Structural Interpretation of Rockbridge County, VA
Central Appalachian Valley and Ridge Province

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Introduction

Balanced cross section methods can aid in structural interpretations of fold thrust belts where data are absent or insufficient for subsurface constraint. Line length and/or area restoration ensure that a section is balanced: one that is geometrically correct and restorable to it's initial state through kinematically reasonable steps (Mitra, 1992). This approach at least ensures that the interpretation is a realistic possibility. Restoration does not imlpy a correct interpretation, but rather establishes a reasonable origin. Balancing techniques are best applied to deformation which is confined above a basal detachment, such as the Canadian Cordillera or the Appalachian orogen.

The Central Appalachian Valley and Ridge is a blind-thrust terrane characterized by plunging anticlinoriums and synclinoriums. The purpose of this project was to use balancing methods to aid in the construction of a cross section through Rockbridge County, Va., 35km northwest of Lexington. Surficial geologic mapping and a unpublished seismic profile across an 20km transect were used in conjunction with data and interpretations from adjacent structures. Subsurface structures were thus interpreted from surface outcrops, basement depth and the proximal deformation style.

Deformation Style and Previous Investigations

COCORP, USGS, and private seismic reflection profile interpretations, and drill hole data have led to the general acceptance that crystalline basement was not directly involved in Appalachian foreland deformation (Perry, 1975). The thrust fold belt was first recognized to deform by décollement (detachment) and overthrusts by Rich (1934). The sedimentary column has since been divided into three competent and two incompetent lithotectonic units (fig. 1) which partially control the deformational mechanics and structure of the Appalachians (Jacobeen, Kanes, 1974). Décollement in the Waynesboro and Martinsburg shales formed two chronologically and structurally distinct thrust sheets. Deformed rocks above the Waynesboro and Martinsburg décollements will be referred to as the Waynesboro sheet and the Martinsburg sheet, respectively (fig. 1).

The upper-level detachment in the Martinsburg occurred before the lower Waynesboro décollement (Perry, 1978; Kulander, Dean 1986). The present structural style of the Martinsburg sheet is dominated by short-wavelength, asymmetrical, overturned folds, and forelimb and backlimb thrust faults (Kulander, Dean, 1986). The later, deeper-seated Waynesboro décollement thrust the lower competent unit of Cambrian-Ordovician carbonates into duplex geometries (Evans, 1989) and further displaced the overlying Martinsburg sheet, creating a complex deformational history. Imbrication in the lower thrust sheet is interpreted from extensive seismic studies, structural culminations, and deep well data. These lower thrusts deform the Cambrian-Ordovician carbonates into fault-bend and fault-propagation folds (Evans, 1989) which are exposed in places in the Valley and Ridge. In Pendleton County, Va., 70km from the study area, the Ray Sponaugle well penetrates the Wills Mountain Anticline (Perry, 1975). Drill hole and seismic data indicate that the structure developed as a fault-propagation fold along a detachment in the Martinsburg at 3300m depth. This characteristic blind thrust terrane is continuous throughout the Valley and Ridge.

Field Area and Investigation

Immediately west of the Great Valley, the Maury and Cowpasture Rivers slice through the easternmost folds of the Valley and Ridge. The lower, Waynesboro thrust sheet is not exposed here, so data from proximal studies were used to aid in modeling the lower deformation. Field investigation along the 20 km transect involved mapping the exposed Martinsburg sheet; upper Ordovician through Lower Devonian carbonates, shales, and sandstones (fig. 1). Bedding orientation, faults, fold axis, and fold styles were recorded in detail to provide for cross-section control.

The principal structures, three anticlinal ridges of Silurian orthoquartzite separated by two broad valleys of Devonian shale, are structurally distinct. The orthoquartzites of the eastern anticlinorium are displaced by two northwesterly dipping backthrusts. The eastern backthrust was evident from repetition of Silurian units. The Western backthrust is well exposed and also repeats the breadth of the orthoquartzites. The western anticlinorium is tightly folded and overturned to the northwest; it's forelimb is thinned and dips 55° southeast. The Tuscarora formation exposed in the core displays kink geometry and disharmonic folding, causing variable bed thickness. Elsewhere, all competent units exhibit kink folding

DISCUSSION

The rock units in the Lynchburg Reservoir area, specifically the Cotoctin greenstones, are well exposed and mapped. This traverse has rapidly varying, total-field anomaly readings. An examination reveals a decrease followed by an increase of 3000 nT. This rise at 1500 feet coincides with a suite of closely spaced greenstones. Correlation of greenstone exposures and the magnetic traverse suggests that rapidly varying readings with ranges of 1000 nT apparently are related to the greenstones. A magnetic model substantiates the correlation between the greenstones and these 1000 nT anomalies. When several closely spaced greenstones were modeled using closely spaced, steeply dipping polygons, it proved impossible to match anomaly curves exactly, but the general magnitude and broad dimension of anomaly and model curves are similar.

The Beverlytown traverse has fewer exposures of greenstone. Covered primarily with the metasedimentary rocks of the Chilhowee group, there is little reason to expect significant anomalies. However, the total-field curve for this traverse illustrates anomalies of approximately the same magnitude as those at the Lynchburg Reservoir (Fig. 1). The largest anomaly begins at a traverse location of 10,000 feet. This coincides with the DDZ. As this is simply a zone of deformation, it is difficult to explain such a large anomaly. This 2400 nT rise is on the same scale as that produced by the Cotoctin greenstones at the Lynchburg Reservoir. This would suggest that perhaps there are buried greenstones intermixed with the metasedimentary rocks of the Chilhowee. Figure 2 illustrates that a greenstone dike models the anomaly size and shape quite nicely.

CONCLUSIONS

Exactly modeling the closely-spaced suite of Cotoctin greenstones proved difficult. Though one outcrop of greenstone could be effectively modeled, more than one outcrop could not. Some of this difficulty arises due to the uncertainty of the structure at depth as well as susceptibility magnitudes and variations.

The most successful aspect of this project was the specific correlation of greenstone outcrop and magnetic anomaly curves which provided a standard for suggesting the presence of subsurface greenstones. The rocks that outcrop along the Beverlytown traverse are not highly magnetic, but significant magnetic anomalies are present in the area. The fact that greenstones outcrop directly north of the traverse and that the anomalies are strikingly similar to the greenstone anomalies at Lynchburg Reservoir suggests greenstones are present at depth along the Beverlytown traverse.

Using magnetics as a mapping tool is helpful in that it demonstrates the presence and location of magnetic units in the subsurface On the other hand magnetics is less useful for mapping exact locations of closely-spaced, highly-magnetic, suites of rock due to the complex anomaly patterns such geometries produce.

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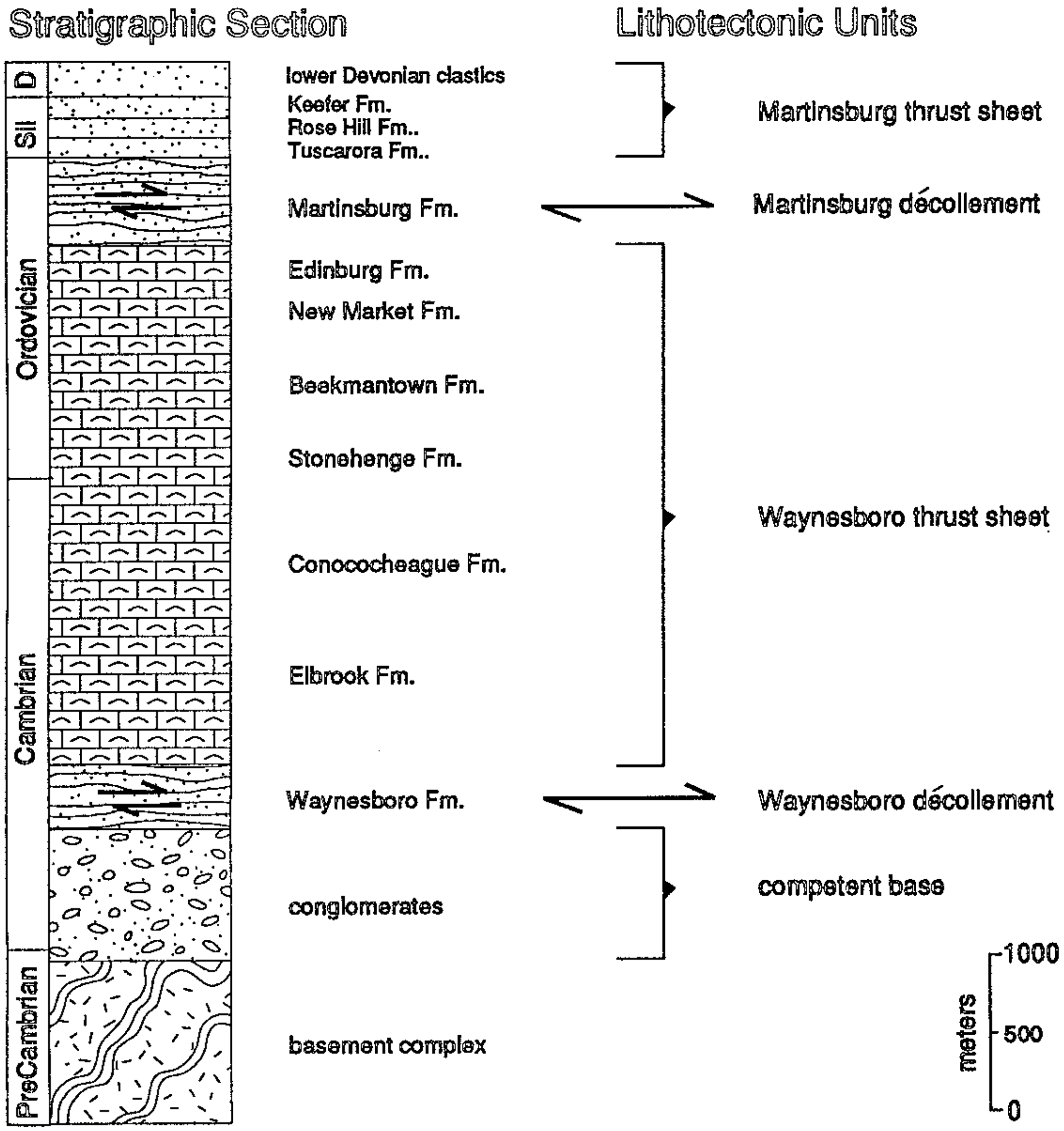

Figure 1. Stratigraphic and lithotectonic units of the study area. Décollement exists in the Waynesboro and Martinsburg shales.

Stratigraphic thicknesses of Silurian orthoquartzites were calculated from local outcrop and thicknesses of lower unexposed units were taken from nearby areas of outcrop: thickness of the Cambrian-Ordovician carbonates was adopted from the Ray Sponaugle Well (Perry, 1964); the lower Cambrian from Evans (1989).

Seismic interpretation of basement depth, 5150m, was provided by Edgar Spencer (unpublished data). Extensive seismic surveys have been completed in the Valley and Ridge and Evans' (1989) compilation of data is in accord with the 5150m interpretation. One drill hole has reached the basement in Russel Country, VA, 300km away at the equivalent depth of 5152m.

Discussion

Balancing developed as a means to constrain interpretation of complexly deformed fold belts. It accomplishes this with relatively simple models of deformation which do not absolutely adhere to the realities of folds and thrusts. Use of simple line-length and area-balanced models outlined by Suppe (Mitra, 1992) requires the following assumptions about deformation mechanics: constant bed thickness, conserved bed lengths, angular folds and faults, and flexural-slip. Such conditions are not completely met in the Valley and Ridge nor the study area. Beds do not maintain uniform thickness nor do they deform only into kink geometries. Flexural-slip along bedding planes was the dominate deformation mechanism but, flexural-flow was involved as well. With balancing assumptions, these conditions will be neglected, and a small degree of error will be introduced into the interpretation.

To employ balancing techniques and facilitate cross-section construction, the following assumptions will be made: (1) uniform bed thickness, except for the Martinsburg shale, (2) flexural-slip along bedding, except for flexural-flow in the Martinsburg, (3) lower unit thicknesses adopted from the Great Valley are equal to those in the study area, (4) accurate seismic interpretation, (5) lower sheet deformation style is analogous to proximate structures, and (6) thrusts in the Cambrian-Ordovician are straight and dip at equal angles.

Ramping in the lower carbonates effectively doubles its height in places. Modeling the lower thrust sheet will be primarily accomplished by filling in these structural culminations with fault-bend and fault-propagation folds. Line-length restoration will be used to balance competent, key-beds, and area restoration will be used to balance the Martinsburg. Since the interior foreland is 150km west, no regional pin line can be established, but local pin lines in areas of no interbed slip may facilitate balancing. Restoration is also complicated by the two phases of deformation in the Valley and Ridge. The first episode deformed the upper sheet and the second deformed both the lower and upper sheets. This two-phase event likely influenced the differential shortening experienced in the two thrust sheets; upper sheet shortening exceeds that in the lower sheet (Kulander, Dean, 1986). Thus, the two episodes of deformation must be restored and balanced separately (Mitra, 1992), starting with the lower, younger event in the Waynesboro sheet.

Conclusions

The discrepancy between basement depth (5150m) and the stratigraphic height (4150m) is due to significant thrusting and folding which has effectively added 1000m of relief to the sedimentary package. This deformation is reflected at the surface by the folded Martinsburg sheet. Anticlinoriums and synclinoriums represent zones of structural highs and lows in the lower thrust sheet, controlled by the position of lower thrusts. Estimates on shortening for the lower and upper thrust sheets will be established pending completion of a balanced cross-section.

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