Plate I. Deformation in the Core of the Southern Appalachian Triangle Zone - Part I

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Abstract

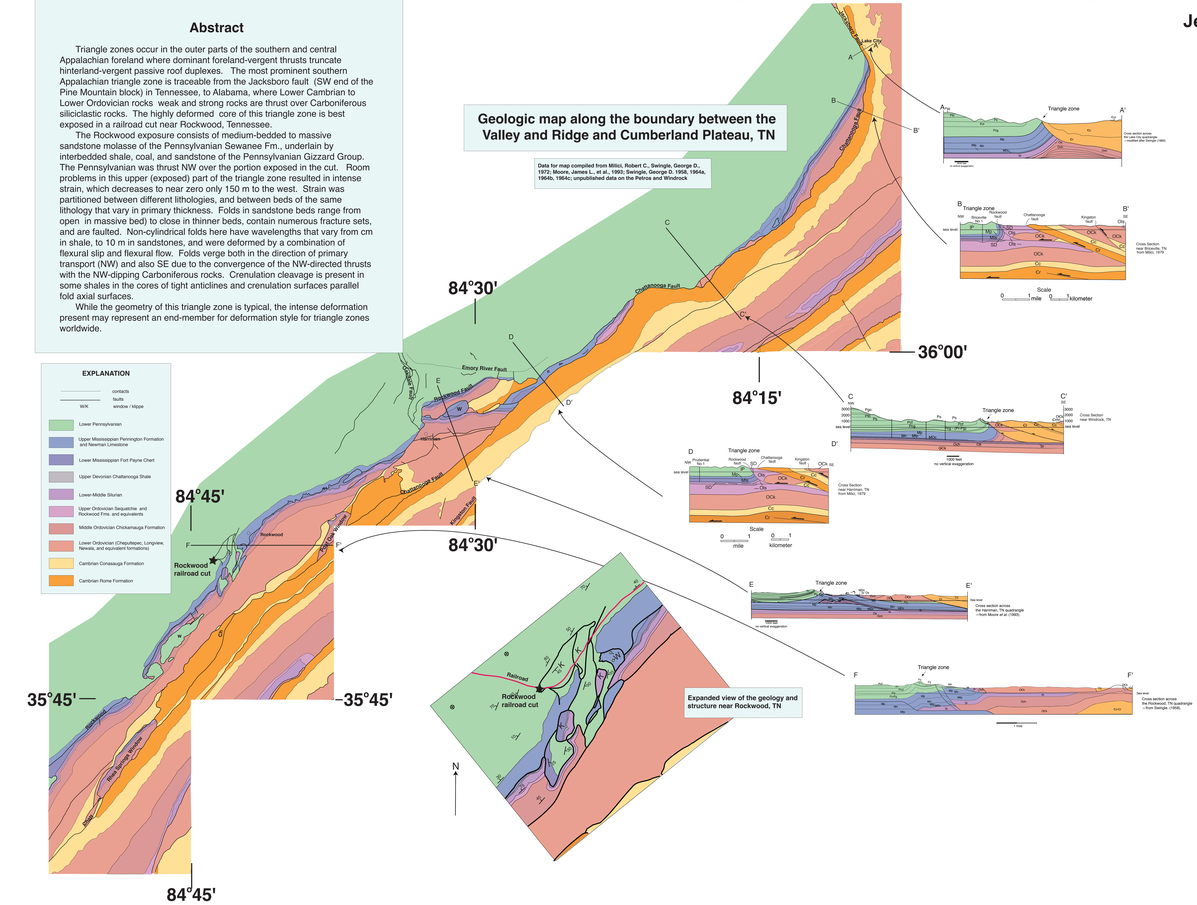
Triangle zones occur in the outer parts of the southern and central Appalachian foreland where dominant foreland-vergent thrusts truncate hinterland-vergent passive roof duplexes. The most prominent southern Appalachian triangle zone is traceable from the Jacksboro fault (SW end of the Pine Mountain block) in Tennessee, to Alabama, where Lower Cambrian to Lower Ordovician rocks weak and strong rocks are thrust over Carboniferous siliciclastic rocks. The highly deformed core of this triangle zone is best exposed in a railroad cut near Rockwood, Tennessee.

The Rockwood exposure consists of medium-bedded to massive sandstone molasse of the Pennsylvanian Sewanee Fm., underlain by interbedded shale, coal, and sandstone of the Pennsylvanian Gizzard Group. The Pennsylvanian was thrust NW over the portion exposed in the cut. Room problems in this upper (exposed) part of the triangle zone resulted in intense strain, which decreases to near zero only 150 m to the west. Strain was partitioned between different lithologies, and between beds of the same lithology that vary in primary thickness. Folds in sandstone beds range from open (in massive bed) to close in thinner beds, contain numerous fracture sets, and are faulted. Non-cylindrical folds here have wavelengths that vary from cm in shale, to 10 m in sandstones, and were deformed by a combination of flexural slip and flexural flow. Folds verge both in the direction of primary transport (NW) and also SE due to the convergence of the NW-directed thrusts with the NW-dipping Carboniferous rocks. Crenulation cleavage is present in some shales in the cores of tight anticlines and crenulation surfaces parallel fold axial surfaces.

While the geometry of this triangle zone is typical, the intense deformation present may represent an end-member for deformation style for triangle zones worldwide.

Geologic map along the boundary between the Valley and Ridge and Cumberland Plateau, TN

Data for map compiled from Millici, Robert C., Swingle, George D., 1972; Moore, James L., et al., 1993; Swingle, George D. 1958, 1964a, 1964b, 1964c; unpublished data on the Petros and Windrock



Geologic Setting

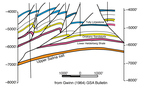
A triangle zone has recently been recognized in the outer part of the southern Appalachian foreland fold-thrust belt (FFTB). Triangle zones in general comprise a structural front that marks the transition from more complex deformation in the more internal parts of a FFTB to the less complex outer parts where shortening gradually diminishes to zero. The southern Appalachian triangle zone is traceable from the Jacksboro fault (at the SW end of the Pine Mountain block) in Tennessee all the way to Alabama, along the boundary between two physiographic provinces: the Valley and Ridge, and the Cumberland Plateau. Convergence of the two provinces is marked by a prominent topographic feature called Walden Ridge (seen in the cross sections to the left), caused by movement of a thick package of Lower Cambrian to Pennsylvanian rocks of the Valley and Ridge up a ramp, and over Carboniferous siliciclastic rocks of the Plateau. In the footwall of this easternmost thrust of the Valley and Ridge (either the Rockwood or Chattanooga fault) , Plateau rocks are folded into a tight syncline at the boundary, forming a triangle-shaped zone of intense strain. The highly deformed core of the southern Appalachian triangle zone is best exposed in a railroad cut near Rockwood, Tennessee, in a portion of the Rockwood Fault.

The Rockwood exposure consists of medium-bedded to massive sandstone molasse of the Pennsylvanian Sewanee Conglomerate. underlain by interbedded shale, coal, and sandstone of the Pennsylvanian Whitwell Shale. The Sewannee rocks were thrust NW over the Pennsylvanian rocks exposed along the railroad. Room problems in the upper portion of the triangle zone (exposed in the cut) resulted in intense strain, which decreases to near zero only 150m to the west.

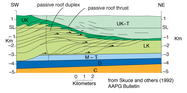
All of these rocks are highly deformed (folded and fractured), especially the shales and coals of the Gizzard Group. This intense brittle deformation in the core of the triangle zone likely extends as far down as the detachment in the Chattanooga Shale, and may have produced fractured reservoirs sealed by shales in different parts of the section. We here report the results of preliminary efforts at characterizing the deformation in this well-exposed portion of the triangle zone.

Triangle Zones

Triangle zones have been divided by Couzens and Wiltschko (1996) into two classes. Type I triangle zones occur above very weak horizons, where more competent units respond to compression by forming conjugate faults (Price, 1986), potentially in combination with detachment folds (Gwinn, 1964), creating a triangle-shaped zone of deformation, as in the figure below from West Virginia.



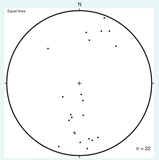
Type two triangle zones require two detachment horizons: one as a floor thrust accommodating foreland-ward migration of competent rocks, and one as a roof thrust, as in the figure below from Alberta. Backthrusting on this passive roof thrust allows the duplex to continue displacement into the foreland without appreciable deformation of the overlying rocks. This passive roof duplex (Banks and Warburton, 1986), that delaminates rocks above the roof thrust is essentially a triangle shaped wedge, and was named a triangle zone for its characteristic shape on seismic lines.



The southern Appalachian triangle zone at Rockwood displays many of the characteristics of a Type II triangle zone.

Folds

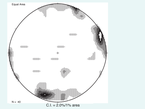
Fold style in the Rockwood cut varies widely. Some shale is folded, especially in the cores of anticlines. At one location (photo 4) folding was sufficiently intense to have initiated formation of a weak crenulation cleavage. In most of the exposure, however, fracturing is more common than folding in shales (photo 2). The geometry of sandstone folds generally depends on their thickness. Massive (>1m) beds form open, long wavelength folds, and medium to thinly bedded sandstone folds are frequently close, with proportionally shorter wavelengths. Thrust faults verging both east and west break through fold limbs (photos 5 and 6) where the rocks could no longer accommodate shortening via buckling. Many folds are asymmetric to overturned, and may verge to either the foreland or the hinterland. At the east end of the outcrop, curving fold hinges (photo 7) show the non-cylindrical nature of the folds in this exposure, as does the variation in the plunge of fold axes as pictured in photos 5, 6, and 7 (folds plunge to the south) and photos 1, 3, and 4 (folds plunge to the north). Plentiful slickenlines on fracture surfaces and disharmonic folding in the core of large folds suggest that deformation occurred primarily by flexural slip, although hinge thickening in some folds indicates flexural flow may also have occurred.



Fold axes from the Rockwood railroad cut

Fractures

Fracture characteristics in the Rockwood railroad cut vary in different lithologies. The organic-rich shales are penetratively fractured and have high vitrinite reflectance values (as yet not quantitatively determined. Sandstone units contain spaced fractures, and fracture frequency is inversely proportional to bed thickness, as can be seen in photos 5, 6, and 7 to the right, although this relationship was not quantified. The aperture on most fractures is small (<0.5mm). Minor displacement on fractures is common and ranges from 1-3 cm, as measured on exposed bedding surfaces. Fracture planes, especially in thicker sandstone beds may exhibit slickenlines, but the slickensides are generally not stepped, so sense of motion on the surfaces cannot be easily determined. The fractures appear by visual inspection to occur as four separate steeply-dipping sets (see photo 8 to the right). One set strikes generally E-W parallel to the trend of the exposure. A second set strikes almost perpendicular to the exposure (subparallel to axial surfaces). This set appears to fan around the folds, implying that it formed before folding occurred. The third and fourth sets are most easily observed on bedding surfaces. They are sub-orthogonal, and cross fold axial planes at an oblique angle. Most fracture measurements were obtained from the first and second sets, because these are most frequently exposed. A plot of all fold axes (both directly measured and calculated from β and π plots) is shown to the right, along with 1% area plot and a Rose diagram of the same data.



Rose diagram of fracture orientations

Summary

The study area is located in folded units in the footwall of the westernmost thrust of the Valley and Ridge. Deformation in the Rockwood railroad cut is intense. Strong units (sandstones) define the geometry of non-cylindrical, hinterland- and foreland-verging folds. Fold axes plunge to both the NNE and SSW. Folds deformed by a combination of flexural slip (slickenlines, disharmonic folding) and flexural flow (weak beds thicken in hinges). Sandstone units are frequently thrust both up-to-the-west and up-to-the-east where folds could no longer accommodate shortening. Shales are pervasively folded and are fractured, and generally deformed to accommodate the surrounding more competent rocks. Sandstones have a more predictable pattern of joint sets, some of which formed prior to folding. This zone of intense deformation best fits the Type II triangle zone category , although it does not have a well-defined passive roof. But it clearly is a triangle zone geometrically and kinematically, because it occurs in the foreland-most edge of a FFTB, has low displacement, a generally triangular shape, intense deformation with both foreland, and hinterland senses of vergence, and is a potential hydrocarbon play.

References

Banks, C.J., and Warburton, J., "Passive roof" duplex geometry in the frontal structures of the Kirthar and Sulaiman mountain belts, Pakistan, Journal of Structural Geology, v. 8, p. 229-237.

Couzens, Brent C., and Wiltschko, David V., 1996, The control of mechanical stratigraphy on the formation of triangle zones, Bulletin of Canadian Petroleum Geology, v. 44, p. 165-179.

Gwinn, V.E., 1964, Thin-skinned tectonics in the Plateau and northwestern Valley and Ridge provinces of the Central Appalachians, GSA Bulletin, V. 75, p. 863-900.

Moore, James L., Finlayson, C. Pratt., Millici, Robert C., 1993, Geologic map of the Harriman Quadrangle, Tennessee; Tennessee Division of Geology, Geologic Map 123-NE.

Millici, Robert C., Swingle, George D., 1972, Geologic map of the Roddy Quadrangle, Tennessee; Tennessee Division of Geology, Geologic Map 117-SE.

Price, R.A., 1986, The southeastern Canadian Cordillera: thrust faulting, tectonic wedging, and delamination of the lithosphere, Journal of structural Geology, v. 8, p 239-254.

Swingle, George D. 1958, Geologic map of the Rockwood Quadrangle, Tennessee; Tennessee Division of Geology, Geologic Map123-SW.

— — — —, 1959, Geologic map of the Lake City Quadrangle, Tennessee; Tennessee Division of Geology, Geologic Map137-NW.

— — — —, 1964a, Geologic map of the Clinton Quadrangle, Tennessee; Tennessee Division of Geology, Geologic Map137-SW.

— — — —, 1964b, Geologic map of the Spring City Quadrangle, Tennessee; Tennessee Division of Geology, Geologic Map118-NE.

— — — —, 1964c, Geologic map of the Ten Mile Quadrangle, Tennessee; Tennessee Division of Geology, Geologic Map124-NW.