Reservoir Characteristics and Oil Production in the Cypress and Aux Vases Formations at Storms Consolidated Field in White County, Illinois

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with contributions by Richard Rice

MAY 16 1997

Department of Natural Resources
ILLINOIS STATE GEOLOGICAL SURVEY
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ABSTRACT

Data (e.g., wireline logs, completion reports, and core samples) from approximately 450 wells were analyzed in this study of the potential for increased hydrocarbon recovery from the Aux Vases and Cypress Formations at Storms Consolidated Field in White County, Illinois.

Storms Consolidated Field, discovered in 1939, is situated on a large anticlinal nose bounded on the east by the Herald–Phillipstown Fault. Two of the producing sandstones, the Cypress and Aux Vases Sandstones, form compartmentalized reservoirs at depths of 2,700 and 2,900 feet. Aux Vases reservoir compartments extend for more than 300 acres and contain 15 or more producing wells. The average initial production test for the Aux Vases was 65 barrels of oil per day. Cypress reservoir compartments rarely extend for more than 40 acres and generally contain only one or two productive wells. The average initial production test for the Cypress was 30 barrels of oil per day.

The recovery of hydrocarbons from Storms Consolidated Field can be improved by evaluating and understanding properties of the reservoir at all scales. During the drilling or completion of a well, the Aux Vases Sandstone, with its continuous clay coatings around sandstone grains, is more susceptible to reservoir damage by freshwater than is the Cypress Sandstone. Not all of the reservoir compartments in either formation have been waterflooded; therefore, additional oil could be recovered by planning a proper water injection program. The most important area of reservoir growth within this field is in discovering new undrilled compartments. The recently drilled Tract 11A compartment has an original oil in place of more than one million barrels. There is a good probability of finding other compartments of similar size within this field.

INTRODUCTION

Storms Consolidated Field is located in the central portion of the Illinois Basin near the town of Carmi in White County, Illinois (fig. 1). The Aux Vases and Cypress traps are formed by stratigraphic pinchouts of reservoir sandstone bodies across a large anticlinal nose. Extending over 19,000 acres, the field produces mainly from the Waltersburg Formation (Mississippian) at a depth of approximately 2,200 feet (fig. 2). The field also produces from the Mississippian Cypress, Bethel, Aux Vases, and Ste. Genevieve Formations at depths of 2,800 to 3,100 feet. Storms Consolidated Field has produced more than 20 million barrels of oil since its discovery in 1939.

This report discusses the reservoir characterization and potential for improved oil recovery from Mississippian Aux Vases and Cypress reservoirs at Storms Consolidated Field. In this study, the reservoirs are characterized at four different scales (terminology after Krause et al. 1987): microscale (grains and pores), macroscale (sandstones, sandstone bodies), and regional scale (anticlinal noses).
Figure 2  Generalized geologic column of Mississippian strata in southern Illinois. Formations that contain hydrocarbon reserves are shown in bold type (modified from Heigold and Whitaker 1989).

mesoscale (near a well bore), macroscale (interwell), and megascale (field-wide). This separation of the reservoir characterization into discrete scales was done to highlight the importance of each scale in improving oil recovery in Storms Consolidated Field.

The ultimate recovery from a field is dependent on understanding reservoir characteristics at all levels of scale. These characteristics determine how a reservoir should be discovered and developed, and they affect the steps that should be taken to significantly improve oil recovery from an existing reservoir (Weber 1986). The relevance of each scale varies with the different phases of field development. Microscale characteristics are most important when considering the effects of outside fluids on the reservoir during drilling, completion, and waterflooding. Mesoscale and macroscale characteristics are more important in efficiently locating the wells and in designing an effective waterflood. Megascale characteristics are crucial in exploring for and in delineating discrete reservoir compartments within a field. An understanding of the megascale is crucial in searching for isolated reservoir compartments.
Unfortunately, analysis at all scales is not always possible. For example, significantly more data were available for the Aux Vases Formation than for the Cypress at Storms Consolidated Field, and thus all four scales were examined for the Aux Vases Formation. Because of the lack of micro- and mesoscale data (there are few modern wireline logs through the Cypress reservoir and no whole core) for the Cypress, this report emphasizes the macro- and megascale characteristics of that formation.

Data (wireline logs, completion reports, and core samples) from approximately 450 wells were analyzed for this study. The location map used in this report (fig. 3) includes only those wells that have penetrated to the Chesterian Cypress Formation or deeper; therefore, none of the shallower Waltersburg producing wells are mapped.

**Production History**

The discovery well at Storms Consolidated Field (Storms no. 1) was drilled in July 1939 by Eason Oil Company (Sec. 14, T6S, R9W) (fig. 3) to a total depth of 3,089 feet. After encountering gas at 2,200 feet, the well was completed in the Waltersburg reservoir, producing 11 million cubic feet of gas and 475 barrels of oil per day (BOPD). Most of the twenty million barrels of oil was recovered from the Waltersburg sandstone. The field was unitized into the Storms Pool Unit in 1951. The waterflood of the Waltersburg Formation commenced in 1955. In 1978 a pilot polymer flood sponsored by the U.S. Department of Energy was initiated in the Waltersburg Formation by Energy Resources Company and Elf Aquitaine Oil and Gas Company (Craig 1984). This polymer flood was discontinued in 1982 because of unfavorable economics. Most of the Waltersburg wells were close to their economic limit by 1984 (Craig 1984).

During most of the life of this field, the Waltersburg Formation was the principal target of development. Since the 1930s, however, 65 wells (with initial productions ranging from 3 to 800 BOPD) have been completed in the Aux Vases Sandstone. There have been 23 Cypress completions, with initial production tests ranging from 2 to 130 BOPD. As of the end of 1994, Storms Consolidated Field had a cumulative production of 24 million barrels of oil from all of the producing horizons. This field produced more than 13,000 barrels of oil in 1994.

**Geologic Data and Methodology**

The microscale and mesoscale interpretations of the Aux Vases depositional system were heavily influenced by observations from a continuous core from the Haley Production Rudolph no. 26 Tract 11A well (Sec. 12, T6S, R9E) (fig. 3). Eight thin sections from this core and nine additional thin sections of the Aux Vases and Cypress Formations were examined from cores from six additional wells (fig. 3, appendixes A and B). The interpretation of the core was supplemented by analysis of wireline log characteristics, including resistivity changes and spontaneous potential (SP) deflections.

Morphology, composition, and distribution of detrital and diagenetic minerals as well as types of porosity were analyzed using thin sections, scanning electron microscopy (SEM) with energy dispersive X-ray (EDX), and X-ray diffraction analysis (XRD). Thin sections were impregnated with blue-dyed epoxy and stained with Alizarin Red-S for calcite identification and with potassium ferri-cyanide to distinguish iron-rich carbonate varieties.

Geologic cross sections were made through individual reservoir compartments and across the entire field (fig. 3). Cross sections and the structure and isopach maps of the reservoir were used to determine the macro- and megascale characteristics within the field.
Figure 3  Base map of Storms Consolidated Field. Only wells that have penetrated to at least the Chesterian Cypress Formation are posted. The locations of the cross sections referred to in this report are also shown.
FIELD CHARACTERISTICS

Stratigraphy
A typical wireline log (fig. 4) for Storms Consolidated Field illustrates the cyclic pattern of carbonate and siliciclastic deposition in the interval from the Ste. Genevieve Limestone to the Beech Creek Limestone. Carbonate lithologies are characterized by high resistivities (greater than 50 ohm-m), whereas the siliciclastics have lower values. Marine transgressions and regressions that reflect relative sea level changes have been identified by the relative abundance of sandstones versus shales and carbonates (Swann 1963). Relative sea level is defined as the position of the sea surface relative to land; it does not differentiate between eustatic (global) and tectonic (local) changes. Vertical variations in lithology reflect the relative position of the shoreline and proximity to sources of deltaic clastics.

The strata between the Ste. Genevieve and Beech Creek Formations (fig. 4) were deposited in a cratonic basin characterized by relatively shallow water. In cratonic basins (or epeiric seas), the depositional slope is low and small relative changes in

Hiawatha Oil and Gas company
W. P. Hanna no. 2
Sec. 29, T5S, R10E
KB 400 feet
comp. 9/61

SP

Beech Creek
Cypress A1
Cypress A2

2800-
long
normal

Cypress B
Cypress C
Ridenhower
Bethel
Downeys Bluff
Yankeetown
Renault
Aux Vases
Joppa Limestone Member
(Ste. Genevieve)

3000-

3100-

Karnak Limestone Member
(Ste. Genevieve)

Figure 4 Type log of part of the Valmeyeran and Chesterian section at Storms Consolidated Field showing key stratigraphic horizons.
sea level can produce dramatic lateral effects on depositional systems (Leighton and Kolata 1991). At Storms Consolidated Field, shale and carbonate deposition dominated during relative rises in sea level (marine transgressions), and siliciclastic deposition during relative drops (marine regressions).

The top of the Valmeyeran-age Karnak Limestone Member of the Ste. Genevieve Limestone marks the beginning of a depositional cycle with an abrupt change from a carbonate-dominated to a siliciclastic-dominated system (Swann 1963, Heidlauf et al. 1986). The Ste. Genevieve and St. Louis Formations represent an interval of abundant carbonate production punctuated by minor siliciclastic influxes. Beginning in the Chesterian and possibly latest Valmeyeran time, widespread tectonic activity in the mid-continent was related to the start of the Alleghenian Orogeny (Kolata and Nelson 1991). Although tectonic activity probably influenced relative changes in sea level within the Illinois Basin, many of these Valmeyeran and Chesterian sea level changes apparently occurred on a global scale (Ross and Ross 1988).

The Karnak Limestone Member of the Ste. Genevieve contains oolitic limestone bodies that are productive within Storms Consolidated Field. These limestones are overlain by 5 to 10 feet of unproductive siltstones and shales interpreted to have resulted from a drop in sea level. These siltstone and shale beds are not laterally continuous across the field; therefore, differentiation of the Karnak Limestone Member from the overlying Joppa Limestone Member is not always possible. The Joppa Limestone Member is composed of abundant echinoderm fragments and has little to no porosity or permeability.

The Aux Vases Formation overlies the Joppa Limestone Member of the Ste. Genevieve. The Aux Vases is about 50 feet thick and consists of porous and permeable reservoir sandstones that are as much as 40 feet thick and grade laterally into siltstones and shales with little or no permeability. Facies transitions commonly occur within the minimum well spacing (a distance of 660 feet). The Aux Vases is overlain by the Renault Formation, a 10-foot-thick limestone with negligible porosity. The Renault is laterally continuous across the entire field and is an excellent stratigraphic marker on old wireline electric logs.

Overlying the Renault Limestone is the Yankeetown Formation, which is 20 feet thick, unproductive, and composed mostly of shale and siltstone. The Yankeetown is overlain by the Downeys Bluff Formation, a transgressive limestone that is continuous across the entire field and provides an excellent stratigraphic marker. Another regressive phase is marked by the Bethel Formation, a succession of more than 50 feet of low permeability siltstone and sandstone beds. The thickness of the Downeys Bluff Formation is approximately the same across the field, suggesting that the Bethel Sandstone was not deposited in channels scoured into the Downeys Bluff. Although this sandstone is productive elsewhere in Illinois, the permeability of the Bethel in this field is usually less than 50 md (millidarcy) and, as a result, there are only two Bethel Sandstone producers at Storms Consolidated Field.

The Bethel Formation is overlain by the shale and limestone of the Ridenhower Formation. The top of the Ridenhower is difficult to recognize because it appears to have been eroded before deposition of the Cypress Formation. In this report, the Cypress Sandstone, which overlies the Bethel, has been subdivided into four intervals (Cypress A1, A2, B, and C sandstones, fig. 4) interpreted to correspond to the sea level fluctuations of Swann (1963). None of the sandstone bodies within these four intervals is continuous across the field. Siliciclastic deposits of the Cypress are capped by the transgressive limestone of the Beech Creek Formation, a consistent marker bed that is about 10 feet thick throughout the study area.
Structure
Storms Consolidated Field is about 7 miles long and 5 miles wide. Structure maps of the top of the Beech Creek Limestone (fig. 5) and the top of a limestone in the Renault Formation (fig. 6) show a broad anticlinal nose with more than 200 feet of relief and a north–south axis. Contour lines off this anticlinal nose parallel the Herald–Phillipstown Fault. Aux Vases production in the field is concentrated along the structural axis, but it is not limited to that area. Most of the Cypress production in the field is not related to structure.

Storms Consolidated Field is bounded on the east by the Herald–Phillipstown Fault, a part of the Wabash Valley Fault System. The Herald–Phillipstown Fault is characterized by a down-to-the-east, high-angle normal fault that generally trends north-northeast and has a maximum displacement of 350 feet at Storms Consolidated Field (Bristol and Treworgy 1979). All of the Wabash Valley faults are structurally similar and probably formed in response to the Alleghenian Orogeny (Atherton 1971, Kolata and Nelson 1991).

AUX VASES RESERVOIRS

Structure
The structure contour map of the top of the lower Renault Limestone (fig. 6) shows a broad prominent anticlinal nose that trends north–south and has no definable four-way closure. Most of the Aux Vases traps are formed by stratigraphic pinchouts of discrete sandstone bodies across this large structural nose.

Multiscale Characteristics
The division of data into micro- (grains and pores), meso- (near a well bore), macro- (interwell), and megascales (field-wide) is not always clear because transitions between the scales are gradual. For example, macro- and megascale characteristics both involve the continuity of a reservoir between individual wells. The difference between these two scales is that macroscale changes occur within a reservoir compartment between wells, whereas megascale changes affect two or more compartments. The characteristics of each of these scales are interrelated, and both affect the potential for improved oil recovery.

Microscale Characteristics
Petrography Analysis of XRD data and thin section point counts of mineral percentages (appendix A) shows that Aux Vases reservoir sandstones typically contain 60% to 80% quartz and less than 10% feldspar. Lithologies of Aux Vases reservoir sandstones range from quartz arenite to subarkose. The sandstones are cemented (in decreasing order of abundance) by calcite, clay minerals, minor amounts of silica in the form of quartz overgrowths, and pyrite. Clay minerals in the reservoir facies constitute less than 10% of the total volume (appendix A) and occur as various proportions of illite, mixed-layered illite/smectite, and iron-bearing chlorite. The best reservoir sandstone is extremely friable and occurs where the detrital grains are cemented primarily by clay minerals. In less friable and lower quality reservoir sandstones, the cement consists of quartz, pore-filling calcite, and some local patches of pyrite.

The microscale characteristics within the Aux Vases reservoir sandstone bodies affecting production are primarily diagenetic variations. The two most important cements in controlling reservoir quality are clay minerals and calcite. Quartz cement is rare in the more productive Aux Vases reservoir facies, and its growth apparently was inhibited where clay minerals coat many of the grains (fig. 7), a feature noted in many other subsurface formations (Pittman et al. 1992). These clay coatings are approximately 3 μm thick and are absent at grain-to-grain contacts. In those facies
Figure 5  Structure map contoured on top of the Beech Creek Limestone. Circled wells are Cypress producing wells. All of the Cypress wells produce from the A1 and A2 intervals except for Cypress B production in Section 28 (contour interval is 10 feet).
Figure 6  Structure map contoured on top of the lower Renault Limestone. Circled wells produce from the Aux Vases Sandstone (contour interval is 10 feet).
where clay coatings are incomplete, an apparent increase in quartz overgrowths and a corresponding reduction in porosity and pore-throat size occur.

Dissolution of the reservoir rock during diagenesis has formed some secondary porosity. Calcite cementation was more prevalent in the early stages of diagenesis, but later dissolution of this calcite appears to have resulted in some porosity enhancement. The amount of secondary porosity created by dissolution is less than primary porosity. Secondary porosity was also created during feldspar dissolution. Feldspars with some microporosity accounted for 9% of a thin section point count. Zones with the best porosity have significant amounts of clay mineral coatings and abundant secondary porosity. Although the evidence is not definitive, the larger secondary pores may have formed by the complete dissolution of feldspar grains. This interpretation was made on the basis of the presence of partially dissolved feldspars in the largest pore spaces and the numerous feldspar grains that appear to have undergone some dissolution.

Two types of calcite cement occur in the Aux Vases Sandstone. The first type of cement, a relatively pure CaCO₃ calcite, is commonly precipitated around carbonate detrital grains (fig. 8) and forms early in diagenesis. The second type of calcite, a ferroan calcite, forms euhedral crystals in pores. It contains iron and generally forms late in the diagenetic sequence (Surdam et al. 1989). Although the iron in this cement will cause the calcite in thin section to stain dark purple when reacting with potassium ferricyanide, the iron could not be detected by EDX analysis because the concentration is below the instrument's detection limit (Scott Beaty, ISGS, personal communication, 1993). Both types of calcite cementation can follow bedding planes and completely fill pore spaces. Ferroan calcite constitutes 0% to 5% of the volume of the reservoir facies, whereas the nonferroan calcite ranges from 1% to 9%. It is

![Figure 7 SEM photomicrograph of continuous diagenetic clay coating around Aux Vases Sandstone grains. Only at the grain to grain contacts (C) are the clay coatings absent. The well formed crystal (Ca) is late-stage calcite (Haley Production Company Rudolph no. 26 Tract 11A; depth 2,942.1 feet).](image-url)
difficult to evaluate the lateral continuity of these calcite-cemented zones in adjacent wells, but even localized zones could impede fluid flow in the reservoir and create unswept areas during a waterflood program. Echinoderm fragments commonly are sites for nucleation because of their single crystal structure (Bathurst 1975).

The Aux Vases Sandstone also may contain rare, isolated patches of pyrite cement. These patches may comprise more than 5% of the rock and, where present, occlude porosity. This cement may follow crossbed laminae or be intermixed with calcite cement. Because these pyritized zones are parallel to the cross laminae and terminate at the bedding boundary, they do not appear to be laterally extensive and should not be a factor in reservoir compartmentalization or local fluid flow.

In summary, Aux Vases reservoir sandstones at Storms Consolidated Field have undergone six major diagenetic events: (1) precipitation of early calcite cement around fossil fragments; (2) dissolution of feldspar and precipitation of continuous coatings of diagenetic clay minerals around quartz grains; (3) precipitation of minor quartz overgrowths where clay coatings are discontinuous; (4) dissolution of some of the earlier calcite cement; (5) precipitation of a second stage of cements, such as diagenetic clay minerals and iron-rich calcite; and finally (6) migration of hydrocarbons into the reservoir, which halted diagenesis.

**Effects on reservoir measurements, quality, and recovery** The abundant microporosity of the clay minerals contains irreducible water that causes anomalously high water saturation measurements on wireline logs (Kieke and Hartmann 1974). Water saturation values calculated from wireline logs can be as high as 60% to 80% in the Aux Vases reservoir interval; yet, these zones produce little or no water (Seyler 1988).

*Figure 8* SEM photomicrograph of a calcareous fragment, possibly a pelloid, with early calcite cement nucleating around the fragment, from the Aux Vases Sandstone. This type of early calcite cement is common within the sandstones and decreases porosity (Haley Production Company Rudolph no. 28 Tract 11A; depth 2,930 feet).
<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>INTERPRETATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>faint traces of crossbedding</td>
<td>bioturbated lithofacies</td>
</tr>
<tr>
<td>moderately bioturbated</td>
<td></td>
</tr>
<tr>
<td>calcite and pyrite cemented along laminae sets</td>
<td>crossbedded lithofacies</td>
</tr>
<tr>
<td></td>
<td>moderate current velocity with medium scale bedforms</td>
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<td>crossbedded</td>
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<td>crossbedded</td>
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<tr>
<td>pyrite along laminae set</td>
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</tr>
<tr>
<td>low angle cross laminae oil stain in coarser intervals</td>
<td>oil staining is interpreted to be transition zone near oil/water contact</td>
</tr>
<tr>
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<td>crossbedded rhythmitic interval</td>
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<td>rhythmitic character suggests regular changes of short duration such as current fluctuations like tides</td>
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<tr>
<td>minor bioturbation</td>
<td>mudstone lithofacies</td>
</tr>
<tr>
<td>mudstone shale rip up clasts contact with Joppa Member or Ste. Genevieve</td>
<td>rip up clasts appear to be from underlying limestones</td>
</tr>
</tbody>
</table>

Figure 9  Detailed core description, wireline log, core analysis, and vertical location of the core photographs and microphotographs of the Aux Vases Sandstone illustrating changes in facies and reservoir quality for the Haley Production Company Rudolph no. 26 Tract 11A.
Clay minerals within the Aux Vases Sandstone may present problems when they come in contact with drilling, completion, or stimulation fluids. Mixed-layered illite/smectite can swell in freshwater (Almon and Davies 1981), clogging pore throats and reducing permeability. The potential for swelling clay problems in the Aux Vases was recognized by Witherspoon (1952): "Field observations indicate that in certain pools the Aux Vases sand contains clay minerals that need to be investigated as to their stability under various flooding conditions."

New waterflood projects in the Aux Vases should use recycled Aux Vases formation brine and not freshwater injection fluid. Surfactants and polymer solutions injected into the formation during chemical floods also can be adsorbed by clay minerals (Ebanks 1987), which can impede enhanced tertiary oil recovery and necessitate the use of greater amounts of these reagents, significantly increasing project costs.

Iron-bearing chlorite could cause problems if hydrochloric acid is used as a completion fluid. Iron is liberated from chlorite by the acid and reprecipitated as ferric hydroxide (McLeod 1984). This amorphous, gel-like precipitate would clog the pore throats and lower reservoir permeability.

In summary, diagenetic alteration of the original sandstone has modified the microscale characteristics of the Aux Vases reservoir. Pores were filled by calcite and clays as well as by quartz in some areas. Secondary porosity was created by partial dissolution of calcite and feldspars. Although the diagenetic clay minerals may have helped preserve initial porosity, they complicate wireline log interpretations and increase the potential for problems in drilling and completing the well. Thus, understanding the microscale features of the reservoir rock will help ensure optimal recovery from each producing well.

**Mesoscale Characteristics**

Mesoscale characteristics are features that can be described in the well bore. Such features define the vertical variation or limits (compartment boundaries) of the reservoir, and many are laterally extensive and can be mapped. They provide the key to the macroscale characteristics within the reservoir. Variations in lithofacies and in their associated reservoir quality properties in the Aux Vases at Storms Consolidated Field are illustrated in core from the Haley Production Company Rudolph no. 26 Tract 11A well (fig. 9). There is a 5- to 6-foot depth correction between core and wireline log depths.
Figure 10  The light colored lower portion of the core is the Joppa limestone. It is separated from mudstone in the Aux Vases by a thin shale. The bottom 2 inches of the Aux Vases is a mudstone with limestone clasts of Joppa Limestone Member of the Ste. Genevieve Limestone (Haley Production Company Rudolph no. 26 Tract 11A; depth 2,950 feet).

Figure 11  Crossbedded sandstone, typical of the most porous and permeable portion of the Aux Vases reservoir. The darker patches are iron pyrite cement (Haley Production Company Rudolph no. 26 Tract 11A; depth 2,940.5 feet).

Mudstone lithofacies  The basal unit of the core is the Joppa Limestone Member of the Ste. Genevieve Formation. The Joppa contains abundant echinoderm fragments, has less than 1 md of permeability, and is not part of the reservoir in any part of the field (fig. 10). A thin shale (less than 1 in. thick) that overlies the Joppa is overlain by a mudstone in which the lower 2 inches contain lighter colored limestone clasts that are petrographically similar to the Joppa (fig. 10). These clasts were probably eroded from Joppa equivalents in nearby areas during turbulent events such as storms. The mudstone grades upward into a high-angle crossbedded sandstone of the Aux Vases reservoir, and the mudstone is the basal Aux Vases unit. The mudstone lithofacies has a permeability of less than 5 md.

Crossbedded sandstone lithofacies  Reservoir intervals with the highest porosity and permeability typically are crossbedded sandstones (fig. 11). If this whole core is from a vertical wellbore, the foresets dip from 15° to 25°. The inclined foresets include planar and curved strata suggestive of transport in the middle to upper part of the lower flow regime as sand waves or subaqueous dunes (Collinson and Thompson 1989). The bedding units ranged from 3 inches to more than 3 feet in
thickness. The individual foreset laminae within the beds are less than 0.5 inch thick. In some instances, the crossbedding is contorted, which is suggestive of deformation by slumping soon after deposition.

The permeability of a core slab of the crossbedded lithofacies from 2,936.5 to 2,937.1 feet (Rudolph no. 26 Tract 11A) was measured at closely spaced intervals along cross-laminae using a minipermeameter (fig. 12). When used on a flat surface, the minipermeameter is reasonably accurate over a range of 10 to 500 md (Weber 1982). Although permeability values within single sets were similar, there was more variation between different sets. For example, while the upper two crossbed sets had average permeabilities of 116 and 74 md, the lower two sets had average permeabilities of 42 and 40 md. Thus, we found sufficient variations between foreset laminae that oil recovery may be reduced because of preferential fluid flow through the zones of higher permeability (Van de Graff and Ealey 1989). The crossbedded lithofacies in the core from 2,935 to 2,940 feet correlates with the interval from 2,942 to 2,946 feet on the wireline log.

Rhythmically bedded sandstone lithofacies
The bed between 2,946.7 and 2,947.2 feet (fig. 9) is composed of thin (0.1 in. or less) alternating laminae of coarse and fine grained sandstone and is similar to lithofacies previously described by Huff (1993) and Leetaru (1993). These beds are interpreted to be rhythmites that formed because of diurnal energy fluctuations during high and low tide (Reineck and Singh 1980, Nio and Yang 1991). This rhythmic lithofacies is characterized by poorer quality reservoir rock. This lithofacies is not a factor in compartmentalizing the reservoir in this well because it occurs at the bottom and not in the middle of the reservoir. However, this lithofacies may bifurcate the reservoir sandstone into two separate units in other wells. This lithofacies had some of the lowest sandstone permeabilities in the core, and no permeabilities were greater than 30 md.

Bioturbated sandstone lithofacies
The top of the Aux Vases reservoir in the Rudolph no. 26 Tract 11A well contains a moderately bioturbated sandstone lithofacies (fig. 13) that lacks continuous laminae. The core contains some large burrows (up to 1 in. in diameter) of unknown origin. The most distinctive trace fossil is characterized by pale, white-walled tubes, 0.25 inch or smaller in diameter, that are commonly crushed and incompletely filled (fig. 13). The permeability in this lithofacies is highly variable, ranging from less than 50 to more than 200 md.

Reservoir characteristics
In the core from the Rudolph no. 26 Tract 11A well, the oil/water transition zone occurs at approximately 2,940 feet (fig. 9). Water saturations in the transition zone of this core were estimated to be greater than 50%. The transition zone also is stained by devolatilized oil particles (bitumen) (fig. 14). Such oil staining (or bitumen) at the oil/water contact is observed in many other oil

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**Figure 12** Crossbedded Aux Vases Sandstone core annotated with permeability values from minipermeameter measurements. Lines drawn on the surface of the core represent scour surfaces that separate the laminae sets. Within each group of laminae sets, the permeability values are similar (Haley Production Company Rudolph no. 26 Tract 11A bar; depth 2,936.5 feet).
fields in the world, and the staining ranges from a few feet to 30 feet in thickness (Dickey 1979, Lomando 1992). No sharp oil/water contact is present within the cored interval in the Rudolph no. 26 Tract 11A well, and the transition zone appears to be at least 9 feet thick. In this core, the devolatilized oil that precipitated in the coarsest siliclastic intervals has clogged pore throats and decreased permeability. This precipitation of bitumen in coarser intervals has been observed in other oil-producing basins (Lomando 1992). This zone of low permeability at the oil/water transition is laterally continuous here and in many other oil fields (Dickey 1979).

Variations in reservoir quality separate the reservoir into multiple vertical compartments. The best quality reservoir rock is the crossbedded lithofacies (2,936–2,939 feet, fig. 9). The permeability of this lithofacies is reduced in other zones in this core by calcite cementation along the foresets (2,925–2,935 feet, fig. 9). The best quality reservoir is not at the top of the formation in this well but is instead 15 feet into the sandstone lithofacies. As discussed later, the most permeable part of the reservoir is not always at the same vertical interval in different wells within this field. Therefore, the high-permeability zones may not necessarily be laterally extensive or correlative. The only whole core available was from the Tract 11A well, and this well does not have any significant shale beds within the reservoir interval. A thin shale present in other wells in the field can vertically break the reservoir into separate compartments.

Macroscale Characteristics

Macroscale characteristics describe the lateral continuity of different lithofacies within an individual reservoir compartment. Under ideal conditions, core lithofacies descriptions would be correlated with well data, and the lithofacies would be mapped. However, only one core, which contains only part of the Aux Vases interval, is available. The only available approach, therefore, was to map out macrosopic characteristics from the lateral continuity and character of log units.

The neutron-density wireline log indicates changes in porosity. In the Tract 11A reservoir, a clear logarithmic relationship exists between measured core porosity and core permeability (fig. 15). Therefore, when it is available, the log porosity from the neutron-density tool is useful for detecting changes in reservoir quality.

Lithofacies continuity Cross section A−A’ (fig. 16) was constructed to show the macroscale (interwell) characteristics of the Aux Vases reservoir at Storms Consolidated Field. The datum for this cross section is the base of the Renault Limestone, directly above the reservoir interval. In the Rudolph no. 26 Tract 11A well (the middle well in this cross section), the most permeable part of the reservoir is 10 feet below the Renault Limestone. In the core (fig. 9), this section is composed of a porous and permeable crossbedded sandstone with little to no calcite cement. By comparison, the most permeable part of the Aux Vases in the left-most well (fig. 16) occurs

Figure 13 Moderately bioturbated Aux Vases Sandstone. The pale white-walled tubes are trace fossils (Haley Production Company Rudolph no. 26 Tract 11A; depth 2,928 feet).
structurally higher in the section at the top of the reservoir sandstone. It is apparent from this cross section that the interval with the greatest permeability does not always occur in the same stratigraphic position and, therefore, the best reservoir zones may not be laterally continuous. Both the most permeable streak and the pay zone of slightly lower quality in the Randolph no. 26 are within the crossbedded sandstone. Zones of lower quality generally fall within the bioturbated interval or are sandstones that have higher amounts of calcite cement. Because of the vertical variability of permeability, wells drilling for the Aux Vases must penetrate at least 10 to 15 feet into the formation to insure penetration of the main producing interval in this depositional/diagenetic environment.

This vertical variability in reservoir quality affects the ultimate recovery from a waterflood (Van de Graff and Ealey 1989). Sandstones with the best reservoir quality have permeabilities of more than 250 md and log porosities of greater than 20%, whereas the lower quality sandstones have reservoir permeabilities of between 100 and 150 md. Water injected during a waterflood generally follows the zones of higher permeability and bypasses zones of lower permeability. These unswept zones, however, may contain recoverable mobile oil (Van de Graff and Ealey 1989).

Macroscale characteristics of a slightly larger scale shown in structural cross section B–B’ (fig. 17) suggest that the Aux Vases reservoir is separated into distinct lateral compartments that are not in communication with each other. In this cross section, the left reservoir compartment is separated from the right compartment at well 31165, where the Aux Vases interval is composed of shale. Although the Aux Vases reservoir is interpreted on this cross section as two separate compartments, the sandstone bodies could be connected out of the plane of section, a scenario that could be ascertained using pressure tests.

As previously noted by Leetaru (1990), the SP wireline log can be an effective tool in evaluating reservoir quality in the Aux Vases Formation. The relatively low SP deflection in well 7589 in cross section B–B’

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**Figure 14** High-angle crossbedded sandstone. The darker intervals contain bitumen that has precipitated in the pores of the coarser grained material (Haley Production Company Rudolph no. 26 Tract 11A; depth 2,947 feet).

**Figure 15** Plot of Aux Vases Sandstone porosity versus permeability measurements determined from core plugs in the Haley Production Company Rudolph no. 26 Tract 11A.
(fig. 17) suggests a poor quality reservoir (tight or shaley). This well had an initial production of 3 BOPD from the Aux Vases Formation, significantly less than the adjoining well’s initial production of 200 BOPD. This wide variation in reservoir quality over relatively short lateral distances is typical of the Aux Vases Formation at Storms Consolidated Field and reflects the lateral lithofacies variations and interwell continuity of the reservoir sand bodies.

Cross section B–B’ (fig. 17) also exhibits the importance of both structure and lithofacies in forming Aux Vases oil traps. Well 7581 (right side) has a good quality Aux Vases reservoir sandstone, as indicated by the relatively high SP deflection. However, because the well was structurally lower and the sandstone thinner than the other wells in the cross section, the well was perforated in a lower quality part of the Aux Vases reservoir and had poor performance. The perforated interval is structurally low as compared with well 6029 to the west and lies in a zone of decreased or rapidly decreasing SP, reflecting lower reservoir quality (Leetaru 1990). The operators attempted to stay above the oil/water contact, and the existence of some oil production indicates that they were partially successful. However, the total fluid flow was low as a result of poor reservoir quality, and water was produced because of the structurally low perforations.

**Pressure analysis**  After 2 months of production, pressures of almost 1,000 psi were measured from the Tract 11A reservoir (George Payne, unpublished consulting report for Haley Production Company, 1991). This relatively high pressure suggests that the reservoir is isolated from Aux Vases reservoirs developed previously. If it was not isolated, decades of production from older nearby Aux Vases producers would have depleted the reservoir, and pressures would have been much lower. The initial production pressure from the Tract 11A reservoir probably was even higher, but pressures were not measured during the initial completion.
Fracturing  Fractures play a role in reservoir connectivity. Nelson and Bauer (1987) measured an east–west orientation for primary vertical joints in shales above coal seams in subsurface coal mines across southern Illinois, including one from central White County near Storms Consolidated Field. The presence of the Herald-Phillipstown Fault suggests that fractures should be present within Storms Consolidated Field.

The effects of fractures in waterflooding have been noticed by operators throughout the Illinois Basin (Lester Moore, MEPCO, Inc., personal communication, 1991). During waterflooding, the injected water appears to follow highly permeable fractures and breaks through much earlier than would be predicted by rock permeability data alone.

Compartment size  Macroscale characteristics also influence well-to-well reservoir performance. The areal extent of Aux Vases production at Storms Consolidated Field indicates that the individual reservoir compartments are usually no larger than 300 acres. Within individual reservoir compartments, the quality (as measured by initial potential) ranges from slightly greater than 900 BOPD to less than 3 BOPD. The interval with the best quality reservoir typically occurs in the clean crossbedded sandstone, but the interval does not always occur in the same stratigraphic position in the formation.

Megascale Characteristics
Depositional environment  The megascale characteristics of the Aux Vases Formation describe how different reservoir compartments relate to each other. No sharp distinction can be made between macroscale and megascale characteristics because both perspectives describe relationships between wells. Cross section C–C', located in the northern part of the field (fig. 18), shows that clean reservoir sandstone intervals are separated from each other by intervals of low permeability shaley sandstone and shale. The clean sandstone thickens and thins across the field, and there seems to be little relationship between the total sandstone thickness and the thickness of the entire Aux Vases Formation. There is also no relationship between sandstone thickness and the thickness of the underlying Joppa Limestone Member of the Ste. Genevieve. The lack of a thickness relationship between the Aux Vases sandstone and the bodies underlying the limestone units suggests that the underlying unit has not been scoured. This observation is important because it indicates that the Aux Vases at this location was deposited not as a channel but probably as marine bars.

The shaley intervals that compartmentalize the Aux Vases reservoir are characterized by SP wireline deflections that are less than 50% of the deflection from a shale base line to the clean, thick Cypress or Bethel Sandstones. An isopach map of the net sandstone thickness in the Aux Vases Formation (fig. 19; intervals with greater than 50% SP deflection) indicates that there are at least three sandstone bodies that trend northeast to southwest and average 15 feet in thickness with maximum thicknesses of 35 feet (fig. 19).

The presence of echinoderm fragments, abundant crossbeds, and rhythmic beds indicates deposition in a tidally influenced, high energy marine depositional system. Both macro- and mesoscale analysis suggests that the sandstone bodies that compose the reservoir facies are not laterally continuous across the field and are instead separated into individual linear bodies oriented northeast to southwest. Crossbeds 3 feet thick seen in the Rudolph no. 26 Tract 11A core indicate that the Aux Vases was deposited in the upper portion of the lower flow regime (Collinson and Thompson 1989). Although wireline log characteristics did not indicate a clear pattern of either upward thinning or upward coarsening, the core from the Randolph no. 26 well (fig. 9) has a general upward increase in porosity (cleaning-upward).
Figure 17  Structural cross section B–B’ showing the stratigraphic nature of the Aux Vases Sandstone trap. The siltstone lithofacies in the Haley Production Ackerman no. 3 separates the Aux Vases reservoir into two compartments that do not appear to be in communication (location of cross section shown on fig. 3). The Haley Production Company Ackerman no. 1 well is also included in cross section A–A’.

Figure 18  Stratigraphic cross section C–C’ illustrating the changes in thickness and continuity in various intervals of the lower part of the Pope Group (location of cross section shown on fig. 3).
Figure 19  Net thickness of clean Aux Vases Sandstone. A clean sandstone is defined as having an SP response that is at least 50% of the SP response of clean, thick Cypress or Bethel Sandstones. Areas with more than 20 feet of sand are highlighted. These Aux Vases sandstone bodies generally trend northeast to southwest. Circled wells are Aux Vases producers (contour interval is 10 feet).
In the absence of sand grain-sized variations, such an increase indicates increasing depositional energy upward. The lack of scouring of the Joppa Limestone Member of the Ste. Genevieve suggests aggradation without erosion. Thus, the preferred depositional setting is one of offshore marine bars, delta mouth bars, or possibly barrier shorelines. Although not conclusive, the evidence indicates that several environmental processes contributed to Aux Vases deposition.

Detailed analysis of cores from the Aux Vases Formation in other areas of Illinois suggests that relative sea level was not constant (Huff 1993). Huff suggested that the middle part of the Aux Vases Formation may have been subaerially exposed at Energy Field in Williamson County, Illinois. Another example where the Aux Vases Formation may have been subaerially exposed is the Triple B no. 1 well of Evans et al. in Franklin County, Illinois (Sec. 13, T7S, R4E), near southwest Dale Consolidated Field. In this well, a zone interpreted to be a paleosol occurs in the upper portion of the formation. At Storms Consolidated Field, however, there is no evidence for emergence. The Aux Vases at Storms Consolidated Field was deposited east and southeast of the Aux Vases deltaic source of clastics proposed by Swann (1963); therefore, it may have been deposited in slightly deeper water and was never emergent. It is the author's interpretation that the Aux Vases reservoirs fields such as Energy (Huff 1993) and Southwest Dale Consolidated (Udegbunam et al. 1993) were formed closer to the clastic sediment source than was the case at Storms Consolidated Field.

**Trapping mechanism** Trapping mechanisms for the Aux Vases Sandstone at Storms Consolidated Field are principally stratigraphic, although a significant structural component is also evident. The Aux Vases producers are located in the thicker parts of the sandstone body. The trap is formed when these sandstone bodies overlie structural noses. Updip closure is formed by pinchout of the sandstone bodies. No significant structural closures were mapped within the field outline.

The potential for new undrilled reservoir compartments is high along the trend of the marine sandstone bodies. Storms Consolidated Field should not be considered fully developed because it is probable that not all of the hydrocarbon-bearing sandstone bodies have been found. The discovery of the Tract 11A reservoir in 1987, after 40 years of continuous development of the field, supports this conclusion.

**Production Characteristics**

**Drilling and completion practices** All of the wells studied at Storms Consolidated Field were drilled with a freshwater bentonite slurry. Most of the Aux Vases wells at Storms Consolidated Field were cased, perforated, and fracture-treated. Commonly, both early and modern wells were treated with a low-volume hydraulic fracture using approximately 3,000 to 5,000 pounds of sand and an equal number of gallons of lease oil.

**Initial production rates and cumulative reserves** The most likely value for an initial production (IP) flow test from the Aux Vases Formation at Storms Consolidated Field has been graphically estimated using a cumulative frequency distribution curve of IP (fig. 20). This curve indicates that an average initial production rate should be approximately 65 BOPD and that there is no more than a 20% chance of a producing well's rate being less than 18 BOPD or more than 150 BOPD. Wells in a new compartment with virgin pressures, such as Tract 11A in 1987, should have higher IP per well than average (fig. 20).

An estimate of total cumulative reserves in each of the individual reservoir compartments is not possible because not enough data are available. Few if any porosity wireline logs were run in the older wells, and oil production data were collected on a lease-wide basis. Most of the oil leases also commingle production from multiple
reservoirs. An exception to this lack of reservoir production data is the recently discovered Tract 11A reservoir, which produces only from the Aux Vases Formation and for which modern wireline logs are available. This 1987 reservoir discovery is still in primary production and has produced more than 230,000 barrels of oil (fig. 21). An independent study indicates that the original oil in place in the Tract 11A reservoir exceeds one million barrels (George Payne, unpublished consulting report for Haley Production Company, 1991).

**Development and production strategies** There is no record of any waterflooding program of the Aux Vases reservoir in two areas (Secs. 31, 28, and 33 of T5S, 10E) (fig. 5). Most of the former Aux Vases completions in these two areas have been plugged and abandoned. New injection and production wells would have to be drilled to enable a waterflood to sweep bypassed areas that may not have been drained by the original wells. Illinois Basin operators commonly achieve a primary recovery efficiency in the Aux Vases of 10% to 20% (Joseph Hahn, Hahn Engineering, personal communication, 1995), which is a typical rate for solution gas reservoirs (Craft and Hawkins 1959). In other Aux Vases reservoirs in the Illinois Basin, waterfloods have increased recovered reserves by 15% or more (Leetaru 1991, Huff 1993). The Aux Vases reservoirs at Storms Consolidated Field may contain sufficient reserves to make redevelopment economically feasible, depending on oil price and operator overhead.

Problems in waterflooding naturally fractured areas are amplified when the Aux Vases Formation is hydraulically fractured during well completion (Udegbunam et al. 1993). Hydraulically induced fractures tend to align themselves sub-parallel to natural fracture trends and form high-permeability pathways that enable the injected water to bypass much of the reservoir. Udegbunam et al. (1993) simulated reservoir production in an Aux Vases reservoir in the southwest part of Dale Consolidated Field, Franklin County, Illinois, to address this bypassing problem. Their model indicated that, in areas where the Aux Vases has induced fracture permeability, drilling of injection wells on a repeat inverted five-spot pattern gives the best waterflood results. New injection and production wells should not be aligned parallel to the east–west fracture direction. At Storms Consolidated Field, the hydraulic fracture treatments were not as large as at Dale Consolidated Field, and far reaching fractures do not appear to be as big a problem.

**CYPRESS RESERVOIRS**

**Structure**

Most Cypress reservoirs at Storms Consolidated Field are combination structural/stratigraphic traps. The structure on the top of the Beech Creek Limestone is very similar to that on the top of the Renault (figs. 5, 6). The variations in the thickness of the interval between the top of the Beech Creek Limestone and the top of the Downeys Bluff Limestone (fig. 22) probably reflect differential compaction of shales relative to sandstones. This differential compaction is one reason that the two
Cypress has been subdivided (from bottom to top) into four different sandstone packages: C, B, A2, and A1 (fig. 4). The A1 and A2 are the most productive Cypress units within Storms Consolidated Field. The Cypress is a secondary target for development because it has not been as prolific as other pay zones within the field.

**Microscale Characteristics**

**Petrography** The Cypress A was the only interval studied at this scale because rock samples were not available from the other intervals. The distribution of detrital and diagenetic minerals at Storms Consolidated Field is similar to that of other Cypress A reservoirs, such as those in Tamaroa and Bartelso Fields (Grube 1992, Whitaker and Finley 1992). Because of this similarity, the two available core samples are considered to be representative of the Cypress in the entire field. There were no core or biscuit-sized core chips available from the Cypress B or C sandstones.

The Cypress A sandstone has been extensively cemented with calcite. Detrital minerals are finer grained than those of the Aux Vases reservoir sandstones. Feldspar grains are not as common as in the Aux Vases. Quantitative X-ray diffraction analyses and thin section point counts of mineral compositions show that Cypress reservoir sandstone contains 75% quartz and 0% to 6% feldspar by volume. Quartz and lesser amounts of ferroan calcite and kaolinite are the principal diagenetic minerals although there are minor amounts of illite, mixed-layered illite/smectite, and chlorite. All of the calcite was a ferroan variety; iron-free calcite was not seen in the available thin sections.

**Diagenesis and its effect on reservoir quality and recovery** The diagenetic histories of the Cypress and the Aux Vases reservoir sandstones are similar but not identical. The major difference lies in the magnitude of diagenetic alteration occurring at each stage. Cypress reservoir sandstones at Storms Consolidated Field contain four types of cement: (1) silica in the form of quartz overgrowths, (2) calcite, (3) ferroan calcite, and (4) clay minerals. The most significant diagenetic product in the Cypress is silica cement (fig. 23). Unlike the Aux Vases, the Cypress does not have protective clay mineral coatings around detrital quartz grains; consequently, permeability and porosity were significantly reduced by precipitation of silica cement in the form of quartz overgrowths. Late-stage precipitation of kaolinite and iron-rich calcite cement complete the diagenesis sequence. The emplacement of hydrocarbons into the reservoir is likely to have prevented further mineral precipitation.

Kaolinite, the predominant clay mineral in the Cypress Formation, is not known to swell on contact with either freshwater or commonly used completion fluids.
Figure 22  Isopach map of the interval from the top of the Beech Creek Limestone to the top of the Downeys Bluff Limestone. Map represents the approximate differential compaction in the Bethel and Cypress Formations. The highlighted areas are thicker than 235 feet (contour interval is 5 feet).
Kaolinite does, however, have a potential effect on production as a result of its physical mobility. During well completions and waterflooding, the variation of formation salinities (by addition of freshwater) and the high rates of fluid flow increase the chance for migration of kaolinite booklets and for blockage of pore throats (Almon and Davies 1981).

Macro- and Megascale Characteristics and Depositional Environments
The depositional environment discussion is included with the Cypress megascale analysis because, unlike the Aux Vases, the interpretation of the Cypress depositional environment is based on the similarity of the megascale morphology of the sandstone bodies and the shapes of the SP and resistivity curves at Storms Consolidated Field with those of Tamaroa Field (Grube 1992) and Bartelso Field (Whitaker and Finley 1992).

Cypress C sandstone The Cypress C sandstone, which underlies the Cypress A and B intervals, was deposited at Storms Field as two separate lenticular sandstone bodies. Both are at least 5 miles long, 0.75 to 1.5 miles wide (figs. 24, 25), and more than 60 feet thick. Cypress C sandstone wireline logs are characterized by a high SP response and a blocky pattern (fig. 4). Cross section C–C′ (fig. 24) illustrates the sharp transition from sandstone to shale and limestone. The lack of gradual facies transitions at Storms Consolidated Field suggests that these sandstones were not deposited as bars. In general, bars grade downward into lower energy siltstones and interfinger with adjoining shales.

Two alternative interpretations are possible for deposition of the Cypress C sandstones. The first is that the sandstone bodies are channel-fill deposits in previously incised valleys. Across the basin, the lower Cypress interval is characterized by a pulse of regressive sedimentation interpreted to have been caused by a relative

Figure 23  SEM photomicrograph of Cypress A sandstone showing silica cement in the form of quartz overgrowths and diagenetic clay minerals (kaolinite) filling most of the pore space (National Association Petroleum Company Garrison et al. no. 2; depth 2,619 feet).
Figure 24  Cross section C–C’ shows the variation in the thickness of the Cypress sandstones in an east–west direction across the northern part of Storms Consolidated Field. Datum is top of the Beach Creek Limestone (location of cross section shown on fig. 3).

drop in sea level (fig. 4). This drop in relative sea level may have been eustatic and correlative with sea level drops observed in many other basins in the world (Ross and Ross 1988). During this major relative drop in sea level, valleys may have been scoured into the underlying Ridenhower Formation and, during a subsequent transgressive phase, these incised valleys were then filled by the Cypress C sandstone. A second but equally valid interpretation is that these lower Cypress C sandstones are distributary channel deposits of a deltaic system (Potter 1962). Distributary channels of present day deltaic systems range in width from 500 to 5,500 feet, whereas incised valleys are commonly several miles wide (Van Wagoner et al. 1990). The size of the Cypress C sandstone bodies tends to support a distributary channel setting as the more likely depositional environment, but size alone is inconclusive. The general wireline log shape would be similar for both incised valleys and distributary channel deposits if the channels were of comparable depth.

No hydrocarbons have been produced from the Cypress C sandstones. They lack regional four-way structural closure as mapped at either the Barlow or the Renault intervals (figs. 5, 6). Although stratigraphic pinchouts may create traps, either the Cypress C sandstone was never charged or no effective seal separated the lower massive Cypress C from the overlying thinner sandstone packages.
Cypress B sandstone  The Cypress B sandstone overlies the Cypress C sandstone and is composed of at least four different sandstone units separated from each other by shales (fig. 4). These different horizons were combined for purposes of mapping (fig. 26) because they did not appear to have lateral continuity between individual wells. Areas with no sandstone consist of interfingered siltstones and shales (fig. 24). Although there is no whole core of the Cypress B interval at Storms Consolidated Field, possible paleosols (which would be indicative of subaerial exposure) have been described from the top of the unit in cores from stratigraphically equivalent Cypress B sandstones in other fields throughout the basin (John Grube, ISGS, personal communication, 1994). The formation of paleosols suggests a relative drop in sea level after deposition of the Cypress B sandstone.

A minor amount of oil has been produced from both the Cypress B (fig. 5) and Cypress A sandstones adjacent to the Herald–Phillipstown Fault. Unlike the overlying Cypress A sandstone elsewhere in the field, the trap for the Cypress B reservoir at this location is controlled by structure rather than stratigraphy.

Cypress A1 and A2 sandstones  The Cypress A2 sandstone is separated from the underlying Cypress B sandstone and the overlying Cypress A1 sandstone by laterally continuous shales (fig. 24). The Cypress A2 sandstone is thicker, more
Figure 25  Net sandstone isopach of the Cypress C interval. The highlighted areas are thicker than 20 feet (contour interval is 5 feet).
Figure 26  Net sandstone isopach of the Cypress B interval. The highlighted areas are thicker than 30 feet (contour interval is 10 feet).
extensive, and more productive than the Cypress A1, and these two intervals are probably not connected. Hydrocarbons in Cypress A reservoirs are trapped by updip pinchouts of the sandstone, as illustrated by cross section D–D' (fig. 27). The cross section shows a well developed Cypress A2 sandstone in the Dull Storms Land no. 1 well (the right well), which had an initial production of 50 BOPD. The nonproducing well 1,900 feet to the south showed an increase in resistivity, suggesting an increase in pore-filling calcite cement in this direction. The southwesternmost well, the Herndon Drilling Land no. 2, does not contain the Cypress A2 sandstone.

Cypress A1 and A2 sandstones are thin (no more than 14 feet thick), elongate, lenticular sandstone bodies (figs. 28, 29) that have a geometry similar to modern marine bars. The wireline log shape is not useful for interpreting the depositional environment of these sandstones because they are too thin. The Cypress A sandstones at Storms Consolidated Field are nearly identical in morphology and long axis trend to the Cypress reservoirs at Tamaroa Field (Grube 1992) in Perry County and at Bartelso Field in Clinton County (Whitaker and Finley 1992).

Production Characteristics
Drilling and completion practices  Drilling and completion practices in the Cypress reservoirs are almost identical to those described for the Aux Vases. Wells were drilled with a bentonite slurry, and most were completed by hydraulically fracturing the well with 3,000 to 8,000 gallons of lease oil and 3,000 to 8,000 pounds of sand.

Initial production rates and cumulative reserves  The average initial production test for the Cypress reservoirs in Storms Consolidated Field is 30 BOPD (fig. 30); approximately one-half of the average initial potential of the Aux Vases.
Figure 28  Net sandstone isopach of the Cypress A2 interval (contour interval is 4 feet).
Figure 29  Net sandstone isopach of the Cypress A1 interval (contour interval is 4 feet).
The best Cypress wells tested for more than 100 BOPD, whereas some Aux Vases wells produced as much as 800 BOPD initially.

Cypress reservoirs at Storms Consolidated Field were drilled on a 10-acre spacing. The reservoirs (1) are small in areal extent (less than 40 acres, as measured within the field), (2) usually have one or two successful completions, and (3) have recoverable reserves of 10,000 to 15,000 barrels of oil per well. One of the better Cypress producing reservoirs in Storms Consolidated Field is in Sec. 11, T5S, R9E (fig. 29). The two wells in the reservoir produce from the Cypress A1 sandstone. The discovery well, the Haley Production CompanyAckerman no. 1, had an initial production of 150 BOPD. The offset well, the Haley Production Company, Storms Field no. 5 Tract no. 6, began at 50 BOPD. Three additional offset wells did not contact the reservoir sand and were abandoned. Between 1984 and 1995, these two wells have produced at a relatively constant rate of 900 barrels of oil per year.

Cumulative production from these two wells has exceeded 40,000 barrels of oil. In general, recovery efficiency of gas solution drive reservoirs has been less than 20%. Therefore, using two wells as a model, we estimate the individual Cypress reservoirs may have original oil in place of at least 200,000 barrels.

**Development and production strategies** Because of their limited lateral extent, the Cypress A reservoirs should be drilled on a 5-acre spacing (economics permitting), as was recommended by Grube (1992) and Whitaker and Finley (1992) in their studies of equivalent reservoirs. Cypress A sandstone isopach maps (figs. 28, 29) show predictable linear sandbody trends. The greatest potential for new Cypress A reservoir development is in areas where porous Cypress A sandstone overlaps structural noses. If Cypress reservoirs can be extended laterally in size to include three or more well spacings (using 5-acre spacing), then waterflooding may be a viable option. At present, none of the Cypress A reservoirs have been waterflooded.

**CLASSIFICATION OF AUX VASES AND CYPRESS RESERVOIRS**

A common assumption in reservoir characterization is that identical depositional environments will have identical reservoir characteristics and therefore the application of analogous reservoirs is useful in trying to improve oil recovery (Geoscience Institute for Oil and Gas Recovery Research 1990). In this report, the producing intervals in both the Aux Vases and Cypress Formations are interpreted to have been deposited as marine bars, yet the Aux Vases reservoirs are larger and of better quality than those in the Cypress. These differences result from variations in (1) the source of sediment, (2) rate of sedimentation, (3) relative sea level fluctuations during deposition, (4) location of the bars relative to the shoreline, and (5) diagenesis.
Examples from other Cypress reservoirs in Illinois provide good analogs for the Cypress at Storms Consolidated Field. For example, the Cypress sandstone reservoirs at Tamaroa Field (Grube 1992) and Bartelso Field (Whitaker and Finley 1992) appear to have a geometry and petrology similar to those at Storms Consolidated Field. The sandstone reservoirs in the upper Cypress interval at Tamaroa and Bartelso Fields are lenticular, as they also are at Storms Consolidated Field. The sandstones also have a similar mineralogy.

The Aux Vases reservoir sandstone at Storms Consolidated Field is interpreted to have been deposited as a series of marine bars that may have been partly tidally influenced. The tidal influence is suggested by the rhythmic bedding observed in the lowest part of the Rudolph no. 26 Tract 11A core (fig. 9). A tidal influence in the Aux Vases depositional environment has been suggested by other studies (Cole 1990, Huff 1993, Leetaru 1991).

The Cypress C zone is not productive within the field and is interpreted as being either an estuarine valley fill or a distributary channel deposit. In either case, the Cypress C sandstone is a major regressive unit across the basin.

Cypress B sandstone bodies elsewhere have been subaerially exposed, for example, the main pay horizon at Lawrence Field (John Grube, ISGS, personal communication, 1993). The Cypress B sandstone at Lawrence Field is characterized by the presence of paleosols at the top of the unit. Shales separate the B sandstone from the overlying Cypress A sandstones.

The depositional environment of the Cypress A sandstone bodies is interpreted to be marine mostly on the basis of evidence from other similar Cypress fields in Illinois. The Cypress A2 sandstone is more abundant than the Cypress A1 and may therefore have been deposited closer to the source of the sediment or to the currents that transported the sediment. Subsurface correlations within Storms Consolidated Field suggest that the Cypress A1 sandstone may interfere with the Beech Creek Limestone and may have been deposited during the same transgressive event.

SUMMARY AND CONCLUSIONS

Although both the Cypress and Aux Vases reservoirs apparently were deposited in generally similar environments, there are some important differences between these two reservoirs. The Aux Vases has almost twice the clay mineral content of the Cypress. The Aux Vases clay mineral suites contain abundant illite, mixed-layered illite/smectite, and chlorite. These Aux Vases clay minerals tend to form continuous coats around the detrital grains, which impede the nucleation and growth of quartz overgrowths. The Cypress clay mineral suite is composed primarily of kaolinite that has a booklet micromorphology and does not form a continuous clay coating around the framework grains. The lack of a clay coating allowed quartz cement to precipitate as quartz overgrowths directly on the sand grains and partially fill the pores. Porosities in the Aux Vases sandstone exceed 25%, and permeability exceeds 200 md in some cases. Cypress porosity is rarely more than 20%, and permeability rarely exceeds 100 md. The diagenetic clay mineral coatings have abundant microporosity that binds with formation water and results in low resistivities in oil saturated sandstones. As a result, the Aux Vases has anomalously high water saturation calculations from wireline log measurements, yet it still produces oil.

Other microscale features in both the Aux Vases and Cypress Sandstones make them susceptible to formation damage. Mixed-layered illite/smectite, a common component of the Aux Vases clay mineral suite, has a tendency to swell if exposed to freshwater, leading to a decrease in permeability. Kaolinite, the main constituent of the Cypress clay mineral suite, is a relatively inert clay mineral. However, it can
be detached from detrital grains and migrate to pore throats during rapid production of the well or by exposing the reservoir to freshwater.

In the Aux Vases, local calcite cementation can extend parallel to bedding and create baffles that produce a less effective waterflood. The high-permeability streaks or strata are also a concern because, during secondary recovery, the injected fluid follows the high permeability zones and therefore bypasses mobile recoverable oil.

Reservoirs in the Aux Vases and Cypress Formations are quite different although both were deposited as marine bars. Aux Vases Sandstone reservoirs commonly extend for more than 300 acres and accommodate as many as 15 producing wells. Cypress reservoirs rarely exceed 40 acres and usually accommodate only one to two wells on a 10-acre spacing.

A number of the older reservoir compartments have not yet undergone waterflood- ing. Waterflooding typically increases recoverable reserves by at least 20%. Some of the compartments may have their lateral limits extended by drilling new wells. The most important area of reservoir growth within this field is in discovering new undrilled compartments. The recently drilled Tract 11A compartment has an original oil in place of more than one million barrels. There is a good probability of finding other compartments of similar size within this field.

The following important conclusions were derived from this study.

1. The best reservoir facies is not always in the top of the sandstone—it can occur in either the top or middle of the sandstone body.

2. Traps are formed by stratigraphic pinchout of marine bars over structural noses.

3. Neither the Aux Vases nor the Cypress Formations at Storms Consolidated Field has been fully exploited. Detailed mapping of Storms Consolidated reservoir horizons indicates that both formations may contain additional undrilled reservoir extensions.

ACKNOWLEDGMENTS

I thank Jim Haley of Carmi, Illinois, for supplying the engineering report by George A. Payne (Petroleum Engineer, Newburgh, Indiana) on "Storms Aux Vases Water-flood Study." Donald F. Oltz, D. Scott Beaty, Jonathan H. Goodwin, Dennis J. Haggerty, Randall E. Hughes, Kenneth R. McGee, Duane M. Moore, David G. Morse, Beverly Seyler, Emmanuel O. Udegbanam, and several other colleagues at the Illinois State Geological Survey also contributed significantly to the review and production of this report. This research was funded by the U.S. Department of Energy under grant DE-FG229BC14250 and the Illinois Department of Energy and Natural Resources under grant AE-45.

REFERENCES


Geoscience Institute for Oil and Gas Recovery Research, 1990, Reservoir heterogeneity classification system for characterization and analysis of oil resource base in known reservoirs, prepared on behalf of U.S. Department of Energy: University of Texas, Austin, TX, 27 p.


## APPENDIX A  Mineral Components

### Mineral Components from X-ray Diffraction Analysis

<table>
<thead>
<tr>
<th>API number</th>
<th>Depth (feet)</th>
<th>Percentage</th>
<th>Bulk percentage</th>
<th>Absolute percentage</th>
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<td></td>
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<td>I I/S K C</td>
<td>I I/S K C</td>
<td>Q Kf Pf Cc D</td>
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<td>2926.2</td>
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<td>41 33 0</td>
<td>26</td>
<td>0.07 2.8 2.2 0 1.8</td>
</tr>
</tbody>
</table>

1. percentage of illite, illite/smectite, kaolinite, and chlorite, respectively, on 100% basis of the clay minerals from μm smear
2. clay index = 4 x 020 clay peak (19920) + adjusted sum nonclay peaks
3. bulk percentage of illite, etc.
4. absolute percentage of quartz, K-feldspar, plagioclase, calcite, and dolomite, respectively.

### Mineral Components from Point Counting (300 points)

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<tr>
<th>API number</th>
<th>Depth (feet)</th>
<th>Q</th>
<th>POR</th>
<th>PYR</th>
<th>FECA</th>
<th>AFLD</th>
<th>CA</th>
<th>PFLD</th>
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</table>

Q = Quartz; POR = porosity; PYR = pyrite; FECA = ferroan calcite; AFLD = altered feldspar; CA = calcite; PFLD = microporous feldspar; FOS = fossil fragments; FOR = formation; av = Aux Vases; and cyp = Cypress
APPENDIX B  List of Wells with Thin Sections and X-ray Diffraction Analysis
(all wells from Storms Consolidated Field, White County, Illinois)

1219306626
    National Association Petroleum Company
    Garrison et al. no. 2
    Sec. 24, T6S, R9E
    Cypress Sandstone

1219303373
    Parker Brothers, Inc.
    McCarty no. 2 (A-2)
    Sec. 7, T6S, R10E
    Aux Vases Sandstone

1219303359
    Parker Brothers, Inc.
    McCarty no. 1
    Sec. 7, T6S, R10E
    Aux Vases Sandstone

1219302727
    Inland Production Company
    Wright et al. no. 1
    Sec. 15, T5S, R10E
    Cypress Sandstone

1219331131
    Haley Production Company
    Rudolph no. 26
    Sec. 12, T6S, R9E
    (whole core)
    Aux Vases Sandstone
APPENDIX C  Reservoir Fluid Analysis

API number  121933111200
Operator     Jim Haley
Well name    Rudolph Tract 11A no. 25
Location     SE NW SW, Sec. 12, T6S, R9E
County       White
Field name   Storms Consolidated
Producing formation  Aux Vases
Perforations depth (ft)  2,958–2,968
Surface elevation (ft)  389
Waterflooded  no

Brine Analysis
Brine sample number  EOR-B106
Resistivity with atc 0.0639 ohm-m
Eh (mV)  -237
pH  6.1

Anion chemistry (mg/L)

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<td>NH₄</td>
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<tr>
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<td>SO₄</td>
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Cation chemistry (mg/L)

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<td>Zn</td>
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<tr>
<td>Zr</td>
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API number 121930609600
Operator Jim Haley
Well name North Storms no. 5
Location NE SW SE, Sec. 14, T6S, R9E
County White
Field name Storms Consolidated
Producing formation Cypress
Perforations depth (ft) 2,656–2,664
Surface elevation (ft) 386
Waterflooded no
Brine Analysis
  Brine sample number EOR-B111
  Resistivity with atc 0.073 ohm-m
  Eh (mV) -150
  Ph 7.06

Anion chemistry (mg/L)
  Cl  64000  Br  140  I  6.9  SO4 47
  NO3 0.52  NH4 17  CO3 0.024  HCO3 100

Cation chemistry (mg/L)
  Al  0.3  As  0.5  Ba  0.9  Be  0.003
  B  4.25  Ca  2830  Cd  0.05  Co  0.07
  Cr  0.07  Cu  0.06  Fe  12  K  71
  Li —  Mg  889  Mn  0.77  Mo  0.08
  Na 40090  Ni  0.1  Pb  0.4  Rb —
  Sb 0.3  Sc —  Se  0.07  Si  2.2
  Sr 117  Ti  0.04  TI —  V  0.08
  Zn 0.02  Zr  0.02
APPENDIX D  Reservoir Summary

AUX VASES RESERVOIR

Field  Storms Consolidated Field
Location  White County, Illinois
Tectonic/Regional Paleosetting  Illinois Basin
Geologic Structure  Anticline nose
Trap Type  structural-stratigraphic
Reservoir Drive  gas depletion drive
Original Reservoir Pressure  unknown

Reservoir Rocks
Age  Upper Valmeyeran Series of the Mississippian System
Stratigraphic unit  Aux Vases Formation
Lithology  sandstone
Wetting characteristics (oil/water)  NA
Depositional environment  nearshore marine bars
Productive facies  crossbedded sandstone
Petrophysics  (Ø and k from unstressed conventional core; S_w from logs)

<table>
<thead>
<tr>
<th>Average</th>
<th>Range</th>
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</thead>
<tbody>
<tr>
<td>Ø</td>
<td>20</td>
</tr>
<tr>
<td>k air(md)</td>
<td>100</td>
</tr>
<tr>
<td>S_w</td>
<td>50</td>
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</table>

Source Rocks
Lithology and stratigraphic unit  New Albany (Devonian) shales or older
Time of hydrocarbon maturation  Permian-Triassic
Time of trap formation  Mississippian (stratigraphic); Permian (structure)

Reservoir Dimensions
Depth (absolute and subsea)  2,900 feet
Areal dimensions  NA
Productive area  NA
Number of pay zones  1
Hydrocarbon column  unknown
Initial present fluid contacts  no clear oil–water contact
Average net sand thickness  15 ft
Average gross sand thickness  20 ft

Wells
Spacing  10 acre
Total  63 producers

Reservoir Fluid Properties
Hydrocarbons
Type  oil
GOR  NA
API gravity  NA
FVF  NA
Viscosity  NA
Bubble point pressure  NA

Formation Water
Resistivity  0.0639 ohm-m
Total dissolved solids  NA
Volumetrics
- In-place: NA
- Cumulative production: NA

Ultimate recovery:
- Primary: NA
- Secondary: NA
- Additional recovery from infill drilling and secondary: NA
- Secondary (incremental): NA
- Tertiary (incremental): NA

Recovery efficiency:
- Primary: 15%–20%
- Secondary: 15%–20%
- Tertiary: NA

Typical Drilling/Completion/Production Practices
- Drilling fluid: Bentonite
- Fracture treatment: 5,000 gallons of oil and 7,500 pounds sand

Producing mechanism:
- Primary (indicate any period of flow): gas depletion
- Secondary: waterflood
- Tertiary: NA

Typical Well Production (to date):
- Average daily IP: 100 BOPD
- Cumulative: approx. 20,000 BO
- Water/oil ratio (initial/cumulative): NA

CYPRESS RESERVOIR

Field: Storms Consolidated Field
Location: White County, Illinois

Tectonic/Regional Paleosetting: Illinois Basin

Geologic Structure: anticline nose

Trap Type: structural-stratigraphic

Reservoir Drive: gas depletion drive

Original Reservoir Pressure: unknown

Reservoir Rocks
- Age: lower Chesterian Series of the Mississippian System
- Stratigraphic unit: Cypress Sandstone
- Lithology: sandstone
- Depositional environment: marine shelf
- Productive facies: marine bars

Petrophysics (Ø and k from unstressed conventional core; S_w from logs):

<table>
<thead>
<tr>
<th>Property</th>
<th>Average</th>
<th>Range</th>
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<tr>
<td>Ø</td>
<td>16</td>
<td>11–22</td>
</tr>
<tr>
<td>k air(md)</td>
<td>60</td>
<td>10–100</td>
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<tr>
<td>S_w</td>
<td>—</td>
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</tbody>
</table>

Source Rocks
- Lithology and stratigraphic unit: New Albany (Devonian) shales or older
- Time of hydrocarbon maturation: Permian-Triassic
- Time of trap formation: Mississippian (stratigraphic); Permian (structure)
Reservoir Dimensions
- **Depth (absolute and subsea)**: 2,700 ft
- **Areal dimensions**: NA
- **Productive area**: NA
- **Number of pay zones**: 3
- **Hydrocarbon column**: unknown
- **Initial present fluid contacts**: no clear oil–water contact
- **Average net sand thickness**: 5 ft
- **Average gross sand thickness**: 40 ft

Wells
- **Spacing**: 10 acre
- **Total**: 23 producers

Reservoir Fluid Properties

Hydrocarbons
- **Type**: oil
- **GOR**: NA
- **API Gravity**: NA
- **FVF**: NA
- **Viscosity**: NA
- **Bubble point pressure**: NA

Formation water
- **Resistivity**: NA
- **Total dissolved solids**: NA

Volumetrics
- **In-place**: NA
- **Cumulative production**: NA

Ultimate recovery
- **Primary**: NA
- **Secondary**: NA
- **Additional recovery from infill drilling and secondary**: NA
- **Secondary (incremental)**: NA
- **Tertiary (incremental)**: NA

Recovery efficiency
- **Primary**: NA
- **Secondary**: NA
- **Tertiary**: NA

Typical Drilling/Completion/Production Practices
- **Drilling fluid**: bentonite
- **Fracture treatment**: NA
- **Producing mechanism**
  - **Primary**: gas depletion
  - **Secondary**: waterflood
  - **Tertiary**: NA

Typical Well Production (to date)
- **Average daily IP**: 30 BOPD
- **Cumulative production**: 10,000–15,000 BO
- **Water/oil ratio (initial/cumulative)**: NA