

USING STATE-WIDE GIS DATA TO IDENTIFY THE COINCIDENCE BETWEEN SINKHOLES AND GEOLOGIC STRUCTURE

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The Kentucky GIS coverage of sinkholes, completed in 2003, consists of 101,176 polygons representing the uppermost closed contour of every karst sinkhole identified using USGS 1:24,000 scale topographic maps. This resource is a useful tool for delineating karst landscapes in Kentucky because karstified limestones underlie 55% of the areal surface of the state. For hydrologic studies, alignments of sinkholes commonly indicate preferential flowpaths for groundwater; and this information aids in large-scale planning and zoning. In this paper, I demonstrate the effectiveness of using this sinkhole coverage as a tool for delimiting structural features of Kentucky.

INTRODUCTION

The relationship between karst features and geologic structures is well documented. At the largest scale, geologic structures determine the exposure of limestones to karst processes (White *et al.*, 1970). At a medium scale geologic structures determine the flow paths in karst aquifers (Parizek, 1976; Nelson, 1988). At a small scale, geologic structures have a significant impact upon the ultimate morphology of conduit systems (Ford and Ewers, 1978; White, 1988; Palmer, 1991).

Sinkholes are a common feature used to identify subsurface lineaments or “photo-linears” (Littlefield *et al.*, 1984; Howard, 1968; Kastning, 1983; Orndorff and Lagueux, 2000). Thus, sinkhole alignments are considered an indication of preferential flowpaths for groundwater (Elvrum, 1994; Taylor, 1992). The low matrix permeability characteristics of Kentucky limestones enhance the correlation between sinkholes, secondary permeability, and groundwater flowpaths (Worthington *et al.*, 2000). Secondary permeability features, such as fractures, faults, and bedding planes, are frequent in telenetic limestones, such as those in Kentucky, due to brittle deformation during uplift and exhumation (Vacher and Mylroie, 2002).

THE KENTUCKY SINKHOLE GIS COVERAGE

From 2000 through 2003, the Kentucky Geological Survey (KGS), in association with the Kentucky Speleological Survey (KSS) digitized all karst sinkholes in Kentucky using the upper-most closed contour present on 1:24,000 scale topographic maps (Paylor *et al.*, 2003). The complete GIS shapefile coverage is available to the public on the KGS website (www.uky.edu/KGS). The numbers are staggering. In Kentucky, karstified limestones underlie 55% of the land area. In these karst regions, 101,176 topographic sinkholes occupy 4% of the total land area of the state (Figure 1a).

The sinkhole delineation project began in response to individual project needs (Florea *et al.*, 2002); however, by completion it became clear that the GIS coverage would become a

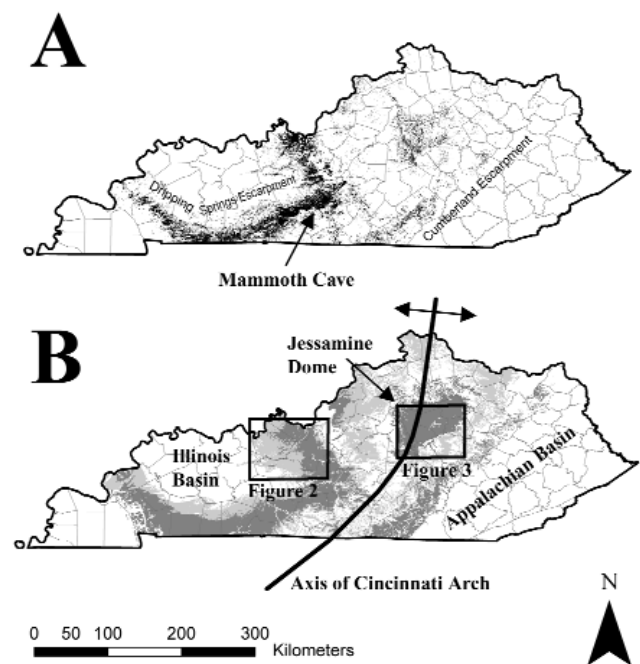


Figure 1. State-wide GIS coverages of sinkhole data (A) and karst occurrence (B) for Kentucky (Paylor and Currens, 2002). Black areas in A denote digitized sinkholes. Dark-gray areas in B denote areas underlain by limestones with a high potential for karstification. Light-gray areas denote areas underlain by limestones with low to moderate potential for karstification. Sinkholes in A correlate well with highly karstified limestones from B. The exposure of the highly karstified limestones and thus sinkholes correlate to large-scale structural features noted in B. The bounding boxes for Figures 2 and 3 are shown in B. High-density sinkhole plains are visible near Mammoth Cave in A.

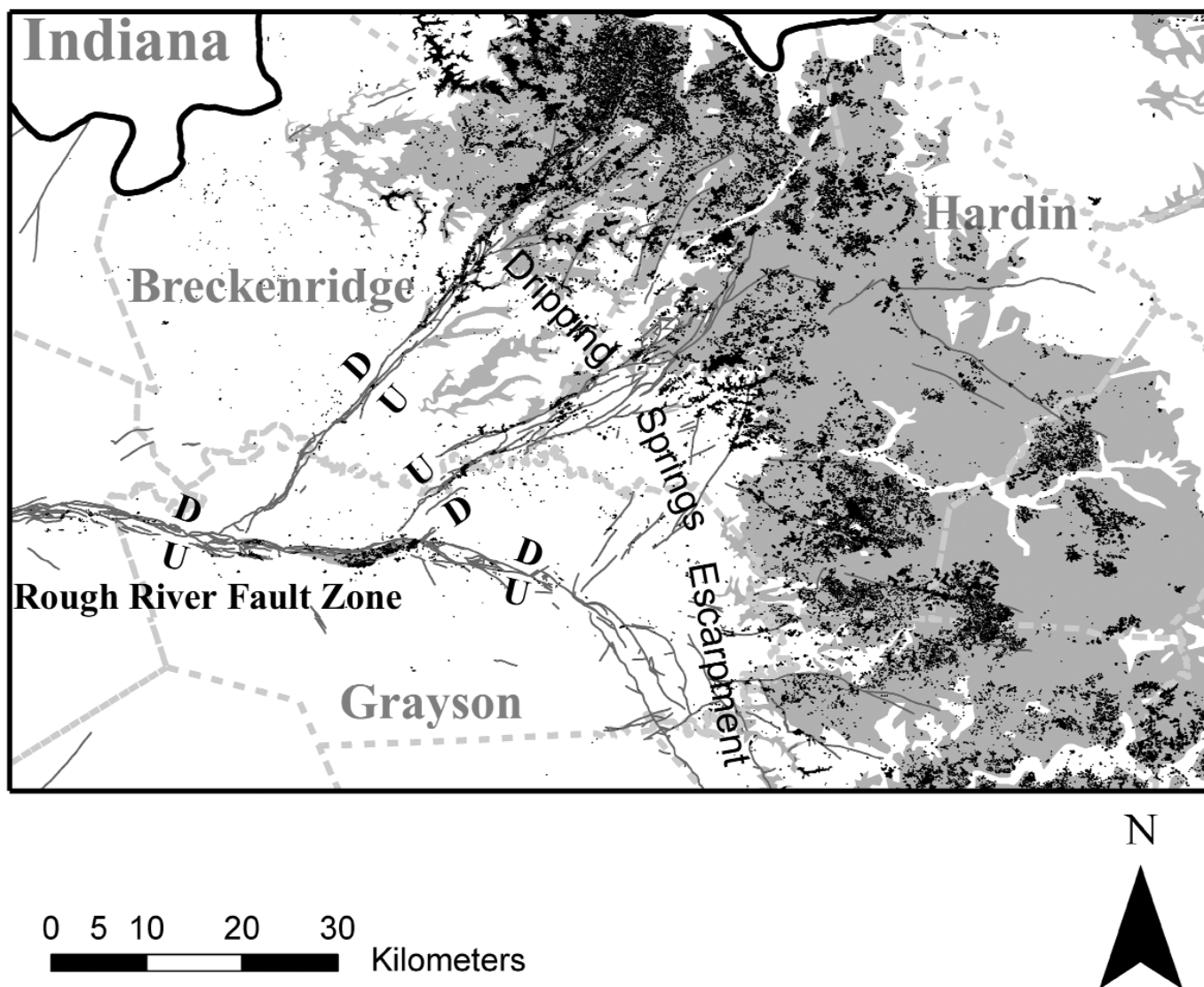


Figure 2. Sinkholes (black polygons), highly karstified limestones (dark-gray area), and faults (solid, dark-gray lines) in Breckenridge, Grayson, and Hardin Counties, Kentucky. Sense of motion for major fault zones is denoted by U for the up-thrown side and D for the down-thrown side. The Dripping Springs Escarpment separates the highly karstified Mississippian limestones from the Pennsylvanian sandstones and shales to the west. A good correlation exists between sinkhole alignments and portions of the Rough River Fault Zone, especially in areas of Grayson County where the up-thrown side of normal faulting has exposed limestones in a region otherwise dominated by sandstone and shale.

valuable resource to state agencies, environmental and transportation industries, and the public. Patterns emerged in the sinkhole distribution during digitization which correlate to geological boundaries and features and reflect the underlying geologic structure of Kentucky.

EXAMPLES OF CORRELATING SINKHOLES WITH STRUCTURAL FEATURES

LARGE-SCALE

The state-wide sinkhole map conveys large-scale geological information (Figure 1a and b). Regions of sinkhole development correlate to the exposure of karstified limestones

(Paylor and Currens, 2002). In the Inner Bluegrass region along the axis of the Cincinnati Arch the Ordovician-age Lexington Limestone is exposed at the center of the Jessamine Dome. On the east flank of the arch, Mississippian-age limestones plunge into the Appalachian Basin along the Cumberland Escarpment. These same Mississippian limestones border the Dripping Springs Escarpment and outline the edge of the Illinois Basin on the west side of the arch. The high-density sinkhole plains in the Mammoth Cave region are clearly visible.

Additionally, the occurrence of some sinkhole groupings correlates to systems of faults. In Breckenridge, Grayson, and Hardin Counties it is possible to trace portions of the Rough

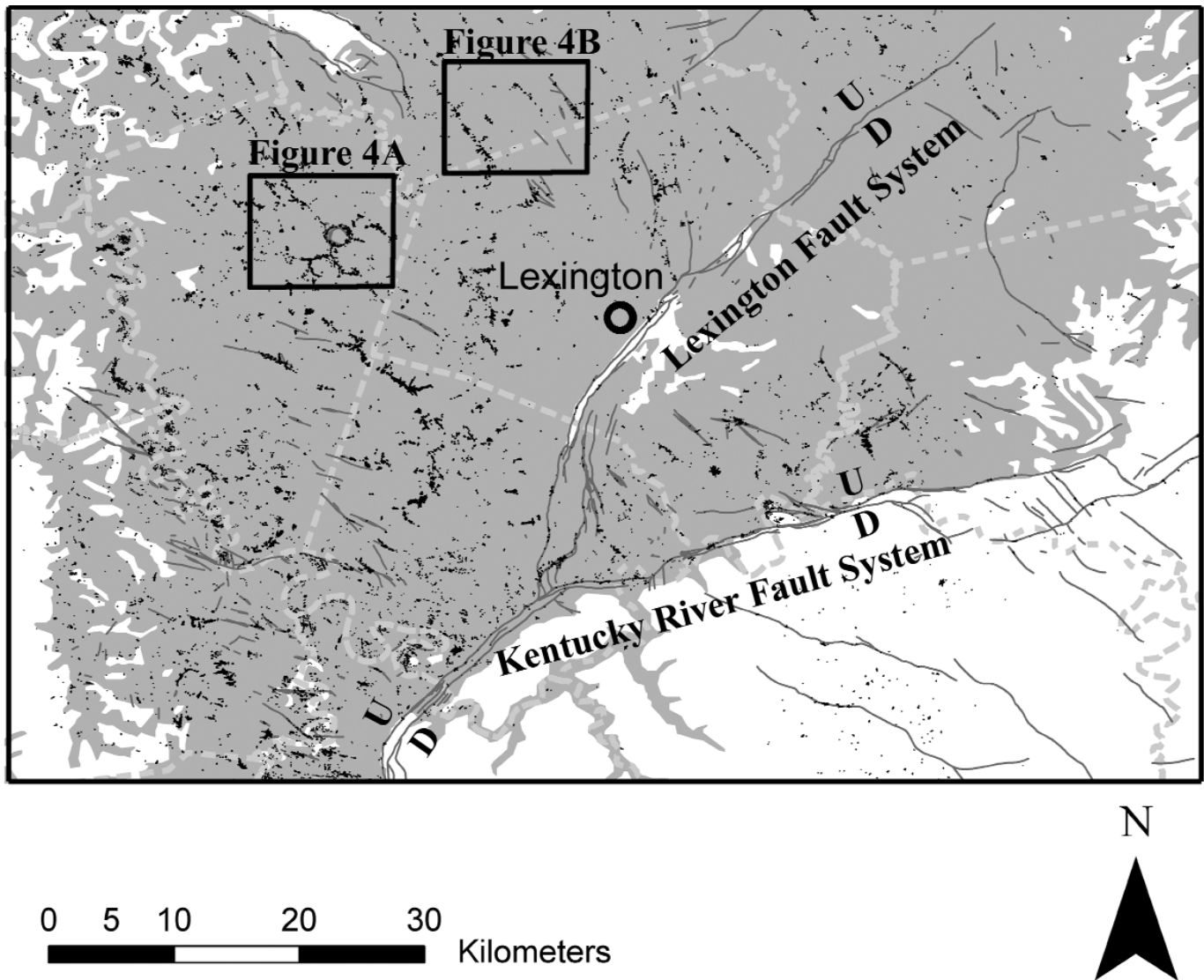


Figure 3. Sinkholes (black polygons), highly karstified limestones (dark-gray area), and faults (solid, dark-gray lines) in a portion of the Inner Bluegrass Region near Lexington. Sense of motion for major fault zones are denoted by U for the up-thrown side and D for the down-thrown side. The Kentucky River and Lexington Fault Systems act as a geologic boundary between the highly karstified Lexington Limestone to the north and west (the up-thrown side) and the argillaceous Clay's Ferry Formation to the south and east (the down-thrown side). The dominant NW alignment of sinkholes in the Inner Bluegrass is clear in the north western portion of the figure. The bounding boxes for Figures 4A and 4B are shown.

River Fault zone using sinkhole alignments (Figure 2). Geologic offsets due to normal faulting in Grayson County expose Mississippian limestones in a region otherwise dominated by Pennsylvanian sandstones and shales (Figure 2).

Fault offsets often produce geologic boundaries for karst development. The division between the Inner and Outer Bluegrass physiographic provinces occurs at the boundary between the karst-rich Lexington Limestone and the argillaceous Clay's Ferry Formation — both of Ordovician age. South and east of Lexington this boundary occurs due to normal faulting along the Kentucky River and Lexington Fault Systems (Figure 3).

MEDIUM-SCALE

The dominant control on sinkhole alignments in the Inner Bluegrass region is a series of NW-trending fractures (Thraillkill, 1992; Elvrum, 1994, and references therein). Taylor (1992) found it difficult to ascribe these fractures to a specific tectonic event even though Stafford (1962) claimed that the fractures resulted from tensional forces related to the uplift of the Cincinnati Arch and Jessamine Dome. Irrespective of their origin, these fracture traces play an important role in the direction of groundwater flow (Taylor, 1992). These NW alignments are clearly visible in the sinkhole GIS data (Figures 3 and 4). Also visible is a circular and radiating alignment of

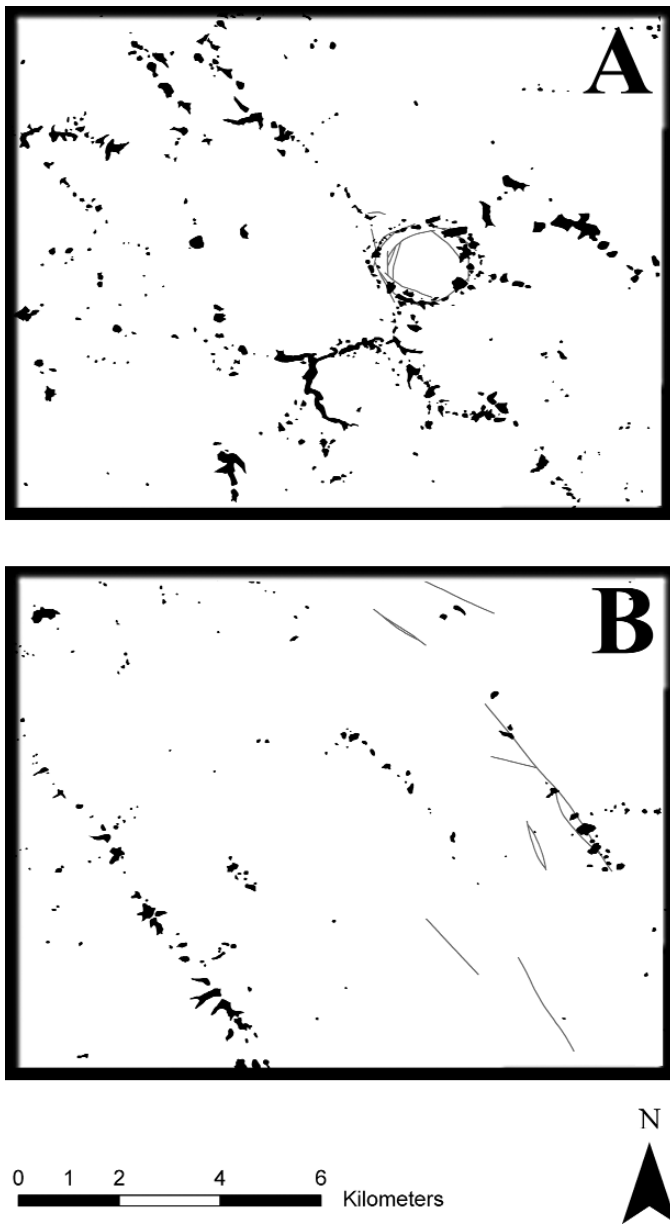


Figure 4. Sinkholes (black polygons) and faults (solid, dark-gray lines) for select portions of the Inner Bluegrass Region expanded from portions of Figure 3. In A the Versailles impact structure is clearly visible as a ring of sinkholes. These correlate closely with a ring of mapped faults. The down-thrown side of the faults is toward the center of the impact structure. While some sinkhole alignments correlate with known faults or fractures in B, other sinkhole alignments indicate the presence of otherwise unknown structural features.

sinkholes that correlates to the Versailles impact structure (Figure 4a). Discovered in 1962, this mile-wide circular structure within the Lexington Limestone is of late Ordovician age and consists of a brecciated central dome, and a marginal structural depression partly bounded by normal faults (Black, 1964).

Interestingly, while some sinkholes align with known faults, other faults have no overlying sinkholes, and many sinkhole alignments suggest currently unknown faults or fracture traces. Taylor (1992) found that only 12% of sinkhole alignments in the Inner Bluegrass overlie fault zones and hypothesized that mylonitization (fault gouge) could prevent groundwater flow. Fractures, with little or no offset and fault gouge, would enhance rather than reduce groundwater flow. These fracture traces are not included in the available GIS coverage of faults.

Considerable supporting data suggests that fractures are the primary control of sinkhole alignments in the Inner Bluegrass. For instance, in the areas surrounding Figure 4, Taylor (1992) found peaks on a rose diagram for sinkhole alignments at 310° – 330° and 340° – 360° . Elvrum (1994) found similar peaks on rose diagrams for topographic map fracture traces (310° – 330° and 340° – 360°), sinkhole long-axis orientations (320° – 330° and 350° – 360°), and color infra-red photolines (330° – 350°).

Sinkhole GIS data, combined with field reconnaissance, is a proven tool for tracing significant medium-scale structural features in Kentucky (Florea, 2002). Additionally, the ability of the sinkhole GIS data to assist in identifying yet unknown structural features is a valuable resource unanticipated at the beginning of digitization.

CONCLUSIONS

The vast number of digitized sinkholes now available in the Kentucky sinkhole GIS coverage provides a useful tool for delineating karst regions, promoting accurate hydrologic studies, and assisting planning and zoning. The correlation between structural features and sinkhole occurrence is well documented in the literature and clearly demonstrated using the Kentucky GIS data. Using the data, it is easy to identify regions of karstified limestone exposure, geologic boundaries, and faults and fracture traces. Of particular interest is the possibility of identifying previously unknown structural features using state-wide sinkhole data.

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