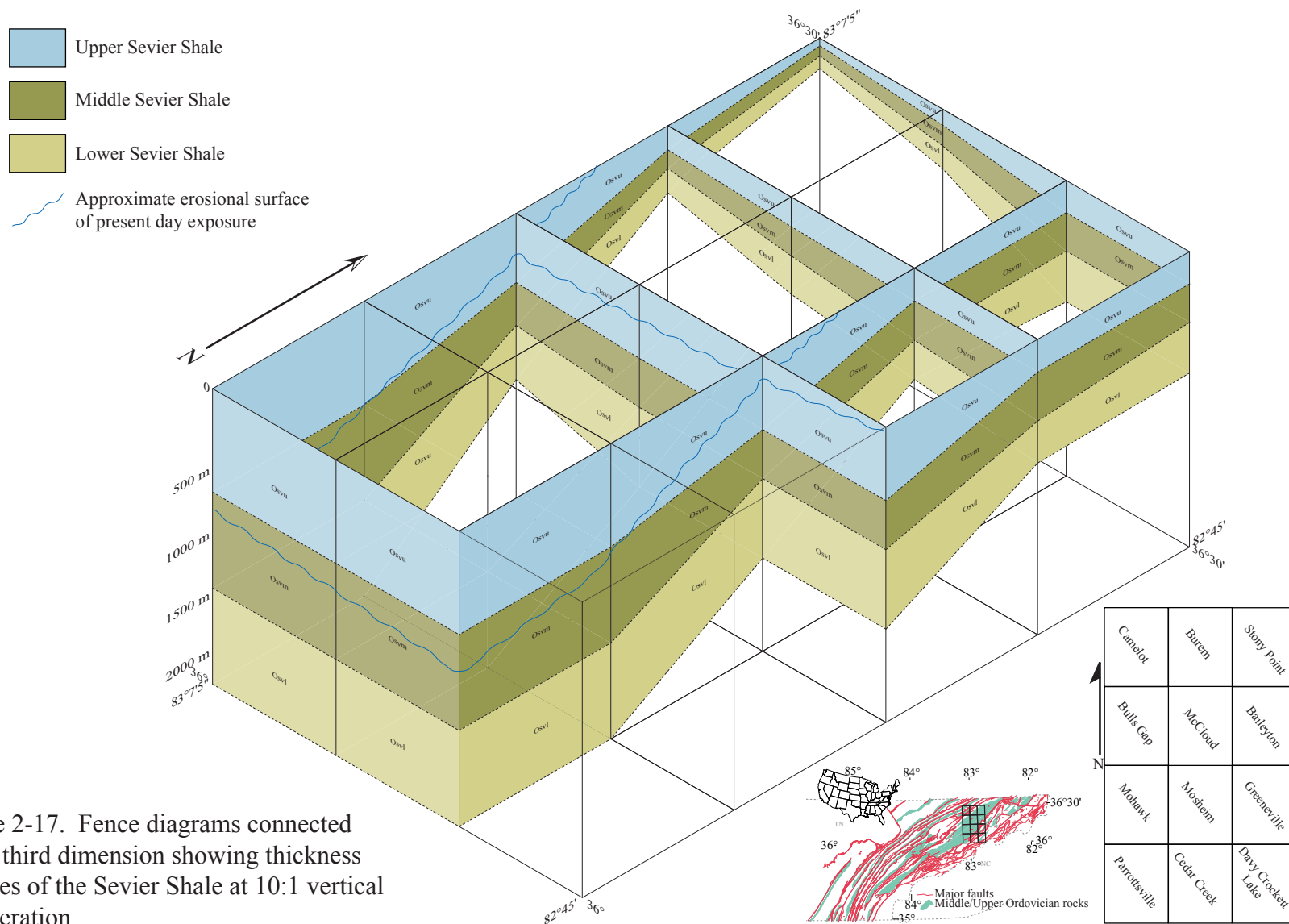




Figure 2-18. Outcrop of Goodwater Branch backthrust in lower Sevier Shale. Outcrop is located along the Nolichucky River near Pate Hill, TN. (Hammer is ~ 12 in long.)

unit in the upper part of the *Nemagraptus gracilis* graptolite zone, consistent with the conclusions of Finney et al. (1996). Thin (10 cm thick), silty/sandy limestone beds are common throughout this portion of the unit. The top of the lower Sevier Shale consists of approximately 274 m (900 ft) of tan, fine-grained shale with interbedded dark gray, thin-bedded (1 cm), shaly limestone. Fresh outcrop of this unit is rare and usually limited to road cuts. In weathered outcrop, silty limestone stringers are the dominant lithology with shale chips common at the base of exposure, weathering out of the soil. The contact with the underlying Lenoir Limestone is marked by the abrupt change from fine-grained calcareous shale to limestone. Total thickness of the lower Sevier Shale in the study area is approximately 762 m (2,500 ft).

Middle Sevier. The Middle Sevier (Fig. 2-19) is thin- to thick-bedded (5 cm to 100 cm), silty/sandy, gray limestone beds with interbedded shale. Interbedded shale is tan, calcareous, fine-grained, fissile, and found primarily as shale chips in soil. Graptolites have not been found in this portion of the Sevier Shale. The contact with the underlying lower Sevier Shale is gradational, and the two units are separated at the first (upward) occurrence of appreciable sand/silt in the limestone. The unit becomes coarser grained in the Mosheim 7.5-minute quadrangle (Lemiszki, 2003) and fellow graduate student John Bultman's field area (Bultman, *in progress*) where the unit varies from fine- to medium-grained calcareous sandstone to fine- to medium-grained sandy limestone. Since the top of the subunit is not exposed in the area mapped, thickness estimates of the middle Sevier Shale are estimated to be 762 m (2,500 ft) thick based on data from the Mosheim 7.5-minute quadrangle (Lemiszki, 2003).

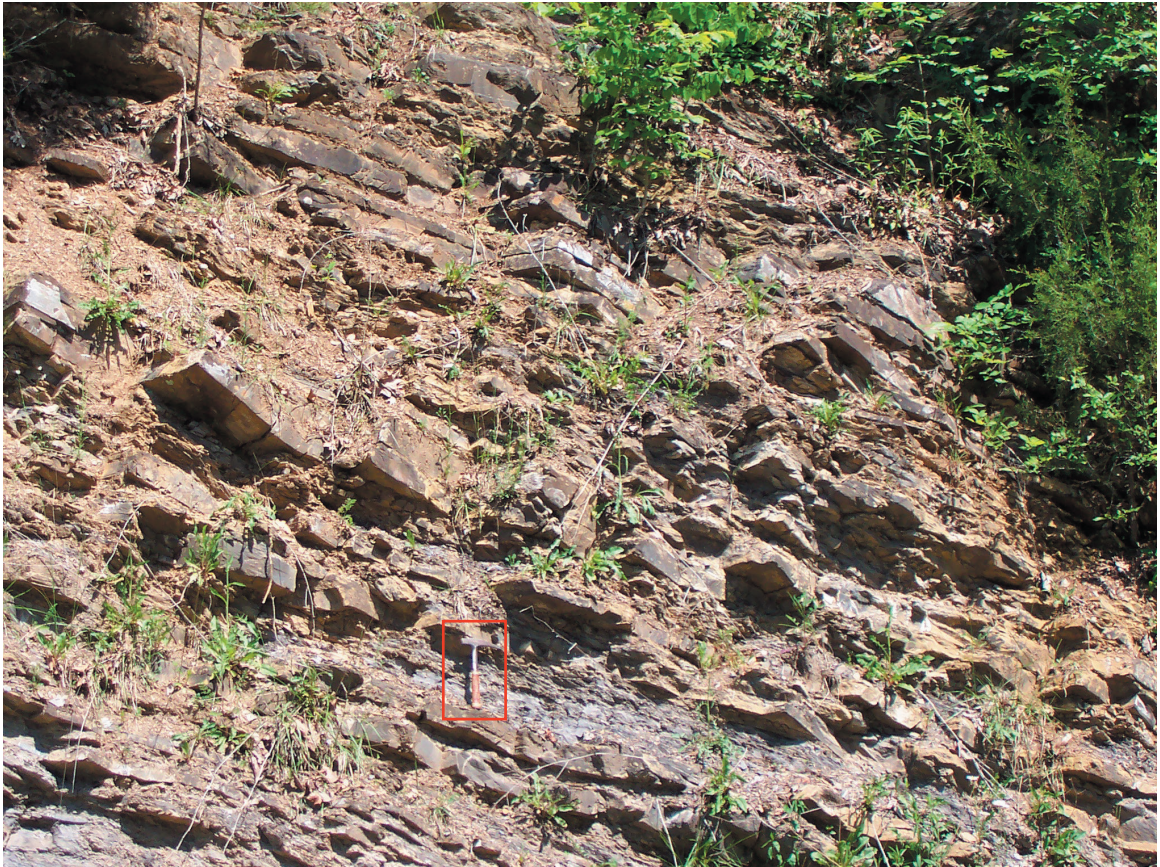


Figure 2-19. Typical exposure of middle Sevier Shale. More resistant units are composed of fine-grained sandy limestone. The outcrop is located along the Oven Creek Rd., 1 mile north of Parrottsville, TN. (Hammer is ~ 12 in. long.)

Upper Sevier. As stated previously, the upper Sevier Shale is not present in the Parrottsville and Cedar Creek 7.5-minute quadrangles of this study. Lemiszki (2003) describes the subunit in the Mosheim 7.5 minute quadrangle as being calcareous dark gray and bluish-gray shale, silty shale, and siltstone that varies from massively bedded to laminated. Thickness of the upper Sevier Shale was estimated using data from the McCloud (Bultman, *in progress*) and Mosheim (Lemiszki, 2003) 7.5-minute quadrangles where it is approximately 610 m (2,000 ft).

Sevier Shale Discussion

Sediment thickness estimates for the Sevier basin strata in East Tennessee are as numerous as the proposed stratigraphic divisions illustrated in Figure 2-14 (e.g. Keith, 1895; Neuman, 1955; Kashfi, 1971; Whisner, 2004; Rodgers, 1953a). Although much attention has been given to the Sevier basin, relatively few studies have focused on the area of the Bays Mountain synclinorium. Rodgers (1953a) estimates that Sevier basin sedimentary rock in the area including the Bays Mountain synclinorium to be approximately 2,560 m (8,400 ft) thick. More recent work by Shanmugam and Walker (1978, 1980, 1983) estimate thicknesses to be slightly greater, approaching 3,000 m (9,850 ft). Although the top of the Sevier Shale is not present in the Parrottsville and Cedar Creek 7.5-minute quadrangles, the work of Lemiszki (2003) and Bultman (*in progress*) have been projected into the area to obtain a thickness estimate of 2,100 m (7,000 ft).

Quaternary Deposits

Unconsolidated clay, silt, sand, and gravel are present in several floodplains along the Nolichucky River and major creek channels. The alluvium is typically light brown to light gray and varies between well-sorted to poorly-sorted. Deposits are poorly to well stratified.

Chapter 3

Structural Geology

Regional Overview

The Parrottsville and Cedar Creek 7.5-minute quadrangles are located in the Valley and Ridge foreland fold-thrust belt of East Tennessee (Figs. 1-1, 2-1). The Valley and Ridge extends from Alabama north through Georgia, Tennessee, Virginia, and into the Hudson Valley south of Albany, New York. It is composed of a wedge of Early Cambrian to Pennsylvanian strata that tapers to the north and west (Hatcher et al., 1989). Deformation in the Valley and Ridge occurred during the late stages of the Alleghanian orogeny as a product of continent-continent collision between Laurentia and Gondwana that assembled the supercontinent Pangea (Hatcher et al., 1989).

The southern Appalachian foreland fold-thrust belt is characterized by northwest vergent thin-skinned folds and thrust faults (Rodgers 1949, 1953a, 1953b, 1964, 1970). The Lower Cambrian Rome formation serves as the basal detachment for the deformation with secondary décollements located in the Cambrian Conasauga, Middle Ordovician Chickamauga, Upper Devonian-lower Mississippian Chattanooga shales, and Pennsylvanian coal (Hatcher et al., 1989). Map-scale synclines are typically located in the footwalls of major thrusts with related anticlines less often preserved because of erosion of hanging walls (Rodgers, 1953a). As the foreland fold-thrust belt deformed, a critically tapered wedge developed that followed Coulomb mechanical behavior criteria described by Davis et al. (1982) and Dahlen (1990). The majority of deformation occurred at the front of the wedge with minor, out-of-sequence deformation within

the wedge to maintain the integrity of the wedge. Chapple (1978) outlined properties of foreland fold-thrust belts as (1) thin-skinned; only layers above a stratigraphic detachment participate in the deformation. (2) The basal layer that bounds the thin-skinned deformation is composed of weak rocks (i.e., evaporates and shale). (3) The sedimentary prism possesses a wedge shape before and after deformation, with the thickest portion of the wedge toward the hinterland where the thrusts originated. (4) The entire wedge has been shortened and thickened with motion of the back end being permitted by shortening within the wedge, with the majority of deformation occurring at the cratonward edge of the wedge.

Seismic reflection data suggest that Cambrian and Precambrian rocks of the Blue Ridge overrode Valley and Ridge rocks for ~ 350 km (Hatcher, 1989; Hatcher et al., 1989). Evidence for this structural relationship is also exposed in several windows through the Great Smoky fault (e.g., Tuckaleeche Cove, Wear Cove, Cades Cove) that expose Valley and Ridge rocks (King et al., 1958). In addition, rocks geochemically resembling Knox Group rocks are exposed as horses along the Rosman fault of the Brevard fault zone (Hatcher et al., 1973; Hatcher et al., 1989).

Previous Geologic Mapping

Several workers produced geologic maps of parts of the Valley and Ridge of East Tennessee that are near or include parts of the study area. Safford (1869) and Keith (1905a, 1905b) were among the first to map the bedrock of the area. Although Keith's (1905a, 1905b) folios cover a large area, small scale (1:125,000 scale) and lack of detail limit the present value of his maps. Rodgers (1953a, 1953b) mapped much of the same

area included in Keith's folios and compiled at a similarly small scale. His mapping at 1:62,500 revealed more details of structural geometry as well as a better understanding of stratigraphy. The Hardeman (1966) geologic map of Tennessee remains the most recent compilation of the area, and the 1:250,000 scale at which it was compiled reflects details gained from several decades of 1:24,000-scale mapping of some areas, although others remained unmapped. Detailed 1:24,000-scale geologic mapping of the study area is limited to a few 1:24,000-scale quadrangles (Byerly, 1966; Lemiszki, 2003, 2004, *in progress*; Bulman, *in progress*). Byerly (1966) mapped the Greeneville and Baileyton quadrangles, located northeast of the study area (Fig. 2-2). Current master's degree candidate John Bultman (*in progress*) has modified and compiled Byerly's (1966) work and combined it with his own detailed geologic mapping of portions of the McCloud, Burem, and Stony Point quadrangles. These maps, combined with the Mosheim 7.5-minute geologic map (Lemiszki, 2003), and mapping of the Warrensburg anticline by Emerson (1963), will result in a compiled geologic map that has adequate detail to allow structural and stratigraphic analysis of that portion of the Sevier basin and neighboring areas not afforded by smaller scale maps (Fig 2-2).

Regional Geologic Structures

Bays Mountain Synclinorium. The Bays Mountain synclinorium extends approximately 145 km from Kingsport, TN southwest to Etowah, TN (Fig. 1-1). It is approximately 26 km wide across strike at the latitude of the study area. Middle Ordovician Chickamauga Group sedimentary rocks make up the core. It is flanked by the Pulaski fault to the

southeast and the Chestuee-Dumplin Valley or Saltville faults to the northwest. Several anticlines expose Knox and Conasauga Group rocks within the southeastern portion of the synclinorium.

Pulaski Fault. With respect to displacement, the Pulaski fault is one of the three major faults in the Valley and Ridge of East Tennessee (Rodgers, 1953a). The Pulaski fault extends for over 560 km along strike from Rockingham County, Virginia, to Cocke County, Tennessee, where it is overridden by the Blue Ridge thrust sheet (Rodgers, 1953a; Lemiszki, *in progress*). Keith (1895) identified portions of the fault in his folios. A lack of stratigraphic understanding, however, prevented realization of the total extent and displacement of the fault. The Pulaski fault remained unnamed until Campbell (1925) mapped a segment from Greeneville, Tennessee to Eagle Rock, Virginia. Successive workers (Butts, 1933; Rodgers, 1953b; Edmundson, 1958; Byerly, 1966) later traced the fault and showed its connection to the Staunton fault in Virginia. Despite the extent of the Pulaski fault, the oldest rocks exposed along the fault trace and in hanging wall folds in northeastern Tennessee belong to the Middle Cambrian Honaker Dolomite (Fig. 2-7). Rodgers (1953a) noticed the same relationship and suggested that the Pulaski fault utilizes a structurally weak shale layer in the lower Honaker as a minor detachment that extends below the Blue Ridge overthrust before cutting down section into the Rome Formation master décollement (Woodward and Beets, 1988).

Several workers have disputed details regarding the emplacement of the fault. Lowry (1979) and Bartholomew (1981) claimed that the Pulaski thrust sheet was emplaced subsequent to deformation in the footwall. The map-scale trace of the fault,

however, is very sinuous. Woodward and Gray (1985) produced cross sections that suggested the Pulaski folded was by footwall duplex horses. In the study area, the Pulaski fault displays a characteristic, sinuous, folded fault trace.

Map-Scale Structures

Oven Creek Anticline. The Oven Creek anticline is doubly plunging and exposes nearly 18 km of Knox Group along its trend, with the Chepultepec Dolomite being the oldest unit exposed in the core. The extent of the fold in the Sevier Shale is hard to ascertain because of the difficulties of tracing it into the Sevier Shale. It is one of many similarly trending anticlines that expose rocks as old as Conasauga Group within the Bays Mountain synclinorium, particularly to the southeast. Dips on the southeast limb of the anticline average 50° SE while dip of the northwest limb varies from 60° NW to steeply overturned to the SE. An equal area stereographic projection of poles to bedding located in the Oven Creek anticline indicate the fold axis has a trend of 238°, 3° in the study area (Fig. 3-1). The axial trend of the Oven Creek is closely aligned with the Johnson anticline located 6.5 km northeast in the Mosheim 7.5-minute quadrangle. The fold is flanked by the Goodwater Branch backthrust (Figure 2-1) on the northwest side and by the Pulaski and Askew thrusts to the southeast.

Warrensburg Anticline. The Warrensburg anticline is cored by Mascot Dolomite (Knox Group) and trends northeast-southwest. The Warrensburg possesses a slightly asymmetrical geometry with bedding of the southeast limb averaging 50°SE and 65°NW on the northwest limb (Emerson, 1963). Orientation of the fold is approximately 045,

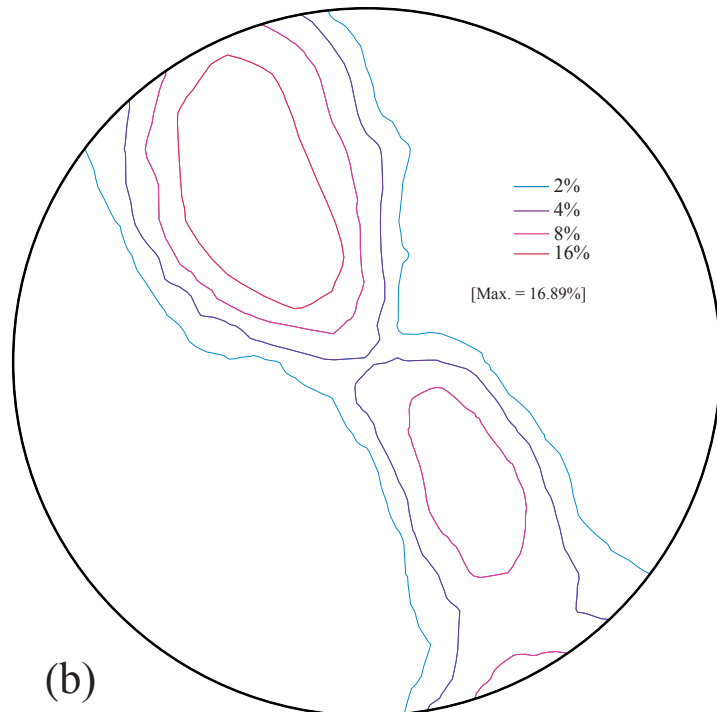
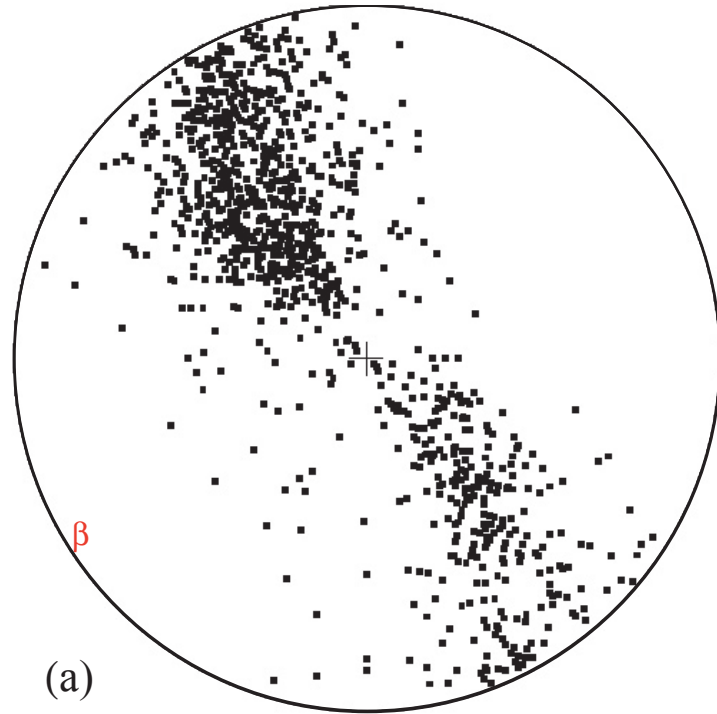


Figure 3-1. Lower hemisphere, equal-area stereographic projection of 983 poles to bedding in the Oven Creek anticline. (a) The beta to the great circle and indicates a fold axis orientation of 238° , 3° . (b) 2, 4, 8, and 16% contours are per 1% area. Plot made using GEORient v. 9.2 by Rod Holcombe (University of Queensland).

and extends 8 km along the axial trace and reaches a maximum across-strike width of 2.5 km. The same stratigraphic and structural difficulties discussed for the Oven Creek anticline make tracing the fold northeastward and southwestward in the Sevier Shale difficult.

Stillhouse Fault. The Stillhouse fault is a northwest verging thrust located between the Oven Creek and Warrensburg anticlines. The fault was originally identified in seismic reflection data by Hatcher (unpublished data) (Fig. 3-2) and later mapped in the study area along the banks of the Nolichucky River on Needmore Branch Road. Displacement on the fault increases to the southwest along its trace, where lower Sevier Shale is thrust over middle Sevier Shale.

Goodwater Branch Backthrust. The southeast-verging Goodwater Branch thrust has been traced along the northwest limb of the Oven Creek anticline. The fault contact is exposed at several locations along Goodwater Branch Road, as well as at the base of Pate Hill (Fig. 3-1). To the northeast, the fault thrusts lower Sevier onto Lenoir Limestone. The fault trace cuts up section to the southwest and places lower Sevier Shale on lower Sevier Shale indicating a decrease in displacement. The fault trace continues northeastward into the Mosheim 7.5-minute quadrangle where it has been traced for an additional 7 km (Lemiszki, 2003). The fault is interpreted to be a backthrust fault that formed by accommodation during the emplacement of the Stillhouse fault.

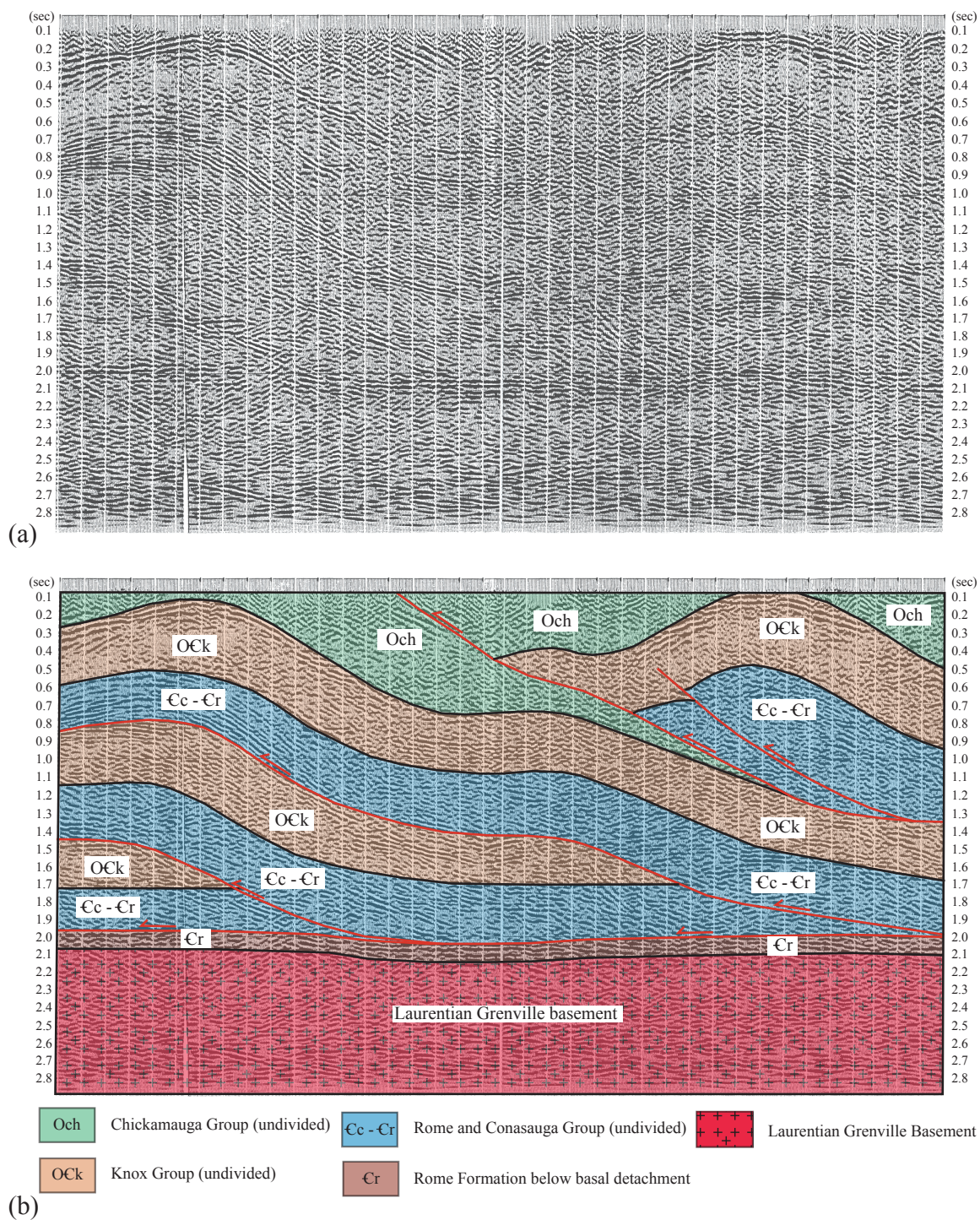


Figure 3-2. Seismic reflection line through part of the study area. (a) Migrated seismic reflection data and (b) interpreted section. See Figure 2-1 for location.

Askew Thrust. The Askew thrust is a northwest verging fault located on the southeast limb of the Oven Creek anticline that thrust rocks as old as Mascot Dolomite onto lower Sevier Shale. The fault increases in stratigraphic displacement to the northeast to a maximum of 50 m, where it connects with a fault thrusting Copper Ridge Dolomite onto lower Sevier Shale.

Brookside Mill Fault. The Brookside Mill fault is a northwest verging located on the northwest limb of the Parrottsville anticline. The fault thrusts rock as old as lower Sevier Shale onto middle Sevier Shale. The fault increases in stratigraphic displacement to the northeast, where it connects with the Pulaski fault.

Parrottsville Anticline. Directly south of Parrottsville, Tennessee is a 065-trending, 6 km-wide outcrop of Knox Group carbonates. The core of the fold exposes rocks as old as Copper Ridge Dolomite and the fold is dissected by a small fault along its hinge. The fault thrusts Copper Ridge Dolomite onto rocks as young as Mascot Dolomite, and may have formed to accommodate increasing deformation in the hinge during emplacement. Heavy cultivation coupled with the susceptibility of carbonate rocks to chemical weathering has made exposure of the core of the anticline very poor.

Meso-Scale Structures

Cleavage. Pressure solution cleavage is locally present in the lower and middle Sevier Shale and the Nolichucky Shale (Fig. 2-5), and is not pervasive throughout the study area. It most often is recognized in the hinges of macro- and meso-scale folds and

close to faults. The cleavage associated with folds typically possesses axial-planar orientation (Fig. 3-3) with pencils forming in the hinges. In the vicinity of the field area, Yust (1975) and Troensegaard (1965) observe the same relationship. They conclude cleavage is commonly associated with the occurrence of folds and typically displays axial planar orientation. Troensegaard (1965) places cleavage development late in fold formation since the cleavage is not displaced by slip along bedding. The plot of Sevier Shale cleavage data on an equal-area stereonet (Fig. 3-4) is very similar to the equal-area stereonet of the Oven Creek anticline bedding data (Fig. 3-1). In addition, the mean orientations of pencil cleavage (Fig. 3-5) and local cleavage-bedding intersections (Fig. 3-6) are $237^{\circ}, 2^{\circ}$ and $060^{\circ}, 2^{\circ}$, respectively. These relationships indicate that most cleavage is axial planar to the larger Oven Creek anticline. Soil-chip exposure of fine-grained shale makes cleavage-bedding relationships frequently difficult to ascertain. Fold geometries were estimated with a moderate confidence level by maintaining the parallel relationship between the axial planes and cleavage. Rare occurrences were observed where cleavage planes fan in fold hinges, suggesting additional tightening of folds during or following cleavage development. Overturning of many folds in the Sevier Shale prevents the assumption that the plane with the steeper dip is the cleavage plane.

Fault-Associated Shear Cleavage. Dip-strike measurements of shear cleavage observed in Sevier Shale that are located near faults are parallel to sub-parallel to bedding. This cleavage is believed to be related to faulting, with the cleavage plane aligning itself with the shear (XY) plane. Shear sense can be assumed from the bedding-cleavage relationship illustrated in Figures 3-7a and 3-7b.



Figure 3-3. Axial-planar cleavage in a road cut of a fold in middle Sevier Shale. Outcrop is located along Knob Creek Rd, north of Bruner Grove, TN. (Hammer is ~ 12 in. long.)

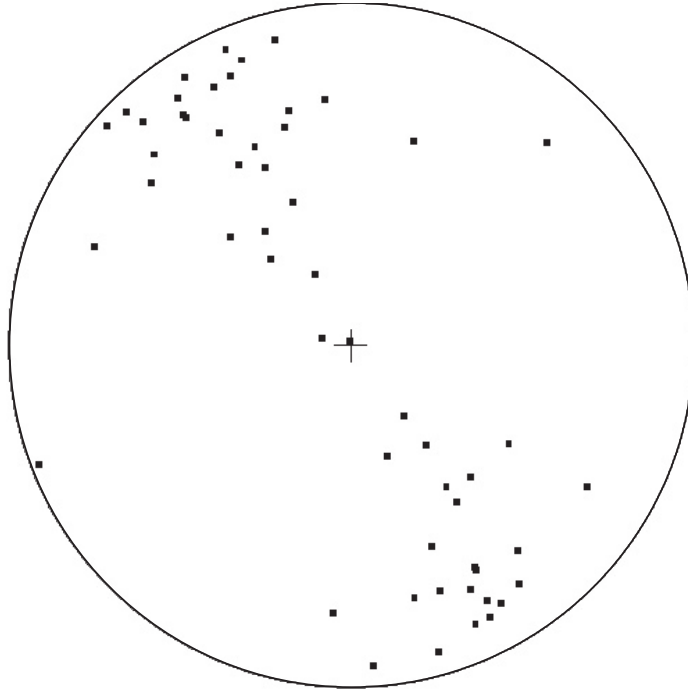


Figure 3-4. Lower hemisphere, equal-area projection of 59 poles to cleavage. Plot made using GEORient v. 9.2 by Rod Holcombe (University of Queensland).

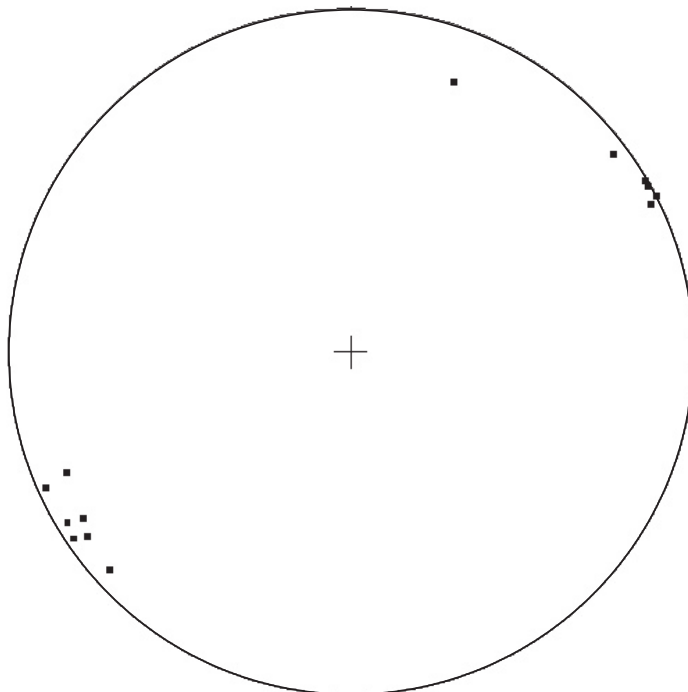


Figure 3-5. Lower hemisphere, equal-area projection of 13 pencil cleavage orientations. The mean principal direction is $237^{\circ}, 2^{\circ}$. Plot made using GEORient v. 9.2 by Rod Holcombe (University of Queensland).

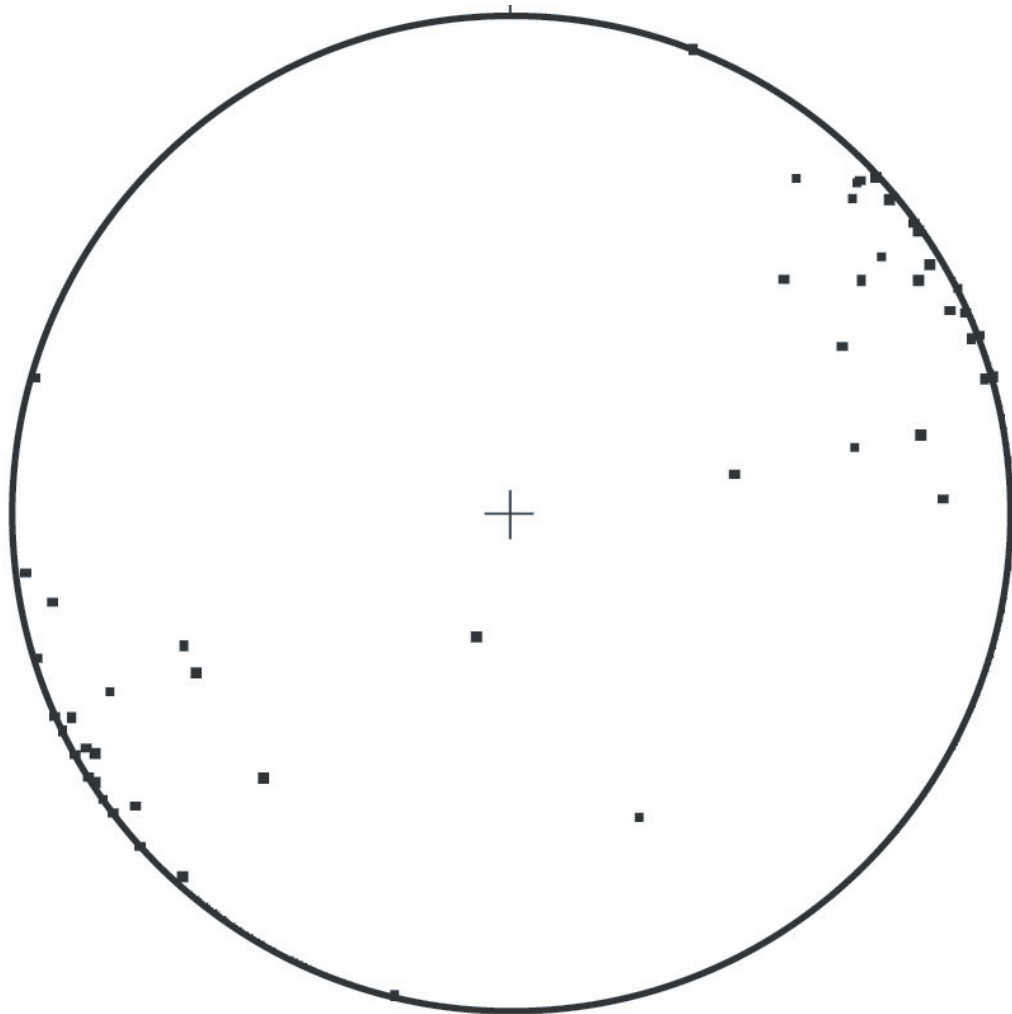


Figure 3-6. Lower hemisphere, equal-area projection of 54 cleavage-bedding intersections. The mean principal direction is $060^{\circ}, 2^{\circ}$. Plot made using GEORient v. 9.2 by Rod Holcombe (University of Queensland).

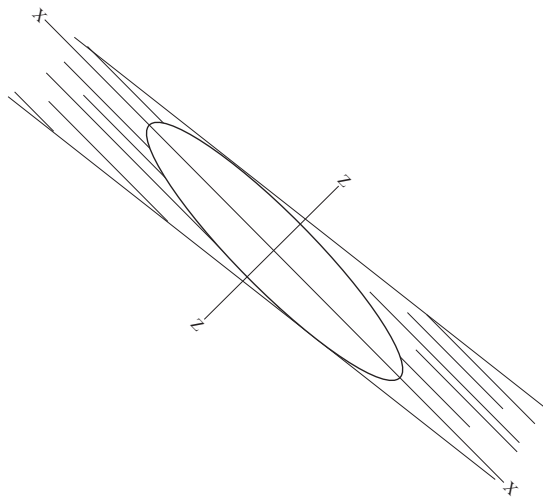
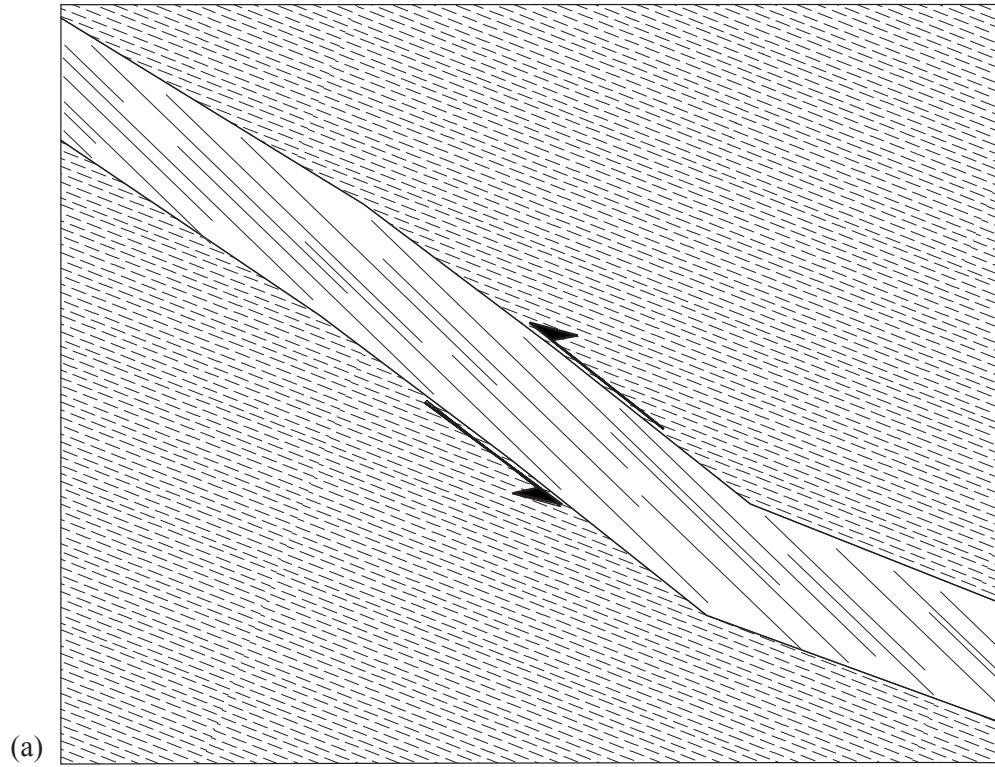


Figure 3-7. S-C relationship observed in the field. (a) Shear cleavage developed in Sevier Shale near fault contacts. (b) The orientation of cleavage is aligned with the XY plane.

Folds. Meso-scale folds exist throughout the study area (Fig. 3-3). The highest frequency of folding was observed in the lower and middle Sevier Shale, where synclines of Sevier rocks are highly deformed between the structurally more competent Knox Group carbonates. An equal-area stereonet plot of poles to axial surfaces (Fig. 3-8) is similar to a plot of poles to cleavage (Fig. 3-4), suggesting they formed in the same strain field. The mean orientation of fold axes on an equal-area stereonet plots at 063° , 12° (Fig. 3-9). Although the trend of fold axes data is similar to the trend of pencil cleavage and bedding-cleavage intersections, the plunge is greater. This discrepancy may be a result of relatively few fold axis measurements.

Fold geometry is typically symmetrical to asymmetrical and shallow-plunging, with steeply inclined to vertical axial surfaces. Interlimb angles range from 30° to $>170^{\circ}$. Meso-scale fold traces have similar trends with those of map-scale folds. Several folds were subjected to Ramsay (1967) isogon analysis. Unfortunately, most of the images were lost, but folds in Sevier Shale commonly exhibit class 1C behavior (Fig. 3-8). Folds composed of homogenous, strong lithologies (carbonates and sandstones) are typically concentric folds and fall into the Ramsay (1967) class 1B with flexural slip between beds. Where folds formed in interbedded lithologies, the more competent beds display concentric class 1B folds and the less competent (typically shales and siltstones) form similar folds with thickened hinges and thinned limbs comparable to class 1C folds (Fig. 3-10) (Ramsay, 1967). Folds display a flexural-slip to flexural-flow mechanism (Donath and Parker, 1964), although crystal-plastic deformation mechanisms are not operating here. Instances of both buckling and fault propagation folding were observed in outcrop.

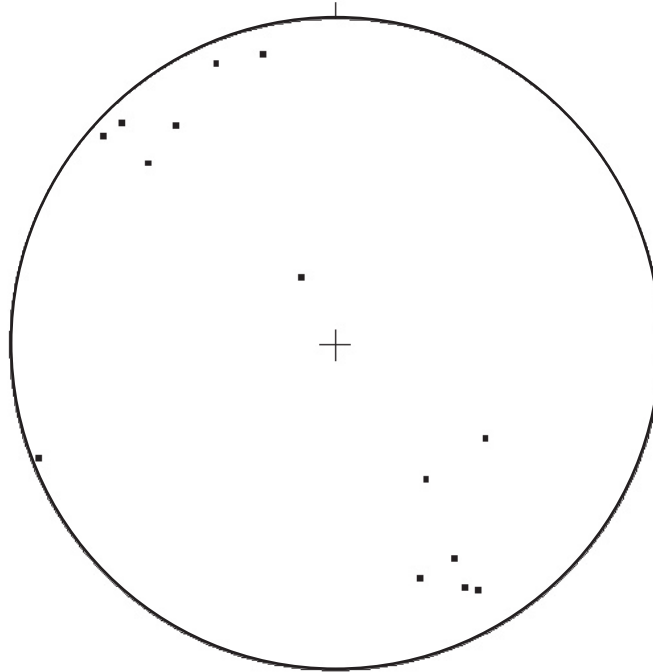


Figure 3-8. Lower hemisphere, equal-area stereographic projection of poles to 16 axial surfaces. Plot made using GEORient v. 9.2 by Rod Holcombe (University of Queensland).

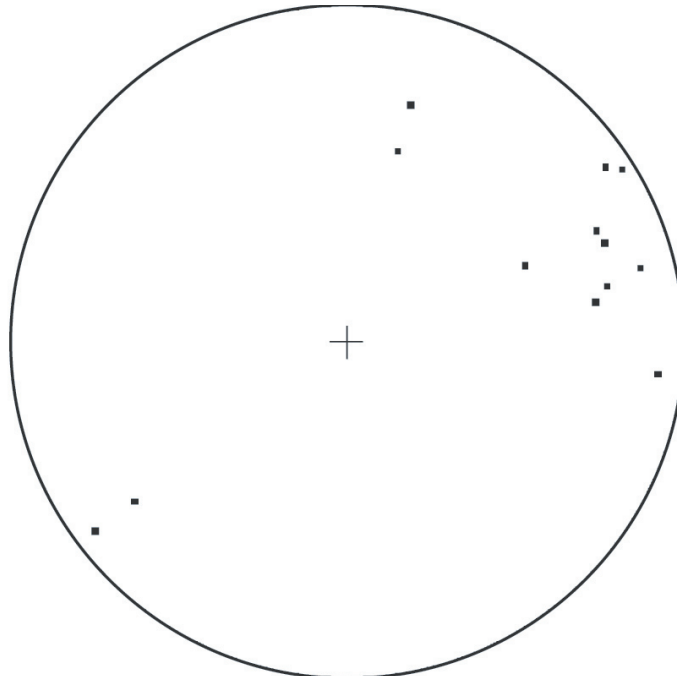


Figure 3-9. Lower hemisphere, equal-area projection of 14 fold axis orientations. The mean principal direction is $063^{\circ}, 12^{\circ}$. Plot made using GEORient v. 9.2 by Rod Holcombe (University of Queensland).



Figure 3-10. Ramsay (1967) class 1C fold in middle Sevier Shale.
 (a) The fold displays slight thickening in the hinge and curvature of the inner arc that is greater than the curvature of the outer arc. (b) Isogon analysis of fold. Outcrop is located along Knob Creek Rd, north of Bruner Grove, TN. (Hammer is ~ 12 in. long.)

Faults. Thrust faults with displacement of a few meters or less were observed in Knox and Sevier rocks in the study area (Fig. 3-11). These faults are typically associated with folds and may be the result of solving room problems.

Joints. Jointing is well developed in all units exposed in the study area (Fig. 3-12, 3-13). In general, the joints in less competent units (shales and siltstones) exhibit close spacing, whereas thick, strong units (carbonates and sandstones) possess more widely spaced joints. Calcite and rare quartz fill the joints. In Knox Group rocks, jointing is most easily observed on weathered surfaces where joints are expressed as recessed lines believed to result from more rapid erosion rates of the calcite-filled veins than the surrounding dolomite.

Stylolites. Bedding-parallel and tectonic stylolites were observed primarily in Knox Group rocks with some rare occurrences in the Honaker Dolomite. Both bedding-parallel and tectonic stylolites appear throughout the Knox Group. Teeth on both types have amplitudes of up to 3 cm.

Cross Sections

Three cross sections were constructed across regional strike at 1:24,000 scale (Figs. 3-14, 3-15). Depth to basement was obtained from Hatcher et al. (1998) and industry seismic reflection data not utilized by previous workers. Cross-section locations were chosen based on the proximity to seismic reflection data (Fig. 3-2) and the ability



Figure 3-11. Meso-scale fault in lower Sevier Shale along the Nolichucky River near Stillhouse Branch. Displacement is approximately 3 meters. (Poison ivy vine ~ 2 m long.)



Figure 3-12. Intensely fractured Mascot Dolomite along the Oven Creek near Harned Chapel, TN. Bedding is approximately parallel to hammer head (subhorizontal). (Hammer is ~ 12 in. long.)

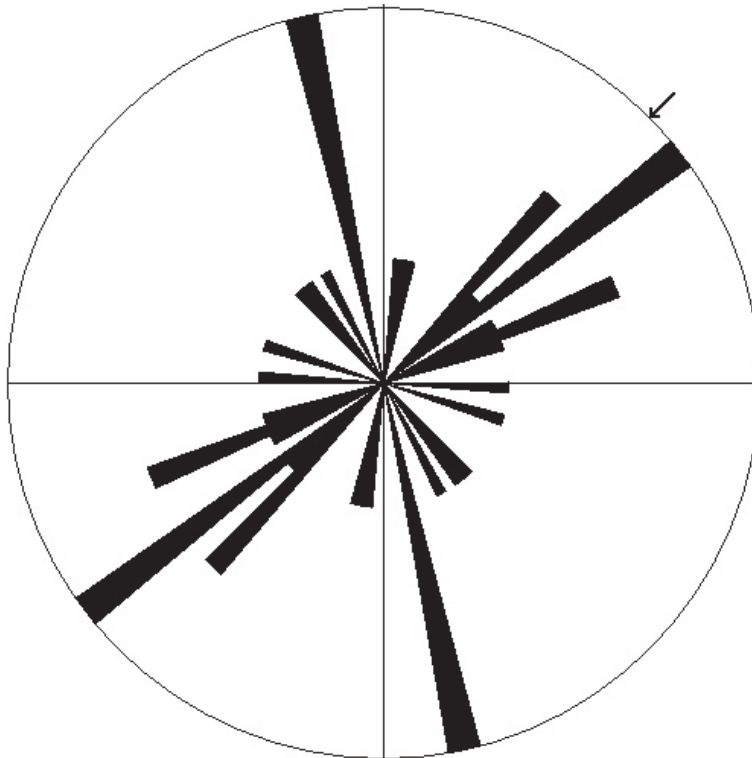


Figure 3-13. Rose diagram of 21 joint measurements measured primarily in Knox Group. Plot made using GEORient v. 9.2 by Rod Holcombe (University of Queensland).

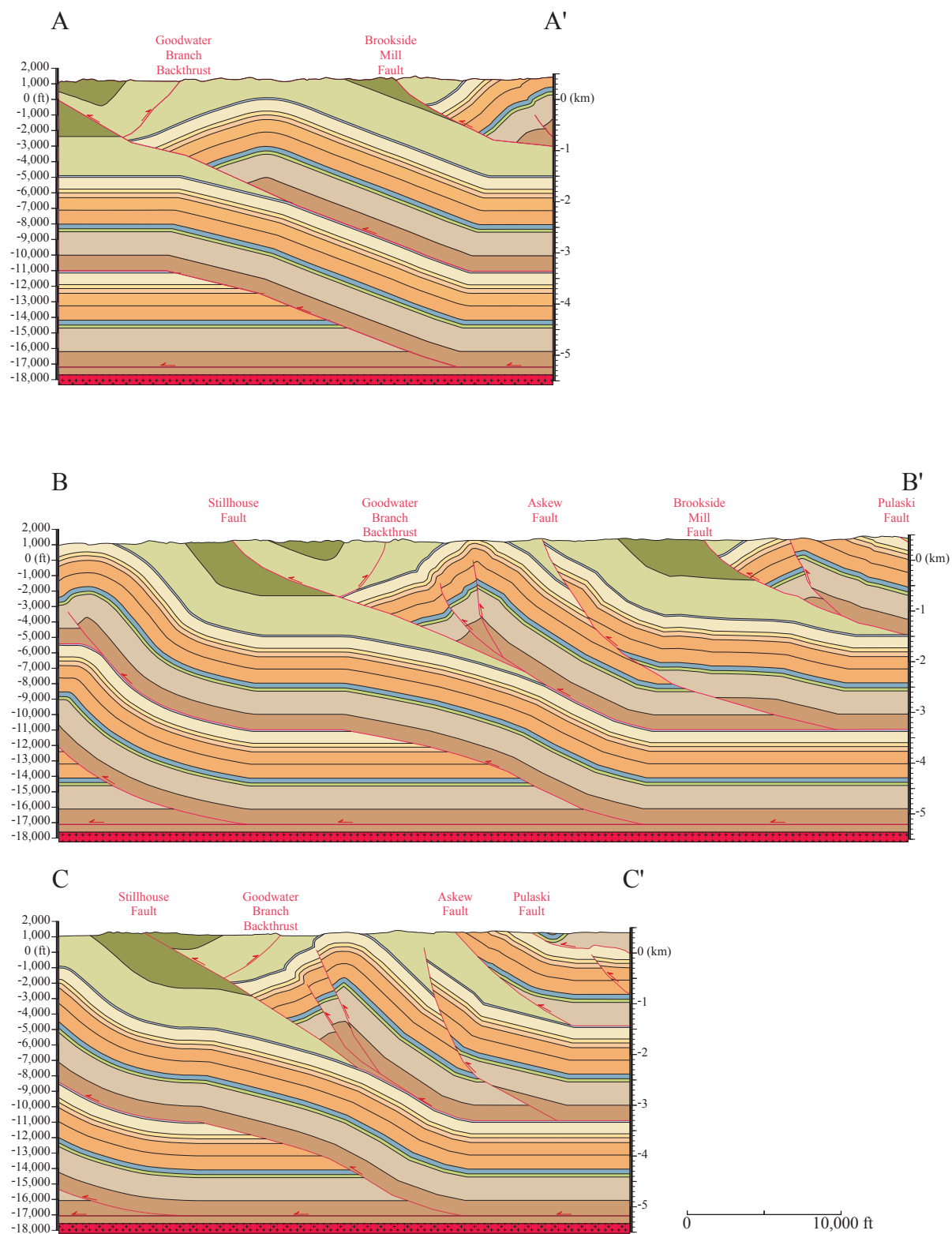


Figure 3-14. Cross sections through the field area. See Figure 2-1 and Plate 1 for location of sections. Sections have no vertical exaggeration. See Plate II for explanation of units.

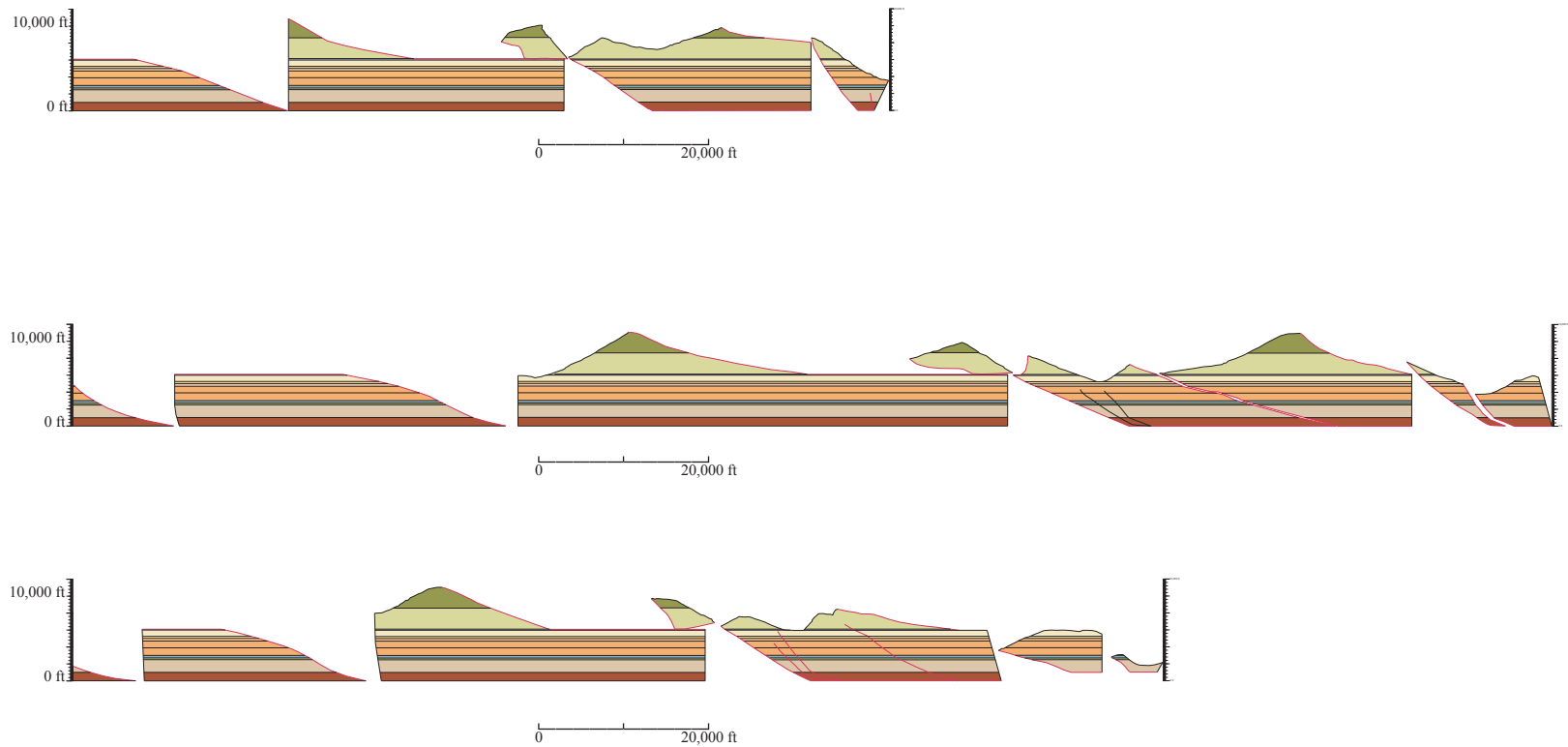


Figure 3-15. Retrodeformed cross sections. Sections have no vertical exaggeration. Calculated percent shortening is 65%, 65%, and 67% for A-A', B-B', and C-C', respectively. See Figure 2-1 and Plate II for explanation and location of cross sections.

to address prominent map-scale structural features and to illustrate regional structural geometries at depth.

Several workers, including Keith (1905a, 1905b), Rodgers (1953b), Emerson (1963), Roeder et al. (1978), Woodward and Gray (1985), and Lemiszki (2003), produced cross sections located in or near the study area, but did not make use of seismic reflection data. As a result, these cross sections contain features that sacrifice accuracy. These include incorrect estimates of depth to basement, inaccurate stratigraphic thicknesses, structural geometries that do not resemble those in seismic reflection data, construction at too small of a scale, and cross sections that do not extend to top of basement.

Keith's (1905a, 1905b) cross sections were constructed before detailed knowledge of regional stratigraphy was available and suffer from mislabeling of Conasauga and Knox Groups at certain locations. Although Lemiszki's (2003) cross sections in the Mosheim 7.5-minute quadrangle and those of Emerson (1963) across the Warrensburg anticline were constructed at 1:24,000 scale, the sections resemble those of Keith (1905a, 1905b) and Rodgers (1953b) in that they do not extend to the master décollement near the top of basement. Although Roeder et al. (1978) and Woodward and Gray (1985) constructed theirs to basement, estimates of depth to basement are several thousand feet off.

Detailed surface geologic data and seismic reflection data were made available to assist in cross-section construction. The seismic reflection line transects the northwest portion of the study area and provide accurate estimates for elevation to the top of basement. The seismic reflection data provides information regarding subsurface

structure geometry and more stratigraphic thickness estimates, when combined with dip-strike measurements and geophysical well log data.

Cross sections were initially constructed using Adobe Illustrator™ 10 software. Surface data including structural measurements and stratigraphic thicknesses were transferred onto topographic profiles constructed from 7.5-minute topographic quadrangles. Subsurface geometries such as bedding dip, fault plane dip, and fold axis orientations were interpreted from seismic reflection data and certain criteria outlined by Hatcher and Hooper (1990) for foreland fold-thrust belts. These criteria are: (1) stratigraphic unit thicknesses remain constant during deformation unless otherwise known to change by depositional processes; (2) deformation progressed from hinterland to foreland, with minor out-of-sequence deformation occurring to preserve critical wedge geometry; (3) cross sections should be constructed perpendicular to regional strike; (4) cross sections that do not balance cannot be correct, and balanced cross sections are not necessarily correct (Elliott, 1983); and (5) thrust faults cannot cut down section.

Completed cross sections were converted to *jpeg* format and opened in LithoTect™ software for conversion into vector files. LithoTect™ is a cross section retrodeforming and balancing program that provides a foundation for assembling geoscientific applications that can build 2D and 3D, statistically meaningful, scientifically constrained geologic models from reservoir to basin scale (Geiser, 2002). LithoTect creates and tests for physical reality in a geological interpretation by removing folding and faulting. This “balancing” process—restoration—to a reasonable undeformed state serves to validate an interpretation. The program represents rock structure and deformation as geometric fields. These fields automatically incorporate mixtures of

influencing elements and combinations of geometric styles (including similar and concentric or angular-bend parallel geometries). They are the basis for reconstructing bedding layers and computing dip or curvature everywhere within a rock package. Fields define the slip systems used for restoration/forward modeling in 2D and 3D, and strain or deformation.

LithoTect™ has the capability for the user to create cross sections without importing *jpeg* files of previously constructed sections from graphics programs such as Adobe Illustrator. I found the graphic design software primitive, difficult to employ, and created inaccuracies, so the graphics program is clearly the best place to begin.

Cross-Section Discussion

Cross sections were constructed using typical fault-bend fold mechanisms for the regional folding mechanism. Parrottsville, Oven Creek, and Warrensburg anticlines are believed to be snake-head folds related to fault-bend fold transportation along fault surfaces. This geometry was chosen based on the presence of footwall cutoffs and resemblance of snake-head folds in seismic reflection data. The faults ramp in more competent strata, such as the Knox Groups, and flatten in less competent, shaly units like the Rome Formation, basal Honaker Dolomite, and Sevier Shale. The master décollement is located in a structurally weak layer in the Rome Formation.

A high level of continuity exists between cross sections and seismic reflection data. Slight variations between the two are manifested as blind thrusts in fold hinges to solve room problems of tightened folds (e.g. Oven Creek anticline, where surface data indicate tighter folding in the area of B-B' and C-C' locations).

B-B' and C-C' show the Pulaski fault as shallow dipping and propagating through shale in the basal Honaker Dolomite as a local décollement. Although Woodward and Gray (1985) suggested the post-fault folding of the Pulaski fault is a result of footwall duplex horses, thrusting was used here to account for the folding. The Goodwater Branch backthrust has been drawn to indicate the southeast verging out-of-sequence thrusting to be a result of room problem solution during emplacement of the Stillhouse fault. Minimum shortening for A-A', B-B', and C-C' equal 65 percent, 66 percent, and 68 percent, respectively, slightly higher than values obtained from sections that cut across the entire Valley and Ridge at this latitude (Whisner et al., 2004).

Chapter 4

Consideration of the Tectonic Significance of the Sevier Basin

The Sevier basin has traditionally been interpreted as a foredeep basin (Fig. 4-1) that formed in response to crustal loading by obduction of a volcanic arc to the east during the Taconic orogeny (Shanmugam and Walker; 1978, 1980, 1983; Shanmugam and Lash, 1982; Drake et al., 1989). If this scenario were true, the Sevier foredeep basin would have acted as a receptacle for sediments shed by the approaching Taconic highlands. Sevier sediments should possess an affinity for the Taconic highlands.

Previous investigations of Middle Ordovician Chickamauga Group sediments (Rodgers, 1953a, 1953b; Shanmugam and Walker, 1978, 1980, 1983) have revealed progradation of carbonates in the northwest portion of the Valley and Ridge province into clastics to the southeast (Figs. 1-2 and 1-3). In addition, several locations of conglomerate outcrop have been identified near the base of the Sevier Shale. Distribution of these conglomerates is geographically in the southeast extent of Sevier Shale exposure, near the Blue Ridge front. Although these facies relationships suggest the source terrane for the majority of the clastics was some distance to the southeast, toward the Taconic highlands, recent studies have created some doubt that the Sevier basin is a Taconic foredeep.

Detrital zircon analyses (Bream, 2003; Thomas et al., 2004) of Sevier basin sedimentary strata lack zircons with Paleozoic dates. In fact, only zircons with dates of 1.1 Ga and older are present in the Sevier Shale (Bream, 2003), indicating a Grenvillian basement source (Bream, 2003). Although these findings indicate that the Sevier basin

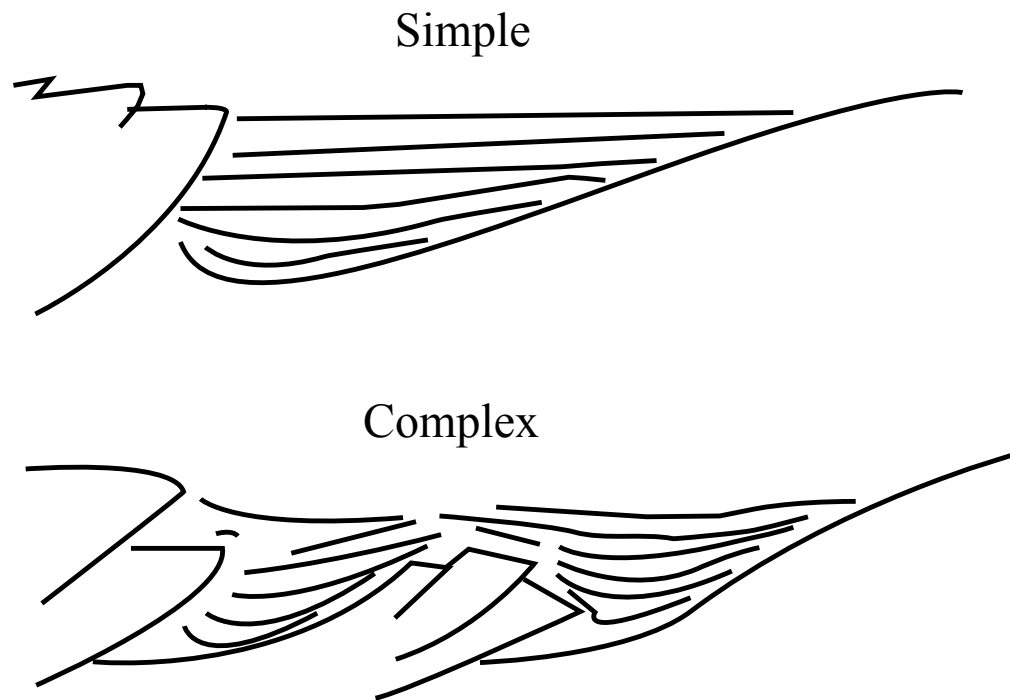


Figure 4-1. Models of types of tectonic basins. The "simple" type is a classic foredeep, while the "complex" type is the model proposed for the Sevier basin. (Modified from Ricci-Lucchi, 1986.)

sediment may not have been sourced by the Taconic highlands and consequently cannot be a Taconic foredeep basin, they are not enough to substantiate an alternative model.

Kellberg and Grant (1956) provided an excellent analysis of Sevier Shale conglomerates from six locations in the Valley and Ridge province of Virginia, Tennessee, and Georgia. Their investigations concluded that the majority of conglomerate clasts were derived from Middle Ordovician to Upper Cambrian carbonate rocks of the Knox Group and even the Lenoir Limestone. A significant contribution also came from rocks as old as Lower Cambrian that included quartz arenite, sandstone, and siltstone, with a few basement clasts, which could be the source of detrital zircons that lack Paleozoic dates.

These studies (Kellberg and Grant, 1956; Bream, 2003; Thomas et al., 2004) indicate new models for Sevier basin formation, such as a back-bulge (Hatcher, 2004) or a complex basin model (Whisner, 2005) should be considered. In the back-bulge model (Fig. 4-2), a peripheral bulge serves as the barrier preventing younger (Taconian) zircons from reaching the Sevier basin. The peripheral bulge would need to be uplifted enough to expose rock as old as Grenvillian basement to source the conglomerates located near the base of the Sevier Shale and supply detrital zircons that lack Taconic affinity. Although back-bulge basins have been proposed for other areas including Acadian orogenic deposits in the central Appalachians (Filer, 2003), this model requires an infeasible crustal load. Using Sevier Shale sediment thickness estimates of 2,100 m (7,000 ft) acquired from Lemiszki (2003), this study, and Bultman (*in progress*), Whisner (2005) concluded it is rheologically impossible to create a crustal load sufficient for a

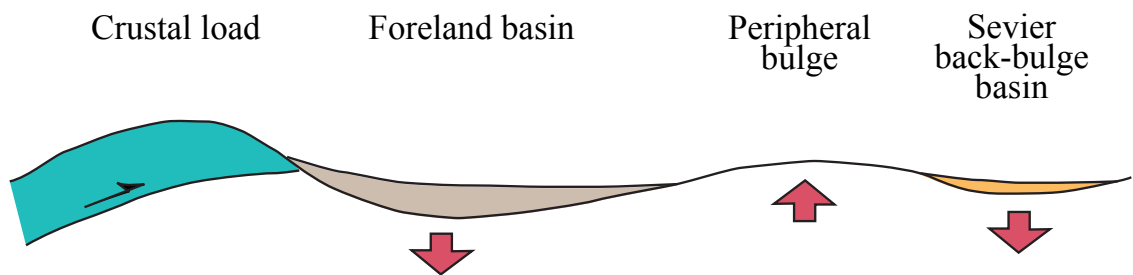


Figure 4-2. Schematic tectonic diagram of possible Appalachian foreland tectonics during Middle Ordovician time with the back-bulge basin representing the Sevier basin (Hatcher, 2003, unpublished figure).

back-bulge basin of that magnitude. Modeling was performed using Lithospheric flexure of crustal response to loading on Matlab™ software created by Nestor Cardozo of Cornell University.

The conclusion that the back-bulge model is not sufficient to account for the Sevier sediment thickness led to Whisner's (2005) "complex basin" model (Fig. 4-1). This model is very similar to the basic foredeep model with minor modifications. Downwarping in the foreland by Taconic loading created a foredeep basin. The difference between the two models is that during basin formation, sufficient basement thrusting took place to divide the basin into two separate basins, which prevented Taconian sediments from reaching the distal basin. Since foredeep basins are not symmetrical along the long axis (Einsele, 2000), one would expect strata in the interior basin to have a greater thickness and possess detrital zircons with Paleozoic dates. Like the "back-bulge" model, this model contains aspects that are difficult to rationalize. If there were a basement thrust fault large enough to isolate the distal basin and expose Grenvillian basement that is covered by 2,440 m (8,000 ft) of strata, where is this fault located today? Seismic reflection data interpreted by Hatcher et al. (1989) and Costain et al. (1989) clearly reveal Valley and Ridge stratigraphy extending beneath the interior of the mountain belt at least as far as the Brevard fault zone with no significant basement thrusts. For this model to be plausible, basement thrusts, as described by Ricci-Lucchi (1986), had to occur west of the Brevard fault zone, yet COCORP data (Cook and Oliver, 1981) does not reveal any such fault.

One possible solution to this problem requires a slight modification of the basement thrust of the “complex basin” model. Rather than the dividing thrust originating in the basement, Taconic thin-skinned thrusting of the Laurentian margin sediments could be sufficient to create the needed barrier. When looking at Valley and Ridge faults for possible candidates, the Pulaski fault is unique. According to Hatcher et al. (1989), the Pulaski fault is 1) complexly deformed; 2) intensely cleaved; 3) metamorphosed in places; 4) exposes Lower Cambrian Chilhowee Group rocks; 5) is shallow over large areas; and 6) may show polyphase deformation (Schultz and Bartholomew, 1980).

The Pulaski fault’s extent of 560 km and the presence of Chilhowee Group rocks in the thrust sheet are adequate to isolate the Sevier basin sediments in the footwall from the Taconic highlands and serve as the source terrane for the Sevier Shale. The detrital zircon studies of Bream (2003) and Thomas et al. (2004) sampled locations in the footwall of the Pulaski fault. To my knowledge, no locations in the hanging wall of the Pulaski fault have ever been sampled. Regardless of whether the Pulaski is a Taconic fault, more work, principally detrital zircon analyses of Pulaski thrust sheet sedimentary rocks, is needed to provide conclusive evidence for any of the models.

Chapter 5

Conclusions

1. An area of the Bays Mountain synclinorium, including the Parrottsville, Cedar Creek, Mosheim, Stony Point, Baileyton, Greeneville, McCloud, and Burem 7.5-minute quadrangles, contains divisible stratigraphic subunits of the Sevier Shale (Lemiszki, 2003). The stratigraphic break between the lower and middle Sevier Shale subunits can be traced parallel and perpendicular to strike in the vicinity of the study area.
2. The total thickness of the Sevier Shale is believed to increase from approximately 790 m (2600 ft) in the Stony Point 7.5-minute quadrangle (Bultman, *in progress*) south, into the study area, where it is approximated to be 2,100 m (7,000 ft) thick based on field data from the Parrottsville, Cedar Creek, and Mosheim (Lemiszki, 2003) 7.5-minute quadrangles.
3. The Pulaski fault serves as a major stratigraphic break for the Knox Group. The Pulaski fault juxtaposes northwest phase Knox Group strata in the footwall against southeastern phase Knox Group strata in the hanging wall.
4. Within the study area, the northwestern phase Knox Group contains more limestone and less chert than more northwestern exposures.
5. The middle Sevier Shale is typically silty to fine-grained sandy limestone in the vicinity of the study area and becomes coarser grained in the Mosheim 7.5 minute quadrangle (Lemiszki, 2003) and John Bultman's study area.

6. The majority of cleavage related to folding displayed axial-planar orientation with rare occurrences of fanning, suggesting additional tightening of folds during or following cleavage development.
7. The plot of Sevier Shale cleavage data on an equal-area stereonet closely resembles the equal-area stereonet of Oven Creek anticline bedding data. The mean orientation of pencil cleavage is similar to the Oven Creek anticline fold axis orientation and local bedding-cleavage intersection orientations. These relationships indicate that most cleavage is axial planar to the Oven Creek anticline.
8. The Goodwater Branch backthrust is interpreted to be a southeast-verging thrust fault that formed in response to room problems during emplacement of the Stillhouse fault.

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Appendices

Appendix A

LithoTect™ 2D Restoration

Project Creation

A new project was created in LithoTect™ 2D for each of the three cross sections created in Adobe™ Illustrator. For each new project, the desired unit of measurement for distances (meters) and velocity for SEG-Y format seismic data had to be selected. Using the Clarke 1866 geodetic data for UTM zone 17, a base map was created from which cross section location lines could be located based on the UTM coordinates of the beginning and end points of the section line. Since vector data cannot be imported directly into LithoTect™ 2D, the cross sections had to be imported in *.jpeg* format and redrawn. A stratigraphic column (Fig. A-1) was created for each project that contained stratigraphic names, thicknesses, and lithologies prior to tracing the *.jpeg* files into vector format.

Cross-section Creation

LithoTect™ 2D has the ability to differentiate vector data into several categories (Fig. A-2) including:

- Stratigraphic top
- Intraformational contact
- Fault
- Boundary
- Topography/Outcrop
- Unconformity
- Bio-stratigraphic boundary

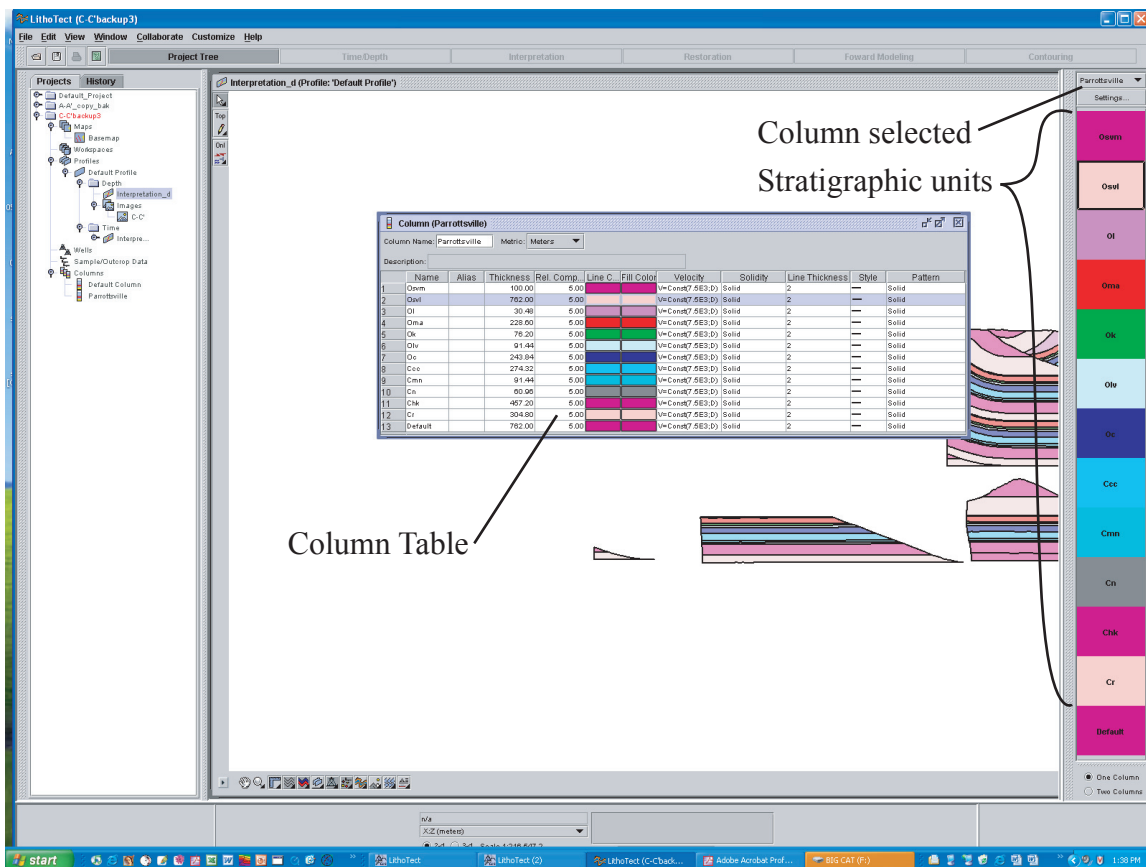


Figure A-1. Illustration of the stratigraphic column and table during construction.

The first step in converting the *.jpeg* of each cross section into vector format was to trace the base and sides of the cross section using the “boundary” line tool and the topographic profile using the “topography” line tool. Next, faults were traced with the “fault” line tool. Stratigraphic tops were then traced using the “top” line tool systematically from the base of the section working up. For each stratigraphic top, the correct stratigraphic unit was selected from the stratigraphic column. Once the top of each unit was traced, LithoTect™ 2D automatically identified and filled the polygon with the proper color corresponding to the stratigraphic column.

Cross-Section Restoration

Once the cross section was converted to vector format, the “*Restoration*” function was selected from the project menu bar. LithoTect™ 2D allows the user to customize which algorithms to employ to remove deformation from a section (Fig. A-3). For the cross sections in this thesis, the following options were used:

- Interactive Operation Mode
 - Flexural-slip model
 - Region Transformation
 - ◆ Parallel-concentric geometry

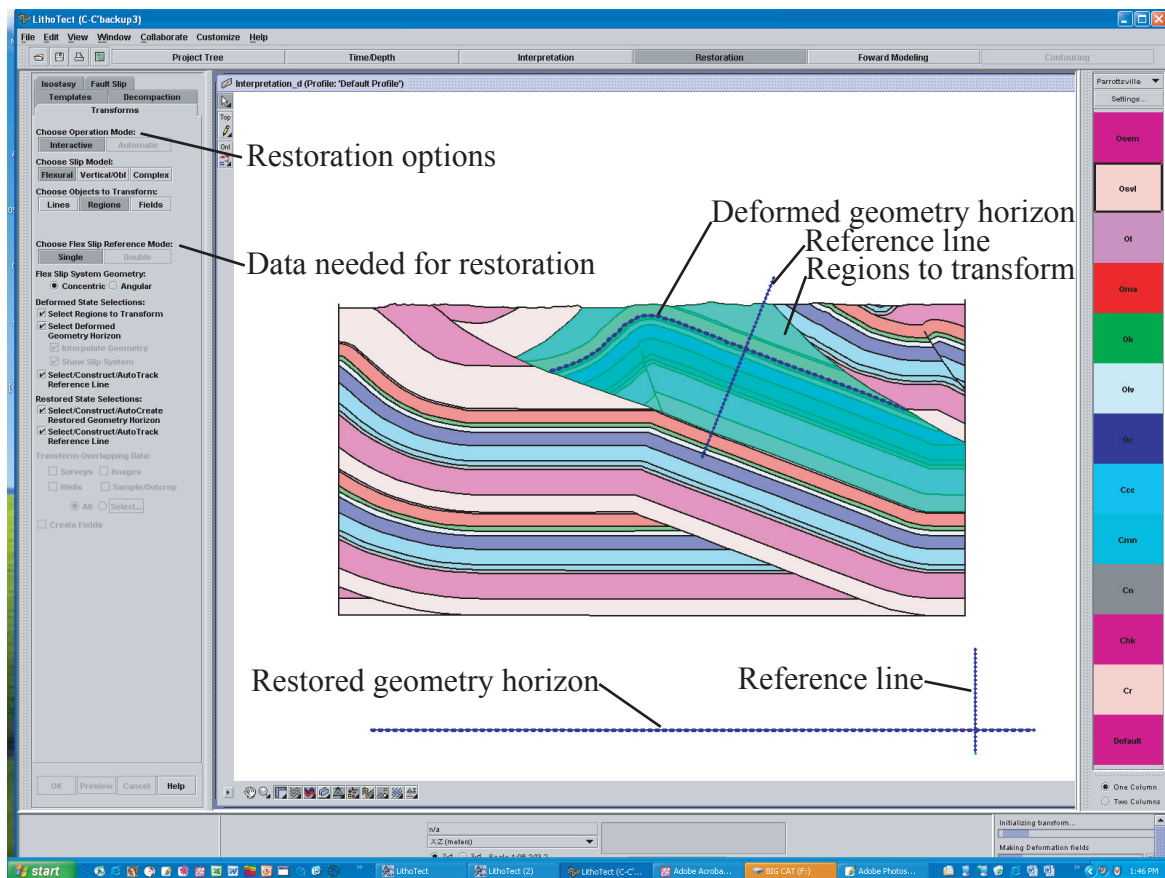


Figure A-3. Illustration showing the options and data entry for the "Restoration" function.

Each cross section was restored one thrust sheet at a time, starting on the hinterland side and working toward the foreland. The “*Restoration*” function prompts the user to enter a series of data during the restoration process for each thrust sheet (Fig. A-3). These include:

- Regions to transform
- The deformed geometry horizon
- AutoTrack reference line (this line needs to intersect the deformed geometry horizon and serves to reference location of the thrust sheet in the restored state)
- Creation of an undeformed geometry horizon
- Creation of an undeformed AutoTrack reference line

Once this information is entered into the respective fields, LithoTect™ 2D transforms the thrust sheet selected into an undeformed state (Fig. A-4). If multiple deformation events were present in the thrust sheet, the above process was repeated on the next deformational event of the first generation restored thrust sheet.

Restoration Evaluation

The restored sections were evaluated based on a set of criteria outlined by Hatcher (personal comm.) that included: 1) stratigraphic unit thicknesses remain constant unless otherwise known to change by depositional processes; 2) hanging wall and footwall cutoff angles must match; and 3) line lengths and area values must be preserved in the undeformed state. Variances in the restored sections from these rules were manifested in

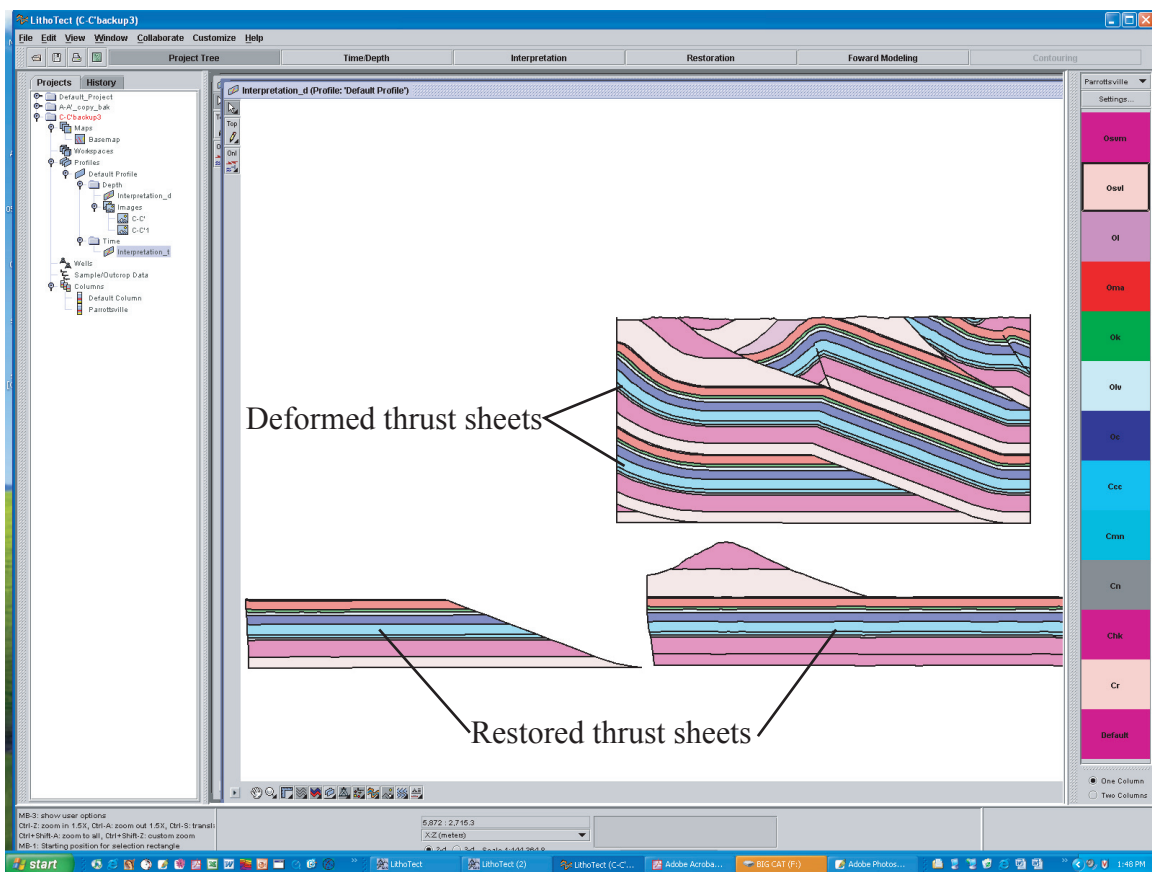


Figure A-4. Illustration of deformed thrust sheets and "acceptable" restorations.

the form of irregular thickness changes and discordant hanging wall/footwall angles (A-5). Corrections were made to the Adobe™Illustrator file and the entire process of project creation, cross-section tracing, and section restoration was repeated until the restored sections were acceptable.

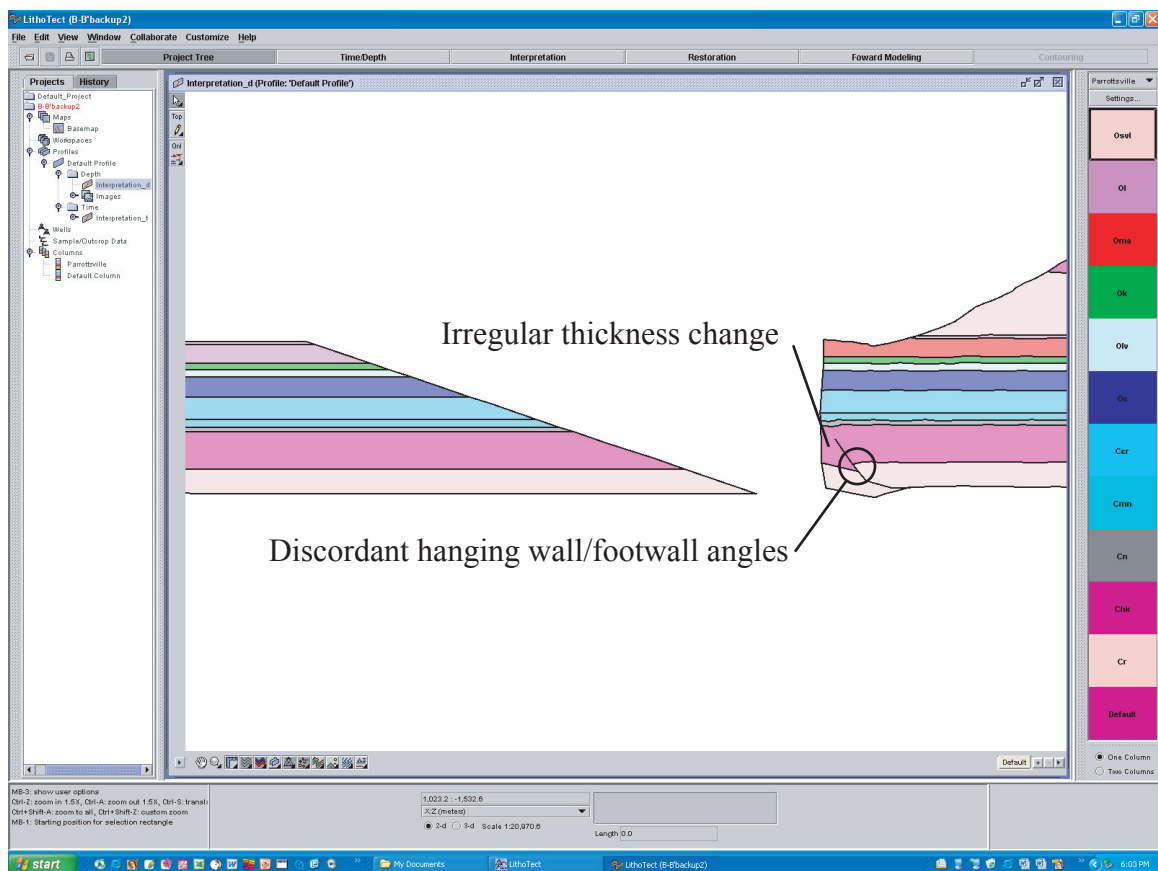


Figure A-5. Variances of an "acceptable" evaluation in the form of thickness changes and discordant hanging wall/footwall angles.

Appendix B

Explanation of numeric abbreviations in the Lithology data column

- Lithology:
1. tan, fine-grained shale
 2. gray, fine-grained shale
 3. silty shale with interbedded limestones
 4. massive limestone
 5. algal limestone
 6. shaley limestone
 7. dark gray dolomite
 8. medium gray dolomite
 9. light gray dolomite
 10. interbedded limestone and dolomite
 11. green shale
 12. interbedded shale and siltstone
 13. quartz sandstone float
 14. silty limestone
 15. Knox Group limestone
 16. chert float
 17. bedded chert
 18. chert clasts
 19. Quaternary alluvium
 20. siltstone
 21. silty shale
 22. calcareous sandstone
 23. oolitic limestone/dolomite
 24. dark gray limestone
 25. bedded sandstone
 26. chert matrix sandstone

Station	Lithology	Bedding		Fold Axis		Cleavage		Axial Plane		Joint		Joint	
		Strike	Dip	Plunge	Trend	Strike	Dip	Strike	Dip	Strike	Dip	Strike	Dip
1	1 & 2	46	52 SE										
2	12	39	48 SE										
3	1	43	44 SE										
4	1	47	47 SE										
5	12	51	48 SE										
6	12	50	50 SE										
7	3	52	53 SE										
8	3	43	54 SE										
9	1	48	49 SE										
10	1	39	51 SE										
11	3	62	57 SE										
12	1	38	54 SE										
13	3	42	44SE										
14	3	37	48 SE										
15	2	65	53 SE			76	81 SE			20	80 SE		
16	1	35	41 SE			60	76 NW						
17	3	85	63 SE			32	45 NW						
18	4	71	83 SE										
19	13												
20	4	46	30 SE										
21	7												
22	7												
23	4	43	54 SE										
24	4	44	64 SE										
25	8	8	16 NW										
26	4												
27	4	0	18 W										
28	4 & 2	23	25 NW										
29	3	46	35 NW										
30	8	54	51 NW										
31	8	35	20 NW										
32	8	160	4 NE										
33	8	12	6 SW										
34	8	61	14 NW										
35	5	38	45 SE										
36	1 & 2	75	54 SE										
37	3	64	49 SE										
38	3	30	59 SE										
39	3	34	37 SE										
40	3	42	29 SE										
41	1 & 2	40	48 SE										
42	1 & 2	46	52 SE										
43	1 & 2	55	32 SE										
44	14	44	40 SE										
45	14	46	39 SE										
46	14	43	37 SE										
47	10	32	39 SE										
48	10	35	33 SE										
49	15	26	42 SE										
50	8												
51	8	37	26 SE										
52	15	41	46 SE										

53	1	7	59 SE		
54	10	42	60 SE		
55	4	31	34 SE		
56	14	44	44 SE		
57	8	38	40 SE		
58	3	50	54 SE	15	41 NE
59	3	161	49 NE		
60	3	111	43 NE		
61	3	115	34 NE		
62	3	141	34 NE		
63	3	10	36 SE		
64	3	25	45 SE		
65	3	0	42 E		
66	3	175	40 NE		
67	10	17	40 SE	315	72 SW 80 63 NW
68	15	2	38 SE		
69	8 & 14	91	38 NW		
70	10	90	51 N		
71	10	15	45 SE		
72	10	149	24 NE	100	72 SW
73	10	16	43 SE		
74	10	42	38 SE		
75	8	38	47 SE	155	69 SW
76	8 & 10	40	32 SE		
77	10	45	44SE		
78	15	34	53 SE		
79	1 & 2	22	50 SE	46	84 SE
80	1 & 2	45	36 SE	42	85 SE
81	1	45	62 SE		
82	3 & 12	35	54 SE		
83	1	44	64 SE		
84	1	41	58 SE		
85	1	40	55 SE		
86	12	44	46 SE		
87	1 & 2	42	54 SE	54	72 SE
88	1	34	41 SE		
89	1	49	39 SE		
90	1	40	39 SE		
91	1	44	43 SE		
92	1	44	42 SE		
93	1	41	44 SE		
94	1	35	39 SE		
95	10	41	50 SE		
96	15	28	39 SE		
97	10	46	38 SE		
98	10	30	35 SE		
99	10	30	37 SE		
100	1	32	36 SE		
101	1 & 2	40	76 SE		
102	1 & 2	39	39 SE		
103	1 & 2	35	62 SE		
104	1 & 2	24	61 SE		
105	1	44	56 SE		
106	1	28	46 SE		

107	1	43	41 SE
108	1 & 2	45	42 SE
109	1	39	36 SE
110	10	169	39 NE
111	4	65	34 SE
112	4	64	28 SE
113	1 & 3	50	39 SE
114	1 & 2	40	39 SE
115	1 & 2	34	45 SE
116	1 & 2	56	44 SE
117	1	50	50 SE
118	14	52	41 SE
119	1	41	39 SE
120	1 & 2	59	35 SE
121	1 & 2	64	39 SE
122	1 & 2	60	51 SE
123	1 & 2 & 4	53	41 SE
124	4	60	35 SE
125	4	74	40 SE
126	1 & 4	66	28 SE
127	2	75	56 SE
128	1 & 4	77	34 SE
129	1	77	34 SE
130	1	69	37 SE
131	1	66	46 SE
132	1	56	38 SE
133	1	63	26 SE
134	1 & 2	58	76 SE
135	4	45	41 SE
136	4	40	33 SE
137	8	39	21 SE
138	8	164	13 NE
139	8	58	26 NW
140	4	52	34 NW
141	4 & 8	58	40 NW
142	4 & 8	59	43 NW
143	1	60	51 NW
144	4	62	53 NW
145	4 & 8	61	52 NW
146	1 & 4	62	61 NW
147	4 & 8	64	65 NW
148	10	59	34 NW
149	8	77	34 NW
150	8	76	16 NW
151	8	46	27 SE
152	4 & 8	45	40 SE
153	1 & 4	48	49 SE
154	2	53	74 SE
155	3	51	34 SE
156	1	45	57 SE
157	1	40	56 SE
158	6	41	67 SE
159	6	51	54 SE
160	14	65	43 SE

44 69 SE

161	1	33	24 SE	
162	2 & 12	60	59 SE	
163	1	36	50 SE	
164	10	17	21 NW	
165	8	23	23 NW	
166	8	18	26 NW	
167	8	24	26 NW	
168	15	25	24 NW	
169	10	60	24 SE	
170	8	34	21 SE	
171	4	50	31 SE	
172	1 & 4	66	31 SE	
173	1 & 4	66	32 SE	
174	4	53	36 SE	
175	10	50	39 SE	
176	4 & 8	80	35 SE	
177	4	55	59 SE	
178	1 & 4	47	45 SE	
179	4	62	57 SE	
180	4	30	52 SE	56 41 NW
181	4 & 8	55	54 SE	62 73 NW
182	10	0	15 W	
183	10	171	12 SW	
184	8	64	34 SE	
185	8	57	18 SE	
186	8	56	19 NW	
187	8	60	34 NW	
188	8	30	41 NW	
189	9	62	44 NW	
190	9	59	32 NW	
191	9	60	24 SE	
192	9	64	11 NW	
193	9	61	7 NW	
194	8			
195	9	61	18 SE	
196	9	61	26 SE	
197	9	67	16 SE	
198	9	46	26 SE	
199	9	51	15 SE	
200	9 & 16	82	16 SE	
201	9	61	26 NW	
202	10 & 16	53	38 NW	
203	10 & 16	59	38 NW	
204	8	39	6 SE	
205	8	39	44 NW	
206	8	35	3 SE	
207	10	144	10 NE	
208	8	149	9 NE	
209	8	56	24 NW	
210	8	64	28 NW	
211	8	59	26 NW	
212	8 & 18	54	16 SE	
213	9	64	27 SE	
214	8 & 18	59	28 SE	

215	8 & 18	59	23 SE
216	10	61	30 SE
217	9	88	24 SE
218	4	86	24 SE
219	4	64	29 SE
220	4	62	26 SE
221	4	64	19 SE
222	4	60	24 SE
223	4	62	21 SE
224	4 & 8	63	21 SE
225	1 & 4	59	29 SE
226	4 & 8	67	26 SE
227	9	56	31 SE
228	10	56	24 SE
229	4	59	29 SE
230	9	59	28 SE
231	4 & 8	53	30 SE
232	4	57	24 SE
233	4 & 8	52	33 SE
234	10	24	21 SE
235	9 & 10	55	21 SE
236	4 & 8	53	46 SE
237	1 & 5	59	44 SE
238	4	131	18 SW
239	1 & 4	23	21 NW
240	1 & 4	21	18 NW
241	1 & 4	32	26 NW
242	1 & 4	35	29 NW
243	4 & 9	34	16 NW
244	1 & 2	31	26 NW
245	4	31	27 NW
246	4	31	33 NW
247	4	35	53 NW
248	4	42	46 NW
249	4 & 9	44	39 NW
250	4	47	42 NW
251	4	52	47 NW
252	4 & 9	50	58 NW
253	4	51	51 NW
254	10	60	74 NW
255	4 & 9	69	83 NW
256	4 & 9	70	86 NW
257	4 & 9	58	74 NW
258	4 & 9	58	84 NW
259	9 & 18	54	51 NW
260	10	49	68 NW
261	15	67	64 NW
262	15	56	59 NW
263	4 & 9	54	56 NW
264	9	54	41 NW
265	4 & 9	44	43 NW
266	4 & 9	45	41 NW
267	4 & 9	44	26 NW
268	4 & 9	29	32 NW

269	4 & 9	21	28 NW
270	4	56	44 SE
271	10	54	34 SE
272	4	52	46 SE
273	1		
274	5	48	49 SE
275	5 & 9 & 18	43	34 SE
276	4 & 5	59	44 SE
277	1		
278	4 & 5	44	34 SE
279	5 & 9 & 18	48	36 SE
280	5 & 9 & 18	44	35 SE
281	4 & 5	43	46 SE
282	1 & 4	46	54 SE
283	5 & 9 & 18	49	27 SE
284	5 & 9 & 18	37	29 SE
285	1 & 4 & 5	46	28 SE
286	10	31	13 SE
287	10		
288	9	37	7 NW
289	9	42	14 NW
290	9	28	8 SE
291	4	61	19 SE
292	4	57	24 SE
293	9	66	16 SE
294	10	49	4 SE
295	10	54	19 SE
296	10	57	17 SE
297	10	44	23 SE
298	9	42	3 NW
299	10	39	2 NW
300	9	45	6 SE
301	10 & 17	159	9 NE
302	7	35	3 SE
303	9		
304	9 & 17	36	11 NW
305	9	22	14 NW
306	9	21	11 NW
307	9		
308	9	69	22 SE
309	9	62	26 SE
310	10	54	26 SE
311	10	62	26 SE
312	1 & 5	43	54 SE
313	9	59	29 SE
314	9	79	23 SE
315	15	78	12 SE
316	10	68	23 SE
317	10	59	21 NW
318	10	45	22 NW
319	4	44	31 NW
320	4	46	29 NW
321	4 & 10	52	24 NW
322	4 & 5	51	27 NW

323	1		
324	4	66	34 NW
325	4 & 9	71	22 NW
326	4		
327	10	51	4 NW
328	10	78	12 NW
329	9	58	14 NW
330	10	12	6 SE
331	9	61	13 NW
332	10	54	20 NW
333	1 & 4	51	44 NW
334	1	109	39 SW
335	1	75	44 SE
336	1 & 4	51	54 NW
337	4 & 19	66	53 NW
338	4 & 19	57	49 NW
339	4 & 19	56	58 NW
340	4 & 19	52	73 NW
341	4 & 19	63	42 NW
342	4	46	40 NW
343	9	62	36 NW
344	10	54	35 NW
345	4 & 9	53	46 NW
346	1 & 2	58	73 SE
347	2	57	69 SE
348	20	55	49 SE
349	20	46	76 SE
350	14	47	41 SE
351	1 & 2	56	63 SE
352	1 & 2	57	57 SE
353	1 & 2	61	50 SE
354	1 & 2	67	65 SE
355	14	46	58 SE
356	14	48	54 SE
357	1 & 2	53	58 SE
358	14	55	74 SE
359	2	61	61 SE
360	1 & 14	64	82 NW
361	1 & 14	51	68 SE
362	4 & 10	56	32 SE
363	1 & 4	46	42 SE
364	1 & 5	56	47 SE
365	4 & 9	54	46 SE
366	4 & 9	55	35 SE
367	1 & 4	67	46 SE
368	9	52	28 SE
369	10	70	14 SE
370	10	58	14 NW
371	10	55	15 NW
372	1 & 4	79	49 SE
373	9	79	68 SE
374	1 & 4	41	49 SE
375	4 & 9	74	46 SE
376	4 & 9	49	14 SE

67 83 SE

377	10	50	71 SE				
378	9	70	19 SE				
379	1	72	49 SE				
380	20	44	84 NW				
381	20	62	84 SE				
382	15						
383	1	34	83 NW				
384	1	46	64 SE				
385	1	46	67 SE				
386	1	56	41 NW				
387	1	78	81 SE				
388	1						
389	1	66	50 SE				
390	1	64	49 SE				
391	4 & 5	44	29 SE				
392	4	59	64 SE				
393	2	59	42 SE				
394	2	55	48 SE				
395	1	58	68 SE				
396	1	64	68 SE				
397	2	59	67 SE				
398	20	48	32 SE				
399	20	54	21 SE				
400	20	44	31 SE				
401	20	53	50 SE				
402	20	52	48 SE				
403	1	45	69 SE				
404	1	54	44 SE				
405	1 & 2	55	53 SE				
406	1 & 2	46	51 SE				
407	1 & 2	53	57 SE				
408	1 & 14	56	47 SE				
409	1 & 14	69	45 SE				
410	1	54	39 SE				
411	1	57	63 SE				
412	1	79	77 SE				
413	1 & 4	66	77 SE		63	19 SE	
414	4 & 9	88	49 SE				
415	1	56	74 SE				
416	1	41	69 NW				
417	1	56	34 SE	78	22 NE	159	87 NE
418	1	79	83 NW	76	11 NE		
419	1	56	48 SE				
420	1						
421	6	77	74 SE				
422	1 & 3 & 20	73	46 SE				
423	1	68	54 SE		70	65 NW	
424	1	72	62 SE				
425	1	89	56 SE				
426	3	61	79 SE				
427	20	63	47 SE				
428	3 & 14	83	29 SE				
429	14	62	52 SE				
430	1	55	47 SE				

431	1	46	51 SE		61	64 NW
432	1	58	68 SE		61	64 NW
433	1	49	46 SE			
434	1	92	54 SW			
435	1	86	72 SE			
436	1	68	49 SE			
437	1	46	39 SE	69	19 NE	47 78 SE
438	1	116	29 NE			68 37 SE
439	1	86	28 SE			84 61 SE
440	1	47	26 SE			
441	1	54	41 SE			
442	1	51	28 SE			
443	1	35	39 SE			
444	1	44	52 SE			
445	20	63	33 SE			
446	20	52	37 SE			
447	1	51	51 SE			
448	14	49	34 SE			
449	1 & 14	66	31 SE			
450	1 & 14	64	64 SE			
451	1 & 14	81	57 FSE			
452	14	67	62 SE			
453	1 & 14	66	39 SE			
454	1 & 14	58	34 SE			
455	1 & 6	58	63 SE			
456	1 & 6	55	45 SE			
457	1 & 6	63	53 SE			
458	1 & 6	56	51 SE			
459	1 & 6	66	61 SE		66	78 NW
460	1 & 6	71	66 SE			
461	1 & 6	51	54 SE			
462	1 & 6	53	59 SE			
463	1 & 6	56	81 SE			
464	1 & 6	58	69 SE			
465	1 & 6	46	66 SE			
466	1 & 6	49	81 SE			
467	1 & 6	56	73 SE			
468	1 & 6	41	71 SE			
469	1	58	69 SE			
470	1 & 6	52	66 SE			
471	1	54	66 SE			
472	1 & 6	64	65 NW			
473	1	77	63 SE			
474	1 & 6	86	43 SE			
475	1 & 6	84	64 SE			
476	1 & 6	71	39 SE			
477	1 & 6	87	46 SE			
478	1 & 6	57	38 SE			
479	1 & 6	57	52 NW			
480	1	49	46 SE		80	88 SE 49 86 SE
481	1	51	63 SE			
482	1 & 6	68	46 SE			
483	1 & 6	73	73 SE			
484	1 & 6	74	61 SE			

485	1 & 6	76	73 SE	
486	1	86	46 SE	76 65 NW
487	1	29	26 SE	
488	1 & 6	158	27 SW	
489	1 & 6	98	62 SW	
490	1 & 6	102	32 SW	
491	1 & 6	71	86 SW	
492	1 & 6	144	19 NE	
493	1 & 6	101	30 SW	
494	1	108	31 SW	
495	14	87	45 SE	
496	1 & 6	71	38 SE	
497	1 & 6	77	62 SE	
498	1	54	29 SE	
499	1	74	81 NW	
500	1 & 6	83	33 SE	
501	1 & 6	86	41 SE	
502	1 & 6	84	34 SE	
503	1 & 6	104	51 SW	
504	1 & 6	81	56 SE	
505	1 & 6	81	70 SE	
506	1 & 6	82	68 SE	
507	1 & 6	79	61 SE	
508	1 & 6	61	46 SE	
509	1 & 6	74	76 SE	
510	1 & 6	76	76 SE	
511	1	69	31 SE	
512	1 & 6	36	42 NW	
513	1 & 6	46	44 NW	
514	1	58	67 SE	
515	1	52	74 NW	
516	1 & 6	22	23 NW	
517	1 & 6	77	57 SE	
518	1	77	64 NW	
519	1	58	42 NW	58 81 SE
520	1 & 6	71	76 SE	
521	1 & 6	79	43 SE	
522	1 & 2	56	27 NW	
523	1 & 2	83	46 SE	
524	1 & 2	32	49 NW	
525	1 & 4	116	30 SW	
526	1	90	51 N	
527	1 & 6	31	34 NW	
528	1 & 6	72	81 SE	
529	1	57	73 SE	53 21 NW
530	1	48	54 SE	48 43 NW
531	1	124	29 SW	
532	1 & 6	16	84 SE	
533	1 & 6	74	34 NW	
534	1 & 6	22	63 NW	
535	1 & 6	22	34 NW	
536	1 & 6	51	83 NW	
537	1 & 6	63	72 SE	
538	1 & 2	54	55 SE	55 74 NW

539	1 & 6	53	31 SE				
540	1	62	74 SE				
541	1	76	82 SE				
542	1	72	84 SE		39	64 SE	
543	1	50	77 NW				
544	1	56	69 SE				
545	1	69	51 SE		68	1 SE	
546	1	28	21 NW		69	78 SE	
547	1	79	60 NW				
548	1	58	48 NW		62	74 SE	
549	1	56	52 NW		58	52 SE	
550	1	64	48 NW		64	48 SE	
551	1	106	84 NE		107	52 SW	
552	1	58	53 NW				
553	1 & 2	53	55 SE				
554	1	54	78 SE				
555	1	64	69 SE				
556	1	60	80 SE	67	42 NE		
557	1	49	83 NW				
558	1	47	62 NW				
559	1	84	40 SE				
560	2	49	40 NW				
561	1	70	31 SE				
562	1	51	46 SE				
563	1	56	62 SE				
564	1	52	29 NW				
565	21			81	26 NE	86	83 NW
566	1 & 6	70	68 SE				
567	1 & 6	61	61 SE		61	63 NW	
568	1	61	14 SE		63	78 NW	
569	1	74	82 SE				
570	1	67	71 SE				
571	1	74	71 SE				
572	1	68	70 SE				
573	1	62	69 SE				
574	1	64	54 NW		64	54 SE	
575	1	65	69 SE				
576	1	84	79 SE				
577	1	74	34 NW		74	82 NW	
578	1	64	85 NW				
579	1	56	32 SE				
580	1	62	47 SE				
581	1	74	69 SE				
582	1	65	87 SE				
583	1	64	76 SE				
584	1	110	56 NE				
585	1	63	79 SE				
586	1	82	49 SE				
587	1 & 6	46	84 SE		31	69 NW	
588	1	79	78 NW				
589	1	74	72 SE				
590	1	68	76 SE				
591	1	79	61 SE				
592	1 & 6	60	43 SE				

593	1 & 6	56	56 SE		
594	1 & 6	51	56 SE		
595	1 & 6	56	65 SE		
596	1	58	60 SE		
597	1 & 2	60	72 SE		
598	1	64	42 SE		
599	1	61	84 SE		
600	1 & 6	62	67 SE	56	8 NE
601	6	55	71 SE		
602	1	55	48 NW		55 77 SE
603	6	64	79 NW		
604	1	61	84 SE		
605	1	69	84 NW		
606	6	65	71 SE		
607	6	66	34 SE		
608	1	64	73 NW		
609	6	66	74 SE		
610	1	66	77 SE		
611	1 & 6	63	52 SE		
612	1	56	81 NW		
613	1 & 6	56	51 NW		
614	6	62	72 NW		
615	1 & 6	51	82 NW		
616	1	65	75 NW		
617	1	82	51 SE		
618	6	52	36 NW		
619	6	64	62 SE		
620	6	59	66 SE		
621	6	61	75 SE		
622	6	56	87 SE		
623	6	57	67 SE		
624	6	60	65 SE		
625	1	52	56 SE		
626	6	52	65 SE		
627	6	61	68 SE		
628	6	51	48 SE		
629	1 & 6	60	81 SE		
630	6	64	69 SE		
631	6	56	69 SE		
632	2 & 6	68	47 SE		66 75 SE
633	2 & 6	76	66 SE		
634	2 & 6	61	80 SE		
635	2 & 6	74	72 SE		
636	2 & 6	72	66 SE		
637	2 & 6	94	45 SW		
638	2 & 6	76	78 SE		
639	2 & 6	52	71 SE		
640	2 & 6	69	78 SE		
641	1	57	76 SE		
642	2 & 6	78	88 SE		
643	2 & 6	57	64 SE		
644	2 & 6	52	60 NW		
645	2 & 6	49	90		
646	2 & 6	61	80 SE		

647	2 & 6	63	64 SE		
648	2 & 6	57	55 SE		
649	1 & 6	64	56 SE		
650	2 & 6	62	68 SE		
651	2 & 6	64	69 SE		
652	1 & 14	61	86 NW		
653	6	53	49 NW	53	7 SW
654	6	53	55 NW		
655	6	49	63 NW		
656	1 & 6	66	72 SE		
657	1 & 6	72	66 SE		
658	1 & 6	69	57 SE		
659	1 & 6	71	62 SE		
660	1 & 6	66	65 SE		
661	1	53	66 SE	53	30 NW
662	1	59	76 NW		
663	1 & 6	62	70 NW		
664	1 & 6	51	52 SE	94	67 NE
665	1 & 6	70	79 SE		
666	1	71	74 SE		
667	1	71	82 SE		
668	1 & 6	71	69 SE		
669	1	46	49 SE		
670	1	62	90		
671	1 & 6	63	84 SE		
672	1 & 6	75	83 SE		
673	1	68	80 NW		
674	1 & 6				
675	1 & 6	72	88 SE		
676	1	69	86 SE		
677	6	0	21 W		
678	1 & 2	54	30 SE		
679	1 & 14	61	62 SE		
680	22	71	56 NW		
681	6 & 21	46	39 NW		
682	6 & 21	71	60 SE		
683	6 & 21	119	17 SW		
684	6 & 21	103	55 SW		
685	1	74	60 SE		
686	1	88	83 SE		
687	1 & 6	69	69 SE		
688	1	47	70 NW		
689	2	60	54 SE		
690	1 & 6	53	61 NW		
691	1 & 6	65	46 SE		
692	1 & 6	41	65 SE		
693	1 & 6	65	64 SE		
694	1 & 6	71	56 SE		
695	1 & 6	59	64 SE		
696	1 & 6	63	81 NW		
697	1 & 6	51	58 SE		
698	1 & 6	52	56 SE		
699	1	47	78 SE		
700	6 & 14	60	67 SE		

701	1 & 6	59	87 SE		
702	6 & 21	39	78 NW		
703	6 & 14	52	70 SE		
704	1	76	62 SE		
705	6 & 14	40	88 NW		
706	1	60	77 SE		
707	1	61	80 SE		
708	6	61	83 SE		
709	6	71	79 SE		
710	6	71	60 SE		
711	6	64	85 SE		
712	6	70	85 SE		
713	2	74	80 SE		
714	2	83	77 SE		
715	1 & 6	64	74 NW		
716	1 & 6	70	84 NW		
717	1 & 6	67	79 SE		
718	1 & 6	76	84 NW		
719	1 & 6	63	84 NW		
720	6 & 14	64	83 SE		
721	6	67	85 NW		
722	6	70	84 NW		
723	1 & 6	69	74 NW		
724	1 & 6	67	69 SE		
725	6	50	34 NW	75	60 SE
726	6	41	38 NW	58	62 SE
727	1 & 6	60	85 SE		
728	1	65	60 SE		
729	1	60	76 SE		
730	1	109	19 NE		
731	14	58	76 SE		
732	14	76	52 NW	73	56 SE
733	1	40	22 SE	96	8 NW
734	14	41	51 SE	66	20 NE
735	14	41	22 NW	51	66 NW
736	14	56	80 SE	54	71 SE
737	14	60	42 SE		
738	14	68	69 SE		
739	14	62	72 SE		
740	14	66	54 SE		
741	14	14	51 NW		
742	6	54	85 SE	53	34 SE
743	1	71	53 SE		
744	14	60	87 SE		
745	6	38	79 SE		
746	6	60	85 SE	56	46 NW
747	14	66	80 SE		
748	14	60	76 SE		
749	14	47	76 SE		
750	14	58	78 SE		
751	14	69	86 SE		
752	14	71	57 SE		
753	14	62	85 NW		
754	14	61	80 SE		

755	14	63	76 SE		
756	14	47	78 NW		
757	14	74	40 SE	53	22 SW
758	10	81	69 SE		
759	10	74	71 SE		
760	10	74	68 SE		
761	4	66	84 SE		
762	1	75	56 SE		
763	1	52	63 SE		
764	4	63	84 SE		
765	4	66	67 SE		
766	4	60	68 SE		
767	10	64	40 SE		
768	10	66	85 SE		
769	20				
770	9				
771	10	63	44 SE		
772	10	59	68 SE		
773	11	63	81 SE		
774	7 & 8 & 9	65	86 SE		
775	7	46	78 SE		
776	11	21	33 SE	21	69 SE
777	10	54	74 SE		
778	7	69	86 SE		
779	11	62	40 SE		
780	9	17	16 SE		
781	9	39	30 SE		
782	15	44	64 SE		
783	15	41	27 SE		
784	10	156	26 NE		
785	8	81	41 SE		
786	7	65	43 SE		
787	15	66	44 SE		
788	10	65	32 SE		
789	10	63	44 SE		
790	10	59	49 SE		
791	9	56	43 SE		
792	8	50	53 SE		
793	10	85	74 SE		
794	4	76	82 SE		
795	4	119	32 NE		
796	4	56	57 SE		
797	15	60	36 SE		
798	15	56	48 SE		
799	15	54	44 SE		
800	15	41	51 SE		
801	4	62	58 SE		
802	15	53	51 SE		
803	10	49	62 NW		
804	15	69	47 SE		
805	10	66	52 SE		
806	10	48	58 SE		
807	8	54	40 SE		
808	10	45	49 SE		

809	10	52	66 SE						
810	10	42	51 SE						
811	10	72	37 SE						
812	2	54	74 SE						
813	14	84	81 SE						
814	14	99	80 NE						
815	1 & 2	66	72 NW						
816	14	56	84 SE						
817	1 & 2	76	85 SE						
818	4 & 5	51	60 SE						
819	9	60	69 SE						
820	1 & 2 & 5	60	75 SE						
821	4 & 9	64	59 SE						
822	1 & 5	64	75 SE						
823	1 & 5	62	66 SE						
824	10	60	82 NW						
825	4	58	64 SE						
826	9	66	43 SE						
827	7 & 18	55	46 SE						
828	4	67	46 SE						
829	1 & 5	69	58 SE						
830	4 & 9	80	46 SE						
831	15	52	17 SE						
832	9	68	34 SE						
833	1 & 2	55	75 NW						
834	1 & 2	62	71 SE						
835	14	65	77 SE						
836	14	73	69 NW						
837	1 & 2	50	84 SE	47	28 SE				
838	4	53	70 SE					138	90
839	4 & 9	50	43 NW					133	78 NE
840	1 & 2 & 4	41	85 NW						
841	14	50	36 NW					144	66 SW
842	14	50	58 NW						
843	6	25	62 SE						
844	6	62	66 NW						
845	6			58	4 NE			58	84 NW
846	14	39	64 SE						
847	14	45	78 SE						
848	14	42	63 NW						
849	14	79	51 NW						
850	14	49	54 NW						
851	14			15	28 NE	42	39 SE	15	57 SE
852	14	14	74 SE			14	7 SE		
853	14	44	76 SE						
854	14	70	88 SE						
855	14	54	62 SE						
856	14	70	70 SE						
857	1	30	24 SE						
858	9	45	49 SE						
859	20	54	74 SE						
860	20	52	60 SE						
861	20	56	60 SE						
862	20	54	72 SE						

863	20	44	61 SE
864	14	51	73 SE
865	3	36	47 SE
866	20	59	71 SE
867	1 & 2	61	83 NW
868	1 & 6	66	86 NW
869	3	32	85 NW
870	1	64	87 NW
871	1	40	78 SE
872	1	56	84 SE
873	1	50	86 NW
874	1	69	66 SE
875	3	64	72 SE
876	1 & 3	64	83 SE
877	3	69	88 NW
878	3	64	77 NW
879	6	82	75 NW
880	6	60	76 SE
881	6	70	83 SE
882	3	64	82 SE
883	6	54	73 SE
884	6	75	72 NW
885	6	59	77 SE
886	6	62	85 SE
887	6	64	74 SE
888	9	54	66 SE
889	9	33	24 NW
890	10	105	29 SW
891	9 & 18	105	11 SW
892	9 & 18	29	20 NW
893	9	32	21 NW
894	10	137	26 SW
895	13		
896	9	81	25 SE
897	1	62	65 SE
898	6	64	68 SE
899	6	70	64 SE
900	6	65	61 SE
901	6	63	54 SE
902	6	64	67 SE
903	1	84	40 SE
904	3	82	47 SE
905	3	76	54 SE
906	3	79	42 SE
907	3	54	16 NW
908	1	86	48 SE
909	1	76	44 SE
910	1	65	54 SE
911	1	68	54 SE
912	3	30	45 NW
913	3	68	54 SE
914	8 & 13	175	34 NE
915	10 & 16 & 18	95	56 SW
916	11		

917	5	121	46 NE	
918	5	90	74 N	
919	9	122	36 NE	
920	13			
921	13			
922	10	25	64 SE	
923	9 & 18	46	44 SE	
924	16			
925	15	55	35 NW	
926	13 & 16			
927	13			
928	13			339 87 SW
929	8	44	55 SE	
930	13			
931	13			
932	10 & 16	66	51 NW	325 81 NE
933	10	65	85 SE	
934	10	65	55 SE	
935	8	25	58 SE	
936	10	37	36 SE	
937	13			
938	8 & 10	64	38 SE	
939	13			
940	10 & 13	56	34 SE	164 87 SW
941	13			
942	10	55	77 SE	
943	10	58	33 SE	
944	10	38	64 SE	
945	10	68	40 SE	
946	13			
947	7 & 18	38	56 SE	
948	11			
949	11	35	56 SE	
950	11	62	51 SE	
951	10	26	78 SE	
952	10	42	30 SE	
953	10	67	56 SE	
954	10	64	44 SE	
955	8	86	39 SE	
956	10	84	41 SE	
957	10 & 23	62	35 SE	
958	8	47	41 SE	
959	13			
960	10	4	23 SE	
961	8 & 13	45	31 SE	
962	1	90	90	
963	10	62	59 SE	
964	10	79	90	
965	1	90	77 N	
966	10	141	46 NE	
967	1			
968	11	55	53 SE	
969	24	60	46 SE	
970	10	64	55 SE	

971	1	59	88 SE				
972	4						
973	25	60	51 SE				
974	4						
975	1 & 2	36	81 SE				
976	1 & 24						
977	10	84	58 SE				
978	10	50	37 SE				
979	13						
980	10	50	44 SE				
981	9 & 13	57	64 SE				
982	13						
983	8	50	53 SE				
984	1	46	64 SE				
985	10	49	53 SE			144	84 NE 64 54 NW
986	7 & 18	72	74 SE			54	28 NW
987	11	58	75 SE	134	71 SW		
988	7 & 8	61	57 NW			159	90
989	11	96	78 SW				
990	8 & 18	30	75 NW				
991	4	86	75 SE			3	74 SE
992	1 & 2						
993	13						
994	8	177	21 NE			101	90
995	8	22	49 SE				
996	13						
997	7	32	47 SE				
998	13						
999	13						
1000	1	50	61 SE				
1001	1	74	47 SE				
1002	9	48	14 SE	72	28 NW		
1003	8	8	25 SE			79	69 NW
1004	1						
1005	1 & 2	42	47 SE				
1006	1	44	61 NW				
1007	1	49	54 NW				
1008	1	51	67 NW				
1009	4	36	84 NW				
1010	26						
1011	15	48	30 NW				
1012	8	50	24 SE				
1013	26						
1014	8	36	28 NW				
1015	26	52	41 NW				
1016	1	39	49 NW				
1017	1	47	72 SE				
1018	6	53	79 SE				
1019	6	101	63 NE				
1020	1 & 6	45	83 SE				
1021	1 & 6	38	79 SE				
1022	1	63	87 NW				
1023	1 & 6	37	62 SE				
1024	8	46	46 SE				

1025	9	48	27 SE
1026	10 & 13	37	29 SE
1027	9	43	34 SE
1028	10	47	22 SE
1029	10	54	29 SE
1030	8	56	32 SE
1031	10	60	38 SE
1032	15	58	23 SE
1033	10	64	31 SE
1034	23		
1035	13		
1036	7 & 11	42	34 SE
1037	7 & 11		
1038	8	47	36 SE
1039	11 & 13		
1040	13		
1041	10	52	26 SE
1042	10	59	31 SE
1043	7 & 11		
1044	13		
1045	10	57	33 SE
1046	15	47	28 SE
1047	7	60	30 SE
1048	7	57	18 SE
1049	10	37	38 SE
1050	10	32	23 SE
1051	13		
1052	13		
1053	13		
1054	13		
1055	8 & 11		
1056	8 & 11		
1057	8 & 11	39	24 SE
1058	8 & 11	21	32 SE
1059	7 & 18	19	26 SE
1060	1 & 3	58	62 SE
1061	1	56	62 SE
1062	1	52	54 SE
1063	1	60	47 SE
1064	1	63	49 SE
1065	1	51	47 SE
1066	6	50	66 SE
1067	6 & 2	67	54 SE
1068	6 & 2	56	71 SE
1069	6 & 2	69	42 SE
1070	1 & 2	55	37 SE
1071	1 & 2	61	41 SE
1072	1 & 2	64	30 SE
1073	1 & 2	69	33 SE
1074	1 & 2	59	35 SE
1075	1 & 2	64	78 SE
1076	1 & 2	44	41 SE
1077	1	46	33 NW
1078	1	42	32 NW

68 53 NW

1079	1	29	19 NW
1080	1 & 2	45	21 NW
1081	1	64	22 SE
1082	1	66	27 NW
1083	1	61	29 SE
1084	1	46	43 SE
1085	1	45	29 NW
1086	1	31	27 NW
1087	1	36	35 NW
1088	1	40	62 SE
1089	1	49	35 NW
1090	1	51	39 NW
1091	1	50	50 NW
1092	1	56	13 NW
1093	1	63	21 SE
1094	1	59	36 SE
1095	1 & 2	48	39 NW
1096	6	39	41 NW
1097	1	34	45 NW
1098	1	33	24 NW
1099	1	56	43 SE
1100	6	51	39 NW
1101	1	58	28 NW
1102	1	49	32 NW
1103	1	55	36 NW
1104	1	34	41 NW
1105	1	50	48 SE
1106	1	37	20 NW
1107	1	40	36 NW
1108	1	47	35 SE
1109	6	28	39 NW
1110	6	38	40 SE
1111	1	49	26 SE
1112	6	40	71 NW
1113	1	53	76 NW
1114	1	58	63 NW
1115	6	51	75 NW
1116	1 & 3	59	22 SE
1117	1 & 3	48	57 NW
1118	1 & 3	47	69 NW
1119	6	52	51 NW
1120	1	38	40 SE
1121	1 & 3	50	50 SE
1122	6	64	60 NW
1123	1	59	61 NW
1124	1	68	42 NW
1125	1	61	54 NW
1126	1	69	64 NW
1127	6	67	51 NW
1128	1	58	22 NW
1129	1	71	60 SE
1130	1	74	53 NW
1131	1	66	70 NW
1132	6	75	63 SE

64 68 NW

1133	6	67	65 SE
1134	1	55	27 NW
1135	6	62	41 SE
1136	6	74	60 NW
1137	1	42	45 NW
1138	1	51	48 NW
1139	1	54	39 NW
1140	6	46	71 NW
1141	6	55	49 NW
1142	1	63	42 NW
1143	6	54	40 NW
1144	1 & 3	63	47 NW
1145	6	47	38 NW
1146	1 & 3	61	44 NW
1147	1	50	39 NW
1148	6	31	41 NW
1149	8	32	55 NW
1150	8	24	61 NW
1151	8 & 18	47	39SE
1152	8	43	45 NW
1153	8 & 18	52	59 NW
1154	8	41	29 SE
1155	8 & 11	37	31 SE
1156	8	40	40 SE
1157	7 & 9	51	21 NW
1158	9	38	52 NW
1159	7 & 13	49	56 SE
1160	11	96	51 SW
1161	8	43	39 SE
1162	8	33	17 SE
1163	8	101	21 SW
1164	1 & 3	53	21 SE
1165	1 & 3	56	34 SE
1166	1 & 3	67	18 SE
1167	1	48	51 NW
1168	6	59	22 SE
1169	6	71	36 SE
1170	1 & 3	67	15 SE
1171	1 & 3	74	30 SE
1172	1 & 3	57	28 SE
1173	1 & 3	45	20 SE
1174	1 & 3	38	24 SE
1175	1 & 3	62	12 NW
1176	6	44	52 NW
1177	1 & 3	51	71 NW
1178	1 & 3	50	32 SE
1179	1 & 3	53	27 SE
1180	1 & 3	46	18 SE
1181	1 & 3	59	26 SE
1182	1 & 3	42	29 SE
1183	1 & 3	55	12 SE

VITA

Neil Eric Whitmer was born in Vincennes, IN on January 18, 1980 to Larry and Debbie Whitmer. He was raised in Lawrenceville, IL where he graduated from Lawrenceville High School in May 1998. In August 1998 he entered Indiana University, Bloomington, and received a Bachelor of Science degree in Geology in May 2002. While in Bloomington, he served as student body Speaker of the House and College of Arts and Sciences representative. The following fall he began the graduate program at the University of Tennessee, Knoxville and began working toward a Master of Science degree in Geology. He graduated in December 2005 with plans of attending Michigan State University College of Law in the fall.