SURFACE ROCKS IN THE WESTERN LAKE CUMBERLAND AREA, CLINTON, RUSSELL, AND WAYNE COUNTIES, KENTUCKY

Richard Q. Lewis, Sr. and Paul Edwin Potter

Annual Field Conference of the Geological Society of Kentucky
1978

Published by
Kentucky Geological Survey
Donald C. Haney, Director and State Geologist
University of Kentucky, Lexington

Massive lime mudstone, containing scattered crinoid and bryozoan fragments and forming lens-like buildups and mounds, constitutes a distinctive and ubiquitous facies in Lower Carboniferous (Tournaisian-Visean) strata throughout the northern hemisphere. The rock of such buildups takes the name Waulsortian, from a village in the Dinant Basin, south of Namur in Belgium.

James Lee Wilson
***Carbonate Facies in Geologic History* (1975, p. 148)**

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FOREWORD

On behalf of the officers of the Geological Society of Kentucky, it is a pleasure and honor to welcome each one of you to the fall Field Conference.

Thanks to the efforts of our field trip leaders and the generous cooperation of the U.S. Army Corps of Engineers, we have a unique opportunity this year to see some Kentucky geology that is not ordinarily accessible. The field trip leaders and the Geological Society of Kentucky are especially grateful to Thomas Wilkerson, George Patterson, Joe Turner, Duane Dyer, Wallace Holcomb, and Oltis Hines of the U.S. Army Corps of Engineers, without whose enthusiasm and help this excursion would have been impossible.

Additionally, we must thank Dr. Donald C. Haney and his staff at the Kentucky Geological Survey for their help in the preparation and printing of the field trip guidebook.

Norman C. Hester, President
Geological Society of Kentucky
October, 1978

FIELD TRIP LEADERS

Dick Lewis has lived and worked in Kentucky for over 18 years. He spent his first 16 years in the State doing field mapping for the U.S. Geological Survey. During this time, he was author or co-author of 33 geologic quadrangle maps, many of which are in the area of the field trip. Dick is now head of the consulting firm, Geological Associates, Inc., in Somerset, Ky.

Paul Potter, professor of geology at the University of Cincinnati, has studied various aspects of the Fort Payne Formation since 1970. He has combined outcrop studies with subsurface investigations in order to unravel the depositional history of this unit. Paul's work on the Fort Payne-Warsaw interval stems from a keen interest in modes of clastic and carbonate sedimentation. He is presently working on a study of the New Albany-Chattanooga-Ohio Shale.

DEDICATION

The Geological Society of Kentucky is especially proud to dedicate this guidebook for its 1978 Annual Field Conference to Dr. Wallace W. Hagan, recently retired State Geologist and Director of the Kentucky Geological Survey.

Dr. Wallace W. Hagan

As research goes, it is not often that a scientist can bring a long-term program to a conclusion at the same time his career is terminated by retirement. But somehow Dr. Wallace Hagan, who has been deeply involved in the geologic mapping of the entire State of Kentucky for nearly the past 20 years, has managed to do this with the help of his staff. The culmination of this unprecedented large-scale cooperative federal/

state venture—begun in 1960 by teams from the U. S. and Kentucky Geological Surveys—was cited by the Director of the U. S. Geological Survey as "clearly a milestone in the history of American geology." Dr. Hagan, Director and State Geologist of the Kentucky Geological Survey, has supervised the Kentucky part of the cooperative program since its inception.

Dr. Hagan, "Wally" as he is known to his friends, is a very unassuming, mild mannered person who has become an "adopted" son of Kentucky. A native of Griggsville, Ill., he was graduated from Urbana High School in 1930 and the University of Illinois in 1935. He received his master's degree from Indiana University the following year.

After serving as a consulting geologist in Greenville, Ky., and Urbana, Ill., he returned to the University of Illinois where he was awarded the Ph.D. in 1942. Shortly after graduation, while serving as a geologist in the Kentucky-Indiana-Illinois area, he found or contributed to the location of 10 new oil fields in western Kentucky and the extension of six others in the area.

He was employed from 1945-48 by Sohio Petroleum Co. in Owensboro where he was involved in exploratory geological work in Kentucky and southern Illinois, and from 1948-52 served as chief geologist in Kentucky for Felmont Oil Corp. For 6 years he was a consulting geologist in Owensboro preceding his KGS appointment in 1958.

Professionally, Hagan has served as president of the Geological Society of Kentucky, president of the Association of American State Geologists, and on numerous committees of various professional organizations, as well as on the board of the Kentucky Geological Survey. He has authored a number of articles for technical journals and publications, some of these coming from speeches he has given before professional organizations.

A member of Phi Beta Kappa, Phi Kappa Phi, and Sigma Xi, honorary organizations, Dr. Hagan has earned a listing in a number of national publications, including *Who's Who in America, American Men of Science* , and *Who's Who in the South and Southwest.* He was named Kentucky Distinguished Scientist of the Year in 1977 by the Kentucky Academy of Sciences. He and his wife, Mary Elizabeth, who reside at 317 Jesselin Drive, Lexington, are the parents of two daughters.

NOTE: This biographical sketch was excerpted from the 1977 Annual Report of the University of Kentucky Research Foundation.

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SURFACE ROCKS IN THE WESTERN LAKE CUMBERLAND AREA, CLINTON, RUSSELL, AND WAYNE COUNTIES, KENTUCKY

Richard Q. Lewis, Sr.[1] and Paul Edwin Potter[2]

ABSTRACT

Rocky shorelines and mature dissection provide excellent exposure of the Mississippian, Devonian, and Ordovician rocks in the western part of the Lake Cumberland area. Here many diverse, interesting, and perplexing lithologies can be observed, fossils can be collected, and a much better understanding of subsurface facies relations can be obtained.

Key Ideas: Platform and slope carbonates, Waulsortian banks, a tidal flat deposit, and black shale.

INTRODUCTION

This guidebook considers the surface rocks of Mississippian, Devonian, and Ordovician age in a small portion of the Cumberland Saddle area in south-central Kentucky (Fig. 1). The Cumberland Saddle is a structural sag between the Jessamine and Nashville Domes in which Middle and Lower Mississippian and Upper Devonian rocks are preserved across the Cincinnati Arch. The Cumberland River closely follows this sag, and mature dissection along its valley provides excellent outcrops.

Surface rocks in parts of Clinton, Russell, and Wayne Counties, Kentucky, along the western end of Lake Cumberland and southward toward Tennessee are examined (Fig. 2). Of prime interest are the Middle and Lower Mississippian rocks (Fig. 3), especially the Fort Payne Formation, which is studied chiefly on a 1-day trip by barge along the shores of Lake Cumberland. Ashore, the Warsaw Formation and the St. Louis and Ste. Genevieve Limestones are seen, as are the Chattanooga Shale and the Ordovician Cumberland Formation and Leipers Limestone. Some of these

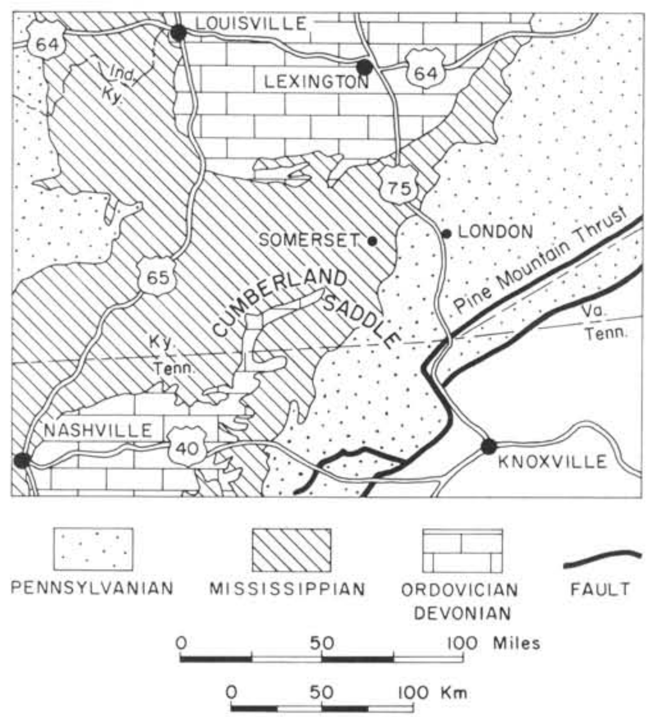

Figure 1. Regional geologic setting of the Cumberland Saddle and field trip area. Routes of Interstate Highways in the area are shown.

[1]Geological Associates, Inc., Somerset, Kentucky.
[2]H. N. Fisk Laboratory of Sedimentology, University of Cincinnati, Cincinnati, Ohio.

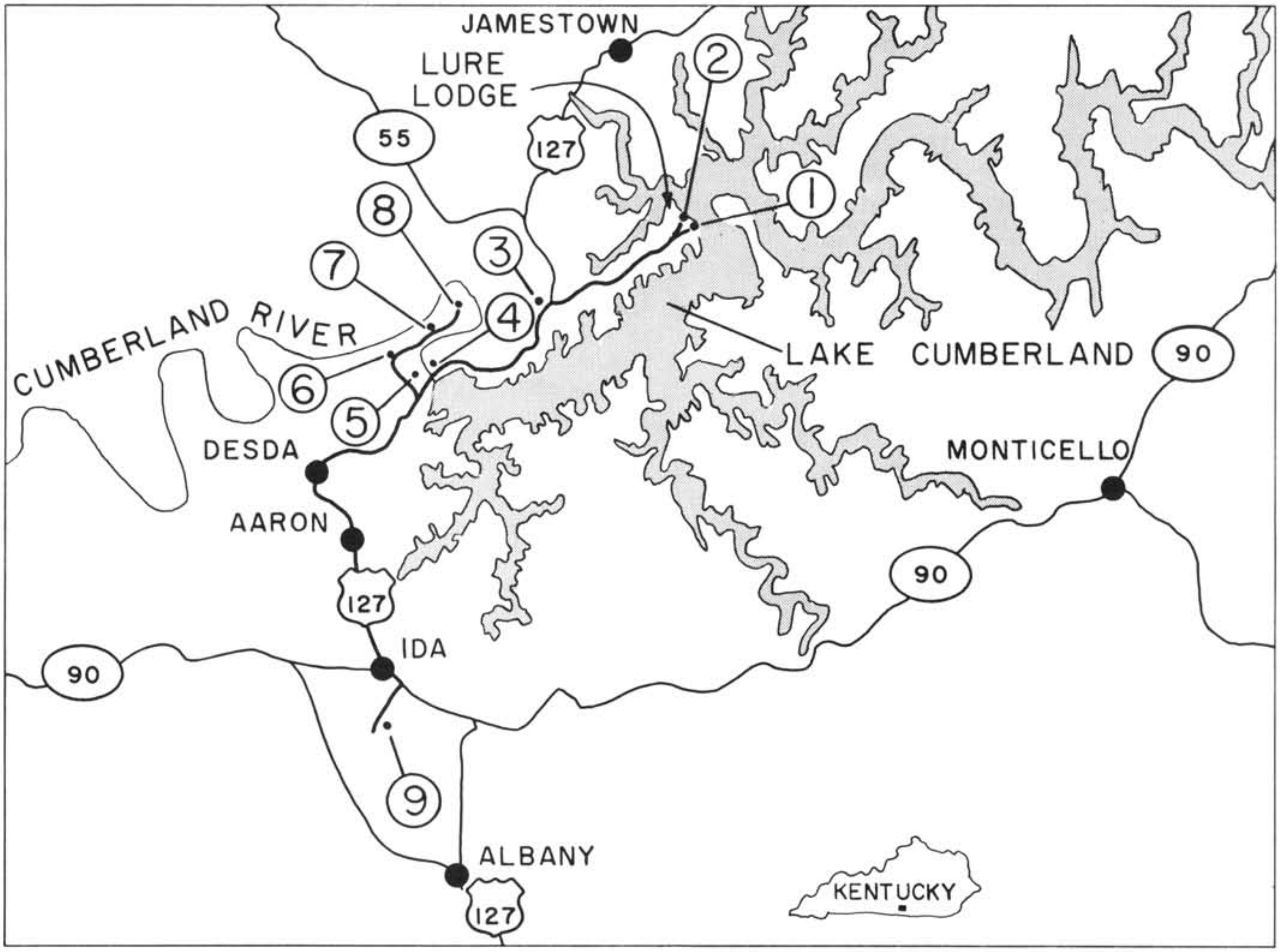

Figure 2. Map of area showing field trip route and locations of road stops.

units are significant petroleum producers in and near the Cumberland Saddle area. The Chattanooga black shale is of interest for its present gas production in eastern Kentucky and its potential production in western Kentucky in the Illinois Basin. Many interesting sedimentological problems, chiefly in carbonate sedimentation and diagenesis, can be studied and solved in this area, and observing repair work on the foundation of Wolf Creek Dam provides an unusual opportunity to learn about the complexities of engineering geology.

The Cumberland Saddle area is also very rich in history, and we have included a brief summary to give you a better appreciation for it as you float along the shores of Lake Cumberland or drive over the rugged topography of the area.

Carbonate rocks predominate at the surface and provide outstanding opportunities for sedimentologic study, although comparatively little has been done. Following are some references to recent summaries of carbonate sedimentology. An excellent general text is Wilson's (1975) "Carbonate Facies in Geologic History," and the more recent "Essai de Caractérisation Sédimentologique des Dépôts Carbonatés" by ELF-Aquitaine (1975 and 1977) also has much of value and is very rich in illustrations, all of which have English subtitles. A short but useful summary is provided by Carr and Rooney (1975). Finally, the recently published "Cretaceous Carbonates of Texas and Mexico" (Bebout and Loucks, 1977) is a model of how much more information about the origin of petroleum in the carbonates in south-central Kentucky could be obtained by careful sedimentologic and petrographic study.

We are indebted to many for their help. The U. S. Army Corps of Engineers stands foremost in

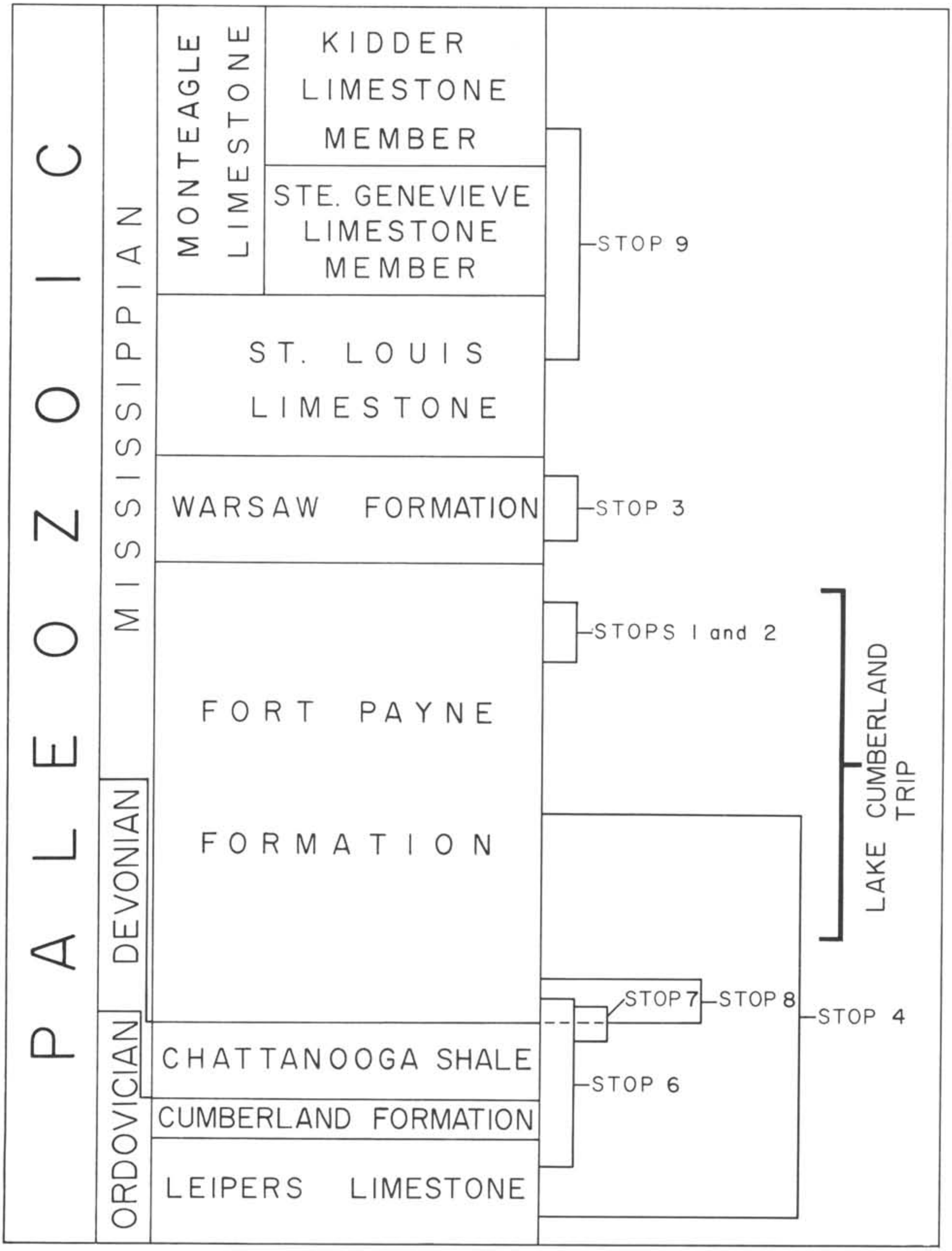

Figure 3. Stratigraphic units examined on the field trips. Numbers refer to stops in the road log.

this list because of its generous contribution of a barge for the boat trip and its contribution to the discussion of the engineering geology of Wolf Creek Dam. James Williams and Ruth Scott of the Geology Department, University of Cincinnati, drafted the illustrations, and Jean Carrol and Wanda Osborne typed the several drafts of the manuscript. Louis Ponsetto of the Kentucky Geological Survey and A. N. Statler of the Tennessee Division of Geology provided data on oil production from the Fort Payne. M. Delmas, Société Nationale ELF-Aquitaine, Pau, France, contributed petrographic information. Dr. Roy C. Kepferle, U. S. Geological Survey, Cincinnati, Ohio, reviewed the manuscript. Dr. John L. Wray, Marathon Oil Co., Littleton, Colorado, kindly examined thin sections of the Fort Payne for calcareous algae. Basil Doerhoeffer III, Louisville Gas and Electric Co., Louisville, Kentucky, helped with the initial planning of the trip.

Finally, both the Geological Society of Kentucky and the writers thank the Kentucky Geological Survey for its generous help with the guidebook and its logistic support of the field trip.

A GLIMPSE OF CUMBERLAND SADDLE HISTORY

Probably the first white man to visit the area of Lake Cumberland was Martin Chartier. While in the company of a group of Shawnee Indians, he spent most of 6 years, from about 1684 to 1690, in the wilderness. Most historians agree that the group was probably along the Cumberland River between the mouth of the Obey River and the Big South Fork. This information is from a hearing and trial testimony for desertion conducted in Maryland (Proceedings of the Council of Maryland, 1687-1688, Baltimore, Md. 1890).

The Cumberland River was named about 1750 by Dr. Thomas Walker, who came over the mountains from Virginia. He named the river for the Duke of Cumberland, who was an uncle of King George of England. Dr. Walker established camps near the present sites of Flat Lick and Barbourville in Knox County, Kentucky (Journal of Dr. Thomas Walker, April 28, 1850).

The earliest record of men going down the Cumberland River by boat was that of a party of five men from South Carolina led by Isaac Lindsay. They "put in" the river somewhere near the mouth of the Rockcastle River, which was named by Lindsay, and floated down to middle Tennessee in 1769. This information on the trip is from a report by John Haywood (1823). Another early account of a trip was made by James Smith (1799).

Prior to 1833 much of the produce from the upper Cumberland River was shipped to market by floating it down the river to Nashville, or beyond to other markets, on homemade flat boats, rafts, and small barges. A small steamboat, the *Jefferson*, captained by E. S. Budge made the trip up the Cumberland River to Point Isabel, now Burnside, Pulaski County, Kentucky, in April of 1833. Both Burnside in Pulaski County and Creelsboro, below Wolf Creek Dam in Russell County, were, before the advent of a good road system in south-central Kentucky, major river ports along the middle part of the Cumberland River (Fig. 4).

An excellent source of information about the Cumberland River valley is provided by Jillson's (1960), "A Bibliography of the Cumberland River Valley," which also includes early studies of its geology and mineral resources. Jillson's bibliography contains over 40 pages of annotated references.

Two of the earliest oil wells in North America were drilled in the Cumberland Saddle area. In 1818 oil was discovered on the South Fork of the Cumberland in McCreary County by the No. 1 Martin Beatty well, and in 1829 the Stockton well found oil north of Beattyville in Cumberland County. Owen and Norwood (1847) published one of the earliest geological accounts of the region.

REGIONAL GEOLOGY AND STRATIGRAPHIC BACKGROUND

The Paleozoic rocks of the Cumberland Saddle area are about 6000 to 7000 feet (1800 to 2100 m) thick. Numerous shallow holes have been drilled in the area, but there are only a few deep ones. In the western Lake Cumberland area surface exposures of this section, from the top of the Ste. Genevieve Limestone to the base of the Liepers Formation, total about 500 feet (150 m). The exposed section includes a major regional uncon-

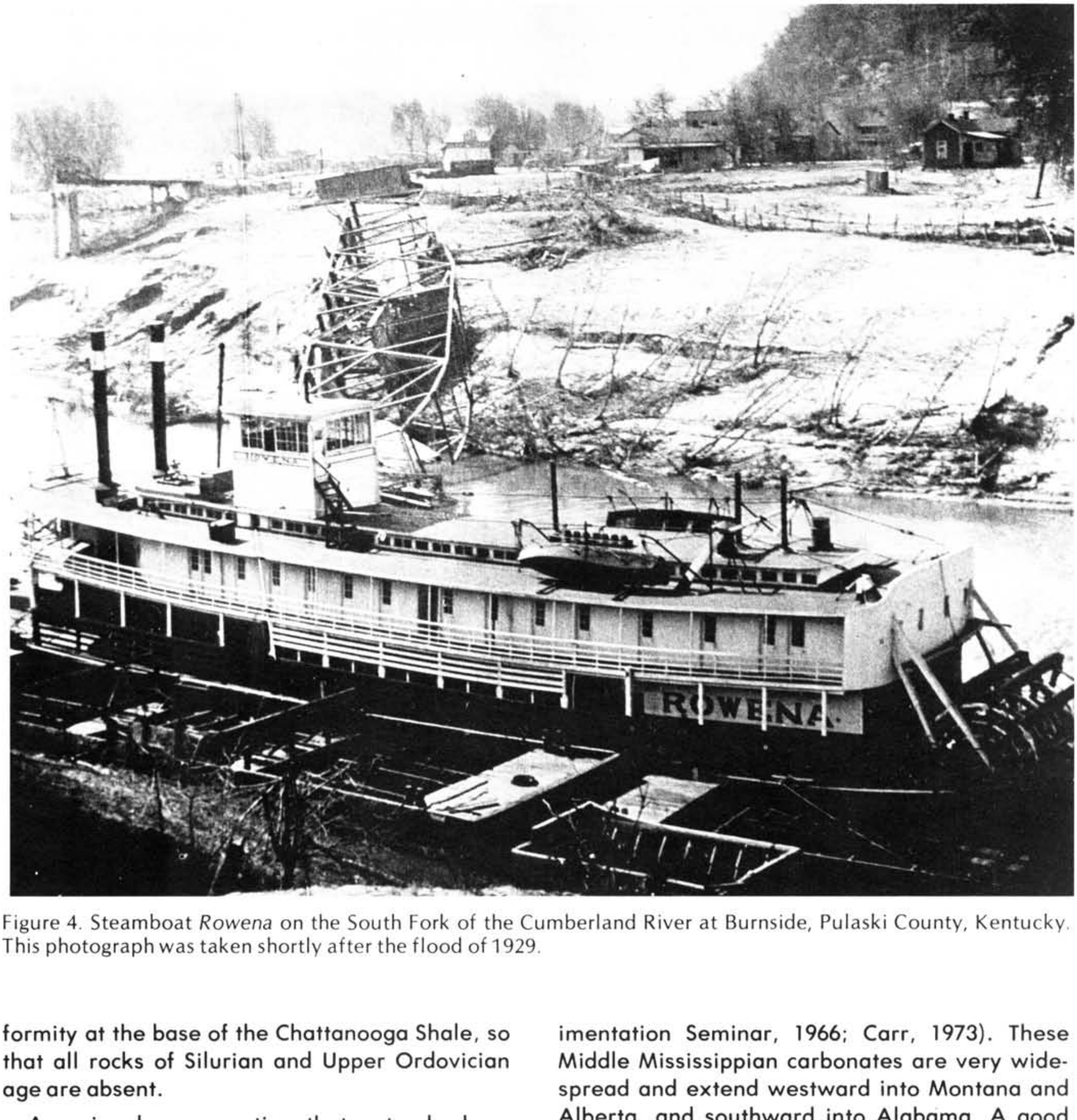

Figure 4. Steamboat *Rowena* on the South Fork of the Cumberland River at Burnside, Pulaski County, Kentucky. This photograph was taken shortly after the flood of 1929.

formity at the base of the Chattanooga Shale, so that all rocks of Silurian and Upper Ordovician age are absent.

A regional cross section that extends down depositional dip from Mount Vernon in Rockcastle County to Albany in Clinton County shows the major units to be seen above the Chattanooga Shale; their facies relations and paleocurrent data are also shown (Fig. 5). The paleoslope of this carbonate platform in the Cumberland Saddle had a southwesterly dip, as is true for most of the Illinois Basin and much of the central and northern parts of the Appalachian Basin (Sedimentation Seminar, 1966; Carr, 1973). These Middle Mississippian carbonates are very widespread and extend westward into Montana and Alberta, and southward into Alabama. A good regional overview for much of the Mississippian of the eastern United States is given by Pryor and Sable (1974); two earlier descriptions, both classics, are those by Butts (1922) and Stockdale (1939).

Each of the formations that we will see is described below, with emphasis on lithology, resource significance, and selected stratigraphic and sedimentological problems.

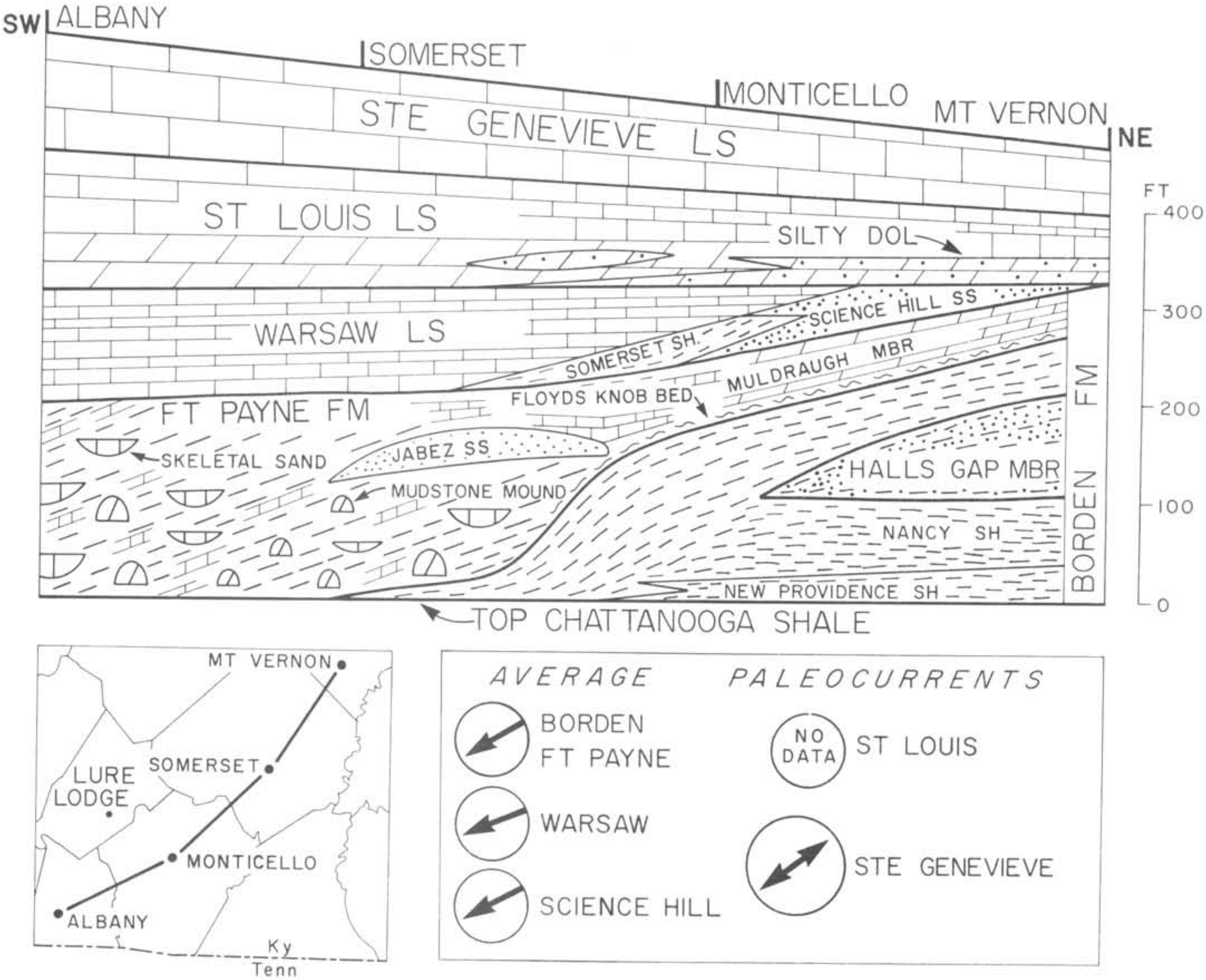

Figure 5. Diagrammatic cross section extending down depositional dip from Mount Vernon, Ky., to Albany, Ky. showing Lower and Middle Mississippian stratigraphic units and their major facies. Datum is top of the Chattanooga Shale. Average paleocurrent directions are indicated by arrows.

Ste. Genevieve Limestone

The Ste. Genevieve Limestone crops out at the higher elevations in the eastern part of south-central Kentucky. It ranges in thickness from about 90 feet (27 m) in the Albany area, Clinton County, to about 50 feet (15 m) in the vicinity of Somerset and Mount Vernon, Pulaski and Rockcastle Counties.

The Ste. Genevieve is composed almost entirely of limestone, interbedded with a few 2- to 4-inch (5- to 10-cm) thick clay shale beds. The limestone is commonly medium to bluish gray. Most of the Ste. Genevieve consists of skeletal and oolitic packstones and grainstones, with some minor mudstone. Many of these beds are exceptionally pure and have more than 99 percent $CaCO_3$ (Dever and McGrain, 1969). Many of the packstones and grainstones have planar cross-beds, some of which exceed 12 feet (4 m) in thickness. The bipolar orientation of this cross-bedding is very strong evidence for its origin as migrating sand waves of skeletal and oolitic sand on a tidally influenced shallow shelf (Carr, 1973).

Megafossils are generally sparse, but a wide variety of species are represented, including the coral, *Siphonodendron* aff. *S. genevievensis* Easton. The crinoid, *Platycrinites* sp., is rare to common.

The contact with the underlying St. Louis Limestone is a sharp lithologic boundary. A thick-bedded replacement chert (Lost River chert of Elrod, 1899) is commonly present within the lower few feet of the Ste. Genevieve, and in the Pulaski County area the contact is marked by an angular chert breccia. The contact with the overlying Kidder Limestone is marked by one or more breccia zones that range from a few inches to several feet in thickness (the Bryantsville breccia of Patton, 1949).

St. Louis Limestone

The St. Louis Limestone has a nearly continuous outcrop across south-central Kentucky and generally thins progressively from west to east. It is about 140 feet (43 m) thick in the western part of the area near Albany in Clinton County, and less than 100 feet (30 m) thick in the vicinity of Somerset in Pulaski County. Commonly, the St. Louis contains two rather distinctive lithologies. The greater part of the formation is composed of thin- to medium-bedded, even-bedded, calcareous mudstone. Carbonate beds are commonly separated by bluish-green to olive-green, thin, clay shales. Carbonates of this type commonly make up two-thirds or more of the formation. The calcareous mudstones, particularly a zone in the uppermost 20 to 30 feet (6 to 9 m), contain abundant gray to black chert nodules. A lesser part of the formation is composed of medium-bedded, olive-gray, somewhat silty dolomite. Dolomite is restricted to the lower part of the formation, commonly the lower few feet. Megafossils are sparse to common; the diagnostic corals, *Lithostrotionella proliferum* and *Lithostrotionella canadensis*, are commonly abundant in the upper few feet of the unit.

Deposition of the St. Louis appears to have been followed by a brief hiatus. In the eastern part of the Cumberland Saddle area the basal bed of the overlying Ste. Genevieve Limestone commonly contains considerable angular chert and carbonate fragments from the underlying St. Louis.

Warsaw Formation

The Warsaw Formation (Salem and Harrodsburg of some authors) crops out across all of south-central Kentucky. The formation is more than 100 feet (30 m) thick in the western part of the area and thins progessively eastward.

The Warsaw contains several lithologies and recognizable lithologic subunits. Butts (1922) named and described several such units including the Garrett Mill Sandstone Member and the Somerset Shale Member. Lewis and Taylor (1974) more recently named and described another distinctive mappable member, the Science Hill Sandstone Member.

Medium- to small-scale crossbedding, commonly bipolar, is typical of the Warsaw and should be more widely mapped. A facies study of the Warsaw Formation in the Cumberland Saddle and southward into Tennessee would be most rewarding.

Fort Payne Formation

Three appropriate adjectives for the Fort Payne Formation are *vast*, *heterogeneous*, and *puzzling*.

The Fort Payne is one of the more widespread formations in the eastern United States. It extends from Alabama and Mississippi through much of Tennessee and Kentucky into southern Illinois and southwestern Indiana. Moreover, rocks lithologically similar to the Fort Payne, but with different names, extend far westward into Missouri, Arkansas, and Oklahoma (Troell, 1962), New Mexico (Pray, 1961), Montana (Gutschick and others, 1976; Rose, 1977), and even Alberta (MacQueen and Bamber, 1967 and 1968).

In Kentucky the Fort Payne thins northeastward, and its northeastern boundary is represented by a wedge of siltstone and shale, the Borden Formation. The sloping transitional contact between the two units occurs regularly in a zone about 10 miles (16 km) wide and has a uniform strike of about N. 45° W. (Fig. 6). This sharp, sloping boundary between the Fort Payne and Borden has been informally called the "Borden Front" (Peterson and Kepferle, 1970, Fig. 4; Sedimentation Seminar, 1972, p. 2). In the area

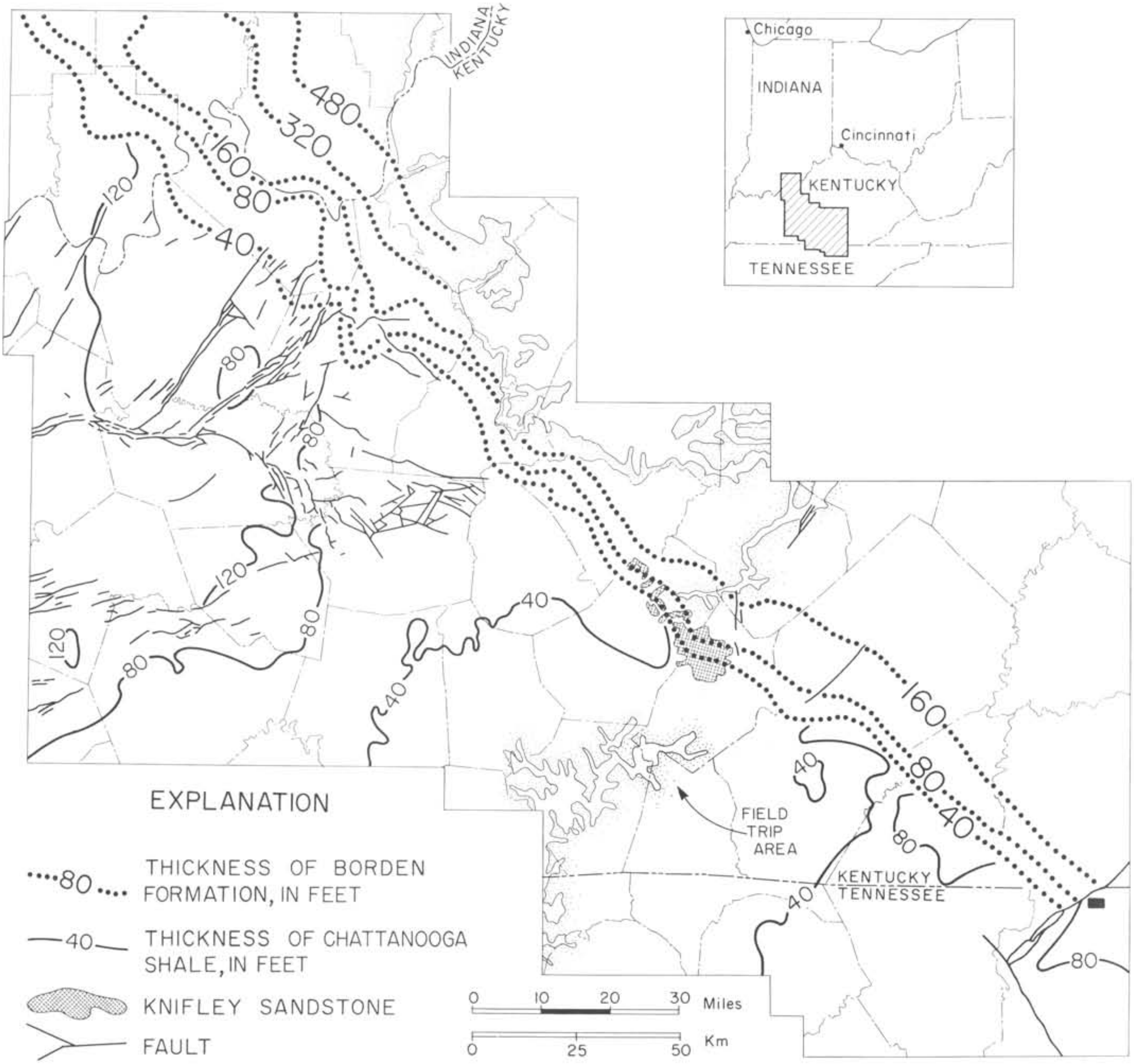

Figure 6. Thickness of Borden Formation and Chattanooga Shale (not shown under Borden Formation) and simplified fault pattern. Forty-foot isopach of Chattanooga Shale parallels axis of Cincinnati Arch.

of the Cumberland Saddle, the Fort Payne and the Borden have comparable thicknesses—commonly between 225 and 300 feet (70 and 90 m).

The lithologic heterogeneity of the Fort Payne is very evident even to the most casual observer. The Fort Payne contains dolomitic and calcareous, silty, medium- to light-gray, bioturbated shales with abundant, scattered quartz geodes; argillaceous, medium- to dark-gray, typically thin-bedded, bioturbated dolomites; chert; and at least two types of carbonate banks, both of which are commonly closely associated with a greenish-gray, fossil-bearing shale. These banks are composed chiefly of crinoidal and bryozoan debris and typically are in part dolomitized and have some minor chert. Some of them may also be locally silicified.

The complex facies relationships of the Fort Payne, especially the abrupt changes, add another dimension to its heterogeneity. Although it is fairly easy to recognize the different facies, *it is not easy to explain why each is where it is, and its relationships to its neighbors.* Slope, or clinoform, desposition in the Borden and Fort Payne has been recognized as a major factor in the localization of facies and in part helps explain the lithologic heterogeneity of the Fort Payne. Master bedding planes, gently dipping to the south, southwest, and west, as well as carbonate skeletal banks with southwesterly primary dip and crossbedding orientation, are all part of the evidence for deposition on a southwestward-dipping slope along the Borden Front and to an unknown distance southeast of it (Sedimentation Seminar, 1972, Fig. 9).

The Fort Payne is a challenging, puzzling formation to understand not only because of its forementioned lithologic variety and complex facies relationships but also because the origin of several of its lithologies, especially the carbonate banks, is obscure. Moreover, the formation as a whole appears to lack a modern analog. However, the Fort Payne does have ancient equivalents both in North America and western Europe, equivalents which are perhaps best described as the "Lower Carboniferous Waulsortian Facies" (Wilson, 1975, p. 148-168). Carbonate mud mounds composed chiefly of mudstone and/or wackestone, crinoidal-bryozoan skeletal limestones, an intermound rock of dark, argillaceous cherty limestone (or, as in the Cumberland Saddle area, dark dolomitic, siliceous shale), minor black shales, the nearly universal presence of dolomite and chert, and deposition along a shelf break, one with only minor coarse clastics, are essential characteristics, almost all of which can be seen in the Fort Payne of the Cumberland Saddle area.

Regional subsurface mapping has contributed to a better understanding of the Fort Payne in the Cumberland Saddle area and indicates five major facies of this formation in central Kentucky and nearby southern Indiana and Tennessee (Fig. 7).

In outcrop along the Cincinnati Arch in south-central Kentucky and in central Tennessee around the Nashville Dome there are many scattered carbonate banks, which, near the Borden Front, generally trend subparallel to it. These banks have been mapped separately on many of the 1:24,000-scale geologic quadrangle maps of the region, and their areal distribution, in part, has been compiled by Thaden and others (1961). At least two types of banks are present—mudstone mounds and a more abundant bedded, skeletal, well-washed and crossbedded limestone, identical with the unit called Cane Valley Limestone Member of the Fort Payne (Sedimentation Seminar, 1972, p. 15; Kepferle and Lewis, 1974). Both types are interbedded principally with dolomitic, silty medium- to dark-gray shale, which may contain thin dolomitic beds. This bank facies is well displayed along Lake Cumberland near Lure Lodge and along the Cumberland River southwestward into Tennessee.

West and northwest of the carbonate-bank facies, and only seen in subsurface, is a widespread, very uniform fine-grained, dark-gray, argillaceous dolomite which contains scattered grains of fine quartz and glauconite and is informally called the "basin dolomite." This facies underlies much of the Western Kentucky coal basin.

Between the basin dolomite and the main Borden Front is another complex of carbonate banks that forms an elongate northwest-southeast trending facies which mantles the Borden Front and in part extends northeastward on top of the front, where it is called the Muldraugh Member of the Borden Formation. Excluding its Muldraugh equivalents, this facies occurs only in the subsurface and is notable for its coarse to very coarse crinoidal-bryozoan packstones and grainstones, many of which have good porosity and minor amounts of anhydrite cement and chert. The thickest and best developed of these banks are pure white grainstones, which are very distinctive in well cuttings. Maximum thickness of these carbonate banks reaches almost 100 feet (30 m).

Located on the crest of the Cincinnati Arch is the Knifley Sandstone Member of the Fort Payne (Sedimentation Seminar, 1972; Kepferle and Lewis, 1974)—a fine-grained, bioturbated sandstone which occurs near the top of the formation. The Knifley Sandstone has a maximum thickness of 200 feet (60 m) and is very porous and weathered in outcrop, probably because its carbonate cement has been removed by weathering. This

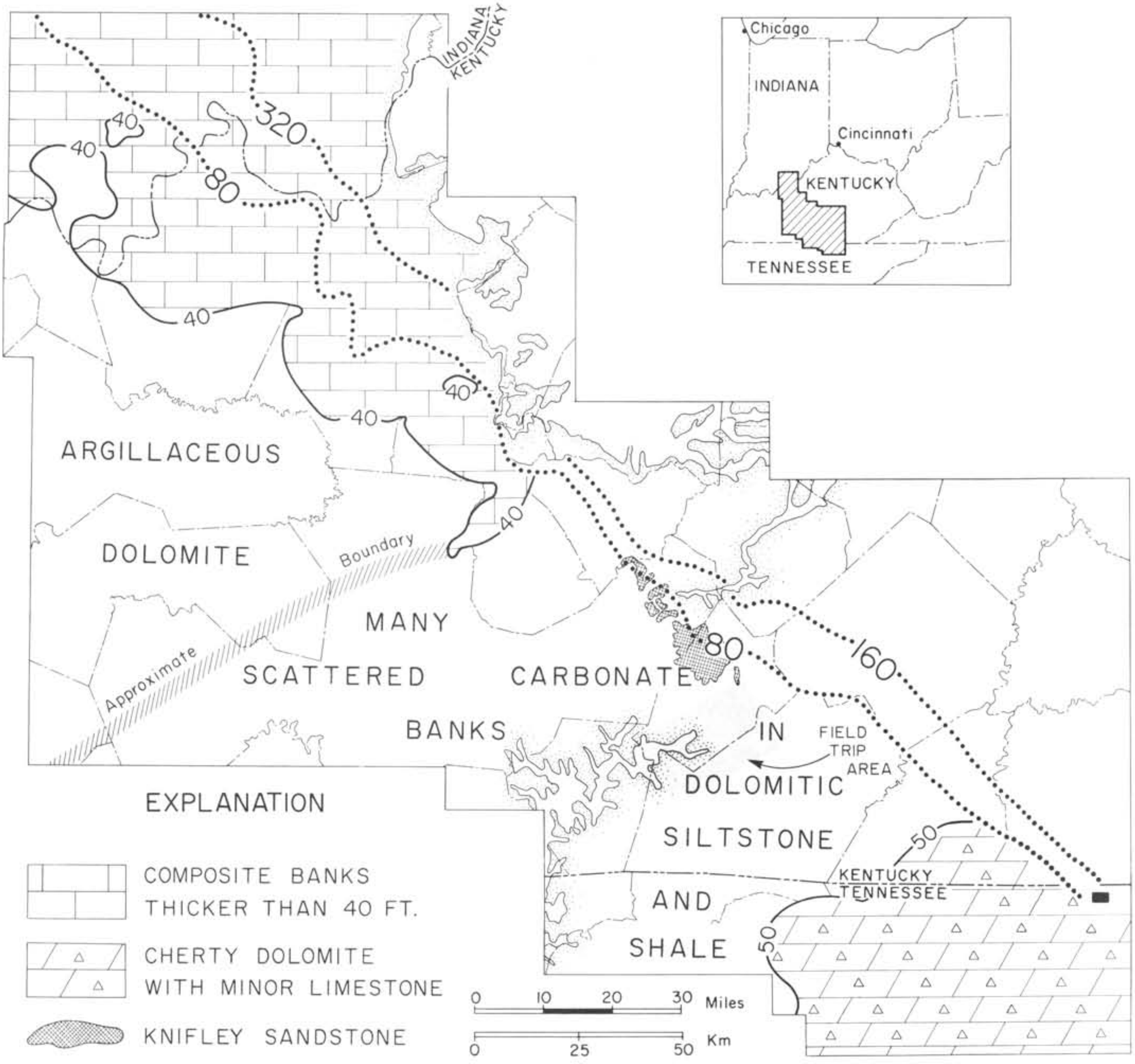

Figure 7. Schematic facies map of Fort Payne Formation and trend of the Borden Front (dotted lines).

sandstone, which also has a northwest-southeast trend, appears to have been formed as a submarine shoal, at or just below wave base. Other somewhat comparable sandstones occur along the Borden Front; one is exposed along Lake Cumberland at the mouth of Harmon Creek in Wayne County, and another sandstone is present near Jellico, Tennessee (Englund, 1968, p. 9). This sandstone facies along the Borden Front is volumetrically a very small part of the Fort Payne, but it is a potential minor petroleum reservoir and appears to have been formed by small quantities of terrigenous sand derived from the northeast that crossed the carbonate flats of the Muldraugh.

A very different facies of the Fort Payne occurs in the subsurface to the east and southeast of the Cumberland Saddle, chiefly in Scott and Morgan Counties, Tennessee, and in parts of adjacent McCreary and Whitley Counties, Kentucky. This facies is mostly a cherty dolomite and in places is overlain by generally northeast-southwest oriented limestones which are of two types—mudstone mounds and skeletal, well-washed packstones, whose chief constituents are bryozoans. The northeast boundary of this facies is also the Borden Front. The transition from the cherty dolomite facies to that found in outcrop in the Cumberland Saddle is everywhere very sharp. This facies has been described by Statler (1971).

The previously described facies are best understood when viewed from the broader perspective of the Illinois and Appalachian Basins (Fig. 8), wherein the Fort Payne is the silty, dolomitic, muddy, bioturbated fill deposited in front of, and mostly after, the deposits of the Borden, a fill that contains scattered mud mounds and well-washed skeletal banks of greatly varying size. Such carbonate bodies, which are its oil producers, are best developed in Kentucky along the Borden Front or southwest of it along the axis of the Cincinnati Arch, and in Scott and Morgan Counties, Tennessee, where they underlie part of the Cumberland Plateau. In sum, the Fort Payne of the Cumberland Saddle area is a shelf-margin fill, one that eventually overlapped the topography that existed at the end of the Borden deposition. Paleocurrent mapping and sedimentological study (Pryor and Sable, 1974, Fig. 17; Kepferle, 1977, Fig. 39) show the Borden to have been derived from the northeast and east (Fig. 9).

The carbonate banks of the Fort Payne in the Cumberland Saddle area are one of its most fas-

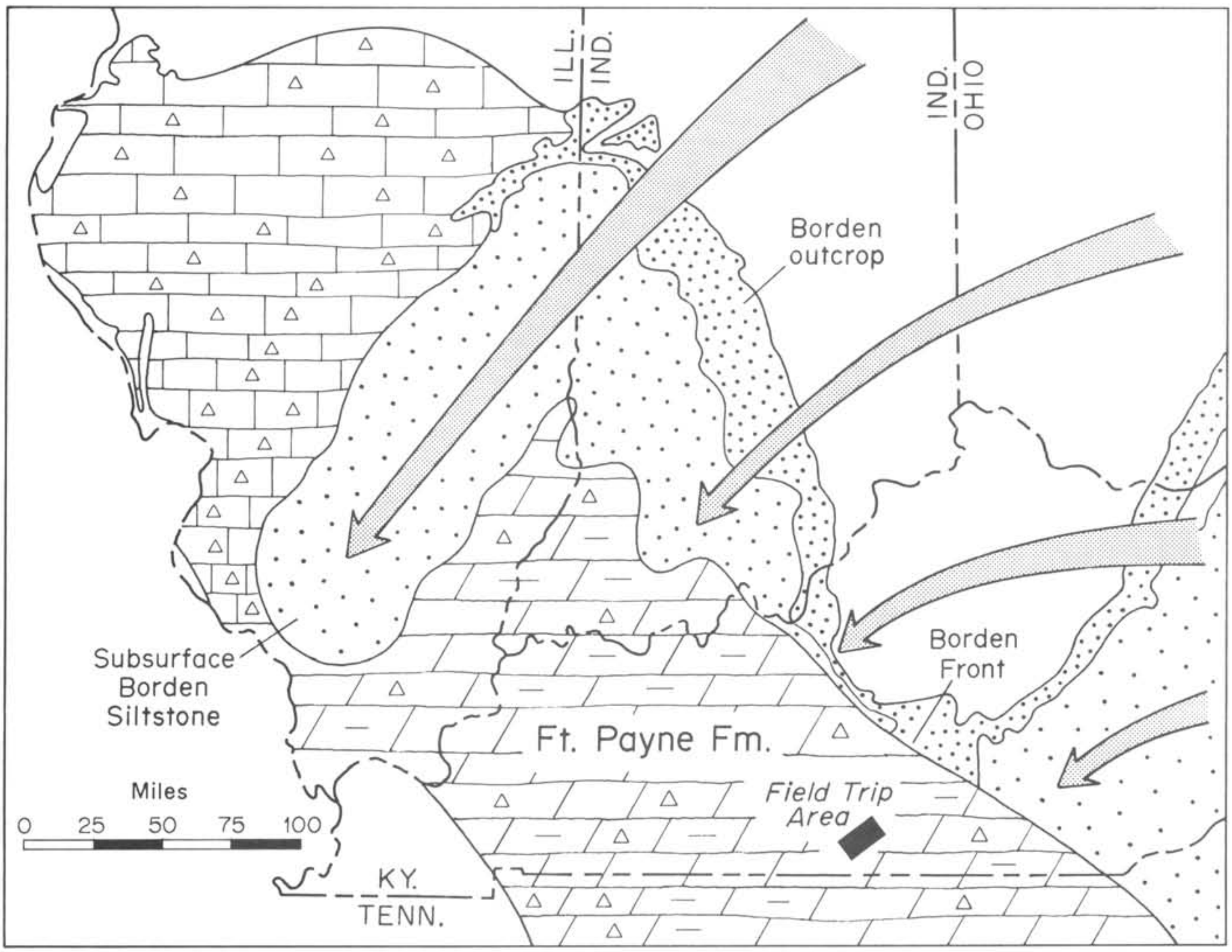

Figure 8. Borden-Fort Payne facies in the Illinois and Appalachian Basins, showing generalized paleocurrent directions. (Adapted from various sources, especially Lineback, 1969, and Kepferle, 1977.)

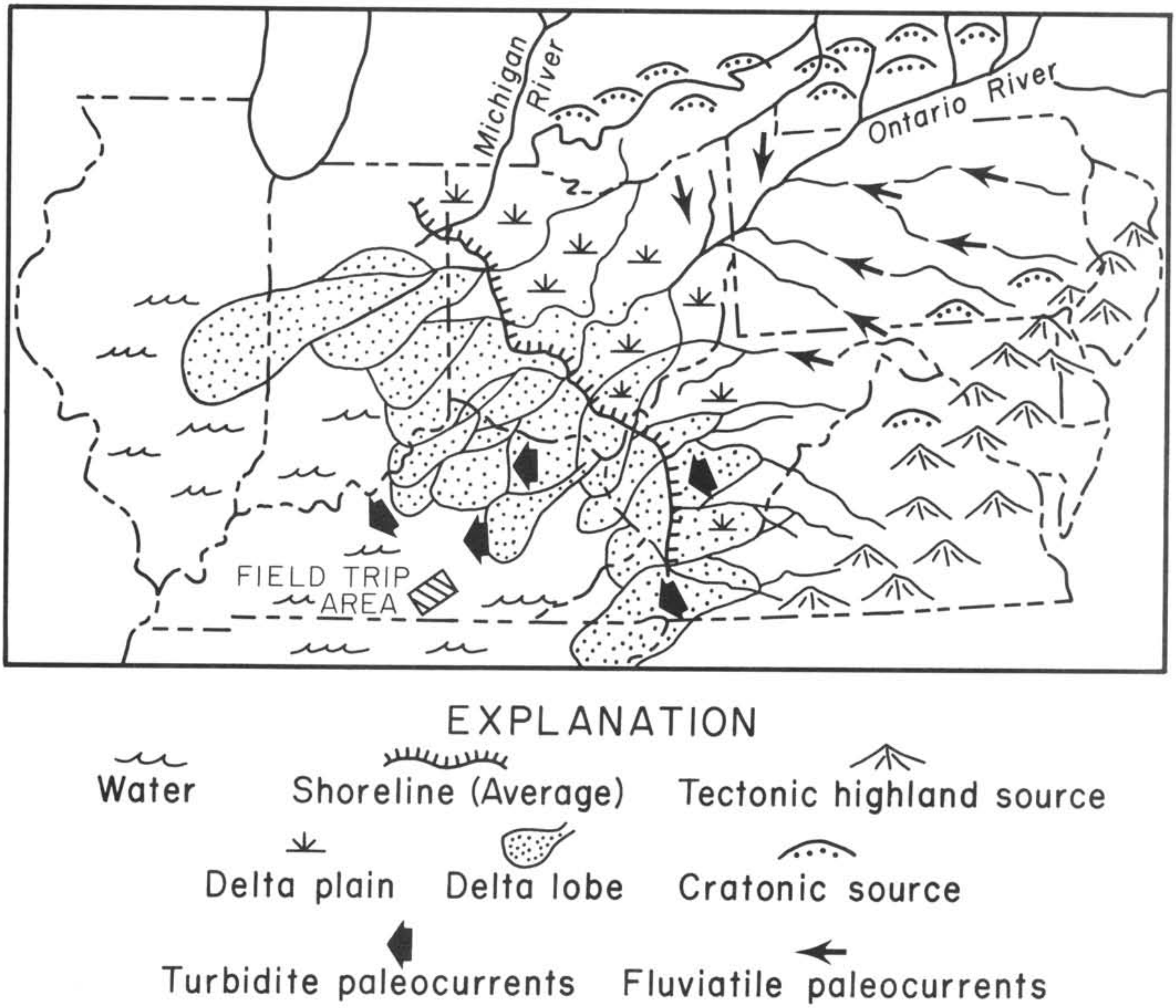

Figure 9. Paleogeographic map of eastern interior during deposition of Lower Mississippian rocks. (Redrawn from Kepferle, 1977, Fig. 43).

cinating features, and they deserve far more attention by sedimentologists than they have received. They are of at least two types (Table 1); selected articles pertinent to the study of such Waulsortian banks are annotated in Table 2.

Skeletal well-washed carbonate sands are three to eight times more abundant than the massive mudstone mounds in the Cumberland Saddle. These skeletal sands are also thicker and more porous; they have well-defined bedding and crossbedding and consist chiefly of packstone and grainstone rather than wackestone and grainstone, which are characteristic of the mudstone mounds. In addition, the mudstone mounds occur at the sides of green shale mounds or may entirely cover a shale core. Even where a shale core is lacking, greenish-gray shale is almost always nearby. A mound-like form—complete or partial—is their prime characteristic. The form of the skeletal, well-bedded and well-washed carbonate sands is, on the other hand, much harder to establish. On a small scale, they are channel fills that can be seen in single outcrops, but they also form large composite banks many thousands of feet long that perhaps accumulated on a slope break. With more study, they

TABLE 1.—CHARACTERISTICS OF CARBONATE BANKS IN FORT PAYNE FORMATION.

	Mud Mounds	*Skeletal Sands*
Geometry	Irregular mounds and pods possible, with a tendency for roughly circular to subelongate map patterns	Elongate fills both parallel and perpendicular to paleoslope. Initial dips of thin beds or tongues of skeletal limestone may extend thousands of feet into surrounding shales
Size	Some more than 1500 feet (450 m) long and as thick as 40 feet (12 m)	Some many thousands of feet long and as thick as 200 feet (60 m)
Composition	Dominantly mudstone, in part dolomitized, with minor zones of coarse crinoidal debris and some chert. Minor gypsum cement in subsurface	Dominantly medium- to coarse-grained, well-sorted, crinoid-bryozoan packstones and grainstones as well as some shale and dolomite interbeds. Minor chert and dolomite; some gypsum cement in subsurface
Bedding	Poorly to crudely bedded with a tendency to irregular nodular bedding and some mudcracks	Very well bedded, typically as thin, 2- to 10-inch (5- to 25-cm) crossbeds with weakly inclined but well-oriented forests
Occurrence	From base to at least middle of Fort Payne. In south-central Kentucky occur as part of a broad, linear, northwest-southeast belt parallel to Borden Front and along axis of Cincinnati Arch. Locally at sides and on top of "shale highs"	From near base to top of Fort Payne. In south-central Kentucky tend to form broad northwest-southeast linear belts parallel to Borden Front and along Cincinnati Arch. Locally as channel fills and accumulations parallel to slope breaks where they are a kind of "washover" sand?
Special Associated Lithologies	Greenish-gray, fossiliferous shales and skeletal crinoid-bryozoan sands	May be close to mud mounds and commonly proximal to greenish-gray shale
Reservoir Characteristics	Chiefly coarse vugular and fracture porosity (some due to stromatactoid structure)	Intergranular porosity with some minor interparticulate porosity

could probably be assigned to one of the major groups recognized in seismic stratigraphy (Fig. 10). Initial dips range from 4 degrees to 7 degrees, and low-angle crossbedding is common. Some of the skeletal sand that formed these banks even traveled as isolated sand waves, as can be seen on Wolf Creek where one example is about 30 feet (9 m) long and 5 feet (1.5 m) high. Greenish-gray fossiliferous shale is also commonly found near the skeletal sands.

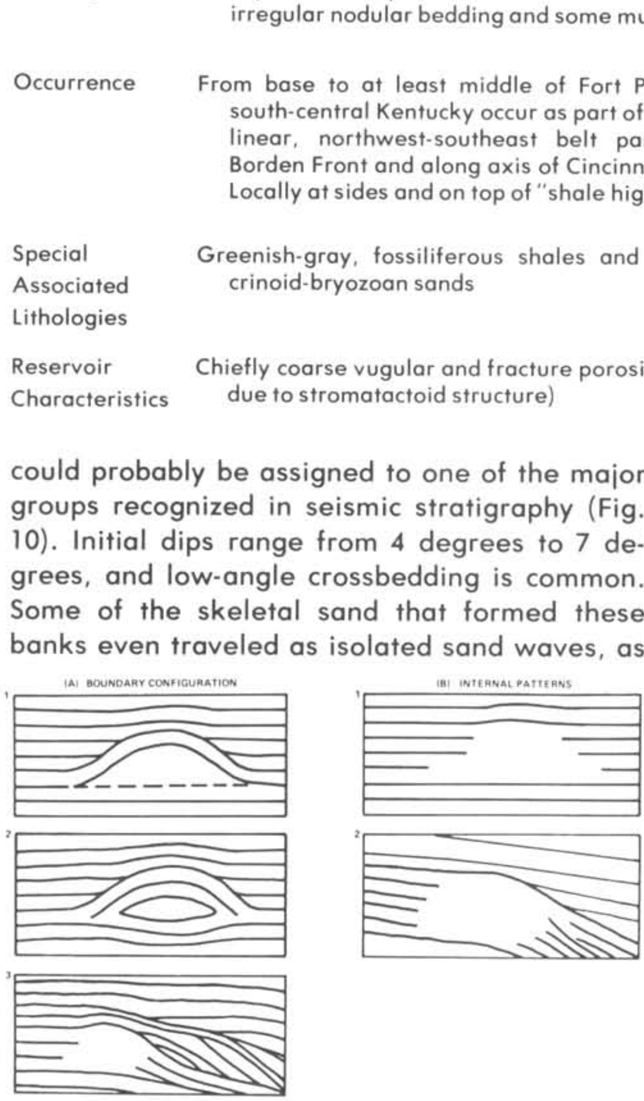

Figure 10. Geometry of carbonate buildups (Bubb and Hatlelid, 1977, Fig. 3). (Published by permission of the authors and the American Association of Petroleum Geologists.)

The origin and significance of the distinctive greenish-gray shales associated with the carbonate banks is obscure but probably could be resolved by careful, detailed mapping and paleoecological study.

Petrographically, the mudstone mounds are lime mudstones and wackestones (Fig. 11A and B) containing scattered crinoidal and bryozoan debris. Stromatactoid structures (Fig. 11B) occur in the mudstone mounds; these pore fillings are typical of Waulsortian banks,[1] although their

[1]William C. MacQuown, Jr. and Jon E. Huffman were the first to apply the term Waulsortian to the carbonate mounds of the Fort Payne in their paper, *Structural and Stratigraphic Aspects of Fort Payne (Lower Mississippian) Petroleum Production from Waulsortian-type Carbonate Lenses and Mounds in North-central Tennessee*, presented at the Fifth Annual Meeting, Eastern Section American Association of Petroleum Geologists, Lexington, Ky., October 6-9, 1976.

TABLE 2.—SELECTED ANNOTATED REFERENCES[1] TO WAULSORTIAN FACIES

Dupont, 1969
An early classic, well referenced outcrop study of the facies, petrography, and fauna of Lower Mississippian carbonates in Belgium where a Carboniferous limestone facies follows Upper Devonian terrigenous sedimentation. The reef knolls in the limestone facies are named Waulsortian; rapid facies changes and dolomitization are common, and slope deposition is inferred. Fourteen plates including photographs and photomicrographs. Short English abstract.

Gutschick, McLane, and Rodriquez, 1976
Many informative illustrations plus sections on Waulsortian banks (p. 110-111), trace fossils, and an interesting depth-of-water curve (Fig. 8-17) that appears to be very relevant to the Chattanooga Shale, Fort Payne, Warsaw, and Ste. Genevieve of the Cumberland Saddle.

Heckel, 1974
A general review of carbonate buildups, which are defined as "circumscribed bodies of carbonate rock, which display topographic relief above equivalent sediment and differ from typically thinner equivalent deposits and surrounding and overlying rocks." Mississippian Waulsortian buildups reviewed on p. 109-110. Recommended background reading.

Lane, 1973
Comprehensive paleontology and paleoceology (p. 30-89) plus sedimentation (p. 17-30) of a carbonate bank in the Borden Formation. Twenty-one plates.

Lees, 1964
Careful outcrop study of bedding is related to bank form and petrography. Good paper to examine if you plan to use a dipmeter in exploration for Waulsortian banks. Key ideas: internal structure, external morphology, sediment baffles, cementation, and porosity.

Meyers, 1974
The concept of "cement stratigraphy," a consistent and ordered sequence of cements, is developed for the Waulsortian banks of the Sacramento Mountains in New Mexico which were earlier described by Pray (1961).

Pareyn, 1959
Careful attention to paleontology and lithic and faunal sequences, most of which are well summarized in Figure 5. Two plates with five figures.

Rose, 1977
Summary of many years work on Mississippian carbonate shelves in the western United States, some of which include the Waulsortian facies. Good schematic illustrations.

Schwarzacker, 1961
Petrography of "reef knolls," 30 to 300 feet (9 to 90 m) thick and several miles wide, in Northern Ireland. Knolls consist of cavernous mudstone. Much on the orientation of fossil debris and vugs.

Sedimentation Seminar, 1972
Good description of Waulsortian banks in the Fort Payne near the Borden Front in south-central Kentucky. Key ideas: slope break, well-washed, crossbedded packstones with strong initial dip to southwest. Table 4 has an annotated bibliography of North American Mississippian bioherms through 1970.

Stone, 1972
Waulsortian banks in Lower Lodgepole Limestone (Mississippian), roughly a Fort Payne equivalent, have a depositional relief of about 60 feet (18 m) and are 300 to 500 feet (90 to 150 m) long. Emphasis on petrography with 11 photomicrographs.

Wilson, 1974
General summary of carbonate platform margins with good illustrations and a **very helpful list of questions** (p. 822-823), all of which apply to the problems posed by Waulsortian facies in Kentucky.

Wilson, 1975
Chapter V, the Lower Carboniferous Waulsortian Facies, is the only general summary of the Waulsortian facies and is very good, in large part because the author has seen most of it himself. Excellent overview, source of references, and summary of theories of the origin of carbonate mud mounds.

[1] See References for full citation.

origin, like that of the banks themselves, is not clear (Wilson, 1975, p. 79-80 and 162-164). The scattered coarse skeletal debris in the mudstone mounds is commonly intact, but much of the micritic material appears to be finely detrital. The skeletal sands consist, on the other hand, of packstones, wackestones, and rare mudstones whose framework composition is about 50 percent bryozoan debris, somewhat less crinoidal debris, and very minor amounts of brachiopods and gastropods, plus a trace of quartz. The crinoidal debris is the preferred host for minor silicification. Typical of the skeletal sands and the mudstone mounds is a fine, 10- to 40-micron secondary dolomite which is almost universally present as scattered rhombs in micritic matrix.

The dolomite beds, which contain abundant burrows and sponge spicules, have a fine, dark, argillaceous groundmass with a few scattered grains of quartz silt. Well-defined lamination is typically lacking (Fig. 11D). A careful petrographic study (size, shape, clarity, mineralogy,

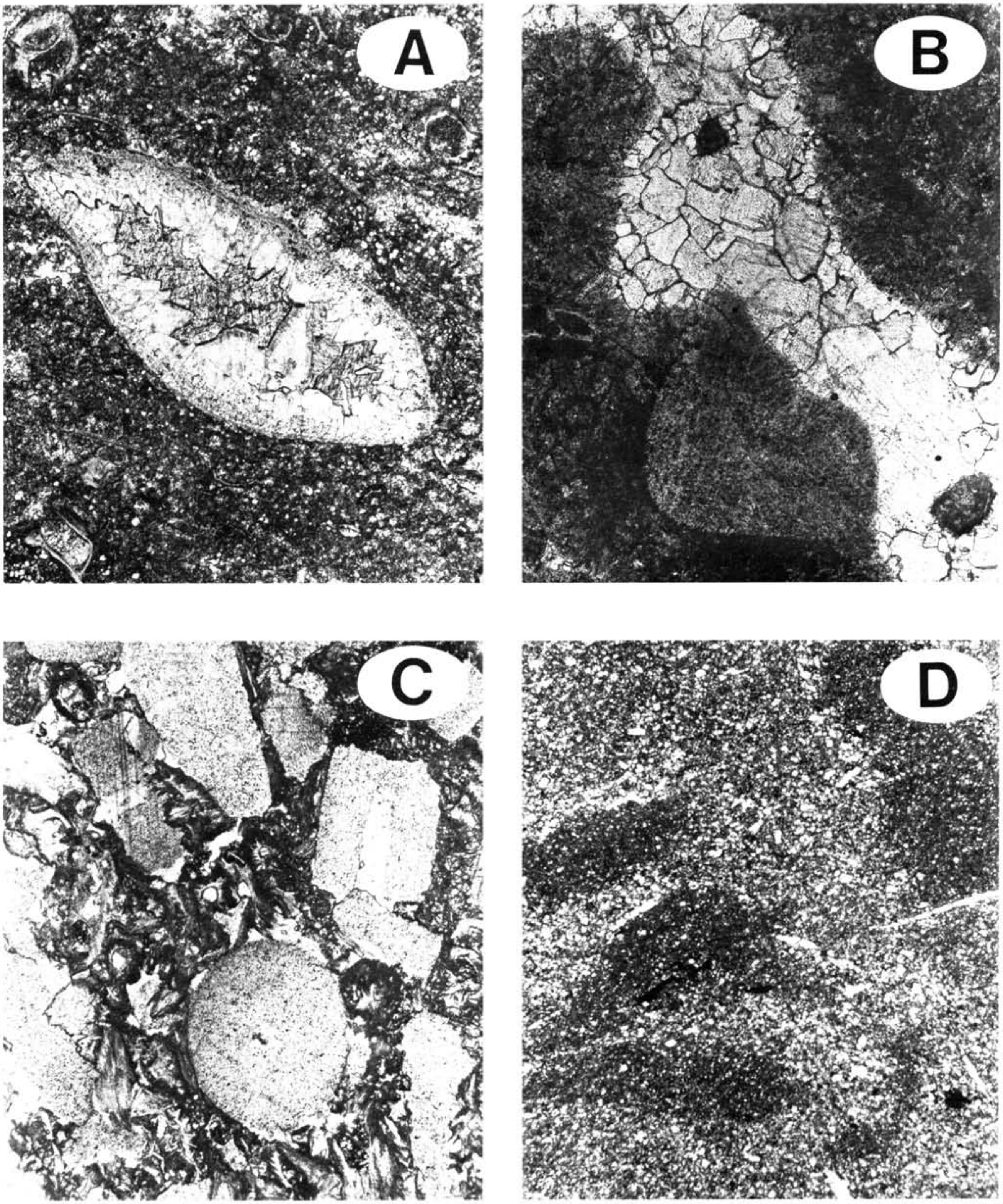

Figure 11. Photomicrographs of carbonate lithologies in the Fort Payne Formation. All X30. (A) Mudstone from mud mound containing brachiopod (?) infilled with two stages of cement; minor, very fine secondary dolomite in matrix. (B) Calcite-filled vein (stromatactis) in wackestone of mudstone mound. (C) Packstone of skeletal sand consisting of echinoderm (large) and bryozoan (smaller) debris. (D) Sponge spicules and burrows (dark ovoid, fine-grained masses) typical of thin dolomite beds.

and preferred hosts) of the dolomite in the Fort Payne, one that was carefully correlated with its host lithology and position in the basin, would go far to clarify its origin and significance (cf. Kerr, 1977, Fig. 11).

Calcareous algae appear to be absent in the Fort Payne.[1] These algae, which are only a small part of modern marine algae (and presumably ancient marine algae), are characteristic of the shelf enviornment as judged by their modern counterparts and by their occurrence in ancient rocks (Wray, 1977, p. 122-138, and especially Figs. 142 and 144). The apparent absence of calcareous algae in the Fort Payne points to its deposition in a muddy basin seaward of a shallow shelf.

The foregoing evidence—Waulsortian facies, slope deposition, a fauna consisting mostly of bryozoans and crinoids in the carbonates and siliceous sponges in the dolomites, slides and slumps, and apparent absence of calcareous algae—all points to deposition along a basin margin. Therefore, the model proposed by Gutschick and others (1976, Fig. 8-4-E) for the Lower Mississippian Lodgepole Limestone of Montana applies, with but very minor modification, to the Fort Payne of the Cumberland Saddle (Fig. 12).

Oil production from the Fort Payne in Kentucky (Fig. 13) has had a long history, beginning in the early 19th century. The east-central sheet of the *Oil and Gas Map of Kentucky* (Wilson and Sutton, 1973) lists over 50 small fields with Fort Payne production, some of which are exceptionally shallow. Munn (1914) published an early study of this production in nearby Wayne and McCreary Counties, Kentucky, a study that is still worth reading. A more recent review was given by Wilson (1971). As far as is known, all the production from the Fort Payne, most of which is oil, is from the carbonate banks. Records at the Kentucky Geological Survey indicate a total cumulative production of about 5,000,000 barrels of oil, most of which has come from Wayne, McCreary, and Metcalfe Counties, although Adair, Allen, Barren, Clinton, and Russell Counties have made minor contributions. The informal names "Beaver," "Corder," and "Stray" have been used for much of this production. Fort Payne production in Tennessee is all from Scott and Morgan Counties except for the small pool at Broken Leg in Overton County; in 1976 this production totalled about 800,000 barrels. In Tennessee, this production

[1]Twelve thin sections of the Fort Payne were examined for calcareous algae by John L. Wray of the Marathon Oil Company, who found only one questionable specimen.

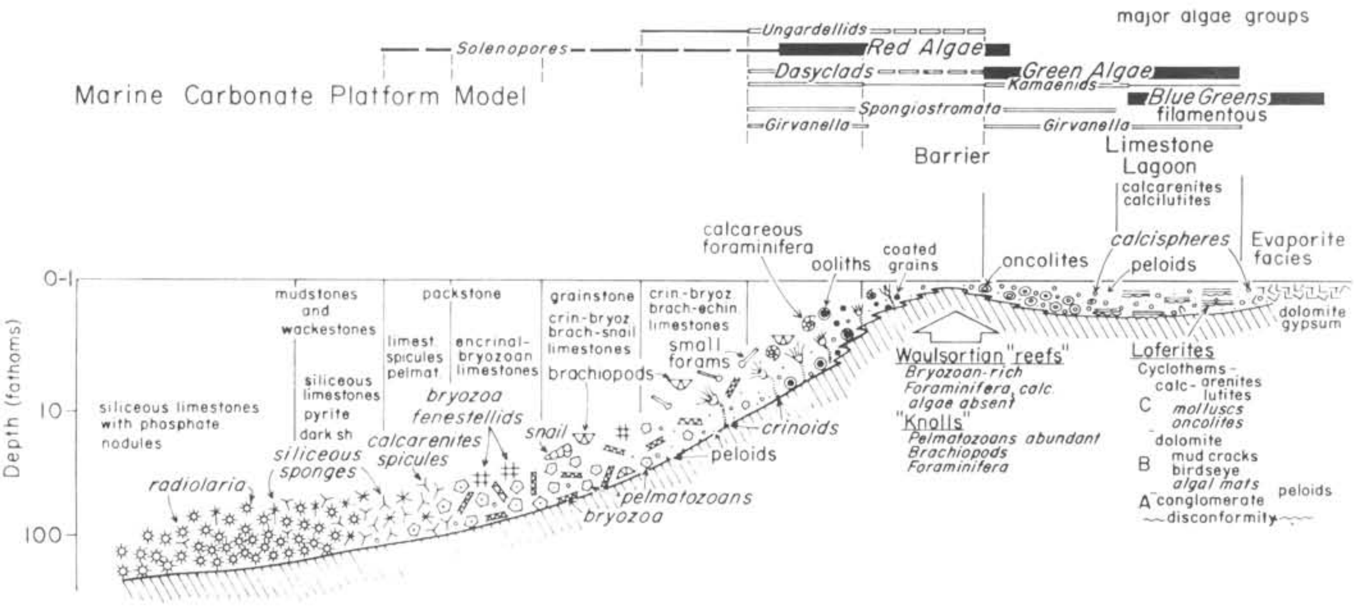

Figure 12. Schematic model emphasizing fauna and water depth developed for the Lodgepole Limestone of west-central Montana (Gutschick, McLane, and Rodriquez, 1976, Fig. 8-4-E). This model appears to fit the Fort Payne of south-central Kentucky.

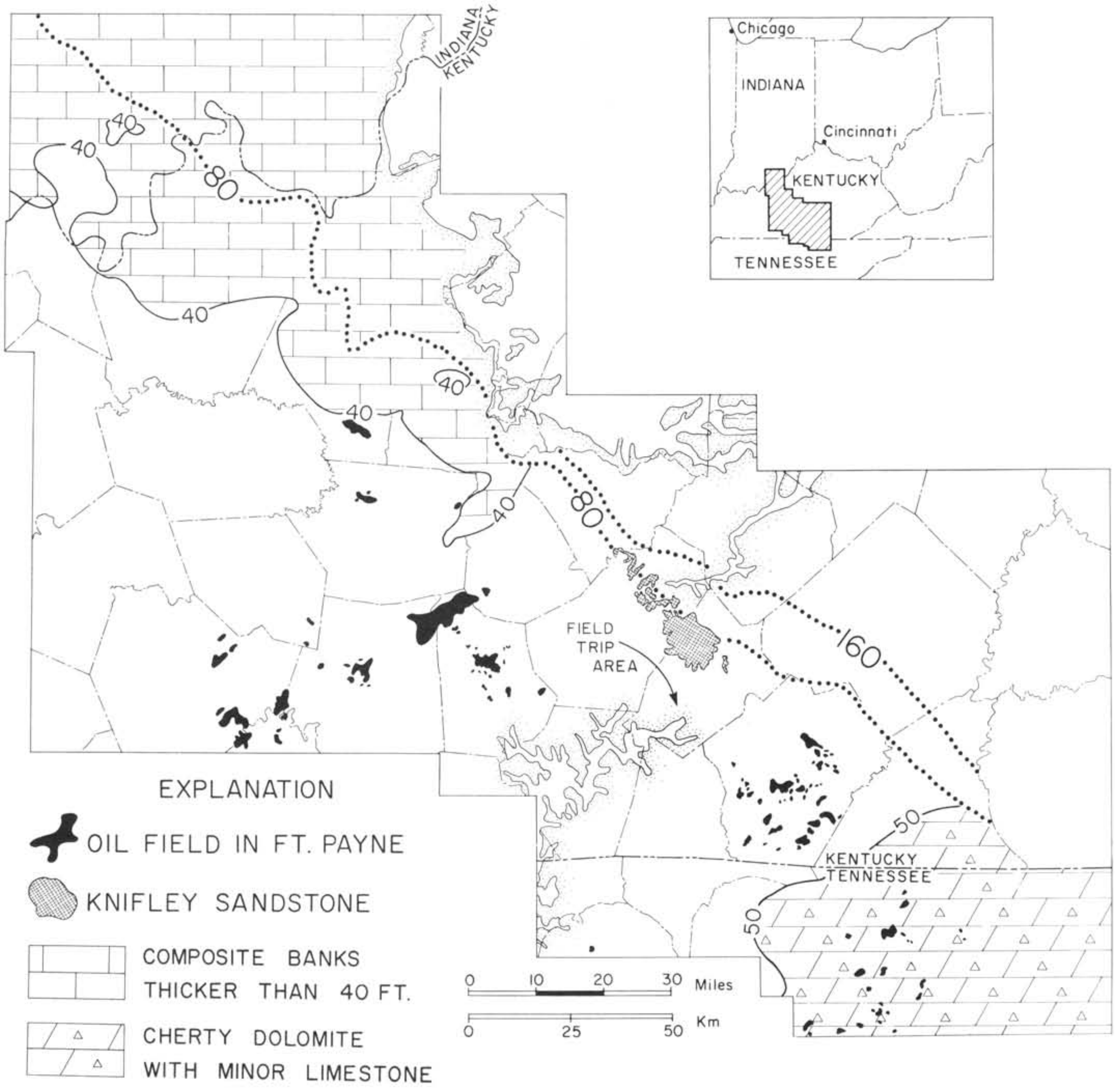

Figure 13. Oil fields producing from the Fort Payne Formation in Kentucky and Tennessee. Trend of the Borden Front is shown by the dotted lines.

comes from northeast-southwest trending carbonate banks above the tight, cherty dolomite that forms most of the Fort Payne (Statler, 1971).

Chattanooga Shale

The Chattanooga Shale and its many equivalents—the Ohio Shale of eastern Kentucky and Ohio, the New Albany Shale of western Kentucky and the Illinois Basin, the Woodfork Shale of Texas and the Percha of New Mexico, etc.—once covered much of North America, and even today is very widely preserved. In the Cumberland Saddle we see a very thin section of the Chattanooga Shale, one that is typical of areas where deposition was limited, near basin margins and over the broad regional arches of the North American craton.

In south-central Kentucky thickness of the Chattanooga Shale generally varies from about 30 to 80 feet (9 to 24 m) (Fig. 6). There are small areas where it is less than 20 feet thick, and two areas where it is known to be entirely absent—one in outcrop northwest of Burkesville on the Waterview quadrangle (Cattermole, 1963) in Cumberland County, and the other in the subsurface in the Center Hill gas field, Carter coordinate section 16-H-46, Metcalfe County (Wilson, 1971, Fig. 7). The Cincinnati Arch is outlined by the 40-foot isopachs of the Chattanooga Shale, thus demonstrating that the arch was a weak positive feature in Devonian time. Prior to deposition of the Chattanooga Shale, most of the Silurian and part of the Upper Ordovician rocks were eroded along the axis of the Cincinnati Arch in south-central Kentucky.

In much of south-central Kentucky it is difficult to recognize an internal stratigraphy within the Chattanooga Shale. It is mostly brownish-black to grayish-black shale with some iron oxide stain on fractures and bedding planes and a few thin laminae of silt. Pyrite is commonly present. *Tasmanites* is abundant, and conodonts and linguloid brachiopods are not uncommon. Weathered fracture surfaces commonly show a weak horizontal "ribbing," an expression of megabedding or cyclicity, whose origin is not well understood, but may be similar to that commonly seen in the silty, dolomitic shales of the Fort Payne Formation.

Near the base of the Chattanooga is a very widespread thin unit called the Three Lick Bed (Provo, Kepferle, and Potter, 1977), which extends from Dale Hollow Lake in Tennessee northward to beyond Cleveland, Ohio. It commonly consists of three thin seams of greenish-gray mudstone, each only 1 to 2 centimeters thick. This bed is a good example of how far thin beds and layers in shales can extend. In eastern Kentucky the Three Lick Bed is readily identifiable on gamma ray-neutron logs.

At the base of the Chattanooga Shale is a rubbly residuum and/or a supermature quartz sandstone, the Hardin Sandstone of south-central Tennessee. This unit may range up to several feet in thickness in south-central Kentucky, and is as thick as 15 feet (5 m) in central Tennessee (Conant and Swanson, 1961, p. 25-27). This sandstone produces oil in the Knob Lick Field of Metcalfe County, Kentucky. In eastern Kentucky, where the Chattanooga Shale is as much as 1700 feet (520 m) thick, it is a major gas producer.

The best regional overview of the Chattanooga Shale is provided by Conant and Swanson (1961). Schwalb and Potter (1978) and Potter (1978) have mapped its regional structure and thickness at a scale of 1:250,000 for the western two-thirds of Kentucky, including the Cumberland Saddle area.

Cumberland Formation

The Cumberland Formation was named by Shaler (1877, p. 152-160 and 387). Shaler referred to the formation as the Cumberland Sandstone. In its limited area along the Cumberland River in south-central Kentucky, the Cumberland Formation ranges from a minimum known thickness of about 25 feet (8 m) in the Burkesville quadrangle (Cattermole, 1963) to more than 120 feet (37 m) in the Dubre quadrangle (Lewis, 1967). Much of the variation in thickness is probably related to pre-Chattanooga erosion.

The Cumberland is almost everywhere dolomitic, being mostly thin- to medium-bedded, light-olive-green to bluish- and olive-brown, saccharoidal, somewhat silty, unfossiliferous dolomite. It commonly contains some thin bluish to olive-green clay shale partings and some thin beds of argillaceous limestone. Jillson (1951a and 1951b) described two thin fossiliferous limestone units within the commonly unfossiliferous dolomitic sequence. A tidal-flat origin seems to best fit this very distinctive and homogeneous formation. The Cumberland correlates with the Sequatchie Formation in Tennessee (Wilson, 1949), a part of which is red mudstone.

In broad aspect, the structure on the Cumberland seems to conform closely with that of the overlying units. The Leipers and the Cumberland both appear to be thicker slightly to the west of the crest of the Cincinnati Arch and thin eastward across the crest.

The Cumberland Formation greatly resembles, lithologically, the Preachersville, Terrill, and

Tate Members of the Upper Ordovician Drakes and Ashlock Formations of the Outer Blue Grass area. Subsurface correlation, however, with the Blue Grass area is at best speculative.

Leipers Limestone

The Leipers Limestone (Formation) was named by Hayes and Ulrich (1903) for exposures along Leipers Creek in Macry County, Tennessee. Although the name has been used by subsequent authors throughout Tennessee, in south-central Kentucky usage has been restricted to the outcrop area of Ordovician-age rocks along the Cumberland River. The Leipers is more than 125 feet (38 m) thick in this area, probably ranging between 125 and 175 feet (38 and 53 m). Rocks beneath the Leipers are exposed in Kentucky in only one very limited area in the Blacks Ferry quadrangle (Van Horn and Griffith, 1969). The Leipers appears to be thickest in the Cumberland Saddle area; in Tennessee it thins abruptly toward the Nashville Dome. The Leipers has not been subdivided into any recognized mappable subunits.

The Leipers is composed mostly of argillaceous, knobby-weathering, thin- to medium-bedded, uneven-bedded, fossiliferous, bluish-gray limestone. Much of the unit appears to be nodules of calcareous mudstone surrounded by calcareous silt. Fresh rock is commonly bluish gray, but weathers to light gray and tan.

The Leipers contains an abundant megafossil assemblage, mostly brachiopods and bryozoans. Fossils are most abundant in the knobby limestone, and absent to sparse in the thin siltstone layers. There is some segregation of fossils by major types: some beds contain an assemblage of nearly all bryozoan species with few or no brachiopods, whereas adjacent beds slightly higher or lower in the section may contain brachiopods to the near exclusion of bryozoans.

The contact of the Leipers with the overlying Cumberland Formation is a sharp lithologic boundary; there appears to be no major break in the depositional sequence, so that the two units are conformable and possible gradational in part.

Petroleum has been produced from the Leipers in the Sulphur Lick quadrangle and from a recent discovery in the Tompkinsville quadrangle. Production appears to be controlled by stratigraphic traps (Sulphur Lick) or fractures (Tompkinsville) and is very irregular.

REFERENCES

Anketell, J. M., Cegla, J., and Dzulynski, St., 1969, Unconformable surfaces formed in the absence of current erosion: Geologica Romana, v. 8, p. 41-46.

Bebout, D. G., and Loucks, R. G., eds., 1977, Cretaceous carbonates of Texas and Mexico, application to subsurface exploration: Texas Bur. Econ. Geology, Rept. Invs. 89, 332 p.

Bubb, J. N., and Hatlelid, W. G., 1977, Seismic stratigraphy and global changes of sea level, Part 10: Seismic recognition of carbonate buildups *in* Payton, C. E., ed., Seismic stratigraphy—applications to hydrocarbon exploration: Amer. Assoc. Petroleum Geologists Memoir 26, p. 185-204.

Butts, Charles, 1922, The Mississippian Series of eastern Kentucky: Kentucky Geol. Survey, ser. 7, v. 7, 188 p.

Carr, Donald, 1973, Geometry and origin of oolite bodies in the Ste. Genevieve Limestone (Mississippian) in the Illinois Basin: Indiana Dept. Nat. Resources, Geol. Survey Bull. 48, 81 p.

Carr, D. D., and Rooney, L. F., 1975, Limestone and dolomite, *in* Lefond, S. J., ed., Industrial minerals and rocks, 4th ed.: New York, Amer. Institute Mining, Metallurgical, and Petroleum Engineers, p. 757-789.

Cattermole, J. M., 1963, Geology of the Waterview quadrangle, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-286.

Chowns, T. M., and Elkins, J. E., 1974, The origin of quartz geodes and cauliflower cherts through the silicification of anhydrite nodules: Jour. Sed. Petrology, v. 44, p. 885-903.

Conant, L. C., and Swanson, V. E., 1961, Chattanooga Shale and related rocks of central Tennessee and nearby areas: U. S. Geological Survey Prof. Paper 357, 91 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 Geol. Survey, ser. 10, Bull. 5, 192 p.

Dupont, H., 1969, Contribution à l'etude des faciés Waulsortien de Waulsort: Mémoir de l'Institut Géol. de Louvain, v. 24, Fasc. 2, p. 93-164.

ELF-Aquitaine, 1975, Essai de caractérisation sédimentologique des dépôts carbonatés. 1. Elements d'analyse: ELF-Aquitaine, Centres de Recherches de Boussens et Pau, 172 p.

ELF-Aquitaine, 1977, Essai de caractérisation sédimentologique des dépôts carbonatés. 2. Eléments d'interprétation: ELF-Aquitaine, Centres de Recherches de Boussens et de Pau, 231 p.

Elrod, M. N., 1899, The geologic relations of some St. Louis group caves and sinkholes: Indiana Acad. Sci. Proc. 1898, v. 8, p. 258-267.

Embry, A. F., and Klovan, J. E., 1971, A Late Devonian reef tract on northeastern Banks Island, Northwest Territories: Bull. Canadian Petroleum Geology, v. 19, p. 730-781.

Englund, K. J., 1968, Geology and coal resources of the Elk Valley area Tennessee and Kentucky: U. S. Geol. Survey Prof. Paper 572, 59 p.

Gutschick, R. C., McLane, M., and Rodriquez, J., 1976, Summary of Late Devonian-Early Mississippian biostratigraphic framework in western Montana, *in* Guidebook The Tobacco Root Geological Society 1976 Field Conference: Montana Bur. Mines and Geology, Spec. Pub. 73, p. 91-124.

Hayes, C. W., and Ulrich, E. O., 1903, Description of the Columbia quadrangle, Tennessee: U. S. Geol. Survey Geologic Atlas, Folio 95, 6 p.

Haywood, John, 1823, The civil and political history of the State of Tennessee, 1st ed.: Knoxville, Tenn., 504 p. (2nd ed. Nashville, 1915).

Heckel, P. H., 1974, Carbonate buildups in the geologic record: a review, *in* Laporte, L. F., ed., Reefs in time and space: Soc. Econ. Paleont. Mineralogists, Spec. Pub. 18, p. 90-154.

Jillson, W. R., 1951a, The geology of Cumberland County, Kentucky: Frankfort, Ky., Roberts Printing Co., 124 p.

Jillson, W. R., 1951b, The Burkesville Limestone: Roberts Printing Co., Frankfort, Ky., 15 p.

Jillson, W. R., 1960, A bibliography of the Cumberland River valley in Kentucky and Tennessee: Frankfort, Ky., The Perry Publishing Co., 46 p.

Kepferle, R. C., 1977, Stratigraphy, petrology and depositional environment of the Kenwood Siltstone Member, Borden Formation (Mississippian), Kentucky and Indiana: U. S. Geol. Survey Prof. Paper 1007, 49 p.

Kepferle, R. C., and Lewis, R. Q., Sr., 1974, Knifley Sandstone and Cane Valley Limestone: Two new members of the Fort Payne Formation (Lower Mississippian), *in* Cohee, G. V., and Wright, W. B., eds., Changes in stratigraphic nomenclature by the U. S. Geological Survey, 1972, p. A63-A70.

Kerr, R. S., 1977, Facies, diagenesis, and porosity development in a Lower Cretaceous bank complex, Edwards Limestone, north-central Texas, *in* Bebout, D. G., and Loucks, R. G., eds., Cretaceous carbonates of Texas and Mexico, application to subsurface exploration: Texas Bur. Econ. Geology, Rept. Invest. 89, p. 216-233.

Lane, N. G., 1973, Paleontology and paleoecology of the Crawfordsville fossil site (Upper Osagian: Indiana): Univ. California Pub. Geol. Sciences, v. 99, 141 p.

Lees, A., 1964, The structure and origin of the Waulsortian (Lower Carboniferous) "reefs" of west-central Erie: Philosophical Transactions Royal Soc. London, ser. B, Biological Sciences, v. 247, p. 483-531.

Lewis, R. Q., Sr., 1967, Geologic map of the Dubre quadrangle southern Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-676.

Lewis, R. Q., Sr., and Taylor, A. R., 1975, The Science Hill Sandstone Member of the Warsaw Formation, south-central Kentucky, *in* Cohee, G. V., and Wright, W. B., eds., Changes in stratigraphic nomenclature by the U. S. Geological Survey, 1974: U. S. Geol. Survey Bull. 1405-A, p. A28-A30.

Lewis, R. Q., Sr., and Thaden, R. E., 1962, Geology of the Wolf Creek Dam quadrangle, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-177.

Lewis, R. Q., Sr., and Thaden, R. E., 1966, Geologic map of the Albany quadrangle Kentucky-Tennessee: U. S. Geol. Survey Geol. Quad. Map GQ-550.

Lineback, J. A., 1969, Illinois Basin—sediment-starved during Mississippian: Am. Assoc. Petroleum Geologists Bull., v. 53, p. 112-126.

MacQueen, R. W., and Bamber, E. W., 1967, Stratigraphy of Banff Formation and Lower Rundle Group (Mississippian), southwestern Alberta: Geological Survey Canada, Paper 67-47, 37 p.

MacQueen, R. W., and Bamber, E. W., 1968, Stratigraphy and facies relationships of the Upper Mississippian Mount Head Formation, Rocky Mountains and foothills, southwestern Alberta: Bull. Canadian Petroleum Geology, v. 16, p. 225-287.

Meyers, W. J., 1974, Carbonate cement stratigraphy of the Lake Valley Formation (Mississippian) Sacramento Mountains, New Mexico: Jour. Sed. Petrology, v. 44, p. 837-861.

Munn, M. J., 1914, Oil and gas fields in Wayne and McCreary Counties, Kentucky: U. S. Geol. Survey Bull. 579, 105 p.

Owen, D. D., and Norwood, J. G., 1847, Researches among the Protozoic and Carboniferous rocks of central Kentucky made during the summer of 1846: Printed pamph. by Keemle and Field, 1847, 12 p.

Pareyn, Claude, 1959, Les récifs carbonifères du Grand Eng occidental: Soc. Géol France Bull., ser. 7, v. 1, p. 347-364.

Patton, J. B., 1949, Crushed stone in Indiana: Indiana Div. Geology Rept. Prog. 3, 47 p.

Peterson, W. L., and Kepferle, R. C., 1970, Deltaic deposits of the Borden Formation in central Kentucky: U. S. Geological Survey Research, Prof. Paper 700-D, p. D49-D54.

Potter, P. E., 1978, Structure and isopach map of the New Albany-Chattanooga-Ohio Shale (Devonian and Mississippian) in Kentucky: Central Sheet: Kentucky Geol. Survey, ser. 10, scale 1:250,000.

Pray, L. C., 1961, Geology of Sacramento Mountain escarpment, Otero County, New Mexico: New Mexico Bur. Mines, Mineral Resources Bull., v. 35, 144 p.

Provo, L. J., Kepferle, R. C., and Potter, P. E., 1977, Three Lick Bed: Useful stratigraphic marker in the Upper Devonian shale of eastern Kentucky: U. S. Dept. Energy, Morgantown Energy Research Center, MERC/CR-77-2, 56 p.

Pryor, W. A., and Sable, E. G., 1974, Carboniferous of Illinois Basin, *in* Briggs, Garrett, ed., Carboniferous of the southeastern United States: Geol. Soc. America, Spec. Paper 48, p. 281-313.

Pryor, W. A., Maynard, J. B., and Kepferle, R. C., 1978, Jabez Sandstone Member, a new member of the Fort Payne (Mississippian) Formation in south-central Kentucky, *in* Wright, Wilma, and Swanson, Roger, eds., Changes in stratigraphic nomenclature for 1977, U. S. Geological Survey Bull., in press.

Rose, P. R., 1977, Mississippian carbonate shelf margins, western United States, *in* Wyoming Geological Association, 29th Annual Field Conference, p. 155-172.

Schwalb, H. R., and Potter, P. E., 1978, Structure and isopach map of the New Albany-Chattanooga-Ohio Shale (Devonian-Mississippian) in Kentucky: Western Sheet: Kentucky Geol. Survey, ser. 10, scale 1:250,000.

Schwarzacker, W., 1961, Petrology and structure of some Lower Carboniferous reefs in northwestern Ireland: Am. Assoc. Petroleum Geologists Bull., v. 45, p. 1481-1503.

Sedimentation Seminar, 1966, Crossbedding in the Salem Limestone of central Indiana: Sedimentology, v. 6, p. 95-114.

Sedimentation Seminar, 1972, Sedimentology of the Mississippian Knifley Sandstone and Cane Valley Limestone in south-central Kentucky: Kentucky Geol. Survey, ser. 10, Rept. Invest. 13, 30 p.

Shaler, N. S., 1877, Reports of progess: Kentucky Geol. Survey, ser. 3, v. 3, 451 p.

Smith, James, 1799, An account of the remarkable occurrences in the life and travels of Colonel James Smith, etc., 1st ed.: John Bradford, Lexington, Ky., 88 p. (Reprinted in 1812, 1831, 1834, 1838, 1870, and 1907).

Statler, A. T., 1971, Fort Payne production in the Oneida west area, Scott County, Tennessee, *in* Proceedings of symposium on future petroleum potential of NPC region 9 (Illinois Basin, Cincinnati Arch, and northern part of Mississippi Embayment): Illinois Geol. Survey, Illinois Petroleum 95, p. 94-110.

Stockdale, P. B., 1939, Lower Mississippian rocks of the east-central Interior: Geol. Soc. America, Spec. Paper 22, 248 p.

Stone, R. A., 1972, Waulsortian-type bioherms (reefs) of Mississippian age, central Bridger Range, Montana: 21st Ann. Field Conf. Montana Geol. Society, p. 37-55.

Thaden, R. E., and Lewis, R. Q., Sr., 1962, Geology of the Jamestown quadrangle, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-182.

Thaden, R. E., 1963, Geology of the Creelsboro quadrangle, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-204.

Thaden, R. E., 1966, Geologic map of the Jabez quadrangle, Russell and Wayne Counties, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-483.

Thaden, R. E., and Cattermole, J. M., 1961, Reefs in the Fort Payne Formation of Mississippian age, south-central Kentucky: U. S. Geol. Survey Prof. Paper 424B, p. B88-B90.

Troell, A. R., 1962, Lower Mississippian bioherms of southwestern Missouri and northwestern Arkansas: Jour. Sed. Petrology, v. 32, p. 629-644.

Van Horn, Richard and Griffith, W. C., 1969, Geologic map of the Blacks Ferry quadrangle, Monroe and Cumberland Counties, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-803.

Wilson, Charles, 1949, Pre-Chattanooga stratigraphy in central Tennessee: Tennessee Div. Geology Bull. 56, 219 p.

Wilson, E. N., 1971, Fort Payne production in the Cumberland Saddle area of Kentucky and Tennessee, *in* Proceedings of symposium on future petroleum potential of NPC Region 9 (Illinois Basin, Cincinnati Arch, and northern part of Mississippe Embayment): Illinois Geol. Survey, Illinois Petroleum 95, p. 79-93.

Wilson, E. N., and Sutton, D. G., 1973, Oil and gas map of Kentucky, Sheet 3, east-central part: Kentucky Geol. Survey, ser. 10, scale 1:250,000.

Wilson, J. L., 1974, Characteristics of carbonate-platform margins: Am. Assoc. Petroleum Geologists Bull., v. 58, p. 810-824.

Wilson, J. L., 1975, Carbonate facies in geologic history: New York, Heidelberg, Berlin, Springer-Verlag, 471 p.

Wray, J. L., 1977, Calcareous algae: Amsterdam, Oxford, New York, Elsevier Scientific Publishing Co., 185 p.

FIELD TRIPS

There are two trips: one along the shore of Lake Cumberland, and the other extending southward from Lure Lodge into Clinton County to see Devonian and Ordovician, as well as Mississippian, rocks.

SHORELINE OF LAKE CUMBERLAND

The lake trip has five stops and seven "look see" outcrops, outcrops where we only sail by slowly or stop offshore (Fig. 14). Depending upon lake level, 30 to 50 feet (9 to 15 m), or more, of the Fort Payne Formation can be seen (Fig. 15), mostly the middle and upper parts. Exposures along the lake are excellent and provide an unusual opportunity to see the great lateral variability of the Fort Payne. We shall also be able to collect fossils and to study the diverse and interesting sedimentary structures in the Fort Payne, as well as its cherts and geodes (Table 3). In the area of the lake trip, the Chattanooga Shale is about 100 to 200 feet (30 to 60 m) below lake level. All of the trip will be included on the Jamestown (Thaden and Lewis, 1962) and Jabez (Thaden and Lewis, 1966) geologic quadrangle maps.

Please be at the State Dock at 8:30 a.m. If you drive to the dock, please fill you car with passengers to avoid parking congestion. A hat or raincoat, plus a camera, are recommended. *Everyone needs a life preserver.*

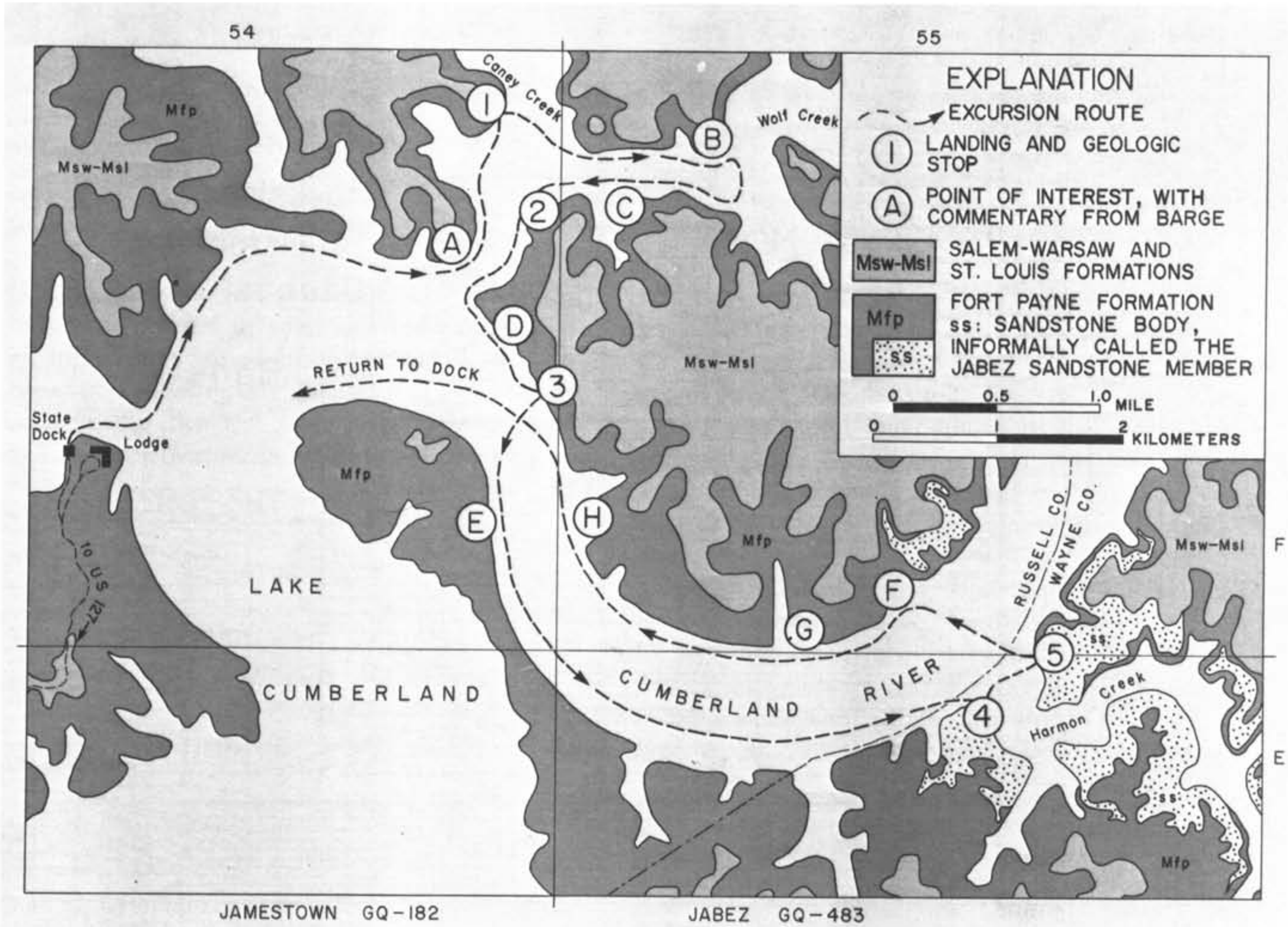

Figure 14. Simplified geologic map of a portion of the Lake Cumberland area showing the excursion route, geologic stops, and points of interest.

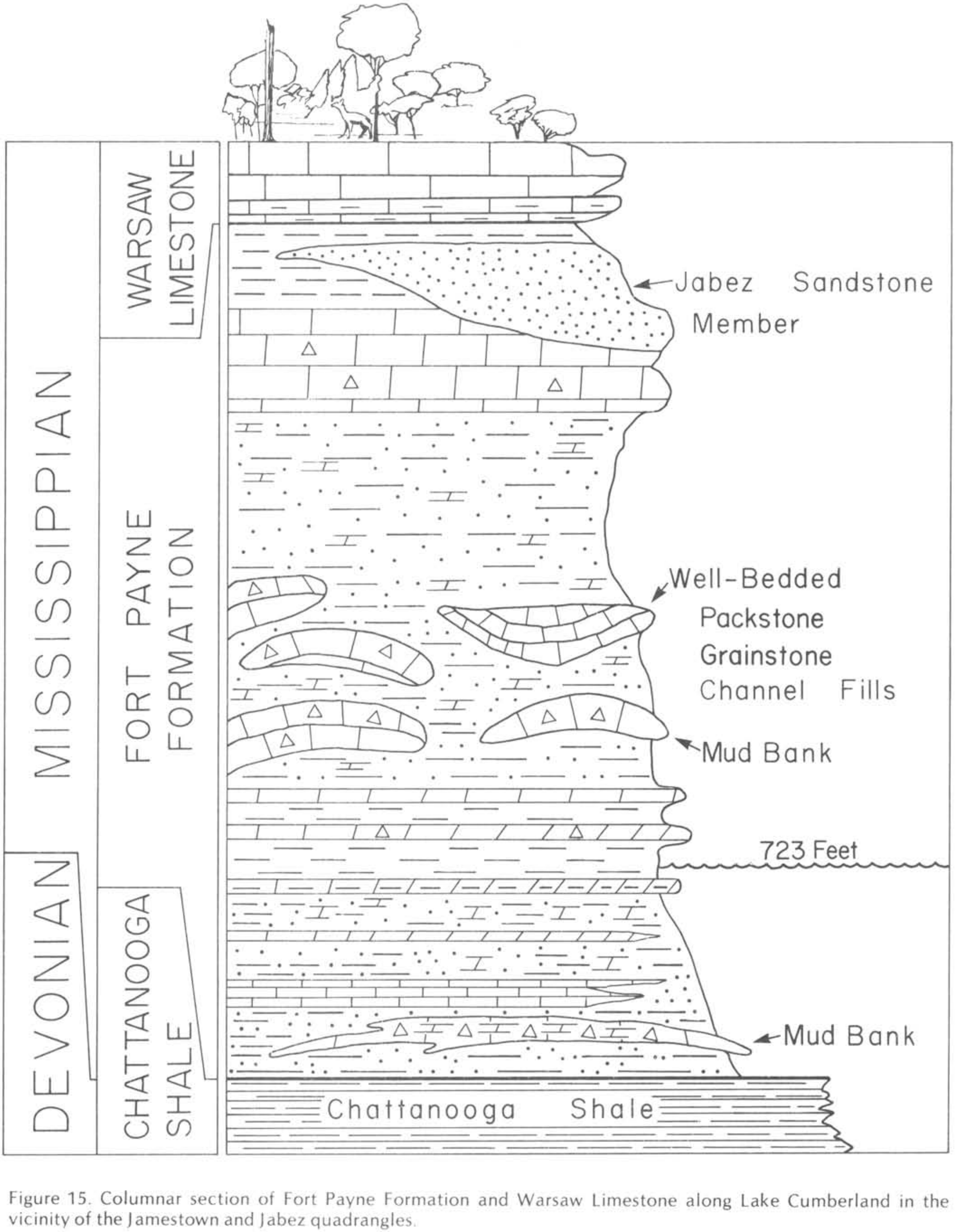

Figure 15. Columnar section of Fort Payne Formation and Warsaw Limestone along Lake Cumberland in the vicinity of the Jamestown and Jabez quadrangles.

TABLE 3.—FEATURES IN THE FORT PAYNE FORMATION ALONG THE SHORELINE OF LAKE CUMBERLAND NEAR LURE LODGE

Lithologic Types and Their Variability

Thin persistent dolomite beds and rare thin crossbedded limestones, two types of carbonate banks (mudstone mounds and skeletal well-washed sands) plus their associated greenish-gray, fossiliferous shale and the Jabez sandstone member of the Fort Payne Formation of probable tidal origin. Especially worthy of your attention is the lateral variability of the above lithologies.

Sedimentary Structures

Low- and high-angle crossbedding, starved sand wave of skeletal limestone, initial dips of mudstone mounds and skeletal carbonate sands, truncation surface, overturned fold, slump and slide complex, clasts, and scour channels.

Fossils and Biogenetic Structures

Spiriferoid brachiopods, bryozoans in the greenish-gray shale and carbonate banks, crinoidal debris (much of it largely intact and some of it but little transported), some gastropods, and rare pelecypods plus trace fossils.

Diagenetic Structures

Replacement cherts and geodes and dolomite (both as beds and as a fine-grained replacement in the carbonate banks).

As you examine the Fort Payne, please consider the following questions:

What was its depositional environment? Water depth?

What does its great lithologic variability mean? Is it related to paleotopography or to shifting sources of silt and mud derived from the Borden Front? How is lithologic variability related to paleocurrent system? How were the mud and silt transported and deposited? What is—and how can we map—the lateral continuity of the thin dolomite beds in the Fort Payne? How successfully can we map in the subsurface the different facies seen along Lake Cumberland? Is a dipmeter log essential for more successful exploration for carbonate banks in the Fort Payne? Can seismic studies be of any value? Can careful binocular study of cuttings be helpful?

What does the slumping mean? Can we map its asymmetry to determine a possible paleoslope? What significance does the overturned fold have?

What is the significance of the two types of carbonate banks? What is the relationship of one to the other? What water depths do they imply? Which has produced the most oil in the Cumberland Saddle area? Do the two types of banks need different types of well completions?

What conclusions concerning water depth, turbidity, bottom substrate, and oxygenation are implied by the fossils and trace fossils of the Fort Payne?

What is the significance of the geodes and chert? Did they form early or late? If early, do they have a water depth significance? How were the thin dolomite beds formed? What is the significance of the fine secondary dolomite in the carbonate banks?

Leave State Dock and cruise along the shore to Outcrop A. As we look at the shore along the way to outcrop A, we can see the Fort Payne Formation which consists of about 60 to 70 percent medium-gray, argillaceous, dolomitic, and silty shale interbedded with well-defined, persistent beds of dolomite and a few rare limestones which together form about 30 to 40 percent of the section (Fig. 16). Higher in the section (hidden in the trees) is a large carbonate bank, a small part of which is exposed at the top of the road to the State Dock. (Please see discussion of Stops 1 and 2 of Road Log.) The dolomite beds are massive, very persistent, and up to 2 feet (0.6 m) thick. The rare limestone beds are chiefly packstones and wackestones, some of which have low-angle crossbedding. Also note the geodes and chert nodules. Looking at the shoreline, one has the impression that these thin carbonate beds extend for several miles or more. Certainly, it would be interesting to recognize and map them in the subsurface using gamma ray-neutron logs. Any ideas about this? And also a key question is their distribution—why are these dolomites well developed in some areas and entirely absent elsewhere? What relation do they have to the other lithologies of the Fort Payne?

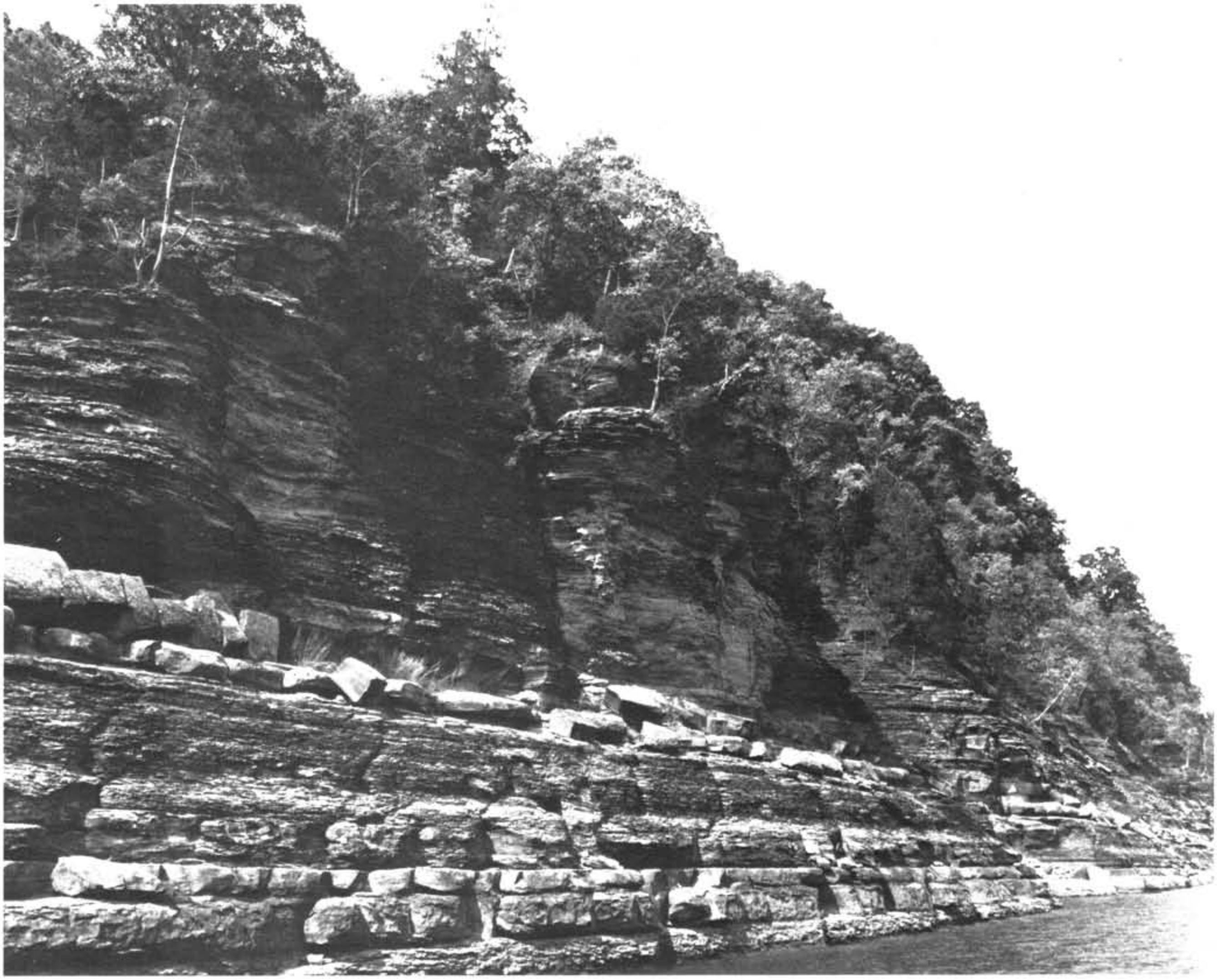

Figure 16. Fort Payne lithology exposed along north shore of Lake Cumberland between State Dock and mouth of Wolf Creek on the Jamestown quadrangle. Note thin but persistent dolomite beds.

Outcrop A, (West side of mouth of Wolf Creek). Here, in a carbonate bank, are several lenses and channels, some of which are filled with a contorted and slumped argillaceous limey mudstone up to 12 feet (4 m) thick. Also present are several small slump structures. Some of the carbonate lenses are up to 100 feet (30 m) wide.

STOP 1. *(North end of Pleasant Hill Boat Dock).*

At this stop we will have an excellent opportunity to study the geometry, lithology, sedimentary structures, and fossils of a white, massive, mudstone mound which has some calcite infillings (stromatactoid structure). This mound (Fig. 17) has a maximum thickness of about 8 feet (2.4 m) and appears to be draped over a core of green clay shale. Dips up to about 18 degrees occur on the side of the clay core. Green clay shale is also present above the mound and lateral to it. Green clay shales such as this are commonly associated—either above, below, or laterally—with the carbonate mudstone buildups in the Fort Payne. Clasts and infilled cracks are gener-

Figure 17. Carbonate mud mound and green shale on north side of Pleasant Hill Boat Dock (1600 ft FEL x 2100 ft FSL, Carter coordinate section 11-F-54, Russell County).

ally present on the tops of such mounds, and they may have coarse crinoidal debris scattered over their surfaces (Fig. 18). We will stop here about 30 minutes.

Outcrops B and C (North and south sides of Wolf Creek in Carter coordinate sections 15 and 16-F-55, Jabez Quadrangle). Please note the two small channels—one filled with shale and the other with skeletal carbonate. Also note the unusual rollover slump (Fig. 19) with northerly orientation. Even more spectacular is the large slide and slump on the south side of Wolf Creek at outcrop C (Fig. 20), which implies an unstable slope or possibly deposition along the side of a sharply incised channel.

We will return to the main part of the lake and follow the east side of Wolf Creek.

STOP 2. *(Small Carbonate-Filled Channel).* Note the sharply defined base of the channel fill. Its lower part consists of shale and dolomite (the same facies we saw cruising along the lake after we left the State Dock), and its upper part consists of white, well-bedded, skeletal limestone (Fig. 21). This geometry is typical of many, if not most, of the small crinoid-bryozoan skeletal banks.

Southward toward Lake Cumberland, note another carbonate mud mound similar to the one at Stop 1. This mound is about 20 feet (6 m) thick; it has dips up to 15 degrees and has some good vugular porosity. There is a 3-inch (8-cm) veneer of coarse crinoidal debris on top of the

Figure 18. Details of upper surface of carbonate mud mound shown in Figure 17. Coarse crinoidal debris, fractures, and clasts are commonly present.

mound and green shale is present at the base.

Outcrop D (Junction of east side of Wolf Creek and Lake Cumberland). From here to Stop 3 we see a complex interbedding of generally southwestward-dipping, mostly skeletal carbonate interbedded with green shale. Note the thin bank composed of skeletal sand with inclined bedding (Fig. 22). In casual appraisal, it is not easy to describe or understand this section, but we are probably looking at a large channel fill. What do you think?

STOP 3. *(Beach on north side of Lake Cumberland, Carter coordinate section 21-F-54).*

On your left you can examine about 40 feet (12 m) of well-bedded, dipping, crinoid-bryozoan packstones—a very typical occurrence. On your right is another exposure of the green shale. We eat lunch here and spend an hour.

Outcrop E (Cross Lake Cumberland to its west side and cruise along the shore for about 4 miles (6.4 km) Carter coordinate section 21-F-54). We see in the "highwall" a long truncation surface, a surface that extends for a mile (2 km) or more and sharply bevels a folded, slumped zone as much as 20 feet (6 m) thick which pinches out to the southeast. This truncation surface is highlighted by the thinly laminated bedding of silty calcareous dolomitic shale overlying it. Anketell, Cegla, and Dzulynski (1969) have experimented with similar structures and suggested that they were formed by an underwater slide in soft sediments and that the upper sharp contact is not an erosional one, but was formed by rising sediment diapirs intersecting the sediment-water interface. At the interface quick sediment flows and dilute suspensions were produced, which settled out as thin layers resting unconformably over the underlying disturbed zones (Fig. 23). Although the deformed zone we see is far larger than the experimental results of Anketell, Cegla, and Dzulyn-

Figure 19. Unusual rollover slump in Fort Payne Formation on the north side of Wolf Creek in the southern part of Carter coordinate section 15-F-55, Russell County.

Figure 20. Large slide and slump structure in Fort Payne Formation on the south side of Wolf Creek in Carter coordinate section 16-F-55, Russell County.

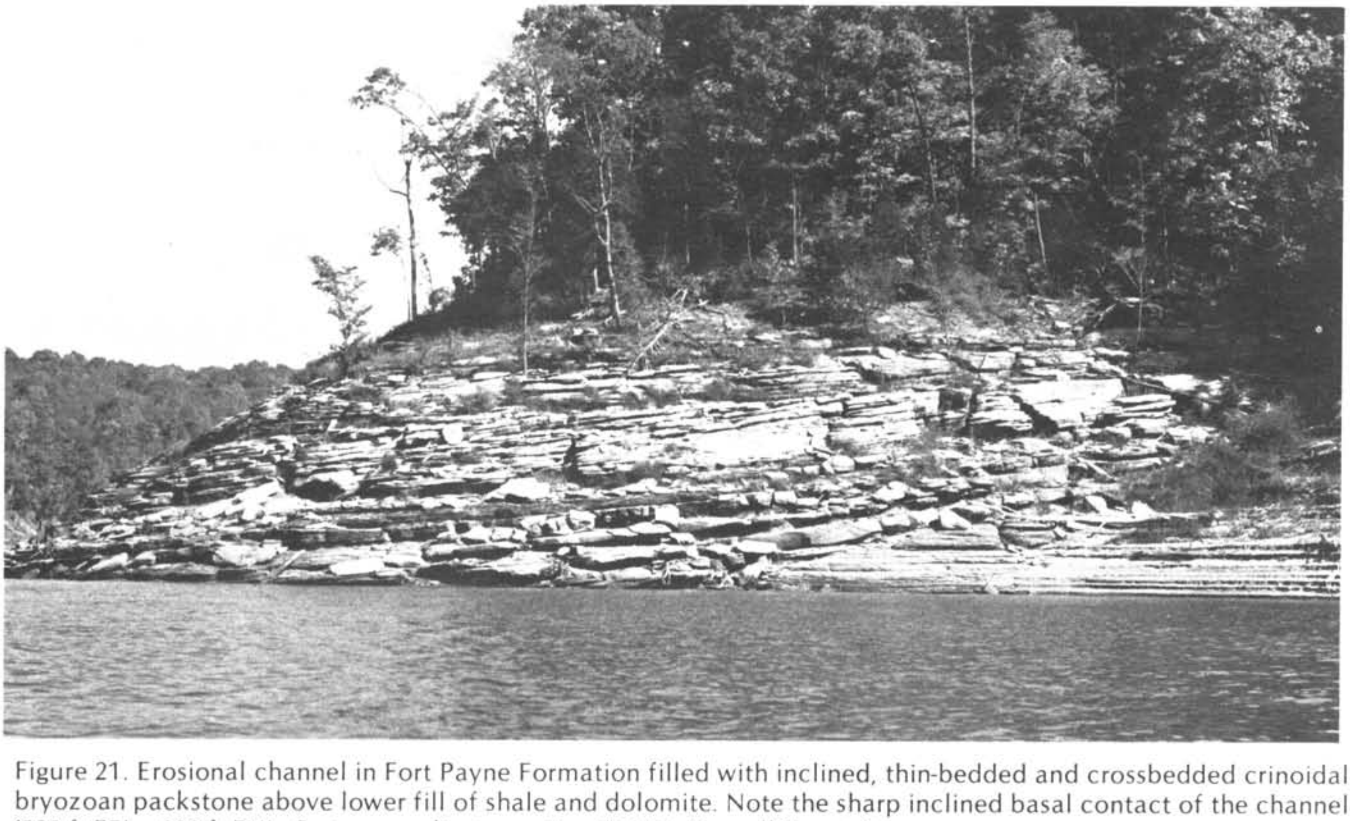

Figure 21. Erosional channel in Fort Payne Formation filled with inclined, thin-bedded and crossbedded crinoidal bryozoan packstone above lower fill of shale and dolomite. Note the sharp inclined basal contact of the channel (800 ft FEL x 600 ft FNL, Carter coordinate section 20-F-54, Russell County).

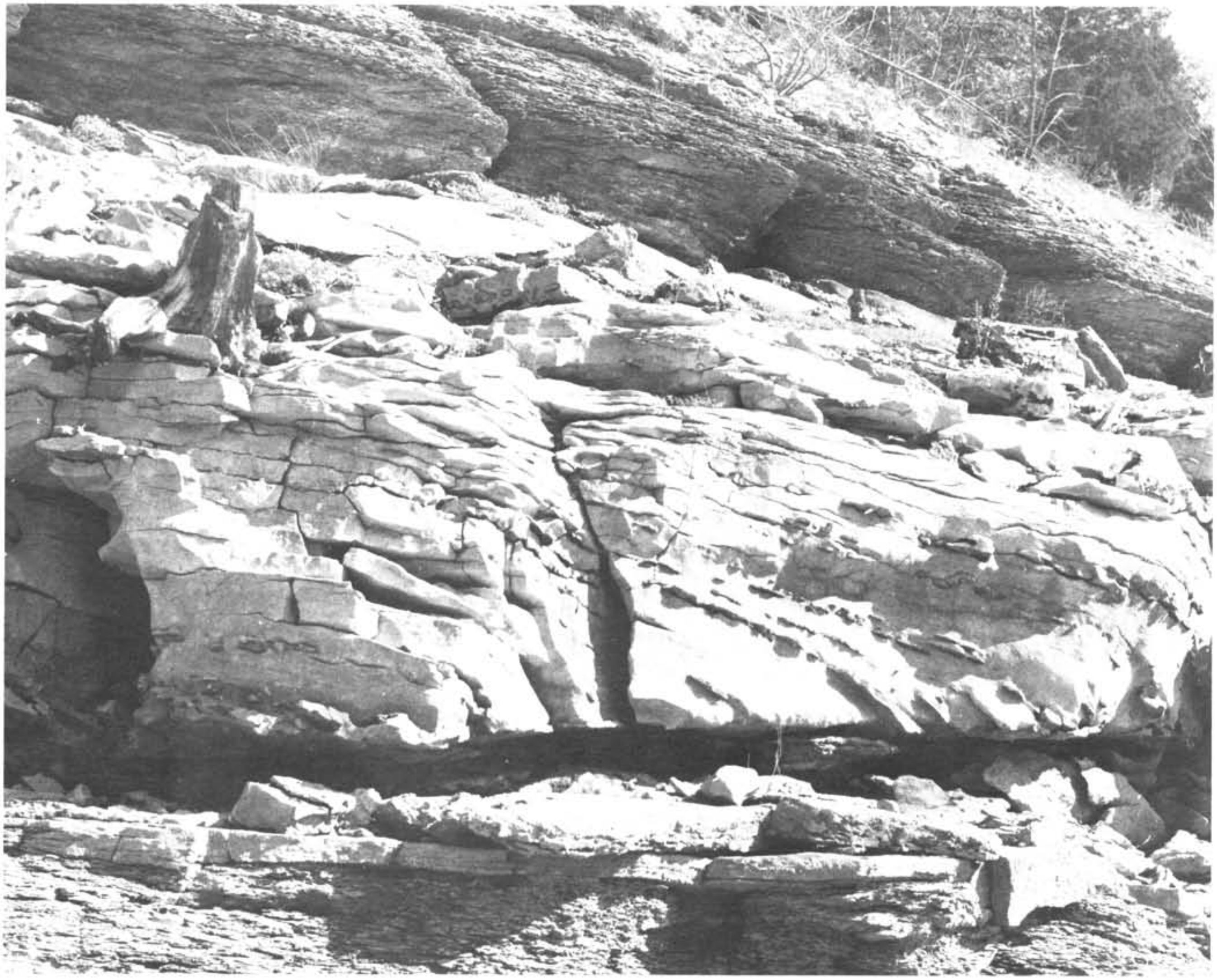

Figure 22. Thin bank composed of skeletal sand with inclined bedding (1700 ft FEL x 2400 ft FSL, Carter coordinate section 21-F-54, Russell County).

ski (1969), both the phenomena and processes appear to be the same.

Enter Wayne County at mouth of Difficulty Creek.

STOP 4. *(West side of mouth of Harmon Creek, Carter coordinate section 3-E-55).*

By climbing up the bank, we can see a good section of the Jabez sandstone (Fig. 24) that occurs near the top of the Fort Payne. The sandstone at Jabez is somewhat comparable to the Knifley Sandstone, which is well exposed at Green River Lake about 20 miles (32 km) to the northwest. Both are fine-grained, bioturbated sandstones near the top of the Fort Payne and occur near the Borden Front. However, the Knifley has a gradational base, coarsens upward, and has little crossbedding, whereas the Jabez has a sharp basal contact and is well crossbedded in its upper part. The Knifley was interpreted (Sedimentation Seminar, 1972, p. 19) as a marine, shelf-edge sandstone; the Jabez is perhaps a tidal sandstone, although more study is

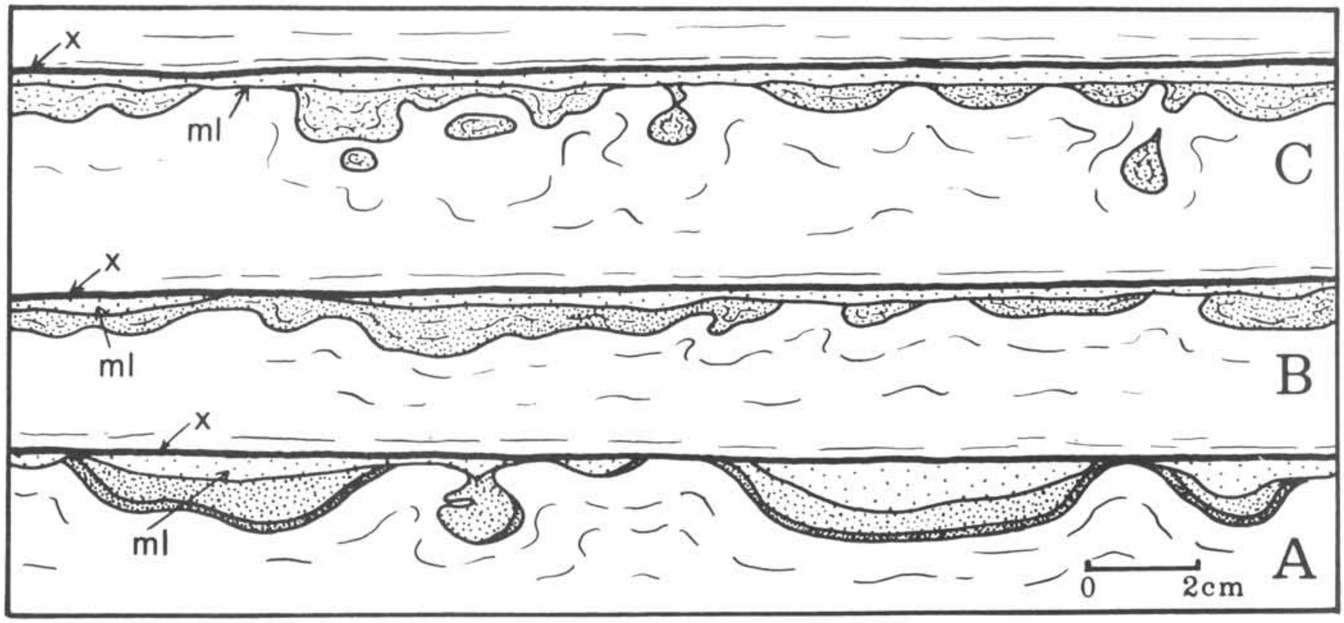

Figure 23. Disconformable surfaces experimentally produced by liquefaction of contorted beds and diapirs at the sediment-water interface (from Anketell, Cegla, and Dzulynski, 1969, Fig. 1). Sequence B was deposited 24 hours after sequence A, and sequence C was deposited 24 hours after sequence B. X marks the interface between sediment sequences, and ml indicates a mixed layer which truncates the deformed structures. Note the sharp upper contact obtained in the experiment and compare the results with the relationships at outcrop E on the south shore of Lake Cumberland.

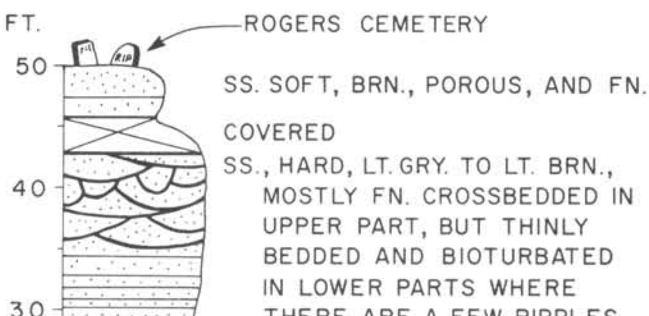

Figure 24. Section of Jabez Sandstone Member of Fort Payne Formation well exposed just east of Rogers Cemetery (1400 ft FWL x 1300 ft FNL, Carter coordinate section 3-E-55, Wayne County).

needed to fully establish this conclusion. Subsurface equivalents of both sandstones probably have much more carbonate cement than is seen in outcrop. Nonetheless, other sandstone deposits similar to these can be expected to occur in the subsurface near the top of the Fort Payne along the Borden Front, and all are potential reservoirs.

Return to the barge and proceed eastward across the mouth of Harmon Creek.

STOP 5. *(Carbonate mud mound)*.
This mud mound (Figs. 25 and 26) has a maximum thickness of about 12 feet (4 m) and is over 600 feet (180 m) long. It has a core of green shale, as well as green shale above it, and is very similar to the mound at Stop 1. Key unanswered questions include the following. What trapped the mud? Why the mound-like form?

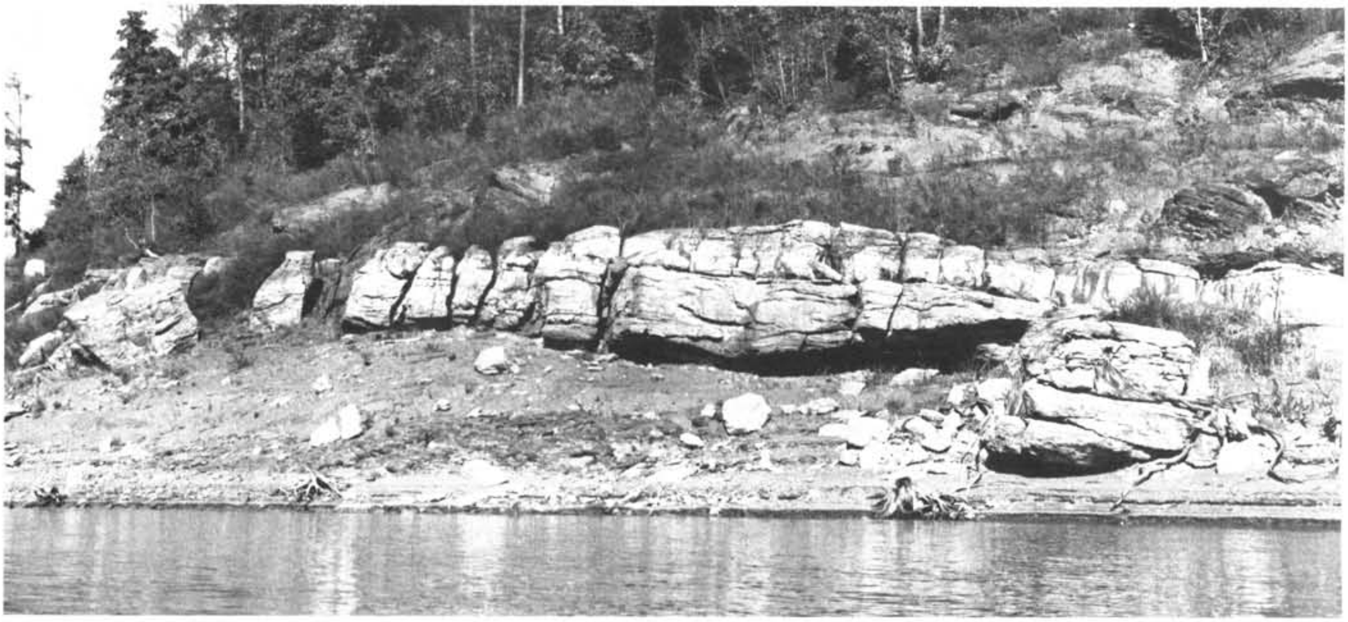

Figure 25. Well-exposed carbonate mud mound and associated green shale (700 ft FSL x 2100 ft FEL, Carter coordinate section 23-F-55, Wayne County).

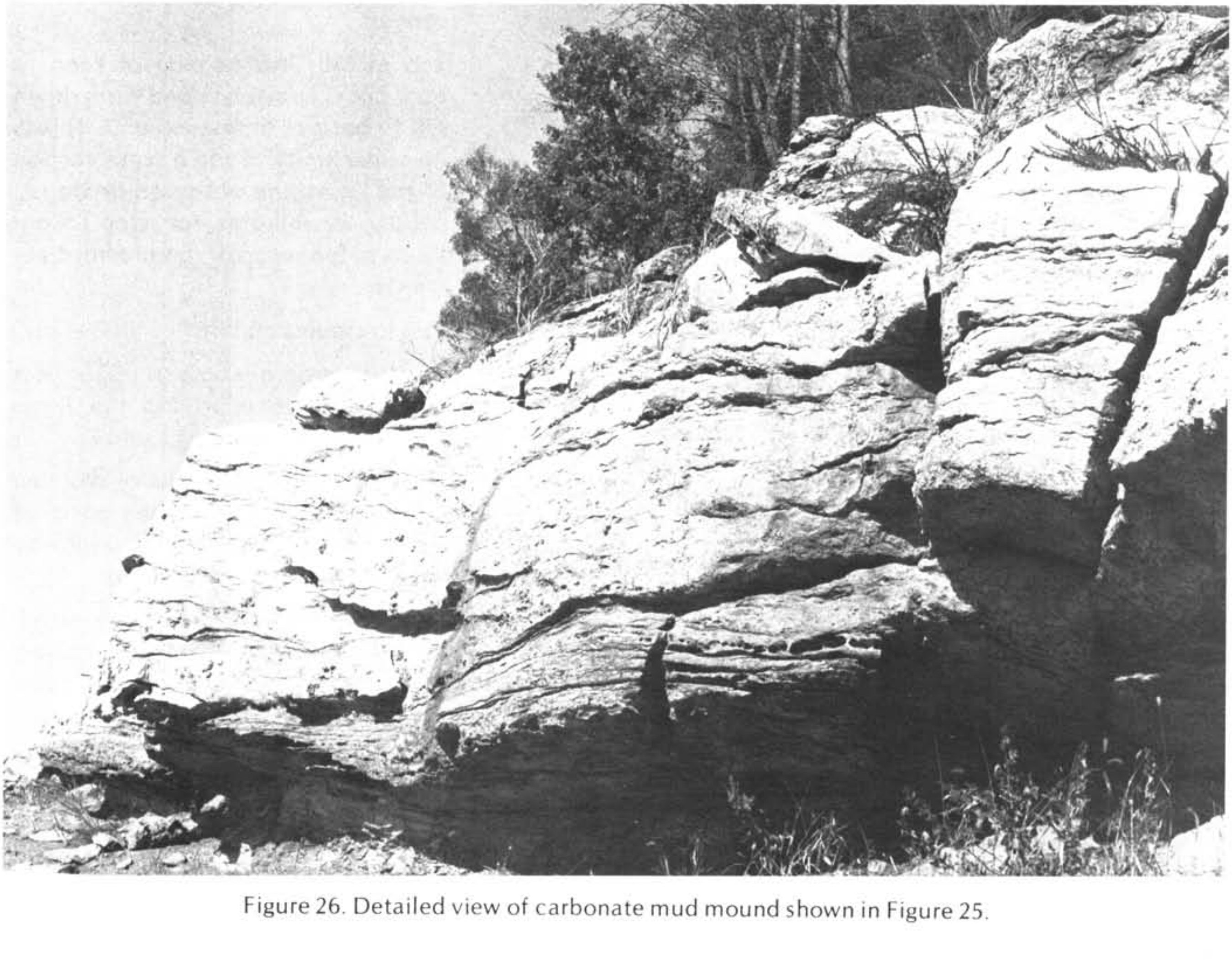

Figure 26. Detailed view of carbonate mud mound shown in Figure 25.

What is the significance of the proximal green shale?

Cross to the north side of Lake Cumberland.

Outcrops F, G, and H. Here, by cruising along the shore, we see three more mud mounds, exposed at low water, that are very similar to the others we have seen.

Return to the State Dock at approximately 4:00 p.m. Have a pleasant afternoon.

ROAD LOG
From Lure Lodge Southward Into Clinton County.

Board bus at 8:30 a.m. in the parking lot in front of Lure Lodge. There are nine scheduled stops (Fig. 2). The geology of these stops is shown on the Jamestown (Thaden and Lewis, 1962), Creelsboro (Thaden and Lewis, 1963), Wolf Creek Dam (Lewis and Thaden, 1962), and Albany (Lewis and Thaden, 1966) geologic quadrangle maps.

Km	Miles	
0.0	0.0	Parking lot in front of Lure Lodge, Lake Cumberland State Park. Go west on loop drive in front of lodge.
0.2	0.1	STOP 1 (2000 ft FWL X 900 ft FNL, Carter coordinate section 24-F-54, Russell County, Jamestown quadrangle.) Lookout point above boat dock. We are near the top of a thick, skeletal limestone bank in the upper part of the Fort Payne Formation (Fig. 27). This bank, or bank complex, is one of a number of carbonate bodies similar to, and probably time equivalent to, the Cane Valley Limestone studied by Sedimentation Seminar (1972). The bank complex covers at least 6 or 8 square miles and is elongate northwest-southeast. It consists of thinly bedded and crossbedded skeletal packstone, and, where measured, the crossbedding is uniformly oriented to the southeast. The skeletal limestones in the upper part of the Fort Payne are very similar to those of the Warsaw Formation, except that they contain less terrigenous sand and silt, and are characterized by an abundance of fossil crinoid debris. (Allow 20 minutes for stop.) Follow park road to junction with road to State Dock.
0.9	0.6	STOP 2 (3500 ft FSL X 1700 ft FWL, Carter coordinate section 24-F-54, Russell County, Jamestown quadrangle). Top of hill; intersection of road to boat dock. Leave bus and walk down hill to base of limestone unit. This is an opportunity to see a cross section of the limestone observed at Stop 1. (Allow 20 minutes for stop.) Continue to follow park road toward entrance.
1.6	1.0	Riding stables on left.
4.6	3.0	Small outcrop of shale in upper part of Fort Payne overlying the limestone exposed at Stops 1 and 2.
5.8	3.6	Small, isolated remnants of Warsaw Limestone cap the higher parts of the ridge followed by the highway for the next 0.1 mile (.16 km).
7.2	4.5	Near the park entrance and junction of U. S. Highway 127, note Warsaw outcrops on right of road—typical crossbedding, skeletal packstone and calcareous shale. The shale is identical in appearance to the Somerset Shale of Butts (1922) exposed to the east near Somerset in the Somerset and Delmar quadrangles in Pulaski County.

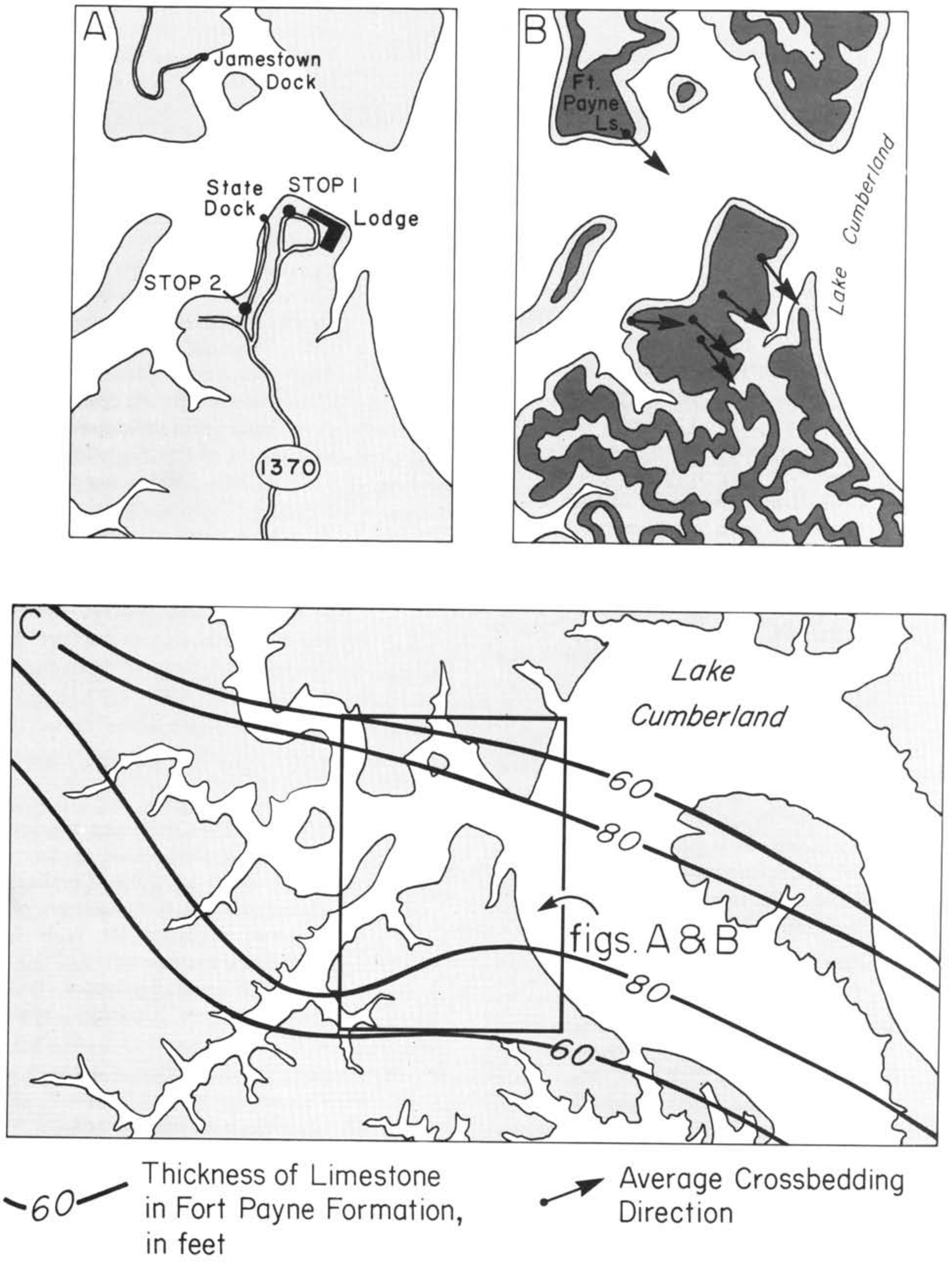

Figure 27. Thickness of carbonate banks in Fort Payne Formation and their crossbedding orientation.

Km	Miles	
7.9	4.9	Junction of park road with U. S. Highway 27 at entrance to Lake Cumberland State Park. Turn left onto U. S. Highway 127.
8.2	5.1	STOP 3 (700 ft FWL X 2700 ft FSL, Carter coordinate section 10-E-53, Russell County, Jamestown quadrangle.)

On the right, at the junction of the Lloyd Orchard Road and U. S. Highway 127, there is an abandoned quarry. Here the typical lithology of the Warsaw Formation in south-central Kentucky can be seen. The quarry was a source of coarse aggregate used in the earth-fill portion of Wolf Creek Dam. The upper 25 feet of the quarry is in a medium- to coarse-grained, well-sorted, crossbedded skeletal packstone that has a sharp basal contact with the underlying mudstone. This mudstone, which forms an 8-foot bench along the east side of the quarry floor, is in part finely laminated, but it is mostly massive, possibly because of complete bioturbation. Small geodes are numerous in the mudstone. Crossbedding orientation in the Warsaw Formation is bimodal, with the major mode being to the southwest. (Allow 20 minutes for discussion.) Proceed south on U. S. Highway 127.

10.5	6.5	Rowena, Kentucky. Elsie Story's store on right.
11.6	7.2	Note thin persistent dolomite beds in lower part of Fort Payne for the next 0.1 mile (0.2 km). Also, note that there are no limestone banks in this section, only dolomitic siltstone and shale.
13.7	8.5	East end of Wolf Creek Dam.
15.4	9.6	STOP 4 (400 ft FWL X 200 ft FSL, Carter coordinate section 14-E-53, Russell County, Wolf Creek Dam quadrangle).

West end of Wolf Creek Dam. Turn off to left. Restrooms and view point. We will walk out on the dam a short distance to overlook the area. There is an excellent exposure of nearly the full thickness of the Fort Payne Formation from near lake level to the hilltop above the highway. Here one sees virtually only the shaly Fort Payne with small, but numerous, gypsum-filled geodes. Chowns and Elkins (1974) reviewed the occurrence of Lower Mississippian geodes, including those of the Fort Payne, and concluded that they had a tidal-flat origin—a conclusion that does not fit well the depositional environment of the Fort Payne in the Cumberland Saddle area. *Caution: Beware of falling rocks if you want to take a close-up look at the Fort Payne.* On the back side of the dam the Chattanooga Shale, Cumberland Formation, and Leipers Limestone are exposed beneath the Fort Payne. We will see these units at our later stops. Proceed south on U. S. Highway 127.

15.7	9.8	Turn right on Kentucky Highway 1730.
16.9	10.5	STOP 5. Picnic area and overlook on right. Beautiful view of dam and lower part of Lake Cumberland. There will be a discussion of the grouting program for Wolf Creek Dam by a representative of the U. S. Army Corps of Engineers. Proceed westward on Kentucky Highway 1730.
18.2	11.3	Note dolomite beds in lower part of Fort Payne. This section with its thin continuous dolomite beds is very similar to the section you see along Lake Cumberland between the State Dock and the mouth of Wolf Creek.
18.4	11.4	Top of Chattanooga Shale in road cut on right.
18.7	11.6	STOP 6 (900 ft FWL X 2400 ft FNL,

Carter coordinate section 15-E-53, Russell County, Creelsboro quadrangle).

Road intersection. We will first walk back up the road to look at the basal and upper contacts of the Chattanooga Shale and the Cumberland Formation, and then walk down the gravel road to see ledges of the Leipers Formation, which offer opportunities for fossil collecting.

Here the Chattanooga Shale is 26 feet (8 m) thick, a thickness that is fairly typical of much of south-central Kentucky in the Cumberland Saddle area (Fig. 6), although there are two very small areas where it is totally absent. At Stop 6 there is no appreciable amount of greenish clay shale of the New Providence or Maury Formations above the Chattanooga, and a thin dolomite of the Fort Payne directly overlies it, a rather unusual occurrence (Fig. 28). At the base of the Chattanooga there is almost 1.5 feet (0.5 m) of sandy, ferruginous conglomerate, consisting chiefly of chert and some dolomite pebbles. This material is the residuum formed during the pre-Chattanooga erosional interval which removed all the Devonian and Silurian along the Cincinnati Arch. In Tennessee as much as 15 feet (5 m) of sandstone, the Hardin Sandstone, occurs at the base of the Chattanooga Shale (Conant and Swanson, 1961, p. 25-27).

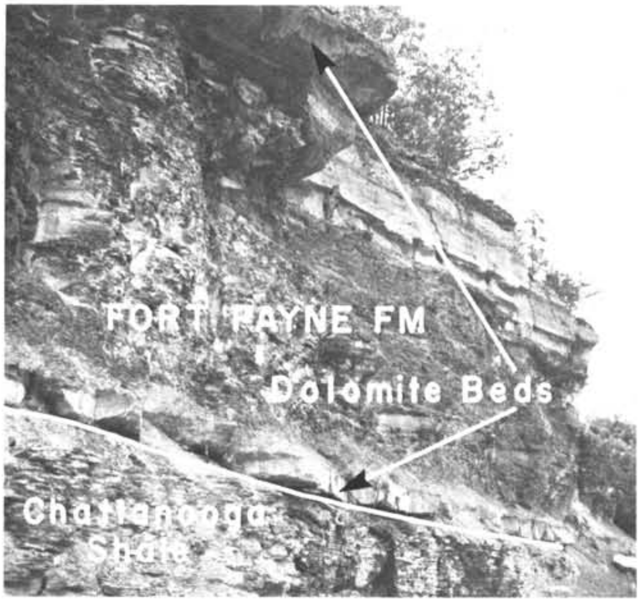

Figure 28. A dolomite bed forms the basal contact of Fort Payne with the underlying Chattanooga Shale (900 ft FWL x 2400 ft FNL, Carter coordinate section 7-E-53, Russell County).

The Cumberland Formation, which is very distinctive lithologically, consists of fine-grained, dense, dolomitic, silty mudstone that weathers brownish, but is bluish green on fresh surfaces. Closer examination shows it to be poorly to moderately laminated, but most of the original lamination has been destroyed by bioturbation. Some small vertical, glauconite-filled burrows attest to this bioturbation. A few ripple marks and mud cracks are present. This evidence, plus the scarcity of macrofauna, suggests a tidal-flat origin. Porosity is minimal and, as far as we know, the Cumberland has never produced any petroleum in the area. In outcrop the Cumberland ranges from 25 to over 120 feet (8 to 37 m) in thickness. Part of this variation may be related to pre-Chattanooga erosion. The Cumberland Formation may be in part equivalent to the Sequatchie Formation of Wilson (1949).

The Leipers Formation is conformable with the Cumberland, but is very different lithologically; it consists of fossiliferous silty and argillaceous wackestone with some minor packstone. In outcrop, it occurs as rough, bluish-gray ledges. Thicknesses of 125 to 175 feet (38 to 53 m) are typical. There is some limited oil production from the Leipers. Return to bus and proceed on Kentucky Highway 1730.

Km	Miles	
18.8	11.7	Manntown.
20.3	12.6	STOP 7 (100 ft FSL X 1400 ft FWL, Carter coordinate section 7-E-53, Russell County, Creelsboro quadrangle). We are at the top of the Chattanooga Shale. Note the greenish-gray to olive-gray clay shale immediately above the Chattanooga in the basal part of the Fort Payne. From this point we will walk along the road about 0.4 mile (0.6 km) to the next stop, noting particularly the shale and carbonate units at road level and their relationship to the large carbonate mud mound at Stop 8. The section you see along the road is very puzzling, and we invite your comments and help. Also stop and examine the green shale mound flanked by two wedges of mudstone and wackestone (Fig. 29). Bus will proceed ahead 1.1 miles (1.8 km) to turn-around point and then meet us at Stop 8.
21.2	13.2	STOP 8 (900 ft FSL X 1200 ft FWL, Carter coordinate section 7-E-53, Russell County, Creelsboro quadrangle). Walk along the base of the large mudstone mound, which is more than 30 feet (9 m) thick and has green shale at its base. This mud mound is over 1100 feet (335 m) wide and 2600 feet (792 m) long and is probably related to the smaller, thinner, more irregular mudstones interbedded with green shale that you saw as you walked along the road up to this stop. As you walk along the base of the mud mound, please note the crude, irregularly inclined bedding, the vuggy and even cavernous porosity, and the coarse crinoidal debris and minor chert. Four thin sections showed a typical crinoid-bryozoan mudstone-wackestone (Fig. 11). This is the same type of mud mound that is present along the lake, but much larger. Board bus and retrace route to U. S.Highway 127.
26.4	16.4	Junction with U. S. Highway 127. Turn right. From here to the Clinton County line we see mostly roadcuts in the Fort Payne, some of which are capped by a thin Warsaw section. The Fort Payne topography is marked by mature dissection with steep slopes, reflecting its poor permeability. This is very different from the more subdued and more fertile karst topography of the St. Louis Limestone to the south.
27.6	17.2	High-tension line. Base of Warsaw Limestone in the roadcut which is about 60 feet (18 m) high (no stop).
27.8	17.3	Clinton County Line.
29.8	18.5	Community of Desda. The area, which is on a broad southward-plunging anticlinal structure, was drilled extensively in the 1930's for oil. Most of the production is from the shallow Granville pay (Ordovician), about 300 feet (90 m) below the Chattanooga Shale.
36.0	22.4	Entering outcrop area where the St. Louis Limestone caps the higher elevations; Warsaw Limestone is below.
37.6	23.4	Aaron, Kentucky. Post office is on the right.
38.1	23.7	Typical outcrop of Warsaw Limestone on right.
39.1	24.3	Grider Hill Dock road on left; proceed on U.S. Highway 127. From here to the Wago quarry the highway is on St. Louis Limestone. Generally the St. Louis has a well-developed karst topography and weathers to a thick, red, cherty, clayey colluvium.

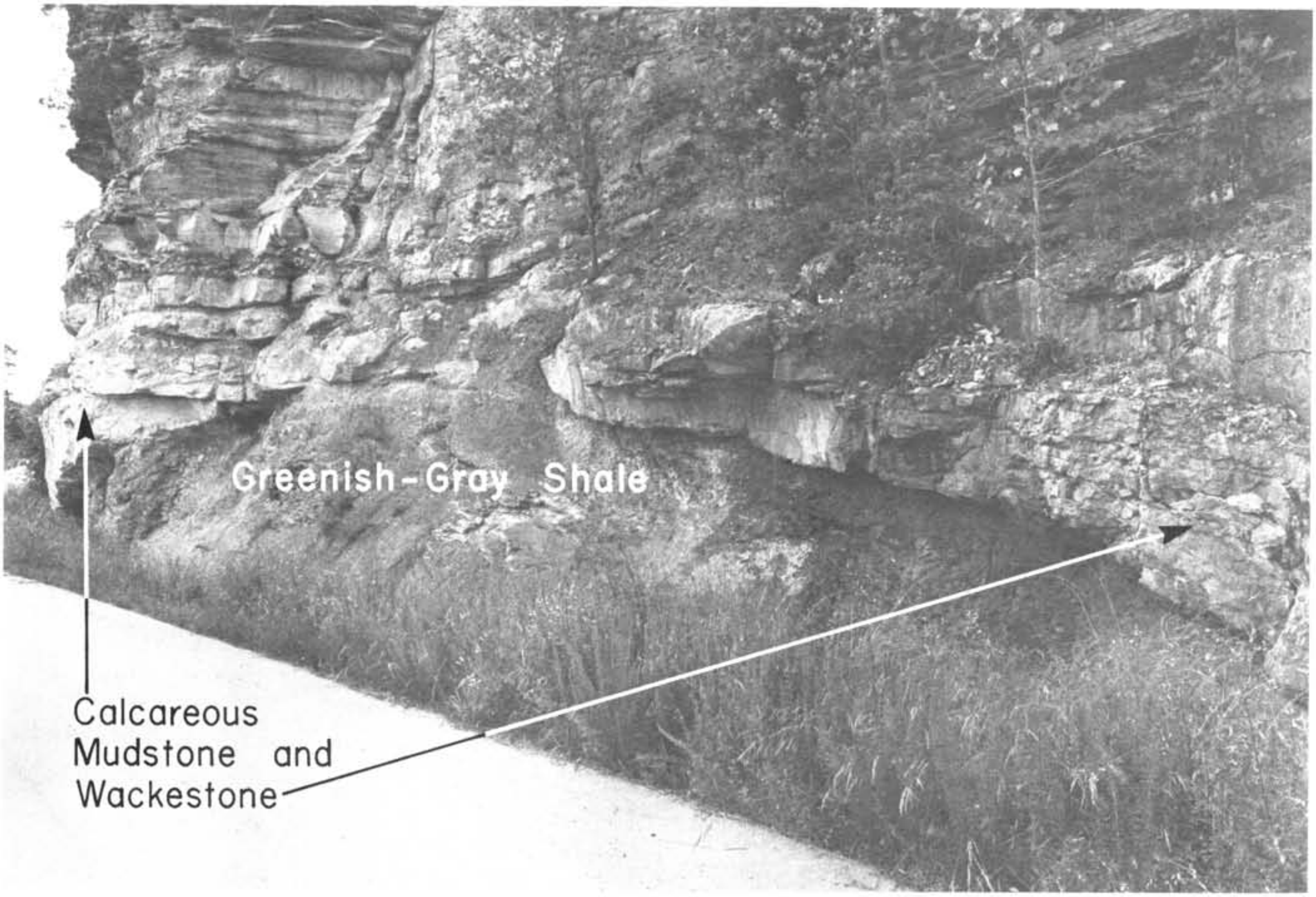

Figure 29. Green shale flanked by two wedges of wackestone and mudstone along Kentucky Highway 1730 in the southern part of Carter coordinate section 7-E-53, Russell County.

41.4 25.7 Ida, Kentucky. Junction with Kentucky Highway 1590 on the right. We are crossing the axis of the Indian Creek syncline at this point. The Ida oil pool, which was drilled in the late 1950's and early 1960's, is just to the west of us; production was chiefly from the Sunnybrook (Ordovician).

42.5 26.4 Junction with Kentucky Highway 639. Turn right onto Kentucky Highway 639.

43.1 26.8 Cross Kentucky Highway 90. CAUTION! Stay on Kentucky Highway 639 south.

44.3 27.5 STOP 9 (800 ft FNL X 350 ft FEL, Carter coordinate section 1-C-52, Clinton County, Albany quadrangle).

Take gravel road to left into old Wago quarry opposite oil-tank battery. After a short distance there is a fork in the road; the road to the right below the quarry leads to its floor, and the road to the left, for which a four-wheel drive vehicle is necessary, leads to a contact near the top of the quarry. We will take the lower road and park near the quarry entrance. The Wago quarry, which was abandoned about 25 years ago, is just east of the old Highway oil pool that produced from the Granville (Ordovician).

The Wago quarry is the westernmost exposure in Kentucky of the Upper Mississippian section underlying the Cumberland Plateau, except for Pilot Knob, a far outliner which occurs along the Tennessee-Kentucky line in the Blacks Ferry quadrangle

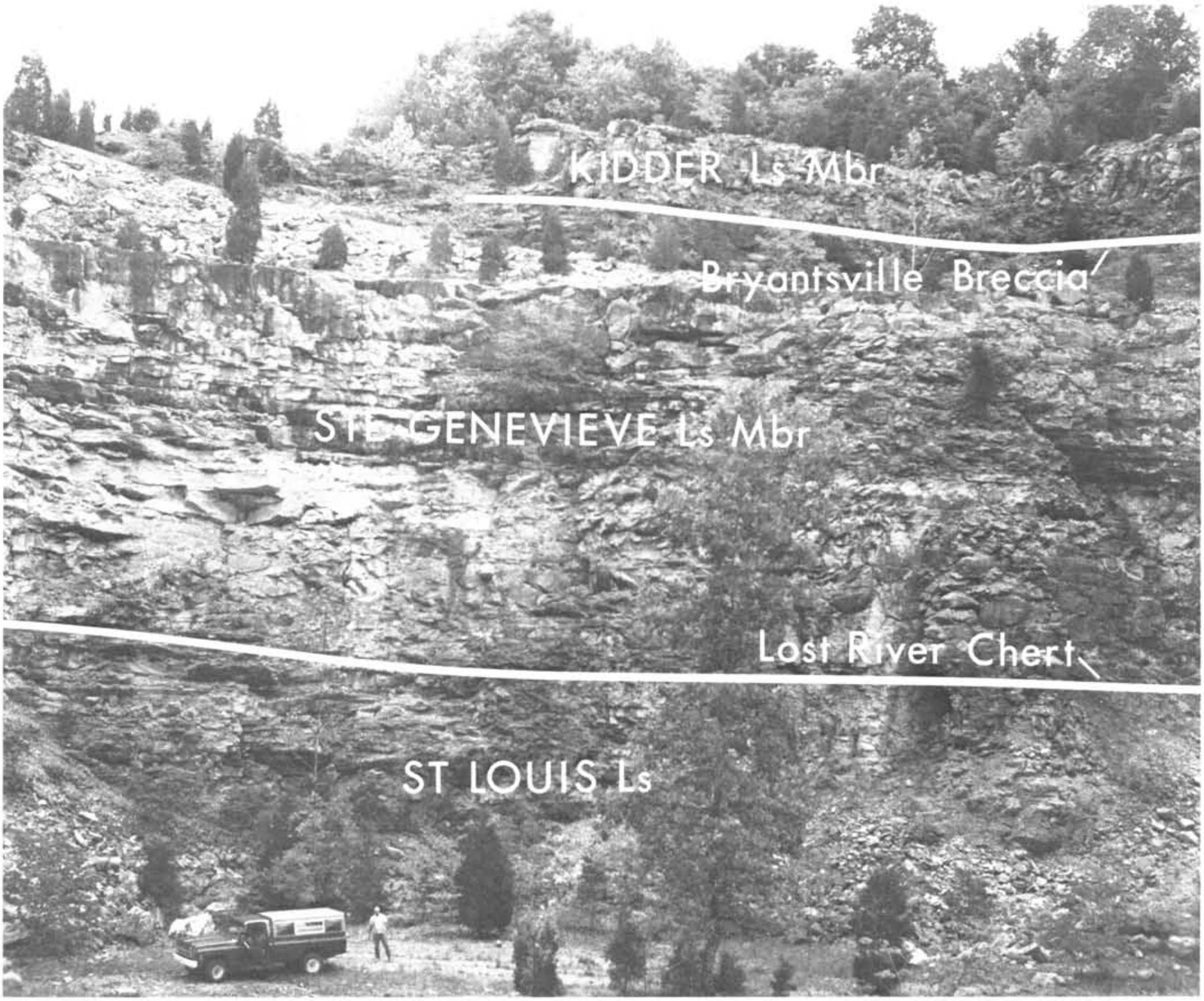

Figure 30. Abandoned Wago quarry where parts of the St. Louis and Monteagle Limestones are exposed (350 ft FEL x 800 ft FNL, Carter coordinate section 1-C-52, Clinton County).

approximately 20 miles (30 km) to the west.

About 150 feet (46 m) of stratigraphic section is exposed in the quarry; it includes the upper part of the St. Louis Limestone, the Ste. Genevieve Limestone Member of the Monteagle Limestone, and the lower part of the Kidder Member of the Monteagle Limestone (Fig. 30). Both the Lost River chert of Elrod (1899), near the base of the Ste. Genevieve, and the Bryantsville breccia of Patton (1949), near its top, are well exposed here. Both of these beds are very widespread; they are traceable from the Indiana outcrop into south-central Kentucky and northeastward as far as Berea, Kentucky. Several white, massive mudstones, 3 to 6 feet (1 to 2 m) thick, are also readily apparent. These appear to be traceable over a fairly wide area in Clinton and Wayne Counties. A large set of crossbeds occurs in the Ste. Genevieve midway up the quarry wall on the southeast side. On the quarry floor you can see some excellent

Figure 31. Dripstone breccia in Wago Quarry.

pyrite-coated brachiopods in micritic limestone and some spectacular blocks of dripstone breccia (Fig. 31). This breccia may be related to the collapse structure seen at the northwest side of the quarry. There also is a typical display of St. Louis chert. And finally a question: can you identify any caliche horizons in the quarry?

END OF TRIP: Thank you for your presence; we hope you had a pleasant and interesting two days! See you next fall!

PRACTICAL CLASSIFICATION OF LIMESTONES[1]

<table>
<tr><th colspan="6">ALLOCHTHONOUS LIMESTONES
ORIGINAL COMPONENTS NOT ORGANICALLY BOUND DURING DEPOSITION</th><th colspan="3">AUTOCHTHONOUS LIMESTONES
ORIGINAL COMPONENTS ORGANICALLY BOUND DURING DEPOSITION</th></tr>
<tr><td colspan="4">Less Than 10% >2 mm Components</td><td colspan="2">Greater Than 10% >2 mm Components</td><td rowspan="4">BY Organisms Which Act as Baffles</td><td rowspan="4">BY Organisms Which Encrust and Bind</td><td rowspan="4">BY Organisms Which Build a Rigid Framework</td></tr>
<tr><td colspan="3">Contains Lime Mud (<.03 mm)</td><td>No Lime Mud</td><td rowspan="3">MATRIX SUPPORTED</td><td rowspan="3">>2 mm COMPONENT SUPPORTED</td></tr>
<tr><td colspan="2">MUD SUPPORTED</td><td colspan="2" rowspan="2">GRAIN SUPPORTED</td></tr>
<tr><td>Less Than 10% Grains (>.03 mm <2 mm)</td><td>Greater Than 10% Grains</td></tr>
<tr><td>MUD-STONE</td><td>WACKE-STONE</td><td>PACK-STONE</td><td>GRAIN-STONE</td><td>FLOAT-STONE</td><td>RUD-STONE</td><td>BAFFLE-STONE</td><td>BIND-STONE</td><td>FRAME-STONE</td></tr>
</table>

[1]Embry and Klovan (1971, Fig. 2)

SURFACE ROCKS IN THE WESTERN LAKE CUMBERLAND AREA, KENTUCKY—GEOL. SOC. KENTUCKY GUIDEBOOK—1978