EAST TENNESSEE GEOLOGICAL SOCIETY

Field Trip Guide

Folds in the Ft. Payne Formation near Celina, Tennessee: Tectonic or Non-Tectonic Origin?

October 13, 2018

Field Trip Leader:

Bob Hatcher

UT Distinguished Scientist
& Professor Emeritus

Elizabeth Phillips, ETGS President
J. Brad Stephenson, ETGS Secretary
Seaira Stephenson, ETGS Treasurer
Bob Gelinas, ETGS Webmaster

Acknowledgments

The magnificent exposures near Celina, Tennessee, were first shown to RDH by Francis (Fitz) Fitzgerald and Gene Lockyear in December, 2012, during a reconnaissance of the Ft. Payne Formation in the northern Highland Rim in Tennessee and nearby Kentucky. Phillip M. Derryberry had previously provided RDH with a photo of part of Stop 2 that contains some of the intriguing features exposed there. The outstanding GIS skills of cartographer Andrew L. Wunderlich produced the location maps in this guidebook.

Introduction

Folds are geologic features of great variety that are formed under a variety of temperatures and pressures, ranging from the near-surface—or even the Earth's surface—to the depths of the lower crust and mantle. They are commonly assumed to have a tectonic origin, but there are clear exceptions. The purpose of this East Tennessee Geological Society field trip is to examine several new exposures of fresh Ft. Payne Formation near Celina, Tennessee, which expose sections of the lower part of the unit at about the same stratigraphic level <10 m above the underlying Chattanooga Shale (Fig. 1). These roadcuts are interesting and yet contrasting, because of the nature of the rocks and their depositional environments, and how deposition managed to produce a suite of folds that initially suggest they had a tectonic origin (Fig. 2). When we look at structure contours of the base of the Chattanooga Shale, we find that this surface is folded to an amplitude that it is difficult to explain the origin of these folds as a product of deposition on an irregular surface (Fig. 3). Some of these folds have amplitudes of 25 m. The Ft. Payne, however, is said to be the most complex rock unit in Tennessee, with widely varying facies, and some facies, like the bryozoan-dominated reefs that have produced major amounts of oil, are not exposed at the surface (e.g., Scruggs, 2015).

We will depart Knoxville on Saturday morning via I-40 and drive to the area northwest of Livingston and southeast of Celina, TN, to examine at the well-exposed section of lower Ft. Payne that contains many interesting stratigraphic features, including many supratenuous folds. The way these structures first appeared at Stop 1 is as dipping beds below horizontal beds—intraformational unconformities: diastems—in the Ft. Payne exposed in the new roadcuts, and then we saw the supratenuous folds developed above these dipping beds (Fig. 4). Dip of bedding below the diastem at Stop 1B ranges from less than 10 degrees to between 10 and 15 degrees (Fig. 5 Stop 1).

Regional and Local Geology

The Celina, Tennessee, area is located on the eastern Highland Rim in primarily Mississippian rocks (Hardeman, 1966). The geology of this area has been mapped in detail and published in several 7.5-minute quadrangles by the Tennessee Geological Survey. The

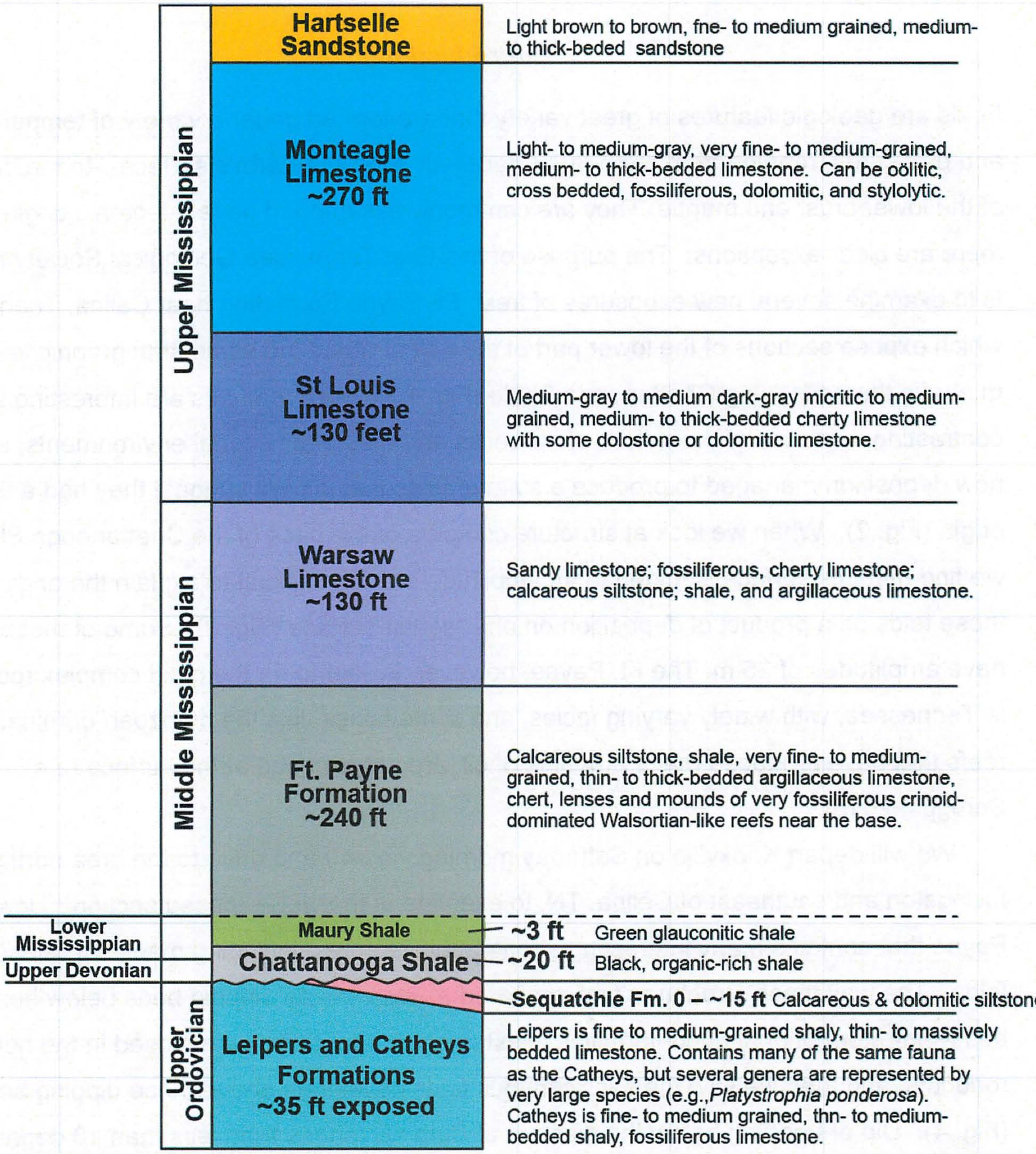


Figure 1. Stratigraphic column for the area around Celina, Tennessee. Thicknesses and rock descriptions modified from Wilson (1987) and Wilson et al. (1987).

Burristown (Wilson, 1989), Celina (Wilson, 1987), Dale Hollow Dam (Wilson et al., 1981), and Hilham (Wilson and Colvin, 1968) quadrangles depict the distribution of rock units in this area. Rocks in this area range from the Upper Ordovician Leipers and Catheys

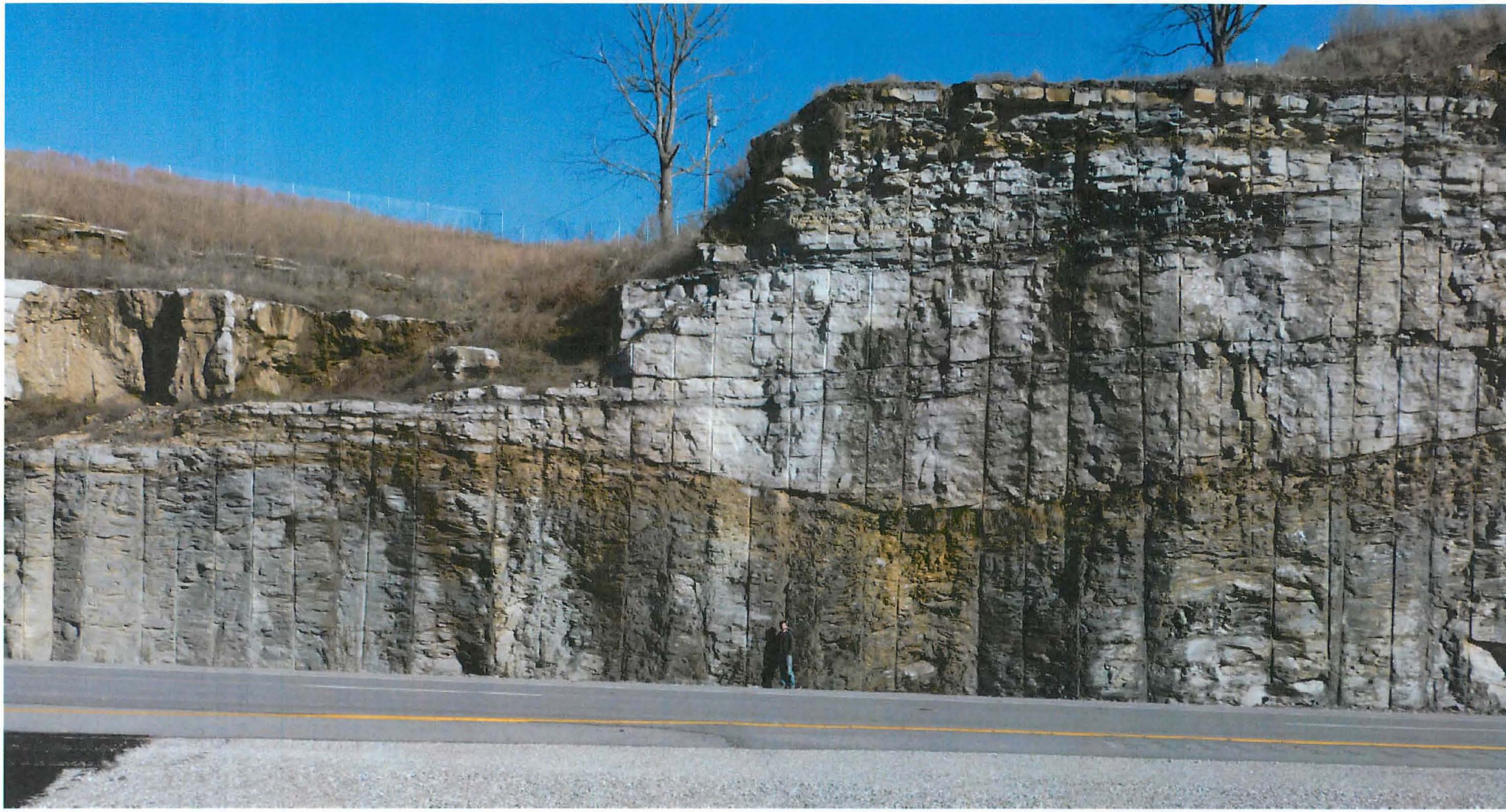


Figure 2. supratenuous anticlines and syncline at Stop 1A southeast of Celina, Tennessee. Note person near center of photo for scale.

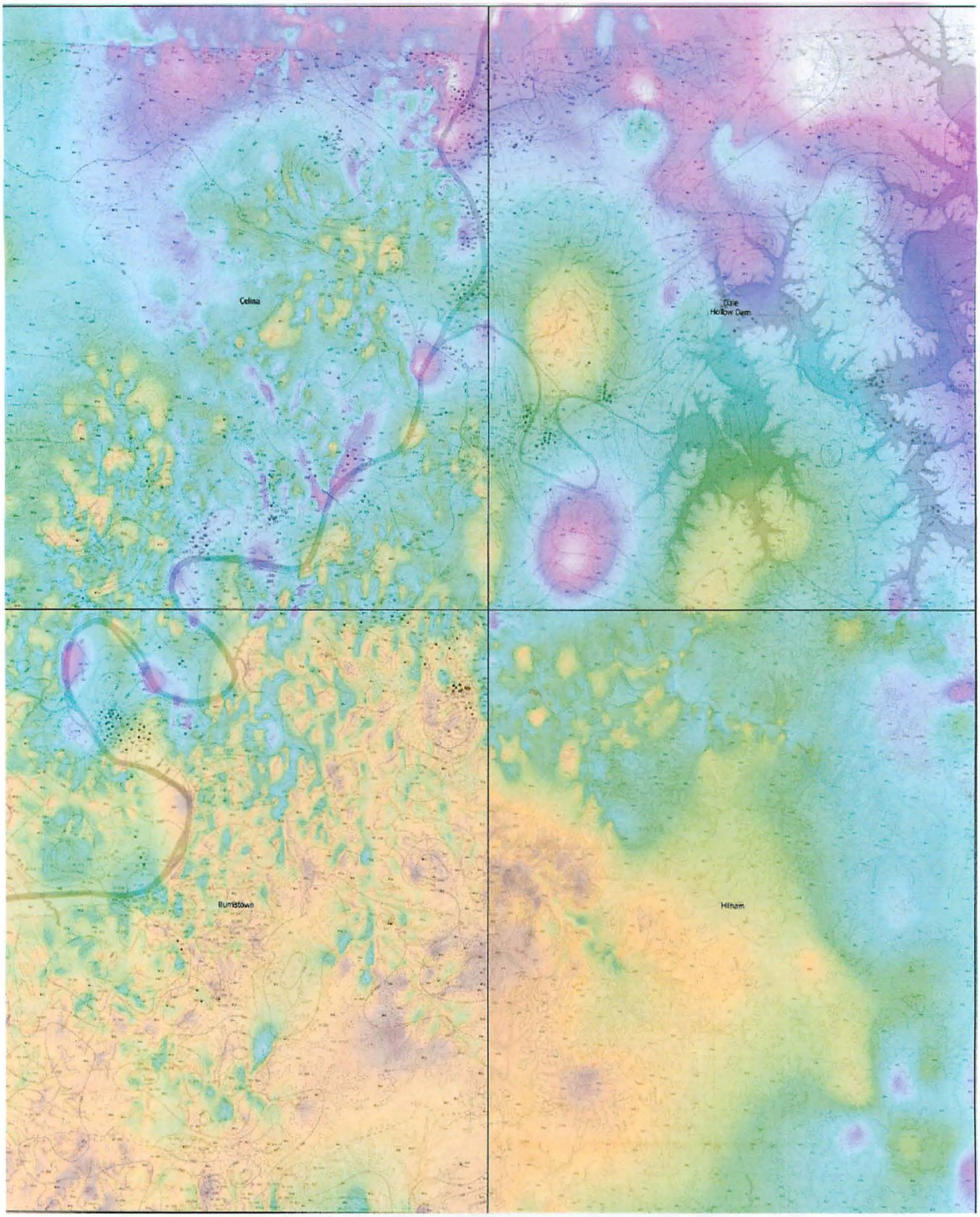


Figure 3. Structure contours (in color) on the top of the Chattanooga Shale in four 7.5-minute quadrangles in the Celina, Tennessee area. The structure contours in the top two quadrangles were published with the geologic quadrangles. Colored structure maps were generated in ArcGIS by Ken Boling (UTK Ph.D. student) based on both surface and subsurface data.

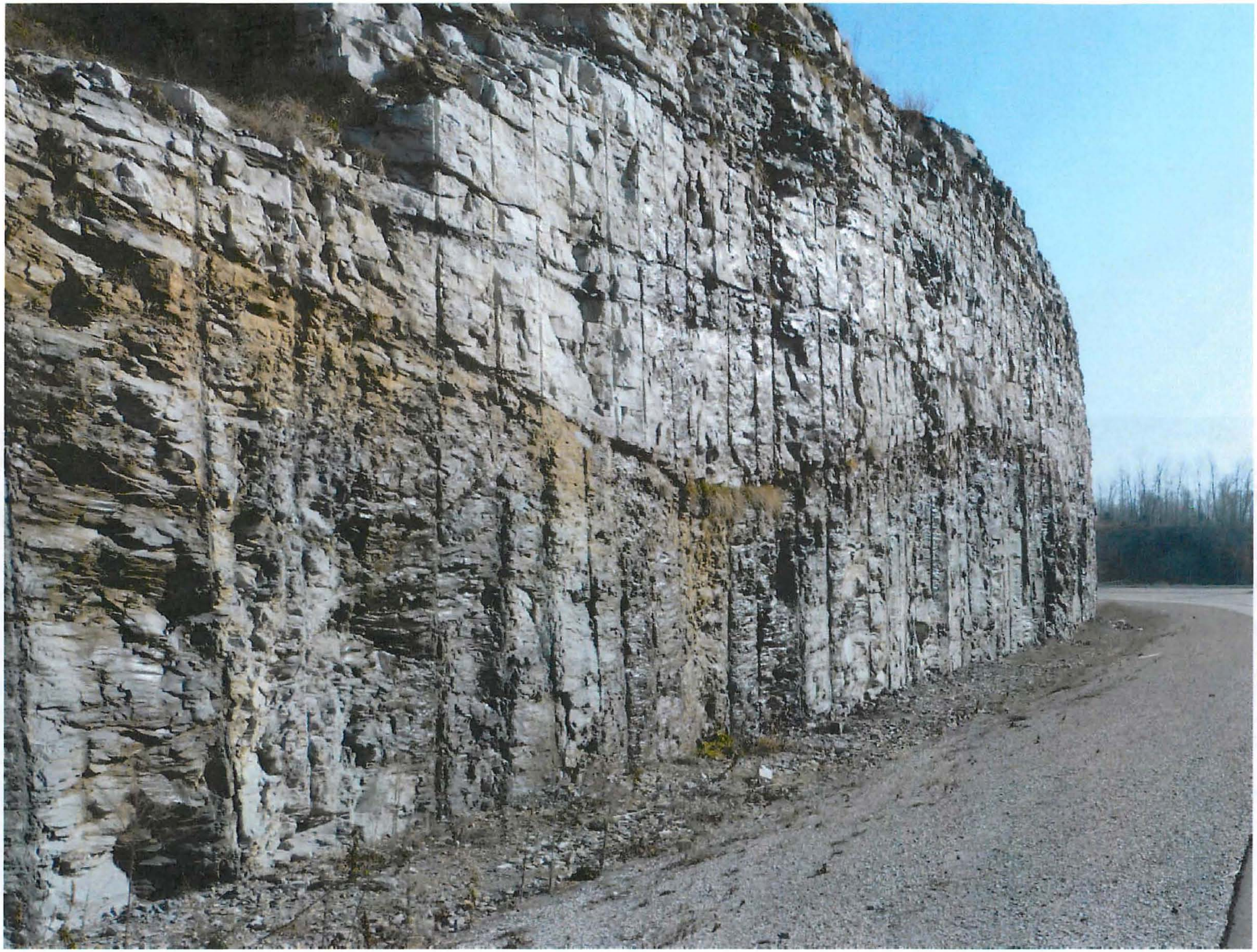


Figure 4. Supratenoous folds in Ft. Payne Formation at Stop 1A viewed at a low angle to the roadcut give the appearance of greater fold amp tude, and possibly a tectonic origin of the folds.

Figure 5. Truncating layering in the Ft. Payne Formation at Stop 1B.

Formations (undivided) through the Upper Ordovician Sequatchie Formation overlain unconformably by the Chattanooga Shale (Uppermost Devonian-Lower Mississippian), the very thin Maury Shale (Lower Mississippian), Ft. Payne Formation (Middle Mississippian), Warsaw Limestone (Middle Mississippian), St Louis Limestone (Middle Mississippian), Monteagle Limestone (Middle Mississippian), and Hartselle Sandstone (Upper Mississippian) (Fig. 1). The Hartsell Sandstone occurs as outliers that occupy several hilltops in these map areas, but forms an extensive flat or "bench" topography farther east to the immediate west of the Cumberland Plateau (Hardeman, 1966).

The Ft. Payne Formation in these exposures consists predominantly of a suite of greenish-gray to variegated, fine-grained siltstone and beds of greenish-gray to orange-brown, mostly crinoid debris with a silty component. Channels (Wolak et al., 2015) or Walsortian reef-like mounds are present at Stops 2 and 3, but those at Stop 2 consist of lenticular beds of very porous, weathered, crinoid-dominated limestone (Fig. 6).

The geology at all of the stops in our trip has also been described by Wolak et al. (2015) for a field trip related to the 2015 meeting of the Southeastern Section of the Geological Society of America in Chattanooga, Tennessee. Their guide emphasizes the fauna and depositional environments in the Ft. Payne, whereas our trip emphasizes the geometries of the intraformational deposition-related supratenuous folds, more regional lower Ft. Payne stratigraphy, and kinematics of movement of some of the Walsortian-like mounds that were deformed as they moved downslope under the influence of gravity.

FIELD GUIDE

Depart Knoxville/Oak Ridge at 9:00 am, get onto I-40W, and drive 88 mi W to Monterey, TN, exit I-40 N and drive into Monterey to intersect TN 84 (Fig. 7). Follow TN 84 N (~17 mi) to where it intersects TN 111 S of Livingston. Turn N (right) on TN 111 and follow the Livingston bypass (TN 111) around the W side of Livingston to its intersection with TN 52 and turn left (NW) toward Celina. Follow TN 52 ~13 mi to Stop 1A (Fig. 8). Park on the N side of the road and carefully walk along the highway to see the cuts on the S side of TN 52. Cross the highway very carefully to get a closer look at the stratigraphy.

Figure 6A. Panoramic view of Ft. Payne Formation exposed in teh west-side roadcut at Stop 2. The brown-colored areas are highly porous, crinoid-dominated mounds, or possibly channels. The light tan beds associated with the brown beds are massive limestone. Note cars for scale.

Figure 6B. Roadcuts on both sides of Tennessee Highway 52 looking north toward Celina.

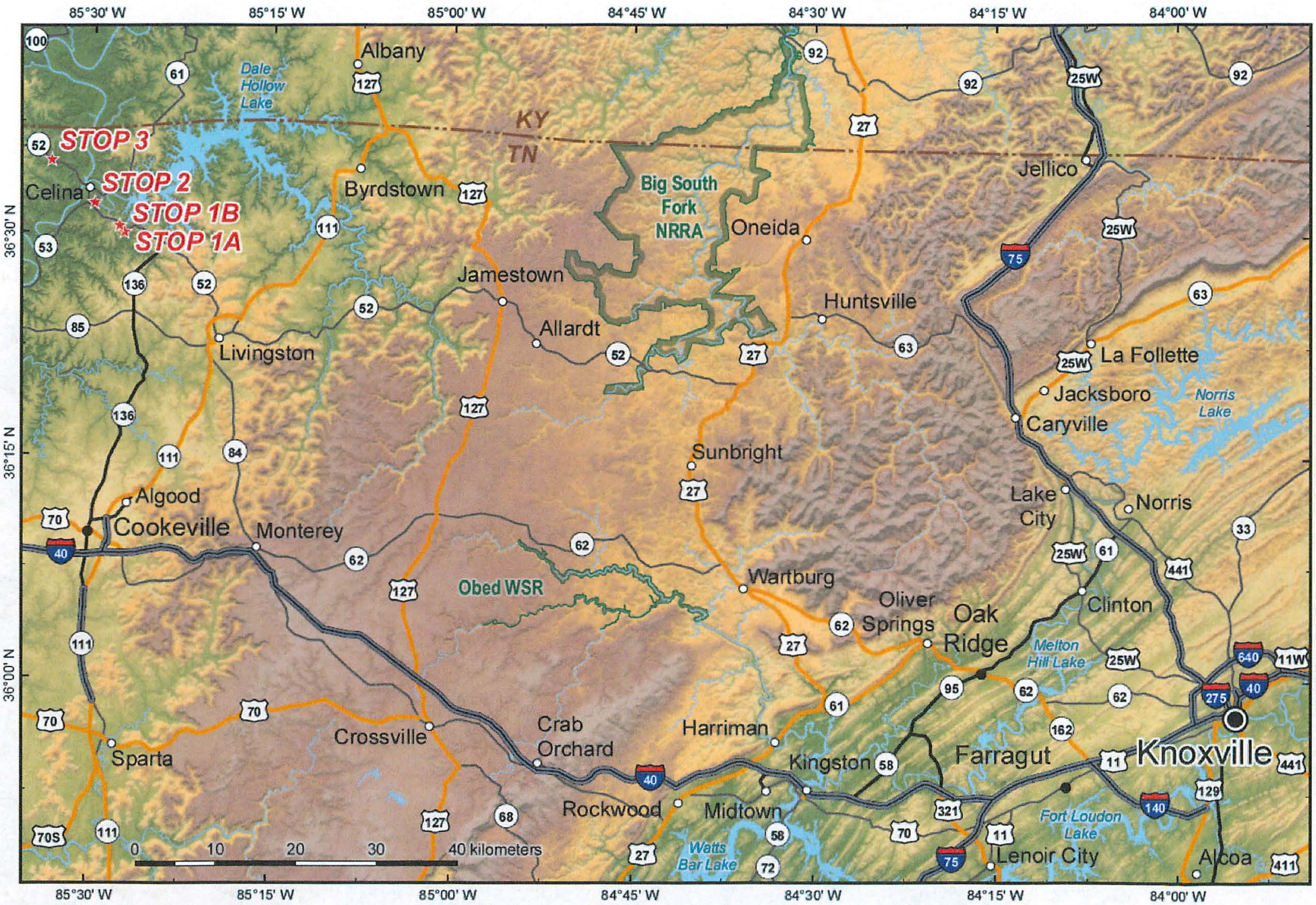


Figure 7. Regional location map for the ETGS October field trip. All stops are in the northwestern part of the map.

Figure 8. Google Earth image of the Celina, Tennessee, area showing the locations of field trip stops.

Stop 1A. Exposures of Ft. Payne Formation along TN 52 southeast of Celina, TN. GPS location: 36° 30' 11" N; 85° 26' 48" W

Stop 1B. Exposures of Ft. Payne Formation along TN 52 southeast of Celina, TN. GPS location: 36° 30' 16" N; 85° 27' 20" W

Purpose: To examine truncating relationships and supratenuous folds in Ft. Payne Formation rocks.

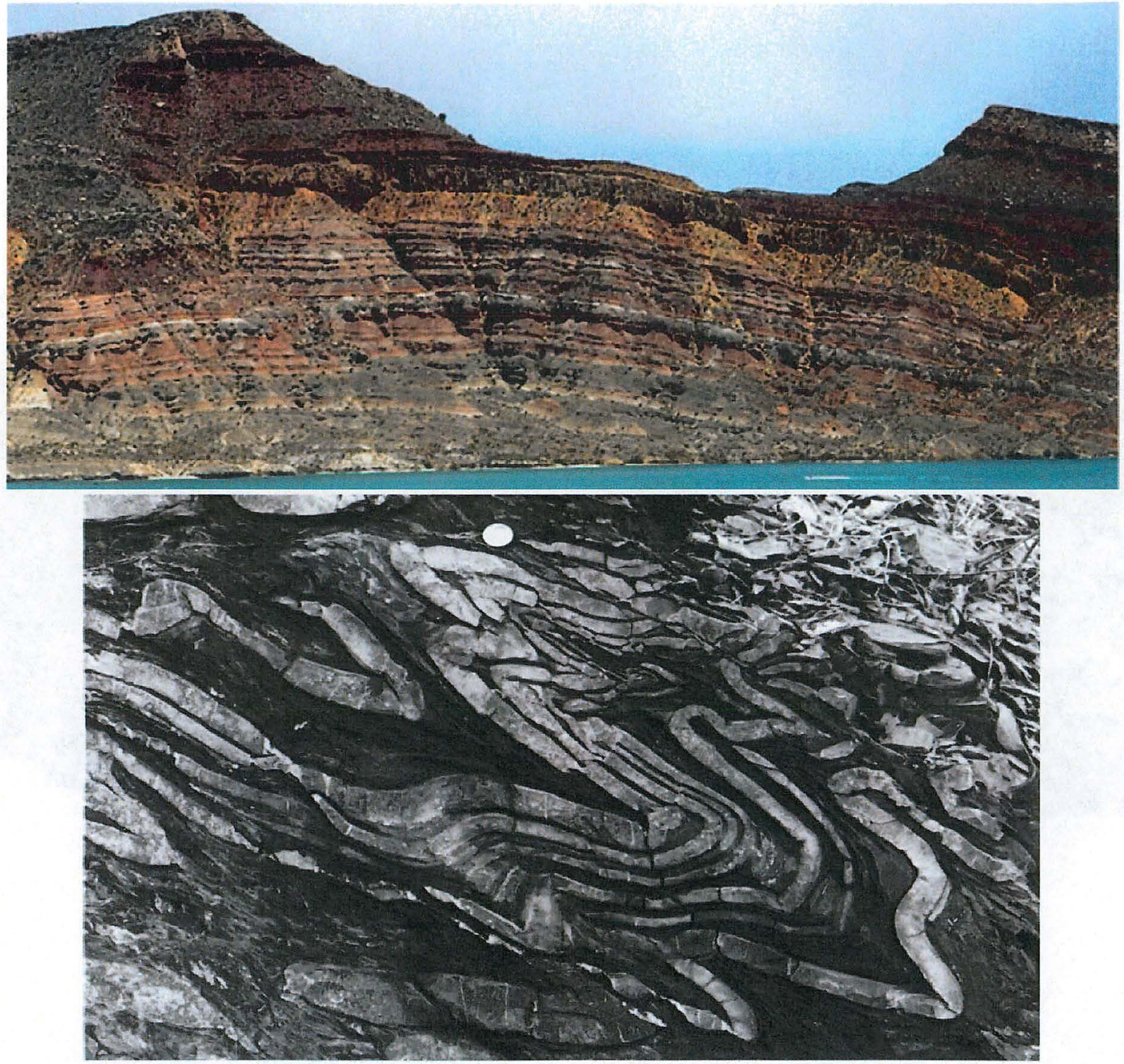
The rocks here consist of light greenish-gray, thin- to medium-bedded calcareous siltstone and shale of the Ft. Payne Formation. Within the several roadcuts along TN Highway 52 is what appears to be a folded unconformity at about the same stratigraphic level, but the folding was produced by draping of sediments over low-amplitude topographic highs (Fig. 9). Classic supratenuous geometries developed over the highs, with the draped sediments thinning over the highs and thickening into the lows (Fig. 2). These structures are developed here along intraformational unconformities—diastems. Ironically, beneath the unconformities beds dip from a few degrees to 10 to 15 degrees, perhaps representing an earlier cycle of erosion and deposition over highs on the seafloor in still older sediments (Fig. 5). This contrasts with folds in most tectonic regimes, where folds maintain bed thicknesses through the crests of anticlines and troughs of synclines in brittle flexural-slip folds, or exhibit thickening into hinges and thinning along the limbs of both synclines and anticlines (Fig. 10 A & B).

Continue northwestward toward Celina along TN Highway 52 to a large set of roadcuts on both sides of the highway. The crest of the highway looking north provides an overview of downtown greater metropolitan Celina.

Stop 2. Exposures of Ft. Payne Formation along TN 52. GPS location: 36° 32' 11" N; 85° 29' 58" W

Purpose: To examine channels or low-amplitude Walsortian-like mounds in Ft. Payne Formation rocks.

Figure 9. Supratenuous folds in Ft. Payne Formation at Stop 1A along Tennessee Highway 52 southeast of Celina, Tennessee. Note person for scale in photo.



A

B

Figure 10. Contrasting styles of brittle and ductile folds. A. Open anticline in Mesozoic sedimentary rocks in Washington County, Utah. Bed thicknesses remain the same throughout this fold. B. Ductile fold in Ordovician black shale and limestone near Whitehall, New York. Both photos from Hatcher and Bailey, in press, Structural Geology 3rd edition: Oxford University Press.

The rocks exposed here consist of greenish-gray and some reddish-brown calcareous siltstone and shale and massive, coarse-grained limestone of the Ft. Payne Formation with several prominent interlayered lenticular highly porous, light brownish-tan crinoid-dominated fossil debris limestone beds (Fig. 11). Wolak et al. (2015) interpreted these crinoid-dominated beds as channels, but they more closely resemble mounds. The lenticular shapes of these features is more convex upward-more like mounds—than downward if they are channels.

Lunch at Gone Country Restaurant, 302 Dow Ave., Celina 38551

Continue northwestward on TN Highway 52 for some 4 mi to a large exposure on the right.

Stop 3. Exposures of Ft. Payne Formation along TN 52. GPS location: 36° 17' 79" N; 85° 33' 57" W

Note: The following discussion is modified from a section in Hatcher and Bailey (in press).

The exposure at Stop 3 consists of gray-green siltstone, shale, and massive limestone of the Ft. Payne Formation (Figure 12). It contains several kinds of structures, all produced by gravity sliding on a very gentle slope on the seafloor of a Mississippian shallow sea. The light-colored material in Figure 13 consists of crinoids and bryozoans that formed reef-like mounds on the Mississippian seafloor. These mounds were built to a height of possibly 4–5 meters, and fine-grained mudstone and siltstone. and reef debris, were deposited around the flanks of and probably on top of each mound.

Normally these features become covered with younger sediment and are preserved in the stratigraphic record in their original geometry. In this case, however, there was enough of a slope that something, perhaps an earthquake, made the reef-like mounds unstable, and they moved suddenly downslope, producing a number of thrust faults and folds that stacked poorly consolidated masses of reef material, mud, and reef debris on top of other material of the same kind. The reef material was consolidated enough that it broke

Figure 11. Supratenuous folds in Ft. Payne Formation southeast of Celina, Tennessee, at Stop 1A. Note person for scale.

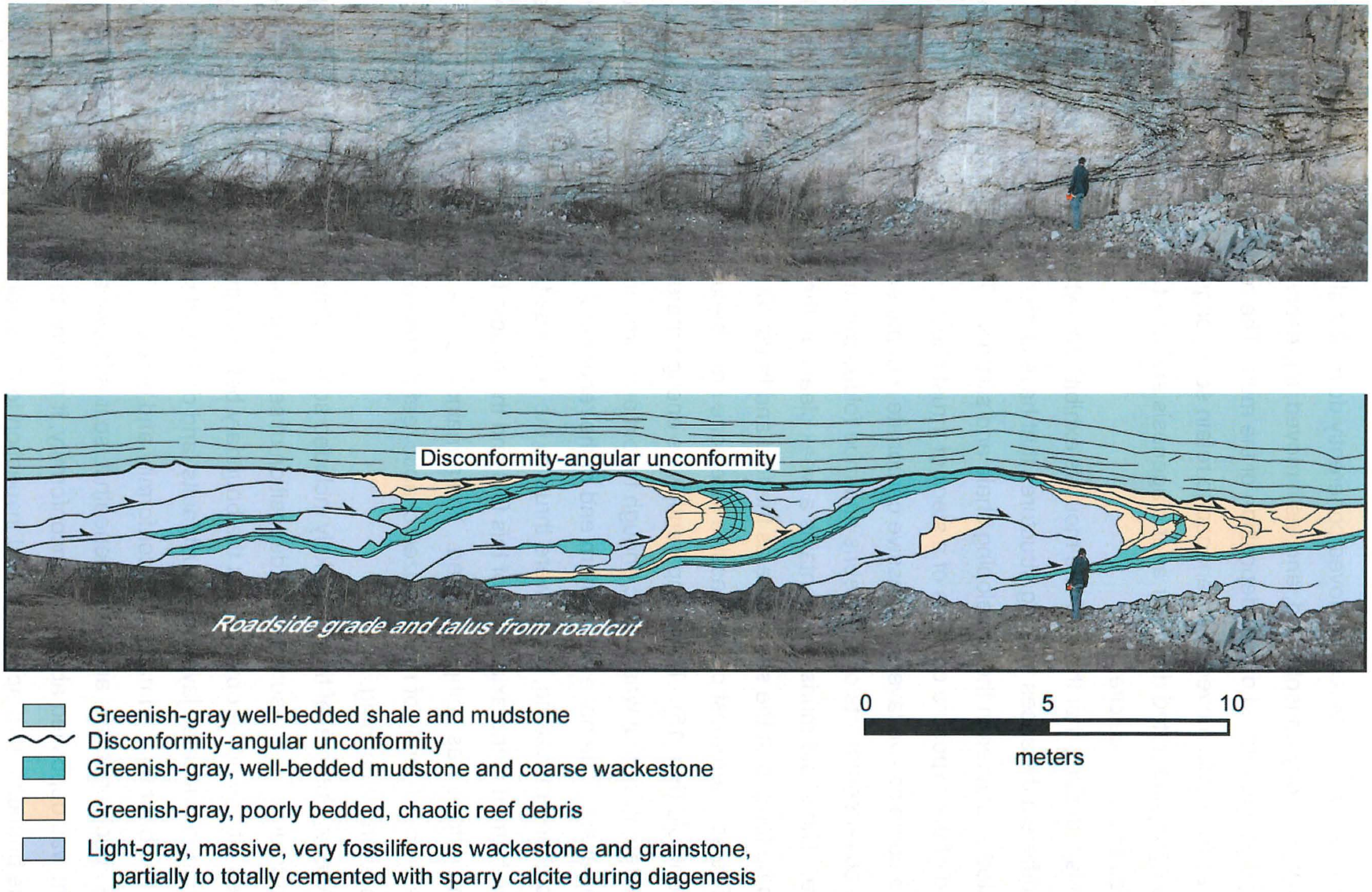


Figure 12. Folds and thrust faults in early Mississippian Ft. Payne Formation on TN Highway 52 north of Celina, Tennessee. All of the folds and thrusts have the same transport direction (vergence). The folds to the center and right became overturned, and the fold on the right became an isoclinal recumbent nappe. Note the weak fanned cleavage in the hinges of the center and right folds. Deposition of greenish shale and mudstone occurred unconformably over these folds so they also form suprataneous folds over the reefs. The driving force that formed these structures was gravity that caused the reefs to become unstable and move downslope (triggered by an earthquake farther east in the Appalachians?). From Hatcher and Bailey, in press, Structural Geology: Oxford Univefrsity Press.

into semi-cohesive sheets and moved coherently down the slope. The fine-grained clastic material was poorly consolidated, and, as it moved, it preserved some of the original bedding that had formed during deposition of the mud. The reef debris became more chaotic as the mass moved but managed to retain some original bedding. The reef debris became tightly indurated during or after diagenesis and most of the fossil material was converted to sparry calcite.

It is intriguing that the reef-like mounds exhibit somewhat different rheologies and moved different distances forming structures that have contrasting geometries and associated structures in the enveloping shale and siltstone. The structure at the northern (left) end of the exposure consists of a stack of thrust sheets (Fig. 13), whereas the middle structure contains two layers of massive carbonate reef material thrust over itself (Fig. 14), with the cover sediments of reef debris and mud folded around the southern end of the structure. The shale-mudstone contains a weak cleavage that is axial planar to this fold, so it had to be formed at the same time as the fold and thrust faults that we see here.

The southernmost of the massive limestone beds became a less faulted Z-shaped recumbent fold (Fig. 15). There apparently was enough material deposited in a single layer a few meters thick that was plastic enough to fold and form only minor faults between the principal layers. The nose or southern end of the recumbent fold is enveloped by layers of reef debris and mudstone, which were thrust to the south as they were all folded. A weak cleavage formed in the axial zone of this fold and the middle fold where a more cohesive bed of mudstone was being deformed. The remainder of the southernmost structure consists predominantly of recrystallized chaotic reef debris containing some faults and poorly preserved bedding.

After an interval of time that likely included some submarine(?) erosion of the tops of these structures, and resumption of deposition of sediment that was draped over these structures. It should be obvious that the boundary between the almost flat-lying, overlying sediment and truncates layering, thrust faults, and deformed massive limestone below, making this boundary primarily a disconformity and diastem. This unconformity, however, truncates bedding, folds, and faults beneath it, so it is locally an angular unconformity. As sediment was deposited above the unconformity, it records the topographic highs and lows along the boundary that appear on first inspection to be tectonic folds, but they are

Figure 13. Northwesternmost slumped mound containing thrust faults and relict bedding. There was not a significant topographic high on top of this mound so deposition of the overlying Ft. Payne Formation siltstone and shale has only a slightchange in thickness.

Figure 14. Configuration of the slumped middle mound. Note the weak axial-planar cleavage around the hinge of the thrusted recumbent fold. Also note the massive nature of the limestone making up the core of this and the other two mounds.

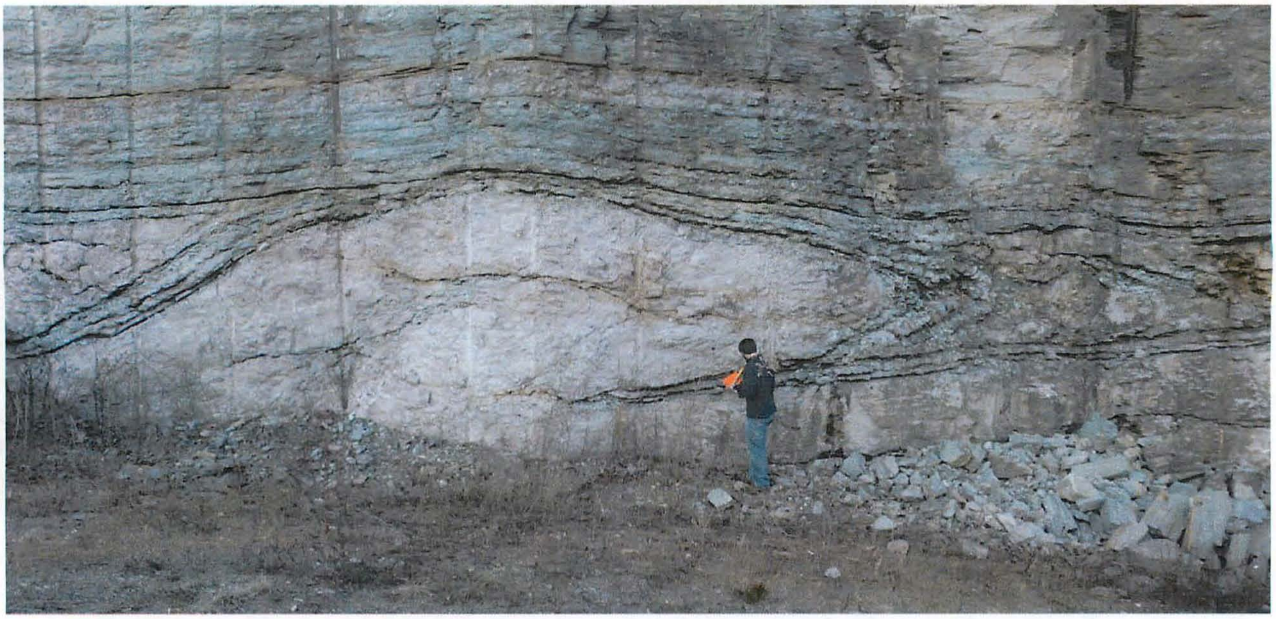


Figure 15. Recumbently folded slumped massive limestone bed in Ft. Payne Formation siltstone and shale. Note the axial-planar cleavage in the anticlinal hinge of the fold and the thinning of beds that were deposited on top of the mound.

supratenuous folds produced as sediment was draped over the topography that remained along the boundary. So the anticlines and synclines above the unconformity are also non-tectonic structures.

Now having described the structures and a little about how they formed, some interesting questions can be posed (Fig. 16): (1) How much displacement of these layers has occurred? (2) How far apart were these reef-like features were before they moved? (3) What was the physical state of the material before it began moving downslope? There probably are others you can think of. Because these features formed on the seafloor, all of the sediments would have been water-saturated. In order to address the questions posed above, the easiest way to solve the problems would be to retrodeform these structures so that each piece of massive carbonate would be again in a horizontal orientation as it would have been when it was deposited. The way to begin is to isolate the sheets of massive carbonate that are separated from each other by either layers of shale–mudstone or reef debris, because they are the most coherent and strongest deformation markers in the structures.

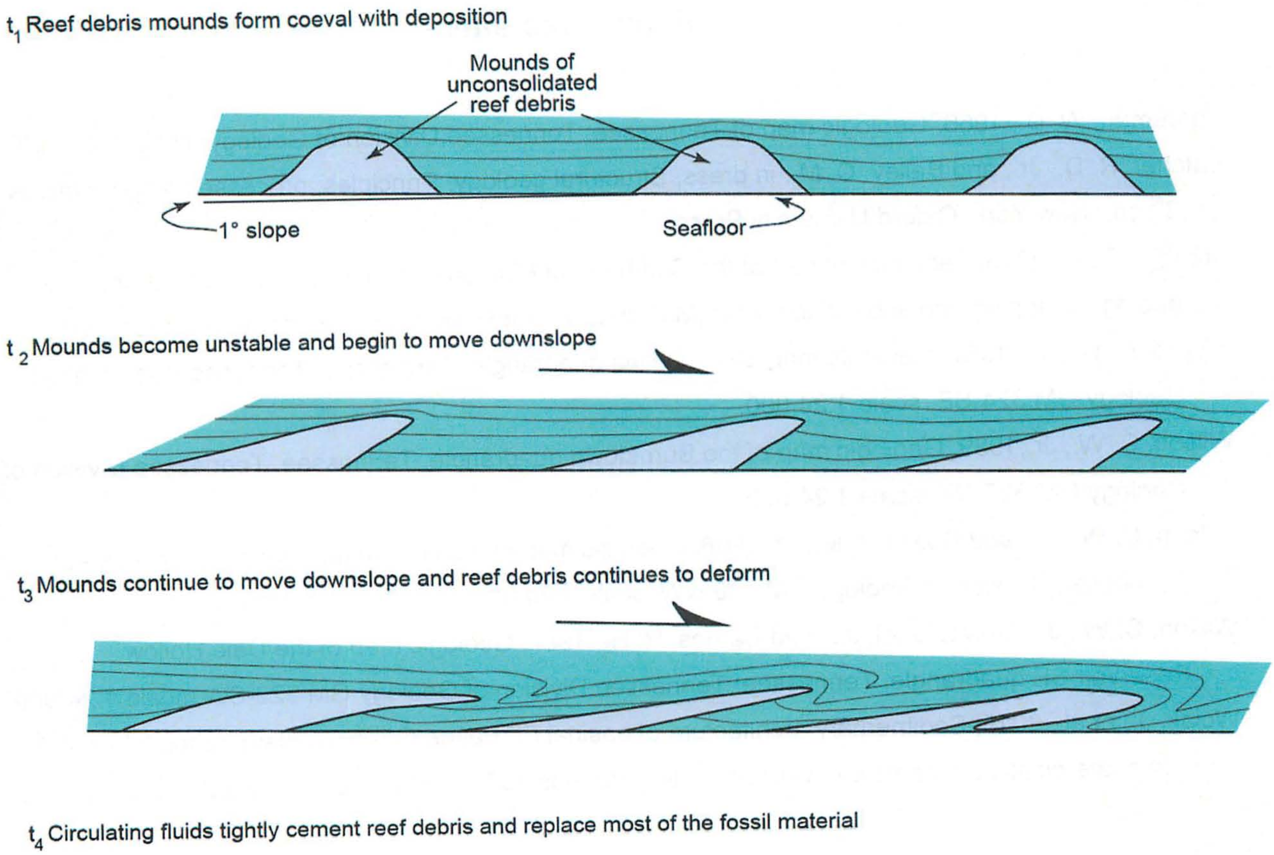


Figure 16. Cartoon depicting a possible scenario for the development of the structures at Stop 3.

References Cited

Hardeman, W. D., 1966, Geologic map of Tennessee: Tennessee Division of Geology, scale 1:250,000.

Hatcher, R. D., Jr., and Bailey, C. M., in press, Structural geology: Principles, processes, and problems 3rd ed.: New York, Oxford University Press.

Scruggs, P. L., 2015, Tectonics of part of the Cumberland Plateau in Tennessee: Data from detailed geologic mapping and subsurface wells [M.S. thesis]: Knoxville, University of Tennessee, 188 p.

Wilson, C. W., Jr., 1987, Geologic map of the Celina quadrangle, Tennessee: Tennessee Division of Geology GM 324-SE, scale 1:24,000.

Wilson, C. W., Jr.,1989, Geologic map of the Burristown quadrangle, Tennessee: Tennessee Division of Geology GM 325-NE, scale 1:24,000.

Wilson, C. W., Jr., and Colvin, J. M., Jr.,1968, Geologic map of the Hilham quadrangle, Tennessee: Tennessee Division of Geology GM 330-NW, scale 1:24,000.

Wilson, C. W., Jr., Colvin, J. M, Jr., and Barnes, R. H., 1987, Geologic map of the Dale Hollow Reservoir SE quadrangle, Tennessee: Tennessee Division of Geology GM 329-SW, scale 1:24,000.

Wolak, J., et al., 2015, Sedimentary architecture of basinal Ft. Payne (Mississippian) deposit: Mixed carbonate-clastic channels and Walsortian-like mounds: GSA field guide, p. 245-266.