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STRUCTURE OF THE ALLEGHANIAN THRUST BELT UNDER THE GULF COASTAL PLAIN OF ALABAMA

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ABSTRACT

Mesozoic and Tertiary sedimentary rock of the Gulf coastal plain covers the Paleozoic Appalachian orogen in central Alabama, obscuring the intersection of the northwest-trending Ouachita thrust belt and the northeast-trending Alleghanian thrust belt. Direct observation of the thrust belt system is not possible, and few studies exist because of the lack of well control and limited public availability of seismic reflection profiles. This study uses existing multichannel seismic reflection data and well log data to clarify the subsurface structures and estimate the amount of shortening in the Alleghanian thrust belt in west-central Alabama under the Gulf coastal plain.

The seismic line extends 34.2 mi in a nearly north-south direction, perpendicular to the thrust belt, from the Black Warrior basin in the north to near the Talladega slate belt in the south. To correct the two-way travel times of the seismic sections to depth, we built a synthetic seismogram from a nearby deep well, constructed two velocity models, and interpreted and balanced two cross sections. In west-central Alabama, the thrust belt is forward propagating and hinterland dipping, with thrust sheets that range in length from ~5–17 mi and have thicknesses between 11,000–14,500 ft. Depth to basement is between 23,500–26,000 ft. Estimates of shortening from the balanced cross section are between 26–33%. No indication of interference structures exists between the northeast-trending Alleghanian thrust belt and northwest-trending Ouachita thrust belt. These structural data, in addition to gravity and magnetic data, indicate that the Alleghanian thrust belt continues along a similar northeast-southwest trend toward the Suwannee-Wiggins suture, which marks the boundary between Laurentian and Gondwanan (African origin) crust, and does not sharply curve toward the Ouachita thrust belt.

INTRODUCTION

The southern Alleghanian thrust belt of the Appalachian Mountains in Alabama is bounded by the Black Warrior basin to the northwest, the Nashville dome to the north, and the metamorphic terrane of the Talladega slate belt to the southeast (Fig. 1). The Alleghanian thrust belt formed during Late Carboniferous-Permian time and consists of large-scale, northeast-striking, northwest-verging imbricate thrust faults and associated folds (Hatcher et al., 1989). These imbricate thrust sheets contain a succession of sedimentary rocks of Cambrian through Pennsylvanian age. Thrust sheets are detached at a regional décollement near the base of the Paleozoic rocks above the Precambrian crystalline basement rocks (Rodgers, 1950; Thomas, 1985a). Cretaceous coastal plain sedimentary rock onlap the physiographic expression of the Appalachian Mountains in central Alabama (labeled Fall Line in Figure 1). The overall purpose of this study is to better understand the Alleghanian thrust belt structures under the coastal plain by integrating geophysical, stratigraphic and structural data. This is the first study to balance a cross section based on seismic data through the buried thrust belt in western Alabama. Researchers have argued that the orogen bends sharply from its southwest trend in the southernmost Appalachians in central Alabama to an inferred northwest trend in the subsurface into Mississippi to link up with the Ouachita Mountains in Arkansas (e.g., Branan, 1968; Thomas, 1991, 2004). The cross section presented here provides insight into the kinematics and interaction between the two thrust belts at this critical location.

The seismic data in this study, provided by Vastar Resources, were collected using a Vibroseis source with a 22 s,

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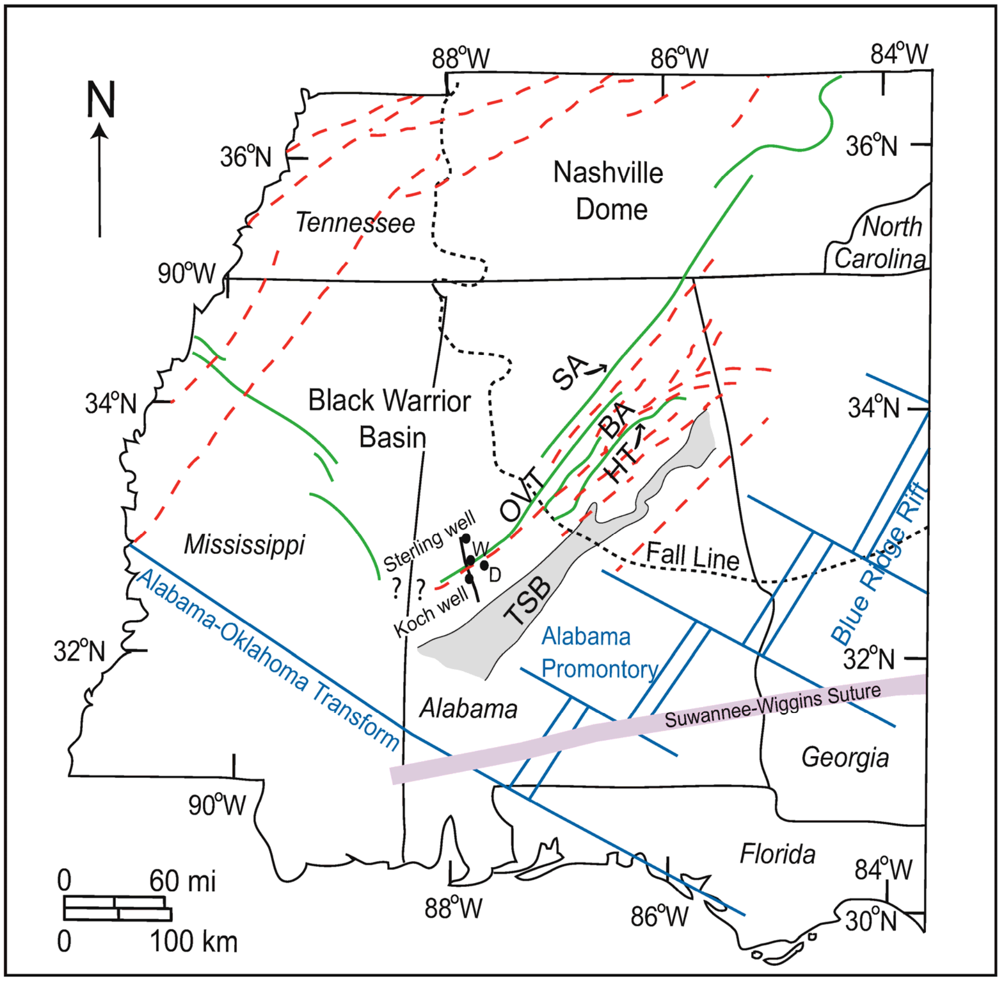

Figure 1. Map showing major tectonic features located in Alabama. Black line is the location of the seismic line. Green lines in the thrust belts mark major structures in the Alleghanian thrust belt in Alabama and the most foreland-ward structures in the Ouachita thrust belt in Mississippi. Wells are shown by the solid black circles, and are described in the text. Dashed black line marks the exposed angular unconformity between the Gulf coastal plain and older rocks (Fall Line). Red dashed lines are the location of the Birmingham graben in Alabama and the Mississippi graben in Mississippi and Tennessee. Blue lines delineate the Laurentian rift margin. Geographic location of the states traced from Thomas (1988) but modified to match the state outlines in Figure 6. Location of the Birmingham and Mississippi grabens, Alabama-Oklahoma transform, and Alabama Promontory traced from Thomas (2004). Location of the Suwannee-Wiggins suture traced from Thomas (2006). Abbreviations are as follows: SA, Sequatchie anticline; OVT, Opossum Valley thrust; BA, Birmingham anticline; HT, Helena thrust; TSB, Talladega slate belt; D, Dollarhide #1 well; and W, Willis #1 well. The OVT and TSB are extended under the Gulf coastal plain to illustrate the possible location of these features in the seismic lines.

12–56 Hz sweep, shot interval of 220 ft, common depth point (CDP) interval of 110 ft and a recording time of 5 s. The seismic reflection section trends nearly perpendicular to the strike of the Alleghanian thrust belt (Fig. 1). Two deep wells, the Ethel M. Koch #1 and James W. Sterling 17–14 (Fig. 2), were used to constrain seismic velocities and produce a synthetic seismogram (Fig. 3). The specific objectives of this study are to determine: (1) the architecture of the thrust belt under the Gulf coastal plain; (2) if the geometry of the thrust belt under the Gulf coastal plain is similar to the thrust belt at the surface in central Alabama; and (3) if any structural influence from the Ouachita thrust belt found in the Alleghanian thrust belt at this location.

TECTONIC HISTORY

Final assembly of the supercontinent Rodinia occurred at ~1 Ga (Hoffman, 1991). Breakup of Rodinia, opening of the Iapetus Ocean, and the formation of the Laurentian margin occurred from 570–535 Ma (Odom and Fullagar, 1984; Aleinikoff et al., 1995). Active transform faulting along the Alabama-Oklahoma transform (Fig. 1) persisted through Middle Cambrian time along part of the southern margin of the Alabama promontory and movement continued on extensional faults in the Birmingham graben and Mississippi Valley systems as recorded by Cambrian synrift deposits (Thomas, 1991).

A passive margin formed as recorded by the transition from clastic units deposited in Cambrian time to stable shelf carbonate ramp facies deposited in Cambrian-Ordovician time (Thomas, 1991; Thomas et al., 2000). Tectonic stability followed until Mississippian time (Pashin, 1993) when an arc-trench system obliquely collided with the southwestern side of the Alabama Promontory (Thomas, 1976; Viele and Thomas, 1989) and forced an accretionary prism onto the former transform margin. Along the eastern margin of Laurentia, a series of Paleozoic mountain-building events, the Middle Ordovician to Early Silurian Taconic, Devonian-Mississippian Neoacadian, and Pennsylvanian-

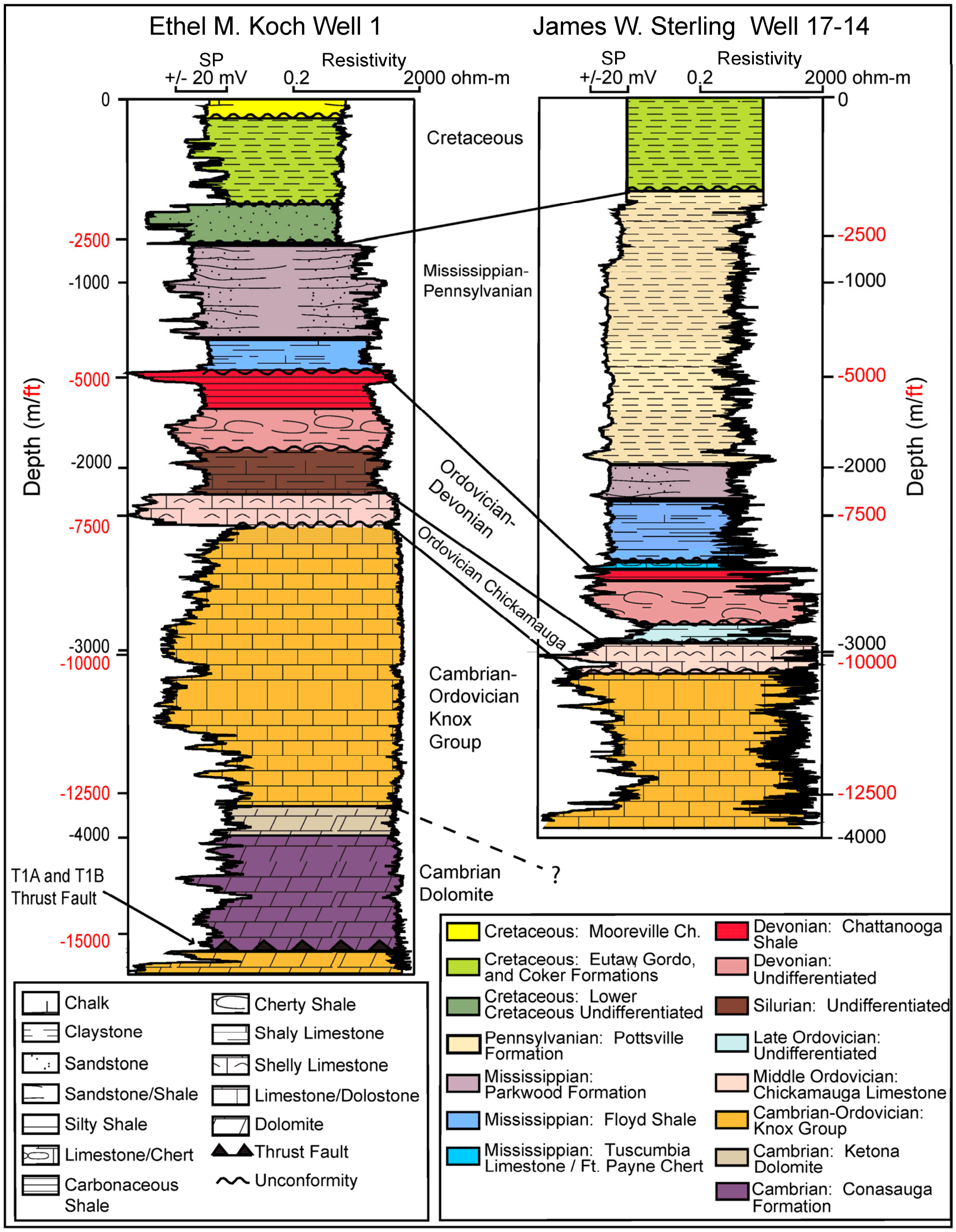

Figure 2. Correlation of the stratigraphy between the Ethel M. Koch Well #1 (Raymond, 1991), which penetrated the thrust belt stratigraphy, and James W. Sterling 17–14 wells (Permit 1810), which penetrated the foreland basin stratigraphy. Location of wells is shown in Figure 1. Seismic units used in this study are labeled between the wells.

Permian Alleghanian orogenies, marked the closure of the Iapetus Ocean and formation of Pangea (Hatcher, 2010). The Black Warrior basin (Fig. 1) is a Late Paleozoic foreland basin formed by tectonic loading during Appalachian-Ouachita orogenesis (e.g., Thomas, 1977)

In Alabama, the distal sediments of the Blount clastic wedge derived from the Taconic orogeny prograded westward during Middle Ordovician–Middle Silurian time over the carbonate facies of the Alabama Promontory (Thomas, 1977). Silurian through Mississippian aged deposits, overprinted by Devonian-Mississippian metamorphism in the Talladega slate belt (Gastaldo et al., 1993; McClellan et al., 2007), indicate that the Acadian orogeny began ~416 Ma. Influences of this orogeny may be locally present in transpressional basement structures along the southeastern side of the Alabama promontory (Ferrill and Thomas, 1988). However, no stratigraphic record of the Taconic or Acadian orogenies is recognizable west of the Alabama Promontory (Thomas, 1989). From Alabama to Virginia, amphibolite-facies metamorphism, polyphase deformation, and plutonism marked the beginning of the Pennsylvanian-Permian Alleghanian orogeny (Hatcher, 2010). This orogeny formed the structural architecture of the southern Appalachians and shed synorogenic sediment into the Black Warrior basin. Maximum subsidence rates in the Black Warrior basin occurred during

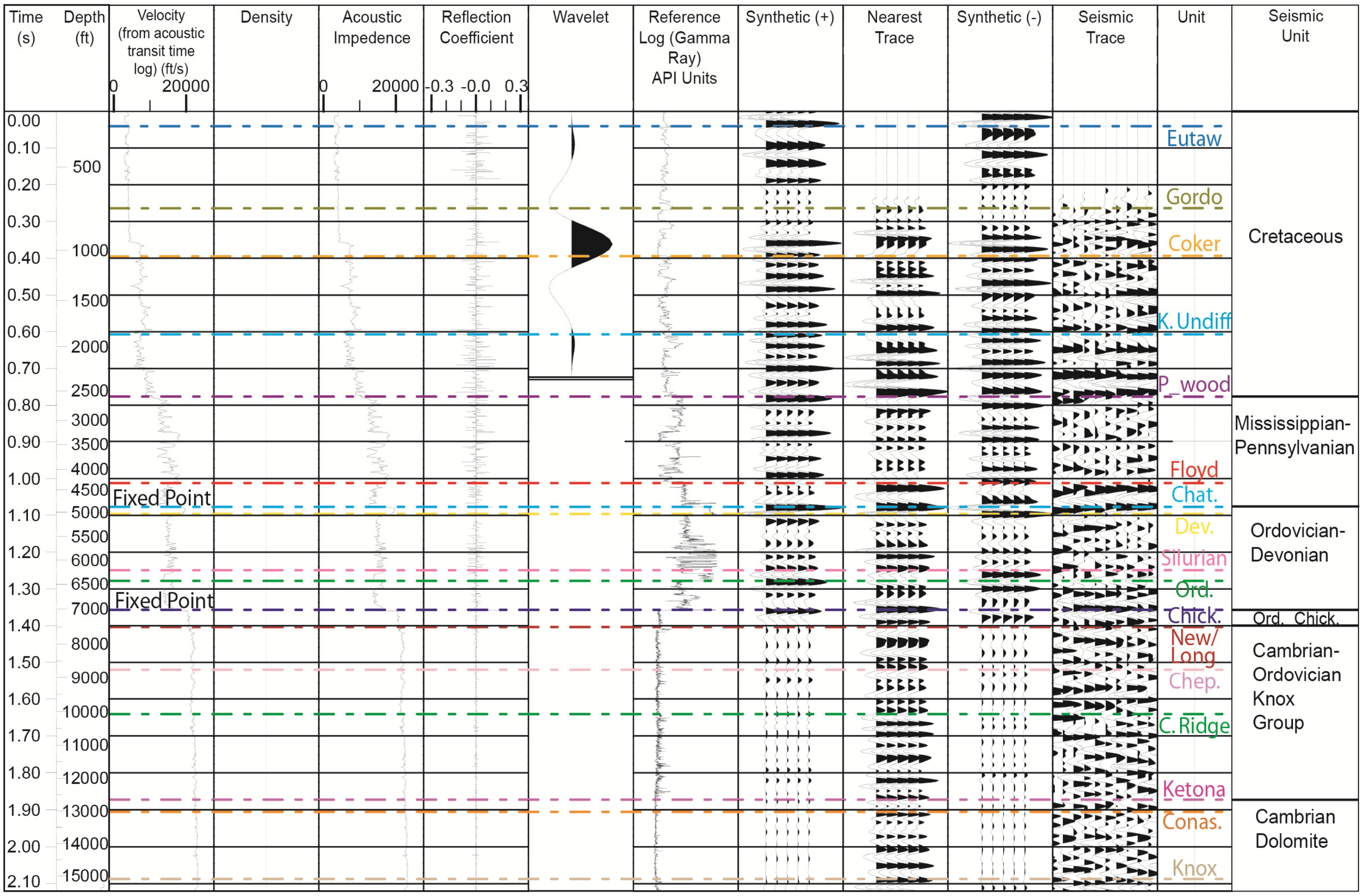

Figure 3. Synthetic seismogram created from the acoustic transit time curve for the Koch well. In the absence of a density log, density was set to unity in order to derive the reflection coefficient. The dashed colored lines are the picked tops for the units and formations identified in the Koch well (Raymond, 1991) (Fig. 2). The Chattanooga Shale and Chickamauga Limestone, identified in the well (Raymond, 1991) and by characteristic reflectors in the seismic reflection data, represent fixed points in the depth conversion, noted by "Fixed Point" on the figure. Abbreviations are as follows: K. Undiff – Cretaceous Undifferentiated; P_wood – Parkwood Formation; Chat. – Chattanooga Shale; Dev. – Devonian; Ord. – Ordovician; Chick. – Chickamauga Limestone; New/Long – Newalla Limestone/Longview Limestone; Chep. – Chepultepec Dolomite; C. Ridge – Copper Ridge Dolomite; and Conas. – Conasauga Dolomite.

Pennsylvanian time (e.g., Pashin, 2004). Synorogenic sediments were incorporated into thrust sheets of the Alleghanian thrust belt and translated to the northwest. Different interpretations of the thrust front at the convergence of the Appalachian and Ouachita orogens (question marks, Fig. 1) have been published (e.g., Coleman, 1988; Thomas, 1988, 2004; Hale-Erlich and Coleman, 1993; Groshong et al., 2009, 2010) but mainly without supporting seismic data. Small displacement normal faults affected the Black Warrior basin during Early Pennsylvanian time (Pashin, 1994, 1998; Groshong et al., 2010).

Opening of the Gulf of Mexico began ~215 Ma based on the northwest-trending system of normal faults that cuts Paleozoic aged rocks and signifies the transition to an extensional tectonic regime (Thomas, 1989) and deposition of syntectonic sediments into Triassic graben. In the Eastern Gulf of Mexico in offshore Florida, a well (GV 707) drilled one of these graben and penetrated Middle to Upper Triassic redbeds, volcanic rocks, and volcaniclastic rocks before hitting Paleozoic pre-rift sedimentary rocks (Dobson and Buffler, 1991; Bartok, 1993). Deposition and lithification of the Gulf coastal plain occurred from Cretaceous time to the present and buried the Appalachian Mountains (Fig. 1).

STRATIGRAPHY

Stratigraphic descriptions and thicknesses are from two wells along the seismic profile. The Ethel M. Koch #1 (Koch well) was drilled and logged to a depth of 15,500 ft and is used to describe thrust belt stratigraphy (Raymond, 1991) (Fig. 2). The James W. Sterling 17–14 (Sterling well) was drilled and logged to a depth of 12,850 ft and is used to describe the Black Warrior basin stratigraphy (State Oil and Gas Board, 1973) (Fig. 2). These well logs were then correlated to the seismic and divided into 8 units (Figs. 2 and 3). Figure 1 shows two other wells, Dollarhide #1 (D) and Willis #1 (W), used to constrain the shallow stratigraphy.

The Precambrian basement is composed of igneous and metamorphic rocks that range in age from 750 Ma to 1 Ga (Neathery and Copeland, 1983). Depths to basement range from 7800 ft on the Appalachian Plateau to 17,000 ft in the Valley and Ridge Province. Seismic studies along strike in the Appalachian thrust belt illustrate a general increase in depth to basement from 6500 ft in northeast Alabama to 21,000 ft in central Alabama (Thomas, 2004). A Cambrian Clastic unit nonconformably overlies the basement rock and consists of the Early Cambrian Rome

Formation, 295–1000 ft thick (Ferrill, 1989), and the lower part of the Cambrian Conasauga Formation, ~650–1000 ft thick (Neathery and Copeland, 1983). Normal faulting and growth sedimentation in the Cambrian and older (?) units are apparent (Nance and Linnemann, 2008). The Cambrian Dolomite unit includes the dolomite part of the Conasauga Formation and Ketona Dolomite with a thickness of ~1300 to 2000 ft (Raymond, 1991). In the Koch well, a thrust fault places the base of the Conasauga unit over the younger Cambrian-Ordovician Knox Group at 15,098 ft (Raymond, 1991) (Fig. 2). The Knox Group is ~5000 ft thick and includes the Copper Ridge Dolomite, Chepultepec Dolomite, Longview Limestone, and Newalla Limestone (Fig. 2). Rheologically, this unit is stiff and controls the structural architecture of the thrust belt (Thomas, 1989). The Ordovician Chickamauga Limestone unit ranges in thickness from ~250 –900 ft (Benson, 1986). In the Koch well, the thickness is 479 ft (Raymond, 1991). Above the Chickamauga Limestone, the Ordovician, Silurian, and Devonian rocks are grouped into the Ordovician-Devonian unit. In the Koch well, the lower part of the unit consists of 590 ft of Ordovician shale and limestone followed by 230 ft of Silurian shale (Raymond, 1991). The Devonian strata have a ~650–1300 ft thick carbonate unit on bottom followed by ~100 ft thick Chattanooga Shale on top. In this unit, the basal reflector is the top of the Chickamauga Limestone and the top reflector is the Chattanooga Shale (Fig. 3).

Five units are included in the Mississippian–Pennsylvanian interval: Fort Payne Formation (chert), Tuscumbia Formation (limestone), Floyd Shale, Parkwood Formation (shale, sandstone, limestone), and Pottsville Formation (sandstone). The Mississippian system is ~2300–3000 ft thick (Raymond, 1991). The Pennsylvanian system contains only the Pottsville Formation, and is ~4800 ft thick in Sterling well in the Black Warrior basin but pinches out to the southeast toward the thrust belt and is not present in the Koch well (Fig. 2). The Pennsylvanian system was formed as synorogenic clastic sediments shed off of the growing mountains in the Alleghanian orogeny (e.g., Pashin, 2004). The basal reflector of this unit is the top of the Chattanooga Shale, and the top reflector is the base of the Cretaceous unit. The Cretaceous unit is part of the Gulf coastal plain sedimentary wedge, and includes the Tuscaloosa Group, Eutaw Formation, and Selma Group with a total thickness of ~1600–2500 ft.

STRUCTURE

The Alleghanian thrust belt of the southern Appalachian Mountains is characterized by large-scale, internally coherent thrust sheets detached near the base of the Paleozoic sedimentary sequence (Thomas, 1985b). The geometry of the thrust sheets is controlled by the competent Knox Group (Thomas, 1989). The basal décollement originates in a shale in the Cambrian Clastic unit (Rodgers, 1950) and cuts up stratigraphic section toward the foreland to form thrust faults (Thomas and Osborne, 1995). Locally, upper-level detachments in Silurian and younger strata exist (Thomas and Osborne, 1995; Pashin and Groshong, 1998; Maher, 2002; Groshong et al., 2010).

The top of the Precambrian basement dips southwestward at 1–2° (Thomas, 1989). Beneath the thrust belt in the Birmingham graben (Fig. 1), normal faults with more than 6500 ft of vertical displacement locally offset the basement. Basement faults commonly cause thrusts to ramp upsection (Maher, 2002; Thomas and Bayona, 2005); however, Robinson et al. (2009) showed that thrusts also cut up stratigraphic section as a result of topographic highs in the basement. In central Alabama, the Sequatchie anticline (SA, Fig. 1) plunges southwestward and does not have a surface expression where the trend of the SA ends (Fig. 1). The Birmingham anticline (BA, Fig. 1) and the Helena thrust fault (HT, Fig. 1) trend northeast-southwest, and are covered by the Gulf coastal plain sedimentary rock (Fall Line, Fig. 1). The Talladega slate belt (TSB, Fig. 1) contains greenschist facies metasedimentary and metavolcanic rocks (Gastaldo et al., 1993). The Blue Ridge thrust system placed metamorphosed Cambrian to early Mississippian-aged TSB rocks over the Cambrian to Mississippian-aged Alleghanian thrust belt rocks (Gastaldo et al., 1993).

METHODS

Seismic Line

The 41-mi seismic reflection profile was donated by VASTAR Resources Incorporated and includes two separate line segments: 691–1 (11 mi) and 691–1A (30 mi). The common midpoints (CMP) were projected onto a straight line 34.2 mi in length in order to remove variations in structural dip due to variations in line azimuth.

A reflection coefficient series was generated for the Koch well using the acoustic transit time log (Fig. 3). In the absence of a density log, density was set to unity. The reflectivity series was convolved with a zero phase wavelet derived from line 691–1A to create a synthetic seismogram (e.g., Kearey et al., 2002). Synthetic data were matched to the seismic reflection data based on two prominent reflectors that could be correlated to known depths in the well (Koch well log and cutting data; Raymond, 1991). These two horizons (Chattanooga Shale, 2575 ft; Chickamauga Limestone, 7021 ft) were used as fixed points on the synthetic seismogram. In addition to the two known reflectors, well log interpretations of the Koch well (Raymond, 1991) placed a fault in the Cambrian Dolomite unit, specifically at the base of the Conasauga Formation (15,098 ft) over the Cambrian-Ordovician Knox Group (labeled T1A and T1B on Figure 2). Preliminary interpretations of the time section also placed a thrust fault ramp at the same two-way travel time, which ensured that the synthetic was tied correctly to the seismic traces.

The tie between the synthetic seismic and 2D seismic reflection data defines a time-depth relationship for the Koch well. Using this relationship, the seismic reflection data were converted to depth (see Figure 4, uninterpreted seismic data). Eight reflector-bounded seismic stratigraphic units were picked. P-wave velocities for the units are as follows: Cretaceous unit, 6644 ft/s; Mississippian-Pennsylvanian unit, 14,951 ft/s; Ordovician-Devonian unit, 15,607 ft/s; Ordovician Chickamauga Limestone unit, 20,564 ft/s; Cambrian-Ordovician Knox Group, 21,991 ft/s; Cambrian dolomite unit, 22,949 ft/s; Cambrian clastic unit, 19,514 ft/s (Pearce, 2002); and basement, 23,622 ft/s. An initial interpretation of the line was completed using the data from the preliminary depth conversion. The interpretation and depth conversion were refined until a balanced cross section could be produced. In order to show alternative interpretations, two structural interpretations were made for the seismic reflection profile (Figs. 5 and 6).

Cross Sections

The Koch well is 0.3 mi to the west of the seismic line, and the Sterling well is ~2.8 mi to the east of the seismic line (Fig. 1). Thicknesses are known in the Koch and Sterling well because of the logs and cuttings collected when drilled (Raymond, 1991; State Oil and Gas Board, 1973) (Fig. 2). Both wells were projected into the seismic line and used to identify unit-bounding

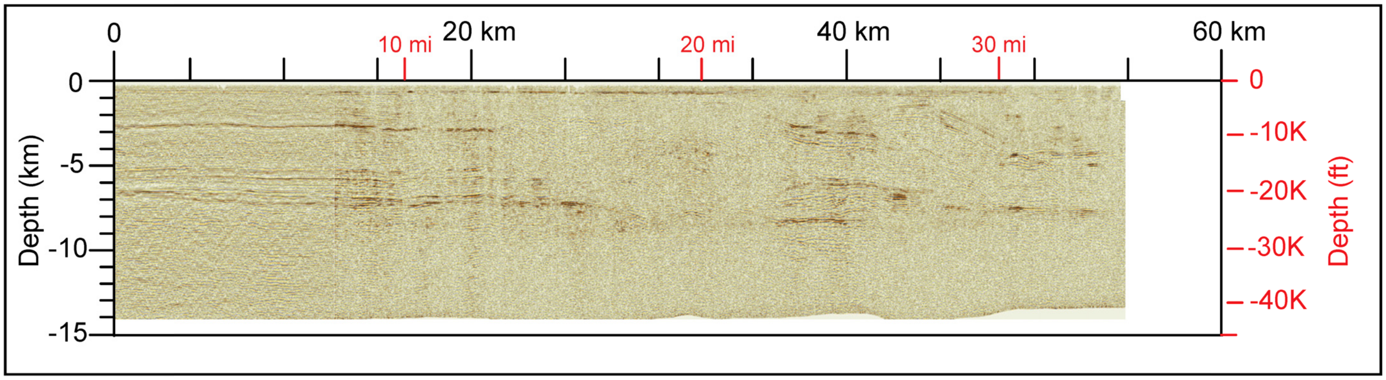

Figure 4. Uninterpreted seismic line for Figures 5A and 6A.

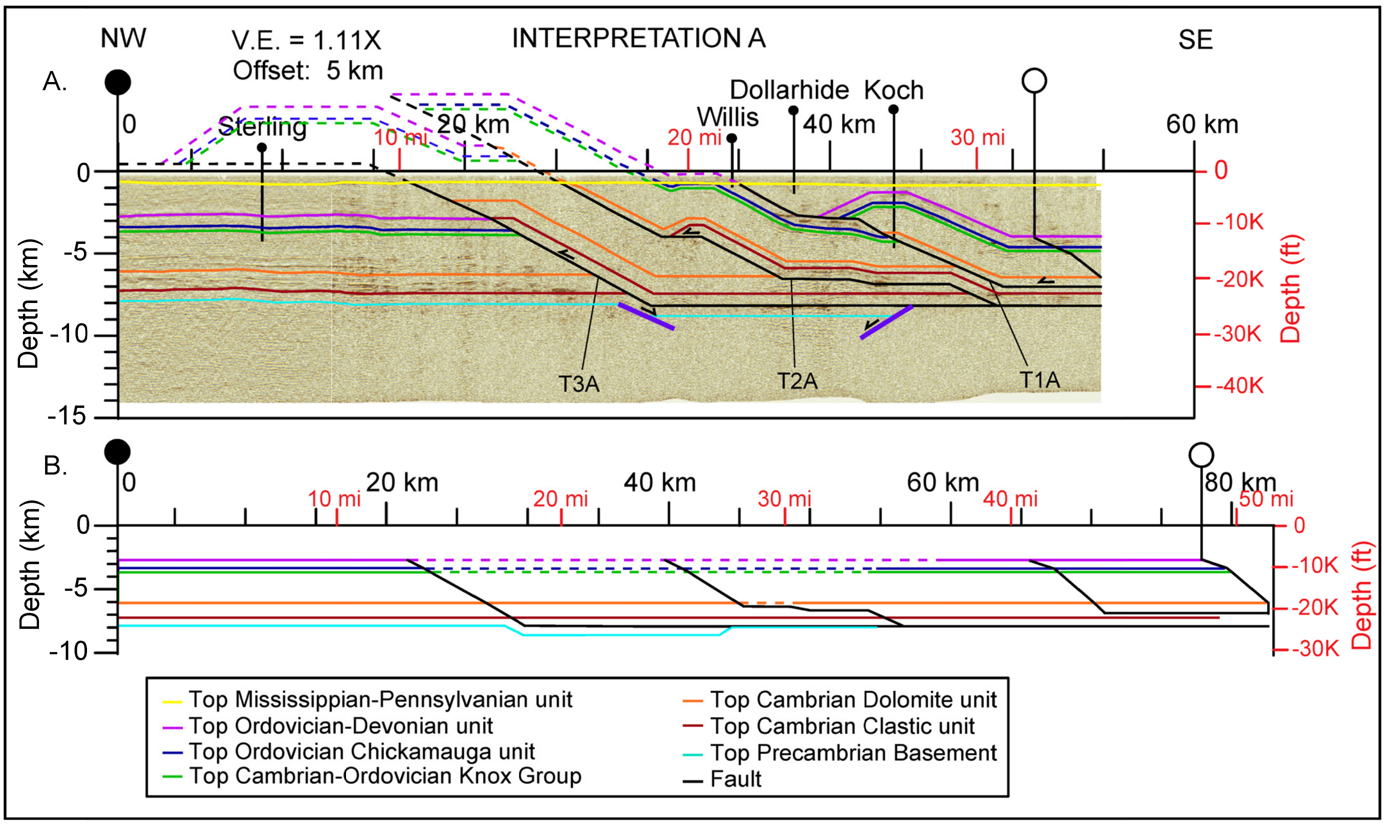

Figure 5. A. Interpreted seismic line and balanced cross section for interpretation A. Colored lines indicate the top of each of the units. Thrust faults are marked as T1A, T2A, and T3A. Fixed pin line is marked with a solid large circle. Loose pin line is an open circle. Wells are marked with small solid circles. Depth in feet is marked in thousands (K). B. Restored cross section derived from Figure 5A. Note the restoration is at a different scale than the balanced cross section.

reflectors. The Koch well defines the depth and thickness of the seismically defined units and the thrust fault (Fig. 1) in the thrust belt. The Sterling well defines the depth and thickness of the seismically defined units in the Black Warrior basin (Fig. 1). Dipping reflectors indicated the location of footwall and hanging wall ramps. Basement normal faults were interpreted from the seismic section. A fixed pin line was established in the undeformed foreland rock. Cross sections were interpreted and balanced using the sinuous bed method (Dahlstrom, 1969) in which lengths of the top and bottom of each formation between faults were drawn on the restored section. Two separate structural interpretations (cross sections) were made and balanced because a zone of poor imaging above thrust T3 between 13.5 and 22 mi made interpretations ambiguous (Figs. 5A and 6A). In interpretation A, a loose line, which is a marker line perpendicular to strata, was placed at the southeastern end of the line, allowing the lengths of the units in that thrust sheet to be maintained.

INTERPRETATIONS

Interpretation A

Interpretation A (Fig. 5A) illustrates an in-sequence, forward-propagating thrust belt with an upper detachment, lower décollement, and 3 thrust faults. The thrust sheet carried by thrust 1 (T1A) contains the Cambrian dolomite through Ordovi-

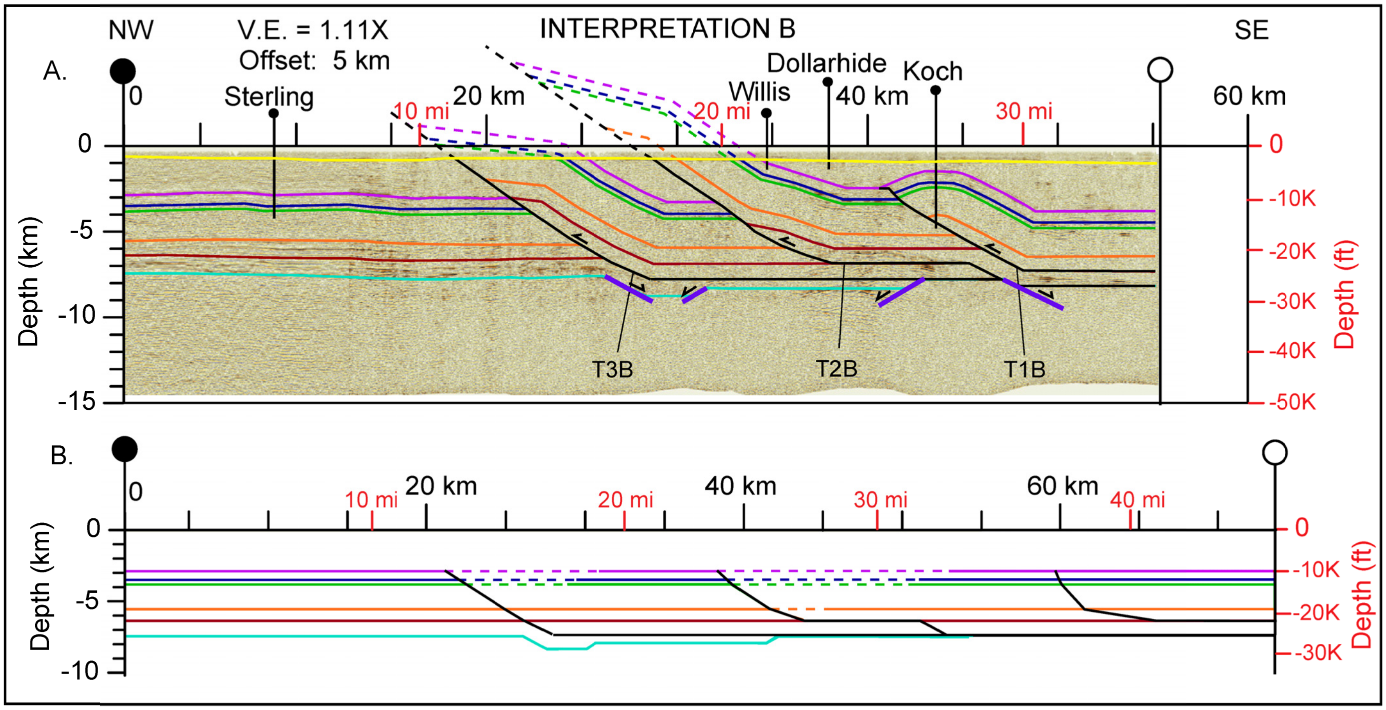

Figure 6. A. Interpreted seismic line and balanced cross section for interpretation B. Colored lines indicate the top of each of the units and are the same as in Figure 5. Thrust faults are marked as T1B, T2B, and T3B. Fixed pin line is marked with a solid large circle. Wells are marked with small solid circles. Depth in feet is marked in thousands (K). B. Restored cross section derived from Figure 6A. Note the restoration is at a different scale than the balanced cross section.

cian-Devonian units. T1A rides on an upper level detachment, ramps at 25°, and produces a fault-bend fold. T1A is the same fault found in the Koch well that places the Cambrian dolomite unit over the Knox Group. The thrust sheet carried by thrust 2 (T2A) contains the Cambrian clastic through Ordovician-Devonian units, ramps from a lower detachment at the base of the clastic unit and consists of three footwall ramps with matching hanging walls ramps. T2A is interpreted from dipping reflectors and cuts through the Cambrian Dolomite unit; thus, hanging wall and footwall cutoffs match. In T2A, the Knox Group thickens to the northwest to accommodate thickness differences found in the ramp anticline in comparison to the thickness in the foreland basin. The thrust sheet carried by thrust 3 (T3A) incorporates the Cambrian Clastic unit and lowest 1640 ft (500 m) of the Knox Group. T3A detaches between the Cambrian Clastic unit and basement or within the Cambrian clastic unit and is the frontal thrust ramp of the thrust belt. The overlying stratigraphy is interpreted to exist above the erosional surface (see dashed lines of Knox Group–Ordovician-Devonian unit) and have been transported over the Black Warrior basin because the length was needed to restore the unit correctly (Fig. 5B). As these rocks came through the erosional window, they were eroded and shed into the Black Warrior basin. Length of eroded units is quantitative but the positions of needed hanging wall strata are speculative.

Interpretation B

Interpretation B (Fig. 6A) also illustrates an in-sequence forward-propagating thrust belt with an upper detachment, a lower décollement, and three thrust faults. The thrust sheet carried by thrust 1 (T1B) is the same as T1A except the hanging wall fold that forms is a fault propagation fold. The location of the fault is constrained by the Koch well. T1B has a steeper angle near the tip (~50°) and offset of the strata goes to zero. The thrust sheet carried by thrust 2 (T2B) includes the Cambrian clastic through Ordovician-Devonian units and ramps from lower level detachment between the clastic unit and basement. T2B has two footwall ramps—one at 20° at the base of the section and one farther up section at 36°. The eroded stratigraphy is projected above the erosional surface and is the minimum needed to balance the cross section. The thrust sheet carried by thrust 3 (T3B) includes the Cambrian clastic through Ordovician-Devonian units. T3B is the frontal ramp of the thrust belt and ramps at 35°. Similarly, eroded units are extrapolated above the erosional surface and are the minimum lengths needed to line length balance the cross section (Fig. 6B). These strata were eroded as the rocks passed through the erosional window and were deposited in Black Warrior basin.

DISCUSSION

Differences in Interpretations

In interpretation A (Fig. 5A), thrust T1A has an upper detachment located 980 ft above the Cambrian clastic unit within the Cambrian dolomite unit. In interpretation B (Fig. 6A), thrust T1B has an upper detachment at the base of the Cambrian dolomite unit; thus, a full thickness of the Cambrian dolomite unit must be incorporated into the thrust sheet carried by thrust T2B. Units carried by thrust T1A (interpretation A) are ~2000 ft deeper than units carried by thrust T2B (interpretation B) stemming from the needed depth of the Cambrian clastic unit next to a basement normal fault. The units in thrust T1A are pinned with a loose pin line near 32 mi so that the cross section will balance. Because the seismic profile only represents part of the thrust belt, the loose pin line is justified. Thrust T1A is interpreted to have a fault bend fold in the hanging wall; whereas, the same fault in thrust T1B is interpreted to have a fault propagation fold in the hanging wall. The top of the fold is beveled by an erosional surface and covered by the Cretaceous unit. Thrust T2A has 3 ramps and flats that match dipping reflectors. Thrust T2B has 2 ramps and flats with less attention to reflectors which allows for simplification of the structural architecture. The thrust sheet that is carried by thrust T3A contains the Cambrian clastic unit through the lowest 1600 ft of the Knox Group; whereas, the thrust sheet that is carried by thrust T3B contains the Cambrian clastic through Ordovician-Devonian units.

In the Black Warrior basin, the Sterling well drilled through the foreland basin stratigraphy down into the top 2500 ft of Knox Group; thus, the bases of the Cambrian clastic unit, Cambrian dolomite unit, and Knox Group are not penetrated by this well. Depth of the seismic units is determined by keeping the units at the regional base level.

The two interpretations differ in the thicknesses assigned to the seismic units. In interpretation B, all seismic units maintain the same thickness from foreland to hinterland. The top of Cambrian dolomite unit is placed at ~17,000 ft where there is a marked change in the amplitude of the seismic reflectors. To keep the rocks at the regional level in interpretation A, the top of the Cambrian dolomite unit was shifted down 2600 ft, which also shifted the top of the Cambrian clastic unit and basement down 2600 ft. The northernmost basement fault displaces the top of basement roughly 5900 ft to the southeast and is filled by the syntectonic Cambrian clastic unit. If the basement faults occurred at the same time that thrust T1A formed, then the difference in the regional level is not an issue. In order for the reconstruction to work properly, the southernmost basement fault in interpretation B has to be synkinematic; however, this is not a problem in interpretation A.

Thomas and Bayona (2005) interpreted poorly imaged zones ~60 mi toward the northeast in the Alleghanian thrust belt of central Alabama as a “mushwad,” which they define as a tectonically thickened and ductilely deformed mass with no discernible reflectors. We call this a ductile duplex. In the Thomas and Bayona (2005) interpretation, the ductile duplex is found in the core of detachment folds where the stiff layers are broken and uplifted by the tectonically thickened ductile core. Throughout the seismic line in this study, even in the poorly imaged areas, horizontal and dipping reflectors indicate coherency and thus do not support the formation of a ductile duplex. Thomas and Bayona (2005) inferred a syncline in the footwall of the frontal ramps because the reflectors were discordant. Our data lack these discordant reflectors; thus, the footwall synclines are not present to the southwest in the thrust belt. The depth to the crystalline basement ranges from ~26,000 ft in interpretation A to ~23,500 ft in interpretation B. These values are deeper than the 21,300 ft suggested in Thomas (2004) in cross sections to the northeast. However, our depth to basement adheres to the suggestion that the basement should be deeper toward the southwest in Alabama (Thomas, 1988).

Reconstructions

Figures 5A and 6A show balanced cross sections for interpretations A and B, respectively. Figure 5B is the reconstruction to flat lying stratigraphy for Figure 5A, while Figure 6B is the reconstruction to flat lying stratigraphy for Figure 6A. In both interpretations, the Cambrian dolomite unit is the reference horizon because it does not contain eroded sections. A fixed pin line was placed to the northwest in the Black Warrior basin in the foreland and units were restored back toward the southeast. A loose line was placed in the hanging wall anticline because of the inability to correlate reflectors through the missing data section. Interpretation A has 14.3 mi of minimum shortening or 33%. Interpretation B has 11.8 mi of minimum shortening or 26%.

Other estimates of shortening for other parts of the Appalachian Mountains include: (1) Kaygi et al. (1983), Valley and Ridge Province, Alabama, 40–50%; (2) Harris et al. (1997), Great Valley, Blue Ridge and Piedmont Provinces, central Virginia, 20–30%; (3) Pearce (2002), east-central Alabama from the Talladega slate belt to the Black Warrior basin, ~30%; and (4) Whisner et al. (2004), Cumberland Plateau to the western Blue Ridge from Tennessee salient in northwest Georgia to southwest Virginia, 60%. Estimates from nearby cross sections in central Alabama from Thomas and Bayona (2005) from the Talladega slate belt to the Black Warrior basin indicated ~29% shortening (#17) and ~42% shortening (#18). In comparison, our estimates are similar to that of Pearce (2002) and are near the lower estimates of Thomas and Bayona (2005).

Interaction between the Alleghanian and Ouachita Thrust Belts

Because this cross section is located near the bend in the trend of the Alleghanian and Ouachita thrust belts, one might expect to see structures in the cross section that would not balance if produced by oppositely trending thrust belts. However, the thrust system appears continuous and balances. This suggests that at this location, the rocks do not display any structural influence from the bend before changing to the northwest-southeast trend of the Ouachita thrust belt. In fact, the southern extension of the Opossum Valley thrust (OVT, Fig. 1) coincides with the frontal thrust interpreted on the seismic lines presented (T3A or T3B). The other thrusts in the cross sections (T1A or T1B, and T2A or T2B) may be the southern extensions of the Birmingham Anticline (BA), which is in the hanging wall block of the Jones Valley thrust (Hnat et al., 2008), and the Helena thrust (HT). These data suggest that the Alleghanian thrust belt does not curve and merge with the Ouachita thrust belt but continues along a northeast-southwest trend into the subsurface where it is buried by the coastal plain sedimentary rock.

Figure 7 shows maps of the free air gravity anomaly (Fig. 7A), magnetic anomaly (Fig. 7B) topography (Fig. 7C) and the surface and buried structures (Fig. 7D) for the southern Appalachian Mountains and Gulf Coast region. The free air gravity and magnetic maps highlight the basement structure under the coastal plain sedimentary rock. Key features in the gravity and magnetic anomaly maps include the southwest-trending Alleghanian thrust belt and the Suwannee-Wiggins suture (distinct west-southwest trending magnetic low in southern Alabama) beneath the coastal plain. This suture delineates the North American continent, the Laurentian margin, from the continental crust with African origin, the peri-Gondwana Uchee terrane (Steltenpohl et al. 2010) (Fig. 1). The Alleghanian thrust belt, seen clearly in the topography (Fig. 7C), can be traced to the southwest beneath coastal plain and is interpreted to continue along the southwest trend until the Suwannee-Wiggins suture is encountered (Thomas, 2006) (Fig. 1). This interpretation is consistent the lack of evidence for interference structures in the balanced cross sections presented herein and suggests that the trend of the Appalachian Mountains continues to the southwest instead of curving toward the Ouachita Mountains.

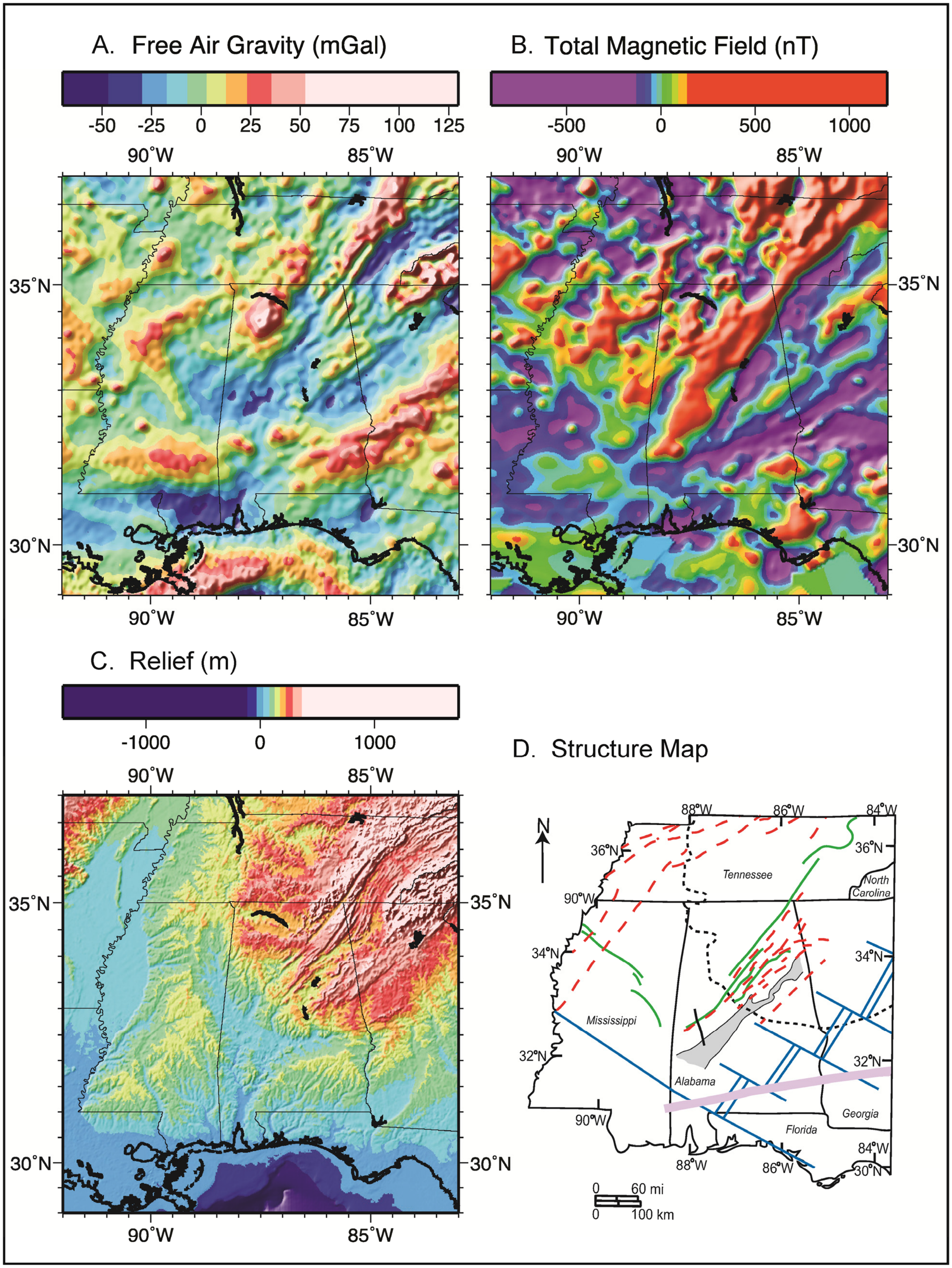

Figure 7. A. Free air gravity map (Sandwell and Smith, 2009). Hot colors (gravity highs) indicate surface/basement highs. Cool colors (gravity lows) are indicative of lows in the surface/basement. B. Magnetic map (Maus et al., 2002). Magnetic highs (hot colors) and lows (cool colors) delineate basement structure. The N15E-trending Suwanee-Wiggins suture is the prominent linear low in southern Alabama. C. Topography and bathymetry (Smith and Sandwell, 1997) shows the surface expression of the Appalachians, the coastal plain, and the Gulf of Mexico in the south. High elevations are shown by hot colors. Deep bathymetry is shown by cool colors. D. Structure map simplified from Figure 1 for comparison with Figures 7A–7C.

CONCLUSIONS

The seismic line presented in this study is located near the transition from the Alleghanian thrust belt to the east to the Ouachita thrust belt to the west. coastal plain sedimentary rock covers the region; thus, direct observation of possible interaction between the two thrust belts is not possible. However, the seismic sections and interpreted cross sections provide unparalleled insight into the geometry of the subsurface Alleghanian thrust belt. The thrust belt is a forward propagating, hinterland dipping thrust system with thrust sheets that vary from 5–17 mi in length and with thicknesses of 11,000–14,500 ft. Long thrust flats with ramps producing hanging wall anticlines suggest that the buried thrust belt is similar in appearance to the Alleghanian thrust belt exposed at the surface; however, the fault geometry is complicated with multiple matching ramps and flats. Depth to basement ranges from ~26,000 ft in interpretation A to ~23,500 ft in interpretation B. Estimates of minimum shortening are 14.3 mi or 33% in interpretation A and 11.8 mi or 26% in interpretation B. These values are similar to other estimates of minimum shortening in Alabama. Instead of interpreting a ductile duplex in the thrust belt as seen in central Alabama, we suggest that at this location in west-central Alabama, the units are coherent and can be balanced in a cross section. The structural data do not show interference structures that one might expect at the Alleghanian/Ouachita thrust belt junction and the cross sections balance. Magnetic and gravity data also indicate that the Alleghanian thrust belt continues to the southwest along a similar strike toward the Suwanee-Wiggins suture and does not curve westward to merge with the Ouachita thrust belt.

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