STRUCTURAL CONTROLS ON EPIKARST AND SURFACE WATER DRAINAGES IN THE OZARKS

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Abstract

Recent studies substantiate the importance of structural controls (joints, lineaments, faults, dips) on the surface and groundwater hydrology of the Ozarks. Structural controls tend to dominate in the upper, weathered bedrock (epikarst), which affect both shallow groundwater and surface water hydrology.

Several Ozark studies show a correlation between joint (fracture) orientation and straight stream segments, indicating that the fractures provide zones of enhanced weathering that can be highly susceptible to pollution. High groundwater yields along lineaments (fracture traces) indicate their influence on bedrock permeability. Fracture and bedding plane controls in Ozark caves are well documented.

Most of the Ozarks is characterized by mantled karst, which is covered with residuum/soil, and may have no readily observable karst features. Groundwater flow in most Ozark aquifers is dominated by fractures and conduits. Solution enlarged, vertical fractures can reach high densities in the epikarst, representing potential discrete recharge points across the landscape. Ozark residuum can have high permeability, providing little protection. In many cases, karst influences on hydrology can only be observed after rainfall events.

Mantled karst systems may have similar susceptibility to pollution as the more recognizable (geomorphic) karst, especially if the soil cover is disturbed. Land surface impacts along structural features can have a disproportionably high impact to groundwater quality. Ozark water resources can be better protected if the nature and extent of structural/karst influences on surface water and groundwater hydrology are better understood.

Key words: karst structural geology, hydrology, Ozarks

Introduction

The Ozark Plateaus Physiographic Province (Ozarks) consists of a broad, asymmetrical geologic dome that rises above surrounding lowlands (Figure 1). The Province covers approximately 65,000 square miles mostly in Missouri and Arkansas, but also includes parts of Oklahoma, Kansas and Illinois. Erosion of the dome has exposed a sequence of older rock at the center and progressively younger bedrock toward the edge. The Province consists of four sub-sections: Salem Plateau, Springfield Plateau, St.Francois Mountains, and the Boston Mountains (Imes and Emmett 1994). The St.Francois Mountains are the exhumed igneous (Precambrian) core of the Ozark dome, consisting of igneous peaks surrounded by carbonates and clastics. The Salem Plateau roughly coincides with the outcrop of Cambrian and Ordovician bedrock, composed primarily of carbonates with minor clastics. The Springfield Plateau consists of an irregular shaped band of resistant Mississippian carbonates.

Both the Salem and Springfield Plateaus include broad upland plains, which are highly dissected in proximity to large streams. The Boston Mountains are capped by resistant Pennsylvanian sandstone, underlain by Mississippian strata.

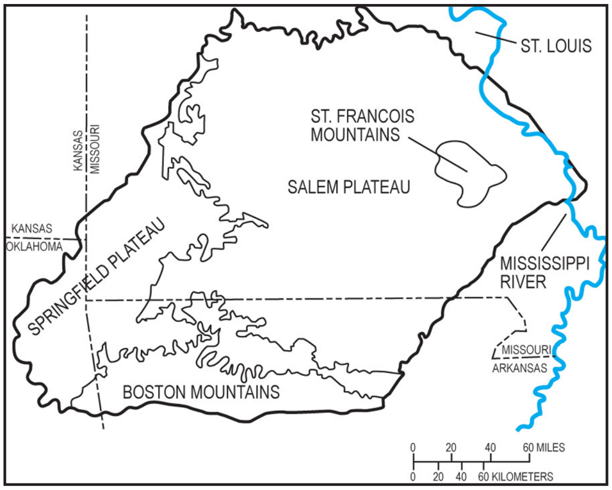

Figure 1 Ozark Plateaus physiographic province and subsections (modified from Imes and Emmett 1994).

The regional bedrock dips are generally low (<5 degrees), away from the center of the dome, with higher dips on the east side of the Province. Thousands of smaller scale structures (faults, anticlines, synclines, etc.) overlie the regional trends. The Missouri Environmental Geology Atlas (MEGA 2007) has over 5,600 "Geo-Structures" documented in an ArcGIS database. The Ozarks have undergone at least six episodes of structural deformation: Precambrian, Upper Ordovician, Pre-Mississippian, Post-Mississippian, Post-Pennsylvanian, and Tertiary (McCracken 1971). The entrenched streams and current seismic activity reflect a continuing uplift of the Ozark dome.

A fractured and faulted igneous basement complex, composed of extrusives (mostly rhyolite) and intrusives (mostly granite), underlies the Ozarks, similar to the St. Francois Mountains. This provided an uneven surface for the subsequent deposition of Paleozoic sediments. The differential compaction across this terrain and reactivation of Precambrian faults may be responsible for some of the structural features exposed in the Ozarks today (McCracken 1971, Harrison et al. 2002).

The Ozarks are noted for well developed karst, with thousands of springs, caves, sinkholes and losing streams. The predominantly carbonate Paleozoic bedrock ranges from hundreds of meters thick to less than 100 meters in proximity to the igneous knobs. Good overviews of Ozark hydrogeology are presented by Imes and Emmett (1994), and Miller and Vandike (1997).

Lineaments and Fracture Traces

Lineaments (>1.6 km or 1 mi. long) and fracture traces (<1.6 km) are mapped based upon tonal patterns that reflect changes in soil, bedrock and vegetation, and the alignment of straight stream/valley segments, and sinkholes. Lineaments are considered (Palmer 2007) to represent zones of intense fracturing (facture swarms), which enhance both surface weathering, and permeability/dissolution in karst aquifers. These features have long been used to locate water wells in karst areas (Ford and Williams 1989).

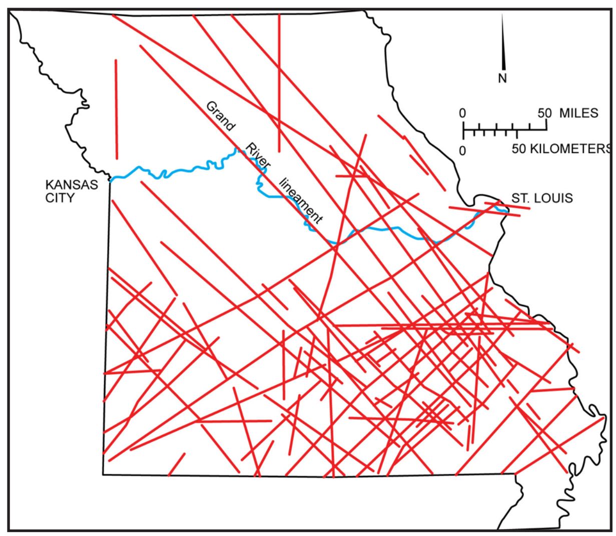

Figure 2 Missouri lineament map (after Kisvarsanyi and Kisvarsanyi 1976).

Missouri has a distinct pattern of roughly orthogonal lineaments (Figure 2), which correlates with the major structural features of Missouri (McCracken 1971). The highest density of lineaments is centered on the St. Francois Mountains, where the basement complex is shallow or exposed. The St Francois Mountains have numerous examples of structurally controlled streams. One of the best examples is the approximately 16-km-long (~10 mi.) segment of the St. Francis River that flows along a prominent lineament (Figure 3).

A correlation between lineaments and faulting has also been noted in the Arkansas Ozarks (Miller and Appel 1997). Lineaments in northern Arkansas were found to correlate with high-yield water wells, especially in the Roubidoux Formation and the Gunter Sandstone member of the Van Buren Formation (Miller and Appel 1997).

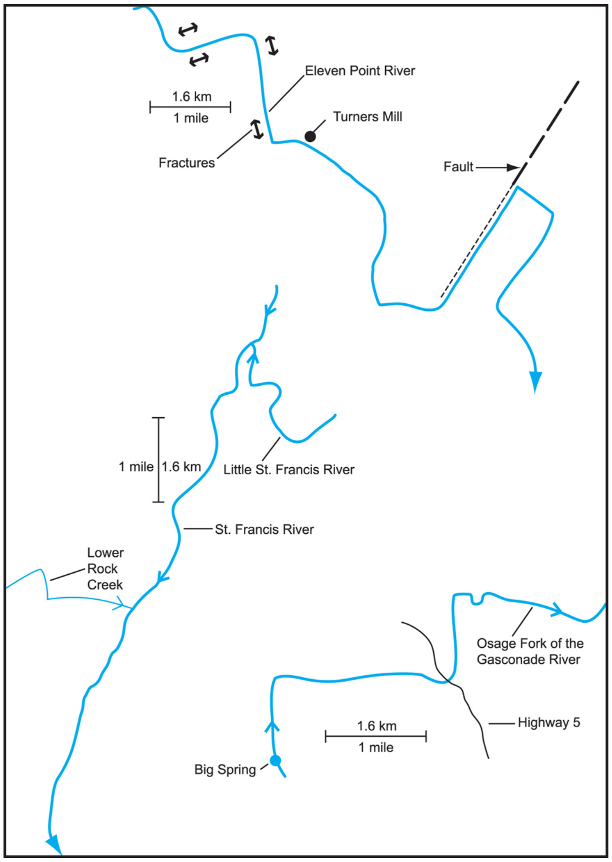

Figure 3 *Examples of structurally controlled rivers in the Missouri Ozarks: St. Francis River, Madison County; Eleven Point River, Oregon County; and the Osage Fork of the Gasconade River, in Laclede County*

Regional Studies

The surface water and groundwater hydrology for parts of the Osage and Gasconade River watersheds was characterized with detailed geologic mapping, stream gauging, stream profiles, groundwater potentiometric maps, and dye tracing (Figure 4) (Harvey et al. 1983). This study concluded that, "The most important controlling factor on the hydrology of Ozark basins is the amount and type of structural deformation. Faulting and jointing deflects streams, alters stream flows, and deflects the underground movement of water". Several of the tributaries studied have a modified dendritic drainage patterns with numerous straight stream segments and abrupt (90°) stream bends, which are attributed to structural controls. A prominent set of northwest trending faults is apparently responsible for the inter-basin flow of groundwater from Dry Auglaize Creek to the Niangua River (Figure 4).

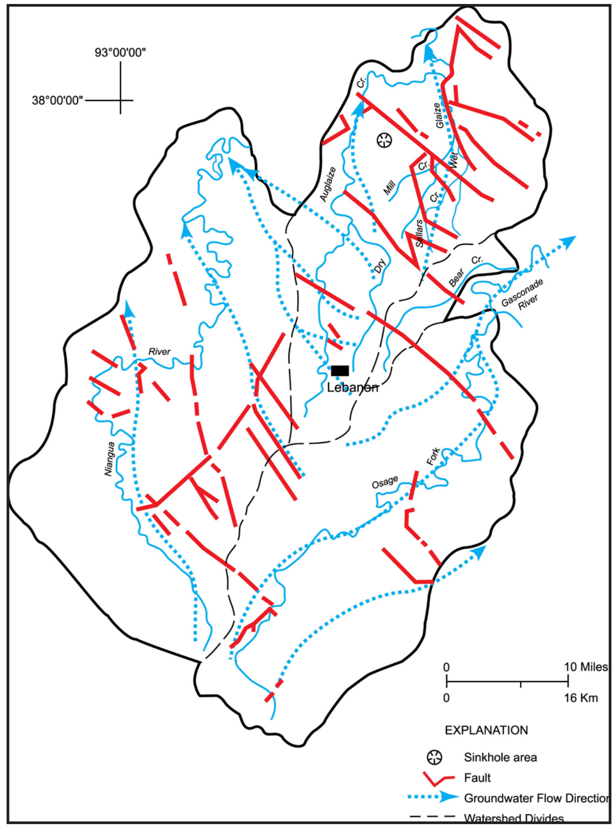

Figure 4 *Structural influences on groundwater flow directions in Osage and Gasconade River tributaries (modified from Harvey et al.1983).*

In his hydrogeologic studies in the Salem Plateau, Aley (1978) and Aley and Aley (1982) found a correlation between lineaments, and both large springs and losing streams. The two largest springs in the Missouri Ozarks (Big and Greer Springs) are located at the intersections of lineaments (Figure 5). Mammoth Spring, the largest spring in the Arkansas Ozarks, is associated with intensely faulted bedrock (Hedden 1968).

In a study on the North Fork basin, Vandike (1979) looked at the relationship of "photo-geologic linear features" (lineaments and fracture traces) and hydrogeology, karst features, and surface drain-

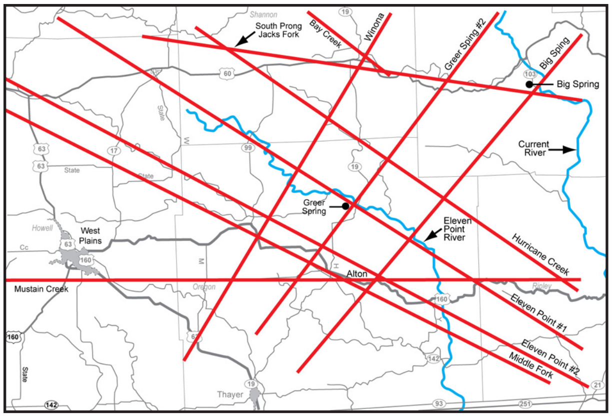

Figure 5 *Lineaments in the Eleven Point River and Current River areas (modified from Aley 1978).*

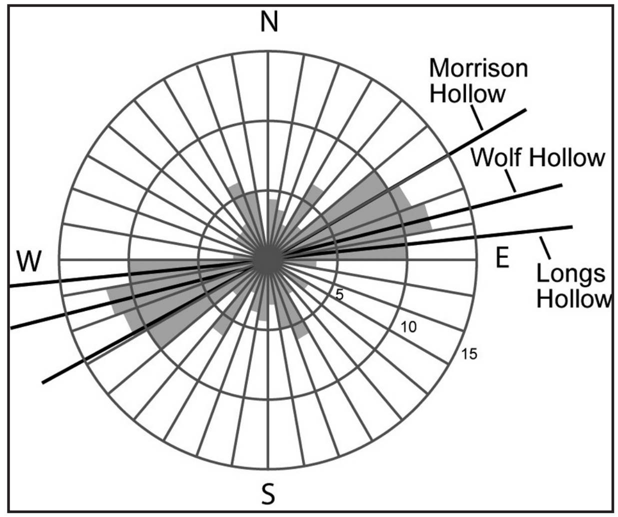

Figure 6 *Compass-rose diagram of bedrock fractures in the Brickey Hills along the Mississippi River, and comparison to straight streams.*

age systems. All of the large springs in the watershed were found to occur at or near the intersection of lineaments. The study found a correlation between bedrock fracture orientations and straight stream segments. Lineaments were also found to correlate with losing streams, faults and the long axis of sinkholes. In addition, several perennial streams lose flow into the subsurface at the intersection of lineaments (Vandike 1979).

In the Turner's Mills section of the Eleven Point River this deeply entrenched river makes several abrupt turns that follow prominent fracture orientations (Figure 3) (McDowell 1998). Just downstream, the River again makes abrupt bends, and in one case matches a fault line (Harrison and McDowell 2003).

Several tributaries of the Current River (Rocky Creek, Mill Creek) form a modified (angular) dendritic drainage pattern that roughly matches fracture and fault orientations (Harrison et. al. 2002). At the Mill Creek Fault crossing of Mill Creek, the perennial surface flow is lost into the subsurface (Harrison et. al. 2002).

The Brickey Hills along the Mississippi River are noted for a series of very deep, straight streams that are roughly parallel to anticlines and synclines, indicating possible structural control (Baker 2001a and 2001b). Dominant fracture orientations were also shown to correlate with these straight streams (Figure 6).

Epikarst

Several studies have documented the intensity

Figure 7 *Fractured epikarst, Johnsons Shut-Ins State Park, Missouri.*

of fracturing in Pre-Pennsylvanian bedrock of the Ozarks (McCracken 1971, Unklesbay and Vineyard 1992). In the Stegall Mountain Quadrangle fracture densities were classified as follows: widely spaced (>1.8 m, 6 ft.), medium spaced (0.6 to 1.8 m, 2 to 6 ft.) and closely spaced (<0.6 m, 2 ft.) (Harrison et. al 2002). This intense fracturing is one of the key components of the Ozark epikarst. Fracture intensity typically decreases with depth as groundwater flow coalesces into master conduits that may be controlled by bedding planes as observed in many Ozark caves. An excellent example of fractured epikarst was recently (2005) exposed in Johnson's Shut-Ins State Park, Missouri (Figure 7). These steeply dipping beds of the Bonneterre Formation show the influences of fracturing and bedding planes on the flow of water through the epikarst. Upon encountering bedrock, water moves laterally along bedding planes until reaching vertical fractures that allow water to descend to lower levels. The fracture orientation may create preferential groundwater flow pathways. Also evident is enhanced dissolution near bedding planes due to the higher groundwater flow (note arrow in Figure 7).

Caves

Geologic structure has also been shown to affect Ozark cave development (Bretz 1956, Taylor 1997). In a study of the hydrogeologic controls on carbonates in Christian County, Missouri, Dreiss (1976) found a correlation between joint orientation and cave passage trends. Brod (1990) identified 22 Missouri caves that may have been influenced by faulting. Brod (1964) also discussed possible structural control in the formation of fissure caves in eastern Missouri. Further discussion of Ozark cave speleogenesis is beyond the scope of this paper (see Elfrink, this volume).

Residuum

Most of the Ozark karst is covered with a thick mantle of overburden, composed predominantly of decomposition and solution residuum (Richman and Weide 1993). The residuum can inherit structures (fractures, clay seams, etc.) from the underlying bedrock (Madole et. al 1991). Ozark residuum typically contains a high percentage of coarse-grained material and can be highly permeable (Aley 1978, Madole et. al 1991). The selective removal of fines in the more porous zones can result in discrete recharge points through the residuum with no surface expressions (Aley 1978). Thus, the overburden can provide little protection to a karst aquifer from surface degradation.

Precipitation Events

In addition to the overburden concealing karst features, the Ozarks have many karst features that are not, under normal conditions, visible at the surface. Examples include gaining and losing streams that may not show either function except after significant precipitation events. In order to understand local hydrogeology, streams must be observed during both dry and wet conditions.

Vulnerability Assessments

The vulnerability assessments of karst aquifers to water degradation have long identified sinkholes and losing streams as high-risk areas because of the direct (unattenuated) entry of surface water (Figure 8). It has become apparent that additional factors need to be considered in assessing vulnerability:

1. The high permeability zones associated with lineaments/fracture traces may be more susceptible to degradation and may have a disproportionately high impact to groundwater quality,
2. Bedrock structure (faults, anticlines, synclines, etc.) can influence surface water and groundwater interactions and flow directions,
3. Fracture density and orientation controls the entry and flow of water and contaminates in the epikarst, and
4. The structure and permeability of Ozark residuum may allow the relatively un-attenuated entry of surface water into karst aquifers.

As more detailed hydrogeologic information becomes available to natural resource managers, it will allow a better assessment of land use risks. Examples include limiting certain activities along lineaments because of enhanced permeability, and more accurate predictions of contaminant migration based upon fracture orientations and geologic structures.

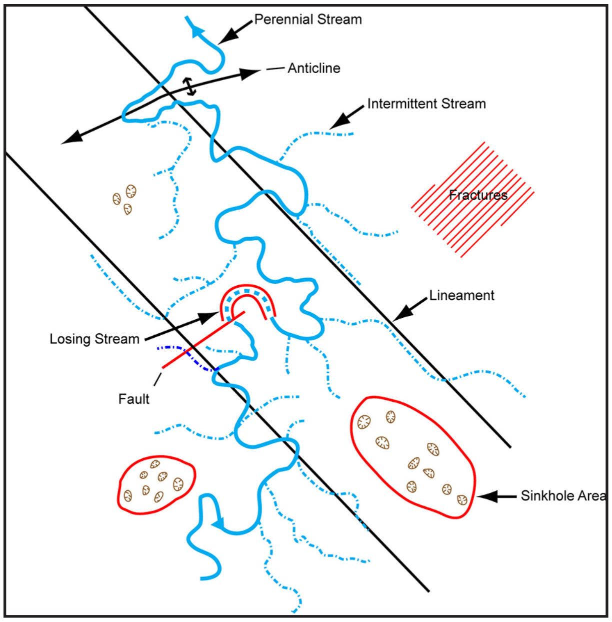

Figure 8 *Vulnerability assessment of a theoretical Ozark watershed.*

Acknowledgments

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