CARVING UP THE PRE-ILLINOIAN CENTRAL HIGHLANDS:TRANSVERSE SPELEOGENESIS AND EMERGENT BEDROCK MEANDERS IN THE OZARKS

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Abstract

New data fail to support the prevailing theory that meandering bedrock valleys inherit their sinuosity from ancient alluvial rivers. In the Ozarks, observations indicate that bedrock meanders emerge during incision as a result of erosion by emergent groundwater and surface flow. Crustal tilting pressurizes deep aquifers that feed a huge base flow to large springs. Because of their large size and persistence in time, these artesian conduits have the potential to create new base levels of erosion. Transverse speleogenesis causes groundwater flow lines and surface streams to converge toward the springs, thereby further increasing the rate of landscape lowering and creating bedrock meanders. Groundwater outflow accelerates stream piracy, creates asymmetric drainage patterns and cuts channels across structural upwarps. By contrast, the antecedent meander theory favors long-term drainage stability that cannot explain the incredible diversity of the freshwater fauna found in the Central Highlands. Widely disjunct species of highland fish that thrive only in clear, high-gradient streams indicate that the Ouachitas, the Ozarks and the Eastern Highlands were once a continuous upland connected by a "land bridge" in southern Illinois. This connection allowed ancestral species to become widespread enough to be affected by a vicariant event, usually attributed to onset of glaciation. However, a 400-km eastward shift in Gulf of Mexico sedimentation indicates this vicariant event may have occurred in the middle Pleistocene, when it is proposed that the Mississippi River dissected the Central Highlands, separating the Interior Highlands from the Eastern Highlands.

Key words: United States/Middlewest, Ozarks, Quaternary geology, bedrock meander, karst, speleogenesis, biogeography, phylogeography

Introduction

A bedrock meander is a resistant, sinuous channel that forms a relatively steep-sided, narrow, winding valley on the surface of a terrestrial planet. The large bedrock meanders of Missouri Ozark streams were among the first to attract the attention of scientists (Davis 1893). Ever since this early work, subaerial bedrock meanders on earth have traditionally been described as "incised" or "entrenched," terms that bear a genetic meaning based on overland flow. One purpose of this manuscript is to propose an alternative origin for the Ozark bedrock meanders based on the upward discharge of meteoric groundwater. Recognition that Ozark streams exist, in part, to efficiently drain confined aquifers has significant implications for the geomorphic history of the midcontinent region.

Artesian transverse speleogenesis is the hypogenic karst process whereby conduits evolve as result of vertical hydraulic communication between aquifers across a soluble bed (Klimchouk 2003). In transverse speleogenesis, water comes to a soluble unit from an adjacent, generally underlying, aquifer. Hypogenic karst is a relatively new concept in which the source of groundwater aggressiveness originates beneath the surface of the earth, implying some degree of confinement or rising flow. Artesian conduit systems are built from the bottom up by transverse speleogenesis, for example Lechuguilla Cave in Carslbad Caverns National Park, where deep basinal brines provided the aggressive fluids. Less familiar are hypogenic karst examples in less deep-seated, more meteoric, but still somewhat surface-independent systems such as the Ozark Salem Plateau. Traditional epigenic karst processes that rely upon downward percolation of surface recharge cannot explain many Ozark landscape enigmas, such as underwater caves that extend down to sea level and huge springs with extraordinary base-level flows of ancient meteoric water. These caves and springs commonly occur in rock units that yield relatively small amounts of water to wells. The water that transforms low-permeability dolomites into conduits comes mainly from adjacent, initially more porous layers such as the Gunter Sandstone and the vuggy Potosi Dolomite.

For 200 years John Playfair's (1802) theory that rivers carve the landscape has dominated geomorphology. Most researchers today regard the groundwater table as merely a subdued reflection of the surface topography and not an important part of forming the landscape itself. But this river theory has recently met with a problem, and that is the surface features found on the planet Mars. The Martian landscape features intricate networks of recent channels that include bedrock meanders and asymmetric drainage basins. Yet conditions on Mars preclude persistent rivers. Most Martian valley networks form by the process of groundwater sapping (Malin and Edgett 2000). The strong focus on river erosion on Earth cannot explain many landforms. An alternative framework advocated here views groundwater erosion as an important process vector along with surface tools such as glaciers and rivers. Playfair is still relevant. Zones favorable for transverse speoleogenesis (groundwater's sharpest erosion tool) are typically found in the rock layers beneath rivers (Klimchouck 2003). The emerging idea that the surface topography can be influenced by groundwater also has important phylogeographic implications. Groundwater erosion can isolate species by relocating rivers. Groundwater erosion can also aid species dispersal by helping stream piracy cut across upland barriers (Pederson 2001).

Perhaps nowhere on Earth is groundwater's important role in the formation of landscapes more apparent than the Ozarks. Dye tracing has shown that groundwater basins can extend well beyond surface watershed boundaries and there is a general lack of fine-scale dissection on interfluves. This study reinterprets Ozark landforms, such as bedrock meanders and transverse drainages, taking into account both groundwater and surface-water-process vectors. The purpose is to produce paleogeographic maps that are based on hydrogeological and biological observations to help explain the current Ozark landforms and the distribution of species within the area.

The maps presented here differ from most interpretations by linking the pre-Illinoian Teays River with Texas along a broad topographic low that extends in an arc from northeastern Oklahoma to the Missouri River in central Missouri (Figure 1). The connection is based in part on biology, such as fish and mollusk distribution (Barnhart 2001) and in part on stratigraphy, such as Appalachian-derived sediments in Pleistocene Sabine River sediments (Mange and Otvos 2005). The connection implies that the Ouachitas, the Ozarks and the Appalachians were once a continuous upland—The Central Highlands (Mayden 1988).

The first part of this paper reviews the concepts of bedrock meanders. A theory is then proposed that explains how bedrock rivers can meander as a result of the natural processes of groundwater and surface water erosion. The second part of the paper compiles some diverse geohydrological and biological evidence that indicate the Ozark landscape was preceded by the Central Highlands and not a low elevation plane as previously implied by the antecedent meander theory. The experimental ideas presented here are meant to elicit a dialogue concerning the landscape evolution of this complex region.

"Entrenched" Bedrock Meanders

The very term "entrenched meander" is an indication of geologists' confidence in the correct-

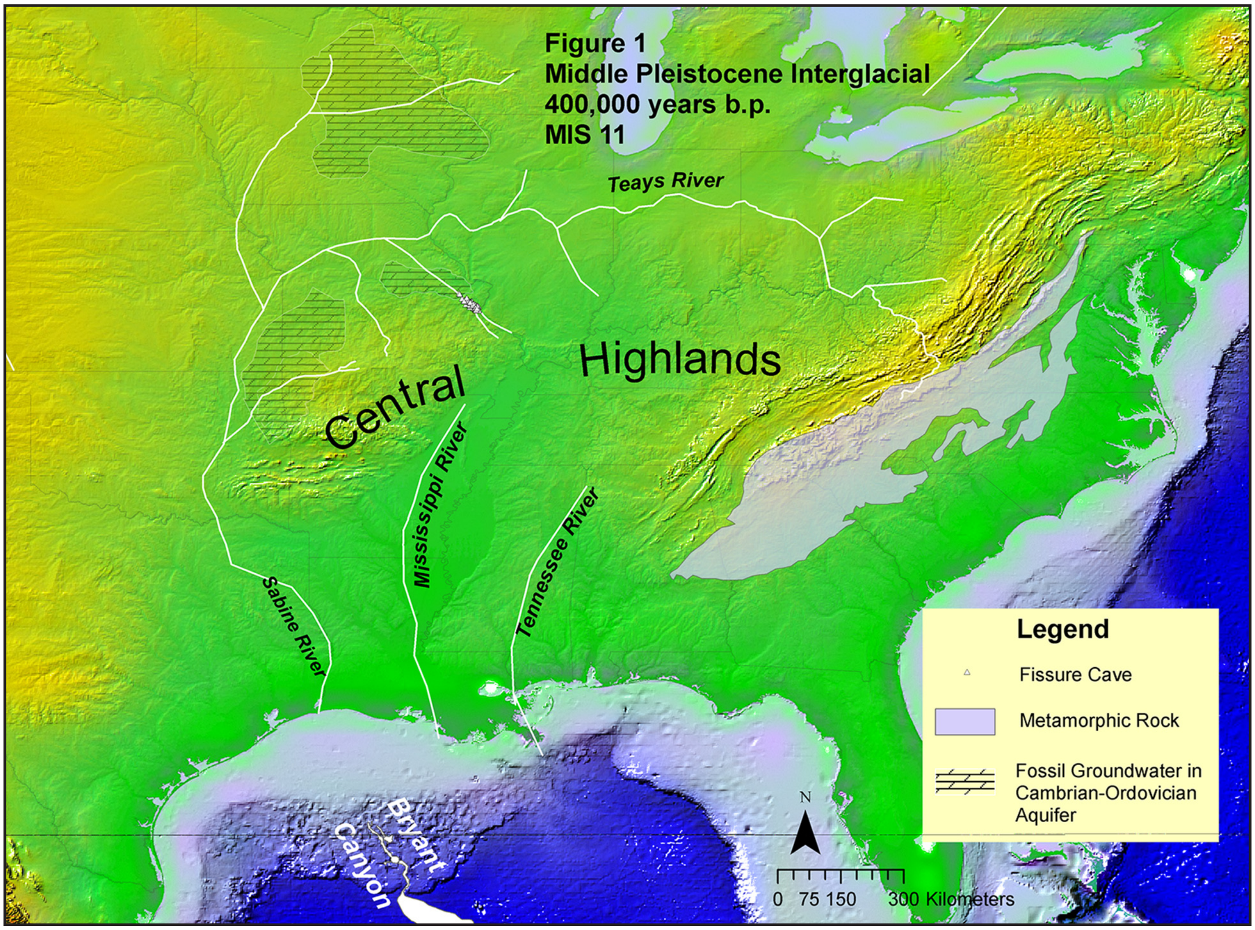


Figure 1 *Reconstructed pre-Illinoian drainage routes, shown just before the Mississippi River captures the upper Teays valley, splitting the Central Highlands. High-grade metamorphic sediments erode from the Appalachians, flow down the Teays River to the Ancestral Neosho River in Kansas (Aber, 1997) and are deposited in the Sabine River Valley of Texas (Mange and Otvos 2005). Precipitation falls on exposed Cambrian-Ordovician rocks of the Salem Plateau and the Wisconsin Arch feeding an underflow that recharges confined aquifers (Jorgensen et al. 1986). Today, groundwater flow directions have changed and these confined aquifers are no longer downgradient of their former recharge areas.*

ness of the landform's inferred origin. The standard explanation for "entrenched meanders" is that they are relics of an ancient, low-gradient floodplain or peneplain. However, bedrock meanders have now been identified in other environments that are unlikely to have ever included low-gradient meandering rivers. The alluvial inheritance theory is unable to explain bedrock meanders carved on Mars, the deep ocean and Taiwan. Mars and the sea floor lack persistent rivers, while meandering low-gradient rivers are rare on Taiwan, one of the most tectonically and erosionally active regions on earth (Stark et al. 2003). Rather than antecedent alluvial meanders, what all these environments may have in common is groundwater discharge.

Renowned geomorphologist William Morris Davis (1893) called attention to the wide meanders of the Osage River in Missouri and proposed that the meanders were inherited from an ancient river wandering almost aimlessly on nearly level ground, a floodplain or peneplain. As later uplift progressed the meanders were no longer able to wander and instead became entrenched. Winslow (1893) objected, citing gravel deposits common on Ozark ridgetops that indicate a fairly rapid flow of sediments within a landscape similar to modern Ozark rivers, as opposed to fine-grained sediments that might be expected from a low-gradient, freely meandering river. Marbut (1896) proposed a theory whereby erosion in tributaries could deflect a

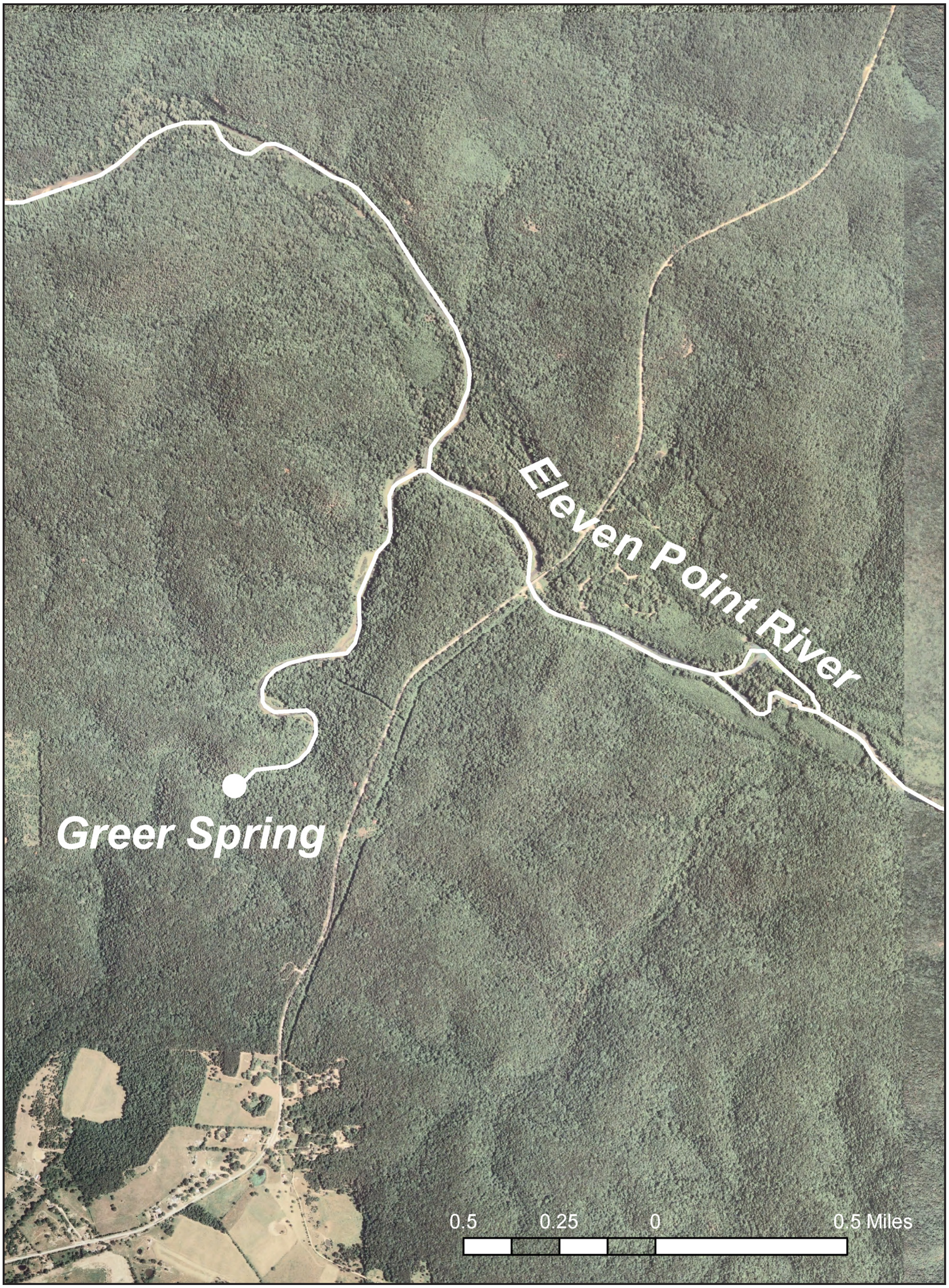


Figure 2a (see page 6 for explanation)

Figure 2b (see page 6 for explanation)

(see page 6 for explanation)

Figure 2
Previous pages *A comparison of (a) the Eleven Point River and (b) the Current River shows how a meander can naturally initiate within a relatively straight bedrock channel and grow into a highly sinuous reach. Greer Spring (a) represents the early stage of the process. Big Spring (b) is the largest spring in Missouri and Greer Spring is the second largest. Each spring produces over 9,500 L/sec. The Greer Spring Branch is one of the steepest streams in Missouri, dropping approximately 18 m in 2 km. As groundwater continues to flow from Greer Spring, the steep spring branch will incise deeper and deeper, deflecting the Eleven Point River toward the spring in a manner first described by Marbut (1896). Eventually the Eleven Point River may engulf Greer Spring, just as the Current River is now trying to flood Big Spring.*

stream and create emergent meanders. However, Davis' alluvial-inheritance argument was regarded by most scientists of the day as the accepted explanation because typical bedrock-meander wavelength and amplitude were seen to increase downstream, just like alluvial meanders. Today Davis' alluvial-inheritance explanation of the landscape remains popular among geologists. However, hydrologic data collected by scientists is starting to show there is more to the history of the Ozark landscape.

A newly released study on Big Spring, the largest spring between Florida and Idaho, has determined that much of the spring's huge base flow may have been underground for several hundred years or longer (Imes et al. 2007). In the case of Big Spring, the soluble Cambrian Eminence Dolomite forms the confining unit as the base-flow water comes from the underlying vuggy and prolific Potosi Dolomite. It is proposed that throughout the pressurized portions of the Ozarks' multistory, artesian, aquifer system, old groundwater moves upward from deep aquifers bringing tons of dissolved rock to the surface and lowering the landscape. The idea that a large artesian spring can erode faster than neighboring streams may come as a surprise to many researchers who tend to think the base level of erosion is determined by sea level. In transverse speleogenesis, the base level of erosion is determined by hydraulic pressure in the confined aquifer (Brod 1964).

The creation of an emergent bedrock meander is illustrated in Figure 2. Greer Spring represents the early stage of the process. Surface streams tend to meander from spring to spring, at times engulfing a spring, masking and eventually erasing the work done by underground waterways. Big Spring would be drowned by the Current River now if not for a system of levees. Thus, the meandering valleys that are a trademark of the Ozarks are primarily a consequence of spring and karst processes that lower the landscape and direct valley alignment as surface streams incise.

Transverse speleogenesis can also explain why bedrock meanders tend to increase in size downstream. Spring erosion is a competitive process and only a few major, deeply incised springs feed the surface streams as they encompass more watershed area. As the discharging aquifer is drained, the "cone of depression"around large springs and gaining streams naturally widens with incision and exploitation/interception of more remote, discrete, discharge features and additional volumes of pressurized groundwater. Groundwater discharges tend to increase with contributing area in a downstream direction and the springs tend to get larger and farther apart. Streams that meander between the springs tend to carve bedrock meanders that increase in size and amplitude in a downstream direction, the logical consequence of hydraulic optimization. Furthermore, a longer, meandering river allows more water to escape from underlying aquifers than a straight channel.

Biogeography

Biogeographic evidence suggests a relatively recent faunal connection between the Ozarks and the Appalachians (Mayden 1988). Many sister species of fish (Pflieger 1997), crayfish (Crandall and Templeton 1999) and salamanders (Routman et al. 1994) occur across these regions. The studies show that northern Ozark populations tend to be most closely related to populations in the Ohio River drainage. While Southern Ozark populations may be related to populations from the Tennessee River.

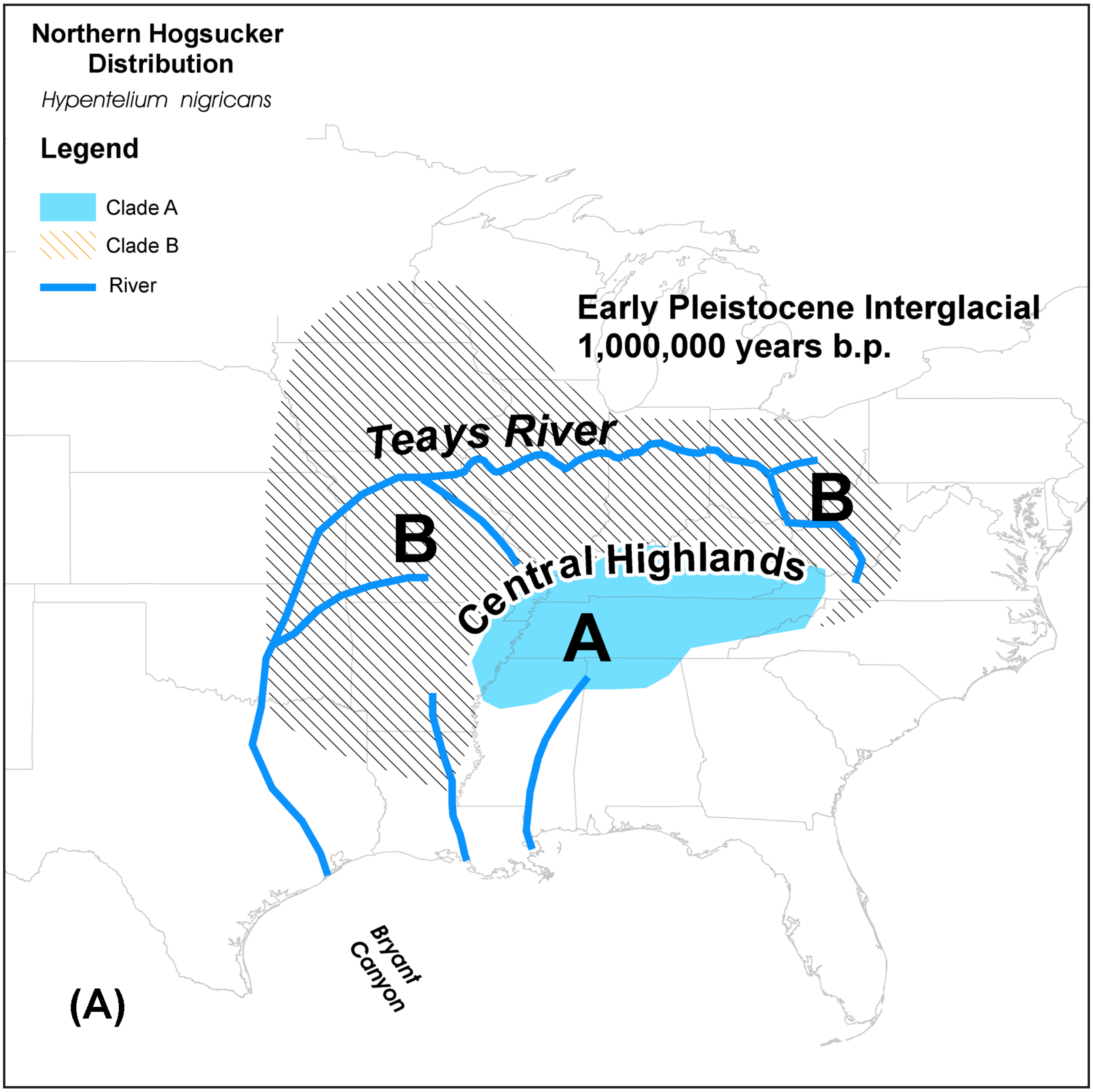
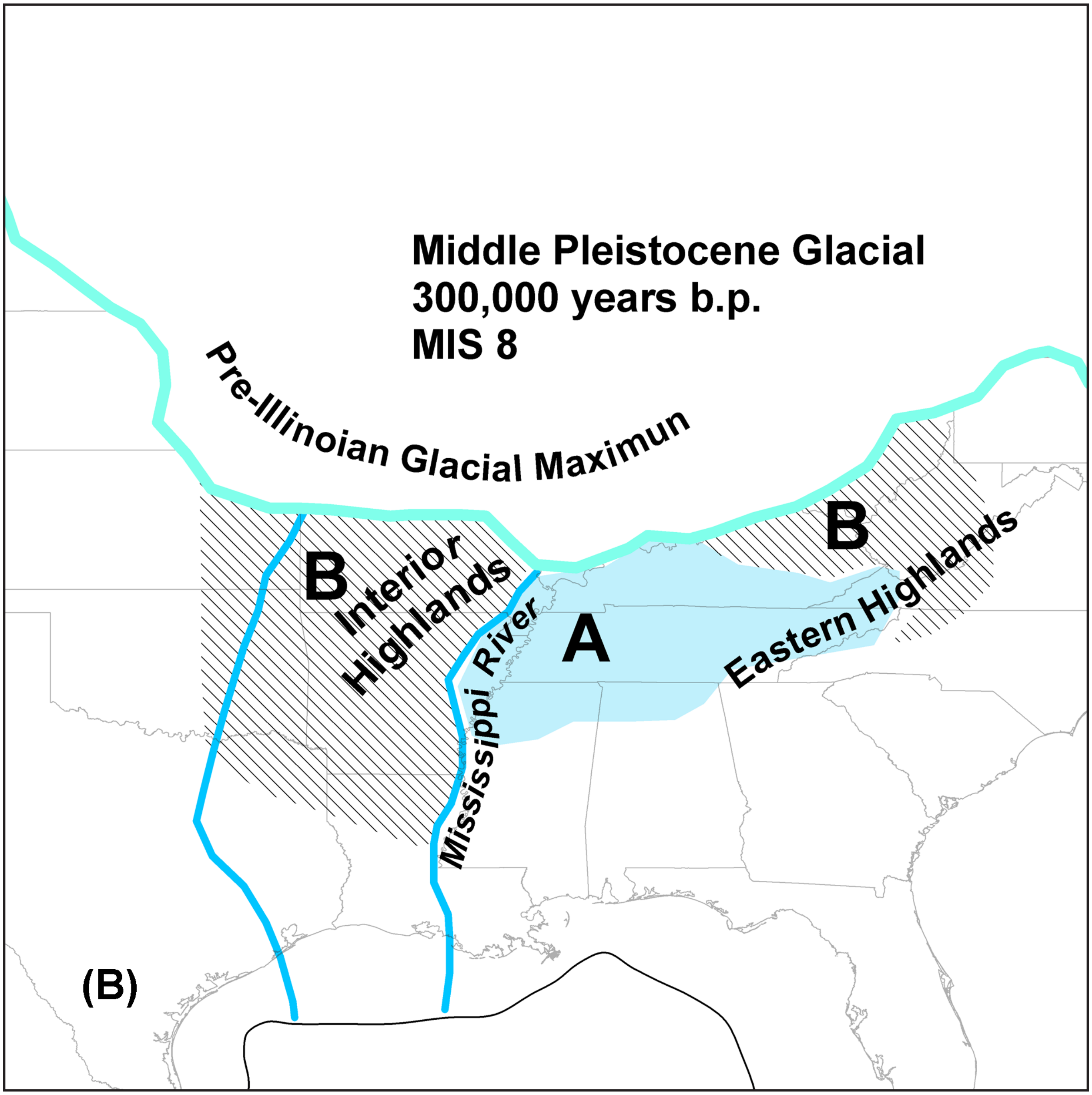


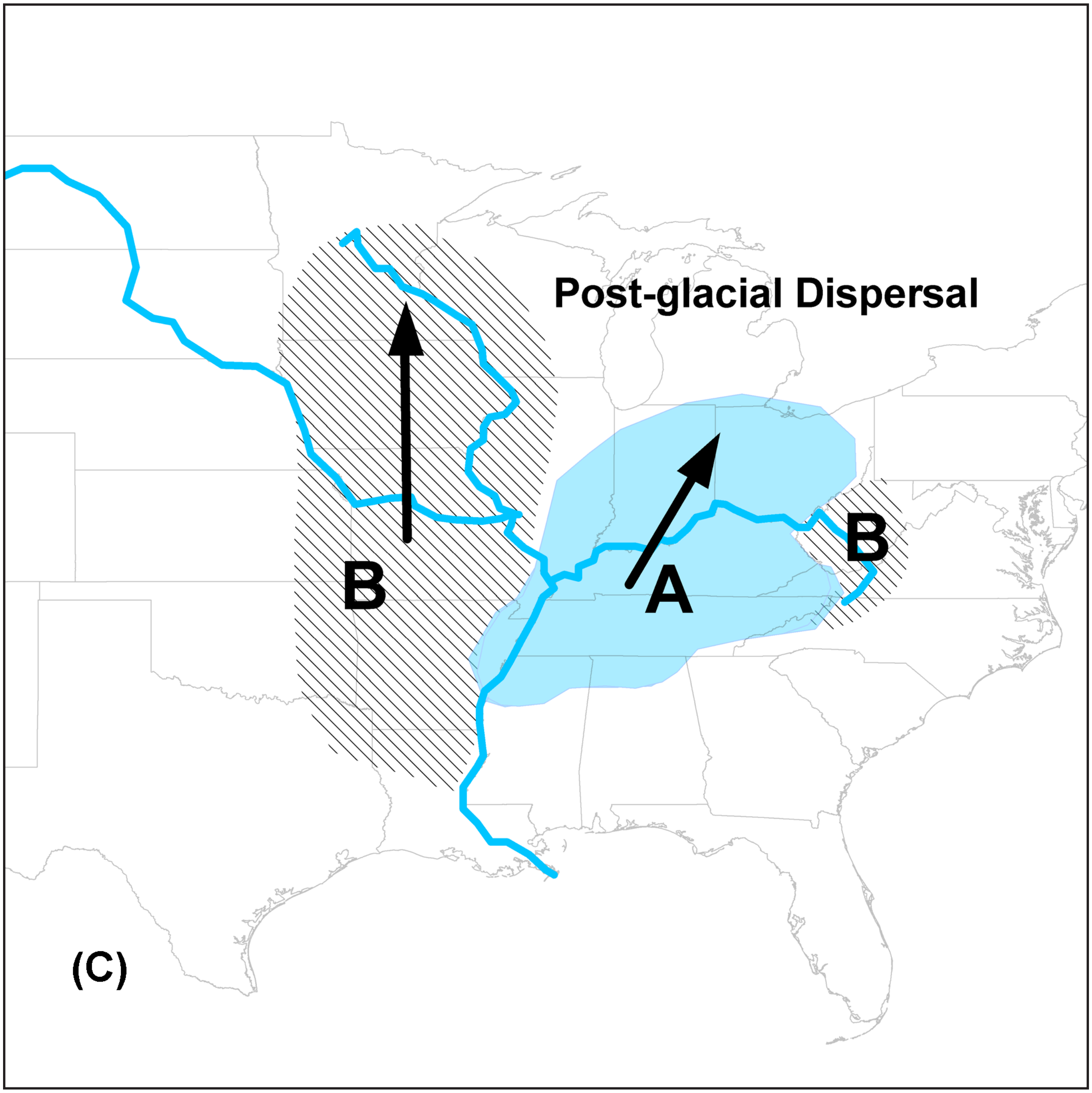
Figure 3 *(a) Hypothetical early Pleistocene distribution of Hypentelium nigricans, northern hogsucker, across a continuous Central Highlands. Clades A and B are separated because the Mississippi River does not extend north of the Central Highlands.*
(b) The Mississippi River breaches the Central Highlands. The first glacial outwash reaches the lower Mississippi valley, resulting in deposition of the Crowley's Ridge Loess (Rutter et al. 2006).
(c) Post-glacial distribution of H. nigricans. The widely separated, disjunct pattern of clade B is replicated in other clades of fishes (Berendzen et al. 2003).

This deep divergence is difficult to explain if the Mississippi River has been in its present position for millions of years. In contrast the Mississippi River itself is not a continuous barrier as evidenced by the current distributions of many modern taxa not expected to survive in large muddy rivers (Austin et al. 2004). The existence of a continuous Central Highland that was fractured in the Middle Pleistocene by the Mississippi River can better explain these patterns. The process is illustrated in Figure 3 using now disjunct clades of a fish, the northern hogsucker (Berendzen et al. 2003).



The Mississippi River is a barrier to some species such as the American Bullfrog and biological dates of isolation match the Middle Pleistocene vicariant event proposed in this report (Austin et al. 2004). In other cases, vicariant dates proposed in this study are younger than molecular estimates of isolation. For example, the abandonment of Bryant Canyon (Figure 1 and Figure 3a) in the Gulf of Mexico suggests that the Arkansas River separated the Ouchitas and the Ozarks sometime before the end of Marine Isotope Stage 5 (MIS 5), about 110,00-130,000 years before present (Tripsanas et al. 2007). Most molecular clocks estimate this vicariant event occurred earlier.

There are examples of karst-related relicts separated by the Mississippi River such as the blind Caney Mountain crayfish, the only cave-adapted *Orconectes* found west of the Mississippi (Elliott 2007). It is closely related to the crayfish, *O. pellucidus*, found in Kentucky. Kentucky and Tennessee's southern cavefish, *Typhlichthys subterraneus,* also has close relatives in Missouri and Arkansas (Niemiller and Fitzpatrick 2008 in this volume). Once again, the vicariant event that separated these stygobites is estimated by molecular methods to be older than what geological evidence presented in this manuscript would suggest. However, headward erosion up the Ozark segment of the Mississippi



River may have caused vicariant events prior to the final connection that eventually integrated the entire drainage system.

Tectonism

Antecedent entrenched meanders are tectonically significant because they require uplift without significant tilting in order to form. However, global positioning system (GPS) studies suggest that the Northern Mississippi embayment may be slowly subsiding relative to the Salem Plateau (Mattioli and Jansma 2007). GPS stations on both sides of the Reelfoot fault in the tectonically active New Madrid Seismic Zone appear to be subsiding. Subsidence rates emerging from the GPS surveys are fast enough to lower the Mississippi Embayment a few hundred meters since the early Pleistocene. Mississippi Embayment subsidence can generate tectonic relief, create high hydraulic heads, reorient the groundwater flow fields and influence drainage-basin development, thus setting up conditions favorable for transverse speleogenesis.

I propose that vertical tectonic movements produce the high hydraulic pressure in the confined portions of multistory Ozark aquifers. Once the surrounding seals of the overlying massive carbonates are broken, groundwater will flow through

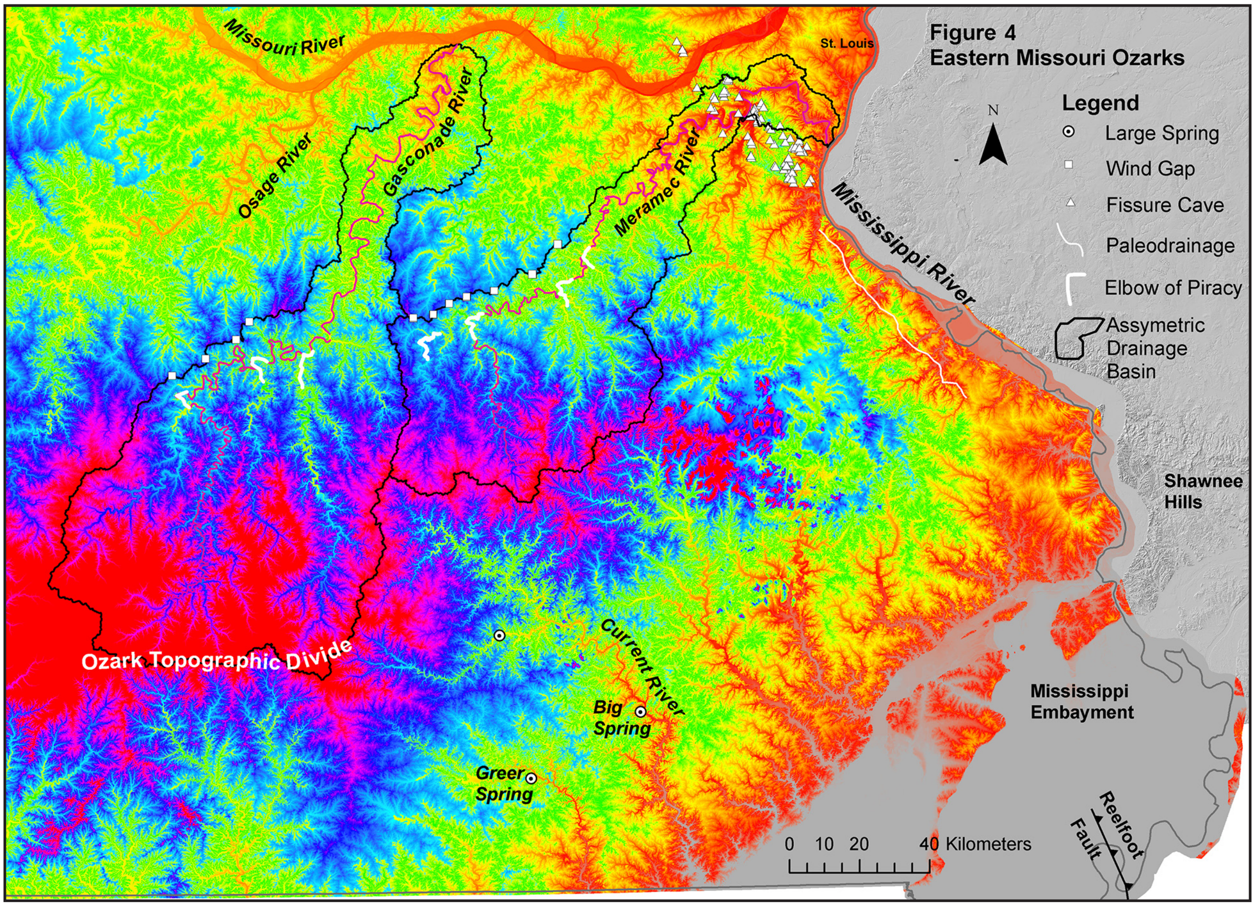


Figure 4 *Study area showing modern rivers and a paleochannel that is now followed by Interstate 55. Headwaters of the Gasconade and Meramec Rivers flow north to northwest, relicts of a drainage network that once flowed off the Central Highlands. Their diversion to the east has created asymmetric drainage basins.*

fracture outlets to the surface.

Fissure Caves of Eastern Missouri

The flow of pressurized groundwater along primary conduits that results in speolegenesis can be seen in an area known for its "fissure caves." The caves are found in a 5-km-wide by 60-km-long belt southwest of St. Louis and are comparable to large Ozark spring conduits as reported by SCUBA divers. These include many caves in Jefferson County such as Crankshaft Pit, Pleasant Valley Cave and Rice Cave, and St. Louis County, such as Horneker and Rankin caves. The artesian nature of the fissure caves and their ability to affect base level was initially recognized and described by Brod (1964). According to Brod, conduits evolve as a result of vertical hydraulic communication between aquifers across a soluble bed. Brod's recognition that an artesian spring can erode the landscape below the level of nearby streams is a critical observation for the groundwater-outflow theory of emergent bedrock meanders.

Ford (2006) agreed with Brod's interpretation, but considered this type of transverse speleogenesis to be rare. However, the recent discovery of pre-modern groundwater feeding the huge base flow of one the nation's largest springs (Imes et al. 2007) suggests that transverse speleogenesis may be widespread in the Ozarks' big spring country (Figure 4). It now appears that what is really rare is for the underground voids and karst features created by transverse speleogenesis to be preserved. Because of their position beneath rivers, karstic shafts produced by artesian speleogenesis are generally destroyed as the landscape lowers. However, due to a major drainage reorganization that cut the Central Highlands in two, the fissure caves of eastern Missouri were left high and dry and the underground features were preserved.

Caves serve as storehouses of information on past landscapes. Eastern Missouri fissure caves are evidence of a focused, paleogroundwater discharge beneath a large river. Ridgetop, alluvial gravels (Brod 1964) and anomalous, inactive groundwater bodies (Jorgensen et al. 1986) indicate that the pre-Illinoian drainage network in Eastern Missouri was significantly different from the modern one. Paleovalleys in the northeastern Ozarks and in the St. Louis area initially drained off the Central Highlands toward the northwest, but were later disrupted by the middle Pleistocene appearance of the Mississippi River. This flow-reversal resulted from a combination of Pleistocene subsidence in the Mississippi Embayment and pre-Illinoian glaciations. The fissure caves mark the position of a pre-Illinoian river that once flowed northwest toward the Teays River (Figures 1 and 4).

South of St. Louis, Interstate 55 follows remnants of an old headwater valley through Jefferson, Ste. Genevieve and Perry Counties. This lost valley has been interpreted as a south-flowing, proglacial, diversion of the Mississippi River (Brod 1964). However, stream barbs suggest a northerly flow was more likely. The spatial correlation of anomalous groundwater north of the Missouri River, a fossil drainage pattern to the south of the fissure cave corridor and Lafayette gravels found on ridgetops is supporting evidence that suggests that a former path of Central Highlands runoff flowed north through the fissure-cave corridor (Figure 4).

Anomalous Aquifers

Freshwater found in the deep, confined aquifers that ring the Ozarks to the north and to the west provide the best evidence that a Central Highland existed in the relatively recent geologic past (Figure 1). The proposed eastward migration of regional base levels has caused widespread stream piracies, leaving behind large, fossil-groundwater bodies that are now out of equilibrium with the modern Mississippi drainage network (Jorgensen et al. 1986). These anomalous, freshwater, Cambrian-Ordovician aquifers have been cut off from their former recharge areas on the Central Highlands. Modern precipitation falling on Cambrian and Ordovician exposures in the Salem Plateau now flows east and south toward the Mississippi valley. North of the Missouri River, fresh water in the confined Cambrian-Ordovician aquifer is currently being recharged by saline groundwater from the northwest. Flow directions have reversed. Total dissolved solids are supposed to increase in a downgradient direction as water-rock interactions progress. The aquifer is now cut off from its former recharge area on the Salem Plateau by the Missouri River. The anomalous concentration gradients indicate that the freshwater remnants were emplaced under hydrologic conditions that are very different than what exist today.

Transverse drainages

The fissure caves are now found on the uplifted flanks of the Eureka-House Springs Anticline. However, the shafts originally formed beneath a river. Erosion since the conduits' abandonment has greatly altered the landscape. Emergence of groundwater from the structurally disturbed noses of folds is typical of artesian speleogenesis (Klimchouk 2003). Erosion can thin confining units above upwarps, further encouraging transverse speleogenesis near the crest of anticlines.

Rivers intersecting upwarps at their highest structural and topographic position have long puzzled geologists. The dominant theory posed by Powell (1875) for such relationships is that of antecedence. According to this view, the rivers were already in their present positions when the upwarps began to grow. The Osage River is a typical example of a cross-axial, or discordant, drainage that appears to take a most difficult route across the Ozarks. The Mississippi River between the Shawnee Hills of Illinois and Missouri's Ozarks is another river that crosses an upwarp near its apex. Transverse speleogenesis and stream piracy can explain both these cases without appealing to antecedent rivers. One reason rivers carve channels into what appears to be the paths of greatest resistance is because that is where the pressurized groundwater can find disturbed structures that can act as nozzles, focusing groundwater discharge upward and creating springs by hydraulic fracturing. Headward erosion of more hydraulically advantaged streams expands, and in this manner groundwater divides can migrate beneath uplands and produce a stream piracy.

Asymmetric Drainage Basins

It is proposed that paleodrainages, in what are now the Northern Ozarks, flowed to the ancestral

Teays River system to the north and west. A subsequent tectonic phase resulted in the subsidence of the Mississippi Embayment and the St. Louis depression disrupted the pre-Illinoian drainage. Hydraulically advantaged tributaries of the Missouri and Mississippi Rivers have captured the headwaters of other northwesterly flowing Ozark paleodrainages, creating the asymmetric drainage networks of the modern Meramec and Gasconade Rivers, where most inflow to the mainstem is from the south and relatively little from the north. The asymmetric basins contain a series of nested elbows of capture (Figure 4). Initially the flow of the rivers is to the northwest as if going to the old Teays River but this flow has been intercepted and now flows to the east reflecting subsidence in the Mississippi Embayment and the St. Louis area. If the diversion-elbows theory is correct, then the interfluve closest to the main stem should be notched by windgaps that roughly correspond with tributaries that once flowed off the opposite side of the valley. Interstate 44 follows such an undulating interfluve as it rolls along the northern edge of the Meramec Valley and crosses dry valleys. The dry valleys are windgaps where streams once flowed to the northwest before being pirated by a more direct route to the Mississippi River. The I-44 wind gaps should get younger in a westward direction as areas under direct hydraulic control of the Mississippi River expand.

Stratigraphy

Sediments from the Gulf of Mexico show that the mouth of the main mid-continent trunk stream has migrated eastward approximately 400 kilometers since the Middle Pleistocene (Prather et al. 1998). Migration of the river system has caused a profound change in sediment supply during the late Pleistocene. The once abundant fluvial source that previously fed the sand-rich barrier islands off the Texas coast was cut off (Tripsanas et al. 2007). Geohydrologic and biological evidence for a similar eastward shift of mid-continent rivers is the focus of this paper.

Drainage shifts in Kansas and Missouri have left Cenozoic alluvial gravels on modern hilltops (Aber 1997). Aber proposed ongoing crustal tilting toward the Mississippi Embayment to explain this complete inversion of topography. The older parts of what are known as the Lafayette gravels occur on top of an erosional surface that once drained the Central Highlands.

Loess lithology of the modern river system provides evidence that the modern river system was integrated during Wisconsin time. For example, in the Mississippi Valley, only the late Pleistocene Peoria Loess shows any deposits from Rocky Mountain or Great Plains sources. The older Roxana Loess that is found in the Mississippi Valley has a more characteristic reddish color along with a higher magnetic susceptibility. This is an indication that a significant contribution of sediment has come from the more mafic Lake Superior source area (Rutter et al. 2006).

Discussion

There is a growing body of evidence from diverse disciplines supporting the idea that in the early Pleistocene, the Missouri Ozarks comprised the northwest slope of a continuous Central Highland. Patterns of topography, tectonics, drainage, sediments, groundwater chemistry and biogeography in the midcontinent provide evidence for recent subsidence and river capture. Such active tectonics contrasts with the traditional view of the midcontinent, which is seen as a stable craton.

Sustained groundwater outflow requires that hydraulic gradients be maintained by ongoing subsidence. Groundwater outflow is closely linked to subsidence. Ozark karst is in the early stages of erosion, when plenty of water is available from the large upland, and sapping processes dominate. I do not imply that all caves, incised meanders, asymmetric drainages and valleys located near the crests of topographic bulges are formed by dewatering of overpressurized aquifers. Nevertheless, emerging groundwater may have been an important and often overlooked landscape-process vector in other karst regions where vertical movements have subsided and aquifers have reached equilibrium. Dewatering is self-terminating after vertical motions cease and aquifers reach equilibrium, which may help explain why huge springs are present in relatively few karst areas. The south central Ozarks are currently in a very active cave-forming period. Active bedrock meanders can be considered karst features in the sense that they facilitate the circulation of regional groundwater fluid in a downgradient direction.

Conclusions

The ancient landscape paradigm, and methods of hydrogeologic and historical biogeographic analysis stemming from it, has produced an inadequate representation of landscape and biological evolution in the midcontinent. This is because of the overlooked importance of groundwater and tectonism in shaping topography and the overly restrictive range of processes (i.e. glaciers and sea-level fluctuations) that can modify drainage patterns and create vicariant events. New reconstructions of Pleistocene landscape based on groundwater chemistry, stratigraphy and geomorphology result in a pattern that is more in harmony with species distribution. The proposed connection between the Teays River and Bryant Canyon modifies and strengthens the Central Highlands vicariance hypothesis. Evidence presented in this paper challenges the ancient landscape paradigm and draws a tentative geohydrologic connection between the big springs of the Ozarks and subsidence in the Mississippi Embayment.

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