The Mesozoic and Cenozoic Aulacogenic Cycle: Tectonic Setting of the Jackson Purchase Region of Kentucky

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Abstract

The Jackson Purchase region in extreme western Kentucky is within the northeastern part of the Mississippi Embayment physiographic region. The Mesozoic and Cenozoic sediments within the region occur in a shallow structural basin (Paducah-Memphis Basin) with an axis gently plunging to the south-southwest. Unconformably underlying the Mesozoic sediments are Lower and Middle Paleozoic rocks oriented as a structural arch with an axis plunging to the north-northeast. This structural arch is redefined as the Pascola Arch. The unusual structural relationship between the Paleozoic rocks and the post-Paleozoic sediments is a form of structural inversion.

The genetic term "aulacogenic structural inversion" is coined for this relationship in the Jackson Purchase region. Mesozoic aulacogenic development is thought to have formed the Pascola Arch and the subsequent overlying Paducah-Memphis Basin. This paper introduces the aulacogenic cycle and its structural responses. Aulacogenic cycles may help to explain some of the structural inversions in other areas around the world. In addition, structural arches, hidden by overlying basins, may hold unrecognized hydrocarbon resources.

The alternating marine and terrestrial sediments (Mesozoic and Cenozoic) within the basin were once regarded as being wholly the result of tectonic activity; however, a eustatic origin for some of these regressive and transgressive sediments should be considered.

Introduction

Kentucky's Jackson Purchase Region is a part of the Mississippi Embayment physiographic region of the Gulf Coastal Plain (Fig. 1). The extremely low topographic relief and lack of good exposures of surface sediments mask a very interesting subsurface structural feature. This paper attempts to describe this structure in terms of an aulacogenic cycle.

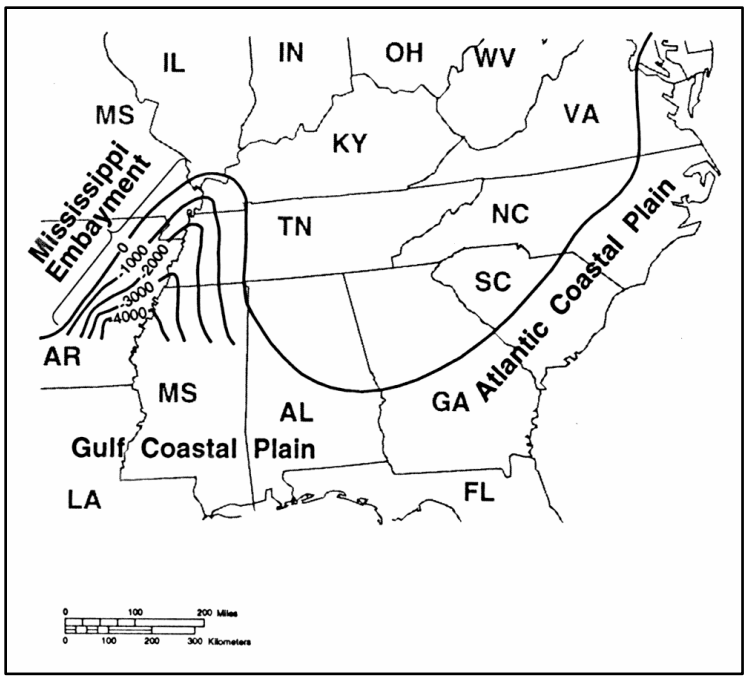

Figure 1.--The Mississippi Embayment physiographic region. The Jackson Purchase region, a physiographic and geographic term used in Kentucky, is the part of the embayment that occurs in Kentucky. Structural contours are depth to Paleozoic bedrock (adapted from Cushing and others, 1964; Crone and Brockman, 1982). The Paducah-Memphis Basin, identified by the contours, is outlined by the Mississippi Embayment.

Basinal Setting

A schematic cross section, shown in Figure 2, is based on information from a variety of published cross sections and other data (Schwalb, 1969; Olive, 1972; Kentucky Geological Survey, 1983). In Kentucky the surface sediments and rocks in the Jackson Purchase are Late Cretaceous to modern in age. These largely unconsolidated sediments fill a concave bedrock depression or basin with an axis located near the western tip of Kentucky. The sedimentary basin is, herein, the Paducah-Memphis Basin; the term, Mississippi Embayment, should be restricted to physiographic usage. The axis of this elongate depression is gently plunging to the south-southwest. Although the upper surface expression of the bedrock-sediment contact is basin shaped, subsurface cross sections show that the Paleozoic bedrocks form a truncated structural arch redefined here as the Pascola Arch (Fig. 2). Underlying the Paleozoic strata are Precambrian and Cambrian structures associated with the Reelfoot Rift (see McKeown and others, 1990). For brevity, the early Paleozoic and Precambrian structures are not discussed in this paper, although they weakened the crust and probably caused the younger structures to form there.

The sediments and rocks underlying the Mississippi Embayment may have undergone incipient tectonic rifting during Mesozoic times in addition to late Precambrian-Cambrian times. Normal tectonic rifting may develop over a hot spot where the crust is buoyed by a heat source in the mantle. The hot-spot uplift causes extension of the lithosphere and actual rifting of the crust may eventually develop. The separation of North and South America from Europe and Africa began as a long rift similar to the Rift Valley of east Africa and the Red Sea. An aulacogen is a failed rift in which a crustal rift was initiated by some means such as a hot spot development, but that died out for some reason (such as the crust drifting away from the hot spot). Underplating of the crust by buoyant material may accompany aulacogen formation and contribute to the structural development of the overlying crust.

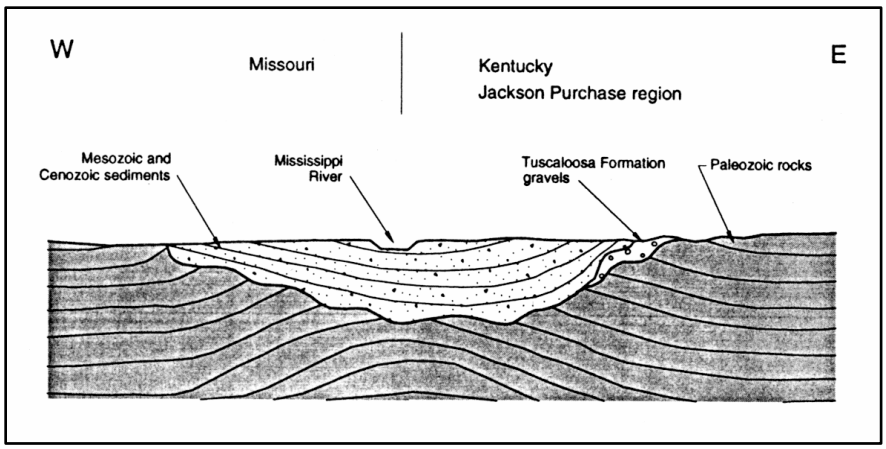

Figure 2.--Schematic cross section through the upper level Phanerozoic rocks and sediments of the upper Mississippi Embayment region of western Kentucky and southeastern Missouri.

Although the Mississippi Embayment region has been regarded as aulacogenic in origin, the stratigraphic and structural framework of the Jackson Purchase and surrounding regions have not been adequately described in terms of an aulacogenic tectonic setting. This paper associates the Jackson Purchase sediments and structures to the development of this aulacogen.

Stratigraphic Framework of Post-Paleozoic Strata

A time-expansion diagram is shown in Figure 3. A summary of the Mesozoic and Cenozoic sediments is given in Olive (1972, 1980) and Self (1993), whereas the subsurface Paleozoic rocks are described by Schwalb (1969). A catalog of subsurface data on Paleozoic rocks of the Mississippi Embayment is available in Dart (1990).

The most significant stratigraphic feature to note in the time-expansion diagram (Fig. 3) is the unconformity between the underlying late- and mid-Paleozoic strata and the overlying Late Cretaceous and younger sediments. The Cretaceous and Tertiary strata are as thick as 2,050 feet in the western part of the Jackson Purchase and thin to zero along the eastern margin of the Purchase (Olive, 1980).

Tuscaloosa Formation.--The Tuscaloosa Formation (Late Cretaceous), from 0 to 180 feet thick, is composed of very coarse gravels of chert with sand, silt and some clay (Fig. 3). It is restricted to a belt along the eastern edge of the Jackson Purchase and extreme western edge of the exposed Paleozoic rocks in Kentucky (McDowell, Grabowski, and Moore, 1981). From its outcrop belt, the Tuscaloosa only extends laterally about 3 or 4 miles down dip (southwest) into the subsurface where it pinches out (Olive, 1980).

Chert gravels and cobbles in the Tuscaloosa are largely derived from Devonian and some Mississippian strata. A concentration of such large grain size suggests a local source for the cobbles. Regional cross sections indicate that Mississippian, Devonian and older strata have been extensively eroded in the Jackson Purchase and might be the local source of these coarse-grained sediments. The regions surrounding the Jackson Purchase are largely composed of Mississippian and younger strata with little exposure of Devonian strata. The belt-shaped occurrence of the Tuscaloosa and the very coarse grain size suggest a fluvial environment, possibly braided, perhaps with attendant debris flows, alluvial fans, etc. An overabundance of cobbles and gravels indicates proximity to an uplifted area.

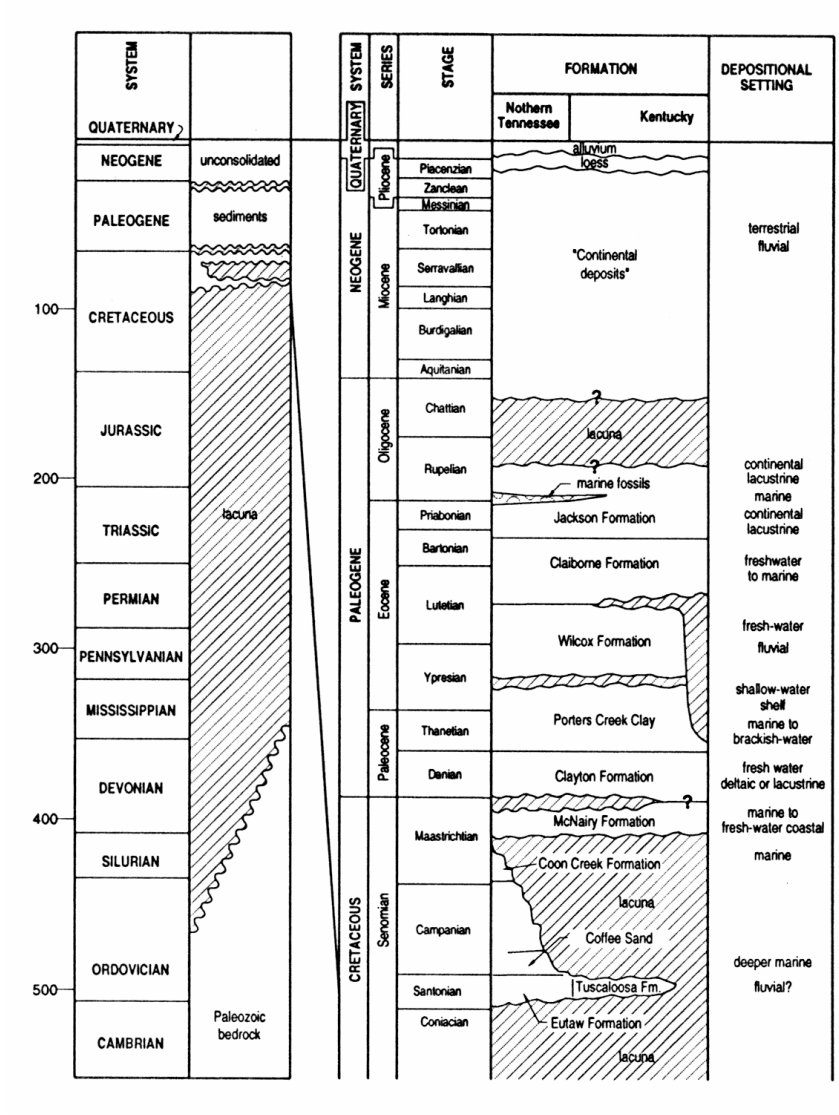

Figure 3.--Time-expansion diagram of the Mesozoic and Cenozoic strata in the Jackson Purchase. Time scale adapted from Harland and others (1989).

Unconformably overlying the Tuscaloosa and Paleozoic rocks are the overlying later Cretaceous and younger strata. These strata are more extensively distributed than the Tuscaloosa. The McNairy and overlying strata are largely unconsolidated (Fig. 3), and composed of sand, silt, clay and minor lignite beds (McDowell, 1986). Although these units are mapped in 47 geologic quadrangles in the Jackson Purchase, a detailed surface and subsurface stratigraphic framework has not been developed. Therefore, only generalized interpretations of their depositional environments can be described.

McNairy Formation.--The Upper Cretaceous McNairy Formation (Fig. 3) contains sand, silt, clay, and some gravels (McDowell, 1986). Lignites have been described in Hower and others (1990) and were deposited in terrestrial environments. The vertical trace fossil, *Ophiomorpha* is locally common in some sands and indicates shallow open marine to estuarine environments (Pollard and others, 1993). Taken altogether, the evidence suggests that the McNairy was situated in a coastal setting with varying relative sea levels.

Clayton Formation.--A regional disconformity separates the Late Cretaceous McNairy Formation from the overlying Paleocene Clayton Formation which also consists of sand, silt and clay (Fig. 3). Only palynological methods have been able to separate the two similar units (Tschudy, 1970). Although an abundance of freshwater palynomorphs suggests a largely freshwater deltaic or lacustrine environment for part of the Clayton (Olive, 1980; McDowell, 1986), marine conditions based on paleontological information also existed (Reed and others, 1977).

Porters Creek Clay.--The overlying Porters Creek Clay (Paleocene) is composed of sand, silt, and clay (Fig. 3). Palynomorphs provide evidence for a marine environment, including shallow-water shelf to shallow epeiric sea, with a possibly brackish-water, nearshore deltaic component to the northeast (Olive, 1980; McDowell, 1986). Oddly, the Porters Creek Clay yields little in the way of macrofossils; foraminifera, fish scales, and marine pelecypods and gastropods have been reported in McCracken County, Kentucky (Roberts, 1931).

Wilcox Formation.--The early Eocene Wilcox Formation also consists of sand, silt, and clay (Fig. 3). Lignite deposits are also known from the Wilcox in the Jackson Purchase (Cobb and Williams, 1982; McDowell, 1986). Palynomorphs and plant fossils indicate freshwater environments (Olive, 1980).

Claiborne Formation.--The middle and upper Eocene Claiborne Formation (Fig. 3) consists of sand, silt, and clay (and fine gravel; John Masters, personal communication, 1994). Lignite deposits occur locally (McDowell, 1986; Rower and others, 1990). Palynomorph investigations suggest a terrestrial environment (Frederiksen and others, 1982; McDowell, 1986) and several macro floras have been compiled by Roberts (1931). Roberts (1931) also reported a termite wing found in Hickman County, Kentucky. However, Olive (1980) reports,

> "Pollen assemblages from most localities indicate fresh-water deposition; however, palynomorphs from six localities that represent the lower and upper parts of the formation indicate marine to brackish-water environments. One of these localities, D3528 (earliest Claibornian in age) in central McCracken County, is almost surrounded by typical Wilcox sediments. Other evidence of marine environment includes glauconitic sand at one locality in southeast Graves County."

Jackson Formation.--The upper Eocene (and lower Oligocene?) Jackson Formation (Fig. 3) consists of sand, silt, and clay. Lignite deposits occur locally (McDowell, 1986; Rower and others, 1990). Olive (1980) states,

> "Palynomorph assemblages from most paleobotanical localities of late Eocene and Oligocene age were deposited in a continental lacustrine environment; however, marine forms are reported from samples at localities D3763, D4196, and D4197 in the southwestern part of the region. These three samples are from sediments of late Eocene age and represent the youngest evidence of a marine environment in the Jackson Purchase Region."

Continental and younger deposits.--Unconformably overlying the Jackson Formation (Fig. 3) are terrestrial deposits loosely termed "continental deposits" or Lafayette gravels (Olive, 1980). These largely fluvial deposits are Miocene, Pliocene and Pleistocene age. The overlying Quaternary sediments are alluvial, lacustrine and loess deposits that drape many of the older units throughout the Jackson Purchase. A more detailed description of these post-Jackson sediments is given in Olive (1980), McDowell (1986), Roberts (1931), and McFarlan (1943).

Tectonic and Eustatic Controls

The depositional settings based on sedimentary, mineralogical, and paleontological features described above are shown in Figure 3. The vertical distribution of these settings shows relative sea level changes for the Mesozoic and Cenozoic sediments of the Jackson Purchase. Olive (1980) attributed all of these relative changes in sea level to tectonic movements in or along the Jackson Purchase. The possibility exists, however, that many of these changes reflect eustatic events (e.g., Mancini and Tew, 1993). Better biostratigraphic control might result in better correlation with published sea level curves.

Although some of the sedimentation may have been affected by eustatic sea level changes, there are several large-scale features that are unambiguously tectonic in origin. These are the subsurface Pascola structural arch, truncation of the arch resulting in a basin, and subsequent filling of the basin with latest Cretaceous and younger sediments (Fig. 2). The tectonic history of events leading to these features is shown in Figure 4.

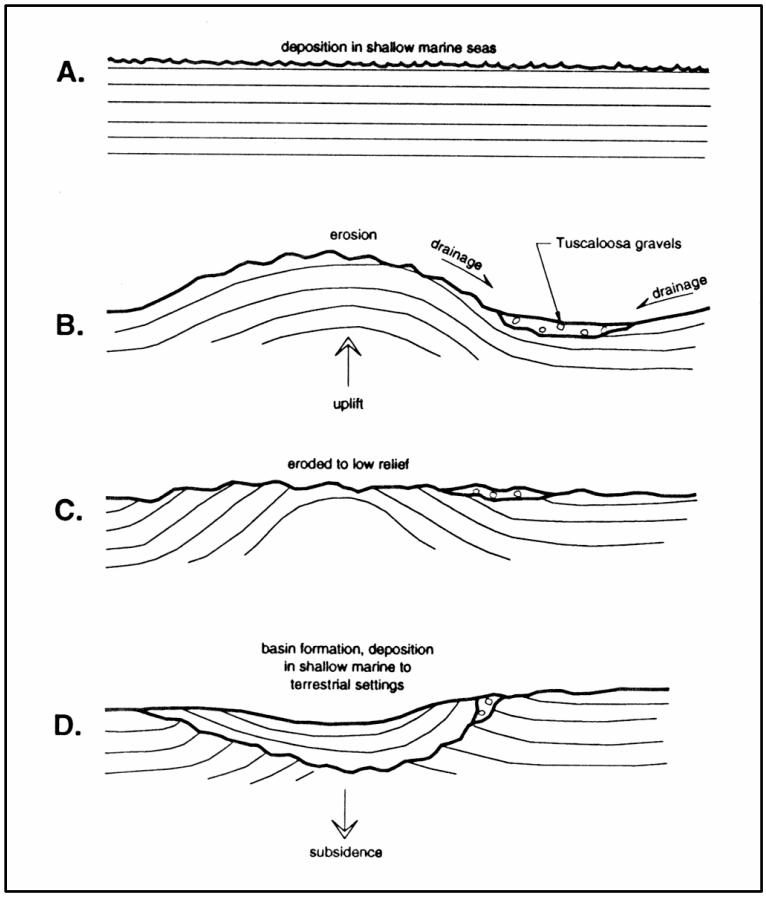

Figure 4.--Generalized geologic development of the aulacogenic structural inversion in the upper Mississippi Embayment; illustrated in the same east-west cross section as Figure 2. A) Late Paleozoic: Relatively flat-lying Paleozoic strata across the region. B) Late Mesozoic: Pascola uplift due to heating of the crust; erosion of the upland areas; deposition of Tuscaloosa gravels in alluvial fans, debris flows, and trunk braided streams. C) Later Mesozoic: erosion of uplift area to a lowland of modest relief of approximately 150 feet. D) Latest Mesozoic and Cenozoic: Subsidence of uplift area due to cooling; subsequent formation of Paducah-Memphis Basin; and incipient infilling of basin.

During most of the Paleozoic, largely shallow marine strata were deposited across the region of the Mississippi Embayment (Fig. 4a). During the Permian through the Middle Cretaceous, we do not know what happened because the rock record is absent. However, environments are thought to have been largely terrestrial. Erosion of the Paleozoic Appalachian highlands probably created an alluvial plain with

clastic sediments that covered the Jackson Purchase. As the Appalachians were reduced by erosion, the alluvial plain itself underwent some erosion, supplying recycled sediments to areas downstream.

During the Late Cretaceous a hotspot or some other thermal event in the area of the present Mississippi Embayment caused the crust to become more buoyant and the Pascola Arch was formed (Fig. 4b). The term Pascola Arch as used here includes the Blytheville Arch which was shown by McKeown and others (1990) to be the same structure as the Pascola. Drainage patterns were altered and the uplift was exposed to erosion that removed a large part of the Mesozoic and Paleozoic rocks (Fig. 4b). This uplift, an aulacogenic uplift, is the dominant cause of the Late Cretaceous-Paleozoic unconformity. Drainage of the uplift joined drainage of the alluvial plain to the east and the Tuscaloosa trunk fluvial system formed along the margin of the uplift (Fig. 4b). Continued erosion reduced the uplifted area to a nearly flat plain with local relief at about 100 to 150 feet (Fig. 4c). As the thermal event subsided and the crust cooled, it became less buoyant and subsided (Fig. 4d). However, because a large part of the Paleozoic and younger rocks were eroded, the crust contained less mass and accordingly did not subside to the same depth as before the uplift. After subsidence, the Pascola Arch, although of less structural relief than before, still existed as a structural arch. The subsidence, however was sufficient to cause the erosional surface to change slope and become a basin, an aulacogenic basin now known as the Paducah-Memphis Basin (Fig. 4d). Parts of the Tuscaloosa sediments were eroded as the slope changed. The newly formed basin attracted Late Cretaceous (McNairy Formation) and younger sediments which were deposited in the basin unconformably over the Paleozoic rocks. In this case, the structural syncline of the Paducah-Memphis Basin overlies a structural anticline of Paleozoic rocks, a genetic relationship called an aulacogenic structural inversion.

Conclusions

In this paper I introduce the aulacogenic cycle and its structural responses. I illustrate this response using the Paleozoic and younger strata in western Kentucky and adjacent areas. Although the study area is small, recognition of an aulacogenic cycle and its responses may have wide applications in other basins. Aulacogenic cycles may help to explain structural inversions in other areas around the world. Moreover, structural arches, hidden by overlying basins, may hold unrecognized oil and gas resources.

Although large scale geologic features in the region of the Embayment were caused by tectonic processes, the alternation of marine and terrestrial sediments in the Paducah-Memphis Basin may have been caused by eustatic processes. A more detailed stratigraphic framework needs to be developed for the region before a eustatic interpretation can be tested for these sediments. A stratigraphic architecture could be constructed showing changing drainage patterns and coastlines which, in turn, could be used to constrain tectonic history and the reconstruction of depositional environments. Additional paleontological studies should help in these interpretations. Furthermore, although no Paleogene or Cretaceous tetrapods have been reported from the Jackson Purchase, I can see no reason why their fossils should not be found there.

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