The Mississippian Cypress Sandstone: Geologic Characteristics of a Potential EOR Target in the Illinois Basin

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Abstract

The Chesterian (Upper Mississippian) Cypress Sandstone has produced over 1 billion bbl of oil in the Illinois Basin (ILB) in the past century and is a candidate for carbon dioxide enhanced oil recovery (CO_2 EOR) and geologic storage. Detailed reservoir characterization research, supported by US Department of Energy and Illinois Department of Commerce and Economic Opportunity grants, was conducted in Lawrence and Mattoon Oil Fields in Illinois to assess the suitability of Cypress reservoirs for CO_2 EOR and storage. Mapping reservoir bodies, identifying flow units, and understanding permeability barriers and potential thief zones with respect to production and injection wells are critical to the success of CO_2 EOR and storage projects.

Much of the oil produced from the Cypress has come from highly compartmentalized, stacked sandstone bars that formed in a low accommodation shelf setting, where a high tidal range deposited sediments into elongate, shore-normal bars. Mapping in Lawrence and Mattoon Fields has identified pervasive very fine- to fine-grained sandstone bars up to 3 m thick, less than a kilometer wide, and up to a few kilometers long. Other sandstone facies are also present in the Cypress as intraformational sequence boundaries separate the bar facies from lithologically similar, but genetically distinct, fluvial and deltaic sandstone facies within the Cypress in different areas of the ILB. Thus, detailed mapping of recognizable facies geometries is necessary to distinguish depositional environments from one another.

Sandstone reservoirs were mapped using geophysical logs. Cores were described and petrographic analyses were conducted to better understand porosity and permeability trends in the region and to characterize permeability barriers and define flow units. Diagenetic alterations that impacted porosity and permeability include development of quartz overgrowths, sutured quartz grains, dissolution of feldspar grains, formation of clay mineral coatings on grains, and calcite cementation. This detailed characterization of the Cypress will assist future simulation modeling and injection of CO_2, and may encourage similar CO_2 EOR and storage projects in similar geologic settings around the world.

Stratigraphy

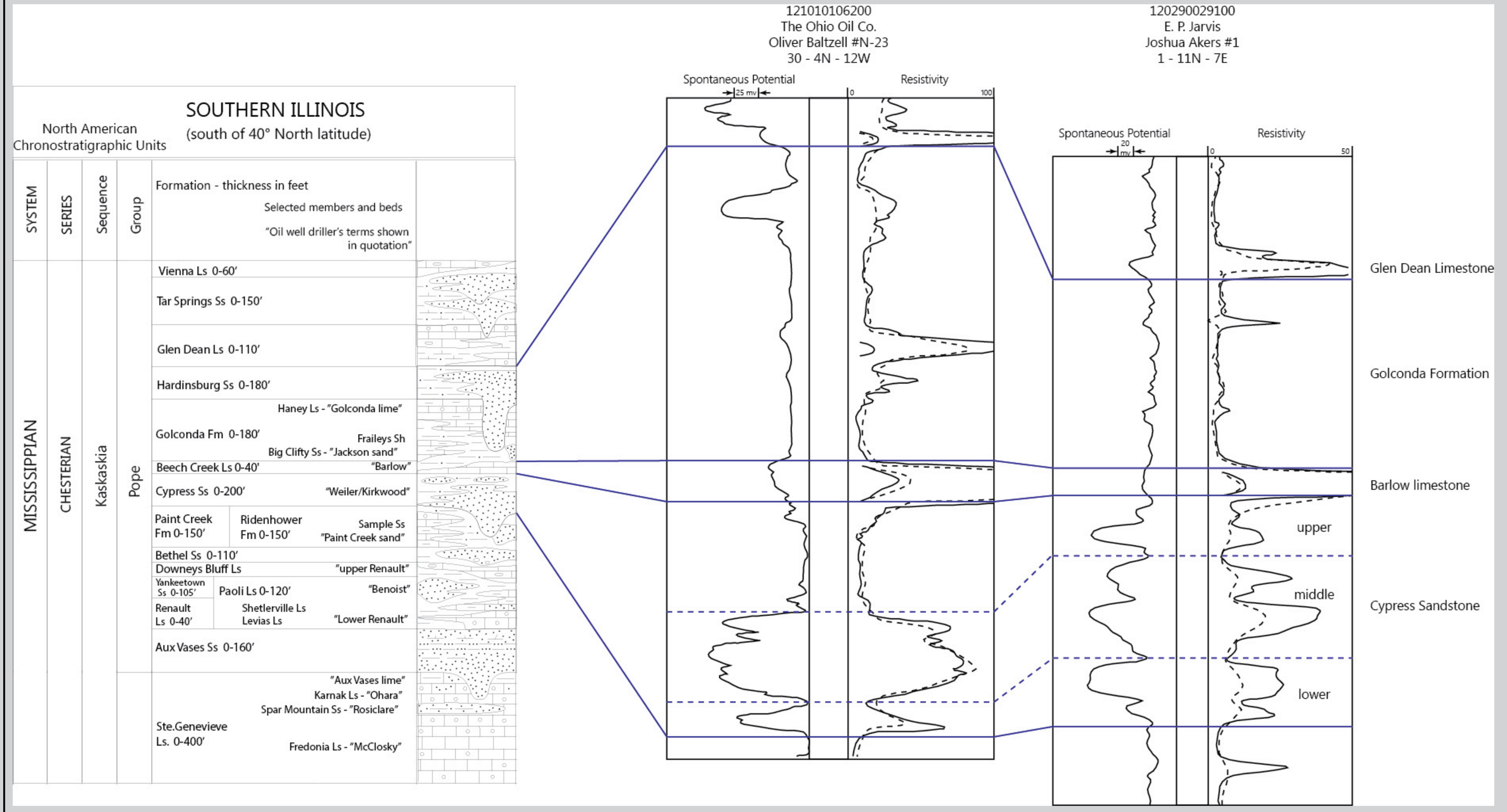
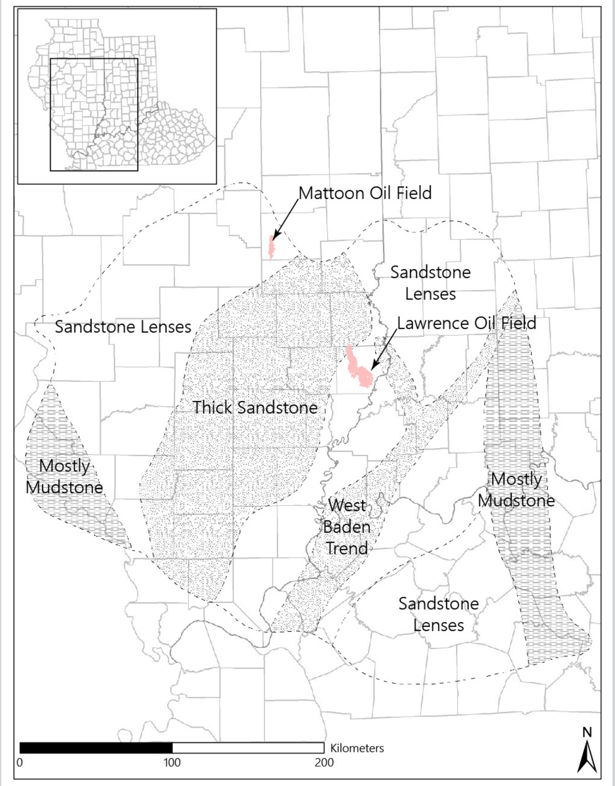
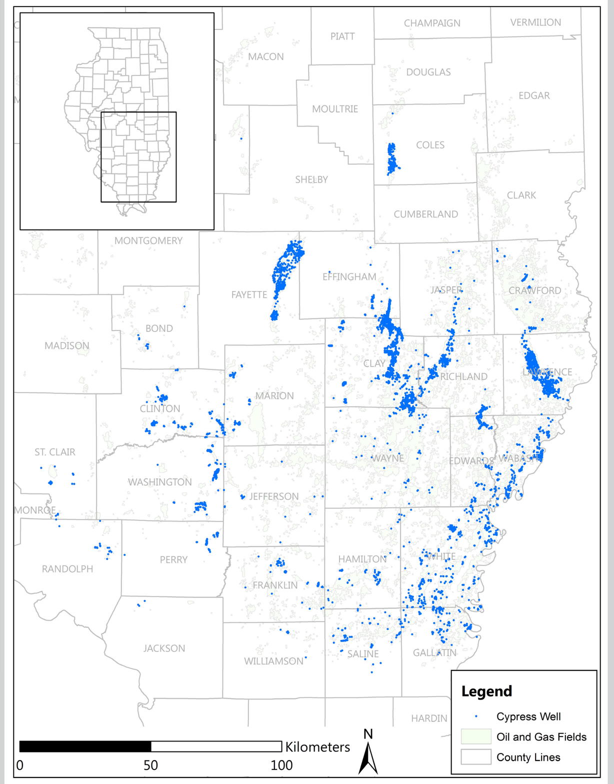


Figure 1. Chesterian stratigraphy in southern Illinois showing the Cypress Sandstone in the context of other cyclical carbonate and siliciclastic units (Left). Type logs are shown from the Lawrence (Center) and Mattoon (Right) Oil Fields.

Cypress Production in the Illinois Basin



<Figure 2. Cypress Sandstone provinces in the ILB. The Cypress is characterized by two NE-SW trends of thick sandstone within the Middle Cypress. Lateral to the thick sandstones in the Middle Cypress and above them in the Upper Cypress, elongate sandstone bars are most common. Lawrence and Mattoon Fields are highlighted. Modified from Seyler et al., 2000; Nelson et al., 2002.



>Figure 3. Oil production from the Cypress in Illinois.

The Cypress Sandstone has produced >0.2 billion m³ (1 billion bbl) of oil and is the most prolific reservoir in the state.

Lawrence Field
- Discovered in 1906.
- Over 65 million m³ (410 million stb) of production from all reservoirs.
- Waterflooded since 1950's.
- Historical success with polymer flooding (Maraflood, 1980's) and alkali-surfactant-polymer flooding (ASP, 2010's).

Mattoon Field
- Discovered in 1940.
- Over 3.6 million m³ (22.9 million stb) of production from all reservoirs.
- Waterflooded since 1950.
- Research CO_2 EOR pilot (mid 1990's) recovered oil.

Recovery, both primary and secondary (waterflooding) in both mature fields is is estimated to be <40% of OOIP.

Upper Cypress Characteristics

- Most common interval of oil production in the Cypress Ss
- Transgressive Systems Tract; overlain by basinwide limestone
- Lenticular sandstone bodies interbedded with shale
- Sandstone bodies commonly form NE-SW trending bars
- Difficult correlations due to coalescing/stacking of bars

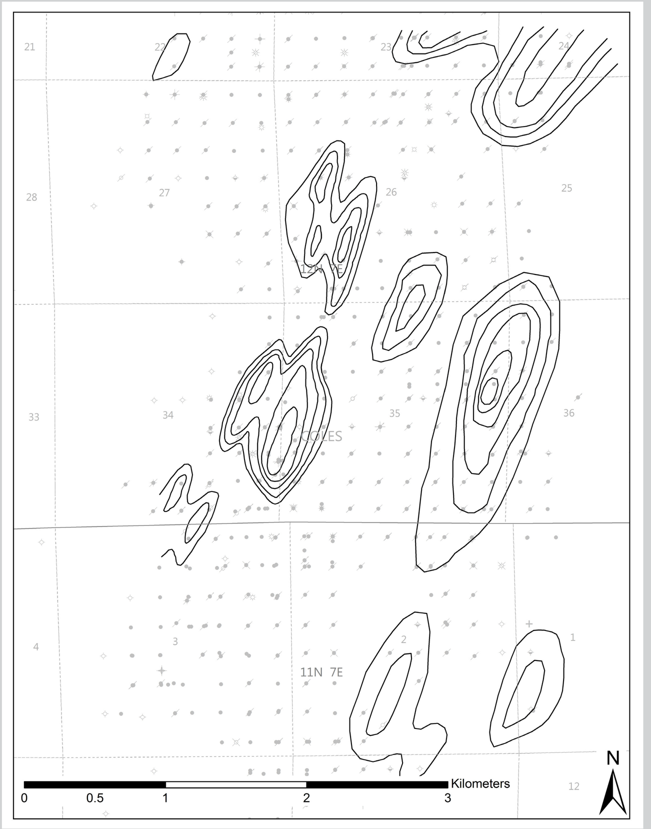
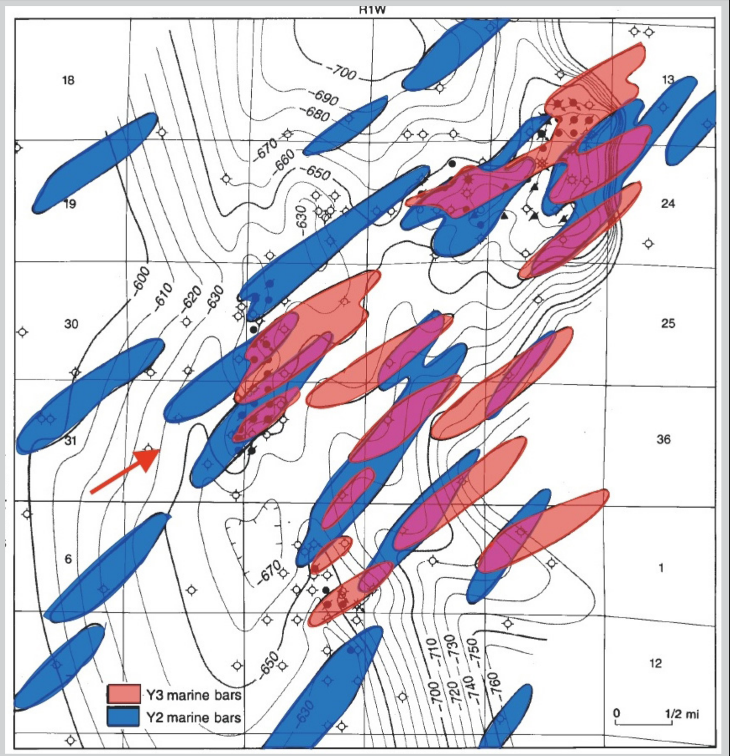


Figure 4. Isopach map of tidal sandstone bars within a correlative interval in the Upper Cypress of Mattoon Field. Contour interval is 0.3 m with a base contour of 1.2 m. The NE-SW oriented, elongated bar geometry is characteristic of the tidal bar facies of the Cypress in the ILB. These reservoir sandstones can exhibit a range of tidally influenced facies (Fig 8).



>Figure 5. Outline of NE-SE oriented tidal sandstone bars >1 m thick in Tamaroa Field in SW Illinois. Different colors represent bars at two correlative intervals within the Upper Cypress. (After Grube, 1992).

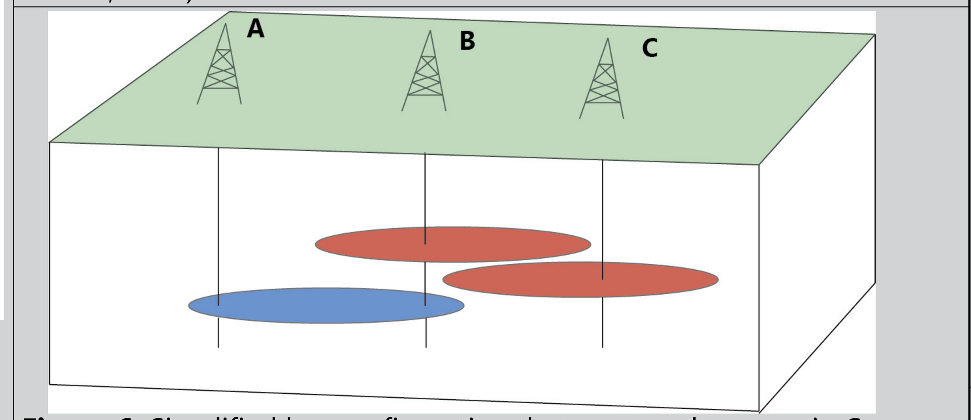


Figure 6. Simplified bar configuration that commonly occurs in Cypress reservoirs. Primary recovery will occur in all three sandstone lenses but only the lower blue lens can be drained by secondary injection through Wells A or B. The red lenses cannot be flooded with this well configuration, although miscorrelation of the lenses could lead to an interpretation that wells B and C or wells A and C are in communication.

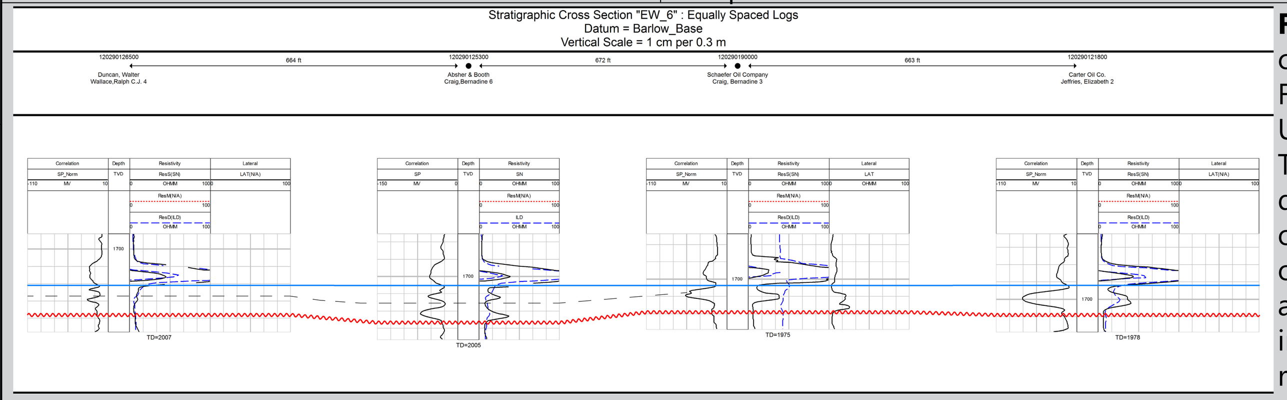


Figure 7. Example log cross section in Mattoon Field showing detail of Upper Cypress interval. Two sandstone bodies develop in the two logs on the left but coalesce over a short distance into a single sandstone body in the two logs on the right.

Cypress Reservoir Facies

Figure 8. Core from Griggs #107 well in Lawrence Field showing typical Cypress facies and diagenetic features.

Reservoir Facies

- Massive (structureless) bedding - excellent porosity and permeability
  Grain size: fine grained
  Sorting: poorly sorted
  Composition: quartz arenite, minor feldspars and clay minerals
- Planar bedding - good to excellent porosity and permeability
  Grain size: fine grained
  Sorting: well sorted
  Composition: quartz arenite, minor feldspars and clay minerals
- Ripple bedding - goot to poor porosity and permeability depending on amount of clay sized ductile grains
  Grain size: fine to very-fine grained
  Sorting: poorly sorted
  Composition: quartz arenite, minor feldspars, laminae of ductile clay sized grains

Non-Reservoir Facies

- Flaser to Lenticular bedding - little to no porosity and permeability
  Grain size: very-fine grained sand interbeddid with shale
  Sorting: well sorted
  Composition: quartz arenite, minor feldspars, common clay drapes
- Calcite cemented sandstone - little to no porosity and permeability
  Grain size: very-fine grained
  Sorting: well sorted
  Composition: quartz arenite, minor feldspars, calcite cement

Middle and Lower Cypress Characteristics

- Middle Cypress is made up of tidal bars in some areas and thick fluvial deltaic sandstone in others (Figure 2)
- All of these facies are commonly juxtaposed and can be oil productive
- Middle Cypress tidal bars have similar geometries, orientations, and lithologic characteristics to Upper Cypress bars
- In some areas, the Middle Cypress is capped by paleosol indicating prolonged subaerial exposure (Figure 9)
- In other areas, the Middle Cypress was partially or wholly eroded by incised valleys during subaerial exposure
- Where eroded, the Middle Cypress can be juxtaposed to younger and genetically dissimilar Upper Cypress sedimnents
- Lower Cypress is separated from the Middle Cypress by another intraformational sequence boundary marked by a paleosol horizon and erosion in some areas, as observed by Nelson et al. (2002) along the margins of the ILB
- The Lower Cypress is rarely oil productive and few core penetrate this zone, making the placement of a second sequence tentative pending the examination of additional core in the ILB interior

Figure 9. Core from J.H. Seaman #15 well in Mattoon Field. Contains zone of pedogenically altered sandy siltstone to mudstone. Carbonized plant fragments, slickensides, and secondary carbonate nodules are common. This zone is mottled dark reddish brown and grades to greenish grey with depth. This zone is interpreted as a paleosol (likely calcic vertisol) and is indicative of the subaerial exposure that formed the sequence boundary at the top of the Middle Cypress.

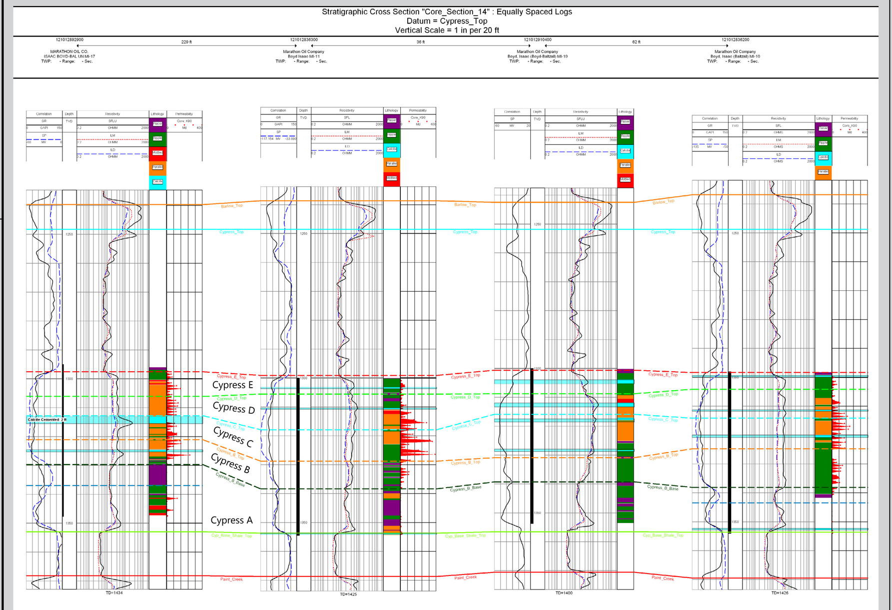


Figure 10. Cross section of cored wells from Lawrence Field showing geophysical log, reservoir facies, and permeability at each well location. The reservoir facies are color coded as in Fig 8. Permeability values are plotted in red. The correlated intervals (E, D, C, and B) are shown in an isopach map (Fig 11).

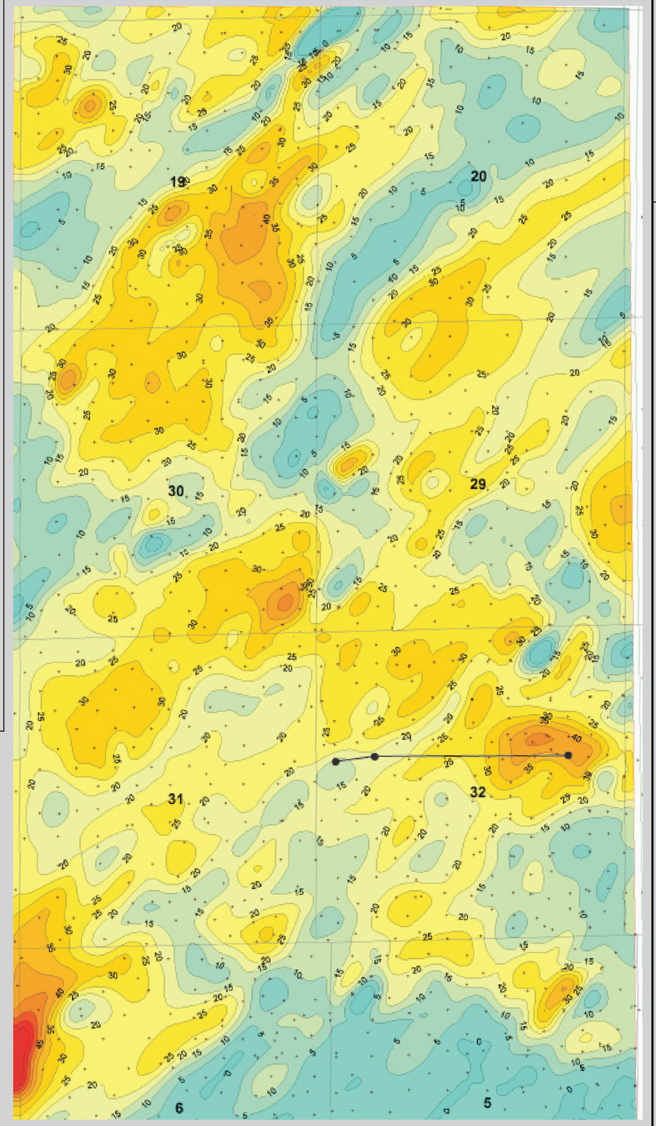


Figure 11. Total Middle Cypress, 50% clean normalized SP sandstone thickness map from Lawrence Field (CI = 5 ft). Map includes the B, C, D, and E intervals. These units are all interpreted to be tidal shoal deposits, analogous to those found in modern high tidal range settings. Note the elongated shoal geometry trending northeast-southwest. The basal Cypress A interval appears to be a deltaic facies that is genetically dissimilar to the remainder of the sandstones and is likely part of the Lower Cypress. The Cypress A is less permeable and is commonly non-productive.

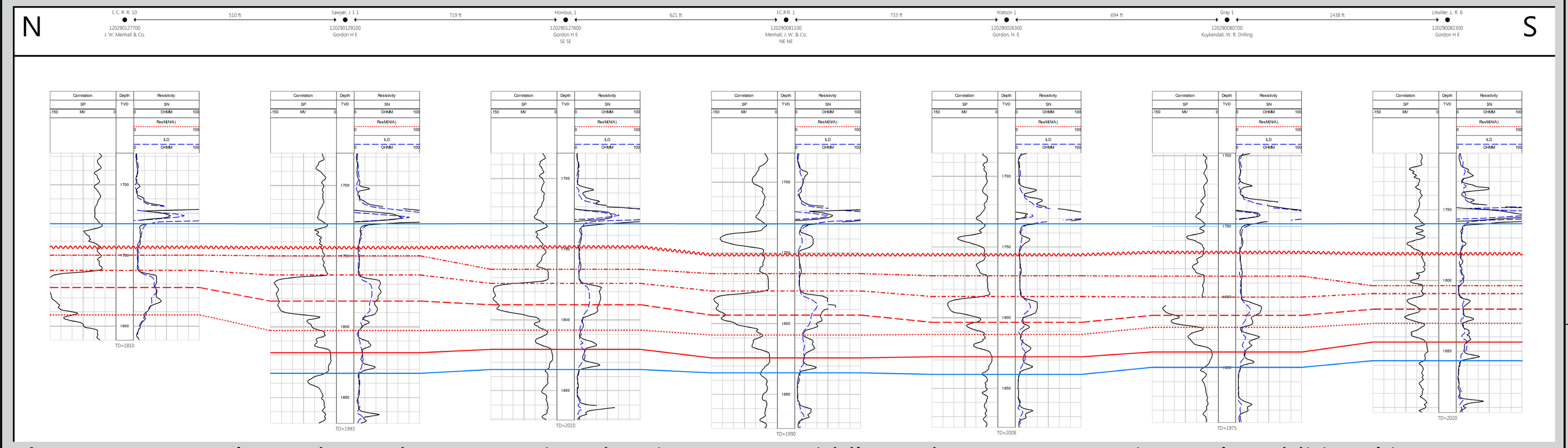
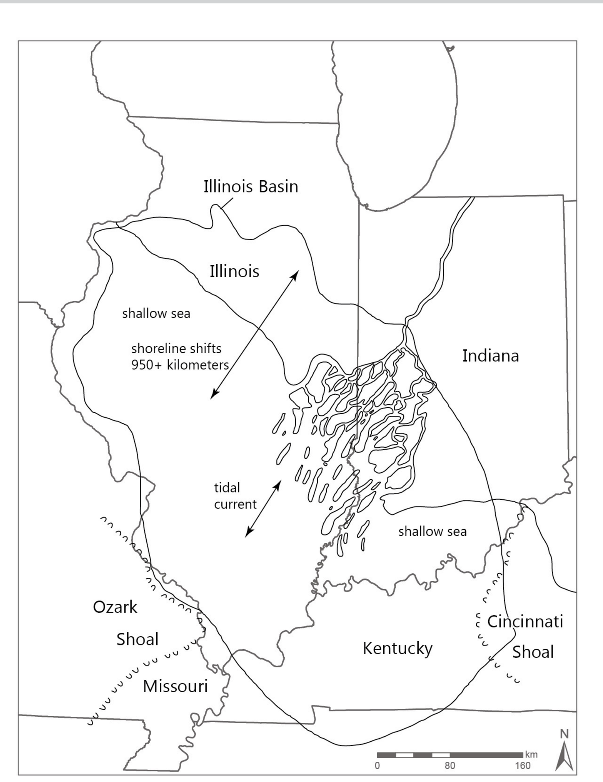


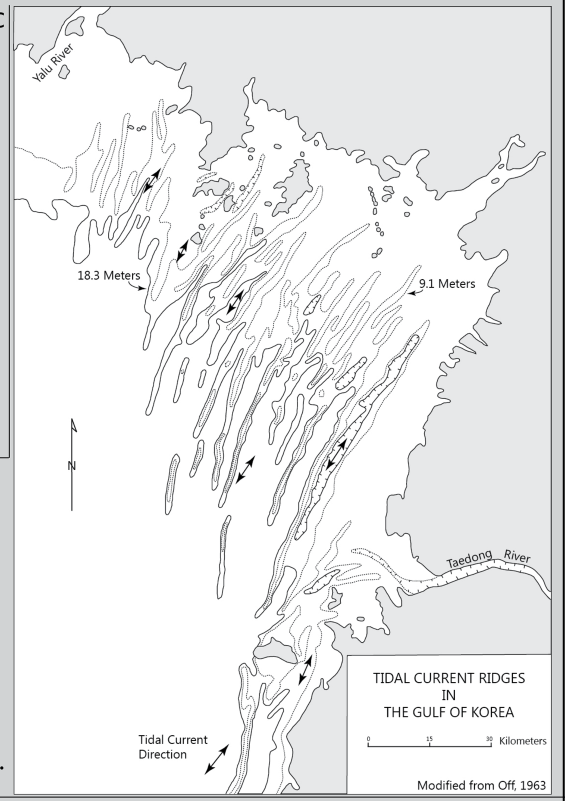
Figure 12. Example north-south cross section showing Lower, Middle, and Upper Cypress intervals. Additional intra-Cypress correlations demonstrate southward progradation of sandstone bodies in the Middle Cypress. Similar geometries were observed in the Middle Cypress of Richview Field (Grube and Frankie, 1999).

Figure 13. Core from Louden Field located in the central part of the ILB. Middle Cypress sandstone overlies greenish grey, slickensided mudstone that contains abundant secondary carbonate nodules. This horizon is interpreted as a paleosol and lends support for separating the Middle Cypress from the Lower Cypress.

Depositional Environments



<Figure 14. Paleogeographic map of ILB illustrating tidally dominated deposition of siliciclastics with shoreline shifting in response to sea level fluctuation or filling of accommodation. Map shows a sea level high stand with a delta prograding into the basin. During low stand, rivers would extend across the basin and incise into underlying deposits.



>Figure 15. Depositional model for elongate tidal sand ridges in the Gulf of Korea (Off, 1963). This modern model is likely analogous to deposition of Cypress Ss bars in the ILB during times of sea level transgression and high stand.

Sequence Stratigraphic Framework

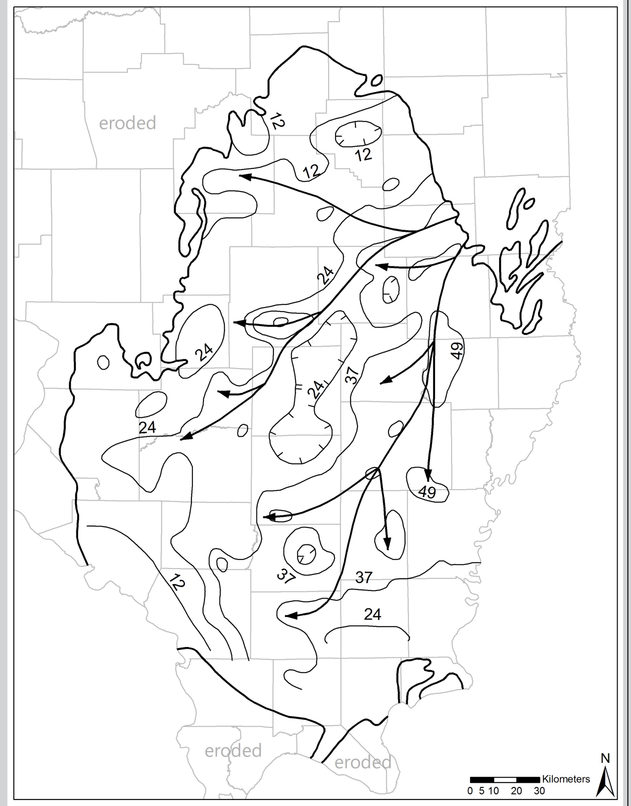


Figure 16. Thickness map of the Cypress Sandstone with a projection of possible trends of prograding deltas, as determined from the trend of thick sandstones. Along the central, active portions of prograding deltas, thick estuarine and probably tidal bayhead deltas to fluvial sands were deposited. These deltas prograded from the northeast down-dip to the southwest and south. Many of these sediments were deposited in valleys incised during lowstands (See Fig 17). (C.I. = 12.2 meters)

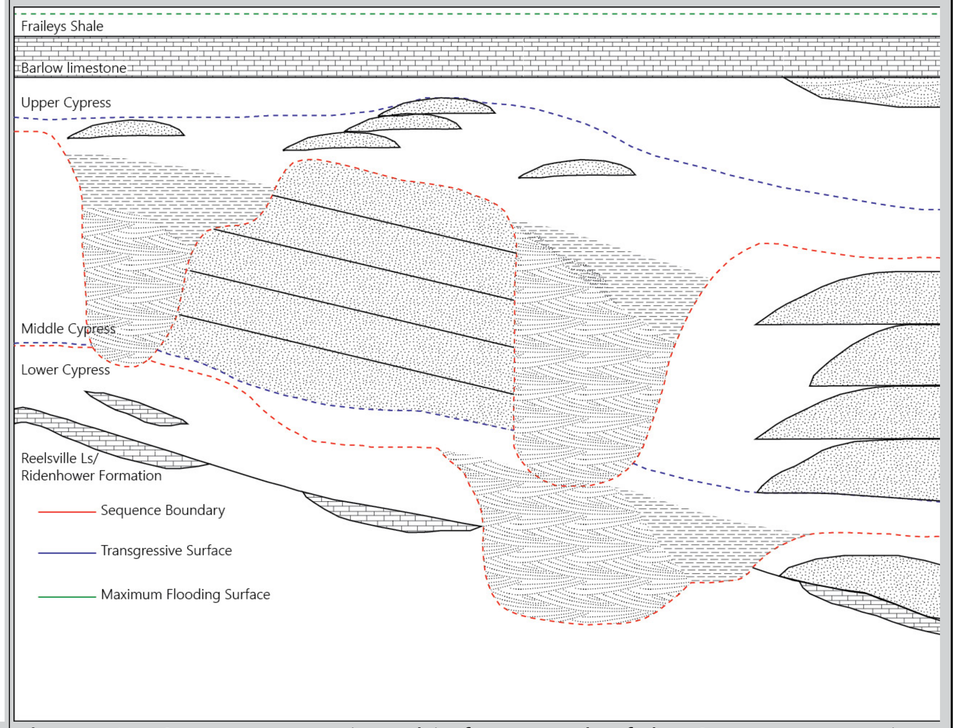


Figure 17. Sequence stratigraphic framework of the Cypress Formation in the ILB (modified from Nelson et al., 2002). Base of Barlow limestone used as stratigraphic datum. Lowstand periods following deposition of Lower and Middle Cypress sediments lead to incision and removal of those highstand sediments. Subsequent infilling of valleys with fluvial and deltaic sediments lead to the lateral juxtaposition of genetically and temporally distinct sandstones. These juxtapositions create difficulty in subsurface correlations without an understanding of the sequence stratigraphic framework. With the examination of additional core, outcrops, and geophysical logs, elements of this framework can be verified.

Summary

- The Cypress Sandstone is the most prolific oil reservoir in Illinois, having produced >0.2 billion m³ (1 billion bbl) of oil.
- The Cypress can be divided into the Upper, Middle, and (tentatively) Lower Cypress based on sequence boundaries.
- The complex depositional history of the Cypress Sandstone with its sequence stratigraphic overprint equates to complex, heterogeneous reservoirs.
- An understanding of the geometry and dimensions of these lenticular sandstone bodies is necessary to define each particular sandstone lens and to correctly correlate the horizon in which the lens was deposited. This is necessary to define compartments and determine communication potential. Only then can each separate lens be efficiently drained.
- Geocellular modeling is an excellent technology that can be applied to better understand the geometry of reservoir and nonreservoir facies in three dimensions and is a useful means to cross check the validity of the conceptual geologic model. Ultimately, the design of an effective CO2 EOR and storage program requires a reservoir simulation analysis that matches and/or projects the flow dynamics of the medium in a reservoir. This is only possible through a thorough understanding of the geologic characteristics of a reservoir.

References

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