

QUATERNARY DRAINAGE SHIFTS IN MISSOURI

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ABSTRACT

Large drainage shifts toward the Mississippi embayment and the Cap au Gres-Waterloo-Dupo Structure are proposed to explain stratigraphic, geomorphic, hydrogeologic and biologic observations in Missouri.

INTRODUCTION

Former Missouri State Geologist William C. Hayes examined the geology of Union Electric's Taum Sauk pumped storage project, in the St. Francois Mountains. Dr. Hayes concluded that the present day rugged topography was formed by uplift and erosion within the last million years or less (Hayes, 1964). Prior to this uplift, rivers that bore little resemblance to modern streams deposited exotic pebbles in chert gravels throughout southern Missouri (Fig. 1). Remnants of these stream channels are now found on Ozark hill tops, high above present-day, unrelated rivers. This inversion of topography was accomplished by wholesale drainage shifts and substantial erosion. It is not feasible to reconstruct the precise sequence and timing of the various drainage diversions that have shaped Missouri's landscape. In this paper, we present an elemental outline of how drainage basin competition shifted the Ozark surface water divide north and west during the Late Pleistocene.

Late Tertiary diversions of Mid-Continent rivers southward and Pleistocene speciation have been proposed to explain phylogenetic relationships among clear water, small river, highland fish (Wilson, 1996). Ongoing crustal tilting has been proposed to explain a systematic shift of drainage directions southward and eastward in both Kansas (Aber, 1997) and Missouri (Elfrink and Siemens, 1997). Tectonic forces have apparently tilted a large part of the crust in Central North America down toward the Gulf of Mexico. Areas that once drained north, toward the Arctic, now empty into the Gulf of Mexico. New rivers have cut steep valleys, leaving Tertiary stream gravels high and dry.

Alluvial Gravel Deposits

Once known as the Lafayette Gravel and more recently as the Mounds Gravel, Missouri's high level gravel deposits are poorly understood (Potter, 1955). According to our view, Late Tertiary rejuvenation of the Nashville Dome (Self, 1993) initiated deposition of the Mounds Gravel (Fig. 1). Pleistocene rejuvenation of the Ozark Dome shifted Mounds Gravel movement back to the south, jumbling cross-bedding directions (Fig 2). In general, Pliocene Mounds Gravel-type gravels, typical of Western Tennessee, were shed off uplifted areas in Tennessee. Whereas, Pleistocene Mounds Gravel-type gravels, common on Crowley's Ridge, were shed off the Ozarks. Both units consist largely of locally derived chert. Both gravels contain components derived from sources in Appalachia or the Ouchitas. Older gravels contain more metamorphics. Topaz, derived from the St. Francois terrane, is restricted to younger gravels.

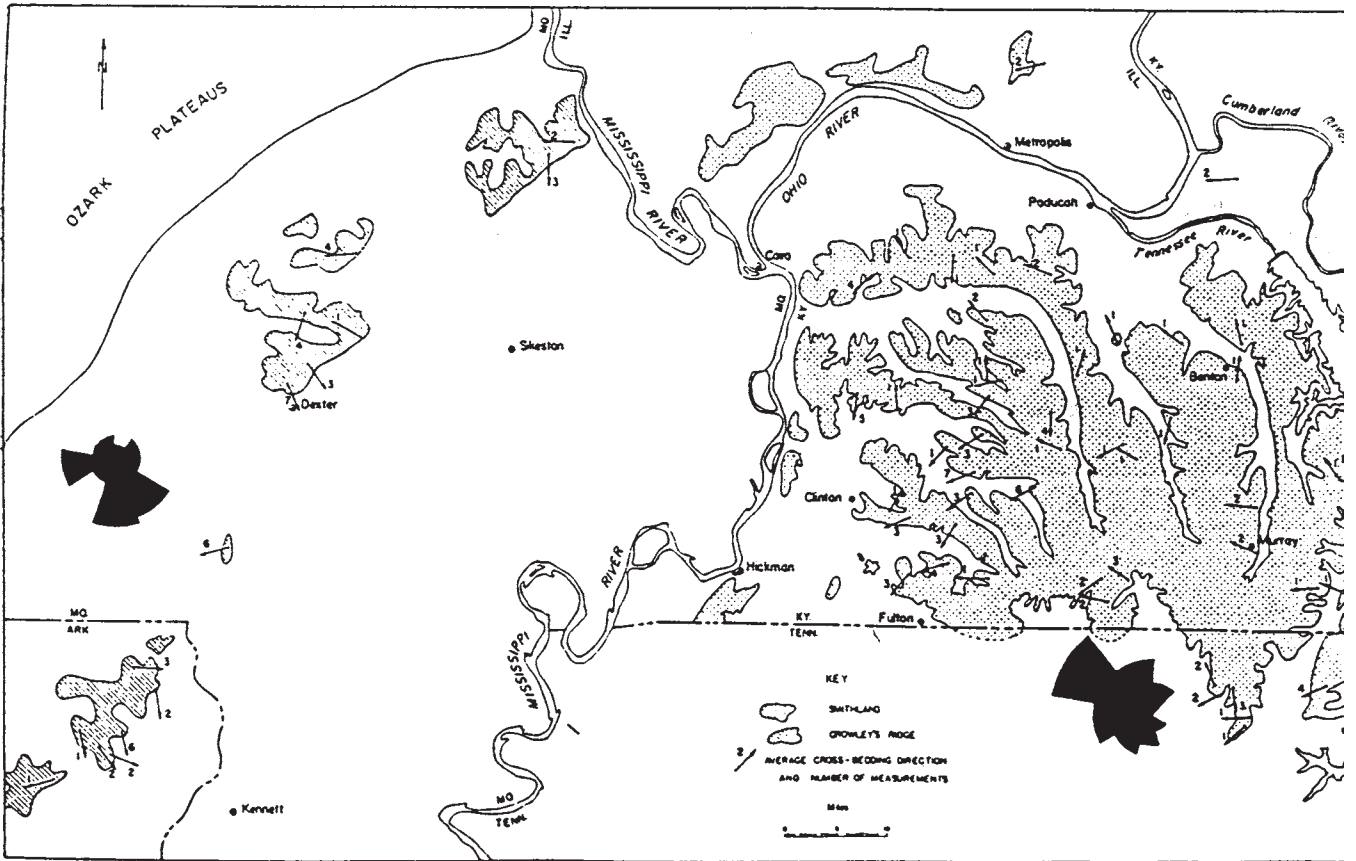
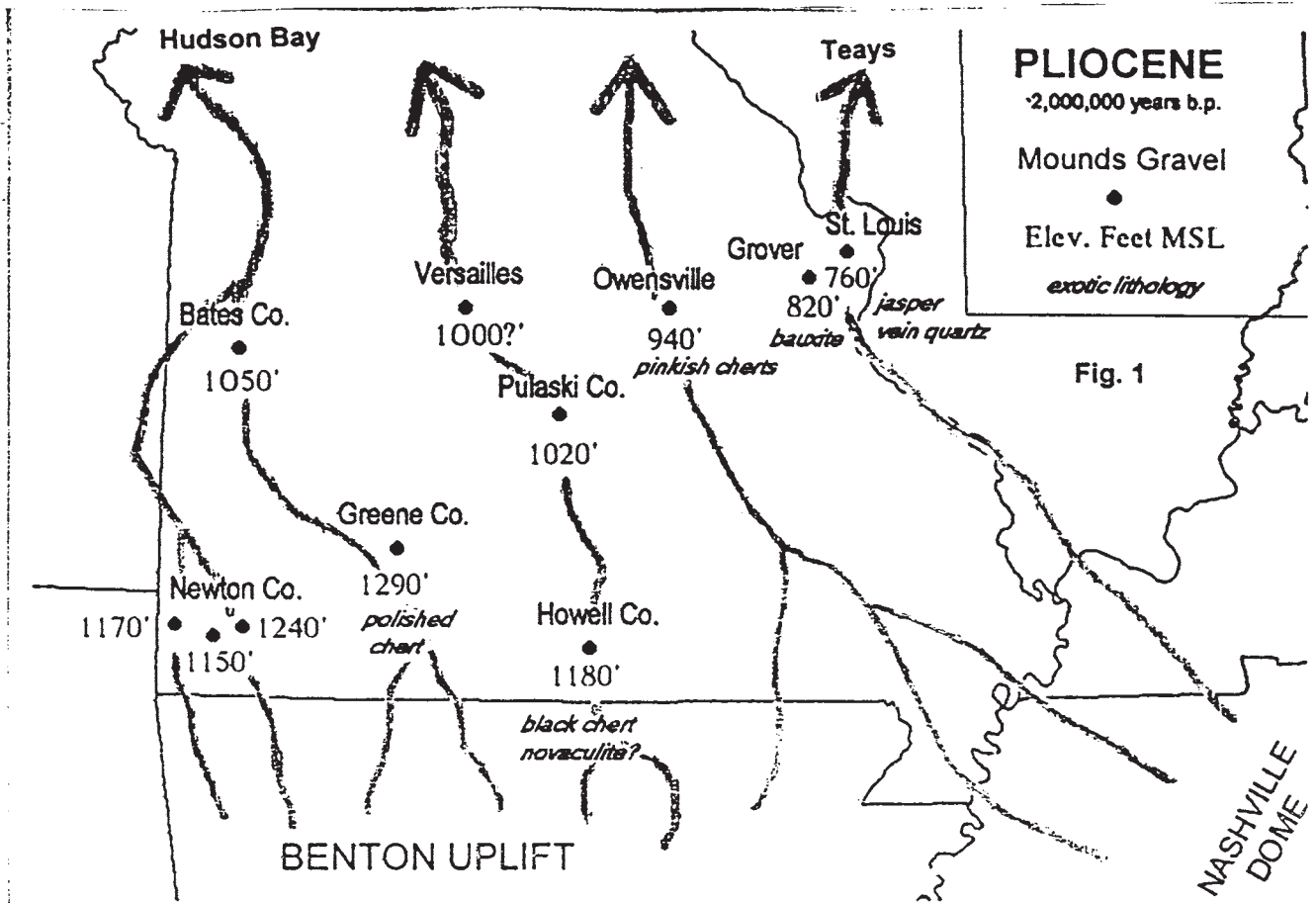


Fig. 2

-Cross-bedding in Lafayette gravel

after Potter, 1955

Pleistocene syntectonic gravels known informally as the Metropolis formation (Fig 3), are found in neotectonic structures along the Commerce Geophysical Linemant (Harrison, et al., 1998). Late Quaternary terrace gravels are associated with modern Ozark rivers. Holocene gravels underlie modern floodplains.

Mounds Gravel-type gravels

In various places in southern Missouri, alluvial gravels cap ridges far above present streams. The gravels are mostly chert, but in some places contain pinkish and purplish quartzite, black chert and bauxite that are clearly exotic (Fig. 1). Lithology suggests that north-flowing streams originating in Appalachia and/or Arkansas deposited some of the older ridge-top gravels. Given the relatively high erosion rates in Southern Missouri and the unconsolidated nature of the gravels, it is highly doubtful that many of the gravels are older than Pliocene. Yet, the gravels are unrelated to present streams. Uplift and subsequent erosion has left them high and dry. We correlate these gravels with the Mounds Gravels, although some may be older.

One of the most extensive Mounds Gravel-type gravel deposits occupies the crest of a high ridge north of Owensville (Fig. 1). Bretz (1965) recognized that this alluvial deposit should not cap the highest levels of a peneplain. The gravels overly hot spring deposits that we believe were formed by the discharge of MVT fluids during the Pennsylvanian. Asher-Bolinder, et al. (1993) suggest that MTV fluids altered filled sink deposits. Once thought to be filled "sinks" that developed on a peneplain, the sinks contain sand and clay deposits with associated iron, diaspore and tripolite deposits. Sinkholes form on uplands, while sediments are deposited in lowlands. Sinkholes are unlikely to survive the erosion that would accompany such an inversion of topography. The deposits were more likely formed by the discharge of hydrothermal fluids that had migrated during the Ouchita orogeny. The "sinkhole" deposits are inconsistent with normal depositional processes. Claystone and sandstone beds in the "sinkholes" commonly slope steeply toward a throat where the bedding approaches vertical. Deposits of silicious sinter are associated with alternating high-alumina and low-alumina clays.

Mounds Gravel-type gravels in Howell, Newton and St. Louis counties may also overlie older groundwater discharge zones. The close proximity of Pennsylvanian hot-spring deposits and Pliocene alluvial gravels suggests that these areas may have occupied the low level of the landscape since the Paleozoic. The gravels now occupy high drainage divides and indicate considerable erosion and inversion of topography since the Pliocene.

Tertiary gravels in St. Louis dip northeast, toward the Cap au Gres-Waterloo-Dupo Structure (Harrison, 1997). This tilting strongly suggests that the Cap au Gris fault has been active at sometime since the Late Tertiary (Rubey, 1951). Significantly, major area rivers, including the Missouri, the Mississippi and the Illinois all converge at the Cap au Gres Structure. Morphology follows historic seismicity. South of the Cap au Gres Structure the Missouri River follows the St. Charles Anomaly and the Mississippi follows the St. Louis Fault Zone. Small earthquakes are associated with both these linear structures. A dramatic stream barb in the Meramec River in south St. Louis County,

Age	Stage	Southern Missouri Beds	Gasconade River Terraces	St. Louis Area Terraces	Northern Missouri Beds
Cenozoic Era	Tertiary	Peoria	Dryknob	Deer Plains	Peoria Loess and alluvial deposits
		gravels and Roxana Silt	Lambeth	Bonfills	
Quaternary System	Pleistocene Series	Sangamon Geosol	High Strath	Brussels	Sangamon Geosol
		Loveland Loess	Falcon	Post-Osage	Loveland Loess
		Yarmouth Soil	Lebanon	Osage Strath	Yarmouth Soil
					Ferrelview
					Macon Till
					Columbia Till
					geosol
					Fulton Till
					Moberly Till
					Atlanta Till

*note: some age assignments based on assumptions; see text

< mantle avalanche?

Metropolis formation; syntectonic, poorly sorted clay, silt, sand and gravel derived from local source areas

?????????

Mounds Gravel, a.k.a. Lafayette, Grover, Pike-ton

Polarity
 Matuyama Reversed
 Brunhes Normal
 ?

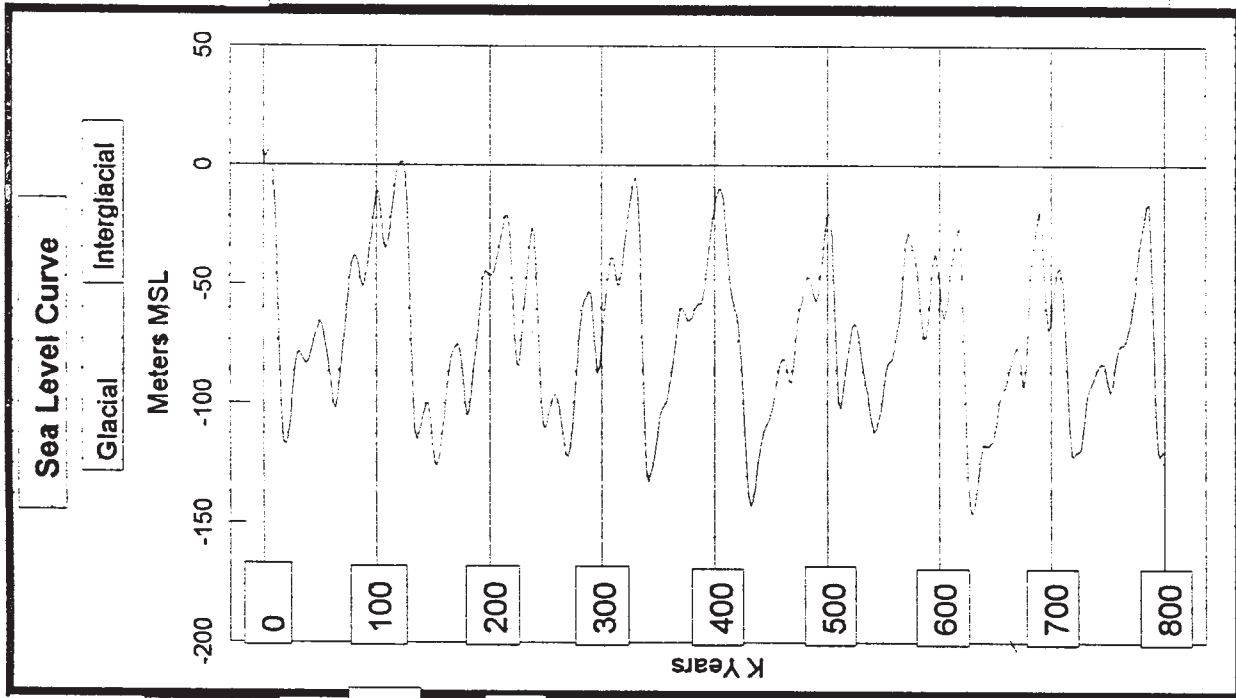


Fig. 3
Neotectonic Stratigraphy

suggests the Meramec also flowed toward the Cap au Gres Structure before being pirated by the Mississippi River along the Eureka-House Springs Structure.

Younger alluvial terraces

Gradients in alluvial terrace deposits associated with modern rivers are not constant, and provide evidence of tectonic instability and surface divide migration. We assume that Quaternary gravel aggradation events in the Ozarks correlate with the rapid warming that ends glacial cycles (Thouveny, et. al., 1994). Increases in local sediment supply, as well as other factors that accompany rapid ice melting-such as base level increases and vegetation changes, combine to form gravel deposition events. Haynes (1976) noted that Wisconsin gravel terraces in the Osage valley were related to the melting of ice sheets over 400 km to the north.

Longitudinal profiles of gravel terraces identified by Gamble (1993) in the Gasconade Basin all project to elevations that are lower than Ferrelview Formation Lake deposits. This suggests that these terraces all formed since the Ferrelview was deposited about 230,000 years ago. The Falcon terrace, the oldest gravel terrace, is now over 210 feet above the current river level. If the Falcon Terrace was deposited when the Illinoian glacier melted approximately 130,000 years ago, an uplift rate of over 0.5 mm/year is indicated. Alternatively, the river that deposited Falcon Terrace may have emptied in a Ferrelview lake, in which case the uplift rate would be slower.

Near the headwaters of the Gasconade, the Falcon Terrace lacks a perceptible gradient (Gamble, 1993; p. 21)! This suggests that when the Falcon Terrace was deposited, the Ozark surface drainage divide was located farther south (Fig. 4).

The Big Rivers

Wholesale drainage shifts mean WHOLESale drainage changes. In Missouri, wholesale distributors of water are the Missouri and Mississippi Rivers. Our understanding of the history of these rivers is based on Neogene stratigraphy (Forge, 1997). Pleistocene sands such as the arkosic Natchez Formation are the oldest Mississippi embayment deposits clearly derived from a northern mid-continent provenance area (Rhinehart, 1991). The oldest embayment sediments possibly derived from a St. Francois Mountain source are the Plio-Pleistocene Citronelle formation sands (Flint, 1941). During the Tertiary and early Pleistocene, a resurgent Nashville dome dominated sedimentation in the upper Mississippi embayment (Self, 1993).

According to our theory, the limits of glacial advance reflect crustal tilting. Ninety percent of all pre-Illinoian till exposures in North America are found on the Iowa, Missouri and Nebraska portions of a jostled tectonic block that includes the Ozarks (Fig 5). The northwest-trending valley of the Mississippi forms the eastern boundary of this reactivated structure (Fig 5). Due to uplift, glaciers stopped visiting the northern edge of the Ozark region about 230,000 years ago. Pre-Illinoian tills elsewhere in North America are generally covered by younger tills, indicating that the Illinoian glaciation returned to the same limit established earlier. The other major difference between the

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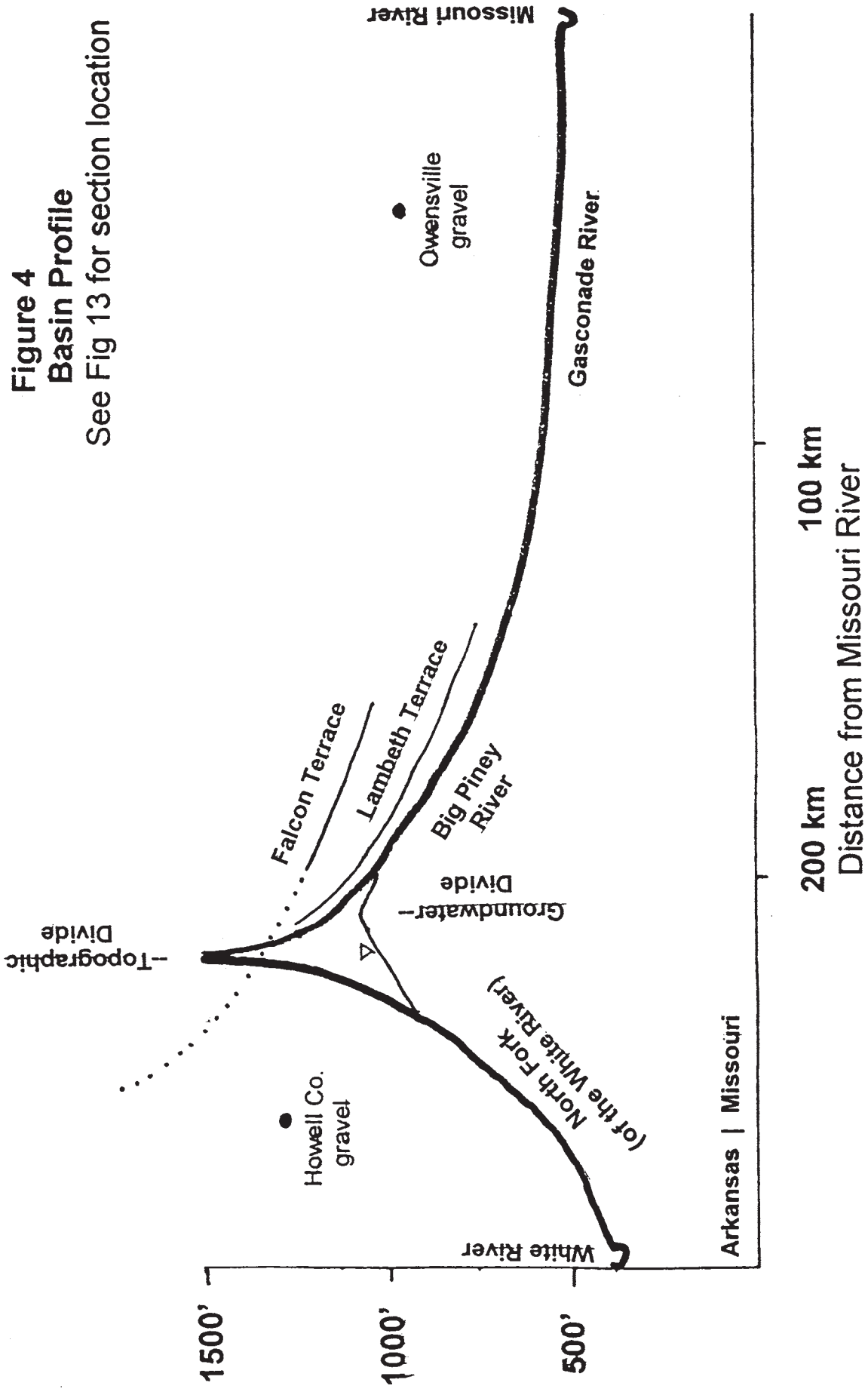


Figure 4
Basin Profile

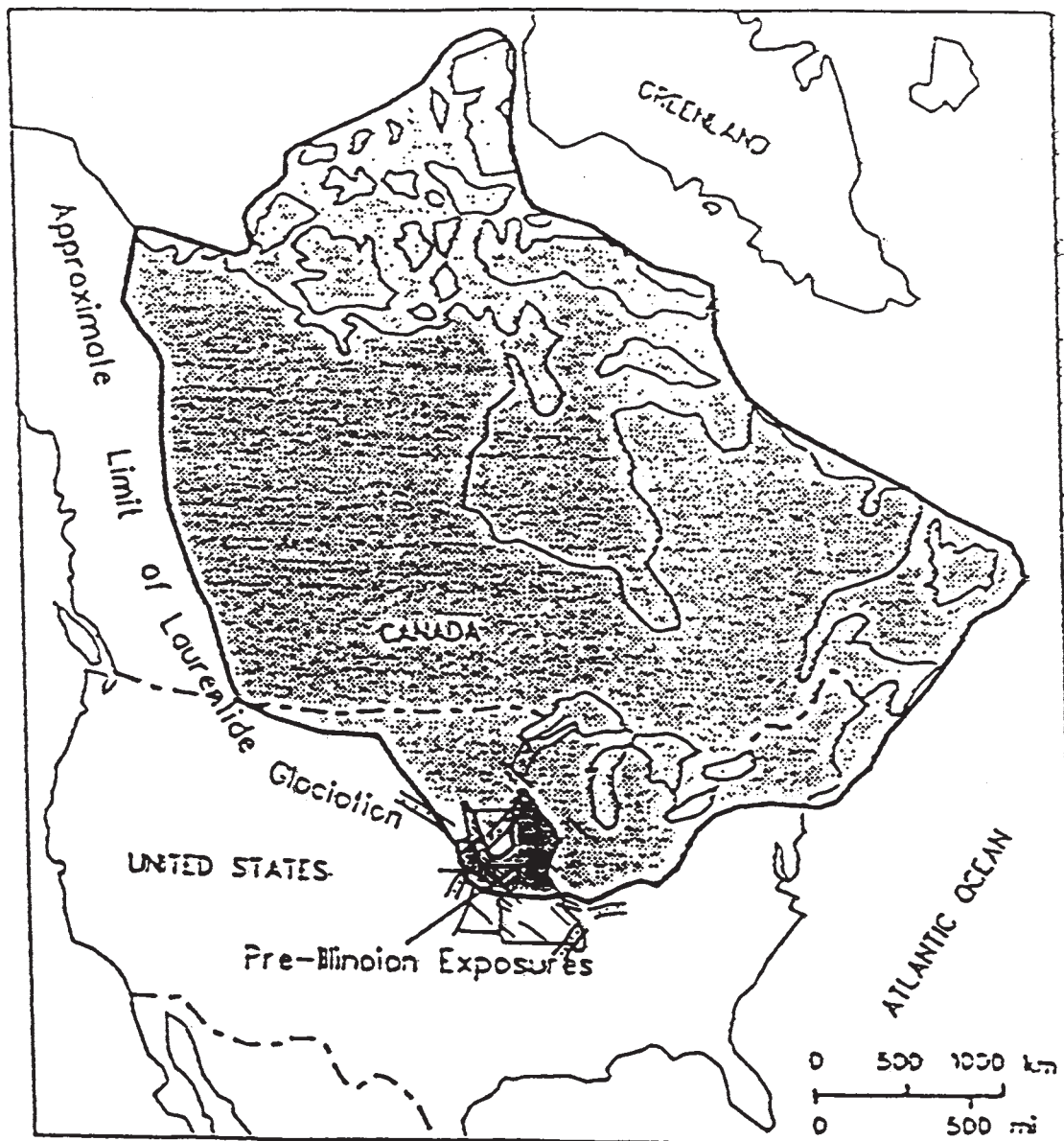
See Fig 13 for section location

Arkansas | Missouri

200 km 100 km
Distance from Missouri River

Fig. 5
Pre-Illinoian Till Exposures
after Rovey and Kean, 1996

Pre-Illinoian Laurentide ice sheets tended to reach the same approximate southern margins (Rovey and Kean, 1996). The Illinoian glaciation broke with this pattern, possibly because of crustal tilting. The Ozarks and the parts of northern Missouri, Iowa, Nebraska and Kansas that were not visited by Illinoian glaciers form a "jostled" tectonic block that is roughly bordered by Proterozoic or Eocambrian cratonic rifts on the northwest and the southeast. Reactivated, northwest-trending fault zones form the east and west boundaries of the block.



extent of Illinoian glaciation and earlier glacial advances, is found in Illinois, where the Illinoian glaciation extended farther south than any previous advances, depressing the crust enough to open a route for melt water to reach the Gulf of Mexico.

Wilson (1996) proposed Pleistocene ponding of the former Teays River drainage to explain the widespread distribution of a subspecies of the Greensides darter, *E. blennioides pholidotum*. Gradient reversals are heralded by very gentling-sloping topography. We propose that the widespread Ferrelview Formation (Howe, 1968) was deposited in a ponded, low-gradient Teays River drainage. When the last pre-Illinoian glacier melted about 230,000 years ago, a southern outlet for melt water was not available (Fig. 6). Stream gradients were flat and the Osage and Gasconade rivers formed large meanders. The Ferrelview Formation was deposited in the same huge pluvial lake system that allowed the *E.b. pholidotum* subspecies to populate a huge area that stretches from the northern Ozarks to New York. In contrast, rivers south of this large lake are inhabited by several subspecies of *E. blennioides*.

Subsequent Illinoian and Wisconsin glaciations did not leave widespread lake deposits. Instead, thick loesses were deposited along the Missouri and Mississippi River system, indicating rapid drainage of the resulting melt waters out these newly formed drainages.

Researchers studying China's Yellow River valley have identified a loess stratigraphy that contains 23 paleosols and dates back almost 2 million years (Li, 1997). Loesses along the southern Mississippi River contain two paleosols and are less than 185,000 years old (Rodbell, et. al., 1997). Tills in northern Missouri record at least six pre-Illinoian glacial advances (Rovey and Kean, 1996). Yet the pre-Illinoian glacial cycles failed to leave a known eolian record anywhere in Missouri (Fig. 3). Follmer (1996) argues convincingly that the lack of earlier loesses is due to non-deposition, not erosion. Numerous occurrences of Loveland loess survived the Sangamon soil development. If older loesses once existed, why didn't any of them survive Yarmouth soil formation? Did the Mississippi Embayment subsidence begin after the Yarmouthian Stage? We believe the simplest explanation for the differences in the Yellow River and the Mississippi valley loess sequences is that a large, south-flowing Mississippi River did not exist prior to the Illinoian glaciation.

In western Tennessee, the pyroxene content of the Roxana Loess is four times greater than the pyroxene content of the overlying Peoria Loess (Rodbell, et. al., 1997). Pyroxene is an easily-weatherable mineral. The older Roxana loess is more weathered and should have less pyroxene, not more. We propose the higher mafic content of the Roxana loess reflects an upper Mississippi River drainage that was restricted to the proto-Lake Superior basin. Then about 25,000 years ago the Mississippi River basin expanded with the addition of the Missouri River; diluting the pyroxene content of the younger loesses.

Flint (1941) recognized the Mississippi River as antecedent to the Ozark Uplift. If the Mississippi River were older than the Ozarks, then the river would have followed an easier path east of the uplift instead of cutting a canyon through the uplift north of Cape

Fig. 6
Ferrelview Deposition
Ponding of the Teays
230,000 years b.p.

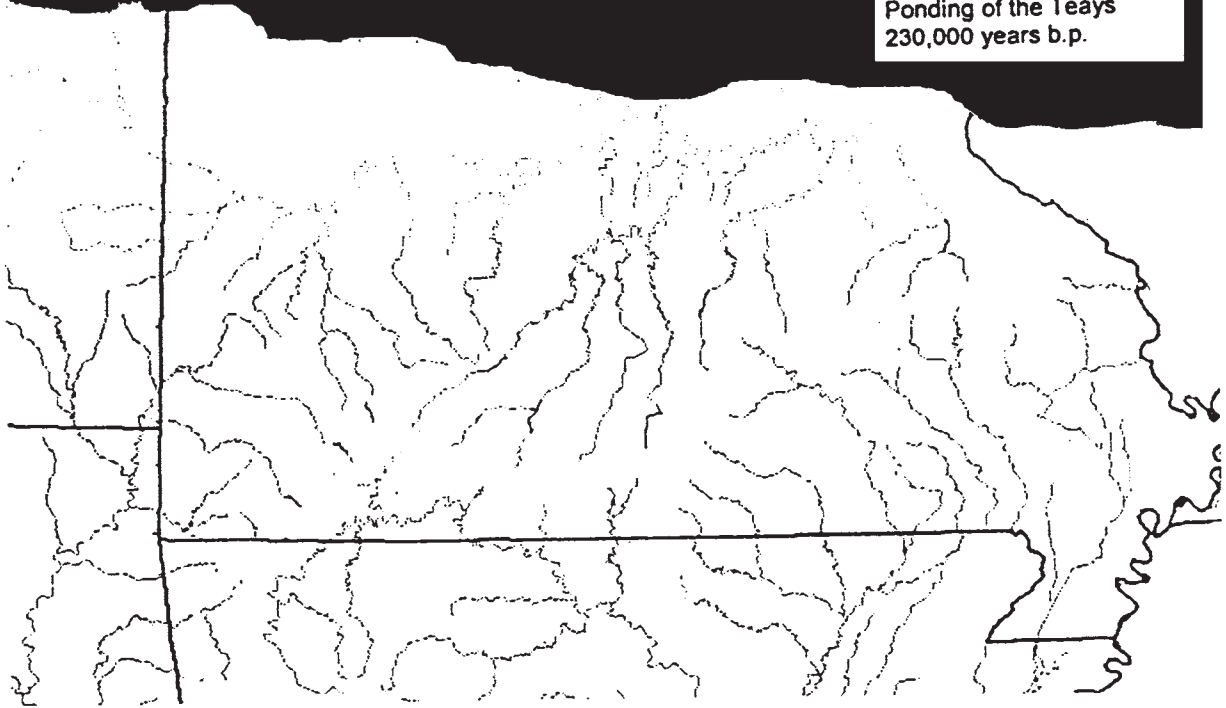
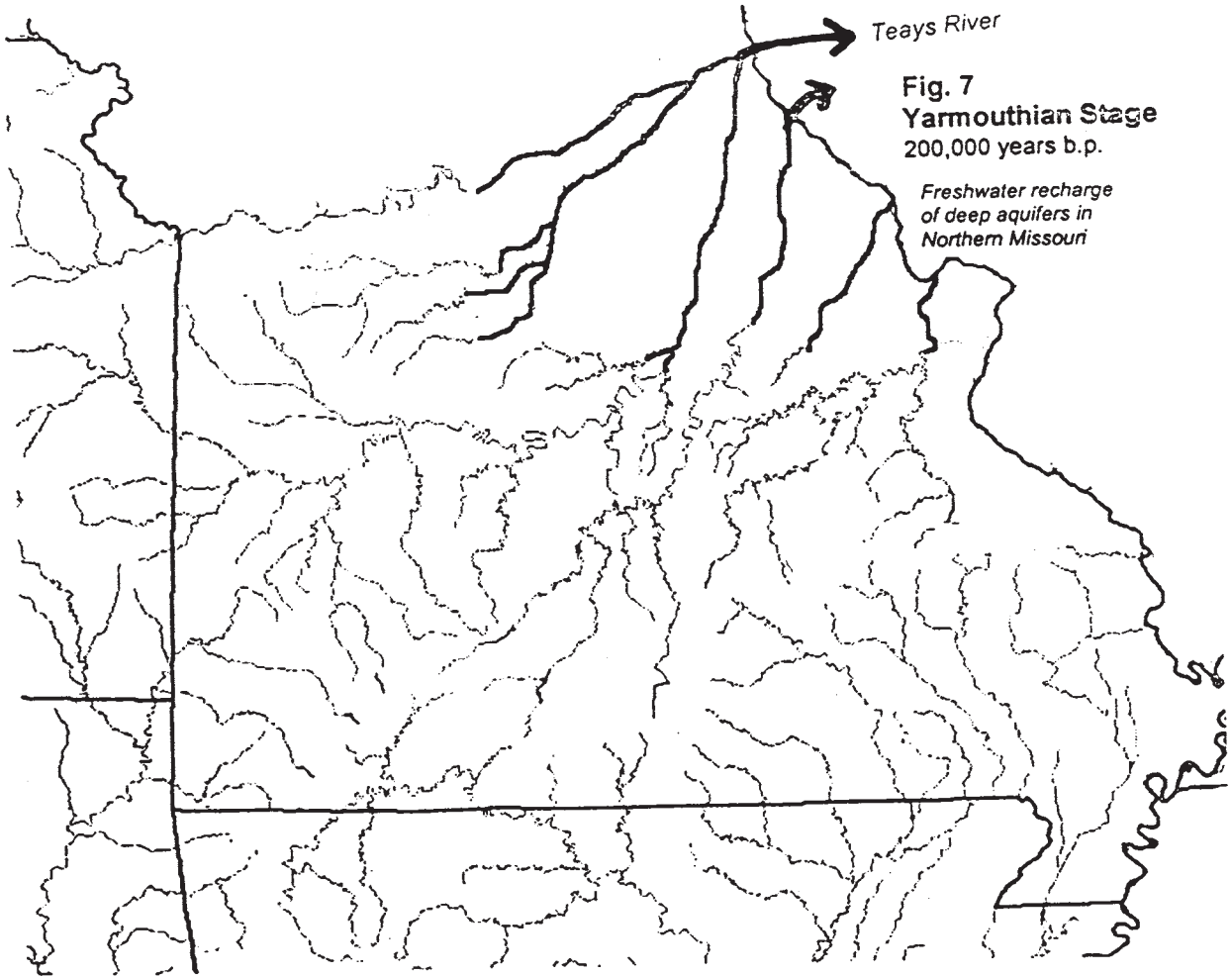


Fig. 7
Yarmouthian Stage
200,000 years b.p.

*Freshwater recharge
of deep aquifers in
Northern Missouri*



Girardeau. This suggests that much of the Illinois section of the Ozarks has emerged in the last two hundred thousand years. However, the eastward bulge of the Mississippi River's course north of Cape Girardeau suggests that uplift in Missouri was already underway by time the Mississippi River began flowing toward the Gulf of Mexico. An observation supported by the eastward migration seen in entrenched meanders of the Gasconade River and the Osage River, and the southward enlargement of the valley of the present Missouri River from the Kansas/Missouri border to Malta Bend. The meanders were originally formed by a low gradient, suspended bed-load stream draining in to a Ferrelview lake (Fig. 6). Crustal tilting had already begun to draw the ancestral Gasconade and Meramec River courses eastward along the 38th parallel lineament and the Baraboo suture in pre-Illinoian time.

The large entrenched meanders of the Osage and Gaconade Rivers are truncated at the Missouri River confluence. The meanders originally formed on a valley floor that was over 3 times wider than the modern Missouri River trench. The present Missouri River from its eastward bend at the Missouri/Kansas border to Malta Bend flows in the lower reaches of the pre-Illinoian Kansas River. Increased flow during the Pliostocene has removed the meanders from the downstream section by erosion, while the decreased flow in the upstream section, the present Kansas River, has preserved the pre-Illinoian meanders through entrenchment. Over 100 years ago, James E. Todd (1896) of the Missouri Geological Survey speculated that the Osage River once continued farther to the northeast, toward Quincy (Fig 7). Evidence is accumulating that Mr. Todd was correct.

Ozarks

The Ozark boundary does not separate highlands from lowlands; except on the southeast where the Ozark border is roughly aligned with the Commerce Geophysical Lineament. Hilly regions grade imperceptibly into surrounding plains. Plains to north and west are typically higher in elevation than many Ozark hilltops. The east-northeast trending Ozark crest is an erosional massif with terrain to north and south eroded away. Steeper gradients (Fig 4) and more aggressive erosion in the streams that drain the southern slopes of the Ozarks have caused the topographic axis of the uplift to retreat northward and westward. Continuing subsidence in the Mississippi embayment is pirating north-flowing Ozark streams.

More than one hundred species of etheostomid darters inhabit the upland riffles of clear streams throughout the central U.S. Darters are adapted to shallow, fast-moving water. One species group, *E. varitatum*, is not known to survive in lakes or large rivers, and is thus particularly prone to geographic isolation of its populations. Natural barriers of deep, slow-moving water inhibit gene flow and spur speciation. Contiguous but not overlapping species can be found in the same drainage basin (Wilson, 1996).

The Missouri Saddled Darter, *E. tetrazonum*, is the *varitatum* species endemic to north-flowing Ozark Streams. If south-flowing Ozark streams pirated north-flowing streams during the Pleistocene, then *varitatum* darter species on both sides of the Ozark divide should be similar due to limited evolutionary divergence. More investigation is needed

but, the Arkansas Saddled Darter (*E. euzonum*), endemic to the White River basin, is very similar to the Missouri Saddled Darter (Wilson 1998).

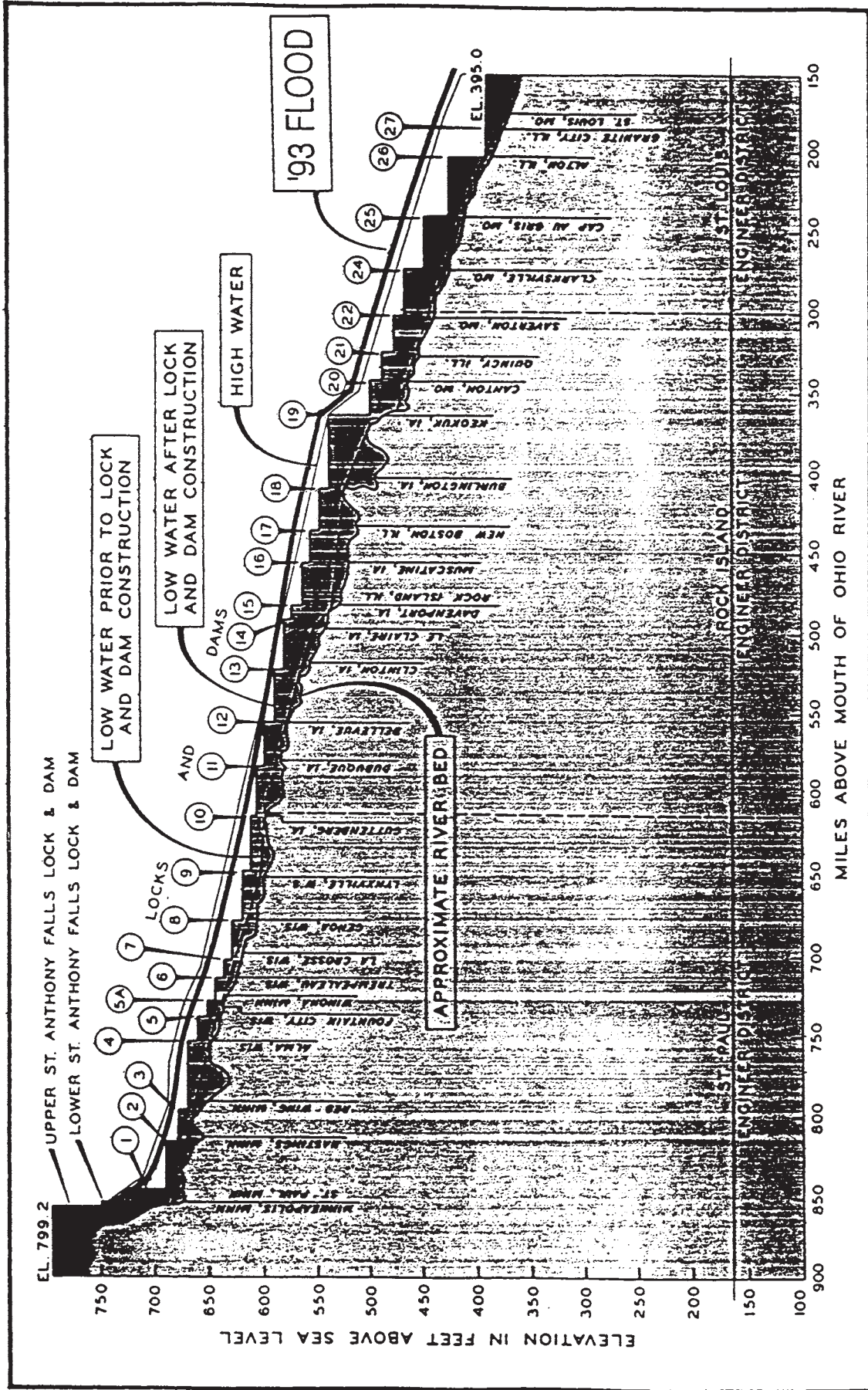
Major Ozark streams occupy steep narrow valleys separated by broad uplands. Despite relatively high denudation rates estimated at more than 100 mm/kyr, erosion has not kept pace with recent crustal tilting. Steep bluffs along the major rivers show that a lot of rock in the Ozarks is available for erosion. Uplift is so recent, that stream profiles have not yet attained the concave upward curve typical of rivers closer to geomorphic equilibrium (McKeown, et. al., 1988). Likewise, if the Mississippi and Missouri Rivers formed recently, then their stream profiles should still be adjusting to the new gradient. Indeed, the big rivers do not display the classic concave upward profile (Fig. 8). Ongoing adjustments to new conditions are not limited to the surface. Groundwater studies provide even more dramatic evidence of a landscape far from equilibrium.

Groundwater

Northern Missouri

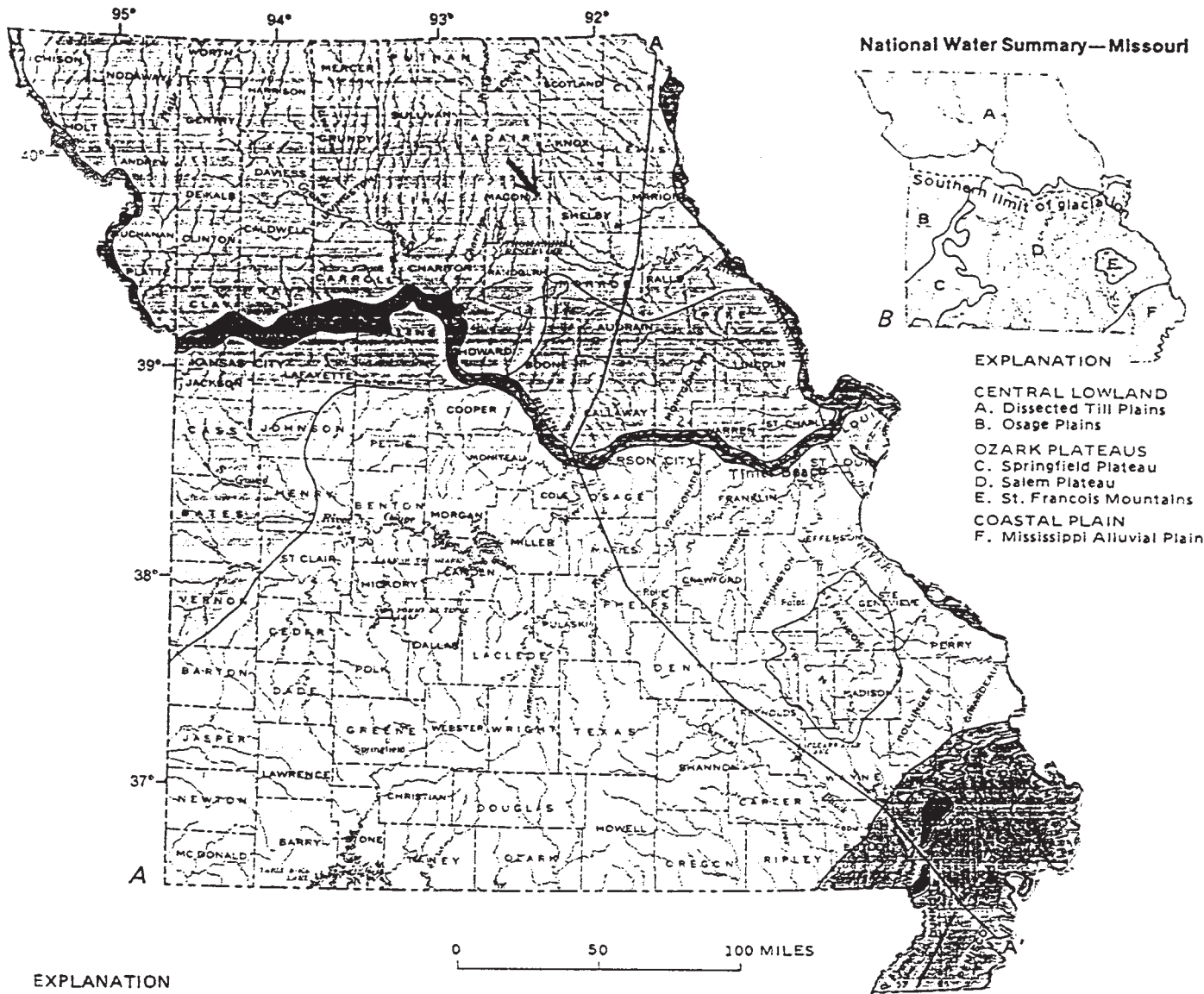
If pre-Illinoian streams flowed northeast toward the Teays River (Fig 7), then groundwater must also have flowed in the same direction. In the modern Ozarks, precipitation falls on exposed Cambrian and Ordovician sediments and recharges the aquifer. During pre-Illinoian time, newly exposed Cambrian and Ordovician sediments in the emerging Ozarks were recharged in the same manner. Gradient reversals are accompanied by a period of nearly flat potentiometric surfaces and slow moving groundwater. If a major north-to-south regional gradient reversal did occur less than 200,000 years ago, then it is possible that groundwater that once flowed northeast may still be present in the subsurface of northern Missouri. Indeed, eight Missouri counties north of the Missouri River enjoy fresh groundwater from deep wells penetrating the Cambro-Ordovician aquifer (Fig 9). This large volume of freshwater originated in the pre-Illinoian Ozarks and then flowed downgradient toward a discharge area located far north of the modern Missouri River.

Cambrian rocks are not exposed anywhere near this eight-county area of fresh groundwater. The only exposures of Ordovician sediments are in groundwater discharge areas near the Missouri and Mississippi rivers. Bedrock discharge zones also border the region in Chariton County to the west and along the Salt River to the northeast. The aquifer currently discharges large volumes of freshwater to deep wells and area rivers. Pre-pumping water levels measured in the Cambrian-Ordovician aquifer show that the current regional-flow system is directed toward the southeast (Fig. 10). Thus, a huge volume of saline groundwater that apparently extends all the way to Iowa currently recharges the fresh water in the aquifer. Well data show that the aquifer is confined by a series of overlying aquitards that include Ordovician, Devonian, Mississippian and Pennsylvanian shales and carbonates (Imes, 1985). Very little precipitation can percolate downward through the glacial tills that blanket the area. The only reasonable source of the freshwater now in the aquifer is groundwater that once flowed north out of bedrock recharge areas in the Ozark region. When the Mississippi began flowing southward, groundwater in the aquifer also reversed directions. At the



from The Great Flood of 1993 Post-Flood Report, Upper Mississippi River and Lower Missouri River Basins, Main Report, September 1994, US Army Corps of Engineers, North Central Division, September, 1994

Fig. 8
Mississippi River



EXPLANATION

PRINCIPAL AQUIFERS

- Major river valleys
 - Alluvial
 - Wilcox and Claiborne
 - McNairy
 - Ozark
 - Kimmswick-Potosi
- } Mississippi Alluvial Plain
- OTHER AQUIFERS**
- Glacial-drift, Pennsylvanian-Mississippian age, Springfield Plateau, and St. Francois
 - NOT A PRINCIPAL AQUIFER
- A—A' Trace of cross section
- Dissolved-solids concentration greater than 1000 milligrams per liter (approximate location)

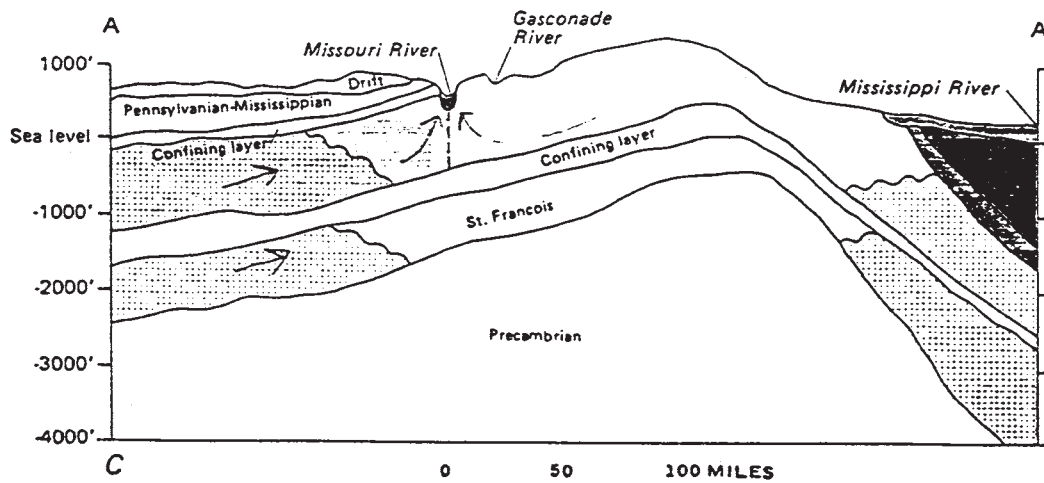


Fig. 9 Principal aquifers of Missouri. A, Geographic distribution of most used aquifers. B, Physiographic diagram and sections. C, Generalized cross sections (A-A'). (See table 2 for more detailed description of the aquifers. Sources: A, C, Compiled by L. F. Emmett from U.S. Geological Survey files. B, Fenneman, 1938; Raisz, 1954.)

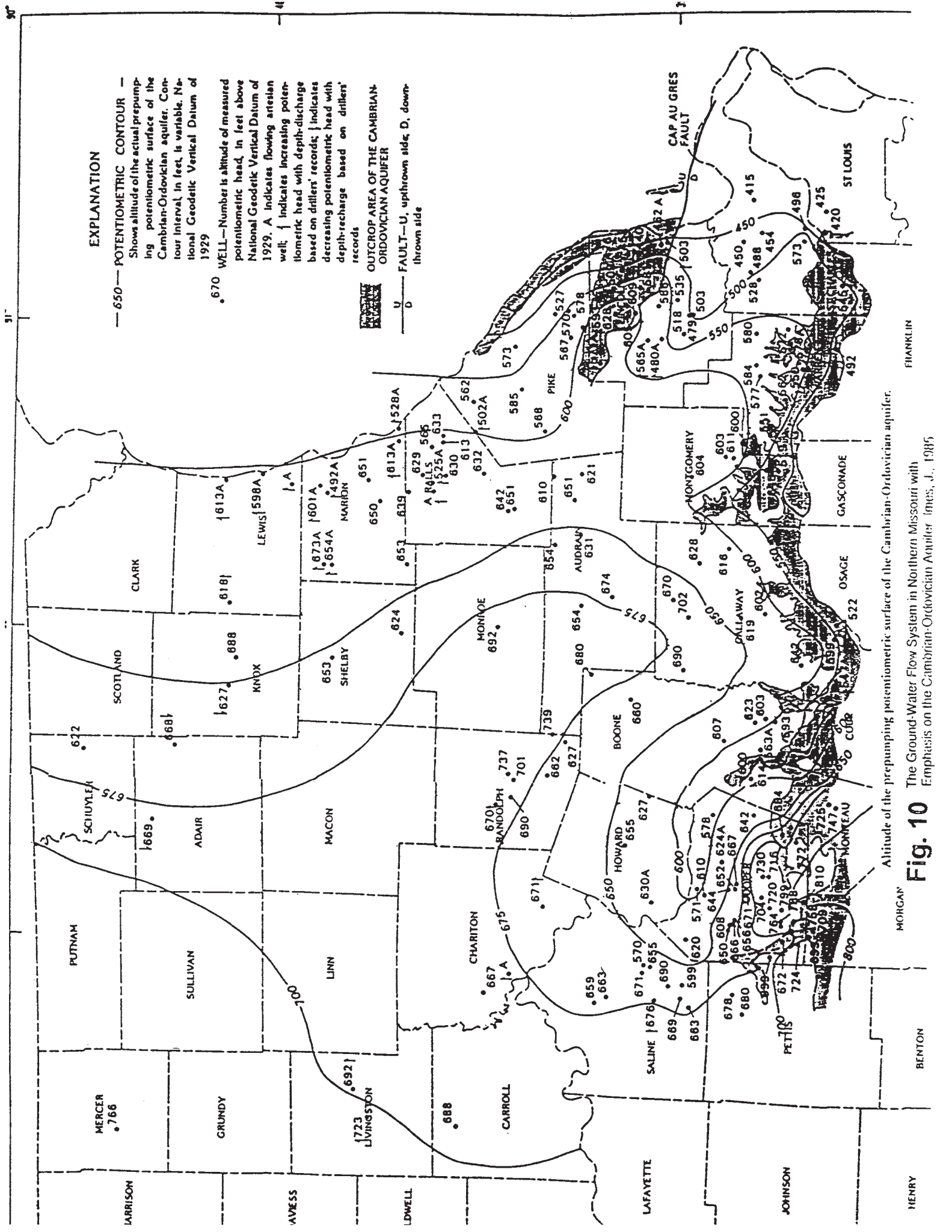
EXPLANATION

— 650 — **POTENTIOMETRIC CONTOUR** —
Shows altitude of the actual pre-pumping potentiometric surface of the Cambrian-Ordovician aquifer. Contour interval, in feet, is variable. National Geodetic Vertical Datum of 1929

• 670 **WELL** — Number is altitude of measured potentiometric head, in feet above National Geodetic Vertical Datum of 1929. A indicates flowing artesian well; † indicates increasing potentiometric head with depth-discharge based on drillers' records; ‡ indicates decreasing potentiometric head with depth-recharge based on drillers' records

OUTCROP AREA OF THE CAMBRIAN-ORDOVICIAN AQUIFER

FAULT — U, upthrown side; D, downthrown side



Altitude of the pre-pumping potentiometric surface of the Cambrian-Ordovician aquifer.

Fig. 10 The Ground-Water Flow System in Northern Missouri with Emphasis on the Cambrian-Ordovician Aquifer (mes, J., 1985)

current groundwater migration rate of 5 to 15 feet per year (Imes, 1985), the entire mass of freshwater will discharge to area rivers in approximately 15,000 to 50,000 years. The fact that any of this freshwater remains at all is further testimony to the youth of the current drainage pattern. Had early Pleistocene glaciers reversed the gradient by pushing the Missouri River down to its present location, then very little of this groundwater would remain north of the river. The surface water drainage shifts seen in southern Missouri are mirrored in both direction and timing by groundwater shifts north of the Ozarks.

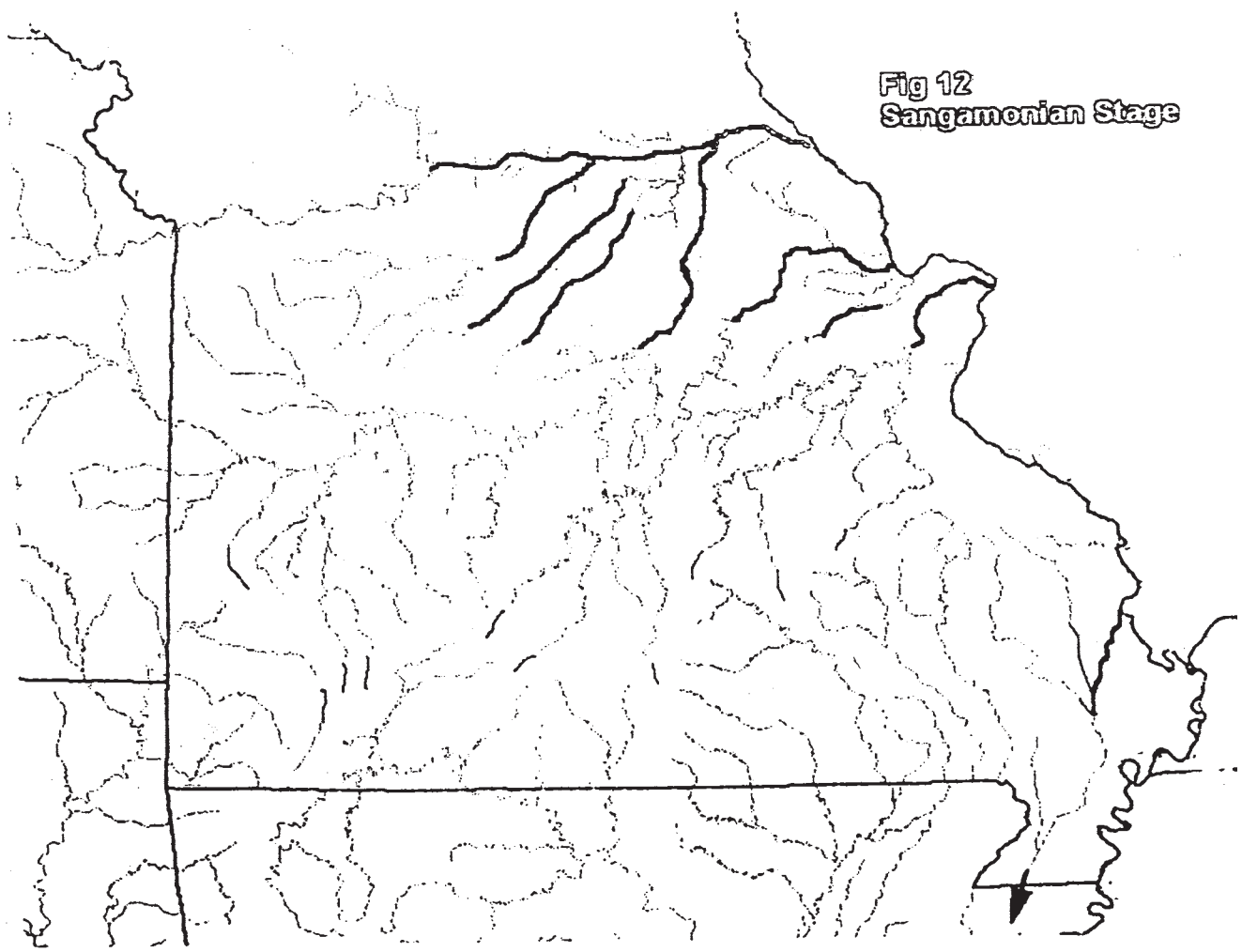
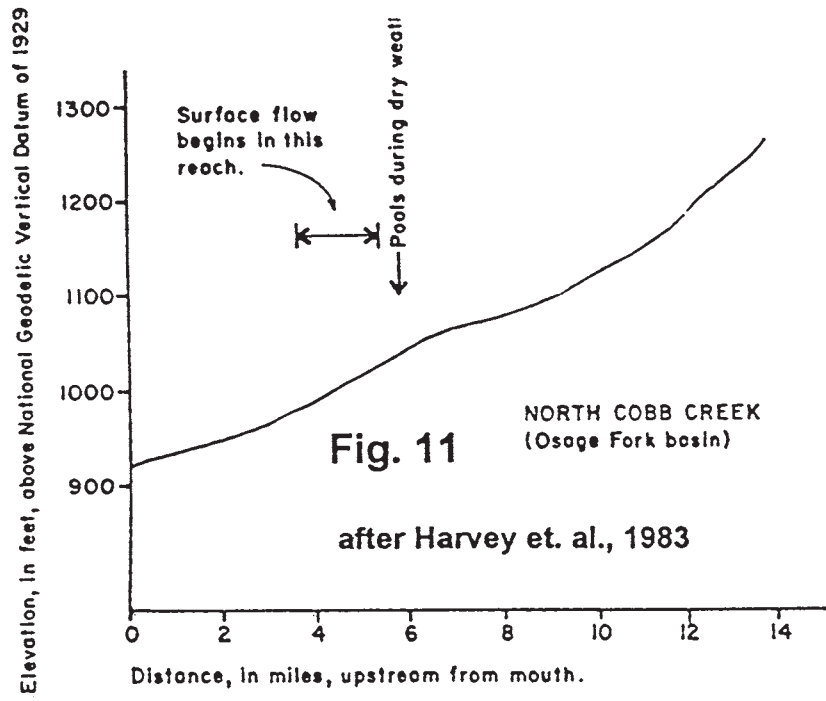
Southern Missouri

During uplift-driven stream piracy, groundwater is captured first. Robbed of base flow, losing stream sections cannot keep up. Resulting in uneven stream profiles with nick points at the beginning of the gaining sections (Fig 11). Drainage densities are not useful as a predictive hydrologic tool for determining hydrologic flow regimes within a drainage basin (Harvey et al. 1983). Losing sections develop as hanging valleys, maintaining the characteristics of their previous gaining condition. Unable to entrench, older surfaces are preserved along their banks. As entrenchment continues in the gaining sections, headward migration of the nick point and valley enlargement eventually removes the losing section and adjoining surfaces (Fig 11).

Crustal tilting creates preferred drainage directions. By Sangamon time the expanding Mississippi River drainage had pirated most of the Teays River's drainage basin in Missouri (Fig 12). Streams flowing in the preferred direction receive more runoff and entrench faster. Allowing them to capture more groundwater (base flow) providing positive reinforcement for entrenchment and headward erosion. Expanding groundwater drainage basins herald expanding surface water drainage basins. In the Ozarks, dye traces cross surface drainage basins north to south and west to east mimicking the recent tectonic shifts (Fig 13).

Sangamon soils are unknown in Ozark sinkholes, suggesting the shallow karst is young. Generally, Pleistocene solution features have only developed to relatively shallow depths. Wells that case out the shallow karst generally produce high quality water and are not affected by high rainfall events. Deeply incised Ozark Rivers are rejuvenating paleokarst features that formed in Mesozoic or Paleozoic time. These ancient solution channels can divert groundwater across basin boundaries to springs up to 39.5 miles away!

Large areas of the Ozarks contain losing streams. Drainage densities, stream profiles and other geomorphic features of the losing basins are virtually identical to nearby gaining basins (Harvey et al., 1983). This suggests recent change from groundwater discharge to recharge. Karst, by itself, does not create huge complex interbasinal groundwater flow systems; gradient shifts are required. Changes in the location of regional groundwater discharge zones are the most reasonable mechanism for developing the complex losing stream basins of the Ozarks.



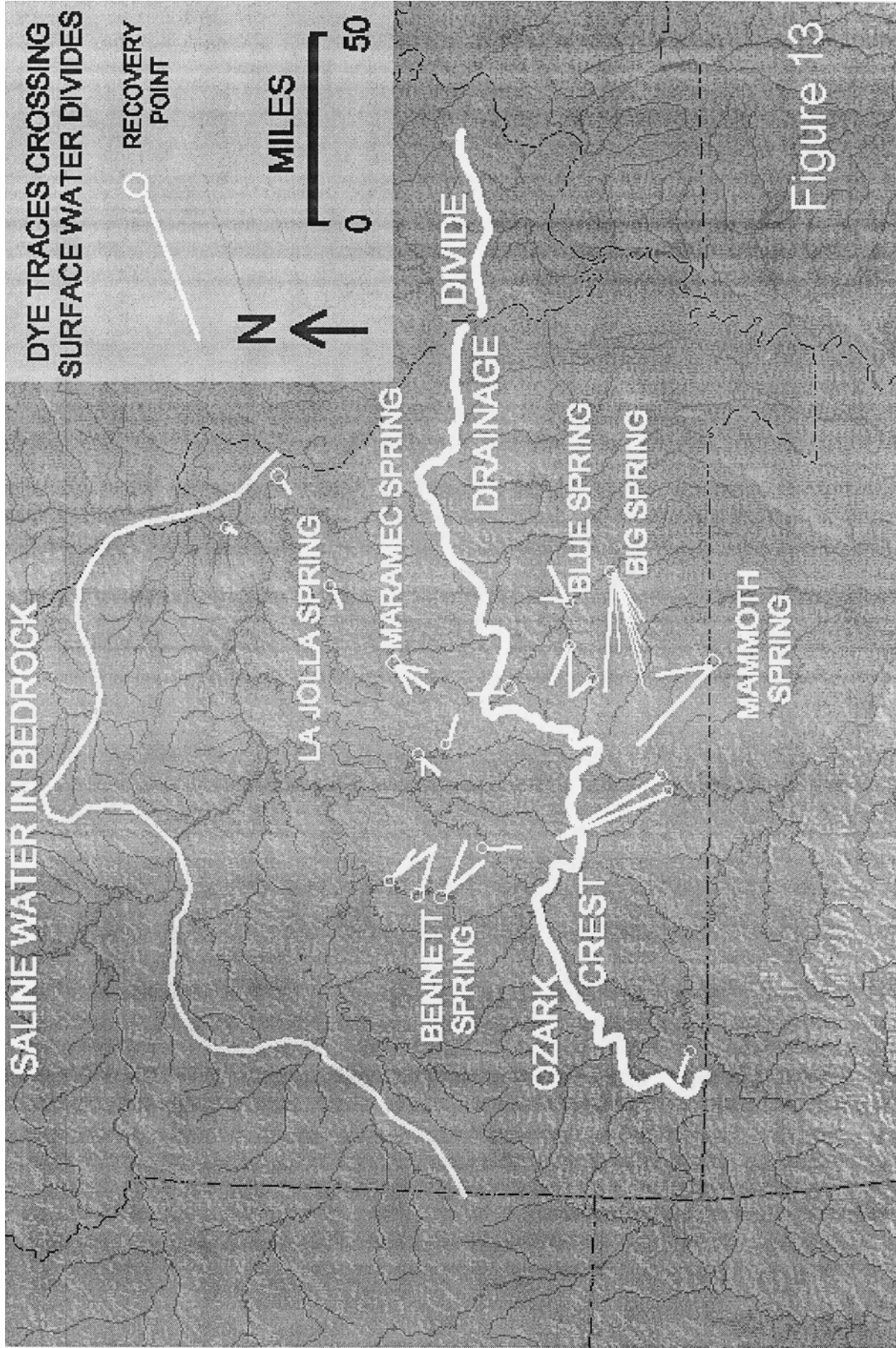


Figure 13

If steeper, south-flowing Ozark streams are pirating north-flowing streams, then water lost in the upper reaches of the losing streams should move south toward the subsiding area. In fact, dye traces that cross basin boundaries do generally head south or east (Fig 13). Exceptions include piracy by the deeply entrenched Niangua River which directs dye northwestward; and subsidence of the St. Louis depression which directs St. Charles County traces northward.

In a mature karst system, water lost in a losing stream should emerge lower in the same watershed. The numerous dye traces that cross basin boundaries, provide further evidence of a young landscape adjusting to relatively recent groundwater gradient shifts.

CONCLUSIONS

Considerable uplift and erosion has occurred across Southern Missouri during the Quaternary, stranding Tertiary gravels high and dry on drainage divides.

The Missouri Ozarks did not form a major topographic or drainage divide prior to Pleistocene glaciation, through drainages crossed the highest parts of Ozark uplift from south to north.

The Ozark crest has retreated northward and westward, due to steeper gradients and more aggressive erosion in modern south-east flowing streams.

A south-flowing Mississippi River pirated the north-flowing Teays River in the Late Pleistocene.

Deep Cambro-Ordovician aquifers north of the Missouri River contain freshwater that originated in the Ozark area and flowed northward under drainage conditions that are now reversed.

The Missouri Saddled Darter and the Arkansas Saddled Darter may be living fossils from a time when the Ozark divide did not exist.

ACKNOWLEDGEMENTS

The authors have had the benefit of assuming Missouri's landscape developed in a tectonically active environment. This assumption would not be possible without the pioneering work of Dave Hoffman, Jim Palmer, and Jim Vaughn of DGLS and Rich Harrison of the USGS. Kurt Hollman and Dave Smith provided moral support. Constructive discussions with them and others too numerous to mention were enjoyable and greatly appreciated. The senior author was able to examine Cenozoic strata along the Commerce Geophysical Lineament in studies funded by the DGLS Geological Survey Program and the USGS. Needless to say; views expressed by the authors should not be blamed on any of these fine individuals or organizations. Comments or rebuttals should be addressed to nrelfrn@mail.dnr.state.mo.us.gov or nrsiemm@mail.dnr.state.mo.us.gov.

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