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GEOLOGIC MAPS OF THE JACKSON PURCHASE REGION, KENTUCKY

By Wilds W. Olive

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INTRODUCTION

The Jackson Purchase region, that part of Kentucky west of the Tennessee River, is in the northeastern part of the Mississippi embayment, a broad south-plunging structural downwarp whose axis approximately coincides with the east valley wall of the Mississippi River. Rocks exposed in the region range in age from Devonian to Holocene. Those of post-Paleozoic age are the principal subject of this report. The post-Paleozoic rocks consist entirely of clastic continental and marine sediments, the oldest of which are Late Cretaceous in age. Although the Late Cretaceous stratigraphic record contains gaps due to erosion and nondeposition, strata representing most stages of the Tertiary are present. Post-Paleozoic sediments attain a maximum thickness of about 2,050 feet near the embayment axis at the Kentucky–Tennessee State line.

Prior to investigations made for this report, knowledge of the areal geology of the Jackson Purchase region was based in large measure on investigations by Loughridge (1888), Glenn (1906), and Roberts, Gildersleeve, and Freeman (1945), which were of reconnaissance type. Owing to the scarcity or absence of fossil fauna and to the general lack of key beds, identification of most stratigraphic units was by homotaxial correlation with type sections, all of which were 100 miles or more south of Kentucky. Berry (1915, 1916, 1924, 1930, 1941) used fossil leaves and fruits for correlation and age determinations of Eocene units, but partly because of errors in the stratigraphy of some of the type areas used for base control, many of Berry's correlations are invalid.

The ages and correlation of stratigraphic units of this report have been determined largely through systematic palynological investigations by R. H. Tschudy and collaborators. The results of these investigations are contained in several published reports (Tschudy, 1966a, 1970a, b, 1973a, b, 1975; Herrick and Tschudy, 1967; Tschudy and Pakiser, 1967; Tschudy and Van Loenen, 1970) and in the open-file reports referred to on Map B. Additionally, the palynological investigations have provided much new data that indicate environments of deposition.

ACKNOWLEDGEMENTS

This report is based largely on all or parts of forty-seven 7½-minute geologic quadrangle maps (see index map) resulting from investigations conducted by 15 geologists from 1960 to 1977, as part of a cooperative mapping program by the Kentucky Geological Survey and the U.S. Geological Survey. Most of the information presented here is a summary of that presented on the individual geologic quadrangle maps; however, data accumulated during the late stages of the mapping program have indicated a need for refinement and revision of some of the earlier interpretations. Most revisions are of this category; however, some, particularly those relating to faulting and to the delineation of concealed boundaries of Eocene formations, are based on opinions derived from a knowledge of the regional geology after the mapping was completed. Such revisions, though consistent with available data, do not necessarily indicate that previous interpretations were incorrect, they merely indicate the preference of the present author.

Ernest E. Russell and Warren I. Finch reviewed the report, and Paul E. Potter, Wayne A. Pryor, and H. B. Willman were consulted during various stages of the investigation. All contributed knowledgeable council and made many helpful criticisms and suggestions.

STRATIGRAPHY AND ENVIRONMENT

CRETACEOUS

UPPER CRETACEOUS

Tuscaloosa Formation

The Tuscaloosa Formation in the Jackson Purchase region was first recognized by Roberts, Gildersleeve, and Freeman (1945, p. 38–41), although a chert-gravel deposit, designated as Tuscaloosa by Wade (1917), had earlier been reported to extend from Tennessee into an area of Kentucky now known as the Land-Between-the-Lakes—bordered by Kentucky Lake on the west and by Lake Barkley on the east. Wade's identification resulted from his tracing of discontinuous outcrops from Wayne County in southern Tennessee, where Miser (1917, p. 200) had reported gravel of the Tuscaloosa Formation beneath the Eutaw Formation. According to Christopher (in press), the Tuscaloosa in Alabama is middle Eaglefordian in age. This age assignment is based on palynologic correlation of the Tuscaloosa of Alabama with the Eagle Ford Group of Texas.

Palynomorph assemblages from localities D3142 and D3331 (Map B) in northeast Marshall and southeast Calloway Counties indicate that the Tuscaloosa of Kentucky is equivalent in age to the Eutaw Formation (Austinian Stage) of Alabama and thus is considerably younger than it is in the type area. The difference in age indicates that the formation is a time-transgressive unit that becomes progressively younger northward from its type locality. The formation in the Jackson Purchase region is equivalent to the nonmarine western facies of the Tuscaloosa of Marcher and Stearns (1962, p. 1371–1374).

McNairy Formation

The McNairy Formation is correlated on the basis of palynology with the McNairy Sand at its type locality in McNairy County, Tenn. where it was originally defined by Stephenson (1914, p. 17, 18) as a member of the Ripley Formation. Subsequently, Russell (1966) raised the unit in Tennessee to the rank of formation. It is designated as McNairy Formation in Kentucky because in the northern part of the Purchase region it is dominantly clay. Stearns (1957, p. 1092, fig. 12), Pryor (1960, p. 1476, fig. 2), and Russell (1975, p. A11, fig. 4) showed the McNairy to be intergradational with rocks of Tayloran and early Navarroan Age. However, in Kentucky, palynological data indicate that this is not true, at least in the area of outcrop, and that sediments of Tayloran and early Navarroan Age are missing, probably because of nondeposition. In the subsurface throughout the Jackson Purchase region, Cretaceous sediments for the most part are lithologically similar to and have about the same thickness as the McNairy in the area of outcrop. No paleontologic data are available to indicate the age of the complete subsurface Cretaceous sequence, but these deposits are considered to be of McNairy age except for a thin sequence of younger sediments at one locality that is equivalent in age to the Owl Creek Formation.

As illustrated by Stearns (1957, p. 1086), "deeper marine" sediments wedge out against overlying McNairy Sand in the subsurface near the Mississippi River, about 20 miles south of the Kentucky-Tennessee State line. The "deeper marine" sediments, as here interpreted, are equivalent in age to the Coon Creek Formation and Coffee Sand and are overlapped by the McNairy in northern Tennessee.

Paleontologic evidence indicates that the depositional environment of the McNairy was marine to freshwater deltaic. The area was occupied by a shallow marine body of water bordered by bays, lagoons, and saltwater marshes that merged landward with freshwater swamps between levees of distributaries. The climate was warm temperate to subtropical.

Owl Creek Formation

The Owl Creek Formation, the youngest of the Cretaceous formations in the northern Mississippi embayment, is not exposed in the Jackson Purchase region and is known in the subsurface only from one drill hole, at locality D4079 in north-central Carlisle County, where it was identified by a comparison of its pollen content with pollen from the type locality in northern Mississippi. The unit in Kentucky consists of about 60 feet of glauconitic sandy clay. The Owl Creek may intergrade with nonmarine sediments of the McNairy Formation, but evidence to indicate an intergradation is lacking. Tschudy (written commun., 1977) stated: "With the exception of samples from Owl Creek marine deposits I am at present unable to distinguish palynologically, upper McNairy samples from those of Owl Creek age." Hence, because of concealment and because the two units cannot be distinguished from one another in areas where the Owl Creek may be nonmarine, the interrelation of the two units in the Jackson Purchase was not determined. In northern Mississippi (Stephenson and Monroe, 1937), the area of its type locality, and in southwestern Tennessee (Russell, 1975, p. A46–A47), the Owl Creek rests unconformably on the McNairy Sand.

TERTIARY

PALEOCENE

Midway Group

Clayton Formation

The Clayton Formation of the Jackson Purchase Region includes an atypical sequence of sediments that is correlated on the basis of palynomorphs with the Clayton Formation at its type locality in southeastern Alabama, where typically it consists of glauconitic limestone, and calcareous sand, silt, and clay. The disconformity at the base of the Clayton is widespread in the Mississippi embayment and Gulf Coastal Plain and is marked by a distinct change in the faunal (Stephenson, 1915) and floral (Tschudy, 1970b, p. 92–93) succession. Throughout its extent in the outcrop area of the Jackson Purchase, the boundary between the Clayton and McNairy Formations is concealed except at one locality in north-central Calloway County, where it is a near-planar surface marked by a thin layer of irregularly shaped ferrous concretions between structureless dark-brownish-gray lignitic clay below and thin-bedded dark-gray to black lignitic clay containing interlaminae and thin lenses of sand above. The position of the contact was established with certainty only after palynological investigation by Tschudy (1970b, p. 94–96). Because of general concealment of the contact and because of lithologic similarity, the Clayton and McNairy Formations could not be distinguished from each other in other areas; therefore, they were combined for mapping purposes. Abundance of freshwater palynomorphs and scarce to absent marine palynomorphs in Clayton sediments give evidence that the Clayton was deposited in a deltaic or lacustrine environment. No pronounced climatic change from conditions that existed during deposition of underlying Cretaceous sediments is indicated by the pollen record (Tschudy, 1970b, p. 107).

Porters Creek Clay

The type locality of the Porters Creek Clay is in Hardeman County, Tenn., about 100 miles south of the Kentucky-Tennessee State line. The formation is persistent, showing little change in lithologic composition throughout the Mississippi embayment. The thickness of the exposed Porters Creek is variable, largely because of erosion that preceded the deposition of overlying Eocene deposits. In most outcrop areas, only the lower or middle parts of the Porters Creek remain; however, in southwest McCracken County, where the formation is thickest, and in northwest Ballard County, palynological data indicate that most of the upper part of the Porters Creek is present.

Fossil palynomorphs (Map B) and fauna (Browne and Herrick, 1963[1]), for the most part, indicate deposition in a marine environment, possibly ". . . a rather warm shallow-water shelf or epeiric sea" as proposed by Herrick and Tschudy (1967, p. B43). Palynomorphs from localities D3458, D3514, D3764, and D3775 in northeast Graves and southeast Marshall Counties, however, indicate a brackish-water, nearshore deltaic environment, suggesting that this area may have been near the mouth of a river that debouched into the Porters Creek sea.

[1]A fossil horizon, described as Clayton(?) Formation by Browne and Herrick (p. 247), is included in the lower member of the Porters Creek Clay as described in this report.

Sims (1972), who conducted a petrographic investigation of the Porters Creek Clay in the Jackson Purchase region, has presented evidence to demonstrate that sediments of the formation are of volcanic origin in part. Although he considered possible source areas in Texas, Louisiana, Arkansas, and Mississippi, he acknowledged a lack of evidence for Paleocene volcanism in these areas. Unknown to Sims, igneous rocks were reported in 1941 by Mrs. Mary H. McCracken[2] from an oil test near New Madrid, Mo., 22 miles west of Hickman. The section containing the igneous rocks is described as "red siderite, porphyry, magnetite," and occurs at the contact between the Porters Creek Clay and the Wilcox Formation between depths of 800 and 810 feet. This occurrence suggest the possibility of volcanic activity during the Paleocene and Eocene and a nearby source of volcanic material during deposition of the Porters Creek.

EOCENE AND OLIGOCENE ROCKS

Eocene rocks of the Jackson Purchase include a sedimentary sequence equivalent in age to the Wilcox, Claiborne, and Jackson Groups of the Gulf Coastal States (Tschudy, 1973a), where each group is represented by two to as many as six formations. Northward across Mississippi, the exposed formations of each group lose their lithologic identity, and near the Mississippi-Tennessee State line, they merge into a sedimentary sequence within which only the boundaries corresponding to group boundaries farther south can be defined on the basis of compositional and paleontological differences. Therefore, in Kentucky, the term "formation," as applied to Eocene stratigraphic units, supplants "group" as used in the Gulf Coast States. Because rocks of Oligocene age cannot be distinguished on the basis of lithology from those of the Jackson Formation, they are included with the Jackson for purposes of this report. The combined thickness of the Eocene and Oligocene formations along the embayment axis, where it crosses into Tennessee, is about 1,400 feet.

Compositional differences among the Eocene formations are subtle. In most of the eastern parts of the region, where exposures are numerous and closely spaced, formational boundaries between the Wilcox and Claiborne Formations can be traced with confidence from one outcrop to another over long distances. However, in much of the western part, outcrops are few and widely spaced, and the positions of boundaries between all Eocene units are less certain or are indefinite. For this reason, the contact between the Claiborne and Jackson Formations was not mapped, although the Jackson is shown as a separate unit along the Mississippi River bluffs in the southwestern part of the region where its lithologic composition is distinctive. A generalized boundary between the Claiborne and Jackson Formations on Map B is based largely on palynological data and in part on lithologic differences.

Wilcox Formation

The thickness of the Wilcox Formation in the outcrop area is extremely variable in part because of the irregular surface on which it was deposited, but largely because of erosion preceding deposition of the overlying Claiborne Formation, which at places overlaps the Wilcox. Only a few paleobotanical samples provided information adequate to indicate the stratigraphic position of the top and bottom of the formation, and all of these indicated an early Wilcox age. Palynomorph assemblages in all samples indicate a freshwater depositional environment. The climate during Wilcox time was probably subtropical and humid; however, two samples from localities D1668 and D3601 in northwest Calloway and northeast Graves Counties contain an abundance and variety of conifer pollen and a relative scarcity of subtropical genera, suggesting a temperate or highland-forest source.

The configuration of the eroded surface on which the Wilcox Formation was deposited in updip areas suggests a drainage system of moderate- to high-gradient streams, probably tributary to a trunk stream that flowed south along the embayment axis. The extent of this eroded surface in downdip areas is unknown. On the basis of a study of subsurface data from the northern Mississippi embayment, Stearns (1957, p. 1092) noted that ". . . there is no lithologically recognized unconformity . . ." between the Porters Creek Clay and Wilcox Formation.

[2](Well log. no. 7309, unpub., on file at Missouri Geol. Survey and Water Resources, Rolla, Mo.)

Claiborne Formation

Claiborne deposits in the area of outcrop range in age from earliest to latest Claibornian; however, as indicated by close proximity of sediments in the upper part of the Claiborne to Wilcox sediments in several areas, the lower part of the formation is either very thin or missing. In one of these areas in central Ballard County, sediments of late Claibornian Age at paleobotany localities D4193 and D4194 are less than a mile south of exposed sawdust sand of the Wilcox Formation. Sediments at locality D4194 are equivalent in age to the Cook Mountain or Cockfield Formation, which are the top two formations of the Claiborne Group in the southern part of the embayment. Locality D4194 is at an altitude of 405 feet and is only 15 feet higher than Wilcox sawdust sand exposed half a mile to the north. As the regional dip of the top of the Wilcox is about 23 feet per mile south-southwestward (Davis, Lambert, and Hansen, 1973, pl. 3), the thickness of the Claiborne beneath the locality is probably no more than 35 feet, only a small fraction of the thickness of the pre-Cockfield section of the Claiborne in downdip areas, where a complete or near-complete section is present. The relation suggests that the lower part of the formation in Ballard County is missing, probably because of onlap and nondeposition.

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. The climate during Claiborne time was warm and humid.

In updip areas, the Claiborne Formation rests on an unconformable surface of moderate relief that truncates the Wilcox Formation and the Porters Creek Clay. The surface, which probably diminishes in relief toward the axis of the embayment, was eroded by streams that drained southward and westward from the embayment margins.

Jackson Formation

Identification of Jacksonian-Age sediments in the Jackson Purchase region is based for the most part on palynological correlations, which indicate that a large area in the southwestern part of the region is underlain by sediments that are equivalent in age to the Moodys Branch Formation and Yazoo Clay of the Jackson Group of Mississippi. Included with the Jackson Formation of Kentucky is a sequence of lithologically similar sediments of Oligocene age that bear a pollen assemblage similar to that of the Bucatunna Clay Member of the Byram Formation of Mississippi.

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. The climate during the late Eocene was subtropical to warm temperate. By Oligocene time, the sea had withdrawn from the northern embayment region, and continental deposition prevailed, but, environmental conditions remained much the same as in land areas during the late Eocene.

TERTIARY AND QUATERNARY

MIOCENE(?), PLIOCENE, AND PLEISTOCENE

Continental deposits

The continental deposits of the Jackson Purchase region include a sedimentary sequence that in the northern Mississippi embayment region is commonly referred to as the "Lafayette Formation" or the "Lafayette Gravel." These deposits are equivalent in age and similar in composition to deposits designated by various names in other regions that are extensive throughout the Mississippi embayment and Gulf Coastal Plain. Their mode of origin and age have been the source of much controversy long waged between two principal schools—one proposing that the deposits are Pleistocene in age and are largely derived from glacial outwash, and the other proposing that they are Pliocene to Pleistocene in age and that only the younger part of the unit, as defined in this report, is related to glaciation. Reviews of the history of the unit and controversies pertaining to its age and origin have been given Shaw (1918), Trowbridge (1954), Potter (1955, p. 1–4), and Willman and Frye (1970, p. 20–22).

An Oligocene or post-Oligocene age for the continental deposits is indicated by the youngest rocks (Oligocene) that underlie the unit and by pollen assemblages from clay lenses in the continental deposits. Although many samples from the continental deposits were examined for pollen, most were barren, and only two, both from southeastern Graves County, yielded an adequate variety of palynomorphs for age identification. R. H. Tschudy (written commun., 1963) stated that the sample from locality D3176 contains an essentially modern generic assemblage that has only two exotic genera; a Pliocene age is strongly suggested. On the basis of a comparison of this sample with control material from Oligocene rocks of Mississippi, he (written commun., 1966) further commented that: "This sample is no younger than Pliocene and no older than Miocene."

The assemblage from locality D1670 from southern Graves County contains only flora living in the region today, and on this basis Tschudy (written commun., 1966) has observed ". . . the probability is great that it represents the Quaternary, however, in absence of detailed control, the Pliocene cannot be entirely ruled out of consideration." J. P. Bradbury (written commun., 1976), who examined a replicate sample from the same locality, noted that the pollen assemblage ". . . suggests cooler climate in the area than at present, and a Pleistocene glacial stage correlation seems likely."

The positions of the paleobotanical samples and the lithologic composition of associated sediments indicate separate epochs of deposition that correspond to the ages of the samples. Sample D3176, a drill-hole sample, was collected from a depth of 35 feet (476 feet in altitude) and is from the upper part of a sequence of gravel, sand, and silty clay that fills a narrow ancient valley incised more than 50 feet below the 500-foot erosion surface. The valley is one of several buried valleys incised to depths of as much as 100 feet below this surface in the southwestern part of the region. These valleys commonly have steep gradients and are ravinelike in their upper reaches; in their lower courses, they are as much as 2½ miles wide and have flat bottoms at or near the level of the 400-foot erosion surface. Buried valleys are also incised 50 to 60 feet below the level of the 400-foot surface in western Carlisle and northwestern Graves Counties. In Carlisle County, one of these valleys, which is filled with as much as 80 feet of continental deposits, heads on the 400-foot surface, which is overlain by continental deposits that rise to an altitude of 515 feet.

As determined from abundant outcrop and drill-hole data, the continental deposits that fill these valleys, except in the upper few feet, show no evidence of an interruption in deposition other than bedding planes and local channeling, and gravel deposits of the fill contain no iron oxide-cemented gravel clasts. From these facts, I conclude that the continental deposits that fill the buried valleys and that gravel without cemented gravel clasts were deposited during a single continuum of deposition, which, as indicated by sample D3176, was during the Miocene(?) and Pliocene. These deposits constitute most of the continental deposits resting on the bedrock surface above an altitude of 400 feet and much of those that overlie the surface between 300 and 400 feet.

Paleobotany sample D1670 is from a bed of clay exposed at an altitude of 495 feet. The bed is underlain by cemented gravel and is overlain by alluvium. At no place were overlying continental deposits found in contact with the clay bed; however, 10 feet of sandy gravel that contains iron oxide-cemented gravel clasts is exposed 600 feet northwest of and 20 feet above the sample locality. The gravel is overlain by Peoria Loess and thus is no younger than early Wisconsinan in age. Its position relative to the sample locality suggests that it is younger than the clay bed and is therefore Pleistocene in age. From the relations at this locality, I infer that gravel deposits in other parts of the region that contain cemeted-gravel clasts and are overlain by loess are also Pleistocene in age. These deposits form a veneer of variable thickness above the older continental deposits in upland areas and are widely distributed in two alluvial terraces at altitudes of 360 to 370 feet and 440 to 460 feet in areas bordering the major valleys. They also probably overlie the 280-foot erosion surface (shown on Map D) in the northwestern part of the region, where they attain a maximum thickness of about 60 feet.

Pollen of Miocene(?) and Pliocene age from paleobotanical locality D3176 suggests ". . . temperate conditions, perhaps colder than the present" (R. H. Tschudy, written commun., 1967). This, and the cooler-than-present climate indicated by pollen from locality D1670 are consistent with analyses of the continental distribution of late Tertiary floras (Barghoorn, 1964; Dorf, 1964, Wolfe, 1975). These analyses show that a warming trend culminating in the Miocene(?) was followed by a cooling trend that extends to the present. This cooling trend was accompanied by a decrease in the mean annual range in temperature and by a moderate decrease in the mean annual temperature (Wolfe, 1975). According to Wolfe (oral commun., 1977), snow accumulation, and probably runoff from spring melt waters, would have been greater during the Miocene(?) and Pliocene than at present. The widespread and thick accumulations of gravel of the continental deposits is also evidence that indicates increased runoff and high-volume flow of streams during this time.

Runoff and flow of streams, except those heading in areas of glaciers, were probably reduced during the Pleistocene. Although data are insufficient to indicate climatic conditions within the Tennessee River drainage basin during most of the Pleistocene, some indication of conditions during maximum advance of the Wisconsin ice sheet has been provided by Watts (1970, p. 29), who stated that a cool climate having a lower precipitation/evaporation ratio than at present would be consistent with elements of full-glacial vegetation of northwestern Georgia during the Wisconsinan.

Potter (1955), on the basis of petrologic and sedimentologic evidence, concluded that the "Lafayette" in the Jackson Purchase region was all of Pliocene age and was deposited as an alluvial fan whose sediment source was to the southeast. Although evidence presented in this report differs from Potter's in indicating that the deposit was in part reworked and redeposited during the Pleistocene, it agrees in general with Potter's observations relative to form, source, and sedimentology of that part of the unit that is of Miocene(?) and Pliocene age. Maps A and C show that a southeast source is indicated by: (1) a southeastward increase in altitude of the bedrock surface beneath the deposit; (2) a southeastward increase in the minimum size of the coarsest percentile; and (3) a southeastward increase in the size of the modal class. Assuming that the coarsest gravel fraction of an aggrading channel is deposited in or near the channel, the contours showing percent distribution of the coarse-gravel fraction indicate that the main source of the gravel above the 400-foot erosion surface was supplied by distributary channels of an alluvial fan that had an apex south of Calloway County. The trunk stream, at least during early and late stages of deposition, occupied much the same position as does the present Tennessee River.

QUATERNARY

PLEISTOCENE

Loess

Silt of the Loveland Loess, Roxana Silt, and Peoria Loess, is mostly of eolian origin and was derived from alluvium deposited by glacial melt waters in the Mississippi and Ohio River valleys. Radiocarbon dating of shell material from the Roxana Silt at radiocarbon locality A (Map B) indicates an age >34,000 years B.P. A plot based on orientation of long axes of quartz grains in the Roxana and the basal part of the Peoria, presumed to reflect prevailing wind directions at time of deposition, indicates that dominant winter-storm winds were from the southwest and northwest as they are at present (Finch, Whitmore, and Sims, 1972, p. 10). Fossils from a locality 1 mile southwest of Hickman indicate that forests were present during the deposition of the Roxana and that probably the climate was cooler than at present (R. G. Browne *in* Finch, Whitmore, and Sims, 1972, p. 24). Similar conditions probably prevailed during deposition of the other loessal units.

Lacustrine deposits

Lacustrine deposits of Lake Paducah (Finch, Olive, and Wolfe, 1964) occur at altitudes below 357 feet in areas bordering the Ohio and Tennessee Rivers east of long 88°45′ N. Radiocarbon dating of shell material from lake sediments at radiocarbon locality B (Map B) gives an age of 21,080±400 years B.P., (early Woodfordian time of Frye, Glass, and Willman, (1962, p. 2). Fossil fauna from the same locality provide confirming evidence of a Wisconsinan Age and indicate deposition in a lake containing cool, slightly alkaline water (Olive, 1966, p. D88).

Most lacustrine sediments in the Jackson Purchase region were derived locally from areas surrounding the lake; however, much of the near-surface silt closely resembles loess and is of the same origin as Peoria Loess of upland areas, except that it settled through water. Gravel bars along the margins of the lake were produced by wave action. The absence of loess cover is evidence that they were awash until near the close of Wisconsinan time.

No glacially derived sediments were found in the lacustrine deposits of the Jackson Purchase, but abundant pebbles and sand composed of igneous and metamorphic rocks were recovered from two test holes drilled on Livingston Point at the confluence of the Ohio and Tennessee Rivers. These glacially derived sediments were washed into the lake during a time when the ancestral Ohio River was in flood and the lake was at a low stage.

PLEISTOCENE AND HOLOCENE

Alluvium

Alluvium at or near the surface in the Jackson Purchase region is Wisconsinan and Holocene in age. At places it is overlain by and intergrades with the Peoria Loess. Four radiocarbon datings of wood and one of peat from four localities (shown on Map B) indicate ages ranging from about 16,000 to 200±200 years before present. The oldest dating is from radiocarbon collection locality C (also, paleobotany locality D1866) near the head of a small deeply entrenched channel in west-central Calloway County. Wood and peat at this locality are overlain by 10½ feet of gravel that closely resembles gravel of the continental deposits. A palynomorph assemblage from the peat contains ericaceous and spruce pollen that suggests a colder climate than that of the present. The age of wood at radiocarbon locality D (also paleobotany locality D3744) from beneath 12 feet of alluvium composed of sandy silt and gravel exposed in an undercut bank of the West Fork of Clarks River in southwest Marshall County was determined as 6,930±300 years B.P. Pollen from the horizon of the wood indicates a warm-temperate postglacial climate; however, an assemblage from locality D3773, 2.3 miles to the northwest, contains palynomorphs that suggest temperate conditions. The sample is from alluvium of a small tributary of the West Fork of Clarks River and was probably deposited during the waning stage of Wisconsin Glaciation; it is thus older than the sample from locality D3744. Alluvium of the Ohio River below the McCracken-Ballard County line is Holocene in age and was deposited after the draining of Lake Paducah when the Ohio became established in its present course. This conclusion is based on an age determination of 6,370±250 years B.P. for wood obtained from beneath 20 feet of alluvium at radiocarbon locality E in northern Ballard County. The base of the alluvium in a test hole 300 feet southwest of the locality is 36 feet below the horizon of the wood.

Alluvium of the smaller streams is locally derived, but much or most of the alluvium of the major rivers that border the Jackson Purchase region is derived from distant and diverse sources. A large part of the alluvium of the Mississippi River was probably deposited during the late Pleistocene when the river was fed by tributaries that headed in areas of glacial outwash. The absence of carbonate clasts in alluvium and load of the major rivers is conspicuous because thick sections of carbonate rocks are exposed along the courses of the Tennessee, Mississippi, and Ohio Rivers in adjacent areas. The clasts must be removed from the river loads within a few miles of their sources as the result of abrasion and solution.

The rate of alluviation of flood plains was probably greatly accelerated during the late 19th century when cultivated areas that had been cleared of forests during the earlier part of the century were abandoned and stripped of soil cover by rapidly eroding gullies (McGee, 1891, p. 373–374). Evidence to suggest rapid alluviation during this period is provided by an amethyst-tinted whiskey bottle found beneath 3½ feet of alluvium of a small tributary draining into the West Fork of Clarks River in northeastern Graves County. Near-surface alluvium at radiocarbon locality F (Map B) of a tributary of Mayfield Creek in southeast Ballard County also probably dates from this epoch of erosion. It contains charcoal that is dated as 200±200 years B.P.

GEOLOGIC HISTORY

During the early stages of the Late Cretaceous, the Jackson Purchase region was an upland having possibly as much as 500 feet of relief (Marcher and Stearns, 1962, p. 1371–1374). The upland was part of an extensive highland formed on the Pascola arch, a structural uplift of Paleozoic rocks that trends southeast beneath the Mississippi embayment from the Ozark dome of southeastern Missouri into west Tennessee (Grohskopf, 1955, p. 25–26). Streams heading in the upland flowed northeast and east across the Purchase region into a trunk stream that drained south, peripheral to the arch. During early stages of the Late Cretaceous, high-gradient and high-discharge streams transported most sediments derived from the arch to depositional sites in Tennessee and Alabama. By Austinian time, however, the gradient of the trunk stream flowing through the Jackson Purchase region was reduced so much that it began to alluviate its valley with deposits now represented by the Tuscaloosa Formation.

During Tayloran and early Navarroan Stages of the Late Cretaceous, the Pascola arch was reduced to an upland of moderate relief bordered on the south by a sea in which the Coffee Sand and Coon Creek Formation and their stratigraphic equivalents were deposited. By middle Navarroan time, the arch had subsided, and a shallow sea in which sediments of the McNairy Formation were deposited encroached northward. The outline of the northern part of the embayment in its present form was established at this time.

Pryor (1960, p. 1502) proposed that Upper Cretaceous sediments, including those of the McNairy ". . . were derived from an area composed principally of high-rank metamorphic rocks, the Blue Ridge and Piedmont Plateau of the southern Appalachians. These sediments were transported to the embayment by a single large stream system." A modification of this concept was presented by Davis, Lambert, and Hansen (1973, p. 30), who proposed that the main McNairy delta was in the southeastern part of the Jackson Purchase and in parts of Tennessee and that a distributary that entered the embayment to the north also deposited clastic sediments. The thick sequence of clay in the northern part of the Purchase region presumably was deposited between the main delta and one constructed by the northern distributary.

The scarcity of chert in deposits of the McNairy suggests that areas of Paleozoic rocks and the Tuscaloosa Formation adjacent to the embayment were at or near base level and were not being appreciably eroded during McNairy time.

Sohl (1960, p. 9) observed that the unconformity between the McNairy and Owl Creek Formations in the southeastern part of the Mississippi embayment represents a widespread withdrawal of the sea during an imprecisely known time interval and that the similarity of faunas in the two formations does not suggest a major hiatus. These facts seem to indicate that the Jackson Purchase was uplifted and eroded after deposition of the McNairy. During Owl Creek time, a shallow sea reoccupied at least part of the region, but owing to a poor record, little is known of the distribution and depositional environment of sediments deposited. They may have been largely removed by erosion at the close of the Cretaceous when the entire Mississippi embayment was uplifted and exposed to subaerial erosion.

As viewed by Stephenson (1915), the widespread unconformity between Cretaceous and Paleocene deposits represents a major hiatus accompanied by the extinction of many species and genera of fauna. Sohl (1964, p. 156) has observed, however, that on the basis of present knowledge of Cretaceous and Tertiary fauna, the hiatus was not as long lasting as Stephenson proposed.

The Midway Group consists of marine and fresh- to brackish-water sediments deposited in a sea that at its greatest extent occupied most of the Mississippi embayment. Initial deposition began with the Clayton Formation, which consists of a sequence of deltaic and lacustrine sediments deposited along the margins of the advancing sea. As the northern embayment area subsided, the sea encroached landward, and these initial deposits were overridden by near shore marine and lagoonal deposits of glauconitic sand and clay of the lower member of the Porters Creek Clay. The middle member, composed dominantly of clay, was deposited largely in an open marine environment during the maximum transgression of the Paleocene sea. Sand lenses in the clay are probably the result of winnowing in areas where the sea bottom was above wave base during times of turbulent weather, although some may have been deposited in tidal channels. The presence of brackish-water and near shore marine palynomorph assemblages at several localities in updip areas of the northern and eastern parts of the Jackson Purchase suggests that the sea did not extend far beyond the limits of the present outcrop. As the sea withdrew during the late Paleocene, the upper member of the Porters Creek was deposited in an environment similar to that of the lower member.

Areas marginal to the Jackson Purchase throughout the Paleocene were low lying and were traversed by low-gradient streams that transported only fine sediments to the embayment. The general absence of chert in sediments of Midway Age indicates that Paleozoic rocks east of the region were not a major source of sand. Much of the sand of the Midway Group was probably derived from the McNairy Formation.

The region was probably seismically active during much of the Paleocene. Local warping during the early Paleocene is indicated by local unconformities at the base of the Porters Creek Clay in Ballard and McCracken Counties. Many clastic dikes that transect the Porters Creek may have been injected during earthquakes that were associated with volcanic activity near the southwest corner of the region.

The abrupt change from marine deposits of the Porters Creek Clay to the coarser freshwater deposits of the Wilcox Formation resulted from regional uplift that caused the sea to withdraw from the northern end of the Mississippi embayment at the close of the Paleocene. The uplift involved greater warping along the axis of the northern embayment than during any previous time. As a result of differential uplift, areas surrounding the embayment were raised well above the level of the embayment. Streams draining from these areas initially had steep gradients that enabled them to erode the irregular topography on which the Wilcox was deposited. Headward erosion and piracy that accompanied uplift probably caused major changes in stream systems that drained into the embayment.

As upland areas were lowered by erosion and as stream gradients were reduced, the regime in the Jackson Purchase changed from erosional to depositional, and streams began to alluviate their courses. The major streams at this time were probably braided or broadly meandering and had broad flat valleys that coalesced in their lower parts. Swamps and cutoff lakes, in which clay, silt, and peat accumulated, were numerous along the courses of these valleys. Deposition of sand was largely during times of high discharge when streams overtopped their banks and flood waters spread over broad areas. As flooding waned, streams reoccupied parts of their previous channels.

Much of the sediment of the Wilcox was probably derived from sources far removed from the embayment, but, the presence of chert in the sawdust sand suggests that Paleozoic rocks along the east margin of the embayment were a source of some of the sediment.

After deposition of the Wilcox, the northern Mississippi embayment was uplifted and eroded. The uplift involved warping, which during early Claibornian time resulted in subsidence of axial areas and uplift of peripheral areas of the embayment, so that at the beginning of Claiborne deposition in the Jackson Purchase, a narrow, shallow sea encroached northward along the embayment axis. At the same time, streams with steepened gradients were eroding the recently uplifted marginal areas.

As uplift waned, streams approached grade and began to alluviate their channels. The larger streams extended their courses seaward by constructing deltas. Some channels of small streams remained open; possibly because of renewed subsidence, their lower courses were drowned and partly filled with nearshore and brackish-water sediments.

During a time of tectonic quiescence that followed, uplands bordering the areas of alluviation were further reduced. The narrow sea along the embayment axis was filled or partly filled with sediments provided by streams, which in their lower reaches produced a constructional plain that steadily encroached onto upland areas. The depositional area of Claiborne sediments during this time was probably as described by Olive and Finch (1969, p. 14–15): ". . . a rather flat plain traversed by south- to west-flowing, meandering, low-gradient, aggrading streams that occupied broad flat shallow valleys. Flooding following seasonal rains caused shifts in the major channels and abandonment of channel segments, which became locales for accumulation of clay deposits and associated sediments."

The northern embayment again subsided during late Claibornian time, and a shallow sea reoccupied the central part of the northern embayment area. Subsidence was probably accompanied by uplift of marginal areas, and a new cycle of erosion and alluviation, similar to that during the earlier part of Claiborne deposition, ensued.

Most of the sediments of the Claiborne were probably derived from much the same sources as those of the Wilcox Formation. The general absence of chert, however, suggests that Paleozoic rocks in areas adjacent to the embayment on the east were not a principal source of sand, although residuum derived from weathering of carbonate rocks in these areas may have been a major source of finer sediments. Black chert pebbles in the Claiborne north of Wickliffe are absent in the formation in other parts of the Jackson Purchase but are common in Eocene sediments exposed in Crowleys Ridge near Dexter, Mo., about 50 miles west of Wickliffe. Their regional distribution indicates that the area bordering the Mississippi River was a zone of intermixing of sediments derived from eastern and western sources.

Because of alluviation or slight regional uplift, the sea at the beginning of Jacksonian time had withdrawn from all but the southwestern part of the Jackson Purchase region, which was occupied by shallow-marine and brackish-water bays and lagoons. To the east and north, the area was a lowland traversed by low-gradient aggrading streams. Before sediments of Oligocene age were deposited, the sea had withdrawn from the northern end of the embayment, but, the similarity of these sediments to the coarser sediments of Jacksonian age suggests that base level was little changed and that the region was only slightly above sea level. The depositional environment during deposition of the Jackson Formation was much the same as that during Claibornian time.

Most sediments of the Jackson were probably derived from older coastal-plain sediments exposed in areas bordering depositional sites, but, chert sand and pebbles of quartz and chert indicate that Paleozoic rocks exposed east and north of the embayment were also sediment sources. The influx of chert and quartz pebbles may have been a consequence of uplift in areas marginal to the embayment.

Volcanic activity, probably far removed from the Jackson Purchase, is indicated by the presence of montmorillonitic clay and fragments of volcanic glass in sediments of the finer facies of the Jackson.

Differential structural movement that resulted in subsidence of the embayment axis and uplift of marginal areas during the Eocene is largely responsible for the thick accumulation of Eocene sediments and for the present structural configuration of the upper Mississippi embayent. The significance of movement during the Eocene was earlier recognized by Stearns and Armstrong (1955, p. 9), who noted that the structure of the embayment ". . . primarily reflects subsidence during Eocene deposition."

Palynological and geomorphic evidence indicates that the present elevation and configuration of the bedrock surface beneath the continental deposits is due to episodic uplift and erosion since Jacksonian time. An uplift of about 400 feet is indicated by presence of marine palynomorphs of late Eocene age in sample number D3763 from an altitude of 320 feet in northwestern Hickman County and by upper Eocene sediments probably deposited near sea level but now at an altitude of 460 feet in east-central Graves County.

Uplift of greater magnitude is inferred from an interpretation of the origin and present altitude of the 500-foot erosion surface. This surface, which originally was far more extensive than that shown on Map D, is bordered on the south by an upland that along the Mississippi-Tennessee River divide in Tennessee rises to concordant levels of about 600 feet. The youngest rocks that now underlie the 500-foot surface are Claibornian in age. In its original form, however, the erosion surface probably truncated the Jackson Formation, which at paleobotanical locality D3377, about 4 miles southeast of Mayfield, is only 20 feet or so below and within half a mile of two outliers of the 500-foot surface.

The stratigraphic and physiographic relations suggest that concordant surfaces at the 600-foot level in Tennessee are remnants of an almost flat erosional plain that merged with the depositional surface of sediments of Oligocene age. After the Oligocene sediments had been deposited, the region was uplifted about 100 feet, and the Jackson Purchase region was reduced by erosion to a near-featureless plain, a plain of denudation, now represented by the 500-foot surface. Thus, on the basis of this interpretation, an uplift of about 600 feet since the Oligocene would be required to explain the present elevation of the 500-foot surface and the elevation of the upland to the south. This explanation does not take into account the likelihood that sea level during the Oligocene may have been different from that at present.

As indicated by erosion surfaces at lower levels, the uplift took place in stages separated by intervals of tectonic quiescence. After the 500-foot surface was formed, the region was uplifted about 100 feet; the 400-foot erosion surface was planed during a period of quiescence that followed (Block diagram 1). Similarly, the 330-foot surface was planed during a quiet interval after an uplift of about 70 feet (Block diagram 2). The erosional surfaces were probably planed by broadly meandering streams that may have been only 100 feet or so above sea level.

The time of formation of the 400- and 500-foot erosion surfaces is inferred from duricrust found in the uppermost few feet of sediments beneath these surfaces at many places. The duricrust consists of ferricrete (iron oxide-cemented sand) and silcrete (silica-cemented sand) in zones a few inches to more than 15 feet thick in sediments ranging in age from Late Cretaceous to late Eocene. The duricrust is generally underlain by a thick zone of weathered yellowish-orange to moderate-brown sand and weathered clay that is mottled pastel yellow, orange, pink, and purple.

On the basis of a study of duricrusts in relation to paleoenvironments, Dury (1971, p. 512) observed that duricrusts and deep-weathering profiles of regional extent ". . . imply former planation, probably pediplanation, and the former operation of pedalogic processes under a climate of the Aw [tropical savanna] or Am [tropical rainforest] or some similar type." From an analysis of paleoclimatological data, he (p. 516) proposed that these conditions prevailed during the Miocene in the middle latitudes of the Northern Hemisphere and in part contributed to the formation of a duricrust in the driftless area of Wisconsin, which, according to Dury (1971, p. 519), probably dates ". . . from not later than the Middle Miocene." Duricrust formation and the planation of the 400- and 500-foot surfaces in the Jackson Purchase region were probably contemporaneous with the duricrust formation in Wisconsin.

The duricrust is the only evidence on the climatic environment during the time of planation of these two surfaces. However, root casts in a 6 inch layer of silcrete exposed half a mile southwest of paleobotanical locality D4334 in northeastern Carlisle County shows that vegetation covered at least part of the region.

Just before the continental deposits were laid down (block diagram 1), the Jackson Purchase was bordered by a trunk stream, the ancestral Tennessee, which occupied much the same position as the present-day Tennessee, Ohio, and Mississippi Rivers along the edges of the region. In Calloway and adjoining Trigg County to the east and in most of western Tennessee, the river, much as it is today, was confined within a narrow valley bordered by steep walls formed on Paleozoic rocks. On entering Kentucky, the river flowed at a moderate gradient to near the Calloway-Marshall County line, where it probably passed through an area of rapids before crossing from Paleozoic rocks onto much less resistant Cretaceous rocks. Downstream from the rapids, the valley widened progressively northward. Because of the weak resistance of sediments over which it passed, the channel was relatively unconfined in the northern and western parts of the region, and the river was either a braided or broadly meandering low-gradient stream that occupied a wide, flat-bottomed valley, remnants of which are now represented by the 330-foot erosion surface (Block diagram 2).

During the Pliocene, or possibly as early as the late Miocene, the flow of the ancestral Tennessee was greatly increased by seasonal rains and spring melt waters in headwater areas. During each spring flood, most of the alluvium that had accumulated within the confined segments of the valley during low-water stages became part of the stream load, and, when each flood season passed, most of this load was reincorporated in the valley alluvium, where it remained at rest until the river was again in flood. At this stage, possibly because of slight uplift, the river in the western part of the region incised its channel 30 to 40 feet below the level of the 330-foot erosion surface.

On reaching the broad, open, flat plain formed on Cretaceous and Tertiary sediments, the flood waters spread out over a wide area, the flow velocity was checked, and the river deposited a large part of its load. Alluviation was accompanied by undercutting and caving of the riverbanks, which were composed of sand and clay of Cretaceous and Tertiary age. This material was intermixed and incorporated with the river alluvium. Initially, the stream load was probably deposited as a small low-gradient alluvial fan on the 330-foot erosion surface in the area where the present Ohio and Tennessee Rivers join (Block diagram 2). In time, the load in the confined segments of the valley increased so much that spring floods could no longer transport alluvium of previous floods, and the valley began to fill with alluvium along the length of its course. Concommitantly, the alluvial fan increased in size. Eventually, the main valley of the ancestral river was filled to a level that caused the river to discharge onto adjacent uplands, covering first the 400-foot surface and then the 500-foot erosion surface (Block diagram 3). As the deposits fanned out in various directions, they filled valleys that headed in the uplands and then blanketed the uplands. Local topographic prominences above the general level of the erosion surfaces were either subdued or removed by undercutting and caving. As the topography was destroyed and buried, the alluvial deposits assumed the form of one large low-gradient fan that eventually spread over most of the Jackson Purchase. Southward encroachment of the fan was limited by the highland area that extended from Tennessee into southeastern Calloway and southern Graves Counties.

The Jackson Purchase fan has an origin analogous to that of a fan currently being constructed by the Kosi River of India. The Kosi fan (Gole and Chitale, 1966) occupies an area of about 8,000 square miles and has a slope that ranges from 1 foot per mile at its base to 5 feet per mile at its apex. Most of the fan is surfaced with sand; however, gravel containing large boulders is being deposited at its apex, and Inglis (1967, p. 96) mentioned boulders, pebbles, and shingle exposed in the bed of the river as far as 16 miles south of the apex. Inglis (1967, p. 96) stated that the gravel is exposed and moved short distances downstream towards the end of the flood season, and that "During the fair season, much of this coarse material is gradually shrouded by less coarse material . . ."

The Kosi River system, which heads in the Himalayas, drains an area of about 23,000 square miles and has an annual runoff of 43 million acre-feet, of which 81 percent takes place during June to October (Gole and Chitale, 1966, p. 112). During times of maximum flow, the discharge ranges from 200,000 to 860,000 cfs. By comparison, the Tennessee River drains an area of 42,200 square miles, and since the earliest date of record in 1875, a maximum discharge of 500,000 cfs was recorded in 1948 at a gaging station 16 miles east of Paducah (U.S. Geol. Survey, 1958, p. 223). However, this represents flow that was regulated by many dams and is probably higher than unregulated flow would have been.

The characteristics of the Kosi are perhaps best described by Inglis (1892, p. 679):

> ". . . after draining nearly the whole of Eastern Nepaul, [the river] emerges by a deep gorge from the hills at the north-west corner of Purneah. The stream runs with extreme velocity. It is known as a snow stream. The water is always cold, and generally of a milky colour, containing much fine white sand. No sooner does it leave its rocky bed than it tears through the flat country by numerous channels. It is subject to very sudden rises. A premonitory warning of these is generally given. The water becomes of a turbid, almost blood-like colour. Sometimes I have seen the river rise over thirty feet in twenty-four hours. The melting of the snow often makes a raging torrent, level from bank to bank, where only a few hours before a horse could have forded the stream without wetting the girths of the saddle."

and (p. 6–7)

> "When swollen by the melting of the snows or by the annual rains, the river overflows its banks, and at such times presents the appearance of a broad swiftly-flowing sea, for its breadth from bank to bank is often ten, and in some places nearly twenty miles across."

The fan of the Jackson Purchase region, like the Kosi fan, was deposited in a humid environment by a trunk stream having a high-volume seasonal flow confined within a narrow valley above the fan. Both fans have a lower gravelly section overlain by a section composed dominantly of sand. The Jackson Purchase fan probably had a low gradient similar to that of the Kosi.

At the onset of glaciation during the Pleistocene, the Tennessee and streams throughout the midcontinent region began to entrench their courses in response to lowering of base level caused by eustatic lowering of sea level. At the same time, the flow of the ancestral Tennessee dwindled because of a decrease in precipitation and runoff in headwater areas. The ability of the river to transport coarse sediments diminished, and growth of the alluvial fan came to a standstill. Eventually, as base level continued to be lowered, the stream gradient steepened, and the ancestral Tennessee and its tributaries, some of which may have been former distributaries, began to erode deep valleys into the fan deposits. As the river approached grade, it widened its valley by lateral corrasion and produced a wide flat bottom, now represented by a terrace on the fan deposits at altitudes between 500 and 515 feet.

During successive changes in base level as a result of eustatic fluctuation in sea level during the Pleistocene, the streams of the Jackson Purchase alternately eroded and alluviated their channels. During glacial advance, valleys were deepened and widened, and during the waning stages of glaciation and the interglacial stage that followed they were alluviated, but to levels below those of previous stages. Thus, former flood plains that correspond to the four glacial stages are now represented by alluvial terraces. These terraces, from oldest to youngest, are at altitudes of 515 to 550, 440 to 460, 360 to 370, and 320 to 345 feet. A comparison of their distribution with a map (U.S. Waterways Experiment Station, 1949, pl. 5) prepared under the direction of H. N. Fisk indicates that they correspond to the Williana, Bentley, Montgomery, and Prairie terraces, which were first described in Louisiana by Fisk (1938, p. 149–172; 1940, p. 63–113).

During formation of the lowest terrace, the trunk stream bordering the northern part of the region scoured the underlying bedrock and produced the 280-foot erosion surface (Map D).

Loess was probably deposited in upland areas of the Jackson Purchase during all stages of glaciation; however, only loess of Illinoian and Wisconsinan Age remains. Loess of Nebraskan and Kansan Age, if deposited, has since been removed by erosion.

During Wisconsinan time, tributaries draining from areas of glaciation poured large amounts of sediment into the Ohio and Mississippi Rivers, causing these rivers to aggrade their valleys. As the flood plains of the rivers rose to higher and higher levels, tributaries in the Jackson Purchase began to alluviate their valleys in response, and flood plains formed that were at grade with those of the Mississippi and Ohio. However, alluviation by the Tennessee River, which headed in a nonglaciated region, could not keep pace, and a lake formed in the lower reaches of its valley. At this time, the Tennessee drained northward and joined the Ohio, which flowed westward through a valley in southern Illinois now occupied by the Cache River. The confluence of the Ohio and Tennessee was then near Golconda, Ill., 21 miles north of the present confluence. Lake Paducah, which formed when the Tennessee drainage was blocked, lasted from early Woodfordian time to near the close of the Pleistocene, when a low divide 8 miles west of Paducah was breached, probably because of escape of water during a high-water stage of the lake. The escaping water rapidly established a channel that eventually drained the lake and caused the Ohio to abandon its course across southern Illinois and to adopt its present position along the border of the Jackson Purchase.

During the Holocene, as the amount of sediment derived from glaciated areas has decreased, the rivers and their tributaries have gradually lowered their courses and have formed new flood plains at levels 20 to 30 feet below flood plains of Wisconsinan Age.

The present topography of the Jackson Purchase region is largely due to periodic uplift, erosion, and deposition since the Oligocene. If, as proposed, the 330-foot erosion surface is due to erosion near sea level near the close of the Miocene(?), an uplift of about 300 feet is implied. However, this uplift is mostly conjectural, as evidence of uplift during the Pleistocene has been largely masked by the effects of eustatic fluctuations in sea level.

STRUCTURE

The strike of Upper Cretaceous and Tertiary formations, except the Tuscaloosa Formation and the continental deposits, parallels the margin of the embayment; the dip is uniformly toward the embayment axis that follows the bluffs of the Mississippi River. As interpreted from structure-contour maps by Davis, Lambert, and Hansen (1973, pl. 3), the tops of the McNairy Formation and the Porters Creek Clay dip 30 to 35 feet per mile, whereas the top of the Wilcox Formation dips about 23 feet per mile.

The northern Mississippi embayment is bordered on all sides by Paleozoic rocks that are broken by numerous faults (Heyl and others, 1965), many of which can be traced to near the point of disappearance beneath Upper Cretaceous deposits in the Jackson Purchase region. However, because of poor exposure and a scarcity of correlatable horizons, it is conjectural in most places whether the younger deposits are offset. Clear evidence of faulting is rarely discernible in the younger rocks, and at only a few localities has offset of post-Paleozoic strata been observed. Maximum offset for which there is clear evidence has taken place along a northwest-trending fault in west-central Marshall County, where the base of the Porters Creek Clay has been displaced at least 50 feet against the McNairy Formation. In a small entrenched channel near the northern end of this fault—the contact between the McNairy and continental deposits of Miocene(?) and Pliocene age—visible offset is about 5 feet. Maximum offset was not determined because the contact in the downdropped block has been displaced below channel level. The contact between the McNairy and continental deposits of Pleistocene age has been displaced about 3 feet along a northeast-trending fault 3 miles west of Kentucky dam, and an offset of about 7 feet of the contact between the McNairy and continental deposits of Miocene(?) and Pliocene age is exposed along the edge of the Ohio River at Fort Massac, Ill., about 7 miles downstream from Paducah.

Anomalous dips as high as 35° have been observed at small isolated exposures in many parts of the region. At most places, however, evidence is insufficient to indicate the origin of the dips, and whether they are due to tectonism or to landsliding and slumping is problematical. Most faults shown on Map A that offset rocks of post-Paleozoic age are based on indirect evidence; many could possibly be attributed to causes other than faulting.

The area bordering the Mississippi is currently tectonically active and is the site of frequent tremors, most of which have epicenters along or near the embayment axis (Fuller, 1912; McKeown, 1978; Moneymaker, 1954, 1955, 1957, 1958; Stauder and others, 1976). The epicenter of the New Madrid earthquake of 1811–1812, one of the most violent earthquakes that has taken place in North America, was adjacent to the westernmost border of the Jackson Purchase region. The earthquake produced many subsidence features resulting from extrusion and compaction of alluvium and caused many landslides along the Mississippi bluffs (Fuller, 1912, p. 47–53). Fuller (p. 64) postulated that the doming in the area of the epicenter was the result of differential subsidence related to compaction of alluvium caused by lateral movement along a fault in the central part of the embayment.

On the basis of a plot of 330 microearthquake foci during a 21-month period, Stauder and others (1976, p. 1953) have identified ". . . linear seismically active zones, corresponding presumably to seismically active faults. Several of these trend N. 40° E., parallel to the axis of the embayment." Others trend northwest parallel to the crest of the Pascola arch.

ECONOMIC GEOLOGY

Economic mineral resources currently being exploited in the Jackson Purchase region are all nonmetallic and include ground water, clay, gravel, and sand. Limestone, oil, gas, and lignite are potential economic resources.

Aquifers in the Paleozoic rocks, the McNairy and Claiborne Formations, the continental deposits, and the alluvium of the Tennessee, Mississippi, and Ohio Rivers are sources of good-quality ground water in amounts sufficient to supply present and foreseeable industrial and public needs (Davis, Lambert, and Hansen, 1973, p. 44–45). In general, the dissolved-solid and iron content of the water varies according to stratigraphic position of the aquifer. The dissolved solids in water from Upper Cretaceous, Paleocene, and Eocene aquifers are commonly less than 100 milligrams per liter (mgl) and are usually higher in aquifers of other units. Water from alluvium of the Mississippi River probably contains on the average a greater amount of dissolved solids, ". . . generally less than 500 mgl" (Davis, Lambert, and Hansen, 1973, p. 24), than that from any other source. Iron content of water from most aquifers of Eocene age is low, whereas it is commonly high in water from other aquifers.

Since the early 1900's, the Jackson Purchase region has been a leading producer of ball clay, which is used in the manufacture of white ware, sanitary ware, artware, enamelling, structural products, and refractories, and in plasticizers and fillers. Currently two companies operating in the region are producing ball, sagger, wad, and bonding clays from 10 pits. All but one are in Graves County, and all but two are in the Claiborne Formation. One pit in southeastern Carlisle County is in the Jackson Formation; another in northeastern Graves County produces from a clay deposit in the Wilcox Formation.

Ceramic tests of clay samples from many localities in the Jackson Purchase (Floyd and Kendall, 1955; McGrain and Kendall, 1957, 1972; McGrain, Kendall, and Teater, 1960; Olive and Finch, 1969; and Walker, 1953) have indicated that many undeveloped clay deposits of Cretaceous and Eocene age may be suited for manufacture of structural products, whiteware, and low-heat-duty refractories. On the basis of a study of clay deposits of Eocene age, Olive and Finch (1969, p. 1) noted that ". . . X-ray data indicate that the Claiborne and Wilcox Formations have greater potential as sources of ceramic-grade clay than has the Jackson Formation."

Because of high shrinkage, the Porters Creek Clay is generally unsuited for ceramic products, except possibly for making pottery and stoneware; it is, however, a potential source of fuller's earth-type clay. Analyses from localities in Calloway, Marshall, and McCracken Counties (McGrain, 1956b, 1965) have indicated that the clay has absorbent properties that compare favorably with the chemical oil standard of the Oil Chemists Society and that it has potential for use in floor-sweep compounds, animal bedding, insecticides, fungicides, and drilling mud. A study by the Spindletop Research Center (1965, p. 10–1) to determine the feasibility of establishing a plant in Marshall County to process clay of the Porters Creek as a source of fuller's earth ". . . indicates that a capital-intensive plant with an initial capacity of 60 tons per day with provisions to expand to 75 tons per day is economically justified . . ." The study recommended that "The plant should initially manufacture mainly floor absorbent and, on a limited basis, soil conditioner."

Gravel of the continental deposits is obtained from many quarries throughout the Purchase region. It is used principally for base construction of paved highways and as road metal on secondary roads. Because of its composition, the gravel is generally unsuited for use as concrete aggregate. The amount of clay in the matrix material ranges from 2 or 3 percent to as much as 20 percent. Also, many of the chert clasts have porous iron-stained surfaces.

The largest and most easily accessible sources of gravel are in the eastern part of the region where the continental deposits are thickest and the overlying loess is generally less than 15 feet thick. Gravel in the western part of the region is in thinner beds or lenses, and in areas bordering the Mississippi River bluffs, it is overlain by loess ranging in thickness from 25 to 80 feet.

Gravel and sand for construction and miscellaneous purposes are obtained by dredging alluvium of the Ohio and Tennessee Rivers near Paducah and from alluvium of the Mississippi between Wolf Island and the bluffs to the east.

Thick deposits of chert gravel in the Tuscaloosa Formation in areas bordering Kentucky Lake are not being exploited. In general, gravel of the Tuscaloosa contains coarser clasts than that of the continental deposits, and at least partly for this reason, it is probably not as well suited for highway use.

Large quantities of high-silica sand, which has many economic uses, are obtainable from most stratigraphic units. Sand of the McNairy Formation is being produced from a pit about 10 miles southeast of Murray. Silica content of the sand ranges from about 97 to 98 percent. The sand is processed without the aid of chemical beneficiation and is marketed to foundry, construction, metallurgical, and ceramic industries (McGrain, 1968, p. 20). Molding sand was formerly obtained from the continental deposits near Mayfield and from alluvium of the Ohio and Tennessee Rivers in McCracken County (Richardson, 1927, p. 34, 54). Analyses of samples from the McNairy Formation in Marshall County and the Jackson Formation in Carlisle and Hickman Counties indicate other sand deposits having high-silica content (McGrain, 1956a, p. 28–29). A sample from the Claiborne Formation exposed near the southeast corner of Graves County, as reported by the Kentucky Geological Survey, contains 97.75 percent silica, raw, and 98.08 percent, washed. The bulk of all samples analyzed is coarser than 40 mesh (0.42 mm) and finer than 200 mesh (0.074 mm).

In areas bordering the Jackson Purchase to the east and north, the formations of Mississippian age are composed largely of limestone; but, in areas of the Jackson Purchase that border Kentucky Lake and the Tennessee River, the limestone has largely been leached and partly replaced by chert to depths ranging from a few feet to as much as 190 feet. As a result, these formations in most surface exposures consist of chert and residuum. Limestone is exposed or is near the surface at only a few widely spaced localities. At one of these localities, near the southeastern corner of Calloway County, limestone for agricultural lime, road metal, and concrete aggregate was formerly produced from the Warsaw Limestone. The upper 6 feet of the deposit has an average calcium-carbonate content of 95.33 percent. As shown by McGrain (1968, p. 25–29) and Dever and McGrain (1969, p. 15–25), total carbonate content of core samples between depths of 21 and 60 feet averages 99.96 percent. The authors also describe other localities in Marshall and Calloway Counties where limestone of the Warsaw is at or near the surface and may have economic potential.

Pre-Mesozoic sedimentary rocks of the Jackson Purchase include a thick marine section, source beds for petroleum, porous zones, and unconformities; structural, stratigraphic, and hydrodynamic traps should be present (Bond and others, 1971; Schwalb, 1969, 1971). The combination of these elements is favorable for the accumulation of petroleum. Although shows of oil and gas have been reported, no commercial quantities have been found. As of 1969, only 27 test holes were known to have been drilled into rocks of Paleozoic age (Schwalb, 1969, p. 18); hence, much of the region remains untested.

Primary targets for exploration, as proposed by Bond and others (1971, p. 1166), are sandstone lenses and porous zones associated with fractures and solution openings within the Knox "Megagroup" (Upper Cambrian and Lower Ordovician) in the vicinity of the Pascola arch. Other possible productive zones may be in rocks of Cambrian, Silurian, and Devonian age.

As many as three lignite beds of the Claiborne Formation are exposed in an area extending about 7 miles eastward from the Mississippi River bluff at Wickliffe. The beds are lenticular and generally are not more than 3 feet thick; however, a partly exposed bed in the upland area between Wickliffe and Mayfield Creek is more than 4½ feet thick. Analyses of two samples (as received) show about 50 percent moisture, 16 percent fixed carbon, 25 percent volatile matter, 6 to 9 percent ash, and 0.7 to 2.5 percent sulfur; heating value is about 5,000 Btu.

A 2-foot-thick lignite bed in the upper part of the McNairy Formation is exposed over a distance of about 150 yards along the banks of a small east-flowing tributary of Jonathan Creek in northeastern Calloway County. The lignite burns with a strong sulfurous odor.

The lignite deposits are not currently exploited, but as costs for energy rise, the lignite may have value as a future energy source for local needs.

A detailed description of the economic geology of Calloway, Marshall, and McCracken Counties has been presented by McGrain (1968, 1970, 1978).

REFERENCES CITED

Barghoorn, E. S., 1964, Quantitation of sequential change in North American Cenozoic floras as a clue to palaeoclimates, *in* Nairn, A. E. M. ed., Problems in palaeoclimatology: New York, Interscience, p. 31–39.

Berry, E. W., 1915, The Mississippi River bluffs at Columbus and Hickman, Kentucky, and their fossil flora: U.S. National Museum, Proceedings, v. 48, p. 293–303.

_________ 1916, The lower Eocene floras of southeastern North America: U.S. Geological Survey Professional Paper 91, 481 p.

_________ 1924, The middle and upper Eocene floras of southeastern North America: U.S. Geological Survey Professional Paper 92, 206 p.

_________ 1930, Revision of the lower Eocene Wilcox of the Southeastern States, with descriptions of new species, chiefly from Tennessee and Kentucky: U.S. Geological Survey Professional Paper 156, 196 p.

_________ 1941, Additions to the Wilcox flora from Kentucky and Texas: U.S. Geological Survey Professional Paper 193–E, p. 83–99.

Bond, D. C., and others, 1971, Possible future petroleum potential of Region 9—Illinois basin, Cincinnati arch, and northern Mississippi embayment, *in* Cram, I. H., ed., Future petroleum provinces of the United States—their geology and potential: American Association of Petroleum Geologists Memoir 15, v. 2, p. 1165–1218.

Browne, R. G., and Herrick, S. M., 1963, Smaller Paleocene Foraminifera from Reidland, Kentucky: Bulletins of American Paleontology, v. 46, no. 210, p. 247–284.

Christopher, R. A., in press, The occurrence of the *Complexiopollis-Atlantopollis* Zone (palynomorphs) in the Eagle Ford Group (Upper Cretaceous) of Texas: Journal of Paleontology.

Davis, R. W., Lambert, T. W., and Hansen, A. J., Jr., 1973, Subsurface geology and ground-water resources of the Jackson Purchase region, Kentucky: U.S. Geological Survey Water-Supply Paper 1987, 66 p.

Dever, G. R., Jr., and McGrain, Preston, 1969, High-calcium and low-magnesium limestone resources in the region of the lower Cumberland, Tennessee, and Ohio Valleys, western Kentucky: Kentucky Geological Survey, ser. 10, Bulletin 5, 192 p.

Dorf, Erling, 1964, The use of fossil plants in palaeoclimatic interpretations, *in* Nairn, A. E. M., ed., Problems in palaeoclimatology: New York, Interscience, p. 13–31.

Dury, G. H., 1971, Relict deep weathering and duricrusting in relation to the palaeoenvironments of middle latitudes: Geographical Journal, v. 137, pt. 4, p. 511–522.

Engel, C. G., and Sharp, R. P., 1958, Chemical data on desert varnish: Geological Society of America Bulletin, v. 69, no. 5, p. 487–518.

Finch, W. I., Olive, W. W., and Wolfe, E. W., 1964, Ancient lake in western Kentucky and southern Illinois: U.S. Geological Survey Professional Paper 501–C, p. C130–C133.

Finch, W. I., Whitmore, F. C., Jr., and Sims, J. D., 1972, Stratigraphy, morphology, and paleoecology of a fossil peccary herd from western Kentucky: U.S. Geological Survey Professional Paper 790, 25 p.

Fisk, H. N., 1938, Geology of Grant and La Salle Parishes: Louisiana Department of Conservation Geological Bulletin 10, 246 p.

_________ 1940, Geology of Avoyelles and Rapides Parishes: Louisiana Geological Survey, Geological Bulletin 18, 240 p.

Floyd, R. J., and Kendall, T. A., 1955, Miscellaneous clay and shale analyses for 1952–1954: Kentucky Geological Survey, ser. 9, Report of Investigations 9, 61 p.

Frye, J. C., Glass, H. D., and Willman, H. B., 1962, Stratigraphy and mineralogy of the Wisconsinan loesses of Illinois: Illinois State Geological Survey Circular 334, 55 p.

Fuller, M. L., 1912, The New Madrid earthquake: U.S. Geological Survey Bulletin 494, 119 p.

Glenn, L. C., 1906, Underground waters of Tennessee and Kentucky west of Tennessee River and of an adjacent area in Illinois: U.S. Geological Survey Water-Supply and Irrigation Paper 164, 173 p.

Gole, C. V., and Chitale, S. V., 1966, Inland delta building activity of the Kosi River: American Society of Civil Engineers Proceedings, Journal of the Hydraulics Division, HY2, v. 92, p. 111–126.

Grohskopf, J. G., 1955, Subsurface geology of the Mississippi embayment of southeast Missouri: Missouri Division of Geological Survey and Water Resources [Rept.], v. 37, 2d ser., 133 p.

Herrick, S. M., and Tschudy, R. H., 1967, Microfossil evidence for correlation of Paleocene strata in Ballard County, Kentucky, with the lower part of the Porters Creek Clay: U.S. Geological Survey Professional Paper 575–B, p. B40–B44.

Heyl, A. V., Brock, M. R., Jolly, J. L., and Wells, C. E., 1965, Regional structure of the southeast Missouri and Illinois—Kentucky mineral districts: U.S. Geological Survey Bulletin 1202–B, p. B1–B20.

Inglis, C. C., 1967, Inland delta building activity of Kosi River: American Society of Civil Engineers Proceeding, Journal of the Hydraulics Division, HY1, v. 93, p. 93–100.

Inglis, James, 1892, Tent life in Tigerland with which is incorporated sport and work on the Nepaul [sic] frontier. Being twelve years' sporting reminiscences of a pioneer planter in an Indian frontier district: London, Sampson Low, Marston, 690 p.

Loughridge, R. H., 1888, Report on the geological and economic features of the Jackson's Purchase region, embracing the counties of Ballard, Calloway, Fulton, Graves, Hickman, McCracken, and Marshall: Kentucky Geol. Survey, [Reports of Special Subjects, v. 5, F], 357 p.

McGee, W J, 1891, The Lafayette Formation: U.S. Geological Survey 12th Annual Report, pt. 1, p. 347–521.
McGrain, Preston, 1956a, Recent investigations of silica sands of Kentucky—No. 2: Kentucky Geological Survey, ser. 9, Report of Investigations 11, 32 p.
_________ 1956b, Sources of fuller's-earth type clay in Kentucky: Kentucky Geological Survey, ser. 9, Information Circular 6, 4 p.
_________ 1965, Fuller's earth resources of the Jackson Purchase region, Kentucky: Kentucky Geological Survey, ser. 10, Bulletin 3, 23 p.
_________ 1968, Economic geology of Calloway County, Kentucky: Kentucky Geological Survey, ser. 10, County Report 2, 35 p.
_________ 1970, Economic geology of Marshall County, Kentucky: Kentucky Geological Survey, ser. 10, County Report 5, 33 p.
_________ 1978, Economic geology of McCracken County, Kentucky: Kentucky Geological Survey, ser. 10, County Report 7, 22 p.
McGrain, Preston, and Crawford, T. J., 1959, High-silica sands in Calloway and Carlisle Counties, Kentucky: Kentucky Geological Survey, ser. 10, Information Circular 2, 14 p.
McGrain, Preston, and Kendall, T. A., 1957, Miscellaneous clay and shale analyses for 1955–1956: Kentucky Geological Survey, ser. 9, Report of Investigations 13, 70 p.
_________ 1972, Miscellaneous analyses of Kentucky clays and shales for 1960–1970: Kentucky Geological Survey, ser. 10, Report of Investigations 12, 62 p.
McGrain, Preston, Kendall, T. A., and Teater, T. C., 1960, Miscellaneous clay and shale analyses for 1957–1959: Kentucky Geological Survey, ser. 10, Report of Investigations 3, p. 4–57.
McKeown, F. A., 1978, Hypothesis: Many earthquakes in the central and southeastern United States are causally related to mafic intrusive bodies: U.S. Geological Survey Journal of Research, v. 6, no. 1, p. 41–50.
Marcher, M. V., and Stearns, R. G., 1962, Tuscaloosa Formation in Tennessee: Geological Society of America Bulletin, v. 73, no. 11, p. 1365–1386.
Miser, H. D., 1917, Structure of the Waynesboro quadrangle with special reference to oil and gas: Tennessee Geological Survey, Resources of Tennessee, v. 7, no. 4, p. 199–219.
Moneymaker, B. C., 1954, Some early earthquakes in Tennessee and adjacent states (1699–1850): Tennessee Academy of Science Journal, v. 29, no. 3, p. 224–233.
_________ 1955, Earthquakes in Tennessee and nearby sections of neighboring states—1851–1900: Tennessee Academy of Science Journal, v. 30, no. 3, p. 222–233.
_________ 1957, Earthquakes in Tennessee and nearby sections of neighboring states—1901–1925: Tennessee Academy of Science Journal, v. 32, no. 2, p. 91–105.
_________ 1958, Earthquakes in Tennessee and nearby sections of neighboring states—1926–1950: Tennessee Academy of Science Journal, v. 33, no. 3, p. 224–239.
Nyman, D. J., 1965, Origin of clastic dikes in the Porters Creek Clay at Pinson, Tennessee: Tennessee Academy of Science Journal, v. 40, no. 4, p. 143–147.
Olive, W. W., 1966, Lake Paducah, of late Pleistocene age, in western Kentucky and southern Illinois: U.S. Geological Survey Professional Paper 550–D, p. D87–D88.
Olive, W. W., and Finch, W. I., 1969, Stratigraphic and mineralogic relations and ceramic properties of clay deposits of Eocene age in the Jackson Purchase region, Kentucky, and in adjacent parts of Tennessee: U.S. Geological Survey Bulletin 1282, 35 p.
Potter, P. E., 1955, The petrology and origin of the Lafayette gravel—Pt. 1, Mineralogy and petrology; Pt. 2, Geomorphic history: Journal of Geology, v. 63, no. 1, p. 1–38; no. 2, p. 115–132.
Pree, H. L., Jr., Walker, W. H., and MacCary, L. M., 1957, Geology and ground-water resources of the Paducah area, Kentucky: U.S. Geological Survey Water-Supply Paper 1417, 214 p.
Pryor, W. A., 1960, Cretaceous sedimentation in Upper Mississippi embayment: American Association of Petroleum Geologists Bulletin, v. 44, no. 9, p. 1473–1504.
Pryor, W. A., and Vanwie, W. A., 1971, The "sawdust sand"—An Eocene sediment of floccule origin: Journal of Sedimentary Petrology, v. 41, no. 3, p. 763–769.
Rhoades, R. F., 1941, Pre-Pleistocene initiation of deep solution in the lower Tennessee Valley: American Journal of Science, v. 239, no. 10, p. 764–770.
Richardson, C. H., 1927, The molding sands of Kentucky: Kentucky Geological Survey, ser. 6, v. 29, p. 1–64.
Roberts, J. K., Gildersleeve, Benjamin, and Freeman, L. B., 1945, Geology and mineral resources of the Jackson Purchase region, Kentucky: Kentucky Department of Mines and Minerals, Geological Division Bulletin, ser. 8, no. 8, 126 p.
Russell, E. E., 1966, Geologic map of the Sardis quadrangle, Tennessee: Tennessee Division of Geology Geologic Map GM 12–NE.
_________ 1975, Stratigraphy of the outcropping Upper Cretaceous in western Tennessee, *in* Russell, E. E., and Parks, W. S., Stratigraphy of the outcropping Upper Cretaceous, Paleocene, and lower Eocene in western Tennessee (including descriptions of younger fluvial deposits): Tennessee Division of Geology Bulletin 75, p. A1–A65.
Schwalb, H. R., 1969, Paleozoic geology of the Jackson Purchase region, Kentucky, with reference to petroleum possibilities: Kentucky Geological Survey, ser. 10, Report of Investigation 10, 40 p.
_________ 1971, The northern Mississippi embayment—a latent Paleozoic oil province: Illinois State Geological Survey, Illinois Petroleum No. 95, p. 44–49.
Shaw, E. W., 1918, The Pliocene history of northern and central Mississippi: U.S. Geological Survey Professional Paper 108–H, p. 125–163.
Sims, J. D., 1970, Authigenic kaolinite in sand of the Wilcox Formation, Jackson Purchase region, Kentucky: U.S. Geological Survey Professional Paper 700–B, p. B27–B32.
_________ 1972, Petrographic evidence for volcanic origin of part of the Porters Creek Clay, Jackson Purchase region, western Kentucky: U.S. Geological Survey Professional Paper 800–C, p. C39–C51.
Sohl, N. F., 1960, Archeogastropoda, Mesogastropoda, and stratigraphy of the Ripley, Owl Creek, and Prairie Bluff Formations: U.S. Geological Survey Professional Paper 331–A, 151 p.
_________ 1964, Neogastropoda, Opisthobranchia, and Basommatophora from the Ripley, Owl Creek, and Prairie Bluff Formations: U.S. Geological Survey Professional Paper 331–B, p. 153–344.
Spindletop Research Center, 1965, Feasibility of establishing a fuller's earth processing plant in Marshall County, Kentucky: Lexington, Ky. (prepared for U.S. Dept. Commerce), [94 p.].
Stauder, William; Kramer, Mark; Gerard, Fischer; Schaeffer, Stephan; and Morrissey, S. T., 1976, Seismic characteristics of southeast Missouri as indicated by a regional telemetered microearthquake array: Seismological Society of America Bulletin, v. 66, no. 6, p. 1953–1964.
Stearns, R. G., 1957, Cretaceous, Paleocene, and lower Eocene geologic history of the northern Mississippi embayment: Geological Society of America Bulletin, v. 68, no. 9, p. 1077–1100.
Stearns, R. G., and Armstrong, C. A., 1955, Post-Paleozoic stratigraphy of western Tennessee and adjacent portions of the upper Mississippi embayment: Tennessee Division of Geology Report of Investigations 2, 29 p.
Stephenson, L. W., 1914, Cretaceous deposits of the eastern Gulf region and species of *Exogyra* from the eastern Gulf region and the Carolinas: U.S. Geological Survey Professional Paper 81, 77 p.
_________ 1915, The Cretaceous-Eocene [Paleocene] contact in the Atlantic and Gulf Coastal Plain: U.S. Geological Survey Professional Paper 90, p. 155–182.
Stephenson, L. W., and Monroe, W. H., 1937, Prairie Bluff Chalk and Owl Creek Formation of eastern Gulf region: American Association of Petroleum Geologists Bulletin, v. 21, no. 6, p. 806–809.
Trowbridge, A. C., 1954, Mississippi River and Gulf Coast terraces and sediments as related to Pleistocene history—a problem: Geological Society of America Bulletin, v. 65, no. 8, p. 793–812.
Tschudy, R. H., 1965a, Palynological investigations in the Upper Cretaceous and Tertiary of the Mississippi embayment region—I: U.S. Geological Survey open-file report, 63 p.
_________ 1965b, Palynological investigations in the Upper Cretaceous and Tertiary of the Mississippi Embayment region—II: U.S. Geological Survey open-file report, 19 p.

Tschudy, R. H., 1966a, Associated megaspores and microspores of the Cretaceous genus *Ariadnaesporites* Potonié, 1956, emend: U.S. Geological Survey Professional Paper 550–D, p. D76–D82.
——— 1966b, Palynological investigations in the Upper Cretaceous and Tertiary of the Mississippi Embayment region—III: U.S. Geological Survey open-file report, 17 p.
——— 1967, Palynological investigations in the Upper Cretaceous and Tertiary of the Mississippi Embayment region—IV: U.S. Geological Survey open-file report, 48 p.
——— 1968, Palynological investigations in the Upper Cretaceous and Tertiary of the Mississippi Embayment region—V: U.S. Geological Survey open-file report, 37 p.
——— 1969, Palynological investigations in the Upper Cretaceous and Tertiary of the Mississippi Embayment region—VI: U.S. Geological Survey open-file report, 29 p.
——— 1970a, Two new pollen genera (Late Cretaceous and Paleocene) with possible affinity to the Illiciaceae: U.S. Geological Survey Professional Paper 643–F, 13 p.
——— 1970b, Palynology of the Cretaceous-Tertiary boundary in the northern Rocky Mountain and Mississippi embayment regions *in* Kosanke, R. M., and Cross, A. T., eds., Symposium on palynology of the Late Cretaceous and early Tertiary, San Francisco, Calif., Nov. 14, 1966: Geological Society of America Special Paper 127, p. 65–111.
——— 1973a, Stratigraphic distribution of significant Eocene palynomorphs of the Mississippi embayment: U.S. Geological Survey Professional Paper 743–B, 24 p.
——— 1973b, *Complexiopollis* pollen lineage in Mississippi embayment rocks: U.S. Geological Survey Professional Paper 743–C, 15 p.
——— 1975, Normapolles pollen from the Mississippi embayment: U.S. Geological Survey Professional Paper 865, 42 p.
Tschudy, R. H., and Pakiser, H. M., 1967, *Fustispollenites*, a new Late Cretaceous genus from Kentucky: U.S. Geological Survey Professional Paper 575–B, p. B54–B56.
Tschudy, R. H., and Van Loenen, S. D., 1970, Illustrations of plant microfossils from the Yazoo Clay (Jackson Group, upper Eocene) Mississippi: U.S. Geological Survey Professional Paper 643–E, 3 p.
U.S. Geological Survey, 1958, Surface water supply of the United States 1956: Part 3B. Cumberland and Tennessee River basins: U.S. Geological Survey Water-Supply Paper 1436, 262 p.
U.S. Waterways Experiment Station, Vicksburg, Miss., 1949, Geological investigations of gravel deposits in the Lower Mississippi Valley and adjacent uplands: Technical Memorandum no. 3–273, 58 p.
Wade, Bruce, 1917, The occurrence of the Tuscaloosa Formation as far north as Kentucky: Johns Hopkins University Circular, new series, no. 3, p. 102–106 [300–304].
Walker, F. H., 1953, Miscellaneous clay and shale analyses for the year 1951–52: Kentucky Geological Survey, ser. 9, Report of Investigations 6, 32 p.
Watts, W. A., 1970, The full-glacial vegetation of northwestern Georgia: Ecology, v. 51, no. 1, p. 17–33.
Willman, H. B., and Frye, J. C., 1970, Pleistocene stratigraphy of Illinois: Illinois State Geological Survey Bulletin 94, 204 p.
Wolfe, J. A., 1975, An interpretation of Tertiary climates in the Northern Hemisphere [abs.]: Geoscience and Man, v. 11, p. 160–161.