Grain-Scale Strain Analysis of Rock in Middle Tennessee

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Abstract

Rock deformation begins at the grain scale. Grain-scale deformation can be expressed as finite strain—the total strain affecting the rock over time. Finite strain can be quantified by a geospatial technique known as Fry analysis that assesses the geometric arrangement of rock grains with respect to each other. Fry analysis is used to measure the amount of strain and the direction of shortening and extension.

In this study, 8 oriented samples that included Hartselle Formation quartz arenite and Monteagle and Bangor Limestone grainstone were collected for Fry analysis. Four samples were collected east of Cookeville, TN and 4 samples were collected from Brown Gap quarry 20 kilometers south of Crossville, TN. Polished slabs of the bedding plane were scanned and imported into *EllipseFit* for Fry analysis.

Six samples yielded shortening directions of east-west to northwest-southeast (azimuth of 257-346 degrees) and one sample showed a shortening direction of 207 degrees (the final sample was too fine grained for the analysis). The strain ratio, a measure of strain magnitude, ranged from 1.1-5.9. The grain-scale deformation was accomplished principally by microfracturing, pressure-solution and calcite-twinning mechanisms. The shortening direction measured in these samples is consistent with the tectonic deformation associated with the Alleghanian orogeny 320-280 million years ago.

Introduction

Low temperature (<300°C) grain-scale deformation is accomplished principally by microfracturing, pressure-solution and calcite-twinning mechanisms in crustal rocks. This deformation can be expressed as finite strain – the total strain affecting the rock over time. In this study, we used grain scale finite-strain analysis in clastic and carbonate rocks to determine the strain ratio (a proxy for strain magnitude) and the tectonic shortening direction. Our results are consistent with the tectonic deformation associated with the Alleghanian orogeny 320-280 million years ago.

Geologic Setting

The study sites for this research are located in two different physiographic provinces of middle Tennessee: the Eastern Highland Rim and the Sequatchie Valley of the Cumberland Plateau. The samples from the Eastern Highland Rim were collected from the Mississippian-aged Hartselle Formation and the Monteagle Limestone (Figure 1). The Hartselle Formation consists primarily of quartz arenite roughly 10 meters thick, tan to cream colored and medium to coarse grained. The Monteagle Limestone is roughly 60 meters thick, light gray to brownish gray and consists of skeletal and oolitic grainstone. The samples from the Sequatchie Valley of the Cumberland Plateau were collected from the Mississippian-aged Bangor Limestone: a thick-bedded unit about 30 meters thick with mostly medium gray oolitic grainstone layers. Both study sites are located in the Appalachian foreland basin, with the Sequatchie Valley being a breached anticline that formed over a thrust ramp during the Alleghanian orogeny.

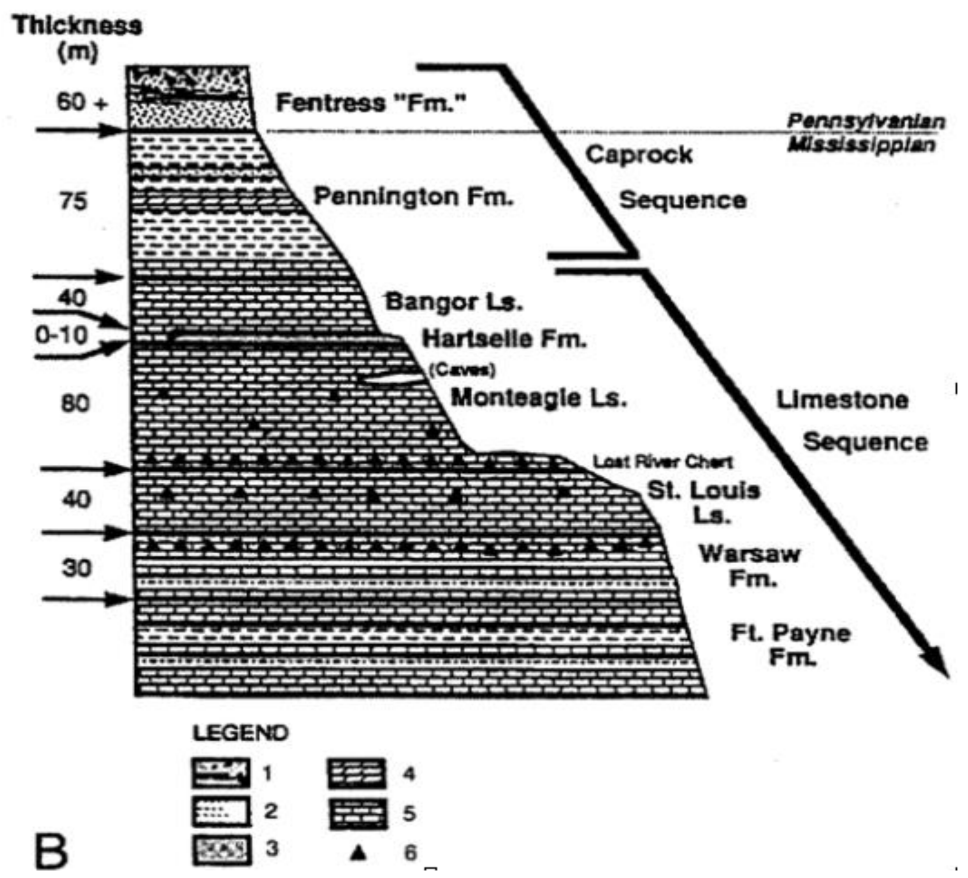


Figure 1. Stratigraphic column of the Cumberland Plateau region.

Methods

Figure 2. Oriented sample of the Bangor Limestone from Brown Gap Quarry, Sequatchie Valley.

Eight oriented samples (Figure 2) were collected, 4 from each study site. From the site in the Eastern Highland Rim (Figure 3), 3 samples were collected from the Hartselle Formation and 1 from the Monteagle Limestone. In the Sequatchie Valley (Figure 4), all 4 samples were collected from the Bangor Limestone. After field collection, the samples were cut parallel to bedding (Figure 5), polished (Figure 6) and scanned. Images of the bedding planes (Figure 7) were then imported into *EllipseFit* for Fry analysis. Fry analysis (Fry, 1979; Erslev, 1988) is a nearest-neighbor technique for determining the strain ratio and the shortening and extension directions. Generally, 90-300 grains were used for Fry analysis for each sample.

Figure 3. (Right) Eastern Highland Rim collection site located near the community of Parragon along Brotherton Mountain Road.
Figure 4. (Below) Brown Gap Quarry with Bangor Limestone.

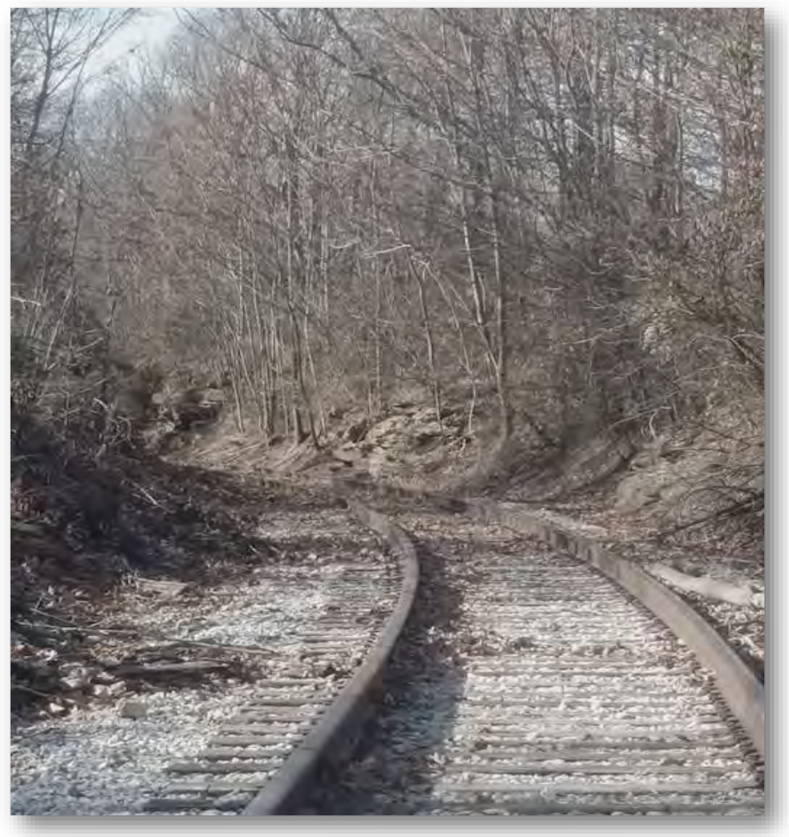


Figure 5. (Below) Cutting samples using a wet saw.
Figure 6. (Right) Polishing the samples along the bedding plane.

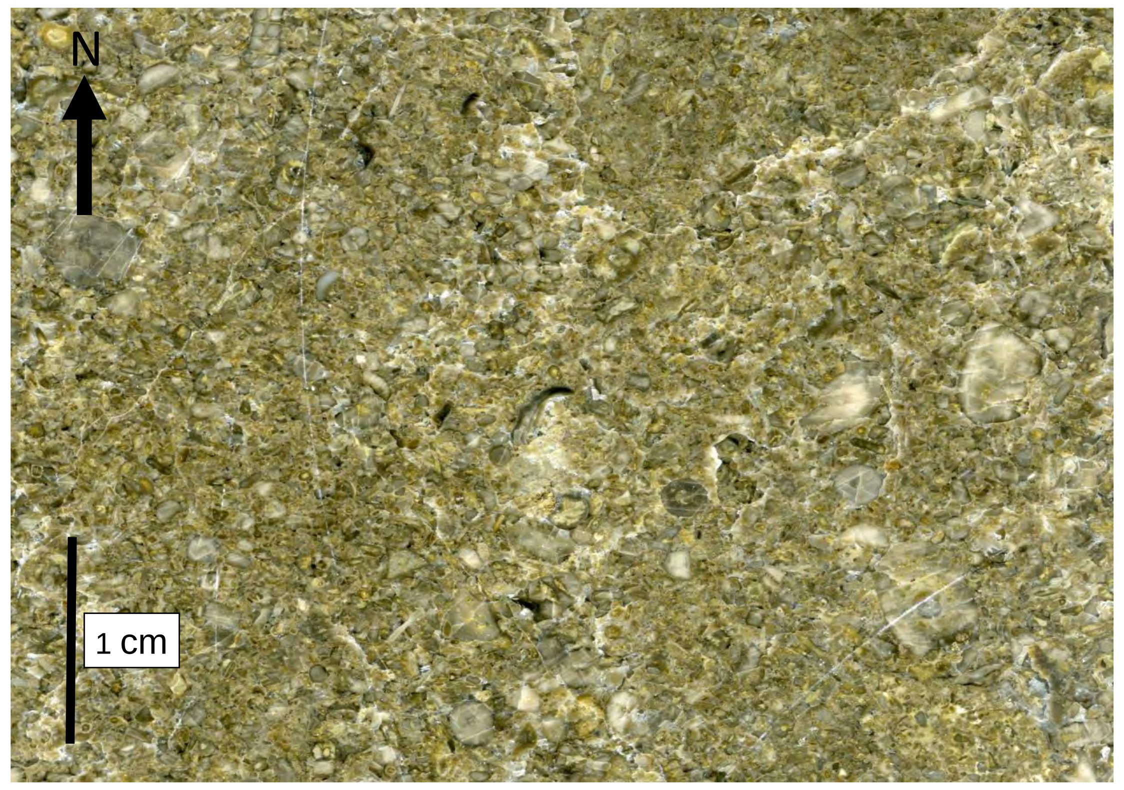


Figure 7. Scanned bedding-plane image of Monteagle Limestone near Parragon, TN.

Results

Six samples yielded shortening directions of east-west to northwest-southeast (azimuth of 257-346 degrees) and one sample showed a shortening direction of 207 degrees (Figure 8). One Hartselle sample was too fine grained for the Fry analysis. The shortening direction is the short axis of the finite strain ellipse. The strain ratio, a measure of strain magnitude, ranged from 1.1-5.9 (Table 1).

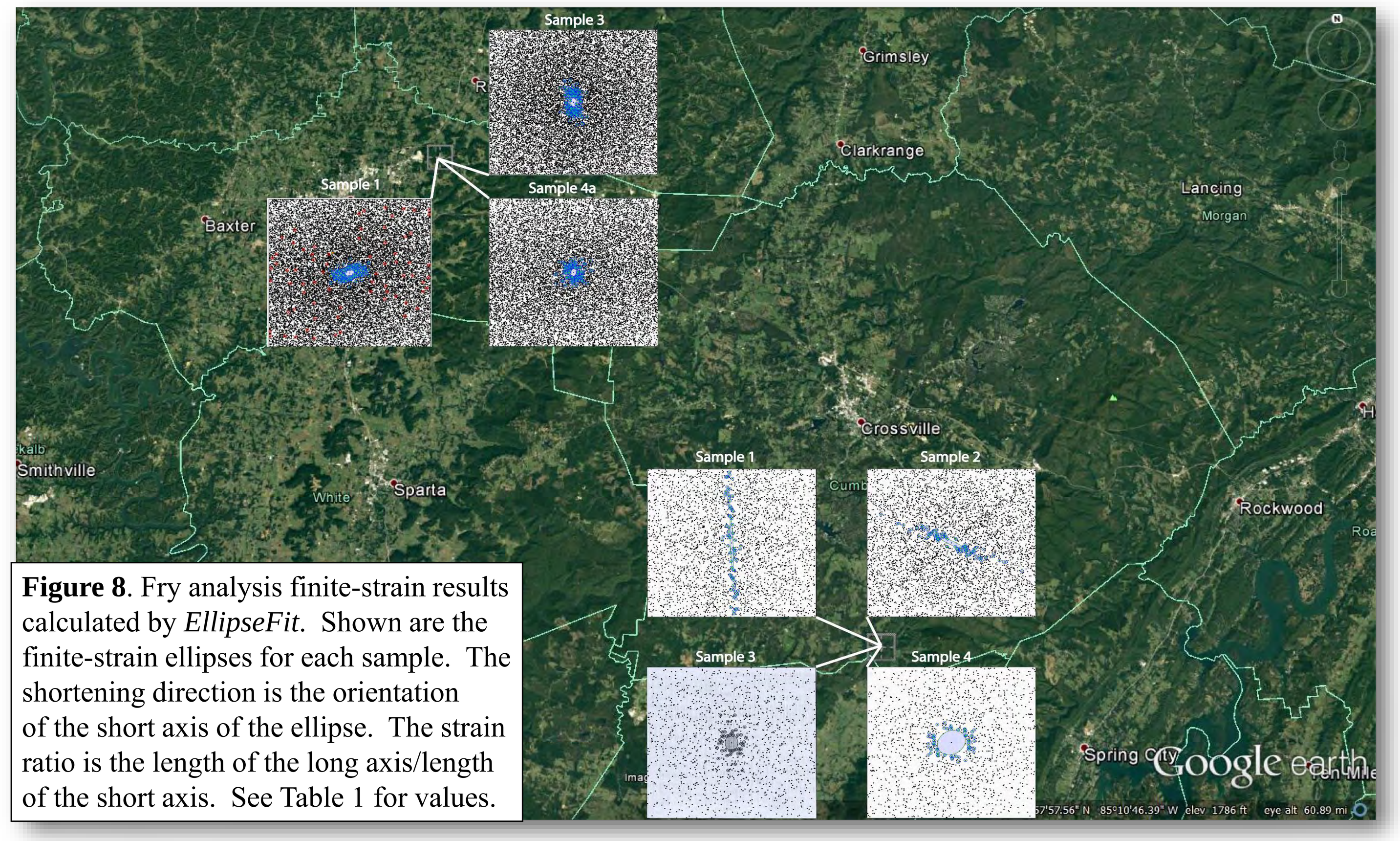


Figure 8. Fry analysis finite-strain results calculated by *EllipseFit*. Shown are the finite-strain ellipses for each sample. The shortening direction is the orientation of the short axis of the ellipse. The strain ratio is the length of the long axis/length of the short axis. See Table 1 for values.

Table 1. Shortening direction and strain ratio for samples.
EHR=Eastern Highland Rim; CP=Cumberland Plateau

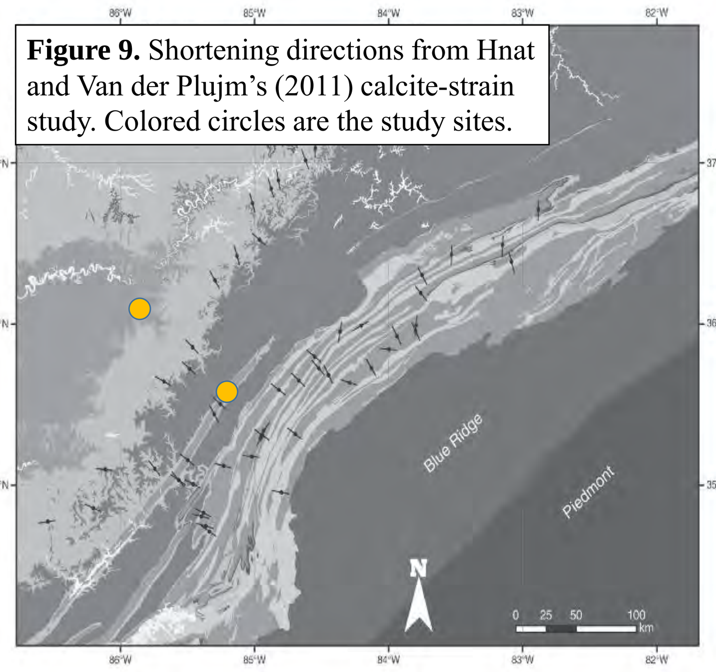
Sample	Shortening Direction	Strain Ratio
1 (Hartselle)-EHR	346	1.9
3 (Hartselle)-EHR	266	2.3
4a (Monteagle)-EHR	257	1.1
1 (Bangor)-CP	268	20
2 (Bangor)-CP	207	5.9
3 (Bangor)-CP	270	1.4
4 (Bangor)-CP	318	1.2

Discussion/Conclusion

Fry analysis was used to determine if grain-scale finite strain could be detected in clastic and carbonate rocks. From our analysis, grain-scale finite strain was detected and the shortening directions align roughly with those of Hnat and Van der Pluijm (2011). Figure 9 shows the geographic distribution and orientation of compression directions in the Tennessee salient determined by Hnat and Van der Pluijm (2011).

Hnat and Van der Pluijm (2001) studied calcite-twinning strain along the Eastern Highland Rim and farther east in the Valley and Ridge. Calcite twins are generally more sensitive to low strain; however, Fry analysis is much faster. This study shows that measurable Alleghanian finite strain is present in rocks far into the Appalachian foreland basin.

Figure 9. Shortening directions from Hnat and Van der Plujm's (2011) calcite-strain study. Colored circles are the study sites.



Acknowledgements/ Works Cited

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