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Waulsortian Mounds and Reservoir Potential of the Ullin Limestone ("Warsaw") in Southern Illinois and Adjacent Areas in Kentucky

Zakaria Lasemi, Janis D. Treworgy, Rodney D. Norby,
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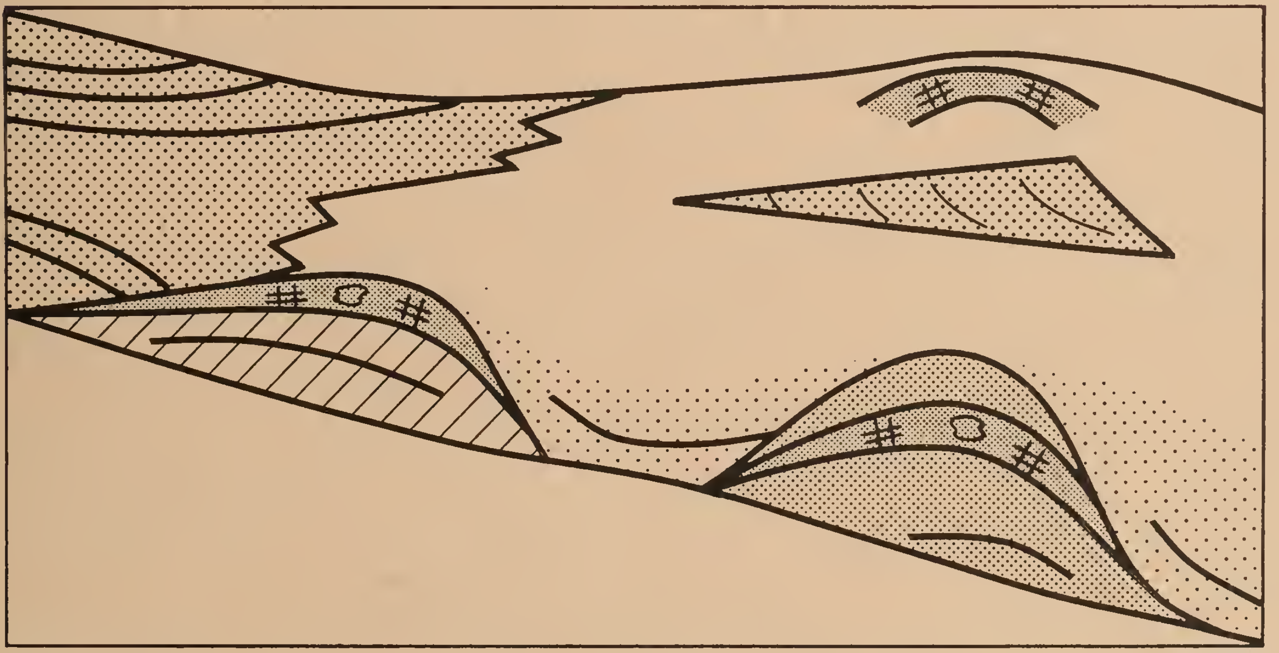

Geologic Field Trip, April 19, 1994
Sponsored by the Illinois Geological Society
and the Illinois State Geological Survey
Illinois Department of Energy and Natural Resources
ILLINOIS STATE GEOLOGICAL SURVEY

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Contributors
Garland R. Dever, Jr.
Kentucky Geological Survey
Terry Teitloff
Vulcan Materials Company, Kentucky
Richard D. Harvey
Illinois State Geological Survey

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Illinois Department of Energy and Natural Resources
ILLINOIS STATE GEOLOGICAL SURVEY
Morris W. Leighton, Chief
Natural Resources Building
615 East Peabody Drive
Champaign, Illinois 61820-6964
Phone 217/333-4747
Fax 217/333-2830

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ULLIN LIMESTONE ("WARSAW") AND FORT PAYNE FORMATION: OVERVIEW AND STOP DESCRIPTIONS

Zakaria Lasemi, Janis D. Treworgy, Rodney D. Norby, John P. Grube, and Bryan G. Huff

OVERVIEW

The Ullin Limestone ("Warsaw") and Fort Payne Formation (fig. 1) will be examined in three quarries in southernmost Illinois and western Kentucky (fig. 2). The petroleum industry in southern Illinois has referred to the limestone unit that underlies the Salem Limestone as the "Warsaw"; however, it differs lithologically from the type Warsaw Shale of western Illinois. Lineback (1966) renamed the "Warsaw" of southern Illinois the *Ullin Limestone* and restricted the term *Warsaw* to the calcareous shale of western Illinois. We follow Lineback's terminology in this guidebook (see Norby, this guidebook).

A wireline log from Wayne County, Illinois (fig. 3), shows one type of log response for the Ullin and Fort Payne in the subsurface; the porous and nonporous zones are clearly differentiated. Distinguishing individual facies, however, requires a study of samples or cores. The number and thickness of porous and nonporous zones vary significantly from one area to another. This field trip provides an opportunity to examine lithologic and sedimentologic relationships that exist between various facies within the Ullin and Fort Payne and are not easily recognizable on the basis of logs, cuttings, and cores.

One of the main hypotheses of our ongoing research has been the possible presence of Waulsortian-type carbonate mounds within the Ullin Limestone. Recognition of mounds in the Ullin in outcrop supports this hypothesis. Waulsortian mounds (named after the town of Waulsort in Belgium) are early to mid-Mississippian (late Tournaisian through early Viséan) carbonate bodies with a lime mudstone–wackestone core facies flanked by dipping crinoid-bryozoan packstone–grainstone beds. These mounds are morphologically similar to reef mounds such as those in the Silurian carbonates of the Illinois Basin, except for the lack of fossil remains from frame-building organisms such as corals and stromatoporoids. Waulsortian mound facies are prolific hydrocarbon producers in several regions of North America (MacQuown and Perkins 1982, Ahr and Ross 1982, Davies, et al. 1989, Burke and Diehl 1993). Recent discoveries of hydrocarbons in the Ullin Limestone ("Warsaw"), in part associated with the Waulsortian mound facies, indicate that the Ullin has a greater reservoir potential than previously recognized. During this field trip, we will observe some reservoir as well as nonreservoir facies of the Ullin Limestone.

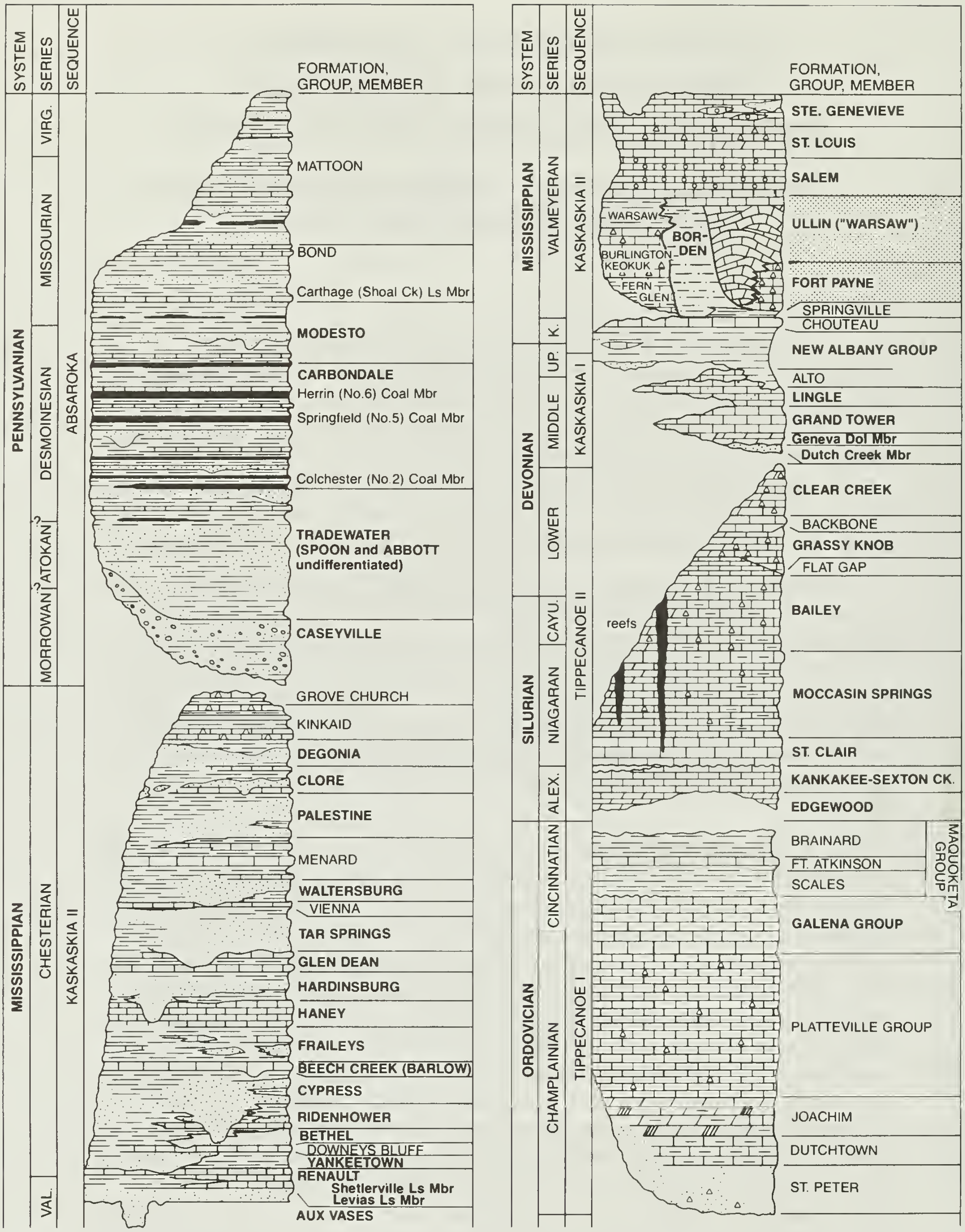

Figure 1 Generalized stratigraphic column (St. Peter and younger) for southern Illinois. Study interval is highlighted. Formations or members that contain hydrocarbon pay zones are shown in bold type. Abbreviations: Alexandrian (Alex.), Cayugan (Cayu.), Upper Devonian (Up.), Kinderhookian (K.), Valmeyeran (Val.), and Virgilian (Virg.). Variable vertical scale. (Modified from Howard 1991.)

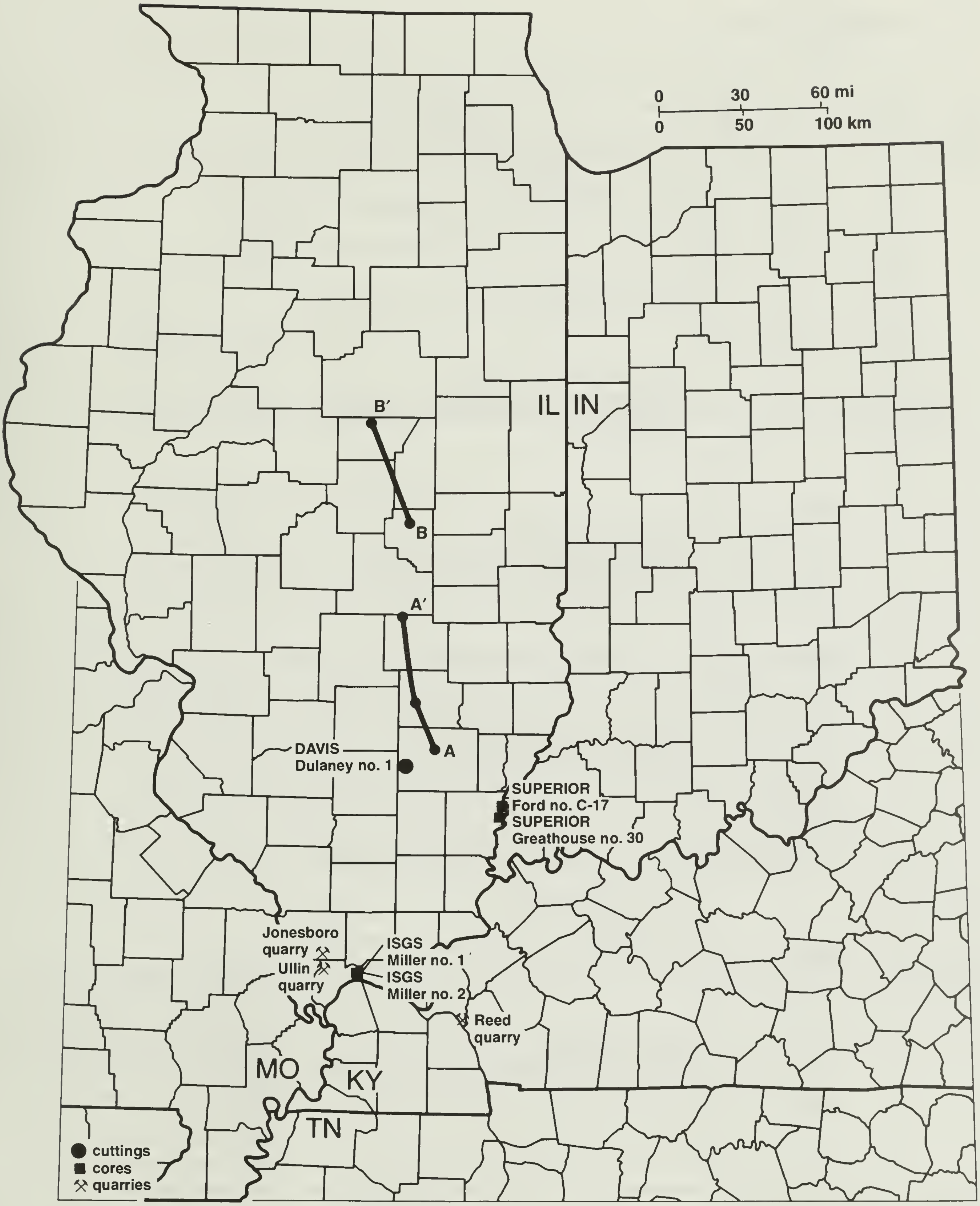

Figure 2 Regional map showing location of quarries, cores, other wells, and cross sections.

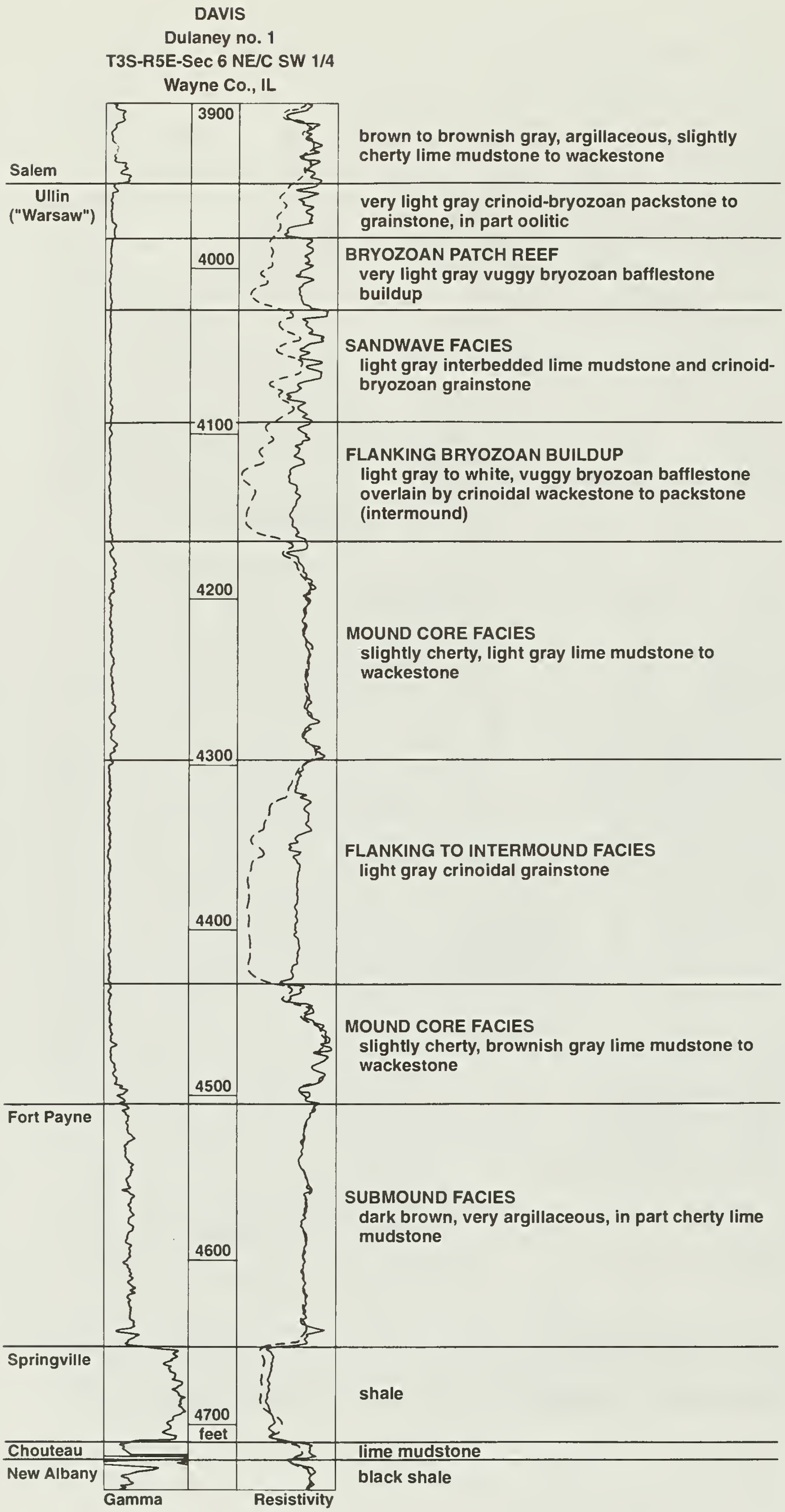

Figure 3 Wireline log (Davis Dulaney no. 1, Wayne County, Illinois) showing various facies of the Ullin ("Warsaw") including the inferred mound facies and in situ bryozoan bafflestone buildup as seen in drill cuttings. The term bryozoan patch reef is used for the more isolated and smaller bryozoan bafflestone buildups in the upper Ullin. Petrographically, these bryozoan patch reefs are similar to bryozoan bafflestone buildups associated with Waulsortian mounds in the lower part of the Ullin.

Table 1 Classification of limestones according to depositional texture (modified from Embry and Klovan 1971, and Dunham 1962).

allochthonous limestones (original components not organically bound during deposition)						autochthonous limestones (original components organically bound during deposition)		
<10% components (>2 mm)				>10% components (>2 mm)		supported by organisms which act as baffles	supported by organisms which encrust and bind	supported by organisms which build a rigid framework
contains lime mud (<.03 mm)			no lime mud	matrix-supported	component-supported			
mud-supported		grain-supported						
<10% grains (>.03 mm, <2 mm)	>10% grains							
mudstone	wackestone	packstone	grainstone	floatstone	rudstone	bafflestone	bindstone	framestone

Carbonate Rock Classification

Terminology for carbonate rocks used in this guidebook (table 1) follows that proposed by Embry and Klovan (1971), who expanded on Dunham's (1962) carbonate classification. This classification is based on matrix-particle relationships, particle size, and the distinction between particles that are organically bound (autochthonous) or not organically bound (allochthonous).

Bafflestone is generally defined as a limestone containing in situ stalked-shaped fossils, which may trap sediments by acting as baffles (Embry and Klovan 1971). In this guidebook, the term *bafflestone* refers to in situ bryozoan-dominated buildups that developed on the flank and crest of Waulsortian-type mounds or on transported skeletal sand piles. The term *bryozoan patch reef* is used for the smaller and more isolated bryozoan-dominated bafflestone buildups in the upper Ullin. The term *coated grains* refers to allochems with dark micritic coats possibly of algal origin; micritized grains result from microboring of allochems and later infilling of those microborings by micritic sediments or cements.

Depositional Model

The Ullin Limestone of the Illinois Basin contains (1) Waulsortian-type carbonate mound complexes, (2) transported mound-like to lenticular bryozoan–crinoid sand piles (packstones to grainstones), and (3) storm-generated sandwaves.

Waulsortian-type mounds developed below storm-wave base in a deeper water, outer ramp setting and, rarely, in shallower, mid-ramp environments (for ramp terminology, see Burchette and Wright 1992). Mound development was terminated as gradual shallowing up to storm-wave base occurred through time. Subsequently, storm-generated sandwaves, lenticular to mound-like skeletal sand piles, and bryozoan patch reefs became widespread in a mid-ramp setting during this later stage of the Ullin deposition. Lenticular sand piles are moderately sorted and partially laminated, suggesting deposition by currents rather than in situ development. The fine grained size and mound-like geometry suggest that the lenticular sand piles were deposited in more distal parts of the mid-ramp setting than were the overlying storm-generated sandwaves. Facies of Waulsortian-type mounds and lenticular skeletal sand piles generally coalesce laterally and vertically into complex carbonate bodies that range from 50 to 500 feet long and 20 to 70 feet thick in outcrop, and thicken basinward in the subsurface of Illinois.

A schematic diagram (fig. 4), based mainly on quarry exposures, illustrates our model for development of mounds and related facies within the Ullin (see Lasemi, this guidebook). The typical log character for some of these facies in the subsurface is illustrated in a sample wireline log from Wayne County (fig. 3). In the early stage of Ullin deposition (fig. 4a), Waulsortian-type mounds (mudstone to wackestone) were developed in the outer ramp setting. In the deeper part of the outer ramp (Reed quarry), mounds grade into the dark-colored, argillaceous, spiculitic lime mudstone of the Fort Payne Formation. These mounds are flanked by dipping, well bedded, transported, low-porosity wackestone to packstone. In the shallower part of the outer ramp setting (ISGS Miller nos. 1 and 2 cores), an in situ bryozoan-crinoid bafflestone buildup developed on the crest and flank of the mound core. This bafflestone buildup is generally porous and could be a potential hydrocarbon reservoir where permeable. Bryozoan-crinoid sand accumulated as storm-generated sandwaves and lenticular sand piles in the mid-ramp setting (Ullin and Jonesboro quarries) and as a debris apron in intermound areas of the outer ramp setting. This facies becomes muddier basinward.

By the late stage of Ullin deposition (fig. 4b), the lower part of the Ullin had built up to a shallower environment above storm wave base. This late stage represents a progradational phase of Ullin deposition. Storm-generated sandwaves (grainstone) are widespread in the upper part of the Ullin. Log character and sample studies indicate that this is generally a porous facies. The sandwaves grade from thicker and coalesced units (up to 150 feet thick) in shallower, mid-ramp settings (Jonesboro quarry) to more isolated units basinward (Reed quarry). The isolated sandwaves interfinger with the denser intersandwave facies, which becomes muddier basinward. Porous bryozoan-dominated bafflestone buildups are also present in the upper Ullin. These buildups developed as patch reefs on isolated mud mounds and mound-like skeletal sand piles. Examination of drill cuttings and core from some producing wells indicates that the hydrocarbon reservoir is mainly in these bryozoan patch reefs in the upper Ullin.

Both sandwaves and isolated mounds probably formed depositional highs in the upper part of the Ullin (fig. 4b). Cluff (1984) also identified the Ullin–Salem contact as irregular. The highs may have been sites for development of oolitic shoals during deposition of the upper Ullin and/or lower Salem Limestones. Thus, the oolite shoals in the Salem may provide a means of locating isolated mounds and sandwaves in the Ullin, all potential hydrocarbon reservoirs.

Hydrocarbon Potential

Waulsortian-type mound facies similar to those in the Ullin Limestone are prolific hydrocarbon reservoirs in several regions in North America. In the Illinois Basin the Ullin is an oil-producer (see appendix), but its potential as a reservoir has been largely overlooked. Recent drilling in southern Illinois has encountered prolific petroleum-producing zones within the Ullin Limestone. This information along with large cumulative production rates from several older

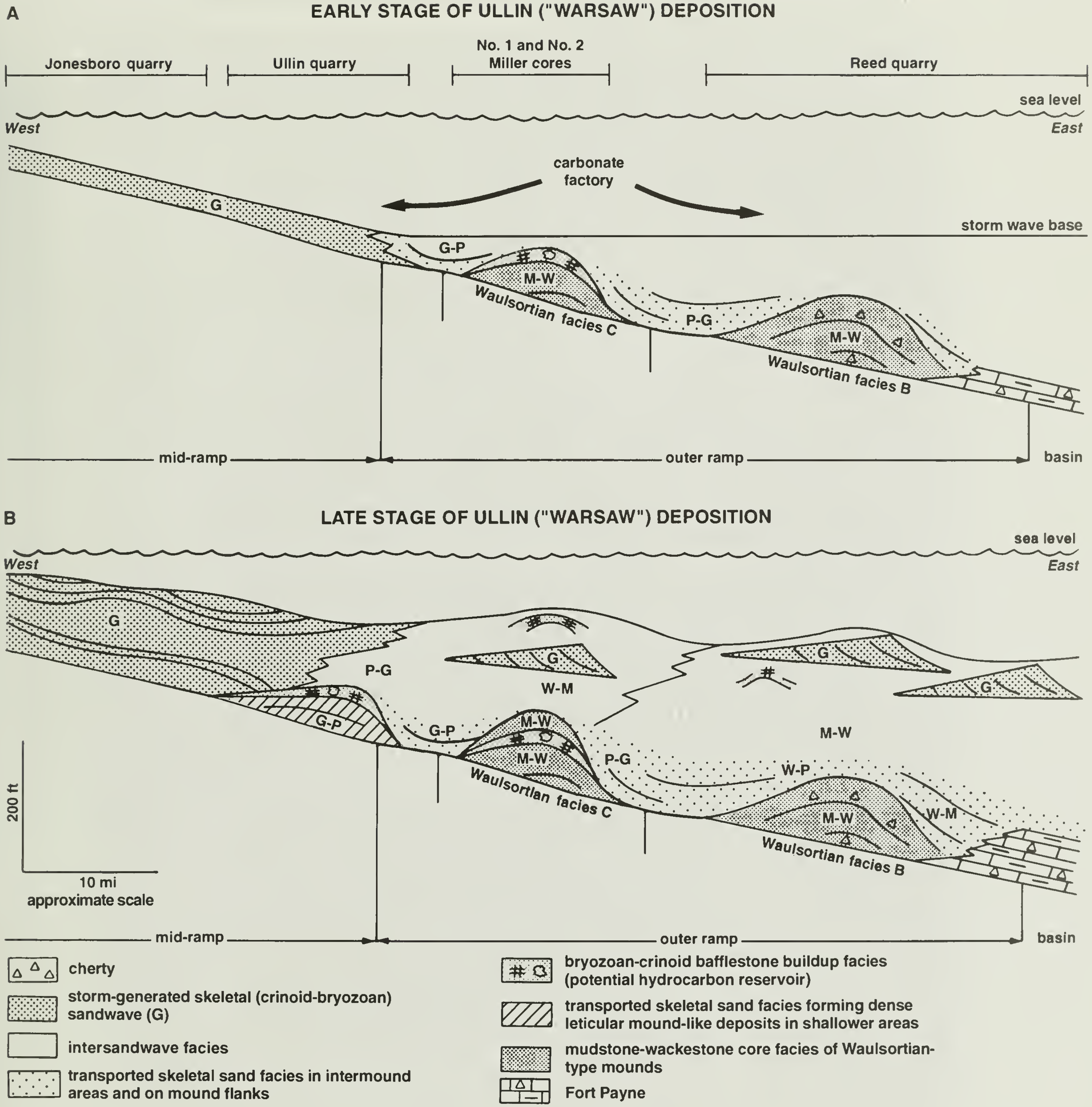

Figure 4 Ullin ("Warsaw") and Fort Payne depositional model, based mainly on quarry exposures: (A) early stage of the Ullin mound development on a ramp after the transgression of the Fort Payne sea (see fig. 31 for description of Waulsortian facies B and C); (B) late stage of the Ullin deposition representing a shallow ramp with widespread sandwave and bryozoan patch reef facies developed on a skeletal grainstone or lime mudstone high. Horizontal distance is approximately 70 miles; vertical scale is approximately 300 feet (outcrop) to 700 feet (subsurface). Slope of ramp is exaggerated. Ramp subdivisions based on Burchette and Wright 1992. Symbols used on diagram: M = mudstone, W = wackestone, P = packstone, G = grainstone.

wells in the Illinois Basin indicates that the Ullin has a greater reservoir potential than previously recognized.

Because of excellent preservation of intra- and interparticle porosity, the bryozoan bafflestone buildup has a high potential for reservoir development where permeable. High porosity is also characteristic of debris aprons (deposited downslope from the mound in intermound areas) and storm-generated sandwaves in the Ullin. Porosity, permeability, and reservoir quality may be variable, however, and depend on the relative abundance of crinoid fragments. This is partly because crinoids are susceptible to overgrowth cementation, which can occlude porosity. Furthermore, permeability could be reduced by the presence of micrite, especially in bryozoan bafflestone buildups. In such cases, the reservoir permeability may be enhanced by fracturing (Tom Partin, consultant, personal communication 1994).

Overview of Stops

Facies observed in the quarries represent a transition from what has been interpreted by the authors as a relatively deep-water setting (Reed quarry in Kentucky) to a relatively shallower water setting (Ullin and Jonesboro quarries in Illinois). Detailed descriptions of quarry exposures begin on page 10.

The various facies will be discussed at each of the stops. Between stops 1 and 2, we will stop at the Kentucky Dam visitors area to have lunch while watching the river traffic.

1. **Reed quarry, about 30 miles east of Metropolis, Illinois, in Kentucky** The Fort Payne, the various facies of the overlying Waulsortian mound complexes of the lower part of the Ullin, and the sandwave and intersandwave facies of the upper part of the Ullin are well exposed here. The morphology of the mounds is clearly observable. The only exposed facies in this quarry that is a potential hydrocarbon reservoir is the transported facies in the upper part of the Ullin.

2. **Ullin quarry about 1 mile north of Ullin, Illinois** Numerous small lenticular mounds can be seen in the lower 45 to 50 feet of the quarry. In one area, a mound complex of the lower part of the Ullin is flanked by a thin reservoir-quality, bryozoan bafflestone facies.

3. **Jonesboro quarry, about 6 miles south of Jonesboro, Illinois** The crossbedded packstone–grainstone of the upper part of the Ullin is well exposed in this quarry. There is evidence for storm deposition of this interval. The relatively high porosity of this facies (see Harvey, this guidebook) makes it promising as a potential hydrocarbon reservoir where permeable.

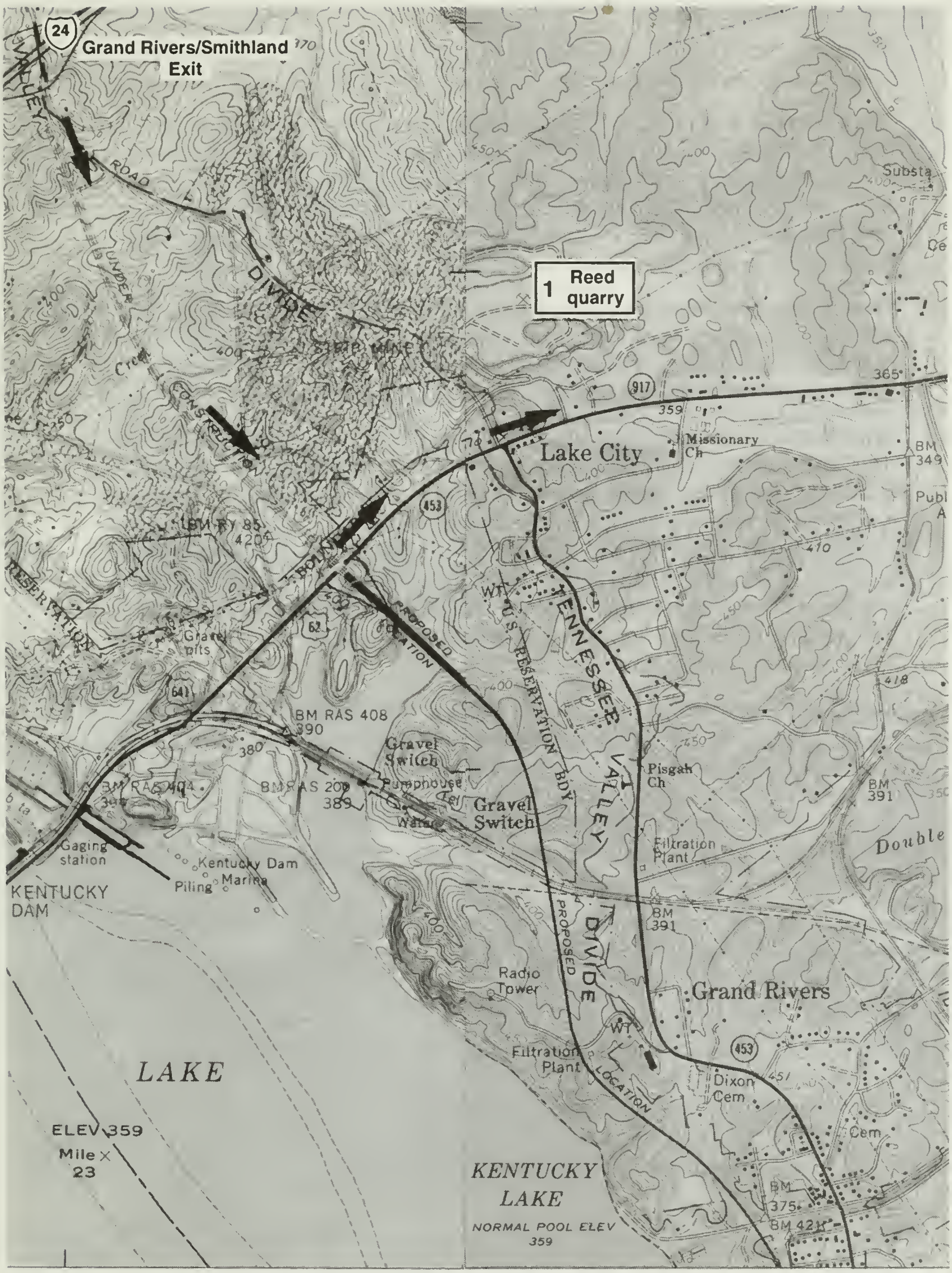

Figure 5 Location of the Vulcan Materials Company Reed quarry, 20-G-15, 16-G-16; Calvert City and Grand Rivers 7.5-minute quadrangles.

STOP DESCRIPTIONS

Stop 1. Reed quarry

■ 20-G-15, 16-G-16; Calvert City and Grand Rivers 7.5-minute quadrangles, Livingston County, Kentucky (fig. 5; see Dever and Teitloff, this guidebook)

The bedded submound facies (Fort Payne), the mound core facies (lower Ullin), the mound flank and intermound facies (lower Ullin), and the overlying sandwave and intersandwave facies (upper Ullin) will be examined in this quarry (figs. 4, 6, 7). The Ullin of Illinois is roughly equivalent to the Warsaw and upper Fort Payne of Kentucky (see Norby, this guidebook). Although the Salem Limestone is partly exposed in this quarry, it will not be covered in this guidebook.

The carbonate rocks exposed in this quarry include approximately the upper 150 feet of the Fort Payne Formation, approximately 240 feet of the Ullin Limestone, and the lower part of the Salem Limestone. Total thickness of the Fort Payne is approximately 500 to 600 feet in this area (Dever and McGrain 1969).

Submound facies (Fort Payne) This facies (fig. 8) is a well bedded, generally 0.5 to 2 feet thick, argillaceous, in part pyritic, spiculitic, and siliceous limestone (fig. 9) with scattered chert bands. It is typically dark brown to dark gray brown and contains some transported crinoid and rare bryozoan fragments. A similar lithology also characterizes the Fort Payne in the subsurface of Illinois (see also Lineback and Cluff 1985). The dark coloration is probably due to the presence of organic matter in the rock, which emits a strong fetid odor when it is broken or sawed. Further work is needed to assess the potential of the Fort Payne as a hydrocarbon source rock.

Dark gray shale partings are common on bedding planes. Laminations are commonly preserved within the Fort Payne because of the lack of bioturbation (fig. 10). Preliminary petrographic data reveal the presence of rare pelagic radiolarians. These features and the presence of *Chondrites* and *Zoophycus* trace fossils (fig. 10) indicate that the Fort Payne was deposited under disaerobic conditions in a relatively deep-water setting, as suggested by Lineback and Cluff (1985).

The Fort Payne Formation in part of this quarry contains large wedges of well bedded lime mudstone. The wedge bases are in sharp contact with the underlying unit. The origin of these features may be related to slumping during or after deposition.

Mound core facies (lower Ullin) Overlying the bedded submound facies of the Fort Payne is a series of carbonate mud mounds. A mound complex is well exposed on the west wall of the quarry (figs. 6, 7, 11). This appears to be a composite mound consisting of laterally overlapping individual mounds and onlapping flanking beds that dip about 20°. The mound complex is about 60 to 70 feet thick and 500 feet wide. The core of the mound is dark gray, massive lime mudstone to wackestone (fig. 12) with common bryozoan fronds, crinoids, and scattered calcified sponge spicules (fig. 13). The mound, in part, appears to be composed of thick multiple layers, which may represent various stages of mound growth during vertical accretion. The massive nature of the mound core is in sharp contrast with the well bedded submound facies.

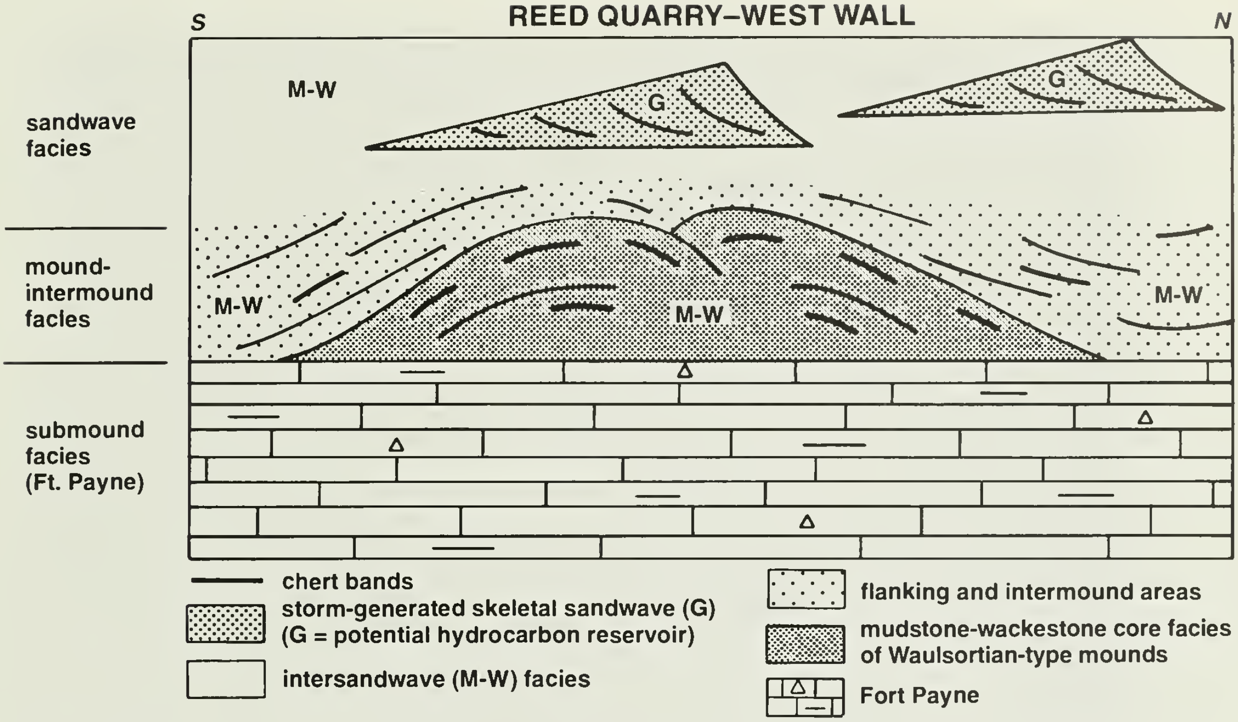

Figure 6 Diagram of the west wall in Reed quarry showing the bedded submound facies (Fort Payne), mounds with flanking and intermound facies (Ullin ["Warsaw"]), and the overlying sandwave facies (upper Ullin). Symbols used on diagram: M = mudstone, W = wackestone, P = packstone, G = grainstone.

Figure 7 Mound complex on the west wall of Reed quarry (see figs. 6 and 11). C = mound-core facies, F = flanking facies, I = intermound facies. Mound core (C) is approximately 70 feet high, top indicated by white dashed line.

Figure 8 Well bedded carbonates of the Fort Payne Formation (submound facies) in Reed quarry. Quarry wall is approximately 60 feet high.

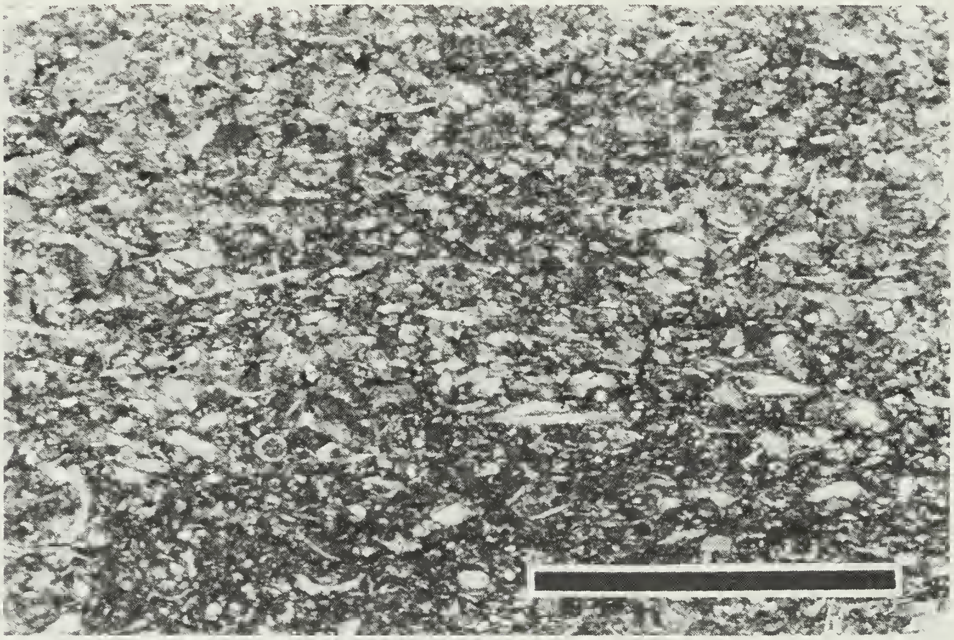

Figure 9 Thin section photomicrograph (plane light) of the Fort Payne lime mudstone (submound facies) containing some comminuted crinoids and scattered calcified sponge spicules (needle-shaped grains). Reed quarry, western Kentucky. Bar scale = 1 mm.

Figure 10 Thin section photomicrograph (plane light) of the Fort Payne Formation from a core. Note well preserved lamination, suggesting the lack of bioturbation. Light colored, churned area on the left in the central part of the photomicrograph might be *Zoophycus*, a trace fossil. Core sample from 4,182 foot depth, Superior Oil no. C-17 Ford, NW SW SE Sec. 27, T4S, R14W, White County, Illinois. Bar scale = 0.5 cm.

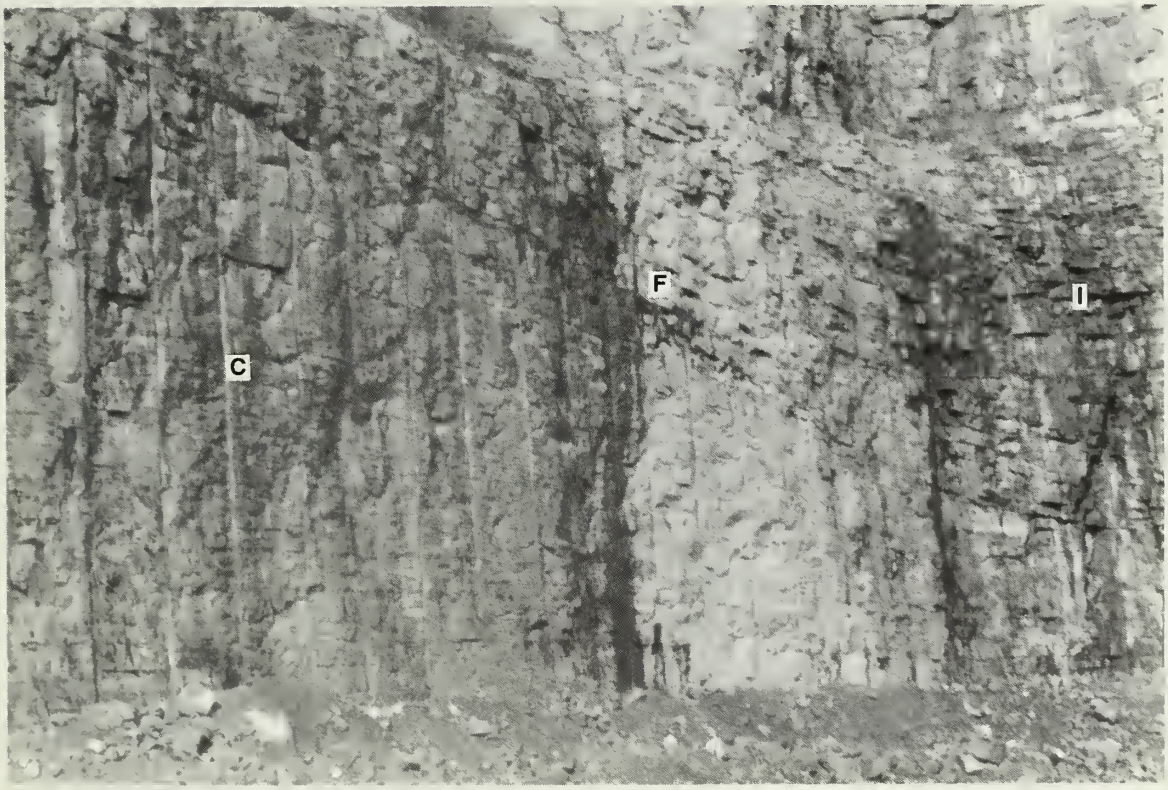

Figure 11 Close view of part of the mound core facies (see figs. 6, 7) with well bedded, dipping flank beds on the west wall of Reed quarry. Flanking beds become horizontally bedded in intermound area to the right. C = core facies, F = flanking facies, I = intermound facies. Quarry wall is approximately 70 feet high in center of photograph.

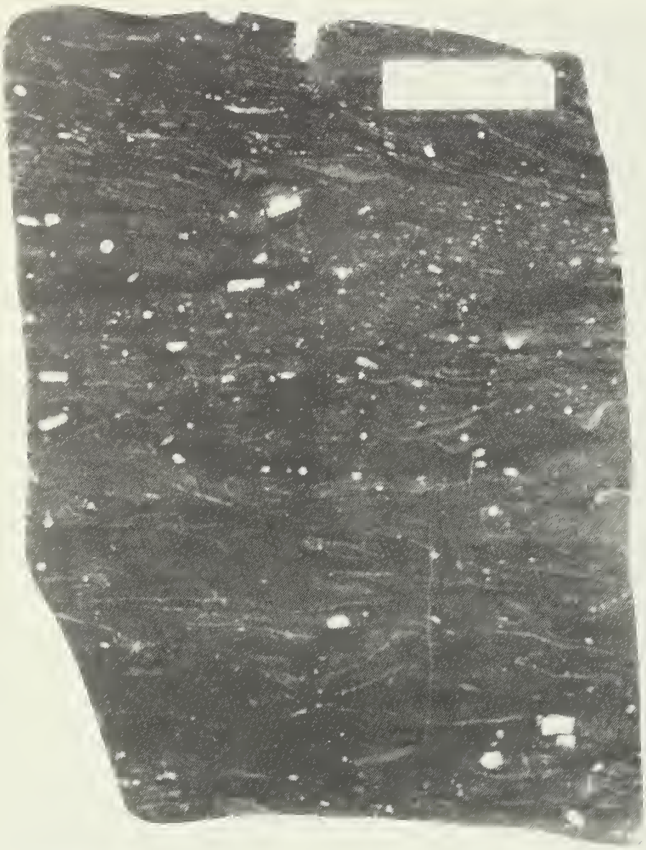

Figure 12 Polished slab of the lime mudstone to wackestone facies of the mound core in Reed quarry (see fig. 11). Note fenestrate bryozoan fronds and scattered crinoid fragments (light colored). Bar scale = 2.5 cm.

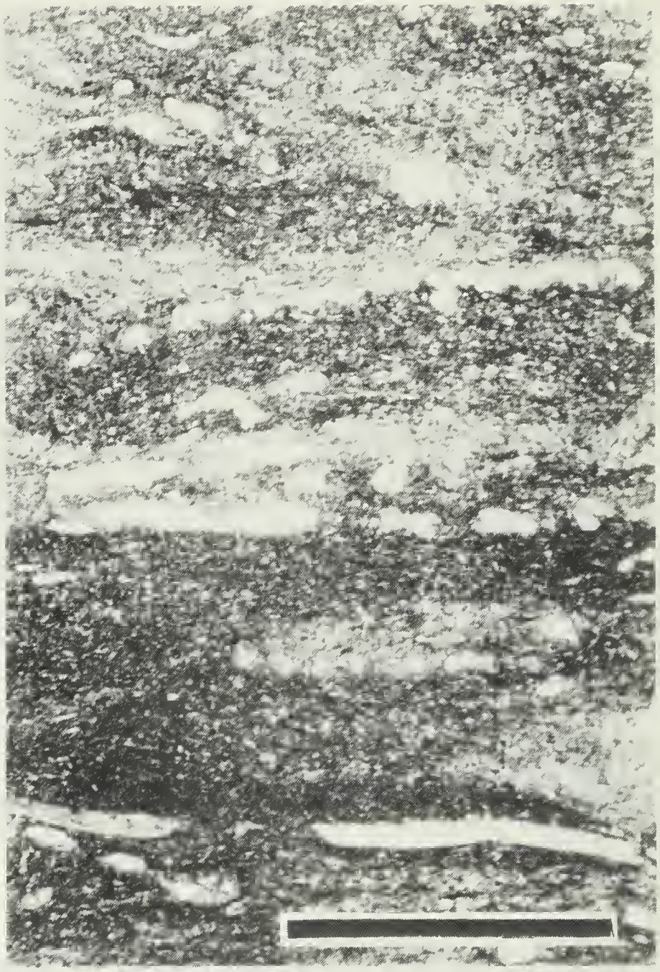

Figure 13 Thin section photomicrograph (plane light) of the mound core facies (Reed quarry) showing fenestrate bryozoan fronds, scattered crinoid fragments, and rare ostracods (e.g., fingernail-shaped grain at top left). Some of the small needle-shaped grains may be sponge spicules. Bar scale = 0.5 cm.

The mound contains abundant narrow and elongate chert bands (fig. 14) that range from less than 1 inch to a few inches thick and from a few inches to several feet long. Crinoid and rare bryozoan debris form a geopetal fabric at the base of some chert bands. This feature suggests to us that chert may have formed as silica precipitated in preexisting cavities. Most cherts are very dark gray to black and commonly pyritic, suggesting the presence of decomposing organic matter prior to or during chert formation. Closer examination shows that the chert bands follow the orientation of the mound. Chert bands rarely crosscut the mound flank into the bedded flanking facies. The chert, whatever its origin, probably formed simultaneously with mound development.

Numerous other mounds are present throughout the quarry at about the same level. Exposure of these mounds is poor, but their presence can be inferred from the dipping flank beds. Some mounds (for example, on the north wall) are bedded (2–3 feet thick), lenticular bodies up to 20 feet thick. Chert bands are rare, but shale partings are relatively common on bedding planes. Flanking beds are partially crinoid-rich and vary from wackestone to rare occurrences of crinoidal packstone with fragmented bryozoan matrix.

Figure 14 Chert bands and nodules in the mound core facies of the Ullin ("Warsaw") in Reed quarry. Hammer (lower left) for scale.

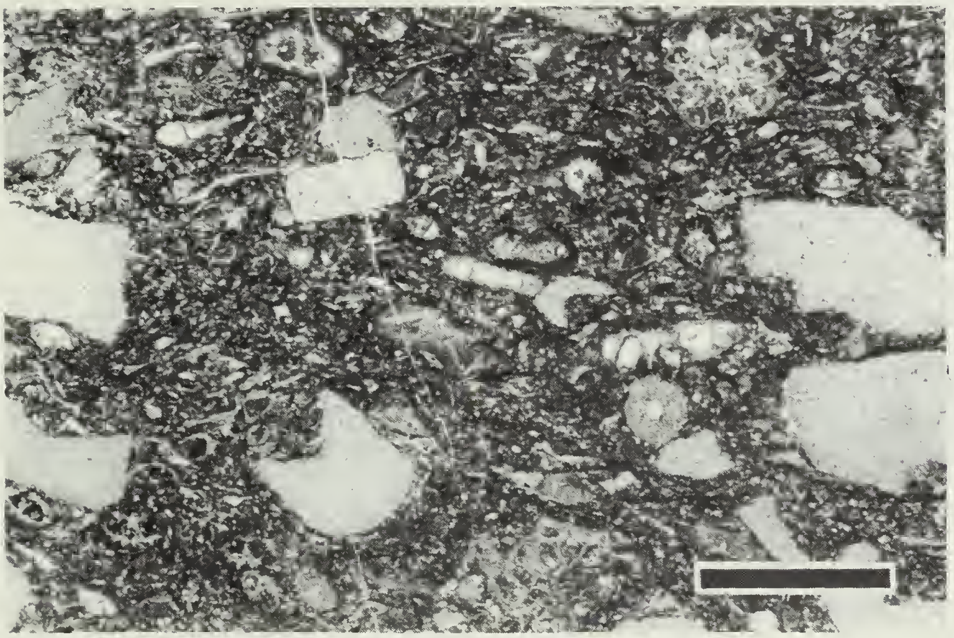

Figure 15 Thin section photomicrograph (plane light) of crinoid-bryozoan wackestone to packstone facies of the flanking beds of the Ullin ("Warsaw") mound in Reed quarry. Note the calcite-filled microfracture. Bar scale = 1 mm.

Mound flank and intermound facies (lower Ullin) Flanking beds onlap the mound core with a dip of about 20° (figs. 6, 7, 11). They are well bedded lime mudstone and wackestone (fig. 15) with scattered crinoid and bryozoan fragments. Crinoid concentrations can be quite high locally, resulting in thin crinoidal packstone beds (fig. 16). Some chert bands are also present in the flanking beds, which grade into horizontally bedded, cherty lime mudstone facies in intermound areas (figs. 6, 7, 11). Graded bedding may be present

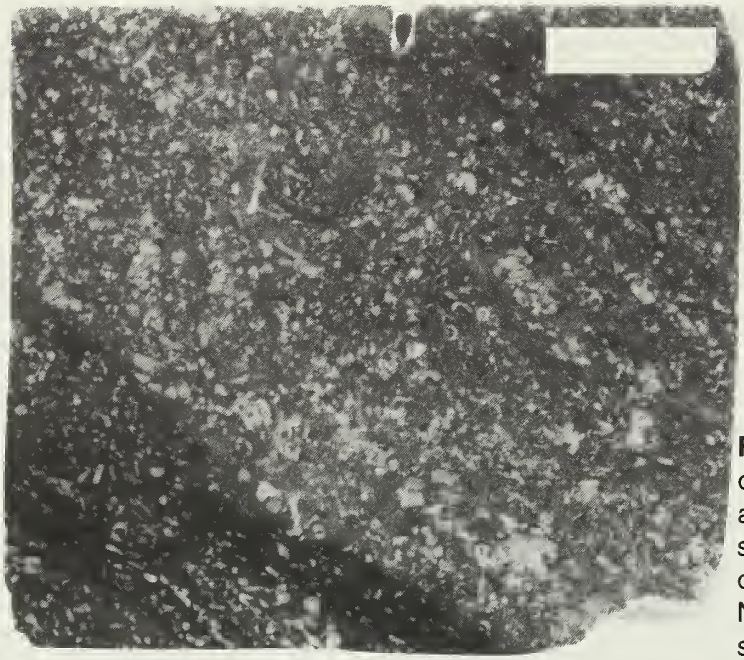

Figure 16 Polished slab of crinoid (light colored) and bryozoan (dark) packstone from the flanking bed of a mound in Reed quarry. Note inclined lamination. Bar scale = 2.5 cm.

Figure 17 Sandwave (light-colored, crinoid-bryozoan grainstone) and intersandwave (dark, dense cherty lime mudstone) facies of the upper Ullin ("Warsaw") in Reed quarry, Kentucky. Quarry wall in center is approximately 70 feet high. Note person at lower right for scale.

in the intermound area, indicating redeposition by downslope off-mound transport. Because of their mud-dominated nature, the flanking beds in this quarry are poor candidates for reservoir development.

Sandwave facies (upper Ullin) Overlying the mound and flanking facies are a series of wedge-shaped, skeletal sand bodies (figs. 6, 17) composed mainly of crinoid-bryozoan packstone and grainstone. These skeletal sand bodies appear to be mostly massive due to partially obscured surface exposure or bioturbation, but some show large-scale, inclined laminations. The geometry of these sand bodies indicates that they probably were deposited as asymmetrical sandwaves. Large-scale inclined bedding may represent slipface migration of the sandwaves. The sandwave facies grades laterally into a dense, cherty lime mudstone of the intersandwave facies. Thin shale partings occur in places, suggesting deposition from waning currents. The sandwaves are interpreted to be storm deposits in relatively deep water, below normal wave base. We will see clearer evidence for storm deposition at Stop 3 in the Jonesboro quarry.

Although the sandwave facies is well cemented at this outcrop, it is generally porous in the subsurface. The dense intersandwave lime mudstone facies provides an excellent barrier for entrapment of hydrocarbons. The low porosity of the sandwave facies in outcrop may be due to a higher susceptibility to subaerial diagenesis and fresh-water cementation (work in progress). Preservation of porosity in the sandwave facies in deeper parts of the basin may be related to rapid burial that preceded subaerial exposure and thus prevented fresh-water cementation. Furthermore, the presence of minor amounts of marine cements in some areas may have been instrumental in preventing the occlusion of pores during diagenesis that occurred after burial of the deposits. Marine cement was apparently sufficient to stabilize the rock fabric without totally occluding all primary pore spaces, which resisted compaction and pressure solution during burial.

Stop 2. Ullin quarry

■ S1/2 SW NE and N1/2 NW SE Section 14, T14S, R1W; Dongola 7.5-minute quadrangle, Pulaski County, Illinois (fig. 18)

An exposure of about 180 feet of the Ullin Limestone appears, upon first inspection, to consist of two facies. One facies, which forms the basal 45 to 50 feet of the quarry, includes a medium gray, in part slightly cherty packstone to grainstone typical of the lower Ullin (fig. 4b). The upper facies is mainly a light gray, fine grained, crinoid-bryozoan packstone to grainstone, typical of the upper Ullin.

Lower Ullin Close examination of carbonates in this quarry reveals a complex facies relationship. The lower Ullin appears to be composed of a series of lenticular carbonate bodies, which may coalesce laterally and vertically into more complex carbonate mounds (fig. 4b). Topographic irregularities in the quarry floor also imply the presence of mounds in the lower, unexposed Ullin. These lenticular mounds, as exposed in the lowest level of the quarry, are about 20 to 30 feet thick and 50 to 200 feet long, and have a lower (<5°) flanking slope angle than that observed in Reed quarry. As a result of blast fracturing, the form of the mounds is not as apparent here as in Reed quarry.

The core of these lenticular mounds is characterized by a generally massive to thick bedded limestone; fine lamination may be present in places. Thin section petrography reveals that the core facies is a moderately sorted, fine grained, bryozoan-crinoid grainstone. Unlike that of the mound core facies in Reed quarry, the micrite content is negligible, mainly limited to infilling of bryozoan zooecia. The lamination, moderate sorting, and lack of micrite matrix are evidence for deposition of these lenticular carbonate bodies by currents.

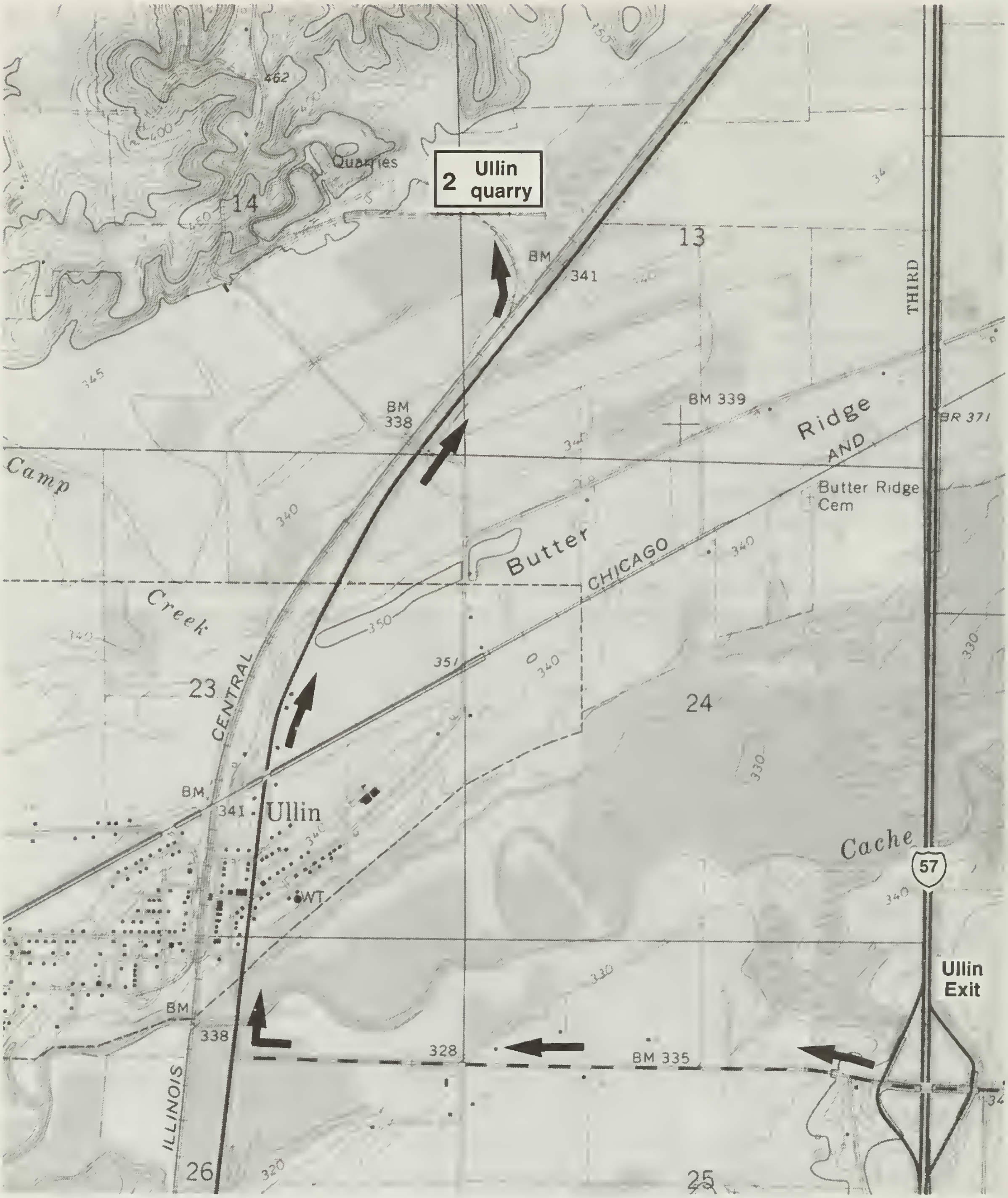

Figure 18 Location of the Columbia Quarry Company's Ullin quarry, S1/2 SW NE and N1/2 NW SE Sec. 14, T14S, R1W; Dongola 7.5-minute quadrangle, Pulaski County, Illinois.

The core facies is slightly cherty with white-weathering, elongate chert nodules (0.5–2 inches thick and a few inches to several feet long) that generally occur parallel to bedding. Many of these cherts have dark gray mottlings and speckles and may contain some disseminated pyrite and pyritic nodules. Dark gray mottling and pyrite imply a possible relationship between decomposition of former organic matter and genesis of the cherts. The massive core facies grades laterally and vertically into slightly coarser, lighter gray, well bedded and laminated to hummocky cross-laminated, crinoid-bryozoan grainstone facies.

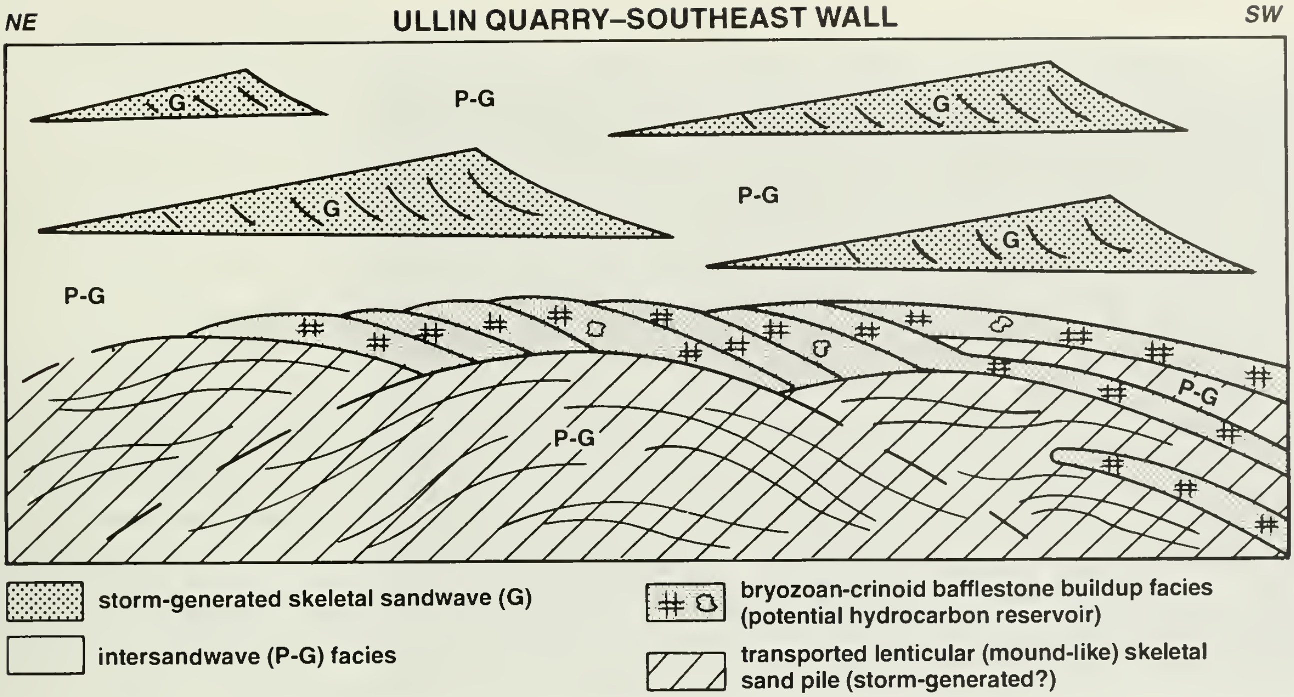

Figure 19 Interpretive sketch (see fig. 20) of a transported mound-like skeletal sand pile (bryozoan-crinoid grainstone) with flanking bryozoan bafflestone buildup (potential reservoir facies) and overlying sandwave facies (Ullin quarry, Illinois). Vertical scale approximately 50 feet; horizontal scale approximately 150 feet. Symbols used on diagram: P = packstone, G = grainstone.

Figure 20 Photograph mosaic of a mound-like skeletal sand pile complex with flanking bryozoan bafflestone beds (area between dashed lines) in the lower Ullin ("Warsaw") exposed on the southeast wall of Ullin quarry (see fig. 19).

Slightly higher in the quarry on the southeast wall along the main ramp, several lenticular mounds and mound complexes may be observed (figs. 19, 20). These mounds coalesce laterally and vertically, resulting in a complex mound system overlain by coarser packstone to grainstone facies of the upper Ullin. Similar to individual mounds, the core facies in these mounds is slightly cherty, massive grainstone (fig. 21). The apparent width of the mound complex is about 150 to 200 feet.

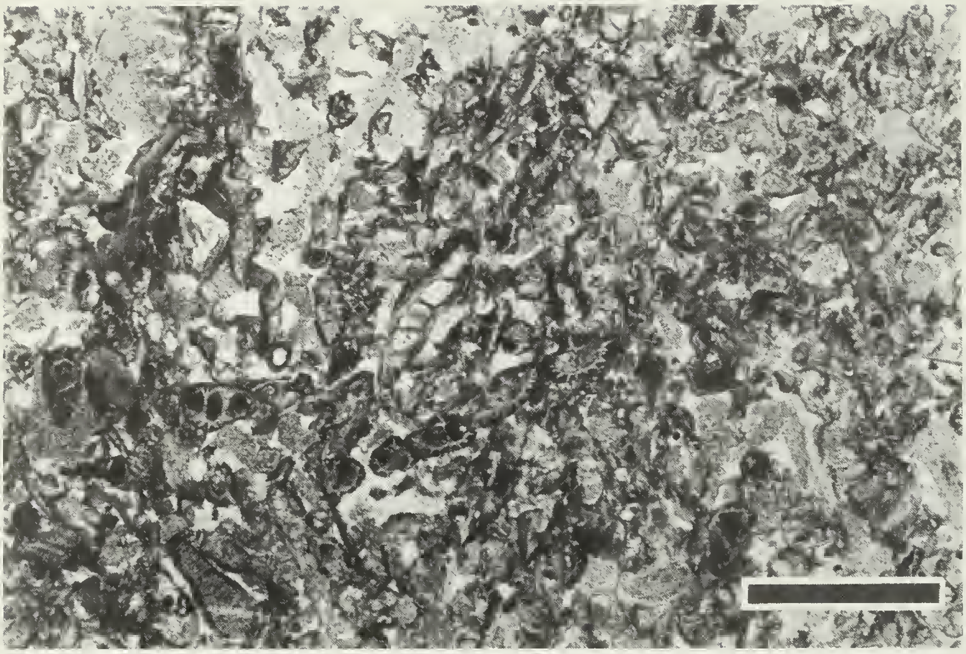

Figure 21 Thin section photomicrograph (plane light) of bryozoan-crinoid grainstone of a mound-like skeletal sand pile in Ullin quarry. White areas are syntaxial calcite cement overgrowths on crinoid fragments (gray). Bar scale = 1 mm.

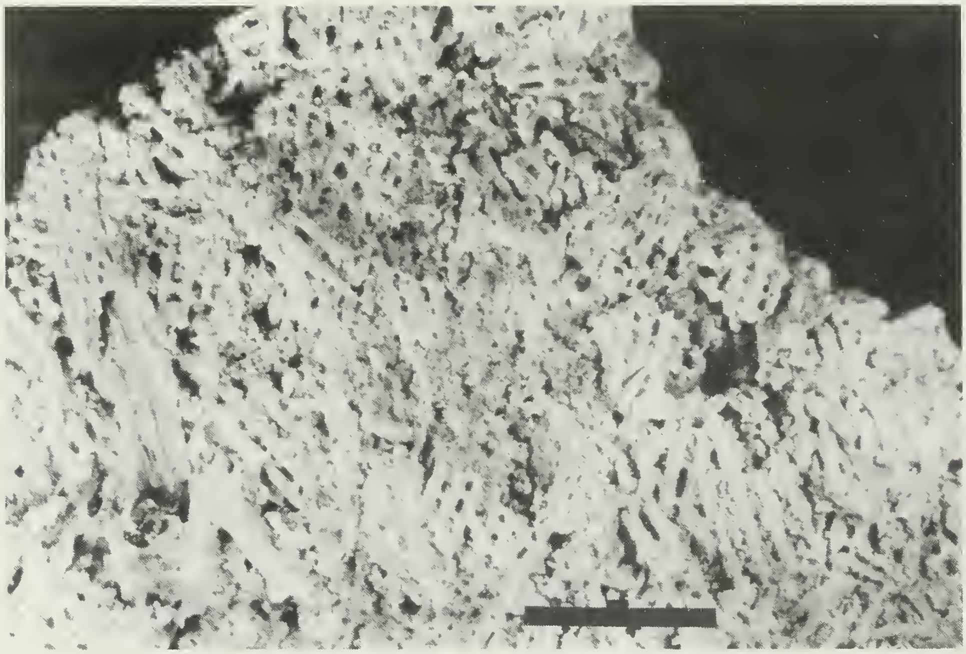

Figure 22a Flanking fenestrate bryozoan buildup from Ullin quarry (see figs. 19, 20). Bar scale = 0.5 cm.

The flanking facies consists of a highly porous and permeable bryozoan (90%) bafflestone buildup. Although it is about 1 to 5 feet thick at the top of the mound, it thins laterally and pinches out down the flank of the mound (figs. 19, 20). This well bedded bafflestone facies has beds 1 to 2 inches thick and an apparent dip of about 3° to 5° in the same direction as the mound flanks. It consists of generally well preserved fenestrate bryozoans (fig. 22a).

This facies occurs in at least three horizons in this mound complex, separated by the dense core facies (figs. 19, 20), forming vertically stacked mounds. Similar facies are also present at various horizons within the Ullin in the subsurface (figs. 3, 22b). The high porosity and permeability of this bafflestone facies (fig. 23) makes it an excellent candidate for reservoir development.

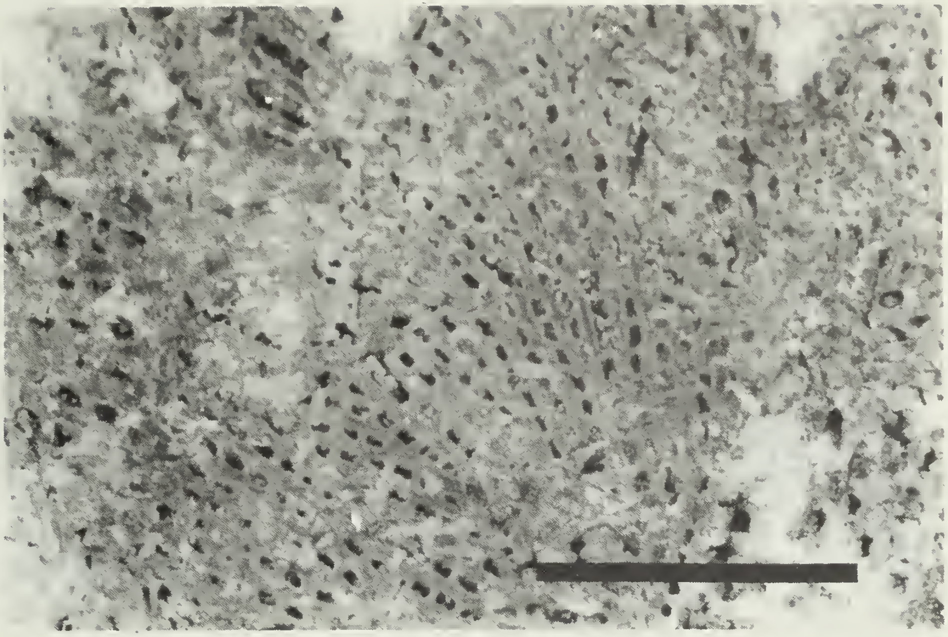

Figure 22b Reflected light photomicrographs of porous bryozoan bafflestone buildup with coarse, relatively well preserved fenestrate bryozoans characteristic of the reservoir facies of the Ullin ("Warsaw"). Core sample (Milestone Petroleum, Burlington-Northern no.1, SE SE NW Sec. 14, T6S, R2E, Franklin County, Illinois). Bar scale = 0.5 cm.

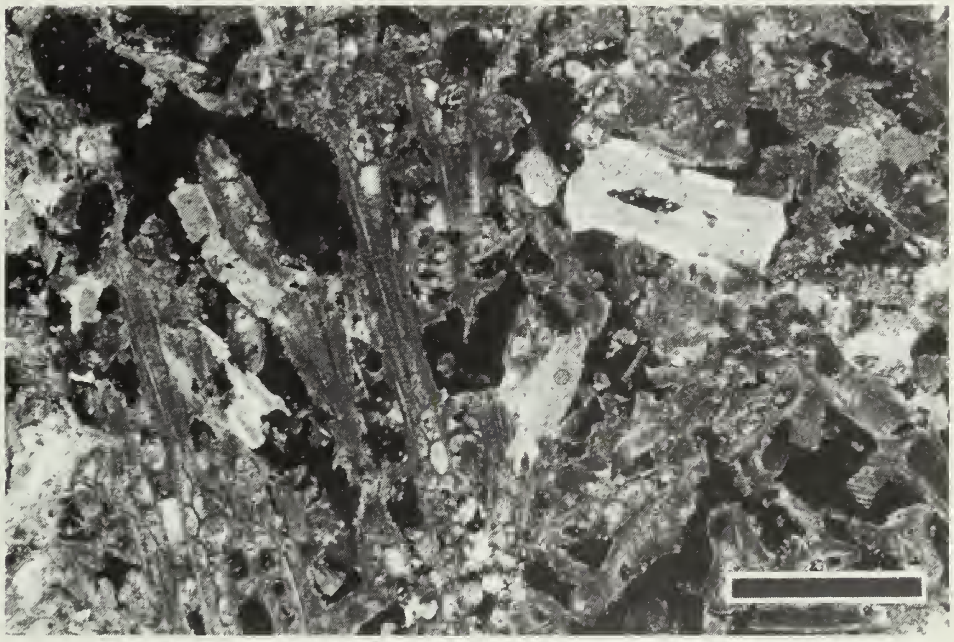

Figure 23 Thin section photomicrograph (cross-polarized light) of the porous bryozoan bafflestone facies (figs. 19, 20) with rare crinoids (Ullin quarry). Note high porosity (black). Bar scale = 1 mm.

This facies appears to be thicker and more laterally extensive northward in the subsurface. This facies of the Ullin produces hydrocarbons in Illinois.

Upper Ullin Very light gray, laminated to hummocky cross-laminated, medium to coarse grained, bryozoan-crinoid packstone–grainstone is interbedded with medium light gray, massive to slightly laminated, fine grained packstone–grainstone. This facies (figs. 4b, 19) is interpreted to represent interfingering sandwave and intersandwave facies (5–10 feet thick) similar to those in Reed quarry. Instead of the lime mudstone intersandwave facies that occurs in Reed quarry, a fine grained packstone–grainstone occurs here in the Ullin quarry. The low carbonate mud content of this facies, compared with that in the Reed quarry is most likely due to deposition in a somewhat

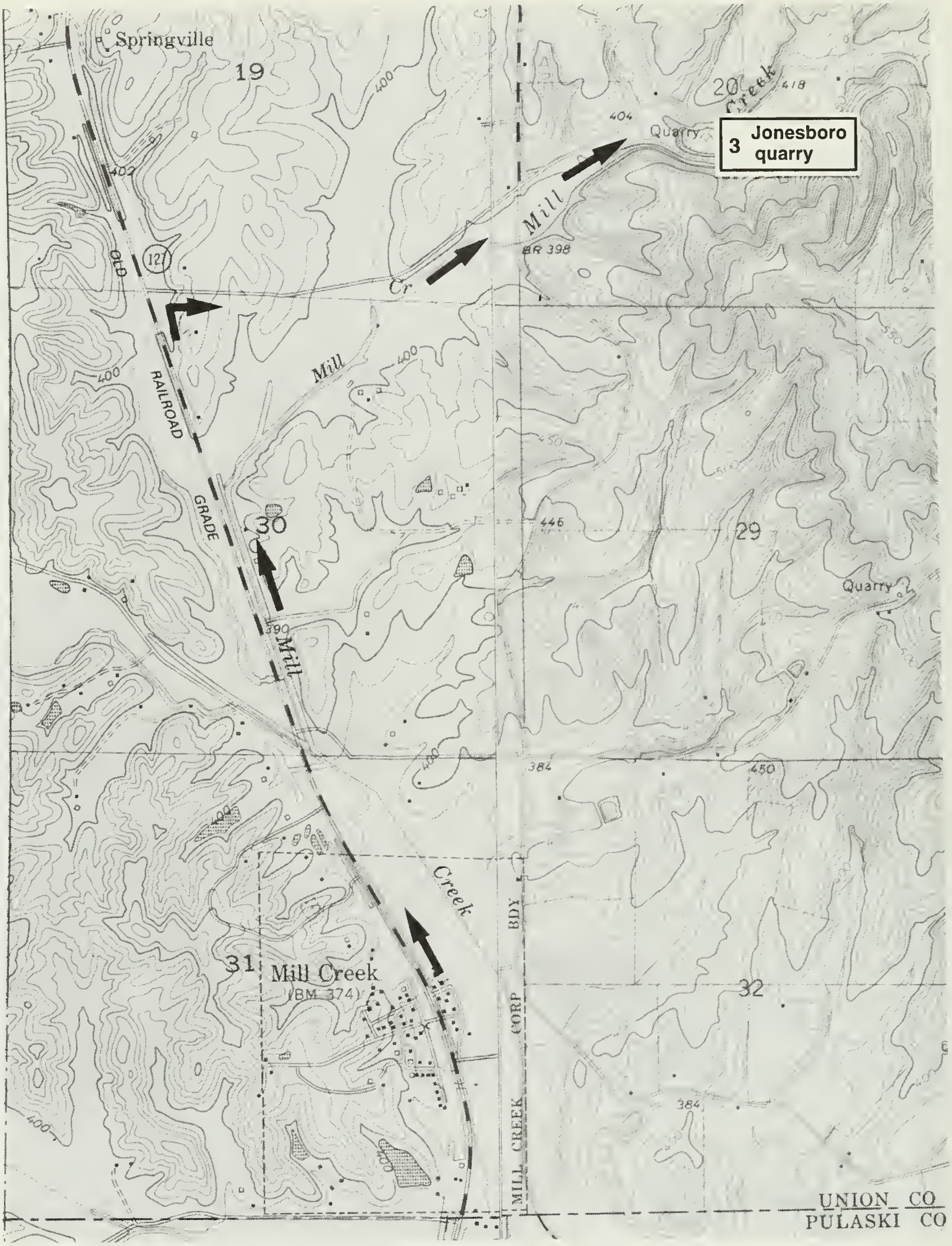

Figure 24 Location of the Columbia Quarry Company's Jonesboro quarry (NE SW Sec. 20, T13S, R1W; Dongola 7.5-minute quadrangle, Union County, Illinois).

shallower setting and thus higher energy conditions. The very light gray, coarser facies includes well developed, large-scale, inclined laminations possibly formed as a result of slipface migration of the sandwaves as a result of storm-generated currents. Storm deposition is supported by the presence of hummocky cross-stratification, as commonly observed in the adjacent and overlying units.

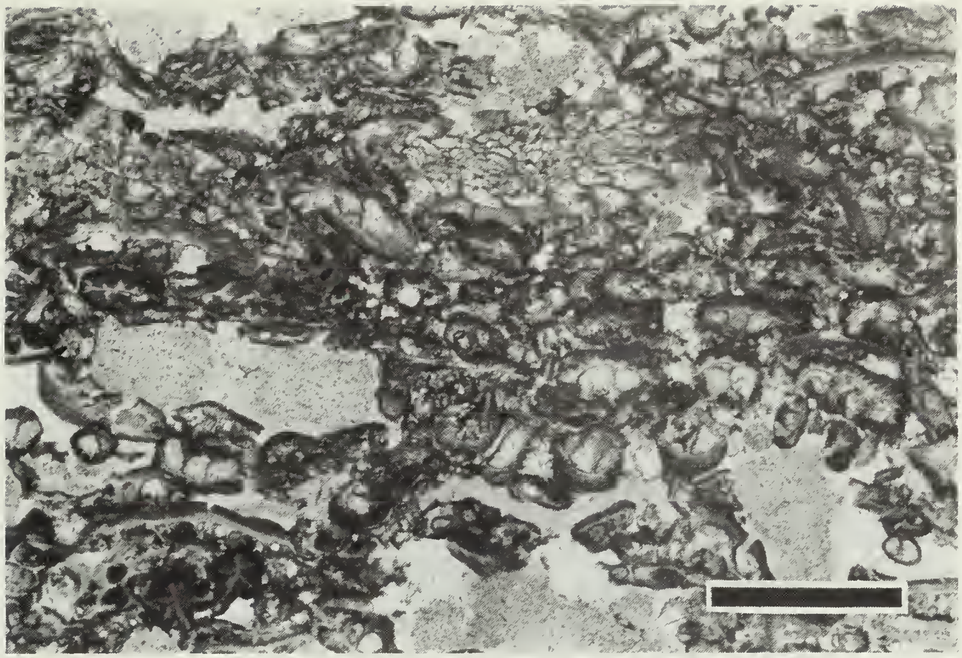

Figure 25 Thin section photomicrograph (plane light) of fenestrate bryozoan-rich, fine grained grainstone facies of the graded storm bed in the upper Ullin Limestone ("Warsaw") in Jonesboro quarry. Bar scale = 1 mm.

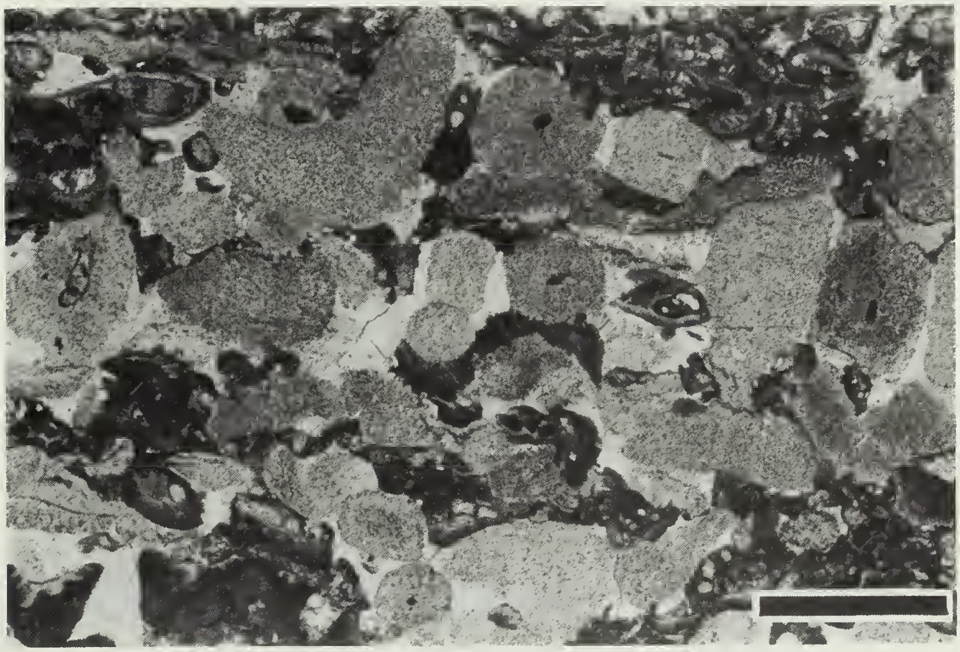

Figure 26 Thin section photomicrograph (plane light) of crinoid-rich, coarse grained grainstone facies of the graded storm bed in the upper Ullin Limestone ("Warsaw") in Jonesboro quarry. Note calcite cement overgrowths (white) on crinoids. Dark fragments are bryozoans. Bar scale = 1 mm.

Stop 3. Jonesboro quarry

■ NE SW Section 20, T13S, R1W; Dongola 7.5-minute quadrangle, Union County, Illinois (fig. 24)

The uppermost and possibly the shallowest facies of the Ullin to be seen on this field trip is exposed in this quarry (fig. 4b). The entire quarry section consists of about 150 feet of the upper Ullin. The limestone is dominated by a very light gray, coarse to very coarse crinoid-bryozoan to bryozoan-crinoid grainstone. The rock is well laminated and cross-laminated with alternating beds of very light gray, fine grained bryozoan-rich hash (fig. 25) and darker crinoid-rich sand (fig. 26). Graded bedding and hummocky cross-laminations (fig. 27) are very common throughout the unit. Evidence of bioturbation is minimal in these rocks, but escape burrow structures (fig. 28) were observed in some beds. These features in the Ullin Limestone in this quarry indicate relatively rapid deposition, probably by storm currents. The uppermost part of the Ullin in this quarry contains large-scale planar and trough crossbedding, indicating a more agitated depositional environment (possibly within normal wave base) than that for the rest of the Ullin.

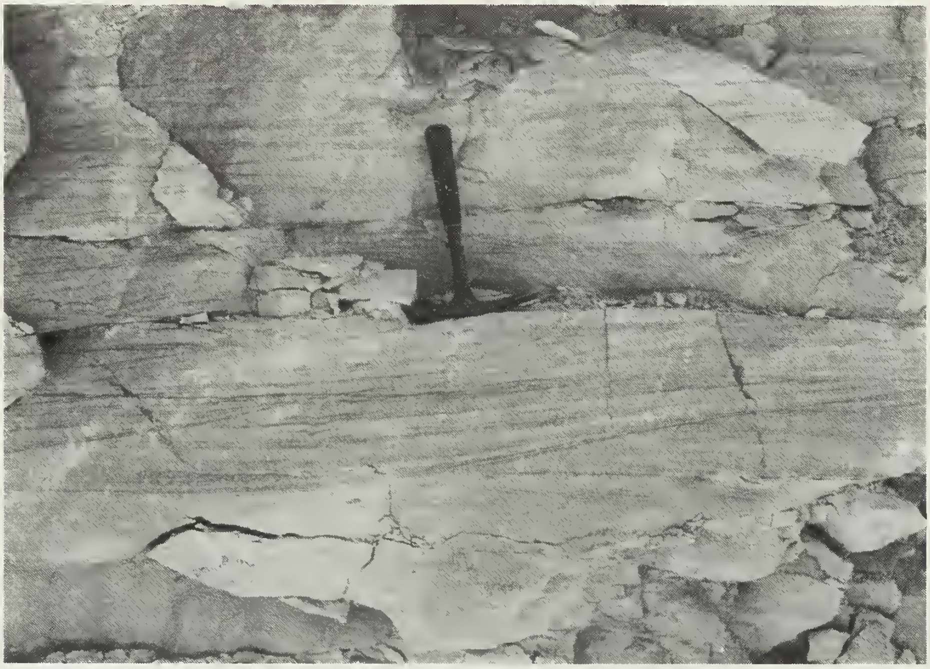

Figure 27 Hummocky cross stratification, common in the upper Ullin ("Warsaw") in Jonesboro quarry.

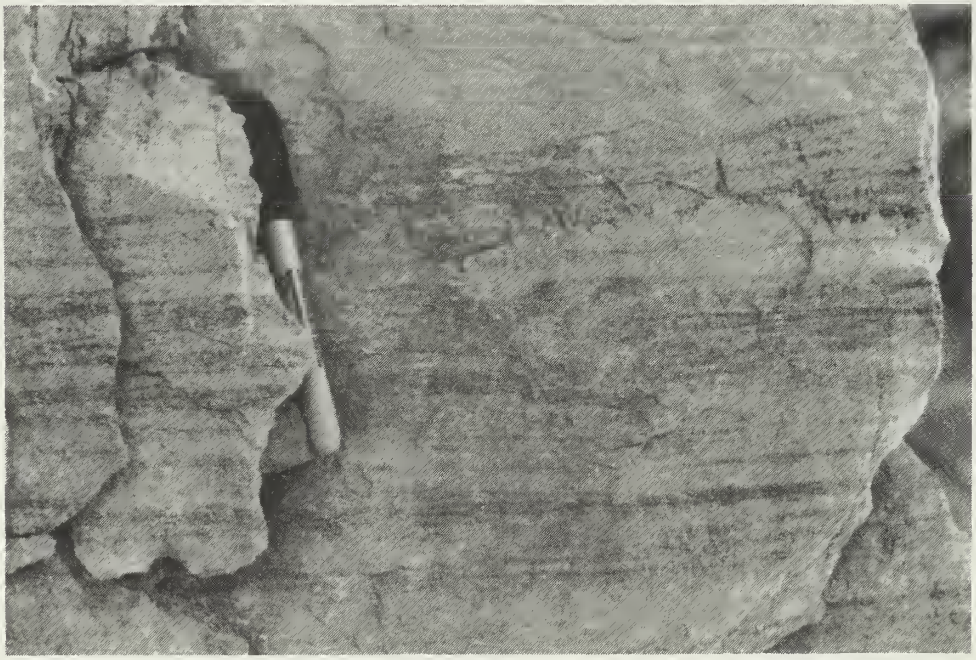

Figure 28 Laminated and graded-bedded bryozoan-crinoid grainstone with escape burrow structure from the upper Ullin ("Warsaw") in Jonesboro quarry.

ACKNOWLEDGMENTS

The field trip leaders thank all the people who assisted with the preparations for this trip. Some contributors to this guidebook also provided valuable services: Garland Dever of the Kentucky Geological Survey provided geological assistance at Reed quarry; Perry Donahoo, president of Reed Crushed Stone Company, a division of Vulcan Materials Company, strongly supported our geological research; Terry Teitloff, manager of Technical Services and Quality Control at Reed quarry, assisted in numerous ways; Roy L. Trexler, president of Columbia Quarry Company supplied quarry information and granted access to the Ullin and Jonesboro quarries; Leslie A. Wright, superintendent and J. E. Jones, office manager of Jonesboro quarry provided assistance on quarry safety; Bernie Brust, manager, provided assistance at Ullin quarry; and Ron Graul of Les Wilson, Inc., vice president/program director and secretary of Illinois Geological Society (IGS) coordinated field trip logistics. Especially appreciated is the help of the ISGS staff in the Geological Records and Samples Library, in particular John Klitzing, Bill Revell, Charles Zelinsky, and Anne Faber. Jacquelyn L. Hannah, graphic artist, provided invaluable assistance.

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STRATIGRAPHIC AND BIOSTRATIGRAPHIC FRAMEWORK OF THE ULLIN LIMESTONE ("WARSAW") AND FORT PAYNE FORMATION

Rodney D. Norby

STRATIGRAPHIC NOMENCLATURE

The Ullin Limestone and Fort Payne Formation are mid-Valmeyeran in age (late Osagean through early Meramecian). Understanding the depositional setting for these units depends upon determining their physical relationship with adjacent units (fig. 29). Biostratigraphy provides one key in deciphering lithostratigraphic relationships (fig. 30). Detailed sequence stratigraphy may provide another key. In this guidebook, the name Ullin Limestone or Ullin (short form) has been employed for the equivalent unit "Warsaw," as used by the oil industry in Illinois, and for the approximately equivalent Warsaw Limestone, as used in Kentucky.

Ullin Limestone

The mid-Valmeyeran Ullin Limestone was named by Lineback (1966), largely for what he described as light colored, fine to coarse grained, bryozoan- and crinoid-rich limestones (packstones, grainstones, wackestones, and lime mudstones of Dunham's classification [1962]) found in southern Illinois. The upper part of the composite type section of the Ullin was described from Ullin quarry (Stop 2). The lower part of the type section was described from natural exposures a few miles away (Secs. 21, 22, T14S, R1W, Alexander County). Most of these natural exposures have been reinterpreted (Nelson, ISGS, personal communication 1993) to be part of the underlying Fort Payne Formation

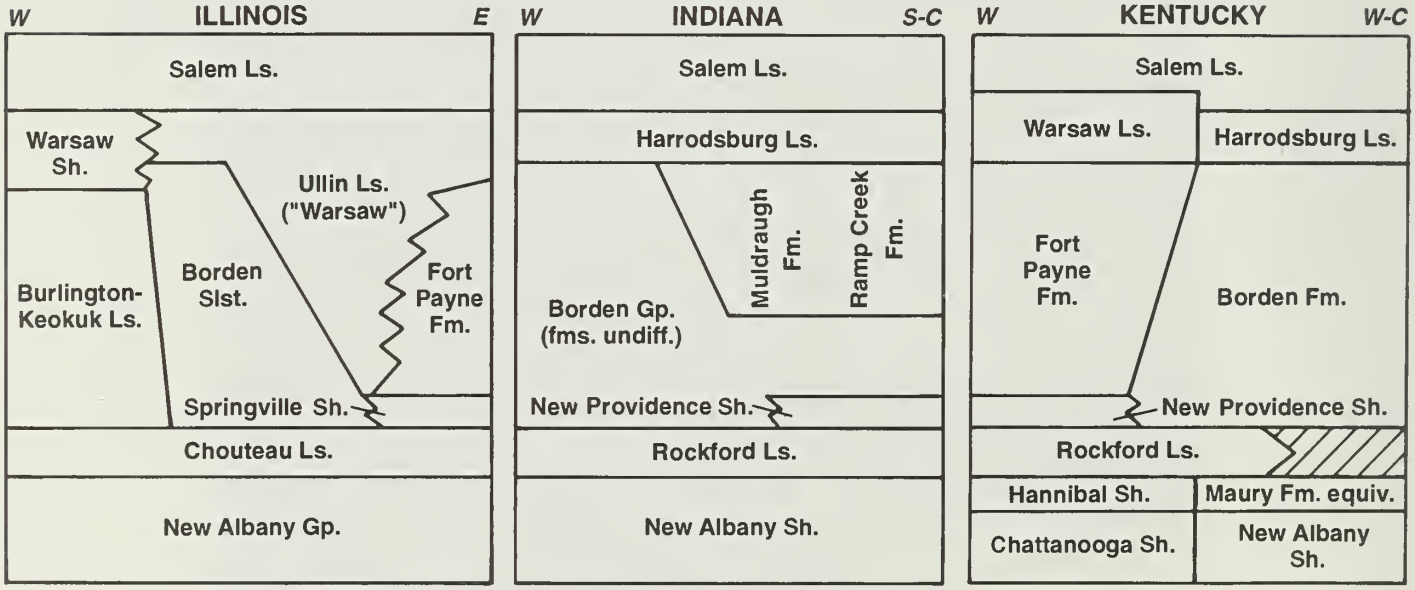

Figure 29 Stratigraphic terminology used in Illinois, Indiana, and Kentucky for units in field trip region. Physical relationships are based on interpretation (this study) of the lithostratigraphy of these units as studied primarily in Illinois.

rather than the Ullin. Thus, at least locally, the thickness of the Ullin Limestone and the relationships of the Ullin and Fort Payne need to be reassessed.

The Ullin reaches thicknesses of more than 800 feet in a small area in Hamilton County, southern Illinois. Although the Ullin generally overlies the Fort Payne, in some areas, it overlies the Borden, Springville, Warsaw, or Chouteau Formations. It underlies and pinches out beneath the Salem to the west and north in Illinois (Lineback 1966) (figs. 32, 34).

Lineback (1966) divided the Ullin into two members, the Ramp Creek (lower) and the Harrodsburg (upper). The boundary between the two members is gradational and the members appear to intertongue. The names of both members are derived from approximately equivalent formations that are recognized in western Indiana. In this guidebook, we have not formally used these member designations because this was not our primary purpose. Our informal usage of lower Ullin and upper Ullin, in general, conforms to the named members. Until we can examine sufficient data to accurately identify the members with confidence, we have employed this informal usage.

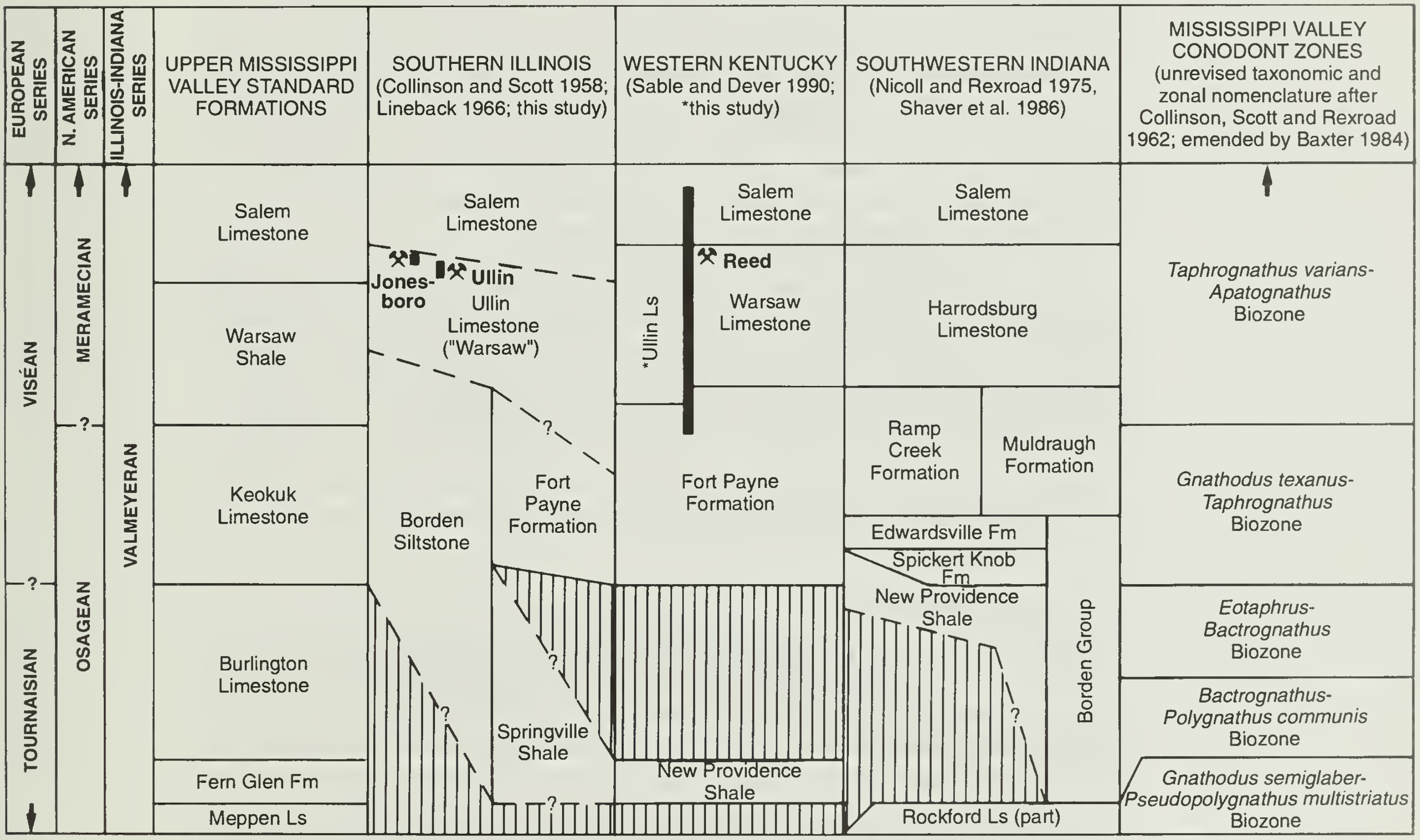

Figure 30 Stratigraphic nomenclature and time correlation of units in the field trip region. Size of unit on diagram does not imply thickness except in a very general way. The dashed lines (primarily southern Illinois column) indicate interpreted time relationships from fossil evidence in Illinois, Indiana and Kentucky and on sedimentation patterns and physical relationships. Question marks are added where no fossil evidence is available. Vertical lines indicate documented or inferred hiatuses. The vertical bars indicate the inferred age range for rock units exposed at the Jonesboro, Ullin and Reed quarries.

"Warsaw," Warsaw Shale, and Warsaw Limestone

Before the Ullin Limestone was named, the term "Warsaw" was employed (and still is for the most part) by the oil industry in Illinois for the limestone package between the Salem Limestone and, in most cases, the Fort Payne Formation.

The Warsaw Shale was named by James Hall (1857) for gray shales and argillaceous limestones at Geode Glen near Warsaw in Hancock County, Illinois. The Warsaw is less than 100 feet thick in the type area, but it is as much as 300 feet thick in west-central Illinois where it consists primarily of siltstones (a facies of the uppermost Borden). Although the Ullin Limestone can be considered a facies equivalent of part of the Warsaw Shale, Ullin is a more appropriate name for this limestone unit in most of the subsurface of southern Illinois.

In Kentucky and Tennessee, the name Warsaw has also been used for limestones with approximately the same lithologies, contacts and age as the Ullin of Illinois. In western Kentucky, the Warsaw or "Big Light" (drillers' terminology) is a 250 to 500 feet thick, light to medium gray biocalcirudite, biocalcarenite, or dolomitic limestone (Sable and Dever 1990). The Warsaw thins to the east and is about 30 feet thick in central Kentucky (Sable and Dever 1990). The type Warsaw of Illinois is neither traceable nor lithologically similar to the Warsaw of Kentucky and Tennessee; and although Sable and Dever (1990) suggested the name should be abandoned for usage in Kentucky and Tennessee, they did not indicate what name should be used in its place. They equated the Warsaw of western Kentucky with the Ullin of Illinois and the Ramp Creek, Harrodsburg, and Muldraugh Formations of Indiana.

For our descriptions of Reed quarry (Stop 1), we have employed Ullin terminology, which does not equate exactly with Kentucky's usage of Warsaw Limestone (Dever and McGrain 1969, Sable and Dever 1990). In our preliminary work, we have drawn the Fort Payne–Ullin contact approximately 70 feet lower in the quarry section and included the mound facies in the lower part of the Ullin. This 70-foot transitional interval shows some of the very dark gray mudstone–wackestone that is more typical of the Fort Payne. However, bedding characteristics, fossil content and the mound facies suggest to us that it should be allied with the Ullin.

Fort Payne Formation

The Fort Payne Formation was named by Smith (1890) for dark, very fine grained siliceous, cherty limestones exposed near Fort Payne, northwestern Alabama. The Fort Payne is widespread over the south-central United States and has its northwesternmost occurrence in southeastern Illinois, where it is more than 600 feet thick in Pope County. The formation thins to the west and north.

In western Kentucky, the Fort Payne is also a dark gray, fine grained, siliceous and cherty limestone with planar beds. It reaches thicknesses of more than 600 feet (e.g. core from Reed quarry; see Dever and McGrain, 1969). As noted above, approximately the upper 70 feet of the Fort Payne (as referred to by Dever and McGrain 1969, Sable and Dever 1990) at the Reed quarry have been included in the Ullin (this guidebook).

BIOSTRATIGRAPHY

The general age of the Ullin Limestone and Fort Payne Formation in the Illinois Basin is moderately well established, partly on the basis of stratigraphic position and partly on paleontologic evidence (Shaver 1985). These two units occupy a position (fig. 30) in the middle of the Valmeyeran Series (late Osagean through early Meramecian). Preliminary conodont microfossil information collected during this study confirms these findings.

Age of Springville Shale (Illinois), Basal Borden Group (Indiana), and New Providence Shale (Kentucky)

Biostratigraphic data from these underlying units are important in establishing the age of the Fort Payne and Ullin. Data on conodonts obtained from a site near Jonesboro, Illinois, indicate that the age of the lowest few feet of the Springville Shale (an equivalent of at least the lowest part of the New Providence Shale of Indiana; fig. 30) is equivalent to the Fern Glen or earliest Burlington (Collinson and Scott 1958) and within the *Bactrognathus-Polygnathus communis* Biozone (Collinson et al. 1962). Collinson and Scott (1958) thought that the Springville in this area was overlain by the Burlington Limestone; but later work by Lineback (1966) indicates that the unit should be the cherty Fort Payne. No information is available for the thicker (about 50 ft) upper part of the Springville; it may be equivalent in age to the Burlington (fig. 30, southern Illinois column).

In southern Indiana and north-central Kentucky, the basal part of the New Providence Shale (the lowest unit of the Borden Group) was found to be no older than late Burlington or even early Keokuk equivalent (fig. 30, southwestern Indiana column); Rexroad and Scott (1964) based their conclusion on the presence of the conodonts *Bactrognathus distortus* and *Gnathodus texanus*. Crinoids recovered from the Button Mold Knob fauna of the New Providence Shale Member of the Borden Formation in south-central Indiana and north-central Kentucky also indicate an age-equivalency to the Keokuk Limestone (Kammer 1984).

Age of the Borden Siltstone (Illinois) and Main Part of the Borden Group/Formation (Indiana/Kentucky)

Age data are not available for the Borden Siltstone in Illinois. It appears to be slightly older than the Fort Payne and Ullin, according to its stratigraphic position and limited fossil data from Indiana and Kentucky. The upper part of the Borden may be the same age as the Fort Payne.

In Indiana, the conodonts *Gnathodus texanus* and *Taphrognathus varians* were recovered from the Edwardsville Formation (Nicoll and Rexroad 1975) and from all three members of the Muldraugh Formation (Whitehead 1978), components of a Borden facies that developed in an outer platform to upper slope setting (Whitehead 1978). These conodonts represent the *Gnathodus texanus–Taphrognathus* Biozone (Collinson et al. 1962), or basically an age-equivalent of the Keokuk (fig. 30). I suggest, on the basis of conodont ranges, that it could also be equivalent in age to the lower part of the type Warsaw Shale. This age would apply to the latest part of the Borden complex in Indiana, but ages could be slightly younger for the last deltaic phase in Illinois.

Several paleoenvironmental studies in west-central Indiana (Ausich et al. 1979, Kammer et al. 1983) involved determining the ages of the Edwardsville Formation and several related units (delta-platform facies of the upper part of the Borden. These upper Borden units were correlated with the Keokuk on the basis of several crinoid and brachiopod species.

Age of the Fort Payne Formation

A Keokuk-age assignment for the Fort Payne Formation (fig. 30) is indicated by conodont information from (1) the upper part of the Fort Payne at Reed quarry, (2) a core (Superior Oil, Greathouse no. 30) in White County, Illinois (fig. 2), and (3) an isolated outcrop just west of Jonesboro. The Fort Payne in southern Illinois was previously equated, based on limited information, with the type Warsaw (Shaver 1985, Norby 1991). No biostratigraphic information is yet available from the lower Fort Payne of Illinois. It should be no older than Keokuk, if the ages of the underlying units have been correctly interpreted.

Conodont data on the type Fort Payne Formation in northwestern Alabama (Ruppel 1971) and the strata bounding the Fort Payne in nearby areas (Drahovzal 1967) all indicate latest Osagean age (equivalent to the Keokuk). A middle Osagean age is suggested for the Fort Payne in northwestern Georgia (Ausich and Meyer 1990). In south-central Kentucky and north-central Tennessee, Ausich and Meyer (1988) recovered a blastoid fauna from several facies of the Fort Payne, which they equated to the Keokuk. The occurrence of the conodont *Gnathodus texanus* with the blastoids confirms this age (Ausich and Meyer 1988). Additional collections of crinoids from this same area also indicate an age equivalent to the Keokuk (Ausich and Meyer 1990).

Age of the Ullin Limestone ("Warsaw")

The Ullin Limestone has been considered to be the same age (earliest Meramecian) as the Warsaw in its type area of western Illinois (Lineback 1966). This age is approximately correct, but the Ullin was more recently considered to range in age from early Osagean to early Meramecian (Shaver 1985). In a general review paper, Norby (1991) correlated the Ullin with the lower part of the Salem.

A conodont fauna dominated by the conodont *Taphrognathus varians* was reported from the Ullin (Collinson *in* Lineback 1966). Nicoll and Rexroad (1975) reported this same fauna from the upper part of the Ramp Creek and Muldraugh and also in the Harrodsburg and Salem Limestones in Indiana. Both reports suggested an age equivalent to the Warsaw. Samples from this study corroborate these reports and indicate an early Meramecian age for the upper part (Harrodsburg Member) of the Ullin in Illinois (equivalent to either the upper part of the type Warsaw or, more likely, the lower part of the Salem). The lower part of the Ullin in Illinois appears to be no older than the type Warsaw equivalent, although no fossil information is specifically available for the lower part of the Ullin. The age of the Ullin ("Warsaw") in the subsurface of Illinois is probably equivalent to the type Warsaw, although parts could be slightly younger. In areas of thick Ullin (600 ft or more), the lower part of the Ullin could be older than the type Warsaw (fig. 30), although this has not been verified biostratigraphically.

The Warsaw Limestone as used in western Kentucky appears to be the same age as the type Warsaw (western Illinois) from preliminary microfossil data recovered in this study.

Sedimentological models suggest a lateral intertonguing of at least part of the Ullin with the Fort Payne (Lasemi, this guidebook). Fossil data from thicker subsurface sections might corroborate this model. No conodont data are presently available, however, for the deeper parts of the Illinois Basin where a thicker Fort Payne–Ullin interval occurs.

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WAULSORTIAN MOUND, BRYOZOAN BUILDUP, AND STORM-GENERATED SANDWAVE FACIES IN THE ULLIN LIMESTONE ("WARSAW")

Zakaria Lasemi

OVERVIEW OF WAULSORTIAN MOUNDS

The early to early mid-Mississippian (late Tournaisian to early Viséan) is characterized by widespread distribution of carbonate mud mounds in various regions in North Africa, Europe, and North America (Wilson 1975, Bolton et al. 1982, West 1988, Lees 1988). These mounds are generally known as Waulsortian mud or reef mounds after the village of Waulsort in the Dinant Basin of Belgium. They are quite variable in thickness and distribution. In Ireland, for example, the mounds are more than 3,000 feet thick and coalesced into large banks covering tens of thousands of square miles (Lees 1961, Sevastopulo 1982).

Facies

Waulsortian mounds vary in shape from lenticular bodies in shallower areas to steep mounds, commonly with slopes of 10° to 50°, in outer ramp to basin environments. Lime mudstone to wackestone with scattered fenestrate bryozoans and crinoids characterizes the core facies of these mounds. The mound core is generally massive to crudely bedded (possibly because of vertical accretion) and may contain sparry calcite-filled cavities generally known as stromatactis (Bathurst 1982).

In general, flanking facies of Waulsortian mounds are well bedded crinoidal to crinoidal-bryozoan wackestone to grainstone. The intermound facies, typically well bedded, includes siliceous and cherty carbonates that are generally dark and argillaceous. In some areas, crinoid-bryozoan packstone to grainstone may be an important component of the intermound facies. These coarser intermound facies represent debris apron deposits formed by off-mound transport of skeletal debris.

A Waulsortian mound complex is generally overlain by a packstone to grainstone facies, which may be storm-generated skeletal sandwaves (Lasemi et al. 1994a, b) or oolitic limestone of the overlying units. Some mounds are capped by deeper water limestone and shale, indicating a drowning event (Precht and Shepard 1989) that terminated mound development.

North American Waulsortian-type mounds are generally similar to those in Europe except that, in many areas, the core facies appears to be generally thinner and the flanking facies is thicker bryozoan and crinoid grainstone. Also, in situ bryozoan-dominated bafflestone buildups, which are developed on the crest and flanks of mounds, appear to be a characteristic feature of some mounds, such as those in the Illinois Basin (Lasemi et al. 1994a, b and this study). Similar buildups may be present in other North American mounds (Ahr and Ross 1982, Davies et al. 1989) but have been interpreted, perhaps erroneously, by those authors to represent the core facies of Waulsortian-type mounds. The Ullin mounds in the Illinois Basin are also distinguished from those reported in Europe and other regions in North America by an abundance of chert bands and nodules (fig. 14), possibly representing former cavities similar to stromatactis.

Source of Micrite

The source of the micrite that constitutes the core facies of Waulsortian mounds is controversial. Baffling and trapping of transported carbonate mud by bryozoans and crinoids (Pray 1958, Wilson 1975, Philcox 1967) and trapping and binding by organic mats, probably blue green algae (Pratt 1982), have been suggested as possible mechanisms for mound development. Lees and Miller (1985) questioned these interpretations based on the rare occurrences of baffling organisms in some mounds, the large size of many mounds, and textural and compositional differences in the mound core and intermound and flanking facies. They suggested that the carbonate mud for mound growth may have been formed in situ by microbially induced (i.e. by bacteria and cyanobacteria) precipitation. A similar origin was also suggested by Monty et al. (1982) and Tsien (1985) for the lime mudstone in some Devonian mud mounds.

Distribution of Mounds

In some areas, structure is a possible control on the development of Waulsortian mounds. There is evidence for block faulting and subsidence in several areas where Waulsortian mounds have developed (Wilson 1975, Miller and Grayson 1982). Miller and Grayson (1982) suggested a tilted block fault model for the development of a ramp-like depositional setting in the Lower Carboniferous units of England. In this model, Waulsortian mounds developed on the deeper, downthrown side of the fault. Some mounds show a linear arrangement, either parallel to but some distance from an anticlinal axis, or on the downthrown side of a block fault (Wilson 1975). However, some mounds regarded by Wilson (1975) as Waulsortian are younger, perhaps shelf margin-type reefs (Lees 1988).

Waulsortian mounds are, for the most part, randomly distributed on ramps and do not form a shelf slope break (Ahr 1989). They are generally initiated downslope on ramps and in basinal settings below storm wave base in deeper water environments. Mounds in basinal settings developed into vertically stacked buildups similar to pinnacle reefs. Others, such as those in Ireland (Sevastopulo 1982, Lees 1961), accreted laterally into complex banks thousands of square miles across. A deeper water origin of the mounds is indicated by the lack of shallow water indicators such as calcareous green algae, coated grains, and subaerial exposure features. Additional evidence for a deeper water origin includes the (1) smooth geometry of the mounds with no channel or spur and grooves, (2) deeper water origin of the equivalent and enclosing carbonate and shale (some with pelagic fauna), and (3) overall paleogeographic position (Wilson 1975). During the later stages of their development, some mounds may have built up into the photic zone, as indicated by the appearance of coated grains, green algae, and micritization (Lees and Miller 1985).

A depth-related facies distribution for Waulsortian mounds (fig. 31) has been developed by Lees and Miller (1985), who based their interpretaton on the relative abundance of readily recognizable skeletal allochems and the presence or absence of green algae and coated grains:

A. fenestellid-bryozoan facies with abundant fenestellid sheets and calcite-filled cavities or stromatactis,
B. siliceous sponge facies,
C. sponge/cyanophytes (calcimicrobes) facies,
D. skeletal algae and coated grain facies.

Facies A–C are characteristic of subphotic zones, whereas facies D only developed in the photic zone. Because of their depth-dependence, not all facies may be present in any one place. After examining the paleontological data, Lees and Miller (1985) suggested various water depths for different facies of the Belgian mounds (type area): greater than 500 feet (facies A), 400 to 500 feet (facies B), 300 to 400 feet (facies C), and less than 300 feet within the photic zone (facies D).

The development and disappearance of Waulsortian mounds during the early to mid-Mississippian Period is neither well understood nor within the scope of this study. A combination of factors such as tectonism, sea-level rise, and changes in ocean circulation patterns may have been involved. Late

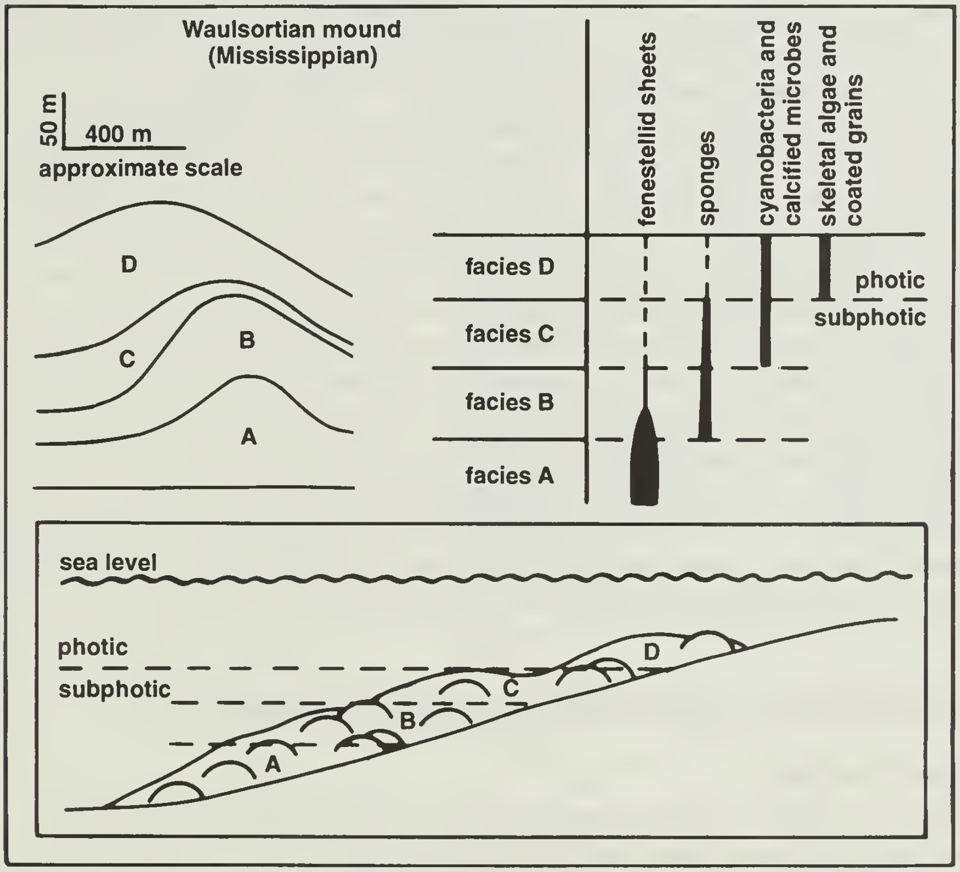


Figure 31 Facies distribution and depth zonation of Waulsortian mounds: Vertical succession (top left) in a Belgian Waulsortian mound (type area); ecological assemblages and depth zonation (top right): distribution of Waulsortian facies on a carbonate ramp (inset). (Modified from James and Bourque [1992] and Lees and Miller [1985].)

Devonian to early Viséan (mid-Mississippian) was a unique time, characterized by several tectonic, oceanographic, and biological events on a worldwide scale. There were nearly synchronous, relatively rapid increases in the rates of subsidence of most preexisting margins and basins of North America (Kominz and Bond 1991). Tectonic subsidence modeling for the Illinois Basin (Treworgy et al. 1991) indicates a subsidence rate increase around mid-Mississippian time.

Major expansion of the oxygen-minimum zone in the ocean during the late Devonian to early Mississippian resulted in widespread development of anoxic conditions (Jenkyns 1986), which may have contributed to deposition of organic-rich black shales (e.g. the New Albany). A major faunal extinction at the end of the Devonian effectively eliminated the frame-building organisms responsible for reef construction. Early to early mid-Mississippian was also a time for the development of widespread carbonate ramp settings (Ahr 1989). Mud mounds became widespread and developed in deeper water settings downslope on such ramps or within basins (Wilson 1975). The distribution of ramps and mud mounds at this time may be related to continuous subsidence and slow recovery of frame builders after the end of the Devonian (West 1988), and shifting of the carbonate factory into a deeper offshore setting (Wright and Faulkner 1990).

Hydrocarbon Production from Waulsortian Mounds

Waulsortian mounds are prolific hydrocarbon reservoirs in several regions of North America. Hydrocarbon production is mainly from porous flanking packstone and grainstone and, less commonly, from fractured and dolomitized core facies of the mounds. The mounds are generally surrounded by or grade into a deeper water facies that is usually dark and, in places, organic-rich. Because of high porosity in flanking beds and proximity to relatively organic-rich rocks, Waulsortian mounds have excellent potential for reservoir development where permeable. Vertically stacked facies in some mounds are sites for development of multistory reservoirs. The dense core facies is an effective barrier for hydrocarbon entrapment in vertically stacked mounds. Waulsortian mounds are productive in Illinois (Lasemi et al. 1994a, b), Kentucky and Tennessee (MacQuown and Perkins 1982), north-central Texas (Ahr and Ross, 1982), and north-central Alberta (Morgan and Jackson 1970, Davies et al. 1989). Drilling by Conoco in the Mississippian Lodgepole Formation in North Dakota encountered a prolific reservoir in a Waulsortian-type mound. Initial production was greater than 2,000 barrels of oil per day and 1.2 million cubic feet of natural gas per day (Burke and Diehl 1993).

ULLIN ("WARSAW") AND FORT PAYNE FORMATIONS

Previous Studies

According to Lineback (1966, 1969), the lower Valmeyeran carbonate and clastic units in the Illinois Basin may have formed during four separate depositional events:

1. Deposition of the Burlington–Keokuk Limestones and the underlying Fern Glen apparently occurred on a carbonate shelf adjacent to a relatively deep, starved basin (Lineback 1981) (figs. 32, 33). A similar

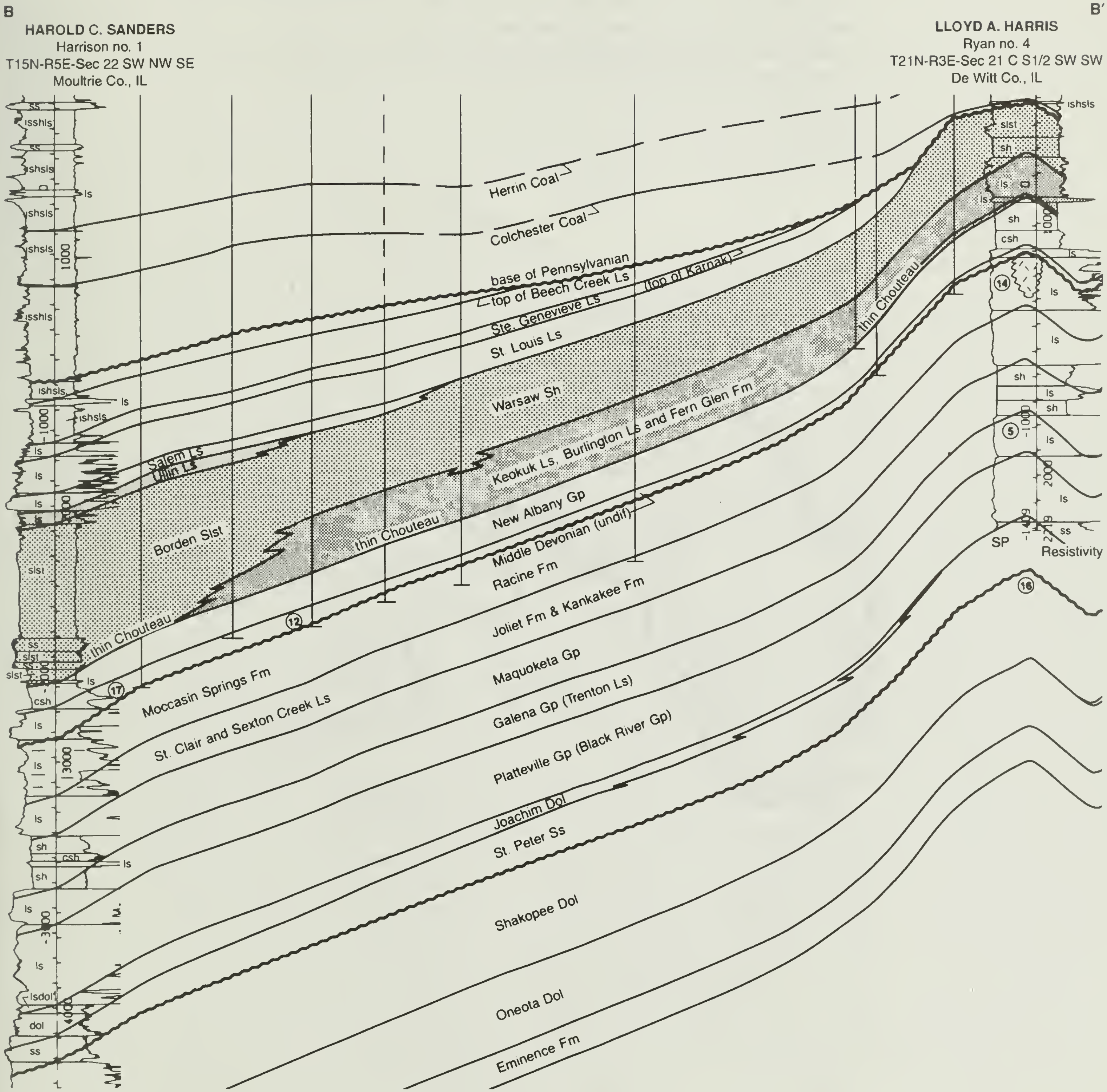


Figure 32 South–north cross section (B–B′) from Moultrie County to De Witt County, Illinois (see fig. 2 for location). Note relationship of Borden, Fern Glen, Burlington and Keokuk Formations (from Treworgy et al., in review).

depositional setting was apparently present at the same time in other regions of North America and western Europe (Lane 1978).

2. According to Lineback (1981), deposition of the Burlington-Keokuk Limestone in the Illinois Basin was terminated by a tongue of the Borden delta, which extended westward into Illinois and then was deflected southward by the bank margin topography (fig. 33).

3–4. Later, the Fort Payne (3) and then the Ullin (4) filled the deeper water areas remaining after cessation of Borden sedimentation (fig. 34).

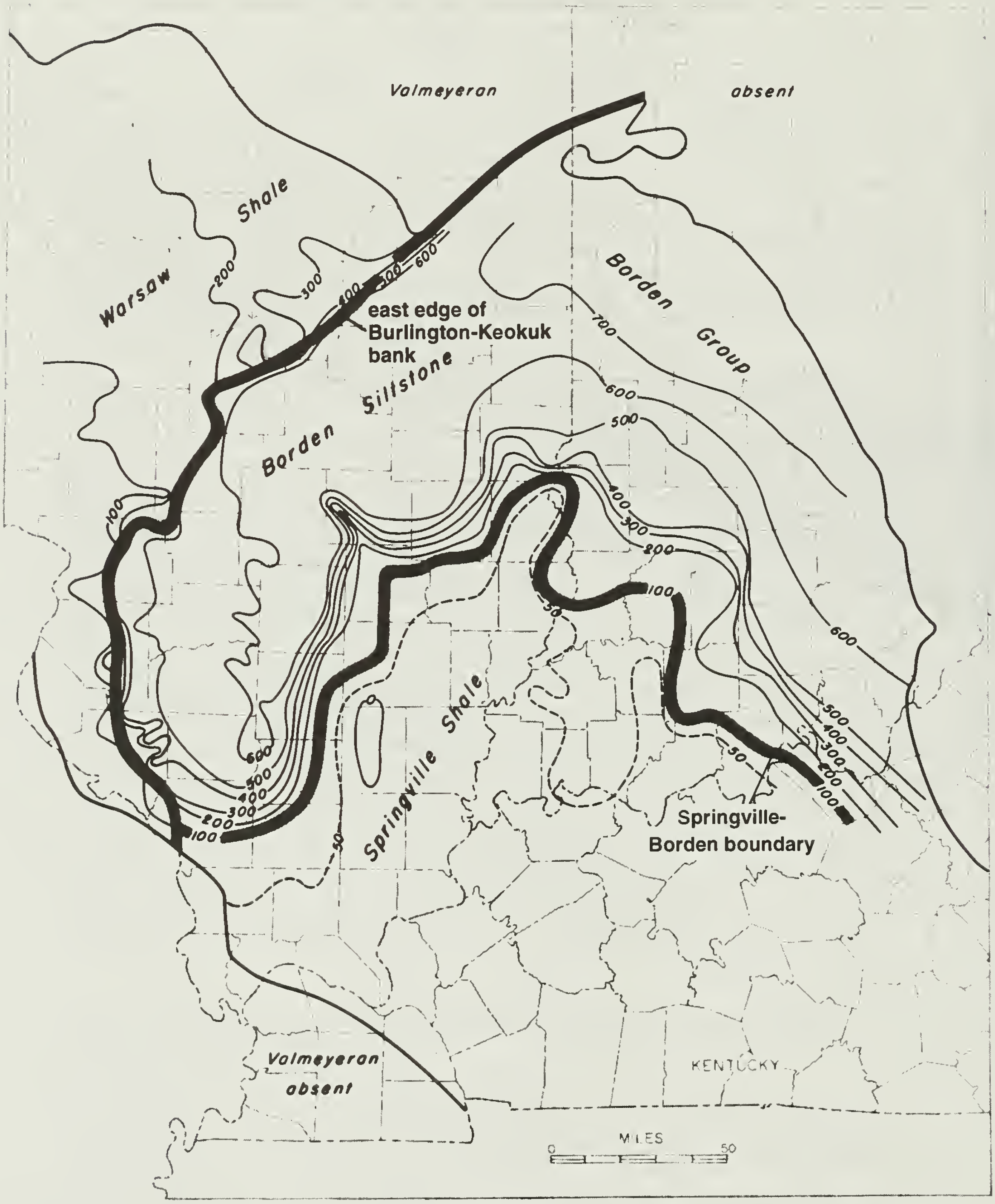


Figure 33 Thickness of early Valmeyeran deltaic sediments (after Lineback, 1966). Note east edge of Burlington-Keokuk bank.

In a more recent study, Lineback and Cluff (1985) suggested that the Ullin and Fort Payne Formations were laterally gradational. They suggested that the Ullin was deposited on a ramp in "structurally higher" parts of the La Salle Anticlinorium and graded downslope into deeper water carbonates of the Fort Payne. They further suggested that the thick areas of the Ullin in the central part of the basin represent carbonates transported from these structurally higher, shallower areas. We agree with the gradational nature of the Ullin and Fort Payne (fig. 34) and an overall ramp depositional setting; however, we do not believe that the source of Ullin carbonates is limited to structurally higher, shallower areas. Presence of relatively well-preserved, delicate bryozoans that constitute the bulk of the bafflestone facies commonly found within the Ullin in these areas indicates in situ development.

Depositional Environment

Various facies of the Ullin and Fort Payne observed in quarry exposures intergrade laterally, forming a facies belt characteristic of a carbonate ramp setting (fig. 4). (For a review of the ramp settings, see Burchette and Wright 1992.) Development of Waulsortian-type mounds represents the early stages of carbonate deposition on this ramp after transgression of the Fort Payne sea. The lithologic character of the Fort Payne represents a deeper water basinal facies, as suggested by Lineback and Cluff (1985), and is similar to deep water carbonates reported from other regions (Wilson 1969, Smith 1977). Deposition below the photic zone is indicated by the absence of calcareous green algae and micritized grains both in the Ullin (except in the uppermost part) and in the Fort Payne carbonates. Lack of storm-generated sedimentary structures within the mound facies indicates that the mounds in the Ullin developed below storm wave base.

The interpretation of a ramp depositional setting for the Ullin–Fort Payne is supported by (1) an apparent lack of evidence for shelf edge reef or shoal (Lineback and Cluff 1985), and (2) the absence of soft sediment deformation features and carbonate breccia, both indicative of a shelf-slope break. A ramp depositional model for the Ullin–Fort Payne is also consistent with widespread ramp development during early to early mid-Mississippian time (Ahr 1989).

Lineback and Cluff (1985) suggested that local thick areas of the Ullin Limestone may represent only local development of Waulsortian mounds. We conclude that these mounds, along with in situ bryozoan buildups, were prevalent and coalesced laterally and vertically, forming several large carbonate banks (20 miles wide by up to 70 miles long; fig. 35) surrounded by the deep-water Fort Payne (Lasemi et al. 1994b and work in progress; fig. 36). This conclusion is supported by the reciprocal thickness relationship of the Fort Payne and Ullin (figs. 35, 36) and by the presence of Waulsortian-type mounds and bryozoan-dominated buildups in the quarry exposures of the Ullin. The Ullin mounds, which died out in the early Meramec (early Viséan), represent the latest stage in the worldwide development of the Waulsortian mounds. Their disappearance in Illinois may relate to a gradual shallowing of the marine environment caused by vertical aggradation of carbonates and a decrease in the rate of subsidence.

There appears to be two general types of mound-like carbonate deposits in the Ulllin Limestone in Illinois. One type (figs. 4a, 6, 7, 11) is similar in part to

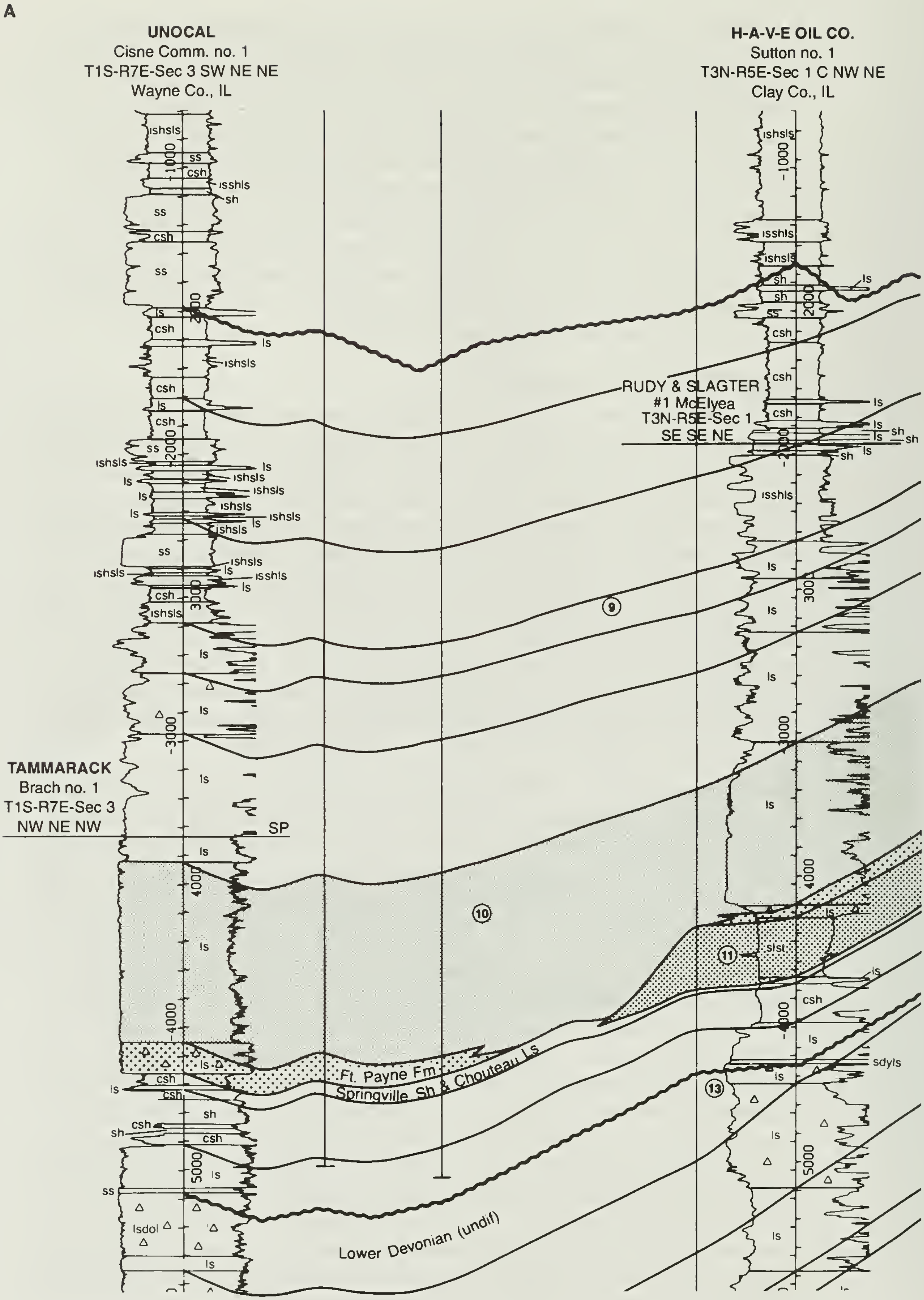
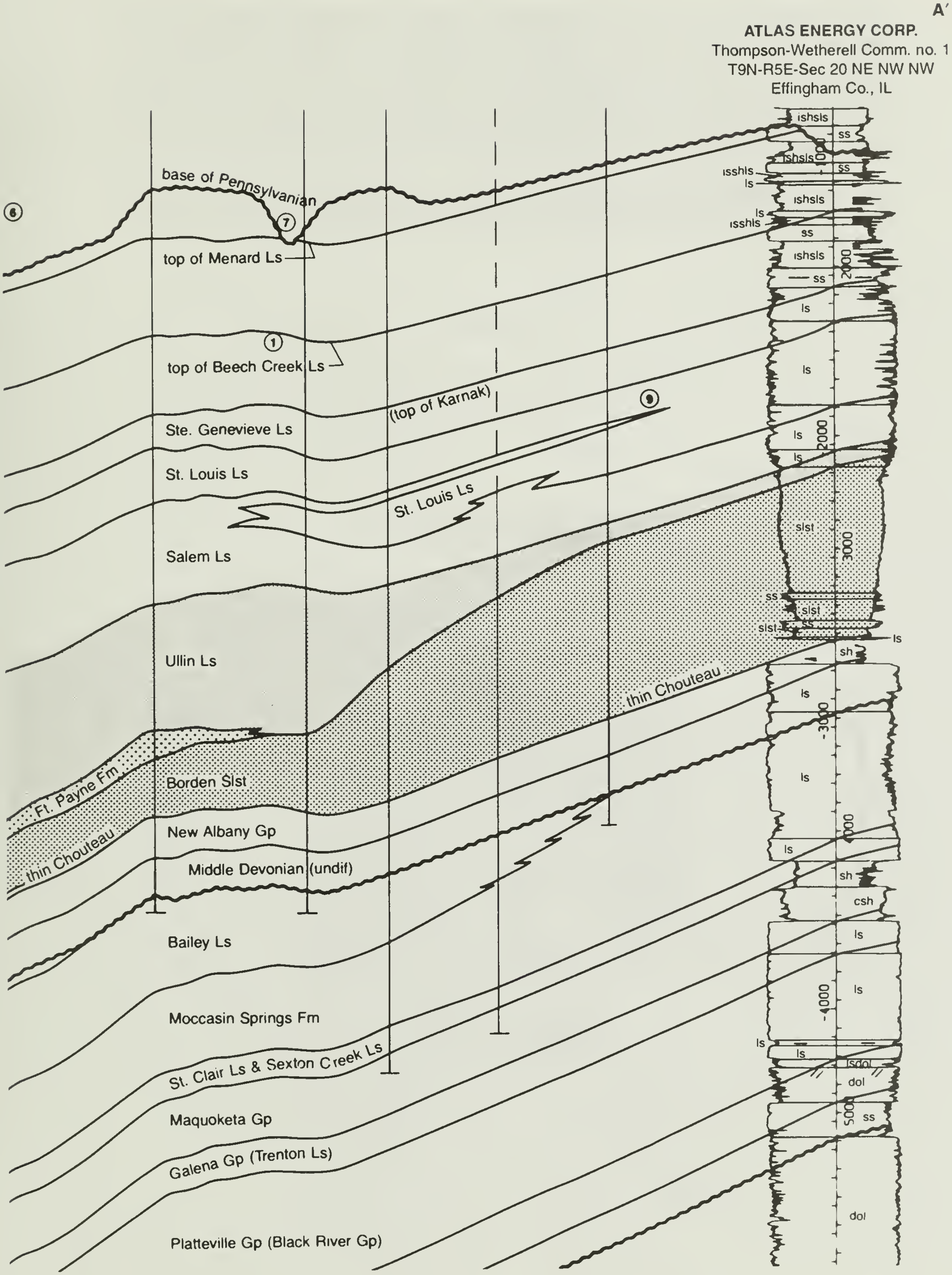


Figure 34 South–north cross section (A–A′) from Wayne County to Effingham County, Illinois (see fig. 2 for location). Note relationship of Borden, Fort Payne, and Ullin ("Warsaw") Formations (from Treworgy et al., in review).


A′
ATLAS ENERGY CORP.
Thompson-Wetherell Comm. no. 1
T9N-R5E-Sec 20 NE NW NW
Effingham Co., IL
⑥
base of Pennsylvanian
⑦
top of Menard Ls
①
top of Beech Creek Ls
(top of Karnak)
⑨
Ste. Genevieve Ls
St. Louis Ls
St. Louis Ls
Salem Ls
Ullin Ls
thin Chouteau
Ft. Payne Fm
Borden Slst
thin Chouteau
New Albany Gp
Middle Devonian (undif)
Bailey Ls
Moccasin Springs Fm
St. Clair Ls & Sexton Creek Ls
Maquoketa Gp
Galena Gp (Trenton Ls)
Platteville Gp (Black River Gp)
lshsls
ss
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many Waulsortian mounds recognized in Europe, south-central Kentucky, Tennessee, and other regions in North America (Lees 1988, Precht and Shepard 1989, Ausich and Meyer 1990, MacQuown and Perkins 1982; see also reviews in Wilson 1975 and Bolton et al. 1982). The other type of mound-like deposit observed in the Ullin appears to be a lenticular, skeletal sand (grainstone) pile (figs. 19–21).

Both the Waulsortian-type mound and lenticular skeletal sand piles in the Ullin were the preferred sites for the development of in situ bryozoan and

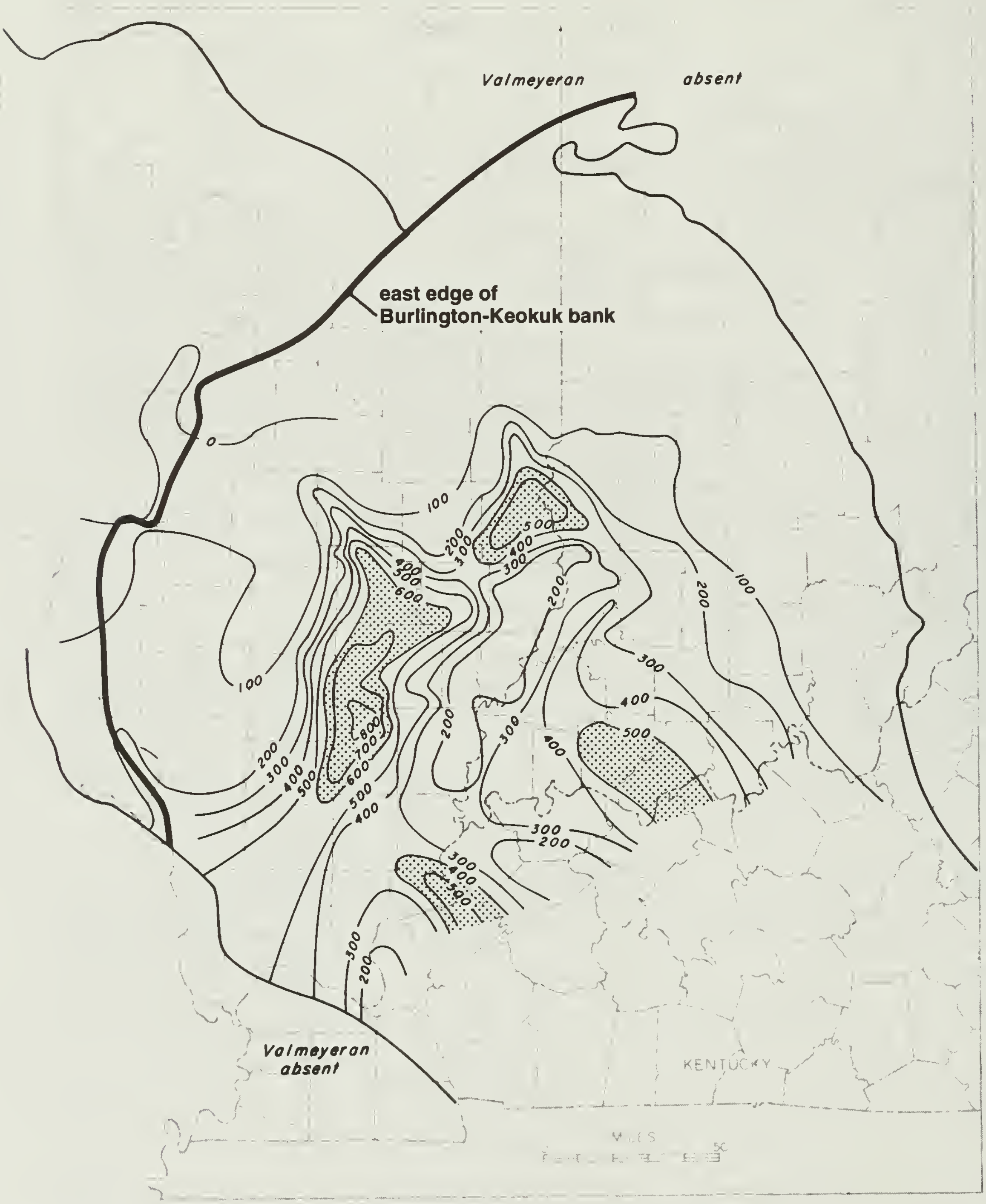

Figure 35 Thickness of the Ullin Limestone ("Warsaw") (after Lineback, 1966). Note highlighted areas of thick Ullin.

crinoid bafflestone buildups (figs. 4a, 22a–b, 23). Data from cores and drill cuttings indicate that such buildups, especially those bryozoan-dominated, constitute a major portion of the Ullin Limestone in Illinois (figs. 4, 22b). They developed on the crest and the flank of carbonate mounds and provided a source for skeletal sands that were deposited as debris aprons in intermound areas and as storm-generated sandwaves in mid-ramp settings. Vertical accretion and lateral progradation of various facies of the Ullin, along with a decrease in the rate of subsidence, resulted in a shallowing-upward ramp setting,

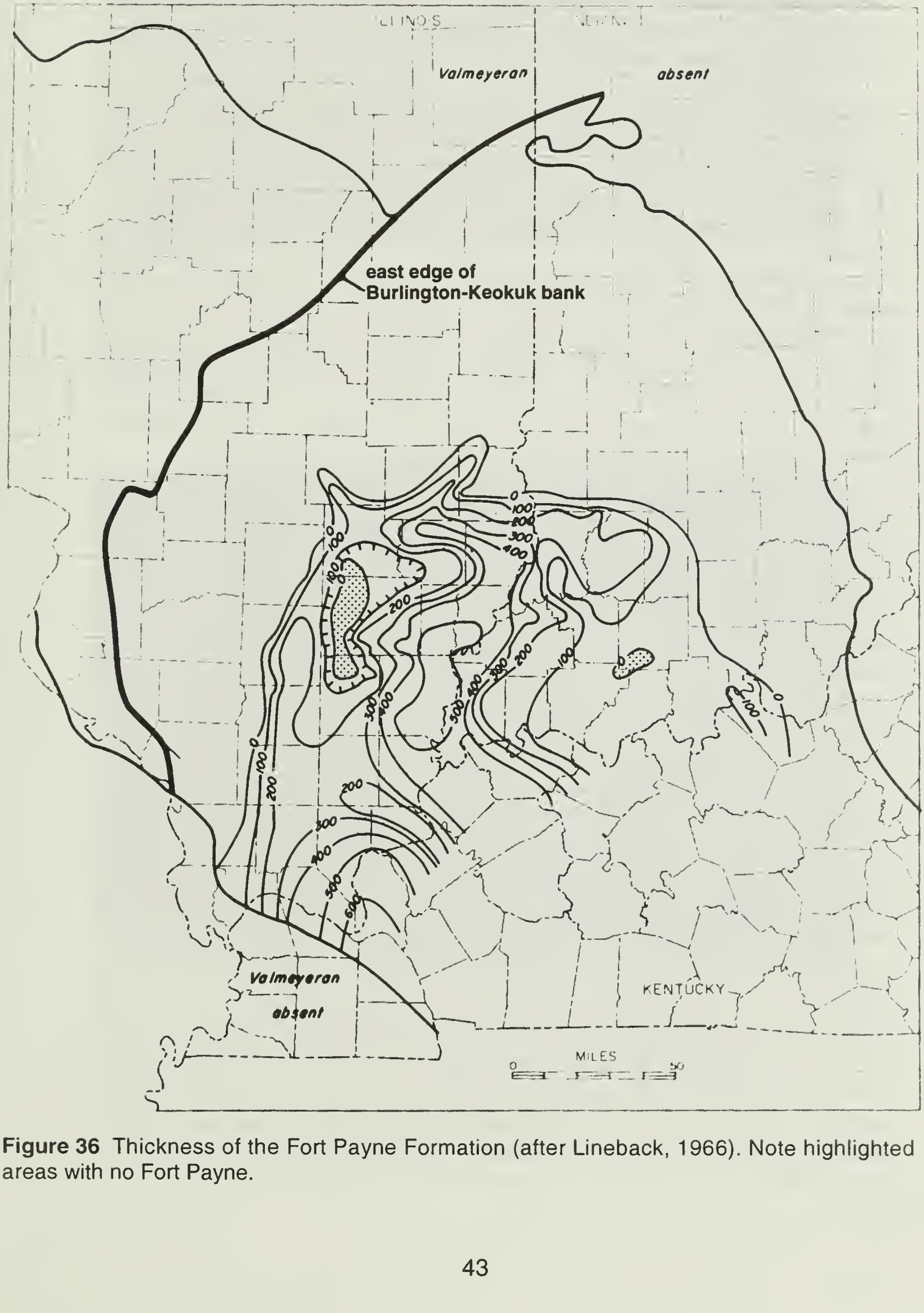

Figure 36 Thickness of the Fort Payne Formation (after Lineback, 1966). Note highlighted areas with no Fort Payne.

which eventually ended extensive mound development during deposition of the upper Ullin (fig. 4b). A gradual shallowing is supported by the appearance of ooids, calcareous green algae (dasyclads), and micritized grains in the uppermost part of the Ullin. Frequent storm events resulted in widespread sandwave development. Shallow water settings were unfavorable sites for further development of thick Waulsortian mud mounds; however, thinner, more isolated mud mounds and mound-like grainstone piles provided the necessary high that supported the development of in situ bryozoan-dominated patch reefs in the upper part of the Ullin. These mounds, together with the sandwaves, formed an irregular topography (fig. 4b) that led to the development of oolitic grainstone shoals during deposition of the overlying Salem Limestone.

Waulsortian-type mounds of the lower Ullin The carbonate mud mound in Reed quarry contains fenestrate bryozoan sheets, scattered crinoidal debris, fenestrate bryozoan hash, calcified sponge spicules, and rare ostracods (fig. 13). The presence of sponge spicules is the basis for interpreting the mound in Reed quarry to be comparable to facies B of the Waulsortian mounds (fig. 4a) recognized by Lees and Miller (1985) (fig. 31). Paleontological data suggest that the water depth in which the facies B of Waulsortian mounds developed was about 400 to 500 feet deep (Lees and Miller 1985). Various facies of these mounds grade laterally into the basinal submound facies of the Fort Payne—evidence for a deeper water, outer-ramp setting for the development of the Ullin mound in Reed quarry (fig. 4a). The deeper-water setting of these mounds was not favorable for the development of the flanking bryozoan bafflestone reservoir facies, as observed in the Ullin quarry.

Examination of samples from two cores (ISGS Miller nos.1 and 2) from a location about 12 miles east of the Ullin quarry (fig. 2) revealed lithologic characteristics suggestive of a Waulsortian-type mound. The core facies of the mound is a lime mudstone to wackestone with scattered bryozoans and crinoids (figs. 37, 38). The mound facies is flanked by a porous bryozoan bafflestone facies similar to that in the Ullin quarry (see section under "Stop Descriptions"). Thin section petrography of the core facies shows the presence of scattered fenestrate bryozoan hash and crinoids (figs. 37, 38). Part of this facies also has a peloidal (clotted) texture and contains rare gastropods, forams, and ostracods (fig. 38). The skeletal allochems in this facies resemble those in facies C (fig. 31) of Waulsortian mounds recognized by Lees and Miller (1985). This facies developed upramp from facies B, as it appears in Reed quarry (fig. 4a), in a relatively shallower water setting. Lees and Miller (1985) suggested a depth range of about 300 to 400 feet for this facies. The water depth here was apparently shallow enough for the development of a bryozoan bafflestone reservoir facies on this mound (figs. 4a, 19, 22a).

Facies D (fig. 31) of Lees and Miller (1985) is characterized by the presence of calcareous green algae and micritized and coated grains. Thus far, it has not been found in the three Illinois and Kentucky quarries; however, it may be present in the upper Ullin in the subsurface. Brown and Dodd (1990) reported a similar facies in the Harrodsburg Limestone and Ramp Creek Formation in southern Indiana and northern Kentucky; however, the mounds that they described are much smaller (4 inches to 7 feet thick) than those we have found within the upper Ullin in the subsurface of Illinois.

Figure 37 Thin section photomicrograph (cross-polarized light) of the lime mudstone core facies of a Waulsortian-type mound in the Ullin ("Warsaw") from a core (ISGS Miller no. 1) taken about 12 miles east of Ullin quarry, Illinois. Note fenestrate bryozoan frond and scattered crinoid fragments. Black particles are pyrite. Bar scale = 1 mm.

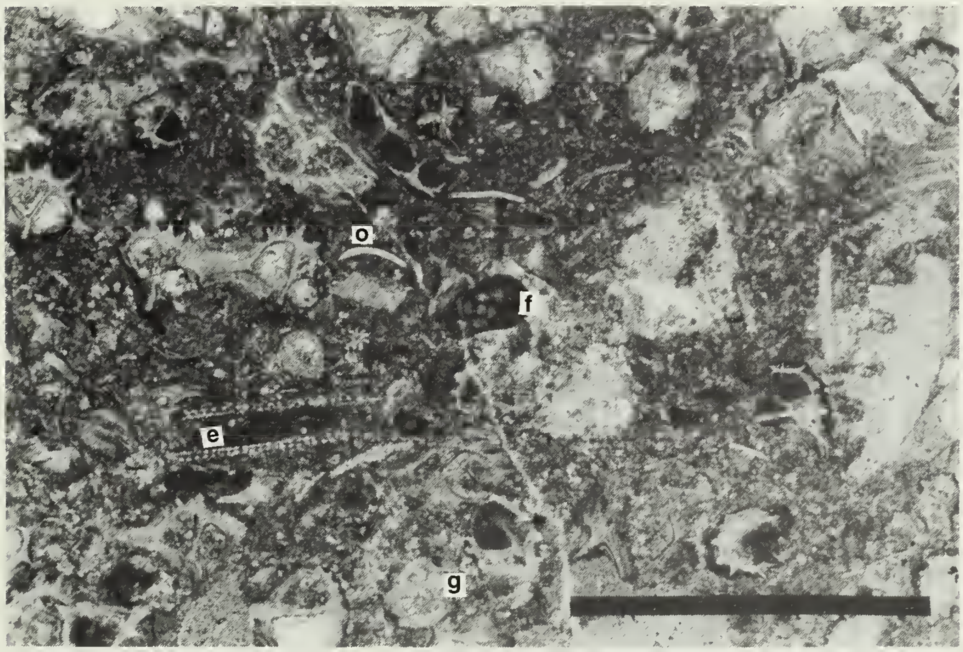

Figure 38 Thin section photomicrograph (plane light) of the wackestone core facies of a Waulsortian-type mound (from the same location as in fig. 36). Note fenestrate bryozoan hash, scattered crinoids, a echinoderm spine (e), a gastropod (g), a foram (f) and ostracods (o). Note clotted texture of the matrix, especially in bottom left of the photomicrograph. Note also a calcite-filled microfracture. Bar scale = 1 mm.

Lenticular grainstone piles of the lower Ullin The lenticular mounds in Ullin quarry have a fine grained, grainstone core facies (fig. 21), indicating that they are not Waulsortian-type mounds. Rather, they appear to be current-deposited bryozoan-crinoid sand piles. This interpretation is supported by the lack of lime mudstone matrix, moderate grain sorting, and in some cases, the presence of current lamination. Mound-like geometry and fine grain size suggest that the environment of deposition for this facies was in deeper water than the depositional environment for the overlying sandwave facies. The presence of relatively well preserved, flanking bryozoan bafflestone buildups (figs. 4a, 19, 22a) indicates that these mound-like grainstones were favorable areas for the establishment of bryozoan communities.

Sandwave facies of the upper Ullin The late stage in the evolution of the Ullin depositional environment (fig. 4b) is represented by this facies, which grades laterally in an upramp direction from (1) a distal facies consisting of isolated sandwaves interfingering with lime mudstone intersandwaves in Reed quarry, (2) an intermediate facies consisting of isolated sandwaves and finer grained packstone to grainstone intersandwaves in Ullin quarry, to (3) a proximal facies consisting of coalesced sandwaves of coarse grained, bryozoan-crinoid grainstone in Jonesboro quarry (fig. 4b). This facies relationship indicates a progressive decrease in water depth and an increase in current energy shoreward, as suggested by a relative decrease in mud content and an increase in grain size. Hummocky cross stratification (fig. 27) and the lack of evidence for persistent current reworking (e.g. the lack of ooids and poor rounding) suggest that the sandwaves were deposited by storm currents in a mid-ramp setting below normal wave base. Repeated graded bedding, a common feature within the coalesced sandwaves in the upper Ullin in Jonesboro quarry, probably represents multiple storm events. Storm-generated sandwaves, which are common in modern carbonate environments such as the Bahamas (Hine 1977), have also been documented from various ramp settings in the Phanerozoic system (Aigner 1985, various articles in Einsele and Seilacher 1982).

RESERVOIR POTENTIAL OF THE ULLIN LIMESTONE ("WARSAW")

The Ullin ("Warsaw") reservoir facies is mainly a bryozoan-dominated bafflestone (figs. 19, 20, 22a, 23) developed on the flanks and crests of Waulsortian-type mud mounds or on transported skeletal sand piles (fig. 4a). Subsurface geology and petrography reveal this porous bryozoan bafflestone facies at various horizons (some with oil shows) within the Ullin (figs. 4, 22b). Hydrocarbon production thus far has been limited to bryozoan bafflestone buildups (bryozoan patch reefs) and possibly storm-generated sandwaves in the upper Ullin. The Waulsortian mound facies in the lower Ullin has not, to our knowledge, been tested. The production of hydrocarbons from similar mounds in other regions of North America has been prolific, therefore the Ullin mound facies may also be potential reservoirs. Oil shows in cuttings from the porous facies of Ullin mounds support this hypothesis.

Petrographic examination shows excellent preservation of primary intra- and interparticle porosity within the bryozoan bafflestone buildups (figs. 22, 23).

The generally stable original mineralogy (low-magnesium calcite) prevented extensive dissolution–reprecipitation and occlusion of pores. Furthermore, the stable mineralogy and minor early marine cementation prevented later compaction and burial diagenesis. There appears to be a general relationship between the abundance of crinoidal fragments and porosity: a decrease in porosity corresponds to an increase in crinoidal material because of preferential cementation by syntaxial calcite (figs. 23, 39).

The porous facies of the Ullin is generally mud-free, thus contributing to a higher reservoir permeability. Acid stimulation is probably an effective method of increasing permeability in the bryozoan-rich facies because the microporous nature of bryozoans generates abundant surface area for acid reaction. This property makes the Ullin an excellent source of the carbonate used in "scrubber" systems for desulfurization of coal (see Harvey, this guidebook).

Some Ullin reservoir facies, although porous, may have little permeability. This condition is common when some micrite is present or cementation has occurred. Under such conditions, the presence of microfractures can enhance permeability (Tom Partin, consultant, personal communication 1994). Examination of drill cuttings and cores indicates that calcite-filled microfractures are common in various facies of the Ullin (figs. 15, 38). Some microfractures are oil-stained. Microfractures were apparently open during migration of petroleum, but were filled later by calcite precipitation and cementation. Where saturated with oil, however, microfractures remained open, thus increasing reservoir permeability in some Ullin plays.

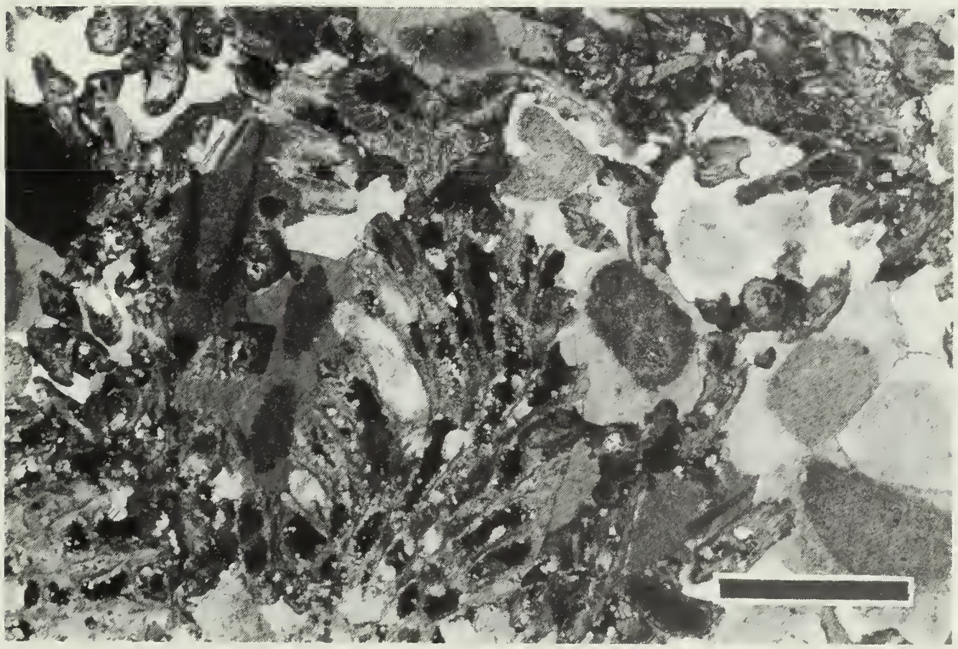

Figure 39 Thin section photomicrograph (cross-polarized light) of a core sample from White County (Superior Oil , Greathouse no. 30, NE SW NE Sec. 4-T5S-R14W), Illinois. This is a bryozoan-crinoid grainstone from the inferred sandwave facies of the upper Ullin ("Warsaw"). Note occlusion of pores in the more crinoid-dominated areas because of preferential overgrowth cementation by calcite. Inter- and intraparticle porosity (black) is preserved in bryozoan-dominated areas. Bar scale = 1 mm.

The distribution of the porous bryozoan facies may be local in some areas, as observed in the Ullin quarry. This may be part of the reason for high initial production occurring with very short flow time in some Ullin plays. However, laterally and vertically extensive mounds and sandwaves with reservoir quality facies occur in many areas of the basin (Lasemi, work in progress) and provide excellent potential for hydrocarbon production.

Preliminary data from core samples and cuttings indicate the presence of an argillaceous lime mudstone to wackestone at the base of the Salem Limestone in many areas (fig. 3). Dense lime mudstone and wackestone facies (usually the mound core facies) are also common in the upper Ullin (fig. 3) and generally cap the porous bryozoan-dominated facies of an underlying mound. The low permeability mudstones and wackestones can effectively seal hydrocarbons within the Ullin Limestone. The presence of these seals, high porosity, and proximity to potential source rocks (New Albany and possibly Fort Payne) indicate that the Ullin Limestone ("Warsaw") has great reservoir potential throughout the basin. This is confirmed by recent discoveries of prolific petroleum-producing zones within the Ullin Limestone in Wayne and White Counties in Illinois.

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PETROLEUM OCCURRENCE IN THE ULLIN LIMESTONE ("WARSAW")

John P. Grube

The thinly scattered petroleum reservoirs in the Ullin Limestone ("Warsaw") in the Illinois Basin (fig. 40) were rarely prolific prior to the 1990s. There are 69 fields with reported "Warsaw" production in Illinois, but only 13 fields list ten or more wells that have produced from the "Warsaw," and 37 fields have three or fewer wells that have produced "Warsaw" oil (appendix). "Warsaw" production accounts for approximately 1% of the more than 4 billion barrels of oil recovered from Illinois Basin reservoirs.

The basin is undergoing a third round of Ullin ("Warsaw") development. There have been two previous periods of development of "Warsaw" fields: one during the late 1950s and early 1960s when the pay was initially discovered, and the second during the drilling boom of the late 1970s and early 1980s. In the early 1990s, the completion of prolific wells in two fields, Johnsonville Consolidated in Wayne County and Enfield South in White County, once again heightened interest and promoted drilling in the "Warsaw" pay. Completions of flowing wells of 200 to 400 barrels of oil per day are not uncommon. These wells continue to have high rates of production. Records indicate that some wells have produced in excess of 100,000 barrels of oil in less than 2 years.

Two of the better fields discovered during the earlier exploratory phases are Bessie and Ewing East, both located in Franklin County, Illinois. Each field has produced approximately 1.5 million barrels of oil. Wells in Bessie Field, discovered in 1979, have average estimated reserves of 90,000 barrels of oil per well (Strothmann 1988). Several wells in this field have cumulative production exceeding 250,000 barrels of oil and are presently pumping about 20 barrels per day (appendix). Ewing East wells have lower reserves; however, at least 12 wells have cumulative production greater than 50,000 barrels of oil per well. Depth to the producing intervals in these two fields is approximately 3,800 to 4,000 feet. Depth to the "Warsaw" pay throughout Illinois ranges from 2,400 feet on the La Salle Anticlinorium to 4,400 feet in the heart of the Fairfield Basin (Wayne, White, and Hamilton Counties).

Hydrocarbon reservoirs in the Ullin ("Warsaw") are found in thin, discontinuous, porous lenses that commonly develop in the upper 100 feet of Ullin-type rock. A porosity log (fig. 41) from the Porter-Weaver Community no. 1, Section 8, T1S, R6E, one of the better "Warsaw" producers in Johnsonville Consolidated, shows the development of excellent porosity in the uppermost part of the Ullin ("Warsaw"). The hydrocarbon charge exists only in the intervals from 3,974 to 3,980 feet and 3,983 to 3,986 feet. The lower porosity zones are wet, typical of "Warsaw" production. Locally in Johnsonville, Enfield South and the Franklin County fields, the porosity equivalent to that below 3,998 feet in the Porter-Weaver Community no. 1 is commonly wet, even where the upper porosity is absent. The Porter-Weaver Community no. 1 has produced more than 240,000 barrels of oil in 22 months.

Core from the Ullin ("Warsaw") is scarce, and therefore measured values for porosity and permeability are hard to obtain. Porosity logs indicate that average porosity for reservoir rock ranges from 8% to 10%. As the experiences of oil field operators and porosity log examination show, wells with less than 6% porosity are nonproductive, probably because of low permeability.

Hydrocarbon reservoirs are generally found in porous zones commonly less than 10 feet thick in the upper 100 feet of the "Warsaw." The most productive

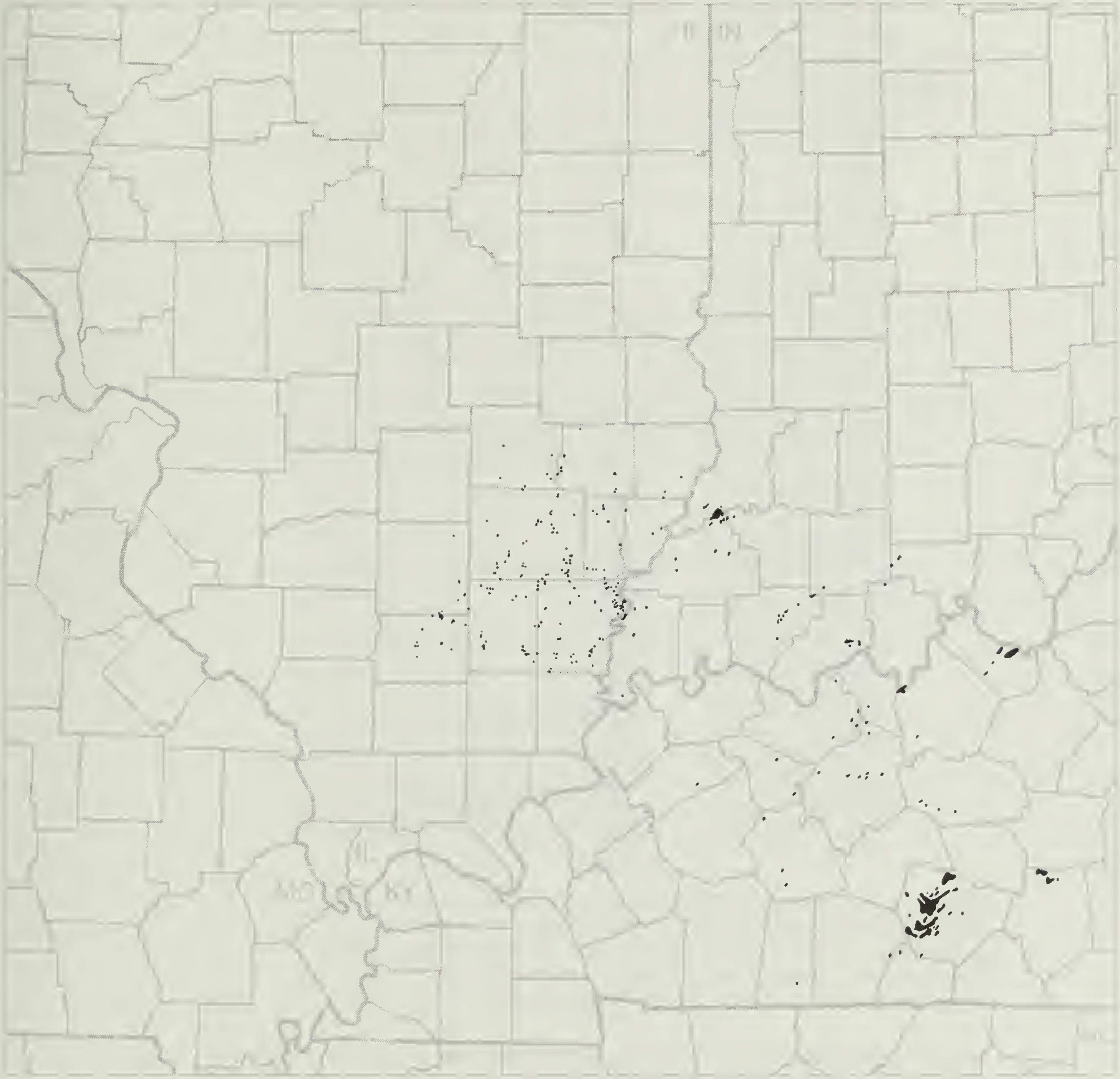

Figure 40 Distribution of Ullin/Harrodsburg/"Warsaw" hydrocarbon production in the Illinois Basin (from Howard 1991).

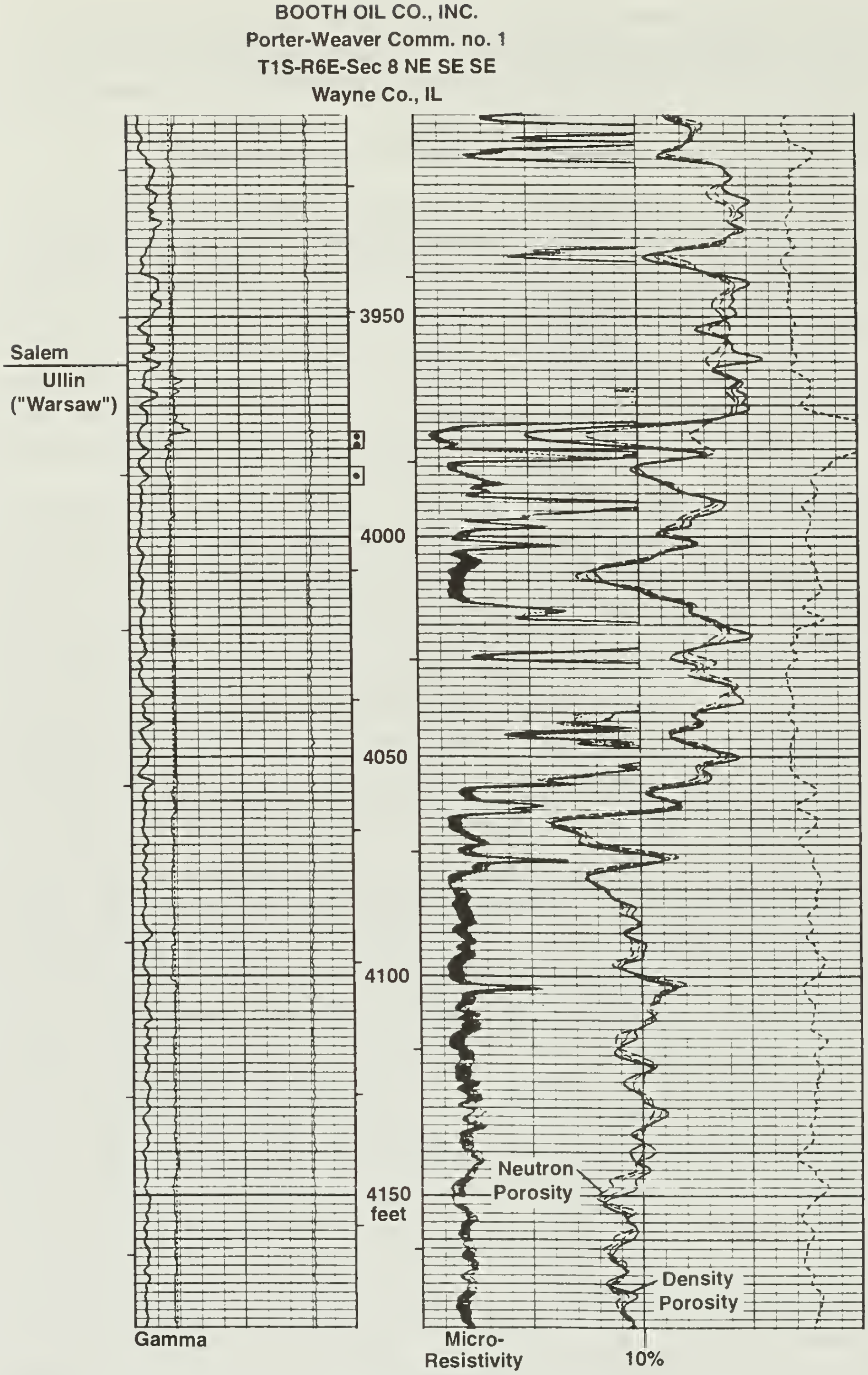

Figure 41 Porosity log of the Porter-Weaver Community no. 1, Sec. 8-T1S-R6E, one of the better Ullin ("Warsaw") producers in Johnsonville Consolidated. Note development of excellent porosity in the uppermost part of the unit. The hydrocarbon charge exists only from 3974-80 feet and from 3983-86 feet. The lower porosity zones are wet.

wells are associated with the development of multiple, porous zones, particularly in the uppermost part of the "Warsaw" (fig. 41). In these wells, only the top one or two porous zones produce hydrocarbons; the underlying porous zones produce only water.

A review of the Ullin ("Warsaw") fields in Illinois shows that a combination of structure and stratigraphy define the play. The critical components for the trapping of hydrocarbons are development of effective porosity and draping of the porous interval across a structure. Structural closure on the reservoir is not critical. Isopach mapping and trend projections based on geometric analysis of specific porosity development are fundamental to the discovery and development of "Warsaw" fields.

Thickness of the total Ullin ("Warsaw") (fig. 35) defines the boundary of the play within the basin. At present, most production is confined to that part of the basin where the thickness of the "Warsaw" exceeds 200 feet. The only production found where the Ullin ("Warsaw") is less than 200 feet thick is in the area that borders the west side of the Wabash River (figs. 35, 40). Further evaluation of porosity development and hydrocarbon migration may expand the boundary of the Ullin ("Warsaw") play.

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VULCAN MATERIALS COMPANY REED QUARRY, LIVINGSTON COUNTY, KENTUCKY

Garland R. Dever, Jr.
Kentucky Geological Survey

Terry Teitloff
Vulcan Materials Company Reed Quarry

The top producer of crushed stone in the United States during recent years has been the Reed quarry in Livingston County, Kentucky. In 1992, its production was 10.27 million tons (Prokopy 1993).

Opened in 1950 by the Clyde Reed Trucking Company, the quarry was operated for many years by the Reed Crushed Stone Company. Vulcan Materials Company purchased the operation in 1990.

Crushed stone has been produced from three Mississippian formations (in descending order), the Salem Limestone, Warsaw Limestone (Kentucky terminology), and Fort Payne Formation.

The Salem is composed of (1) olive to medium gray, fine to very coarse grained, bioclastic limestone that is locally cherty, and (2) olive gray to olive black, very finely crystalline limestone that is partly argillaceous to shaly and locally cherty.

The principal lithology of the Warsaw is very light to medium gray, fine to very coarse grained, bryozoan and crinoidal limestone. The Warsaw, particularly in the lower part, contains lenses and beds of olive gray to grayish black, micrograined to fine grained limestone and fine to coarse grained bioclastic limestone, both of which are commonly argillaceous and cherty.

The Fort Payne mainly is composed of medium dark to dark gray, very fine to fine grained, siliceous limestone. The silica content of the Fort Payne varies, but averages about 20%.

The quarry face is divided into eight ledges, which furnish a frame of reference for describing the quarry. Ledge 1 at the top of the pit and part of underlying ledge 2 are in the Salem. The Warsaw encompasses part of ledge 2, ledges 3 and 4, and the uppermost part of ledge 5. Most of ledge 5 and ledges 6, 7, and 8 are in the Fort Payne. The average height of ledges 2, 3, and 4 is about 60 feet. Each Fort Payne ledge, 5 through 8, is about 70 feet high. Ledge 1, along the lip of the quarry, varies in height.

In recent years, there has been no production from ledge 1 and very little from ledge 2, mainly riprap. Bryozoan-crinoidal limestone of the Warsaw in ledges 3 and 4 was the quarry's principal source of construction and agricultural stone for a number of years. Because they have the highest calcium carbonate content of all ledges in the present quarry, ledges 3 and 4 are now reserved for markets requiring chemically pure stone. From 1984 to 1989, limestone of ledge 3 was used in a flue-gas desulfurization, wet-scrubbing system at the

Big Rivers Electric Corporation, Wilson power plant in Ohio County, Kentucky. It was also used as sorbent stone in a 20-megawatt atmospheric fluidized-bed combustion pilot plant located near Paducah, Kentucky, and operated by the Tennessee Valley Authority. Ledge 4 currently is the quarry's main source for agricultural limestone.

In the early 1980s, the quarry was deepened to open up the Fort Payne for production. Siliceous limestone of the Fort Payne is being used for railroad ballast, bituminous and concrete aggregate, skid-resistant aggregate (Louisiana and Kentucky only), bank-paving material (riprap), and filter beds (both for sewage treatment and scrubber-sludge dewatering).

The Reed quarry ships about 75% of its production by barge, 15% by rail, and 10% by truck. The Gulf Coast region is the destination for most of the stone, mainly riprap and aggregate, that is transported by barge.

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INDUSTRIAL USES OF THE ULLIN LIMESTONE ("WARSAW")

Richard D. Harvey

The Harrodsburg Member (upper part of the Ullin Limestone) has distinctive qualities that make it valuable for the two main uses of crushed stone, agricultural limestone (to neutralize the acidity and improve the texture of soils) and construction aggregates. At the Jonesboro quarry (Stop 3), the limestone generally tests greater than 96% $CaCO_3$, approximately 3% to 4.5% water absorption, and almost 2.4 g/cc bulk density. These data indicate an average porosity of about 11%. Such qualities of purity and implied softness make this stone exceptionally valuable as an agricultural limestone, which represents about 40% of the production at this quarry.

Although tests by the Illinois Department of Highways of various gradations of the crushed stone confirm the quarry products to be too soft (average abrasion loss is 43%) and skid resistance too low for use as aggregates in portland cement concrete pavements, the tests do qualify this stone to be used for other road and construction materials where specifications of abrasion are less stringent. About 10% of the production from this quarry is sold for road-base materials and the coarse aggregates used on county roads.

From a nearby quarry, the Harrodsburg was used during the 1960s and early 1970s as dimension stone. At that quarry, the limestone is uniformly thick bedded, which allowed it to be quarried into big blocks and slabbed. The slabs were easily fabricated into a variety of building uses. The stone takes an excellent polish for special decorative veneers. Several buildings in nearby towns, especially Anna and Jonesboro, are veneered with this stone.

Since about 1970, a new market for limestones and dolomites developed, using their calcined product (lime or magnesia derived from a heating process) as an absorbent of sulfur oxides from flue gases that are generated by combustion of coal. Studies have shown that the Harrodsburg is uniquely suited for certain desulfurization processes, mainly those classified as wet-limestone "scrubbing" (Harvey et al. 1974) and, to a lesser extent, fluidized-bed combustion (Rostam-Abadi et al. 1989). The Harrodsburg, as quarried at Jonesboro, provided the highest SO_2 reactivity of the 11 rather typical carbonate rocks that were laboratory tested. Microscopic analyses suggest that the high reactivity of this stone is due to the high porosity that exists between the 5 to 20 μm calcite crystallites that constitute the abundant bryozoan fragments. Another contributing factor may be traces of highly reactive soluble salts (mainly NaCl) that occur as fluid inclusions within the large crystals that constitute the crinoid fragments. The light gray chert that occurs as a minor constituent in several beds of the Harrodsburg has the negative effect of diluting the abundance of the reactive calcite and causes extra wear on crushing and grinding equipment. Currently about 50% of the production from the Jonesboro quarry is used for desulfurization purposes in scrubbers at two power plants, one in Sikeston, Missouri, and the other (Southern Illinois Power Cooperative) in Marion, Illinois.

In the study by Rostam-Abadi et al. (1989), thermal gravimetric analyses of the 300 to 425 μm particles from this quarry absorbed more SO_2 than all other limestones tested. However, for the same study, in tests designed to simulate desulfurization under pressurized fluidized-bed combustion, this stone did not perform as well as many dolomites. The high reactivity of dolomites in the fluidized-bed environment is thought to be aided by the high porosity that is developed within the calcined products from dolomites. A considerable proportion of the calcium oxide that is produced during heating of dolomites is thought to form as ultrafine grains on the surfaces of the calcine, thus making the calcium readily available and exceptionally reactive with SO_2. To date, the market for other midwestern limestones for desulfurization have not significantly increased. The importation of low-sulfur coal (subbituminous) into midwestern power-generating plants has steadily increased during the past few years, and this trend is not expected to change in the near future. Substitution of fuels other than coal has limited the market for desulfurization with carbonate rocks.

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Appendix Production history to January 1994 for Ullin ("Warsaw") fields (Source: B.G. Huff)

Field	Discovery well Company	Farm name and number	Total depth (ft)	Completion date
Aden Consolidated	H.H. Weinert	Morlan "B" No. 5	4148	6/9/59
Akin West	Texaco	U.S. Steel No. 1	5185	4/19/62
Albion Consolidated	Superior Oil Company	J.C. Blood No. A-10	4511	9/19/80
Allendale	Bridgeport Drilling	M. Pace No. 1	2864	10/21/66
Barnhill	Ivan R. Jones	Zurliene No. 1	4378	9/20/81
Belle Prarie West	Calvert Drilling	Rawls No. 1	4389	5/5/59
Belle Rive	C. E. Brehm	Foster Community No. 1	4100	2/10/79
Benton	Shell Oil Co.	C W & F Coal No. 19	6250	3/16/60
Benton North	Great Plains Resources	Old Ben No. 2-H	3656	11/10/83
Berryville Consolidated	Southern Triangle	H. Pixley No. 1	3688	1/21/75
Bessie	C. E. Brehm Drilling & Producing	Summers-U.S. Steel No. 1	3900	11/27/79
Blairsville West Consolidated	J.D. Turner	F.C. Morris & Sons No. B-1	4565	2/17/81
Broughton	Duke Resources	Bonan No. 1	4269	11/11/77
Browns	Tartan Oil	A.J. Messman No. 2-A	3825	2/14/84
Bungay Consolidated	E.D. Dupont, Jr.	S.L. Moore No. 1-B	4290	12/22/59
Calhoun East	Bunn & Bunn Oil Co., Inc.	B. Williams No. 1	4166	7/9/85
Centerville	Jim Haley Oil Production	Martin R. Barbre No. 2	4140	10/15/82
Clay City Consolidated	Pure Oil Company	E. Walters No. 2	3646	12/23/52
Concord Consoldiated	Jim Haley Oil Production	W.R. Tuley No. 6	3965	3/1/75
Covington South	Peake Petroleum Company	Feathers et al. No. 1	4148	9/7/60
Crossville West	The French Creek Co.	George Spencer No. 2	4207	2/25/83
Dahlgren	Athene Development	C.L. Serivener No. 1	5299	11/27/56
Dahlgren South	Homco Ltd.	Koberlein No. 1	4366	9/24/82
Dahlgren Southwest	Ashland Exploration	Lena Cross No. 1	4585	8/2/83
Dahlgren West	Sun Oil Company	R.W. Aydt No. 1	5245	11/16/60

Discovery well (Sec-T-R)	County	Initial production BO/BW/DAY*	Depth to "Warsaw" zone (ft)	Thickness of zone (apprx ft)	No. of "Warsaw" wells	Comments
33-2S-7E	Wayne	138 BO	4132	16	7	First reported Warsaw production in state, also deepest pay at time
20-6S-4E	Franklin	82 BO	3994	10	2	
1-3S-10E	Edwards	40 BO/130 BW	3978	10	7	I.P. includes production from Salem
33-2N-12W	Wabash	50 BO/50 BW	2806	12	3	
9-3S-8E	Wayne	30 BO/20 BW	4214	11	3	Dry hole drilled deeper, OTD 3602; I.P. includes Salem and Rosiclare
1-4S-5E	Hamilton	24 BO/70 BW	4206	6	5	
22-3S-4E	Jefferson	9 BO/75 BW	3985	4	3	Old well drilled deeper
36-6S-2E	Franklin	261 BO/160 BW	3705	5	8	I.P. from 5 zones including McClosky and St. Louis discoveries
12-6S-2E	Franklin	60 BO/15 BW	3656	14	3	
31-2N-13W	Wabash	7 BO/10 BW	3605	10	2	I.P. includes production from Salem discovery
13-6S-3E	Franklin	150 BO	3825	6	22	
13-4S-6E	Hamilton	20 BO	4336	10	4	I.P. includes production from Salem discovery
27-6S-7E	Hamilton	580 BO	4191	10	9	
33-1S-14W	Wabash	33 BO/70 BW	3810	10	1	Old well drilled deeper; was Cypress and McClosky producer
10-4S-7E	Hamilton	14 BO/100 BW	4190	10	1	I.P. includes production from McClosky
6-2N-11E	Richland	18 BO/8 BW	4099	5	3	
12-4S-9E	White	91 BO/80 BW	4120	20	1	Extension to field
5-3N-9E	Richland	54 BO/96 BW	3600	17	67	I.P. includes production from McClosky, St. Louis and Salem
21-6S-10E	White	20 BO	3868	6	30	
14-2S-6E	Wayne	175 BO	4136	12	6	
22-4S-10E	White	20 BO/10 BW	4128	10	17	I.P. includes production from Aux Vases
27-3S-5E	Hamilton	11 BO/90 BW	4110	15	1	
30-4S-5E	Hamilton	75 BO/20 BW	4275	13	1	
15-4S-4E	Jefferson	3 BO/14 BW	4216	16	1	
1-4S-4E	Jefferson	150 BO/100 BW	4019	6	3	Old well worked over; abandoned 1966

Field	Discovery well Company	Farm name and number	Total depth (ft)	Completion date
Dale Consolidated	Ernest Sherman	W.E. Hunt et al. Unit No. 1	4180	4/25/78
Deering City	The Wiser Oil Company	Peabody Coal Co. No. 1	3748	12/10/85
Divide Consolidated	William & Phyllis Becker	Mammie Floweree No. 2	3601	8/4/81
Ellery East	Sandy Ridge Oil Co., Inc.	Harold Perkins No. 1	4227	11/25/78
Ellery South	Modern Exploration	Glover No. 1	4159	12/4/78
Enfield	Pricefields Oil, Inc.	Fields-West No. 1	4358	8/1/77
Enfield North	R.K. Petroleum	Triple AAA Ranch No. 4	4392	5/17/77
Enfield South	Wilbanks Exploration	Warren No. 1-6	4294	11/1/90
Ewing	Geo. Mitchell Drilling	Dalby No. 1	3821	4/25/81
Ewing East	C.E. Brehm	Clayton Heirs Comm. No. 1	9511	10/12/76
Flora South	Dart Oil & Gas	Levitt-McHenry Comm. No. 5-1	4900	4/22/82
Gards Point Consolidated	Louis A. Pessina	J.A. Fishel No. 1	3705	8/19/75
Goldengate Consolidated	T.G. Jenkins	T.G. Jenkins No. 1	4135	11/8/61
Goldengate North Consolidated	Humboldt Oil Company	E. Webb No. 1	4750	4/17/84
Herald Consolidated	C.E. Brehm Drilling & Production	Rupp No. 1	5285	5/29/76
Johnsonville Consolidated	Mid-American Petroleum	Dickey No. 2	3938	10/31/80
Johnsonville West	Joe A. Dull	Cravens No. 1	3824	8/30/78
Lawrence	Hubert Rose	Ackman No. 1	3387	5/10/83
Louisville	Texaco	John Paul Kincaid No. 1	4865	11/2/74
Macedonia	C.E. Brehm Drilling & Production	Hutchcraft Unit No. 1	5249	2/15/61
Maple Grove Consolidated	Energy Resources	P.M. Weber No. 5	4057	8/10/76
Maple Grove South Consolidated				
Maunie North Consolidated	Collin Bros.	Grover Hines No. 1	6119	4/15/80
Maunie South Consolidated	Rhea Fletcher	Flora Karch No. 3	4256	7/29/74
Mayberry	Commanche Oil Corp.	Parker Comm. No. 1	5373	1/14/77
Mayberry North	E.S. Guilliams	Legg & Bryant	4311	10/2/81
Mayberry South	V.R. Gallagher	Trotter No. 1	4350	8/19/81

Discovery well (Sec-T-R)	County	Initial production BO/BW/DAY*	Depth to "Warsaw" zone (ft)	Thickness of zone (apprx ft)	No. of "Warsaw" wells	Comments
21-6S-7E	Hamilton	20 BO	4124	10	23	Extension to field
16-7S-3E	Franklin	20 BO	3748	13	1	
21-1S-4E	Jefferson	7 BO/10 BW	3502	10	2	
3-3S-10E	Edwards	16 BO/18 BW	4218	9	1	I.P. includes production from Ohara
4-3S-10E	Edwards	125 BO	4156	10	1	Also field extension
17-5S-8E	White	10 BO	4318	19	5	Extension to field
9-5S-8E	White	50 BO	4385	6	1	
6-6S-8E	White	40 BO/100 BW	4294	6	6	
3-5S-3E	Franklin	4 BO/75 BW	3790	6	1	I.P. includes production from St. Louis
2-5S-3E	Franklin	104 BO/70 BW	3880	6	40	
5-2N-6E	Clay	125 BO	3707	9	1	Old well drilled deeper; was D&A, old TD 3102
14-1N-14W	Wabash	14 BO	3698	8	1	
29-2S-9E	Wayne	40 BO	4125	9	33	Old well worked over
5-2S-9E	Wayne	45 BO	4323	7	5	
2-7S-9E	White	25 BO/30 BW	3961	12	35	
20-1S-6E	Wayne	15 BO/30 BW	3823	10	17	
35-1N-5E	Wayne	14 BO/12 BW	3823	10	1	
6-2N-11W	Lawrence	45 BO/100 BW	2420	10	1	
28-4N-6E	Clay	107 BO/60 BW	3534	4	2	Discovery well of field; I.P. includes Aux Vases, McClosky & Salem
24-5S-4E	Franklin	75 BO	4097	12	2	Dry and abandoned well worked over
22-1N-9E	Wayne	25 BO/30 BW	4050	7	4	
						See Samsville West for Warsaw Discovery
2-6S-10E	White	oil well			3	I.P. not reported. Produces from Salem also
24-6S-10E	White	51 BO/240 BW	3964	6	1	I.P. includes production from St. Louis
8-3S-6E	Wayne	200 BO/20 BW	4297	25	9	
27-2S-6E	Wayne	40 BO/70 BW	4194	4	1	
16-3S-6E	Wayne	47 BO/28 BW	4282	5	1	

Field	Discovery well Company	Farm name and number	Total depth (ft)	Completion date
Mill Shoals	Nation Oil	W.P. McIntosh No. 2	4191	11/4/59
Mt. Carmel	Farmers Petroleum Co-op	Wabash-Newton No. 3	3117	11/1/77
New Harmony Consolidated				
Noble West	Hubert Rose	Vida King No. 1	3712	10/29/79
Norris City West	Reynolds & Vincent	Mary Britton Comm. No. 1	4460	4/18/78
Olney South	Frank Yockey and Yockey Oil, Inc.	Walter Schonert No. 2	3935	9/12/90
Parkersburg Consolidated	Viking Oil Co.	Imogene Fishel No. 1	4118	6/28/78
Phillipstown Consolidated	Louis Pessina	E.H. Morris "A" No. 1	4100	2/12/80
Roland Consolidated	Southern Triangle	H. Ward No. 1	4123	1/11/66
Rural Hill North	Juniper Petroleum Inc.	Clark-Meneghin 47-34	4275	3/15/77
Samsville West	Spartan Petroleum	Leonard Garman No. 2	4175	5/31/77
Springerton South	Perry Fulk	Hazelip No. 1	4385	6/18/77
Storms Consolidated	Atek Drilling & Production	L. Cutchin No. 1	4038	12/16/84
Sumpter North	Absher Oil	C. Bohleber No. 1	4335	8/3/74
Taylor Hill	Leo Horton	Webb Heirs No. 1	3970	1/18/61
Walpole	Henry Energy Corporation	Johnson Heirs No. 1	5950	6/20/85
Whittington	H & W Oil Company	Adams No. 1	3719	2/21/77

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*Barrels of oil, barrels of water per day

Discovery well (Sec-T-R)	County	Initial production BO/BW/DAY*	Depth to "Warsaw" zone (ft)	Thickness of zone (apprx ft)	No. of "Warsaw" wells	Comments
31-3S-8E	White	57 BO/110 BW	4110	10	7	
8-1S-12W	Wabash	20 BO/30 BW	3097	10	5	Old well drilled deeper, formerly D & A
			3755	6	70	Discovery well unknown
3-3N-8E	Clay	21 BO/210 BW	3695	5	1	I.P. includes production from Salem and McClosky; also field extension
30-6S-8E	White	38 BO	4204	14	1	Dry hole drilled deeper; also discovery of Norris City West field
17-3N-10E	Richland	10 BO/30 BW	3894	6	1	
17-2N-14W	Richland	20 BO/30 BW	3966	4	3	I.P. includes production from Salem
30-3S-11E	White	8 BO	3990	8	23	
36-5S-8E	White	25 BO	4050	4	19	I.P. includes production from Salem
34-5S-5E	Hamilton	89 BO/64 BW	4220	7	6	I.P. includes production from Ohara and St. Louis discoveries
22-1N-10E	Edwards	20 BO/40 BW	4170	5	1	Incorporated into Maple Grove South Consolidated 1977
28-4S-8E	White	15 BO/100 BW	4379	6	2	
11-6S-9E	White	49 BO	4030	8	1	I.P. includes production from Spar Mountain and St. Louis
21-4S-9E	White	10 BO/30 BW	4230	30	4	
16-5S-4E	Franklin	8 BO	3940	15	14	Old well worked over
27-6S-6E	Hamilton	60 BO	4194	4	9	
30-5S-3E	Franklin	20 BO	3562	7	5	D & A well drilled deeper, I.P. includes production from Salem discovery


Mt. Vernon
Fairfield
Wayne City
Nashville
Pinckneyville
Du Quoin
Benton
Carmi
Christopher
West Frankfort
Herrin
Murphysboro
Carbondale
Marion
Harrisburg
Shawneetown
Eldorado
Ridgway
Cape Girardeau
Jonesboro
Anna
Vienna
Golconda
Rosiclare
Cave in Rock
Metropolis
Brookport
Paducah
Cairo
Mounds
Charleston
Sikeston
Eddyville
Calvert City
Benton
Marion
SHAWNEE NATIONAL FOREST
MISSOURI
KENTUCKY
MO.
KY.
1 Reed quarry
2 Ullin quarry
3 Jonesboro quarry
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