January 2002

Detection of Iapetan Rifting (Rome Trough Tectonism) by Quaternary Karstification: Pulaski County, Kentucky

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Karst Frontiers
Karst Waters Institute Special Publication

DETECTION OF IAPETAN RIFTING (ROME TROUGH TECTONISM) BY QUATERNARY KARSTIFICATION: PULASKI COUNTY, KENTUCKY

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Abstract

Quaternary karstification of Mississippian age carbonates in southern Pulaski County, Kentucky is extensive. Exploration and study of several cave systems in Pulaski County has revealed a high dependence upon geological structure. The spatial location and orientation of the passages and flow paths within Jugornot Cave are independent of surface drainage patterns and continue the trend found in sections of the Coral Cave System. This relationship is shown in sections of several other regional caves. Photographic, statistical, geologic, and seismic evidence gathered from within Jugornot and other regional caves as well as nearby surface features supports the hypothesis that regional speleogenesis has been influenced by faulting. Further evidence suggests this faulting is related to the Rome Trough structure formed during Iapetan rifting in the Late Precambrian to Middle Cambrian. Fractures and lineaments generated by minor reactivation of this fault system have propagated upward through Mississippian and Pennsylvanian strata as fracture swarming. To date 5km of passage have been mapped in Jugornot Cave with a vertical span of 81m. Evidence gathered from this study confirms the presence of the Burnside Lineament previously hypothesized by magnetic anomaly data. Surface and subsurface data from this lineament extends in a 3km band spanning a linear distance of more than 20km at an orientation of approximately 65°. Structural, depositional, and geophysical evidence points toward three sub-parallel right-lateral oblique-slip faults in the Precambrian and Cambrian strata of Pulaski County, including below the Burnside Lineament, related to Rome Trough tectonism.

Introduction

The development of karst aquifers has long been known to be dependent upon geological structure. The dip and strike of strata are well documented to influence the direction of passages based upon their hydrologic conditions. Significant examples have been studied in Mammoth Cave where dip-oriented vadose canyons transition into strike-oriented phreatic tubes (Palmer, 1981).

The speleogenesis, shape, and morphology of conduits are directly related to incipient fractures within the rock strata including bedding planes, joints, and lineaments and faults (Lauritzen and Lundberg, 2000). The organization of this secondary porosity has a significant impact upon the ultimate morphology of conduit systems (Ewers, 1972; Palmer, 1975; White, 1976; Ford and Ewers, 1978; White, 1988; Palmer, 1991). The impact joints have upon the morphology of karst aquifers has been studied significantly. These studies include passage morphology and orientation (Deike, 1969; Ogden, 1974; Palmer, 1975; Kastning, 1981; Ogden, 1983; Cheema and Islam, 1994), surface expression of karst (Howard, 1968; Kastning, 1983; Kastning and Kastning, 1984; Orndorff and Lagueux, 2000), and hydrology (Parizek, 1976; KGS, 1985; Nelson, 1988).

Modern theories relate secondary porosity genesis to speleogenesis. Ferguson (1967) introduced the concept of stress release fracturing as a means to explain the pattern of vertical fractures found in the hillsides and valleys of Appalachia. Sasowski and White (1994) combined this with observations of many cave systems along the Cumberland Plateau to arrive at the Cumberland Style theory of conduit development. In this theory, conduit systems utilize the stress release fracture system, creating master conduits that tend to mimic hillslope topography.

Relationships between conduit development and vertical fracture planes are very apparent in many of the karst areas of the world and is an essential ingredient in the formation of network maze caves (Palmer, 1991). The great gypsum maze caves of western Ukraine (Kilimchouk, 2000) and the maze caves of the Black Hills (Palmer and Palmer, 2000) are the most prolific examples. Other notable examples include the Butler Sinking Cove Complex in Virginia (White, 2000), Anvil Cave in Georgia (Palmer, 1975), and Stykes Cave in Pulaski County, Kentucky (Florea, 2001b).

Faults and lineaments by definition must influence the development of cave systems and examples are found throughout the world. Well known examples include: The Lake Thun system in Switzerland (Haeuselmann et al., 2000), Castleguard Cave System in Canada (Ford et al., 2000), Sistema Cheve in Mexico (Hose, 2000), Timpanogos Cave in Utah (Bullock, 1944), caves of Redwall Limestone of northern Arizona (Huntoon, 2000), Ellison's Cave in Georgia (Taylor, 1997), and the Simmons-Mingo Cave System in West Virginia (Dasher, 2000). Many large karst aquifers with inaccessible conduit systems have been suspected to be influenced by faulting and lineaments including those of the massive springs of Missouri (Vandike, 1979). Dye traces and sinkhole trend analyses in the Bluegrass of central Kentucky have shown that karst development is highly correlative to regional lineament trends (KGS, 1985; Hines et al., 1995). In Kentucky, faults also play a role in the formation of several caves. A few examples include the caves along Pine Mountain in Southeast Kentucky (KGS, 1985), Up-Down Cave in Rockcastle County (Florea, 2001b), and caves along the Kentucky River Palisades.

Study Area

The area encompassed by this study is located in southeastern Pulaski County, Kentucky (Figure 1), in the rugged hills and valleys of the Cumberland Escarpment. The focus of the study area is a region bounded by Pitman Creek to the west, Buck Creek to the east, and the Cumberland River to the south on the Somerset, Dykes, Burnside, and Hail 7.5-minute topographic quadrangles. The region is highly karstified with hundreds of surveyed cave systems and known cave entrances (Florea, 2001b). Primary cave exploration in the study area occurred between 1968 and 1980 by members of the Dayton Area Speleological Society (DASS) and Central Ohio Grotto (COG) of the National Speleological Society.

Regional geologic framework

Stratigraphy

Four limestone units are responsible for the development of karst in study area. The lowermost, the St. Louis Limestone, 23-27m thick, consists of two distinct units. The upper unit, commonly about 6m thick, is composed of micro-grained to coarse-grained, cherty, fossiliferous limestone. The lower unit, 17-21m thick, mainly consists of very finely crystalline dolomite, with interbeds of limestone and minor shale. The Monteagle Limestone, 44-76m thick, is mainly composed of fine- to coarse-grained, bioclastic and oolitic limestones, with varied amounts of micro-grained limestone, lesser amounts of dolomite and chert, and minor shale. It is composed of two primary sub-units the Ste. Genevieve Limestone and the overlying Kidder Limestone. The Hartsell Formation is thin bedded, soft, greenish shale and sandstone that ranges from 1-4m thick in the study area. Above the Hartsell Formation lies the Bangor Limestone, 9-12m thick, a dark-grey, medium-grained limestone. The Paragon Formation, 21-49m thick, is the upper most Mississippian strata composed of shales and claystones, with thin interbedded siltstones, limestones, and dolostones.

Numerous sandstones and shales of the Pennsylvanian age, including the Lee Formation of the Breathitt Group, create an effective caprock prohibiting downward dissolution in the surrounding ridges. The lower part of the Breathitt Group is dominated by thick, cliff-forming, quartzose, conglomeratic sandstones, each 15-30m thick, separated by interbedded shales, coals, and thin, lenticular sandstones of variable thickness. Thickness measurements for units cited are from Greb et al. (2001).

Topography

The outcrop limit of lower Pennsylvanian strata is characterized by the rugged Cumberland Escarpment due to the resistant nature of the conglomeratic sandstones of the lower Breathitt Group. This escarpment is a widespread geologic and topographic feature that separates the Cumberland Plateau to the east from the Mississippian Plateau or Highland Rim, to the west and rises 105-150m above the Mississippian Plateau. These units have a slight regional dip to the southeast of 1-2 degrees. The escarpment is highly karstified. Deep valleys drain from the caprock into large surface rivers and streams incised

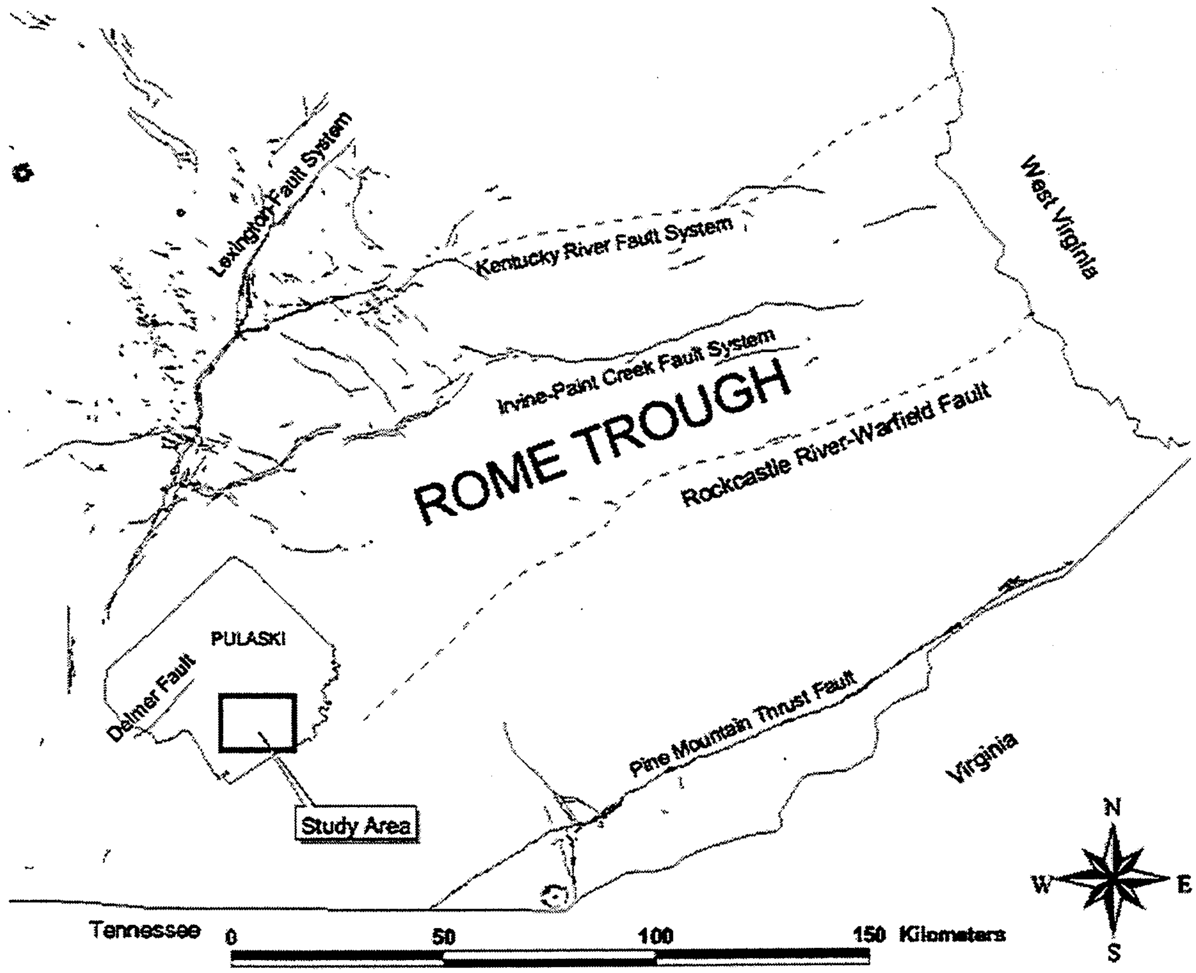

Figure 1: Study area and Tectonic setting.

in the Cumberland Plateau, and karst aquifers of significant size have developed in these valleys.

Tectonics

The study area is located within the Cumberland Escarpment of South Central Kentucky along the eastern flank of the Cincinnati Arch, a broad regional anticline. The Cincinnati Arch is a gentle undulation composed of the Lexington Dome, Cumberland Saddle, and Nashville Dome. It formed due to distant forces during the Paleozoic in association with the formation of the Appalachian Mountains. On the eastern flank of the arch, Mississippian carbonates dip toward the southeast into the central Appalachian Basin.

The Rome Trough is a linear, asymmetrical, graben-like subsurface structure of Kentucky and West Virginia. It is bounded on the north by the Kentucky River Fault System, on the west by the Lexington Fault System, and on the south by the Rockcastle River-Warfield Fault (Figure 1). The southwest boundary of the Trough in the vicinity of the study area has not been identified, though sources such as Black (1989) and Dever et al. (1990) indicate that evidence may exist.

The Rome Trough represents a Late Precambrian to Cambrian rift zone (Ammerman and Keller, 1979; Webb

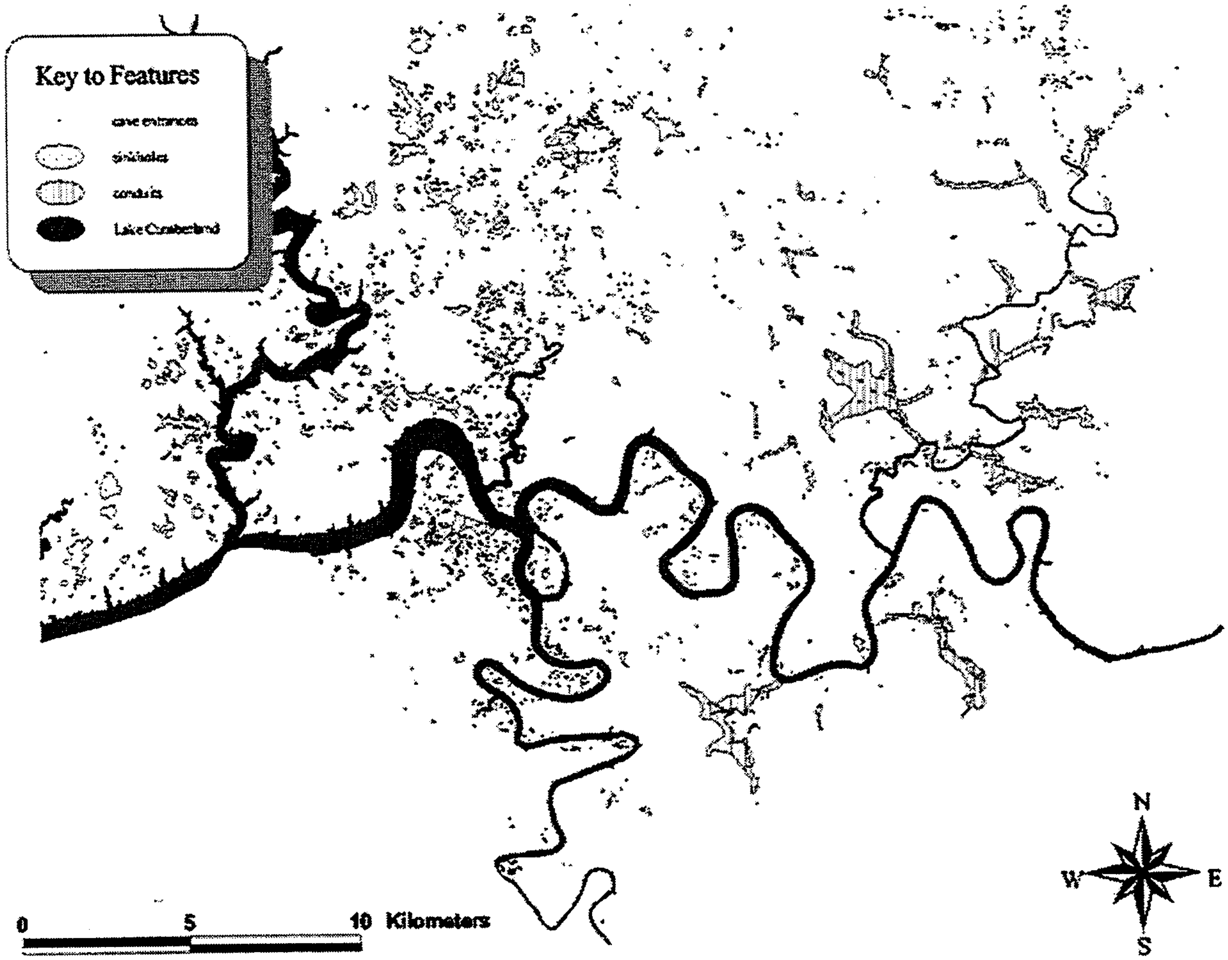

Figure 2: Karst of southern Pulaski County (data from Florea, 2000).

1980) contemporaneous with Iapetan rifting extending from the Mississippi Valley to south-central New York (Webb, 1980). The subsidence of the downthrown blocks of the half-graben system resulted in sedimentary thickening of Paleozoic strata toward the center of the trough. Several Paleozoic stages of synsedimentary movement of sections of the trough amplified sedimentary thickening.

Continued motion along the Rome Trough has been documented within Paleozoic strata. Reactivation uplift along the Irvine-Paint Creek Fault System has resulted in erosional thinning of the St. Louis Limestone on the upthrown side of the Glencarin Fault (Dever, 1986). Pennsylvanian movement of a sub-parallel fault along the Rockcastle River north and east of the study area has been suggested by mass flow deposits and deformed bedding on the downthrown side (Dever et al., 1990).

Current fault delineation for Kentucky does not show mapped faults in the study area. The nearest documented fault is the Delmer Fault northwest of the study area. Other faults have been theorized to the north of the study area due to offsets present between wells (Weaver and McGuire, 1977; Silberman, 1981; Sutton, 1981), others have been observed in road cuts in the vicinity of the Rockcastle River to the north and east of the study area (Dever et al., 1990).

The potential for faults in the study area has been suggested in previous studies. Preziosi (1985) noted that a southern extension of the Rome Trough may exist in Pulaski County due to the presence of a lower velocity basement in the center of the Greenwood Anomaly - a large, linear gravity anomaly extending northward from Tennessee into Central Kentucky (Ammerman, 1976). Black (1989) interpreted magnetic gradients and offset magnetic margins of magnetic anomalies around the study area as evidence of northeast-trending right-lateral basement faults paralleling the Delmer Fault. These were labeled the Burnside and Alpine Lineaments.

Hydrology

Pitman Creek, Buck Creek, and the Cumberland River bound the study area. Pitman Creek drains the central region of Pulaski County and discharges into the Cumberland River at Burnside. This region is intensely karstified with compound sinkhole complexes, integrated conduit networks, and large springs. High residual knobs of the Cumberland Plateau rise above the sinkhole plains. Buck Creek drains much of the eastern half of Pulaski County and has been an important factor affecting the geomorphic development of karst in the region. From its headwaters on the Mississippian Plateau, Buck Creek flows south for 160km across the Mississippian Plateau and through a deep valley in the Cumberland Plateau, discharging into the Cumberland River. The Cumberland River meanders from east to west across southern Pulaski County and is the master base level river for southeast Kentucky.

Cave conduits in the study area are both active and relict. Active conduits continue to form through dissolution processes (vertical shafts, stream and river passages), whereas relict conduits are abandoned from previous dissolution events. Primary recharge to active conduits in the study area is discreet point recharge during precipitation events. This point recharge is allogenic via stream transport from the caprock plateau. Therefore, water is transmitted at a high rate over a considerable elevation difference. Very little water remains within the conduits during times of base flow. These epiphreatic conduits display both vadose and phreatic characteristics.

Methods

Cave Survey

Since the 1960's caves in Pulaski County have undergone extensive exploration and survey (Figure 2). Complex cave systems were mapped, including Sloans Valley (39.6 km), Coral Cave (36 km), Cave Creek (22.4 km), and Wells Cave (18.5 km).

Coral Cave and related caves comprising the Coral Cave System were primarily surveyed by members of DASS between 1970 and 1981. The cave system consists of several unconnected segments: Coral (36 km), Cricket (2.4 km), Church (1.9 km), Dud 2 (1.4 km), Little Canyon Sewer (0.79 km), Briar (0.67 km), Nameless (0.56 km), and Spudbar (0.55 km).

Within the connected portions of Coral, extreme passage complexity and distributions are found. Sections of this cave display changes in hydraulic history; with evident changes in passage morphology and flow direction. It is these sections of the Coral Cave System that contribute to its unique nature. The conduits are organized linearly, penetrating through surface drainage divides and pirating water from other valleys. Analysis of passage walls in the linear sections indicate that high elevation, paleo conduits drained to the southwest toward the Cumberland River. Dye tracing has confirmed that present day flow in sub-parallel epiphreatic conduits is reversed, toward the northeast and then southeast to Buck Creek (DASS, Personal Communication).

Other local caves display similar morphologies. Cricket Cave, east of Coral, consists of a single rapidly entrenching canyon penetrating a drainage divide, dropping 42m within 900m of linear distance. Sawdust Pit (1.8km) continues the trend in the next drainage basin to the east. Further east on the opposite side of Buck Creek is White Lobster Cave (over 2km), another entrenching canyon continuing the linear trend found in Coral, Cricket, and Sawdust Pit. To the West, Newell Springs Cave near Burnside (4.4km) shows similar conduit orientations.

To the west of Coral is Jugornot Cave. In January of 2001, members of the Central Ohio Grotto, Blue Grass Grotto, and other cavers began a project survey of the cave (Florea, 2001a). The cave trends linearly, with a flow direction southwest through the ridge separating Jugornot Hollow from Pumpkin Hollow. Surveyed passages within Jugornot follow the trend found in Coral, Cricket, Sawdust Pit, White Lobster, and Newell Springs and consist of breakdown strewn upper levels, and tall canyons in lower levels (Figure 3). To date 5km of passage have been mapped in Jugornot Cave with a vertical span of 81m.

Early into the Jugornot Cave survey indications of fault related speleogenesis were found. Large calcite veins are present in many passages (Figure 4). Fracture swarming is present in the ceiling of many passages. Slickensides have been documented on breakdown blocks in upper level passages.

Evidence Gathering

Several forms of surface and sub-surface evidence were gathered during the project in an effort to understand the linear nature of the caves in the study area. Overlays and maps produced of the data were generated on ArcView GIS software provided by the Environmental Systems Research Institute to the I-66 Special Project of the National Speleological Society. Data used were partially provided by Florea (2000).

Survey data from Coral and Jugornot Caves were analyzed using the method of moments to detect trends in the azimuth. In the Coral Cave data, linear sections of cave, or sections morphologically identified as joint influenced (approximately 5.4km total) were tabulated and the first and second moments of length-weighted azimuths were calculated (total length of conduit per azimuth range). The first and second moments for the length-weighted azimuths for the Jugornot Cave data set were calculated.

Several forms of surface evidence were recorded. Surface fractures enlarged by dissolution were identified on hillsides in the vicinity of Jugornot and Coral Caves. Joints were observed in road cuts and rock exposures. Stream and hillside orientations from 7.5-minute topographic quadrangles, and available state GIS coverages were looked at for linear segments indicating joint or fault control. Sinkhole alignment patterns available from statewide sinkhole digitizing (Paylor and Florea, 2001) were also looked at. A GIS line coverage composed of features from observed surface data was created.

Mississippian deposition of carbonates is variable and suggestive of synsedimentary tectonic activity (Dever, 1999). Localized sections of the St. Louis are capped by a caliche paleosol near Burnside, suggesting exposure due to uplift. Depositional thinning of the lower Ste. Genevieve limestone occurs in Hound Hollow in the vicinity of Coral Cave. Widespread intra-Ste. Genevieve erosion occurred along the western edge of the Greenwood Anomaly indicating periods of uplift. Mississippian strata thicken to the east of the study area in southwest Laurel County, implying local subsidence.

Seismic data were interpreted from data provided by Seisco Inc. printed at the Kentucky Geological Survey. The seismic line of interest is one of dozens that were taken to help delineate the extent and structure of the Rome Trough. The data used for interpretation in this study is a section of the line beginning north and west of Somerset, crossing through the study area, and continuing to the southeast. Due to license agreements, neither the original data nor the locations of the shot points are displayed. A generalized cross-section was created from the data displaying the location of the principal reflectors at the top of the Precambrian basement, the Rome Formation of Cambrian age, and the Conasauga Formation also of Cambrian age. Faults were traced based on distorted reflectors or observed offsets. The depths to principal reflectors and the maximum offset were calculated from two-way travel times based upon ongoing work at KGS (Tina White, personal communication).

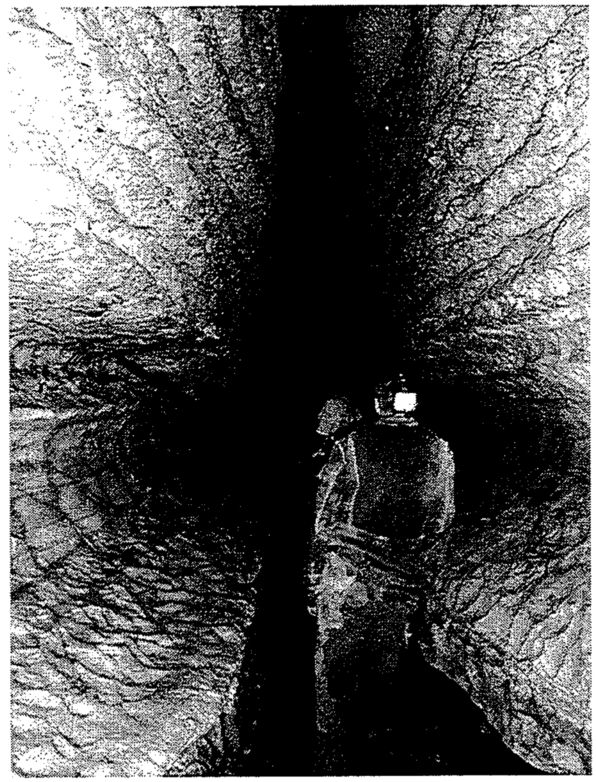

Figure 3: Downstream section of main canyon in Jugornot Cave (photo by author).

Results

Karst Geomorphology

Speleogenesis within the study area displays development inconsistent with regional patterns. Rather than forming as described in the Cumberland Style theory (Sasowski and White, 1994), active and relict master conduits in

Figure 4: Author observing calcite vein in Jugornot Cave (photo by Cynthia Whitney).

several regional caves penetrate drainage divides. The path of these conduits is more linear rather than sinuous.

Many sections of regional caves are composed of entrenching canyons, covering considerable vertical relief in a narrow horizontal band. Jugornot Cave is composed on a single entrenching canyon with 5km of surveyed conduit and a vertical relief of 81m. The morphologies of many sections of these conduits display properties indicative of development along vertical fracture planes including narrow ceiling and floor fissures, and large height to width ratios. Calcite veins are numerous, and fracture swarms are evident in the roof of some passages. Breakdown blocks in these caves show evidence of movement through slickensides.

Azimuth Analysis

Azimuth data from sections of Coral, and Jugornot show linear characteristics. Moment data from length-weighted azimuths of 29 linear or joint influenced conduits in Coral show at mean orientation of 66.6° with a 95% confidence level of + 3.3°. Moment data from length-weighted azimuths of 645 survey stations in Jugornot show a mean of 62.2° with a 95% confidence level of + 2.99°. Moment data for 13 measured surface features have a mean azimuth of 65.4° with a 95% confidence level of +3.88° (Figure 5). Statistical t-tests show that the relationships between subsurface data sets and between surface and subsurface data sets are significantly similar to each other at the 95% confidence level.

Geological Implications

The available geological evidence supports the presence of faulting at depth with periods of post-faulting tectonic activity. A lower velocity basement in the center of the Greenwood Anomaly exists in the study area (Preziosi, 1985), potentially reflecting an extension of Rome Trough tectonism. Similar conclusions are suggested by magnetic anomaly data. Magnetic gradients and offset magnetic margins of magnetic anomalies around the study area potentially reflect northeast-trending right-lateral basement faults (Black, 1989). Intra-depositional exposure of the St. Louis and depositional thinning of the Ste. Genevieve in and around the study area combined with thickening of these units to the southeast (Dever, 1999) suggests the reactivation of a half-graben fault-block with uplift of the northwest block and contemporaneous subsidence of the southeast block.

Seismic Profile

The seismic profile across the study area displays evidence of faulting (Figure 6). The zone between shot points 9 and 13 (approximately 4km wide) shows evidence of a primary normal fault with several offshoots that potentially indicate lateral motion. This zone lies directly beneath the study area in the vicinity of Coral and Jugornot Caves. Maximum offset is on the Precambrian basement with the depth being approximately 2620m on the upthrown side and 3500m on the downthrown side, or approximately 880m of offset. This offset diminishes at the top of the Rome Formation and is negligible at the top of the Conasauga Formation. Depositional thickening is evident on the downthrown side.

Discussion

Combined speleogenetic, geologic, and geophysical data support the conclusion of faulting at depth below the study area. The band of evidence is 3km wide and 20km long oriented at approximately 65°. It consists of joints, minor faults, and fracture swarms propagated from depth

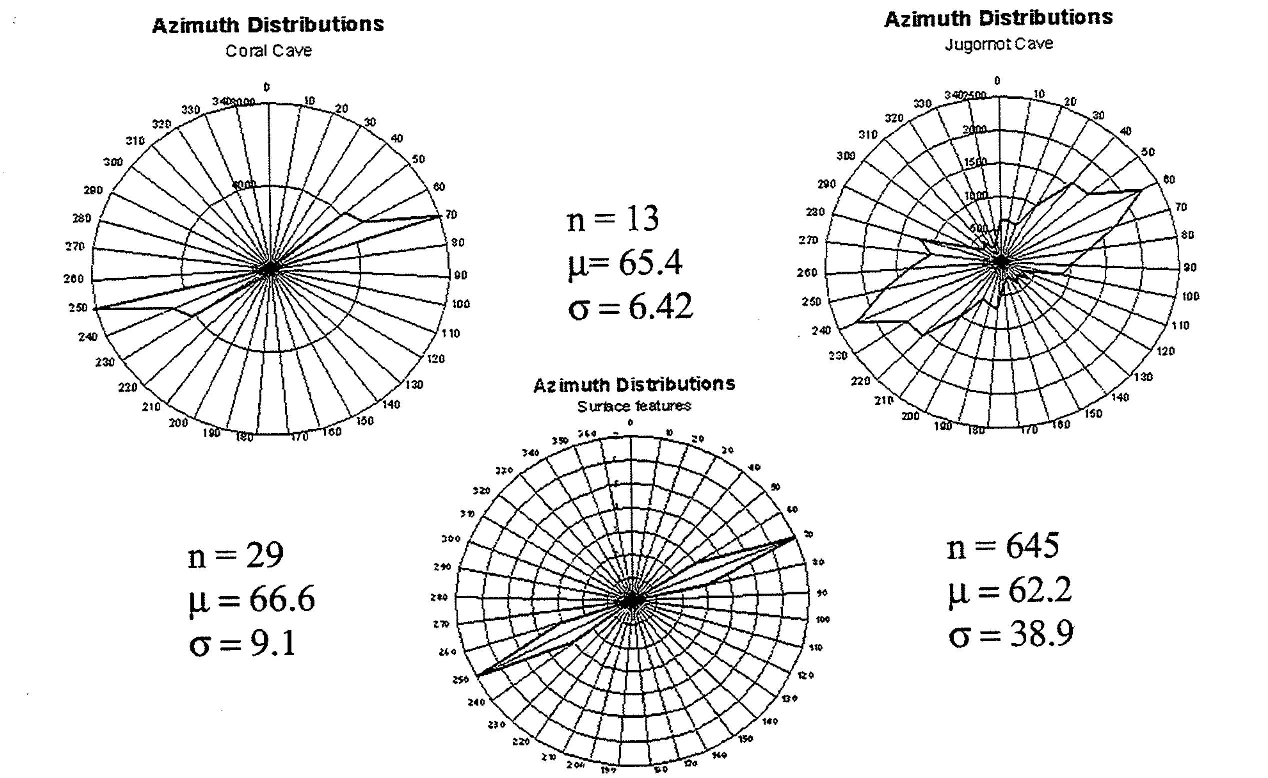

Figure 5: Rose diagram of azimuth distributioms and moment data for Jugornot Cave, Coral Cave, and surface features. "n" is the number of elements, "μ" is the mean (first moment) of the data, and "σ" is the standard devidation (square root of the second moment) of the data

collectively labeled the Burnside Lineament (Figure 7). Data from this study, combined with information from previous work, suggests the following sequence of events.

Iapetan rifting occurred in the late Precambrian to Cambrian (600-540ma) resulting in the formation of a series of half-grabens. The bounding faults (Lexington and Rockcastle River-Warfield Fault Systems) consisted of normal faults. Internal faults around the study area, oriented at an angle to the tensional force, became sub-parallel, right-lateral, oblique-slip faults. This is shown by geophysical evidence by Black (1989), depositional evidence by Dever (1999), and seismic evidence. These faults include one directly within the study area associated with the Burnside Lineament shown by data in this study, the Alpine Lineament to the south predicted by Black (1989), and the Billows Lineament to the north hypothesized due to observations by Dever et al (1990) (Figure 8).

Sedimentation throughout the Paleozoic (540-250ma) filled this rift and the resulting thick sequence of sedimentary rock became what is today referred to as the Rome Trough. Synsedimentary reactivation of the fault below the study area at the end of the St. Louis and during the Ste. Genevieve depositional periods of the Mississippian resulted in uplift of the northwest block and subsidence of the southeast block.

Further tectonic activity during the latter Mississippian, Pennsylvanian, and potentially even more recent produced fracture swarms and minor displacement surfaces observed in regional caves. These vertical fracture planes provided pathways for hydrothermal water to rise from depth and precipitate calcite veins seen in both Jugornot and Coral Caves.

Erosion during the Quaternary (<1.6ma) by downcutting tributaries of the Cumberland River and Buck Creek

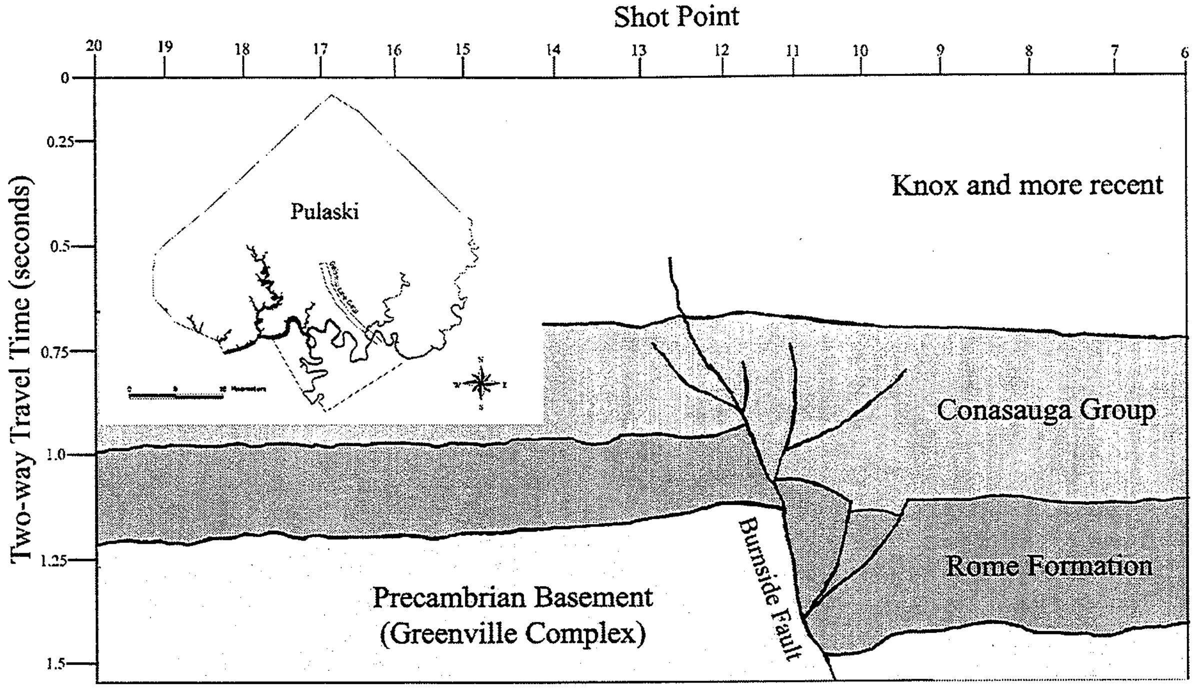

Figure 6: Generalized seismic profile from the northwest to the southeast across the study area. Original data source provided by Seisco Inc. and the Kentucky Geological Survey.

intersected Mississippian carbonates. This initiated the groundwater flowpaths along fracture planes associated with previous tectonic activity. Dissolution along these flow paths initiated phreatic conduit development. Various stages of rapid downcutting mixed with periods of stable base level generated conduits with complex vertical morphologies (narrow vadose canyons connecting several levels of phreatic tubes).

Limitations

While karst evidence in this study supports the existence of a basement fault below the Burnside Lineament, similar evidence is not available to support either the Alpine or Billows Lineaments. Further cave survey and surface observations inside and outside the study will more clearly define the extent and direction of the lineaments and their related basement faults.

It is not clear whether the Burnside and proposed Billows Lineaments are independent or separate segments of the same trend. Scattered verbal evidence from coal operators indicates that offsets were detected when mining coal seams in the lower Breathitt in the region between the projections of the Burnside and Billows Lineaments. There is a possibility that the Burnside Lineament makes a northerly turn east of the study area.

Azimuth data in cave survey is recorded connecting points in a cave that are accessible to humans. The line between points must be free of obstruction to accurately measure distance, azimuth, and inclination. Therefore, the survey line does not necessarily reflect the true trend of the conduit. Thus, the second moment for azimuth data in Jugornot Cave is higher.

Conclusions

Karstification of Mississippian age carbonates in southern Pulaski County, Kentucky is extensive. Geologic structure has proven to be an important factor in regional speleogenesis. Conduits within several regional caves including Jugornot Cave are independent of surface drainage patterns. Evidence gathered from within Jugornot Cave and other locations in the study area support the hypothesis that regional speleogenesis has been influenced by faulting. Further evidence suggests this faulting is related to the Rome Trough structure formed during Iapetan rifting in the Late Precambrian to Middle Cambrian. Fractures generated by minor reactivation of this fault system have propagated upward through

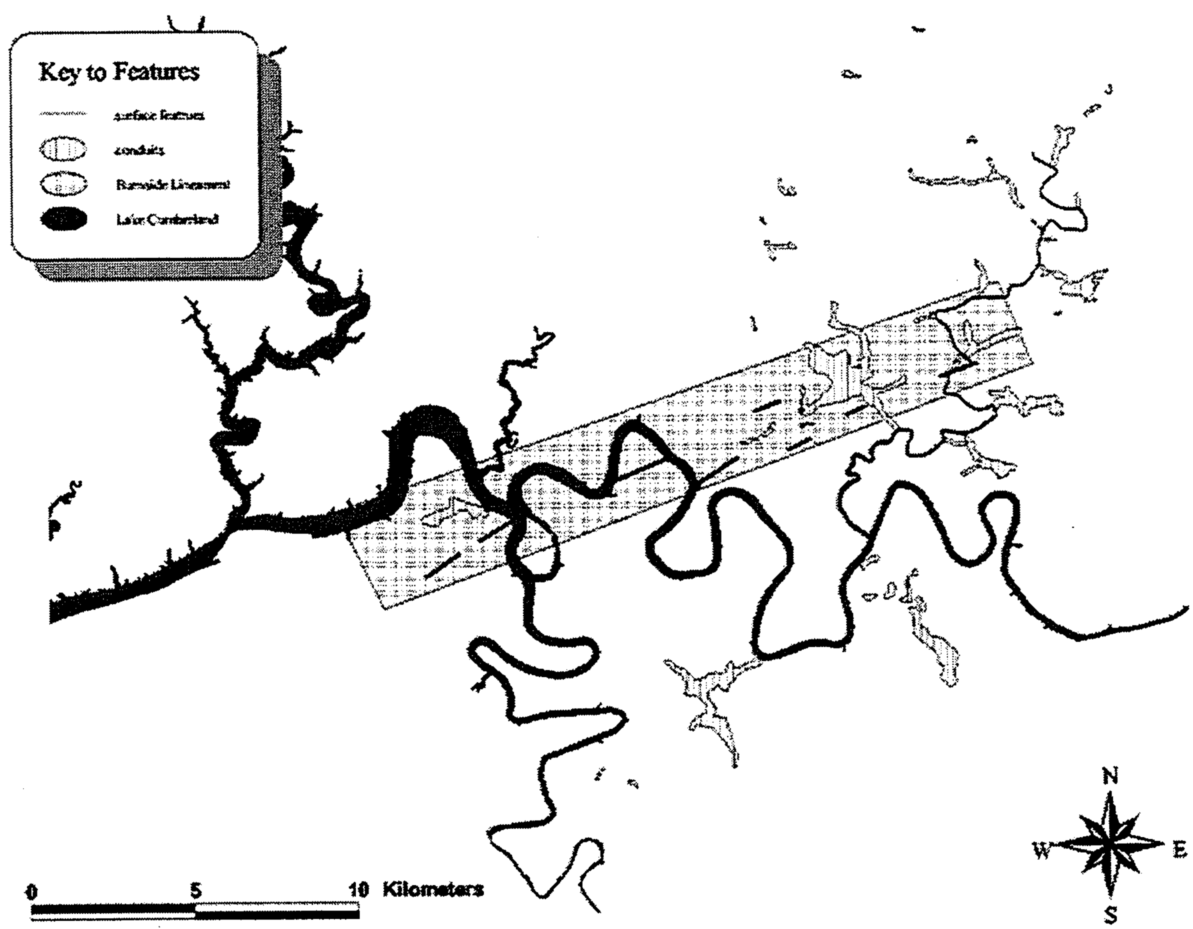

Figure 7: Orientation, width, and extent ot Burnside Lineament band shown with supporting conduit and surface features.

Mississippian and Pennsylvanian strata as fracture swarming. The evidence gathered during the course of this study confirms the presence of a regional lineament termed the Burnside Lineament previously hypothesized by magnetic anomaly data. The expression of this lineament, mapped using surface and subsurface data is a fracture swarm band approximately of 3km wide and 20km long oriented at approximately 65°. To date 5km of passage have been mapped in Jugornot Cave with a vertical span of 81m. Structural, depositional, and geophysical evidence indicates the existence of three sub-parallel right-lateral oblique-slip faults in Precambrian and Cambrian strata of Pulaski County, including below the Burnside Lineament, related to Rome Trough tectonism.

Acknowledgements

Research conducted throughout the course of this project has been possible through the support and resources of the following individuals and organizations: the Blue Grass Grotto, Central Ohio Grotto, Dayton Area Speleological Society, and I-66 Special Project of the National Speleological Society; the Environmental Systems Research Institute (ESRI); Jim Drahovzal, Garland Dever, Dave Harris, and Tina White of the Kentucky Geological Survey; the Kentucky Speleological Survey; and Seisco Inc.. The author would also wish to dedicate this paper to the memory of David Carl McMonigle for first introducing me to Coral and Jugornot Caves. Finally, many thank the landowners of Jugornot Cave, Gary and Jennifer Taylor, for their cooperation and support of this project.

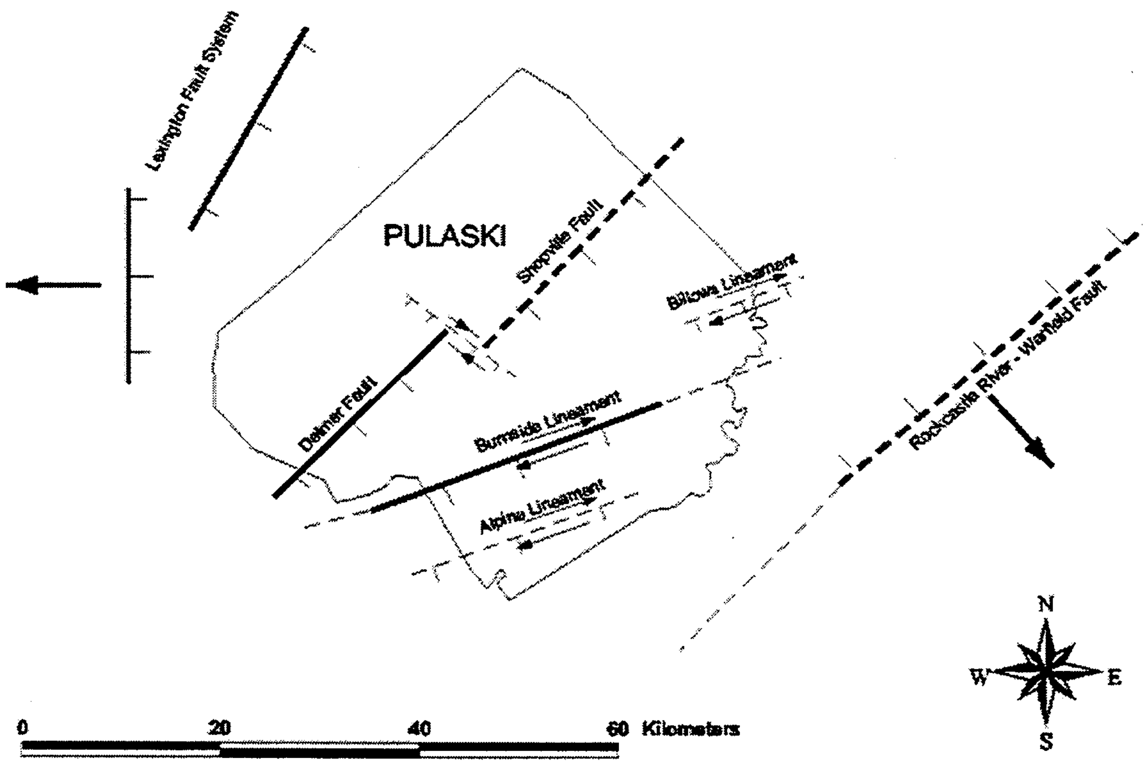

Figure 8: Proposed basement structure of region. Arrows indicate direction of motion. Solid heavy lines are identified faults, dashed heavy lines are faults proposed by other studies, dashed lines are poposed faults in this study.

References

Ammerman, M. L, 1976, A Gravity and Tectonic Study of the Rome Trough (Thesis), Lexington, University of Kentucky, 70 p.

Ammerman, M. L., Keller, G. R., 1979, Delineation of Rome Trough in Eastern Kentucky by Gravity and Deep Drilling Data, American Association of Petroleum Geologists Bulletin, v. 63, no. 3, pp. 341-353.

Black, D. F. B., 1989, Tectonic Evolution in Central and Eastern Kentucky: A Multidisciplinary Study of Surface and Subsurface Structure, U.S. Geological Survey Open File Report 89-106, 151 pp.

Bullock, K. C., 1944, Origin of the Timpanogos Caves, in Proceedings of the Utah Academy of Sciences, Arts and Letters, vol. 19-20, pp. 18-19.

Cheema, T. J., Islam, M. R., 1994, Comparison of cave passageways with fracture traces and joints in the Black Hills region of South Dakota, NSS Bulletin, vol. 56, no. 2, pp. 96-103.

Dasher, G. R., 2000, The Caves of East-Central West Virginia, The Guidebook of the National Speleological Society's 2000 Convention, West Virginia Speleological Survey, 296 pp.

Deike, R. G., 1969, Relations of Jointing to Orientation of Solution Cavities in Limestones of Central Pennsylvanian, American Journal of Science, v. 267, pp. 1230-1248.

Dever, G. R., 1986, Mississippian Reactivation Along the Irvine-Paint Creek Fault System in the Rome Trough, East-

Central Kentucky, Southeastern Geology, vol. 27, no. 2, pp.95-105.

Dever, G. R., 1999, Tectonic Implications of Erosional and Depositional Features in Upper Meramecian and Lower Chesterian (Mississippian) Carbonate Rocks of South-Central and East-Central Kentucky, Kentucky Geological Survey, Bulletin 5, Series XI, 67 pp.

Dever, G. R., Greb, S. F., Moody, J. R., Chesnut, D. R., Kepferle, R. C., Sergeant, R. E., 1990, Tectonic Implications of Depositional and Erosional Features in Carboniferous Rocks of South-Central Kentucky, Geological Society of Kentucky, Kentucky Geological Survey, 53 pp.

Ewers, R. O., 1972, A Model for the Development of Subsurface Drainage Routes Along Bedding Planes (Thesis), University of Cincinnati, 85 pp.

Florea, L. J., 2000, Karst Atlas of Kentucky, unpublished GIS geodatabase.

Florea, L. J., 2001a, (abstract) Survey and Exploration of Jugornot Cave, Pulaski County, Kentucky, 2001 National Speleological Society Convention Program Guide, Howard Kalnitz (ed.), 95 pp.

Florea, L. J., 2001b, Caves and Karst of the 2001 Convention, In NSS Convention 2001 Guidebook: A Cave Odyssey, L. Braley, L. Florea (eds.), 216 pp.

Ford, D. C., Ewers, R. O., 1978, The Development of Limestone Cave Systems in the Dimension of Length and Depth, Canadian Journal of Earth Science, vol. 15, pp 1783-1798.

Ford, D. C., 2000, Lauritzen, S. E., Worthington, S., 2000 Speleogenesis of Castleguard Cave, rocky Mountains, Alberta, Canada, In Speleogenesis evolution of karst aquifers, A. Klimchouk, D. Ford, A. Palmer, W. Dreybrodt (eds.), pp. 332-337.

Ferguson, H. F., 1967, Valley Stress Release in the Allegheny Plateau, engineering geology: Association of Engineering Geologists Bulletin, v. 4, no. 1, pp.63-68.

Greb, S., Dever, G., Paylor, R. L., 2001, Scenic and Karstic Geology of South Central Kentucky, In NSS Convention 2001 Guidebook: A Cave Odyssey, L. Braley, L. Florea (eds.), 216 p.

Haeuselmann. P., Jeannin, P-Y., Bitterli, T., 1999, Relationships between karst and tectonics; case-study of the cave system north of Lake Thun (Bern, Switzerland), Geodinamica Acta, vol. 12, no. 6, pp. 377-388.

Hines D. B., Dowdy, T. C., Sendlein, L, V. A., Felton, G., 1995, Hydrogeologic investigation at an industrial site of Scott County, Kentucky, In Abstracts with Programs - Geological Society of America, vol. 27, no. 2, pp. 62-63.

Hose, L. D., 2000, Speleogenesis of Sistema Cheve, Oaxaca, Mexico, In Speleögenesis evolution of karst aquifers, A. Klimchouk, D. Ford, A. Palmer, W. Dreybrodt (eds.), pp. 358-361.

Howard, A. D., 1968, Stratigraphic and Structural Controls on Landform Development in the Central Kentucky Karst, NSS Bulletin, vol. 30, No. 4, pp. 95-114.

Huntoon, P. W., 2000, Karstification associated with groundwater circulation through the Redwall artesian aquifer, Grand Canyon, Arizona, U.S.A., In Speleogenesis evolution of karst aquifers, A. Klimchouk, D. Ford, A. Palmer, W. Dreybrodt (eds.), pp. 287-291.

Kastning, E. H., 1981, Tectonism, fractures, and speleogenesis in the Edwards Plateau, central Texas, USA, In Proceedings of the Eighth international congress of speleology, B. Beck (editor), pp. 692-695.

Kastning, E. H., 1983, Karstic landforms as a means to interpreting geologic structure and tectonism in carbonate terranes, In Abstracts with Programs - Geological Society of America, vol. 15, no. 6, p. 608

Kastning, K. M., Kastning, E. H., 1984, Fracture control of dolines, caves, and surface drainage; Mississippian Plateau, western Kentucky, U.S.A., Annual Report - Western Kentucky Speleological Survey. 1982-1983, pp. 11-15.

Kentucky Geological Survey (KGS), 1985, Caves and Karst of Kentucky, Special Publication 12, Series XI, Percy H. Doughtery (ed.), 196 p.

Lauritzen, S. E., Lundberg, J., 2000, Meso- and micromorphology of caves; Solutional and erosional morphology, In Speleogenesis evolution of karst aquifers, A. Klimchouk, D. Ford, A. Palmer, W. Dreybrodt (eds.), pp. 408-426.

Nelson, J. W., 1988, Influence of joints and fractures upon the hydrogeology of a karst terrane, In Symposium proceedings of the international conference on Fluid flow in fractured rocks, pp. 432-446.

Ogden, A. E., 1974, The relationship of cave passages to lineaments and stratigraphic strike in central Monroe County, West Virginia, Conf. Karst Geol. Hydrol. Proc, vol. 4, pp. 29-32.

Ogden, A. E., 1983, A morphometric analysis of the Monroe County karst, West Virginia with comparisons to Kentucky, Tennessee, and Indiana, In Proceedings of the Annual meeting of the National Speleological Society, T. Rea (ed.), NSS Bulletin, vol. 45, no. 1.

Orndorff, R. C., Lagueux, K. M., 2000, Using geographic information systems (GIS) to determine geologic controls on the distribution of sinkholes in the Ozarks of south-central Missouri, Abstracts with Programs - Geological Society of America, vol. 32, no. 3, p. 38.

Palmer, A. N., Palmer, M. V., 2000, Speleogenesis of the Black Hills Maze Caves, South Dakota, U.S.A., In Speleogenesis evolution of karst aquifers, A. Klimchouk, D. Ford, A. Palmer, W. Dreybrodt (eds.), pp. 274-281.

Palmer, A. N., 1991, The Origin and Morphology of Limestone Caves, Geological Society of America Bulletin, vol., 103, pp. 1-21.

Palmer, A. N., 1975, The Origin of Maze Caves, NSS Bulletin, vol. 37, no. 3, 56-76.

Parizek, R. R., 1976, On the nature and significance of fracture traces and lineaments in carbonate and other terranes, In Karst hydrology and water resources; Vol. 1, Karst hydrology, V. Yevjevich (ed.), pp. 47-108.

Paylor, R. L., Florea, L. J., 2001, (abstract) The Kentucky Sinkhole Project. Development of a Statewide Sinkhole Map, 2001 National Speleological Society Convention Program Guide, Howard Kalnitz (ed.), p. 86.

Preziosi, G. J., 1985, Velocity Structure of the Precambrian Basement in Southeastern and South-Central Kentucky Determined from Seismic Refraction Profiling (Thesis), University of Kentucky, 134 pp.

Sasowsky, I. D., White, W. B., 1994, The role of stress release fracturing in the development of cavernous porosity in carbonate aquifers: Water Resources Research, vol. 30, no. 12, 3523-3530.

Silberman, J. D., 1981, Exploration along the Northwestern Margin of the Rome Trough, in Luther, M. K. (ed.), Proceedings of the Technical Sessions, Kentucky Oil and Gas Association 38th Annual Meeting, Kentucky Geological Survey, ser. 10, Special Publication 3, pp. 10-28.

Sutton, E. M., 1981, Deep Exploration in Eastern Kentucky by the SCLAW Group During the Early Seventies, in Luther, M. K. (ed.), Proceedings of the Technical Sessions, Kentucky Oil and Gas Association 38th Annual Meeting, Kentucky Geological Survey, ser. 10, Special Publication 3, pp. 31-44.

Taylor, B. B., 1997, Structural controls on Pigeon Mountain Karst (Thesis), Georgia State University.

Vandike, J. E., 1979, Hydrogeology of the North Fork Basin, Missouri Speleology, vol. 19, no. 1-2.

Weaver O. D., McGuire, W. H., 1977, Cambro-Ordovician Potential of the Rome Trough of Eastern Kentucky, Oil and Gas Journal, vol. 75, no. 47, pp. 250-255.

Webb, E. J., 1980, Cambrian Sedimentation and Structural Evolution of the Rome Trough in Kentucky (Dissertation), University of Cincinnati, 97 pp.

White, W. B., 1976, The Geology of Caves, Geology and Biology of Pennsylvania, General Geology Report 66, 71 pp.

White, W. B., 1988, Geomorphology and Hydrology of Karst Terrains, Oxford University Press, New York, 464 pp.

White, W. B., 2000, Cave development in Burnsville Cove, Virginia, U.S.A., In Speleogenesis evolution of karst aquifers, A. Klimchouk, D. Ford, A. Palmer, W. Dreybrodt (eds.), pp. 362-366.