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Using 3-D mapping to understand an Upper Ordovician buildup and facies complex in the upper Lexington Limestone, central Kentucky, USA

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ABSTRACT

The upper parts of the Upper Ordovician Lexington Limestone in central Kentucky, USA, are interpreted to reflect a structurally controlled carbonate buildup, represented by a facies mosaic of shoal complexes and interbedded shale units. Facies intertonguing is complex and two-dimensional (2-D) mapping has been difficult. In this project, we converted 2-D maps to 3-D maps to show the extent of various facies and the complex nature of intertonguing. The resulting 3-D maps can be viewed from various vantage points and show the likely influence of basement structures as well as the results of post-depositional structural activity.

Introduction

The Lexington Limestone, also known as the Trenton Limestone in the subsurface, is a prominent Upper Ordovician (Sandbian–Katian; Chatfieldian–Edenian) limestone and shale unit that crops out in the Jessamine Dome culmination of the Cincinnati Arch in north-central Kentucky, USA (Fig. 1). It was deposited during the Taconic tectophase of the Taconian orogeny across the Lexington Platform, immediately cratonward of the Taconian foreland basin (e.g., Ettensohn et al. 2004). Since the Lexington Limestone was first described in 1898, the formation and its members were interpreted to exhibit relatively tabular, "layer-cake" geometries (e.g., McFarlan 1943), and Lexington only included members up to the level of the Brannon Member (Fig. 2), which are approximately equivalent to the Trenton Series of New York (Brett

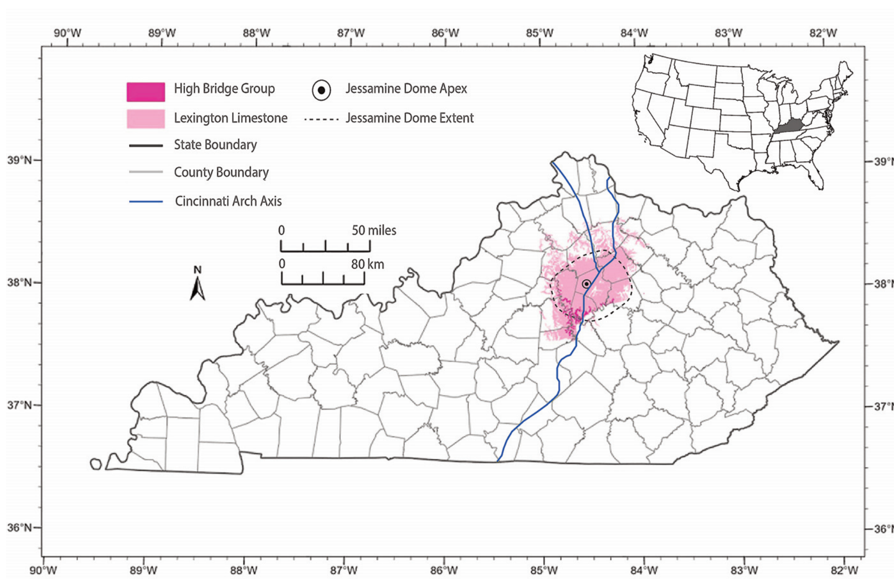

Fig. 1. Distribution of the Upper Ordovician Lexington Limestone and underlying High Bridge Group, exposed on the Jessamine Dome culmination along the Cincinnati Arch. Much of the unit distribution reflects parts of the post-Trenton upper Lexington Limestone (parts above the Brannon Member; see Fig. 2).

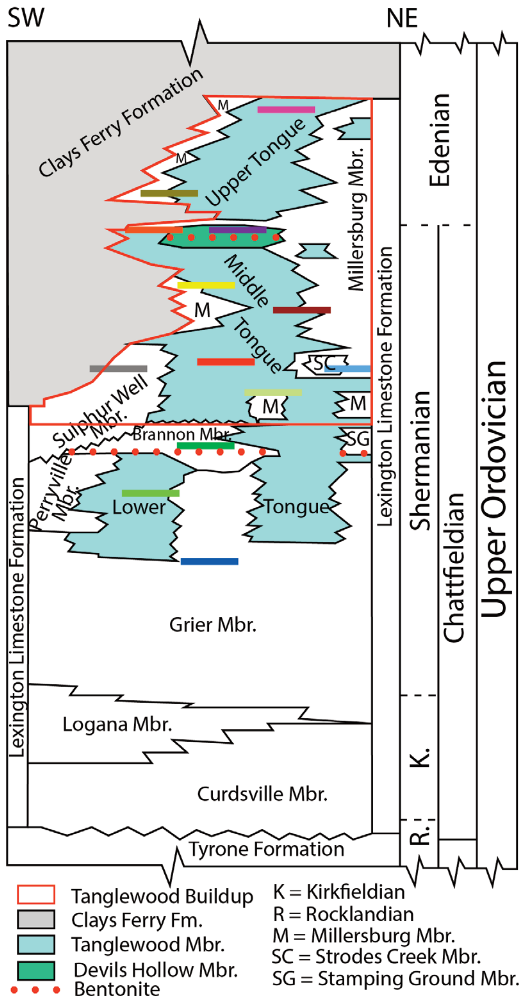

Fig. 2. Schematic stratigraphic column of the Lexington Limestone showing the facies mosaic in the upper part of the unit, or Tanglewood buildup, only part of which is shown. The colored horizontal lines represent contact horizons that were mapped as separate layers or feature classes on the final 3-D map. Each color represents a member or a Tanglewood tongue (adapted from Ettensohn et al. 2004).

et al. 2004). Hence, the Lexington Limestone is called the "Trenton Limestone" in the subsurface of Kentucky (e.g., Shaver 1985) and adjacent states. However, during the combined U.S. Geological Survey-Kentucky Geological Survey Mapping Program from the 1960s to the early 1990s, detailed mapping in central Kentucky showed that "stray" tongues of bioclastic, calcarenitic limestone interbedded with shales and nodular limestones, which occurred above the Lexington Limestone in the Cynthiana Formation, were lithologically similar and intertongued with parts of the Lexington Limestone below (e.g., Black et al. 1965) (Fig. 2). Hence, the term "Cynthiana" was abandoned, and the various bodies of bioclastic limestone were included as the Tanglewood Member of the Lexington Limestone (Black et al. 1965), which expanded the thickness and concept of the Lexington Limestone to carbonate units younger than the Trenton equivalents in central Kentucky (Fig. 2). These re-interpretations meant that the Lexington Limestone in central Kentucky was about 98 m (320 ft) thick, compared to a more typical thickness of 61 m (200 ft) for the more tabular, subsurface Trenton equivalents, which intertongue on all flanks with the shales and fine-grained limestones of the Clays Ferry Formation (Black et al. 1965; Cressman 1973) (Fig. 2).

In 1992, Ettensohn examined the distribution of the coarse, bioclastic, Tanglewood limestones and made cross sections through them, suggesting that the extra thickness of the upper Lexington Limestone in the central Kentucky area (37 m, 120 ft) and its roughly triangular outline reflected a carbonate buildup on reactivated basement structures (Ettensohn 1992). The coarse, bioclastic limestones in the buildup (Tanglewood Member; Fig. 2) were interpreted to represent shoal complexes related to periods of uplift, whereas interbedded shales were interpreted to represent eustatic highstands (Ettensohn et al. 2004). The roughly triangular distribution of these shoal complexes was shown to coincide with modern structures that had basement precursors. This coincidence was the impetus for us to generate a 3-dimensional (3-D), compatible geoframework map to answer two key questions: 1) can 3-D mapping be used to characterize complex geologic surfaces such as those that bound the upper Lexington Limestone and its included members; and 2) can 3-D mapping confirm the likelihood of structural control on the upper Lexington Limestone and its members?

Procedures

The Lexington members or tongues to be mapped were color-coded (Fig. 2), and those colors were applied to contacts in an already digitized state geologic map. Individual, colorized, contact horizons were then mapped as layers or feature classes (Fig. 3). Point features along each line were subsequently generated and associated with an elevation from the Kentucky Digital Elevation Model. Even though the colored layers appear to be horizontal, they represent a range of elevations. A half-mile buffer zone was then generated around each point

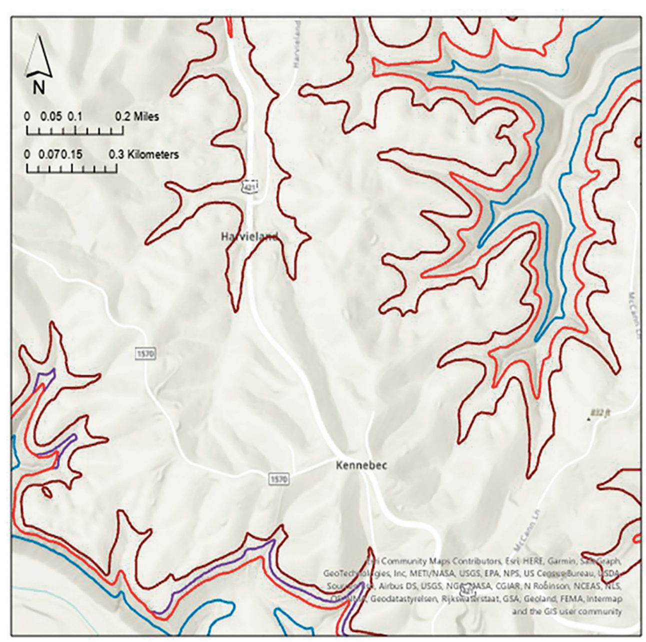

Fig. 3. Outcrop contacts for the Grier (blue), Tanglewood (orange and brown) and Devils Hollow (purple) members of the Lexington Limestone shown as specific, color feature classes, as indicated by similarly colored horizontal lines in Fig. 2.

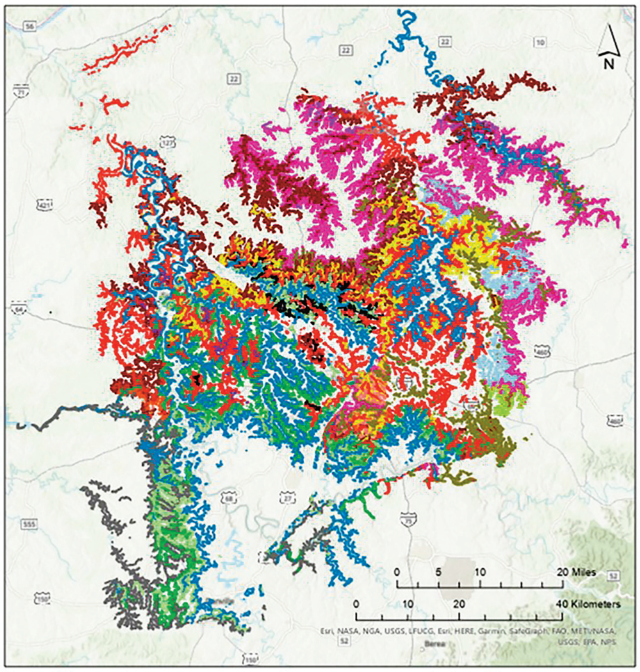

Fig. 4. Expanded (buffered) contacts of upper Lexington Limestone units in central Kentucky as 2-D polygons. Contact colors as indicated in Fig. 2.

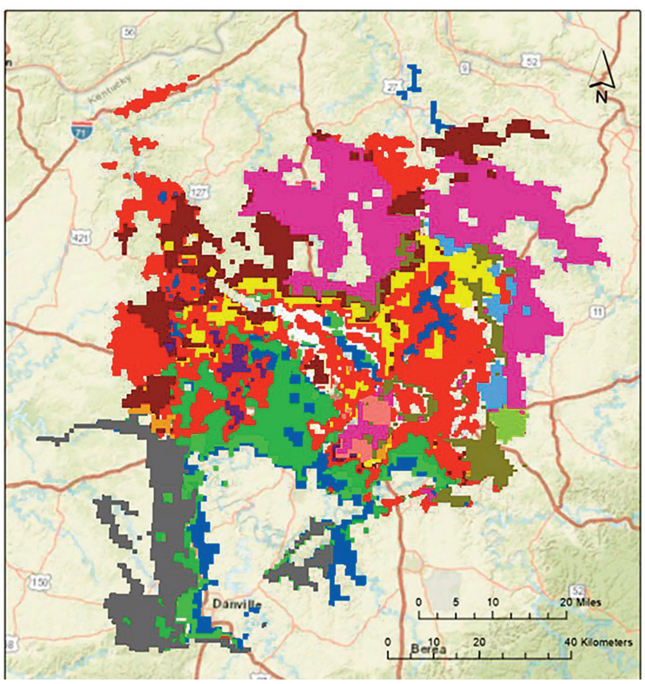

Fig. 5. Aerial view of the 3-D raster file based on the data points in Fig. 4 for units in the upper Lexington Limestone. Colors reflect colored contact lines in Fig. 2.

feature on each color feature or contact so that each contact could be converted into a polygon with contour-like characteristics (Fig. 4). As each point on any one of the color contacts or features has an elevational component associated with it, the two-dimensional (2-D) map files (Fig. 4) can be converted into 3-D raster files, so that each color feature or contact represents a range of elevations (Fig. 5). The polygons in Fig. 5 are now 3-D compatible and presented in a superpositional framework so that colored layers higher in the section in Fig. 2 are superimposed on lower-level, colored layers.

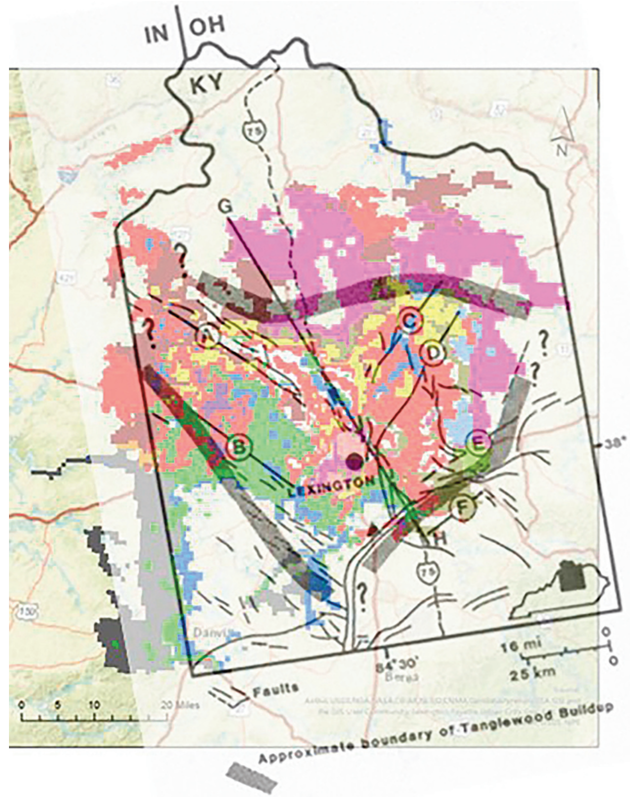

Fig. 6. Superposition of the Lexington area structure map from Ettensohn et al. (2004) on a 3-D raster-file map (Fig. 5), showing patterns that correlate with known structures.

Large-scale structural trends also become apparent when a Lexington area structural map (Ettensohn et al. 2004) is superimposed on the 3-D map (Fig. 6). This superpositional framework enables rotation around multiple axes, as shown in Fig. 7. Figure 7 depicts a cross-sectional view from an eastward-looking vantage point. Different rotational views may show varying trends in elevation, facies interrelationships, and the aerial extent of members and tongues.

Discussion

This study demonstrates the possibility of using 2-D mapping to generate 3-D maps, observable from multiple vantage points. By color-coding important contacts and associating points on the contacts with elevation data, 2-D maps were used to generate 3-D properties, such as stratigraphic and structural trends. Changes in elevation and member distribution align well with the previously mapped 2-D, triangular Tanglewood buildup (Fig. 6), Jessamine Dome, and some major fault zones (Fig. 6). Although mapped structures do reflect reactivated basement faults, and 3-D mapping does suggest facies control by these structures, structural features such as the Jessamine Dome and the sloping beds in Fig. 7 are the product of structural activity during or since the last major orogenic event during Pennsylvanian–Permian time.

The methodology clearly has limitations, including the resolution of the stratigraphic horizons to be mapped, the type of software, and the extent of previous 2-D mapping. Confirming elevation data for contacts in the field is critical for ensuring confidence in the resulting 3-D maps.

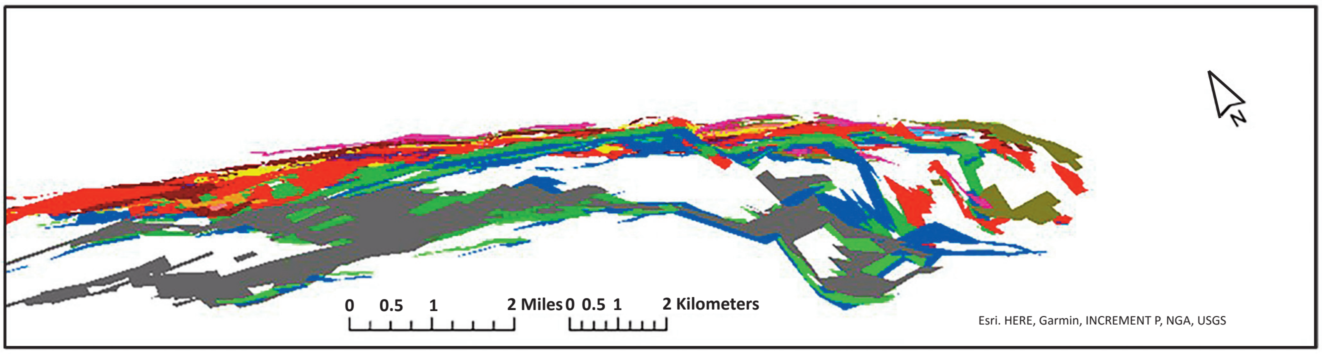

Fig. 7. Three-dimensional sectional view of the map in Fig. 5, looking eastward, generated by rotation around an axis. The view shows the gently dipping nature of beds on the Jessamine Dome, as well as the sloping nature of the Grier (blue), Sulphur Well (gray), lower Tanglewood (light green) along a declivity in the right foreground that is associated with fault zone B and one side of the Tanglewood buildup (Fig. 6).

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