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MORPHOLOGY OF THE CAVES OF MISSOURI

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The morphology of solution caves differs from region to region based on the recharge mechanisms and the dominant type of porosity. The pattern of cave passages representative of the entire Salem and Springfield Plateaus and of the Perryville and Hannibal karst areas was determined. The number of closed loops and the tortuosity of the passages were used to statistically determine the morphology of 633 mapped caves in Missouri. The 633 caves were from 17 counties and from each of the karst areas in Missouri. For most caves in the Salem and Springfield Plateaus and the Perryville karst area, as determined by passage length, the pattern of development is branchwork (71.7, 83.4, and 84.4%, respectively) and rudimentary (16.5, 10.3, and 14.8%, respectively). The Hannibal area shows 2 distinct patterns of development. Three caves are network mazes (81.2%) and the remainder are either branchwork (13.1%) and rudimentary (4.9%). The morphologies of the caves from the Salem and Springfield Plateaus and the Hannibal and Perryville karst areas suggest the distribution of caves within Missouri is similar to that found by Palmer (1991) for cave passages worldwide. However, there is higher percentage of rudimentary caves due to extensive stream incision. Given the high percentage of branchwork and rudimentary patterned caves in Missouri, the origin of Missouri's caves was likely driven by point-source recharge that flowed along bedding plane partings.

Based upon the type of recharge and the dominant porosity of the bedrock, Palmer (1991) concluded that there are 5 fundamental cave morphologies that can be identified from field observations or plan view cave maps. Of the 5 fundamental cave morphologies, ~57% are identified as branchwork, 17% as network, 14% as rudimentary single passage, 5% as ramiform/spongework, and 3% as anastomotic (Palmer 1991). Weighted by length, these relative frequencies of major cave patterns in Palmer's investigation sample (~500 caves) match within 1% all known caves in the world >3 km long.

The branchwork pattern of cave morphology is a product of point-source recharge, through sinkholes, flowing through first order conduits that converge to become higher-order conduits down gradient. The branchwork pattern can be a product of either groundwater flow along bedding plane partings or along fractures/joints. The network pattern of cave morphology is the product of either diffuse recharge through an overlying permeable rock or from streams sinking into jointed/fractured rock. The diffuse recharge allows for simultaneous enlargement of many passageways. The anastomotic pattern of cave morphology is the product of sinking streams. However, the anastomotic pattern is the result of preferential groundwater flow along bedding plane partings. Anastomotic caves, as well as some network maze caves, are the product of periodic flooding, causing sudden short-term increases in groundwater flow that inundate all or part of a cave to the ceiling (Palmer 1975). Fractures and partings in the bedrock are subject to extremely steep hydraulic gradients, allowing for rapid formation of maze-like passages (Palmer 1975). The ramiform/spongework pattern of cave morphology is the product of dissolution by acids from a deep-seated source, cooling of thermal waters, or mixing of two waters sources of contrasting chemistry. Rudimentary single-passage caves form as the result of any of the aforementioned methods.

Missouri's nickname is "The Cave State" as it has >5500 catalogued caves, and more are added to the list every year as new caves are discovered. This study applies Palmer's (1991) classification system of morphology to 633 of the mapped caves in Missouri. These 633 caves represent all 4 karst areas within Missouri.

GEOLOGIC SETTING

REGIONAL GEOLOGY

The Ozark Plateaus physiographic province covers an area of >103,600 km² and comprises parts of Missouri, Oklahoma, Arkansas, Kansas, and Illinois (Thornbury 1965). The Ozark Plateaus of Missouri is divided into 4 karst subprovinces: The Salem Plateau, the Springfield Plateau, the Hannibal Karst Area, and the Perryville Karst Area (Fig. 1).

The boundaries of the Salem Plateau are drawn at the limits of the area underlain by the Cambrian and Ordovician carbonate rocks (Fig. 1). The Salem Plateau is an ancient erosional surface composed of thick sequences of sedimentary rocks (Bretz 1965). Fenneman (1938) defined the Springfield Plateau as that "part of the Ozarks which is underlain by rocks of Mississippian age." Bretz (1965) interprets the Springfield Plateau to be an erosional surface comprised of thick sequences of sedimentary rocks. The Hannibal Karst Area is defined as the area underlain by Ordovician, Silurian and Devonian carbonate rocks. These rocks are dissected by streams that flow eastward towards the Mississippi River. The Perryville karst area includes Perry and Cape Girardeau Counties. Strata gently dipping towards the east with dips of

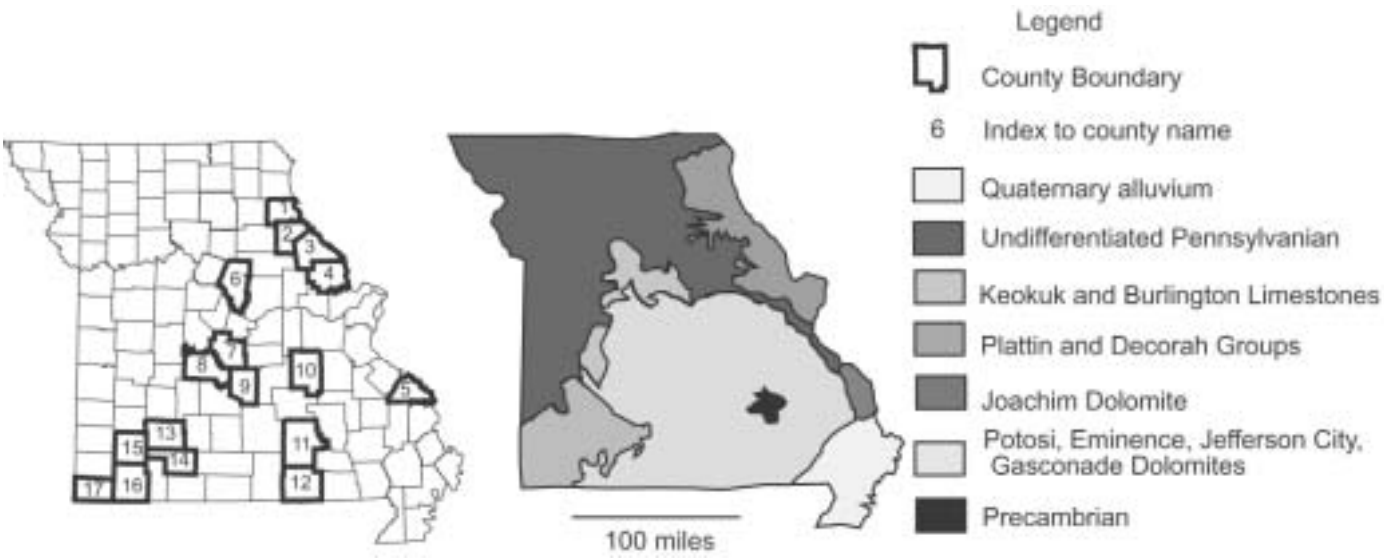

Figure 1: Geographic distribution of selected counties (left panel) and a general geologic map of Missouri (right panel) (Thompson, 1995). The counties are 1 - Marion, 2 - Ralls, 3 - Pike, 4 - Lincoln, 5- Perry, 6 – Boone, 7 – Miller, 8 – Camden, 9 – Pulaski, 10 – Crawford, 11 – Shannon, 12 – Oregon, 13 – Greene, 14 – Christian, 15 – Lawrence, 16 – Barry, and 17 – McDonald.

<19 m/km underlie the area. The rocks of the area are Middle Ordovician or older.

METHODS

More than 5000 cave maps were available for this study from ~70 counties (Table 1). A method was developed to reduce the number of counties selected and then to reduce the number of maps to be analyzed while maintaining representation from each of the 4 subprovinces. The end result was that 633 cave maps from a total of 17 counties were selected as the database for this study. (The Missouri Speleological Survey, Inc., and the Missouri Department of Natural Resources provided the maps to the authors.) The subset of counties was selected by removing all counties along boundaries between 2 or more subprovinces such that only counties that were completely enclosed within one subprovince were used. The final 17 counties were chosen on the basis of the number of cave maps accessible for each county and geographic distribution within the 4 karst subprovinces (Fig. 1). Once the subset of counties were selected, all cave maps within those counties were included in the sample set except for maps for which fewer than 6 orientations could be determined and, in Perry County, cave maps that indicated vertical passages were removed from the sample set.

The metric used to classify the caves into categories was the number of closed loops within a cave and the tortuosity of the cave passages. If a cave exhibited more than one pattern, the cave was classified according to the dominant pattern exhibited.

To distinguish between branchwork passages and anastomotic passages, and between branchwork passages and network passages, number of closed loops was counted and tallied. (Note: Closed loops did not include passages at different levels as nearly all caves in Missouri are horizontal, except in Perry County). If the cave had more than 3 closed loops, it was considered to be predominantly anastomotic or network rather than branchwork. To distinguish between the anastomotic passages and the network passages, the ratio of the length of the cave passage to the straight-line distance between the ends of the passage (tortuosity ratio) was calculated for all caves in this study and for the example of a network pattern cave given in Palmer (1991). The tortuosity ratio for each of the caves was tested against the null hypothesis that they approximate the tortuosity ratio for Palmer's type cave for the network pattern. The statistical test used was a means test for a small sample size with $\alpha = 0.05$. If the null hypothesis was not rejected, the cave was categorized as a network cave. If the null hypothesis was rejected (the tortuosity ratio was significantly different than that calculated for Palmer's example of a network cave), then the cave was categorized as an anastomotic cave. Ramiform (and spongework) passages were determined by the ratio of passage width to passage length exceeding 0.3. Rudimentary caves are single passage caves and a metric was not needed to categorize these caves.

As a check on the metric, the orientation of cave passages was determined with rosette diagrams using a method similar to that used by Deike (1969). Network caves should have a preferred orientation. In addition, if branchwork caves exhibit a preferred passage orientation, then the branchwork caves have a structural control (i.e., joint pattern, presence of faults, etc). The distribution of orientations of each rosette diagram was compared to the uniform distribution (no preferred orientation) using a χ^2 test with $\alpha = 0.05$ (Williams 1972). If a cave exhibited a preferred orientation, then the distribution of ori-

Table 1. The percentages of each cave morphology type for various regions of Missouri and the worldwide average (Palmer 1991).

	Total number of counties	Number in final sample[1]	Total number of caves[2]	Number used[3]
Salem	42	6	1402	327
Springfield	22	6	497	170
Hannibal	9	4	360	39
Perryville	2	1	58	97

[1] Number in final sample is the number of counties that were represented in the final sample.
[2] Total number of caves is the number of mapped caves that were available for use in this study for an entire subprovince.
[3] Number used is the number of cave maps that were analyzed in a study.

Table 2. The percentages of each cave morphology type for various regions of Missouri and the worldwide average (Palmer 1991).

	Anastomotic	Branchwork	Network	Rudimentary	Ramiform[1]	Number[2]	Used in study[3]
World	3.0	57.0	17.0	14	5	not known	500
Salem	11.5	71.7	0.1	16.5	—	1402	327
Springfield	4.7	83.4	1.5	10.3	—	497	170
Hannibal	0.0	13.1	81.2	4.9	—	360	39
Perryville	0.6	84.4	0.0	14.8	—	58	97
Missouri	6.6	67.0	13.4	13.0	—	>5500	633

[1] No ramiform caves were found in Missouri; however numerous examples of galena and sphalerite mines hosted in carbonate bedrock in Missouri conform to Palmer's classification of ramiform caves.
[2] Number of caves is the number of mapped caves that were available for use in this study.
[3] Used in study is the number of cave maps that were analyzed in a study.

entations was not uniform (null hypothesis was not accepted). If a cave did not exhibit a preferred orientation, then the distribution of orientations was uniform (null hypothesis was not rejected).

RESULTS AND DISCUSSION

The results of Palmer (1991) were based on worldwide averages, and certainly there is not an expectation that such a global average would be exhibited in such small areas such as the Salem or Springfield Plateaus. However, qualitative differences between the global percentages and the percentages found in Missouri might provide insight into the karst development of Missouri.

For the Salem and Springfield Plateaus and the Hannibal and Perryville areas, 71.7, 83.4, 13.1, and 84.4%, respectively, of the passages were branchwork pattern (Table 2). The branchwork caves exhibited preferred orientations, thus there appears to be a structural control on passage development. However, this obvious structural control is not easily related to known joint patterns or faulting within the State (Ball & Smith 1903; Barnholtz 1961; McCracken 1971; King 1977; Cole 1991; Davis & Reynolds 1996). For 3 of the areas, the percentage of branchwork caves is higher than the global average of 57%. (This ratio is not necessarily due to a large number of branchwork caves but to having so few network caves.) Previous work by Aley (1978), Halihan *et al.* (1998), Vandike (1985, 1996), and Wicks and Engeln (1997) shows that the dominant recharge of the 4 karst areas is through sinkholes and losing stream reaches. Using Palmer's (1991) classification of cave patterns based upon the type of recharge and dominant porosity, the expected cave pattern would be branchwork.

Only 0.1, 1.5, and 0% (Salem, Springfield, and Perryville, respectively) were network caves, and these caves did indeed exhibit a preferred orientation. This is a much lower percentage than expected by Palmer's work. However, the statewide percent of network caves (13.4%) is close to the global average (17%) due to the high percentage of network caves in the Hannibal area (81.2%; Table 2). The large percentage of network passages is easily explained by the presence of three lengthy caves: Mark Twain, Cameron, and LaBaume Caves. Since these 3 caves were of a different pattern compared to the rest of the state, it is clear that they formed under unique conditions. Mark Twain Cave, Cameron Cave, and LaBaume Cave formed in the Louisiana Limestone, located along a 2-km

stretch of the Mississippi River and each is <1.5 km from the Mississippi River. All 3 of the caves have tall, narrow passages with flat ceilings typical of formation along joint planes (Sasowsky pers. comm. 2002). There are also 2 unmapped caves in the vicinity that have names (Mini Fissure and Mammoth Fissure) indicating an origin similar to Mark Twain, Cameron, and LaBaume Caves. Network caves form by diffuse recharge through a permeable caprock into a jointed/fractured bedrock or because of floodwater injection into jointed/fractured bedrock. Given the proximity of these caves to the Mississippi River, the caves most likely formed due to floodwater injection processes. There is no permeable caprock overlying the cave-forming Louisiana Limestone that would have provided diffuse recharge, allowing for simultaneous passage growth along joint sets. The caves also have fluvial sands and silts, consistent with floodwater injection (Sasowsky pers. comm. 2002).

Anastomotic caves were 11.5, 4.7, 0, and 0.6% of the population for the Salem and Springfield Plateaus and the Hannibal and Perryville areas, respectively. Statewide, the percentage is 6.6%. The global average is 3%. There are a few more anastomotic caves within the Salem than expected. The anastomotic pattern of cave morphology is the product of diffuse recharge through an overlying permeable layer and/or sinking streams that flow along bedding plane partings (Palmer 1991). Given the nearly horizontal bedding within Missouri, flow along bedding plane partings is likely, thus a slight increase in the number of anastomotic caves is expected.

For Salem, Springfield, Hannibal, Perryville, 16.5, 10.3, 4.9, and 14.8%, respectively, of the caves were rudimentary in pattern. The statewide average of 13% matches the global average of 14% (Palmer 1991). However, due to a software limitation (at least 6 orientation vectors were required to produce a rosette diagram), many rudimentary caves were eliminated from the dataset. This artificially lowered the percentage of rudimentary caves and underrepresented the rudimentary caves within our database. Therefore, there could be many more rudimentary caves than we include. Palmer suggests rudimentary caves have many origins. We think that the rudimentary caves in Missouri may be due to surface erosion. The incision of the streams has likely truncated many larger cave systems, leaving behind only short remnants from the much longer cave system. When the remnants are mapped, they appear as short, rudimentary caves. As most of Missouri's karst areas are thought to be ancient erosional surfaces (Bretz 1965), deep stream incision is expected. Without a detailed reconstruction of the paleo-cave systems, it is difficult to determine if the cave map represents a true rudimentary single-passage cave or a remnant of a larger cave system. In some cases, the remnants can be visually extrapolated to determine that they were once one system. For example, in Shannon County, a person can stand in the entrance of Bear Cave #2 and look across the surface valley and see the entrance of Little Bear Cave (Baker *et al.* 1989).

The ramiform and spongework pattern of cave morphology is the product of dissolution by acids from a deep-seated source, the cooling of thermal waters, or mixing of 2 waters of contrasting chemistry (Palmer 1975, 1991). Hydrothermal fluids flowed through the subsurface of Missouri during the Pennsylvanian-Permian and resulted in the ore deposition within the Old Lead Belt, Viburnum trend, and Tri-State regions (Roedder 1977; Leach 1979; Gregg & Shelton 1989; Symons & Sangster 1991). Whereas groundwater flow and deposition of ore in the Viburnum Trend and Old Lead Belt regions were preferentially along old algal reef structures (Gregg & Shelton 1989), in the Tri-State region, the hydrothermal fluids deposited ore in "solution collapse structures" (Brockie *et al.* 1968). For a few mines, there are maps available of the zone of mineralization; these maps appear to be ramiform (and spongework) caves into which the hydrothermal fluids flowed and deposited ore (Brockie *et al.* 1968: p. 415). Because these mines are not caves *per se*, they were not included in the database. However, their formation and occurrence fits the Palmer model.

CONCLUSIONS

We have taken the classification scheme of Palmer (1991), developed a metric, and used the metric to analyze the morphology of the caves of Missouri. We used the metric on caves much shorter than those included in the study by Palmer. Differences between the global percentages of morphology types and the percentages found in Missouri suggest a lack of network caves and a plethora of rudimentary cave within the State. The lack of network caves is likely due to the lack of caprocks, and the plethora of rudimentary caves is likely due to deep stream incision.

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REFERENCES

Aley, T., 1978, Ozark hydrology-A predictive model: Missouri Speleology, v. 18, p. 1-185.

Ball, S., & Smith, A., 1903, The geology of Miller County: Rolla, Missouri Bureau of Geology and Water Resources, 490 p.

House, S., 1989, Bear Caves, Shannon County, Missouri: Cave Research Foundation, scale 1:344,000, 1 sheet.

Barnholtz, S., 1961, Influence of jointing on cavern development in Miller County, Missouri: Missouri Speleology, v. 3, p. 66-73.

Bretz, J H., 1965, Geomorphic history of the Ozarks in Missouri: Rolla, Department of Business and Administration, Division of Geological Survey and Water Resources, 47 p.

Brockie, D.C., Hare, E.H., Jr., & Dingess, P.R., 1968, The geology and ore deposits of the Tri-State District of Missouri, Kansas, and Oklahoma, *in* Ridge, J.D., ed., Ore deposits of the United States, 1933-1967: New York, American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., p. 401-430.

Cole, V., 1961, The Cap au Gres Fault in northeastern Missouri and west central Illinois, *in* King, R.H., ed., Field conference, Wichita, Kansas Geological Society, 26th Annual Field Conference, Guidebook, p. 86-88.

Davis, G., & Reynolds, S., 1996, Structural geology of rocks and regions: New York, John Wiley and Sons, Inc., 776 p.

Deike, R., 1969, Relations of jointing to orientation of solution cavities in limestone of central Pennsylvania: American Journal of Science, v. 267, p. 1230-1248.

Dom, J. E., 2002, Understanding cave geomorphology as an indicator for preferential groundwater flowpaths in Missouri [Masters thesis]: Columbia, University of Missouri, 121 p.

Fenneman, N.M., 1938, Physiography of the eastern United States: New York, McGraw Hill, 714 p.

Gregg, J. M. & Shelton K.L., 1989, Minor- and trace-element distributions in the Bonneterre Dolomite (Cambrian), southeast Missouri: Evidence for possible multiple-basin fluid sources and pathways during lead-zinc mineralization: Geological Society of American Bulletin, v. 101, p. 221-230.

Halihan, T., Wicks, C., & Engeln, J., 1998, Physical response of a karst drainage basin to flood pulses: Example of the Devil's Icebox Cave System (Missouri, USA): Journal of Hydrology, v. 204, p. 24-36.

King, P.B., 1951, The tectonics of middle North America: Princeton, Princeton University Press, 203 p.

Leach, D.L., 1979, Temperature and salinity of the fluids responsible for the minor occurrences of sphalerite in the Ozark region of Missouri: Economic Geology, v. 74, p. 931-940.

McCracken, M., 1971, Structural features of Missouri: Rolla, Missouri Department of Natural Resources, Division of Geology and Water Resources, 99 p.

Palmer, A., 1975, The origin of maze caves: National Speleological Survey Bulletin, v. 37, p. 57-76.

Palmer, A., 1991, Origin and morphology of limestone caves: Geological Society of America Bulletin, v. 103, p. 1-21.

Roedder, E., 1977, Fluid inclusion studies of the ore deposits of the Viburnum Trend, southeast Missouri: Economic Geology, v. 72, p. 474-479.

Symons, D.T.A., & Sangster, D.F., 1991, Paleomagnetic age of the central Missouri barite deposits and its genetic significance: Economic Geology, v. 86, p. 1-12.

Thompson, T.L., 1995, The stratigraphic succession in Missouri: Rolla, Missouri Department of Natural Resources, Division of Geology and Land Survey, Rolla, Missouri, 190 p.

Thornbury, W., 1965, Regional geomorphology of the United States: New York, Wiley, 609 p.

Vandike, J., 1985, Movement of shallow groundwater in the Perryville Karst Area, Southeastern Missouri: Rolla, Missouri Department of Natural Resources, Division of Geology and Land Survey, Rolla, Missouri, 52 p.

Vandike, J., 1996, The hydrology of Meramec Spring: Rolla, Missouri Department of Natural Resources, Division of Geology and Land Survey, 104 p.

Wicks, C., & Engeln J., 1997, Geochemical evolution of a karst stream in Devil's Icebox Cave, Missouri, USA: Journal of Hydrology, v.198, p. 30-41.

Williams, P., 1972, Morphometric analysis of polygonal karst in New Guinea: Geological Society of America Bulletin, v. 83, p. 761-796.