PS Salina Group Lithofacies in the Michigan Basin: Development of an Improved Depositional Model From Core Analysis*

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Abstract

A series of newly archived cores at the Michigan Geological Repository for Research and Education have allowed the first detailed observations of the entirety of the Salina Group in southeastern Michigan. Prior to these acquisitions, due to the inclination of industry, the known curated cores available focused on the Salina A- and F-units. New cores as well as rediscovered historic cores have provided new insights into Salina Group stratigraphy, due to the more complete sampling of the entire Salina Group.

The Salina Group were deposited during the Upper Silurian and represent a series of deposits in a restricted marine basin, punctuated by periods when the basin was connected to the open ocean. In the subsurface of the Michigan Basin, the Salina Group has been subdivided, on the basis of wireline log and cuttings data, into the A-0 through G units. Major evaporite units in the Salina Group include the A-1 and A-2 evaporites, the B-Unit, the D-Unit, and the F-Unit. All of these units reached halite saturation and are characterized by interbedded dolomudstones, anhydrites, and rock salts. In the central basin, the A-1 unit reaches sylvite saturation, and sylvinite deposits are found and have been economically exploited in the past. Thick shales with interbedded anhydrite and dolomite are found in the C-, E-, and G-Units. In the southernmost Upper Peninsula, the Salina Group undergoes lateral facies changes to the dominantly shale Pte. aux Chenes Formation. The Salina Group hosts important rock salt and sylvinite reserves. The lower Salina units serve as seals for important hydrocarbon reservoirs in the Niagaran pinnacle reefs and A-1 carbonate. Significant volumes of natural gas and liquefied petroleum gas are hosted in salt caverns in the A-2 and B salts.

An overview of the Salina Group lithofacies will be presented with review of their distribution in the subsurface of Michigan, including interpretation of depositional environments and patterns in sedimentation. Detailed understanding of the lateral distribution and physical properties of the units of the Salina group will enhance our understanding of its value as reservoir seals and salt storage cavern resource.

References Cited

Catacosinos, P.A., W.B. Harrison III, R.F. Reynolds, D.B. Westjohn, and M.S. Wollensak, 2001, Stratigraphic Lexicon for Michigan: Bulletin, Geological Survey Division, Department of Environmental Quality and Michigan Basin Geological Society, Lansing, MI, v. 8, 56 p.

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ABSTRACT

A series of newly archived cores at the Michigan Geological Repository for Research and Education have allowed the first detailed observations of the entirety of the Salina Group in southeastern Michigan. Prior to these acquisitions, due to the inclination of industry, the known curated cores available focused on the Salina A- and F-units. New cores as well as rediscovered historic cores have provided new insights into Salina Group stratigraphy, due to the more complete sampling of the entire Salina Group.

The Salina Group were deposited during the Upper Silurian and represent a series of deposits in a restricted marine basin, punctuated by periods when the basin was connected to the open ocean. In the subsurface of the Michigan Basin, the Salina Group has been subdivided, on the basis of wireline log and cuttings data, into the A-0 through G units. Major evaporite units in the Salina Group include the A-1 and A-2 evaporites, the B-Unit, the D-Unit and the F-Unit. All of these units reached halite saturation and are characterized by interbedded dolomudstones, anhydrites and rock salts. In the central basin, the A-1 unit reaches sylvite saturation, and sylvinite deposits are found and have been economically exploited in the past. Thick shales with interbedded anhydrite and dolomite are found in the C-, E-, and G-Units. In the southernmost Upper Peninsula, the Salina Group undergoes lateral facies changes to the dominantly shale Pte. aux Chenes Formation.

The Salina Group hosts important rock salt and sylvite reserves. The lower Salina units serve as seals for important hydrocarbon reservoirs in the Niagaran pinnacle reefs and A-1 carbonate. Significant volumes of natural gas and liquefied petroleum gas are hosted in salt caverns in the A-2 and B salts.

An overview of the Salina Group lithofacies will be presented with review of their distribution in the subsurface of Michigan, including interpretation of depositional environments and patterns in sedimentation. Detailed understanding of the lateral distribution and physical properties of the units of the Salina group will enhance our understanding of its value as reservoir seals and salt storage cavern resource.

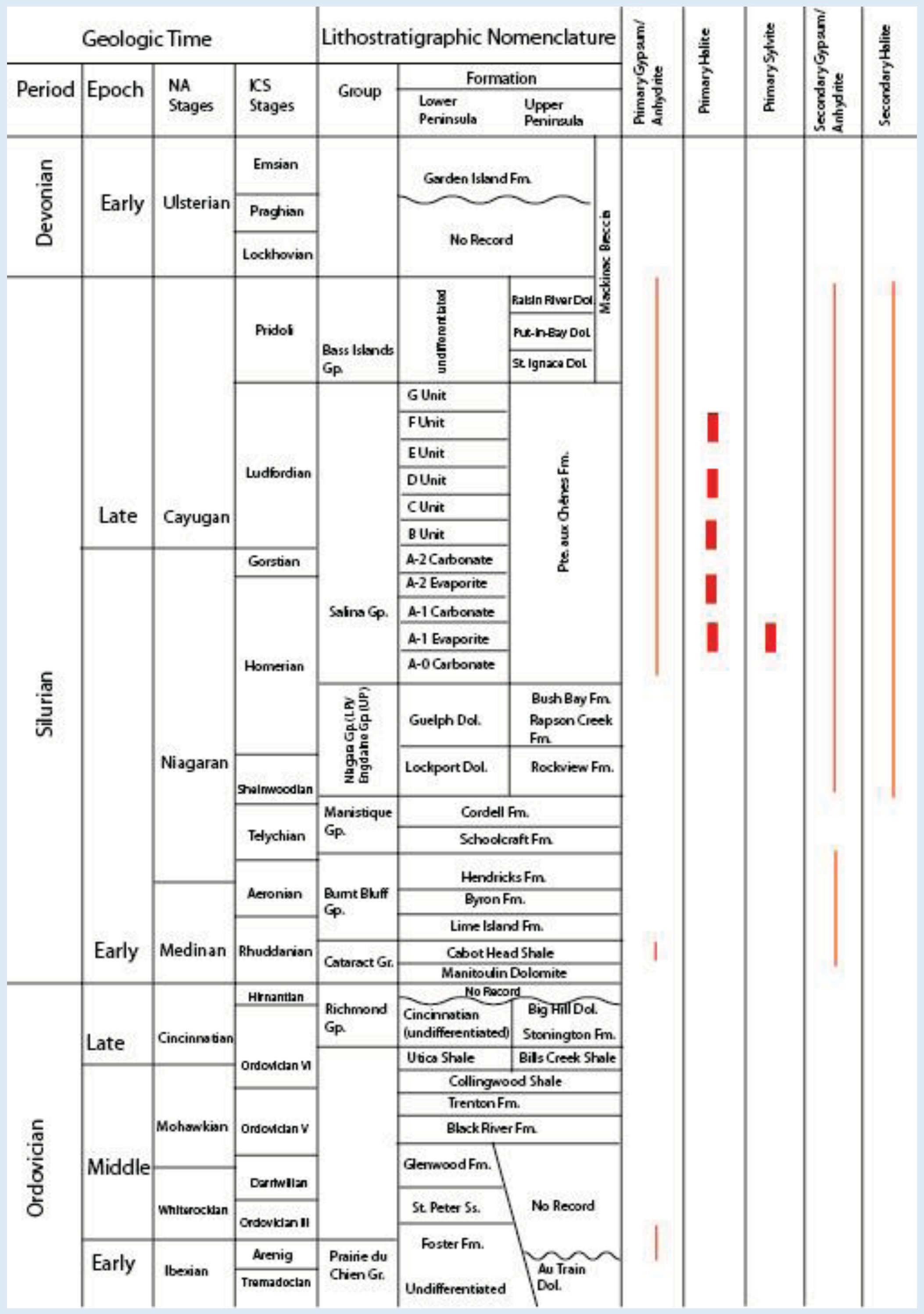


Figure 2: Ordovician to early Devonian stratigraphy in the Michigan Basin (modified from Catacosinos et al., 2001, with new geochronological data from Rine, 2015). The distribution of primary and secondary evaporite minerals is shown as a function of stratigraphic age. The thickness of the bar corresponds to abundance of that phase.

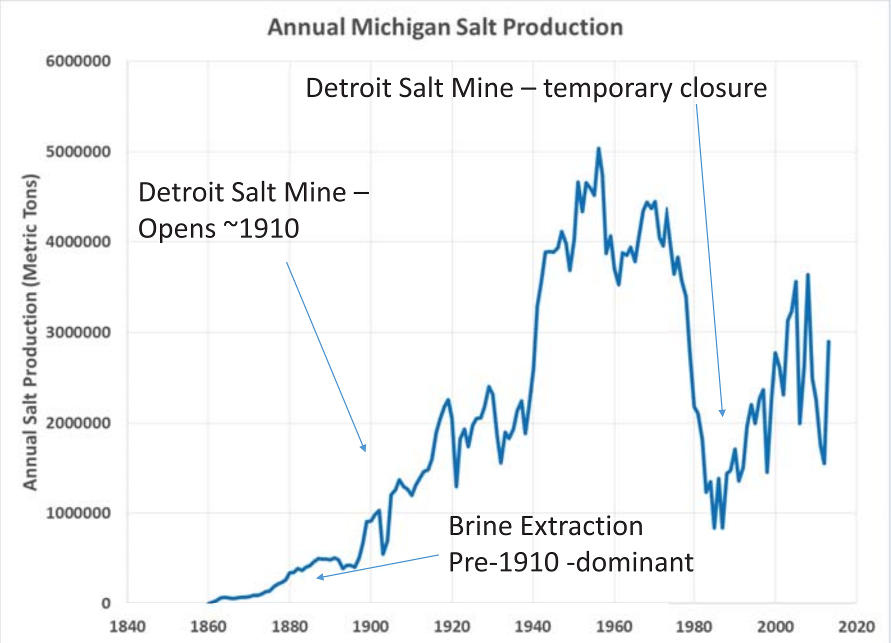


Figure 3: Cumulative Salt Production in Michigan. The Bulk of the production is from the Salina F Unit.

Total estimated production: 300 million metric tons of rock salt and brine – mostly from the Salina F Unit.

Some sylvite production from the A-1 Evaporite (max: 160,000 metric tons per year)

Most rock salt – produced for road deicing

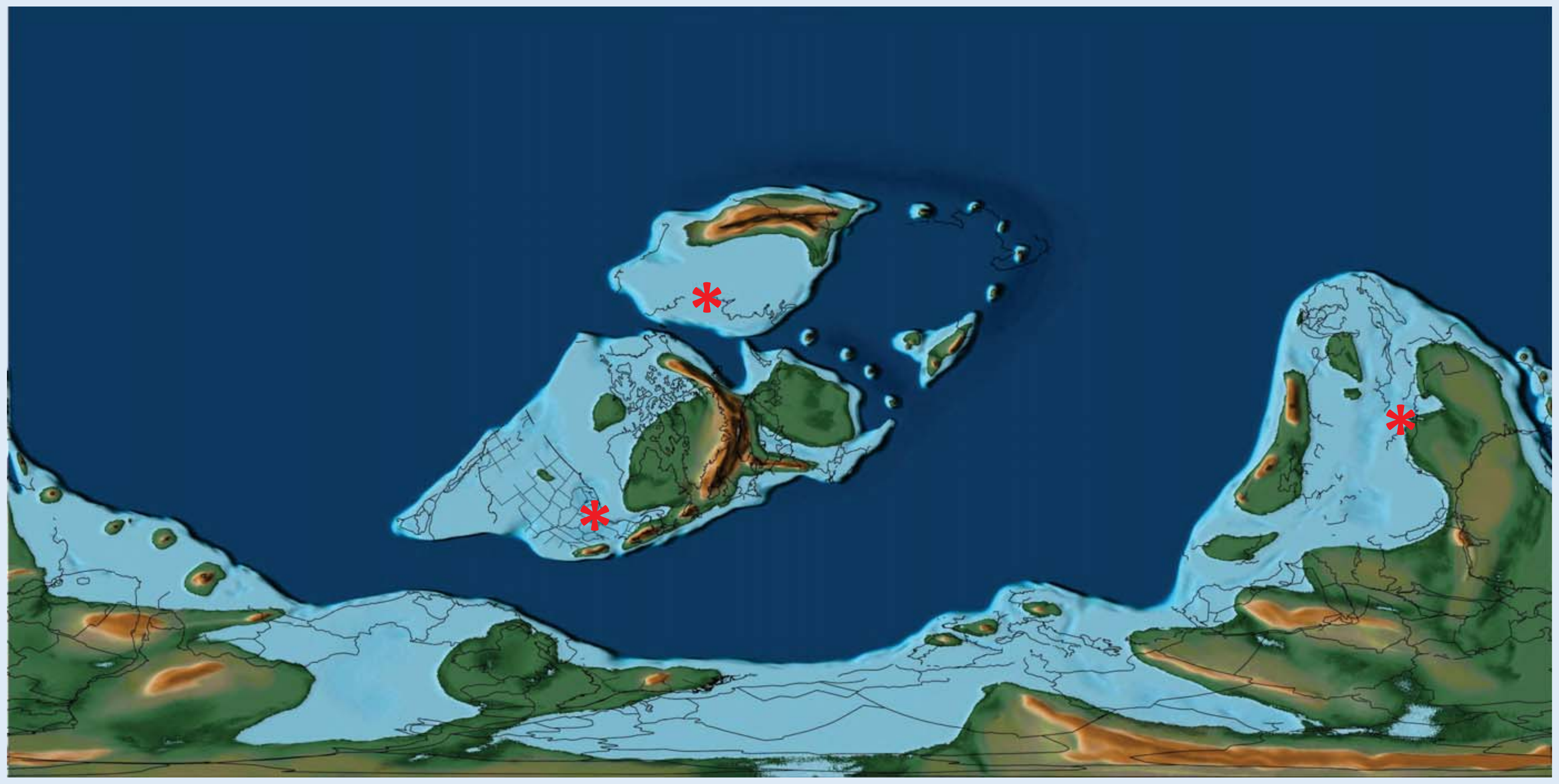


Figure 1: Late Silurian paleogeography. Major Salt deposits formed in the arid tropical climatic belts. Silurian salt deposits are today found in the Michigan-Appalachian Basins, northwestern Australia, and northern Siberia. Figure modified from Scotese (2013).

Hydrocarbon Significance

- Upper Salina Units – seal for the unconventional A-1 Carbonate Reservoirs
- Salina Group – ultimate seal for Lower Silurian Reservoirs (Burnt Bluff Group [hydrothermal dolomite or patch reefs], Niagara Group [Reefs])
- Ultimate Seals for Gas storage fields hosted in Lower Silurian carbonates as well as storage caverns in Salina units

Salina A Units

Stratigraphic Nomenclature

Top
- A-2 Carbonate
- A-2 Evaporite
- A-1 Carbonate ("Ruff Fm.")
- A-1 Evaporite
- A-0 Carbonate ("Cain Fm.")

Base

After Catacosinos et al. (2001).

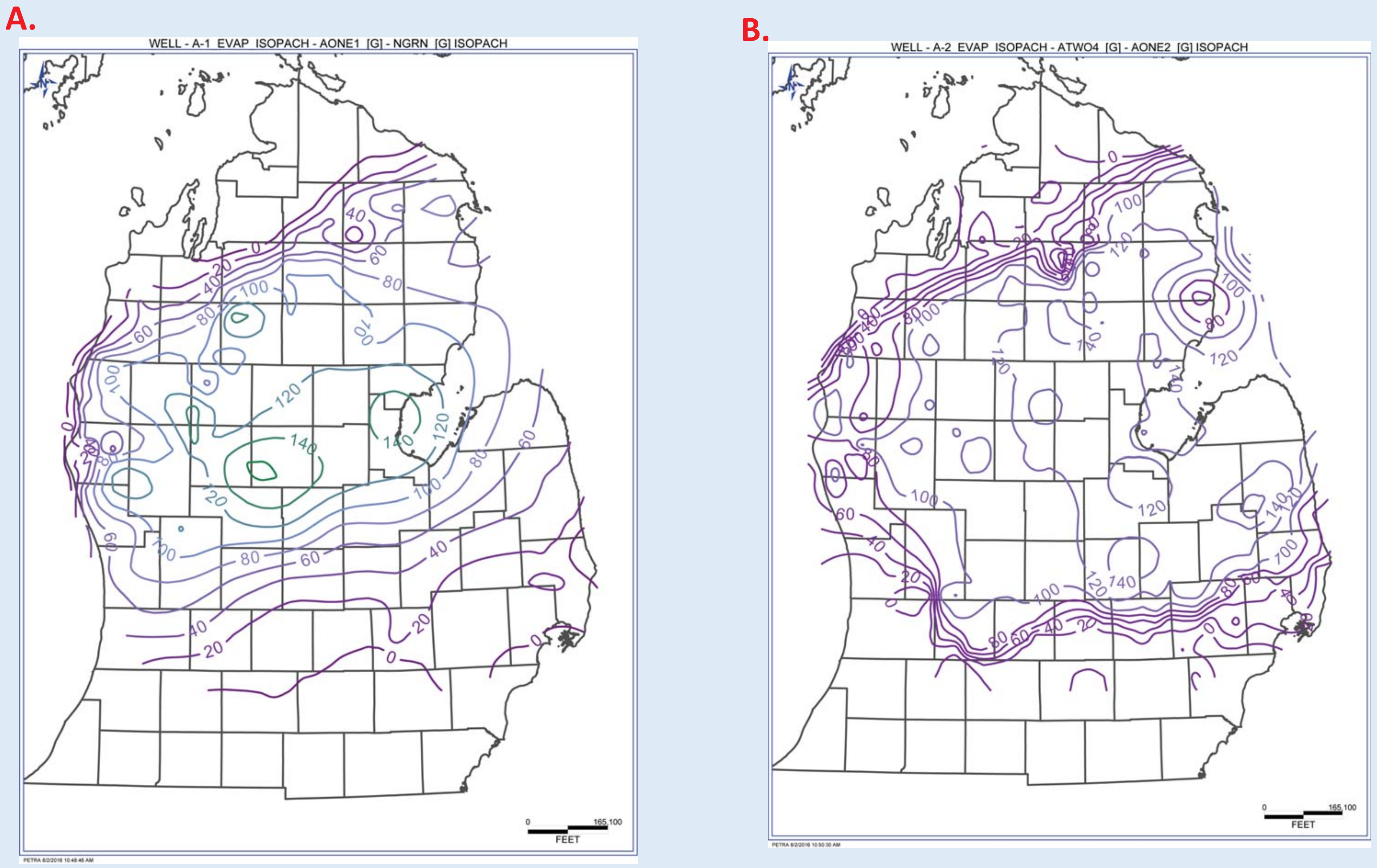


Figure 4: Isopach Maps for the A.) A-1 Evaporite and B.) A-2 Evaporite. Note that both Units are limited to an area confined by the pre-existing paleo-topography of the Niagaran reef tract. The A-1 Evaporite has a depocenter that is shifted further west than in most Salina units.

Contour interval in both maps is 20 m (65.5 ft).

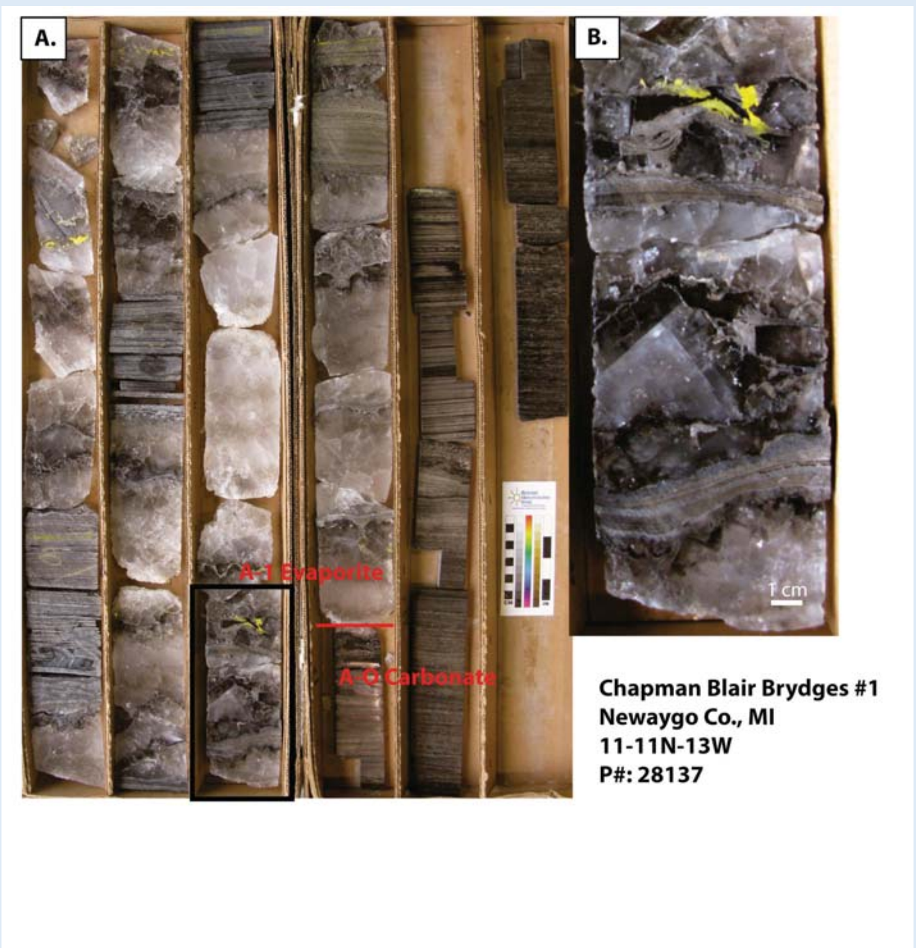


Figure 5: Selected core intervals from the Chapman Blair Brydges #1, Newaygo Co. (PN: 28137).
A.) Core exhibiting the contact between the A-0 Carbonate (microbially-laminated carbonates) and the A-1 Evaporite (interbedded rock salt with thin lenses of dolomite and anhydrite).
B.) Close-up view of A-1 Evaporite (from black box) note the bottom growth halite chevrons in lower right of image.

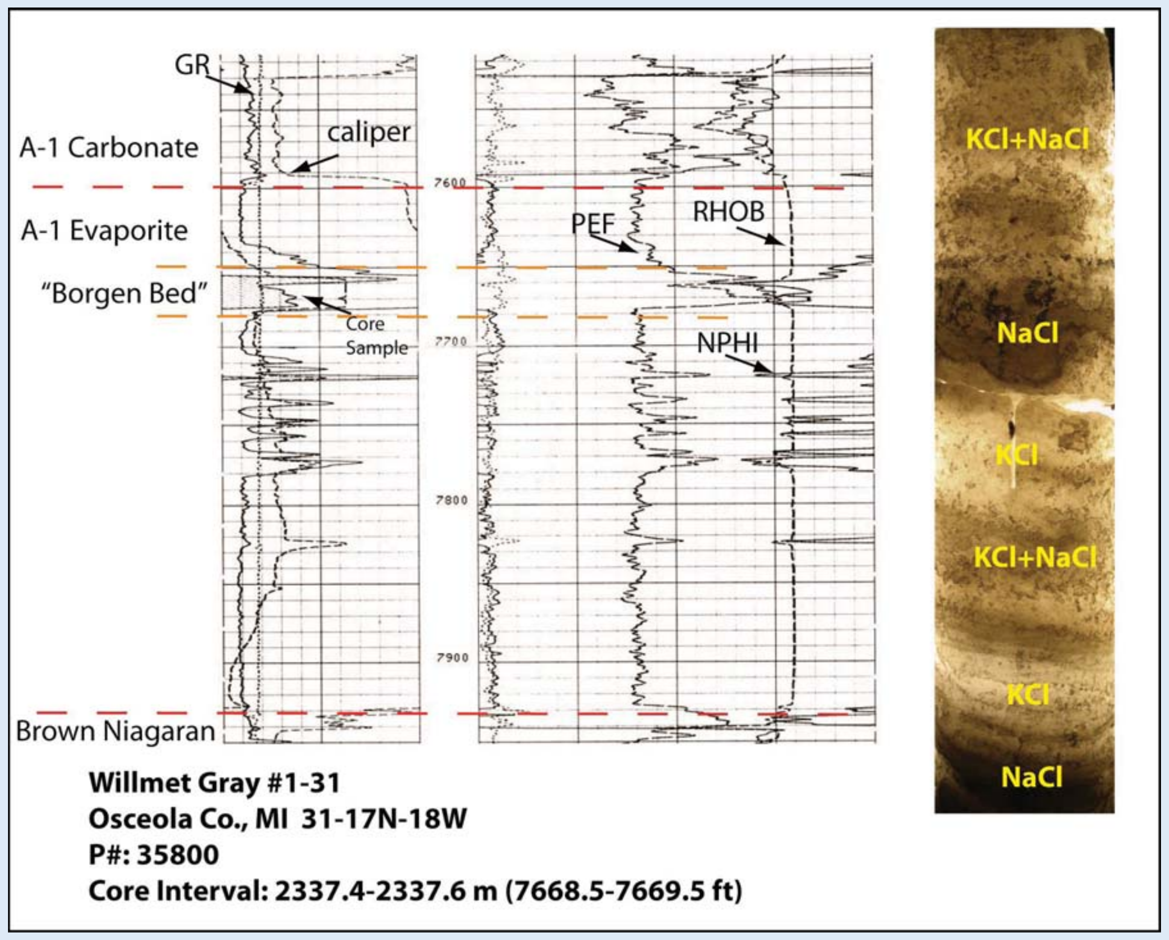


Figure 6: The A-1 evaporite is the only unit in the Salina Group with bedded sylvinites. The sylvinites are recognized in the upper A-1 Evaporite from their log signatures – an increase in caliper width paired with a gamma ray high (radioactive K content). The backlit Core photograph from the Willmet Gray#1-31 shows the evenly bedded textures of these salts and the dispersion of organic matter. Cored interval represents approximately 1 ft of material.

Figure 7: Selected Core interval from the Bruske #1-26a (PN: 59271, Osceola Co) showing the contact between the A-1 Evaporite and A-1 Carbonate. Note the coarsely recrystallized fabric of the A-1 Evaporite. The A-1 Carbonate consists of microbially-laminated dolomites with intraclastic horizons and disrupted laminations from soft-sediment deformation.

Salina B and C Units

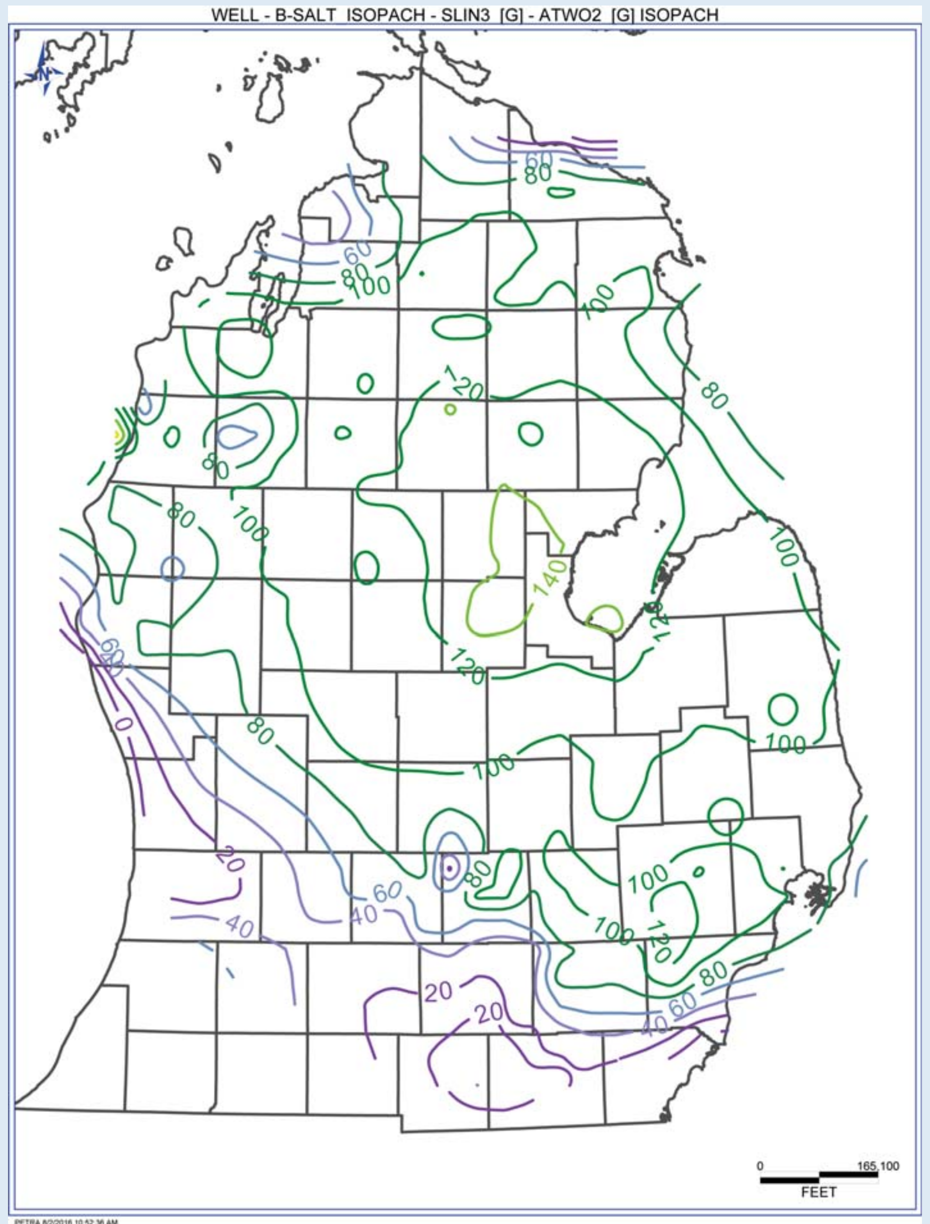


Figure 8: Isopach Map of the B Evaporite. Note the depocenter is centered west of Saginaw Bay. Contour Interval – 20 meters (65.5 ft.)

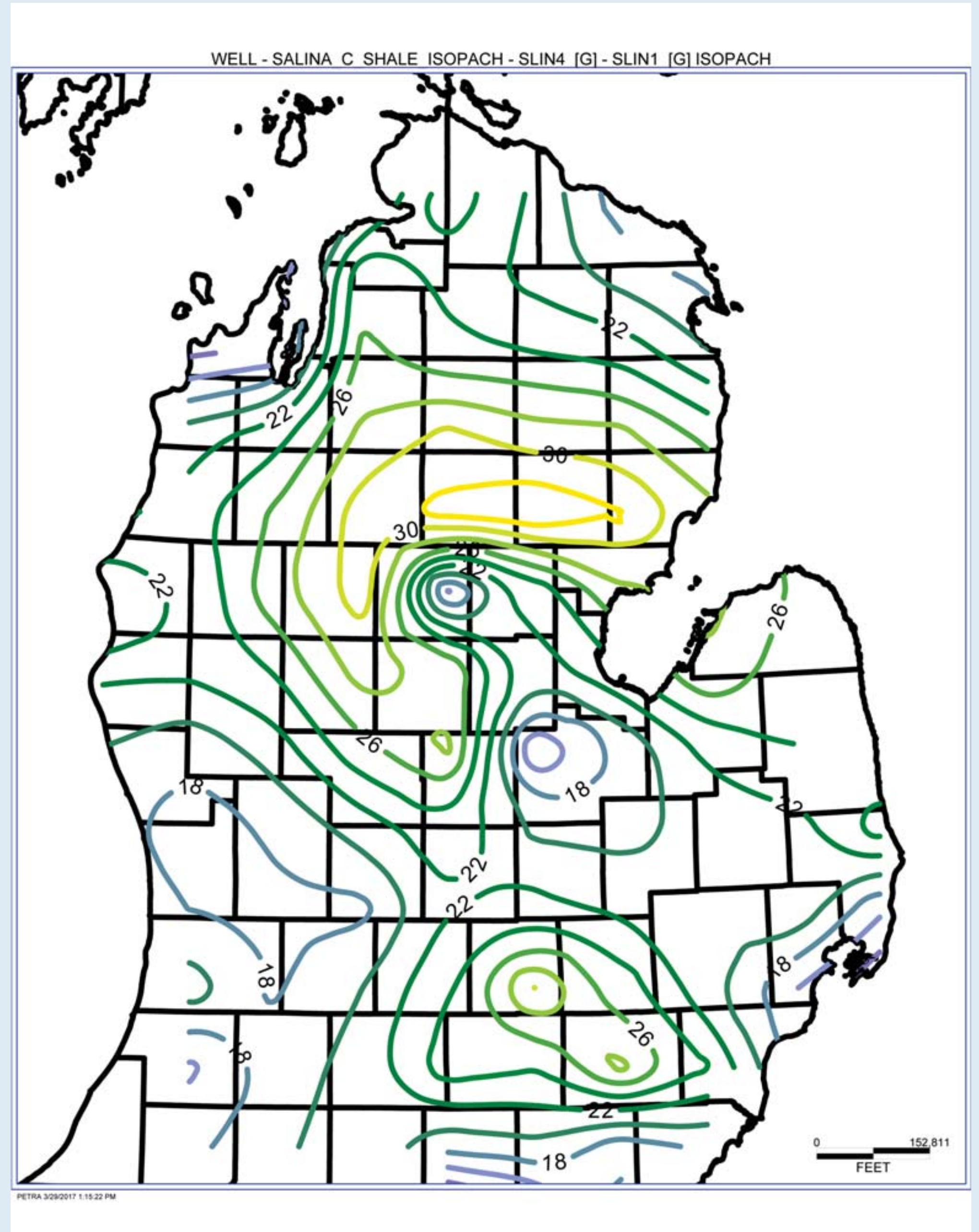


Figure 9 – Isopach map of the C Unit. The C Unit is thickest in the northern central Lower Peninsula. Contour Interval = 2 m.

A. B.

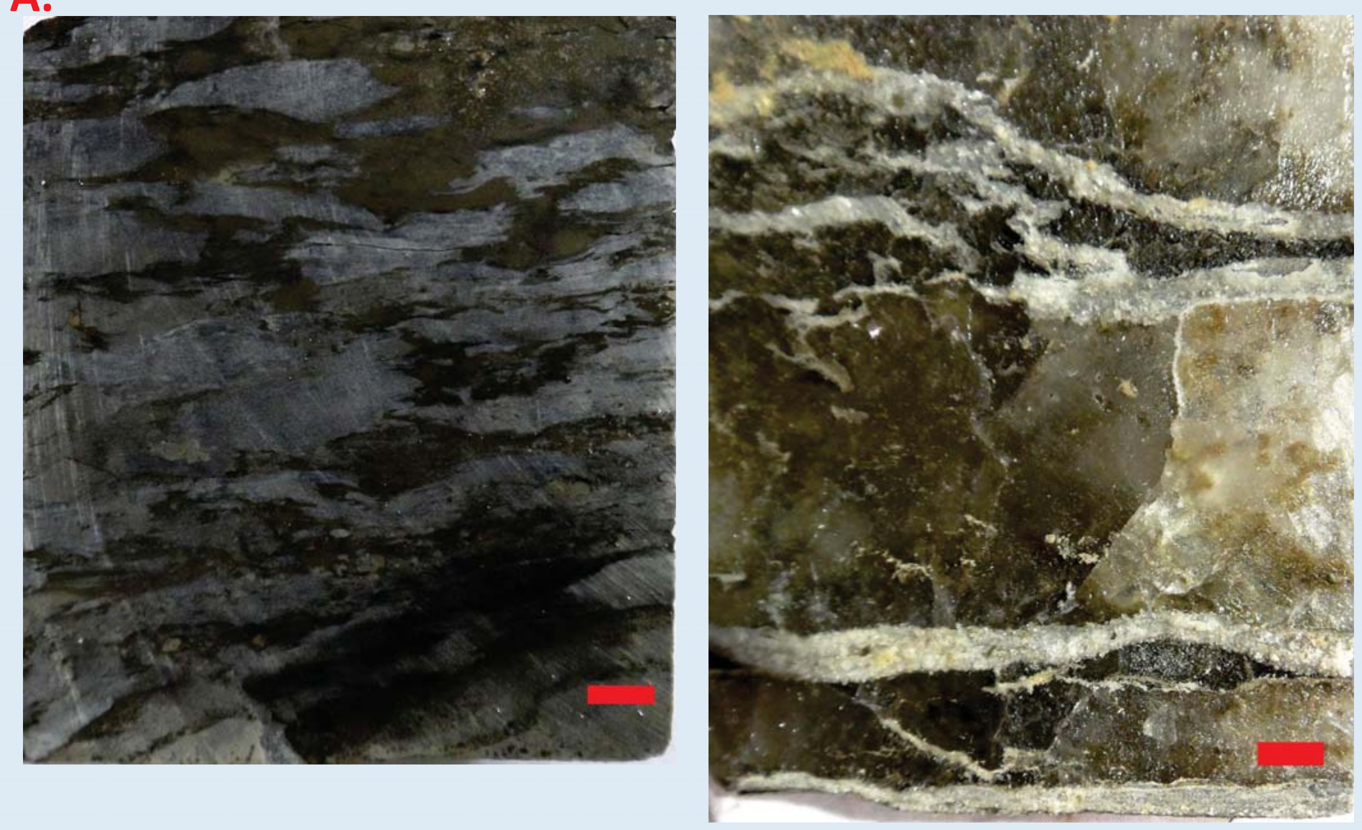


Figure 10 – Selected core photographs from the B Evaporite, Willow Cavern #1, (PN: 26603), Washtenaw Co., MI. Scale bar for both images: 1 cm.
A.) Nodular anhydrite in dark dolomite
B.) Interbedded coarsely recrystallized rock salt with thin bands of dolomite

A. B.

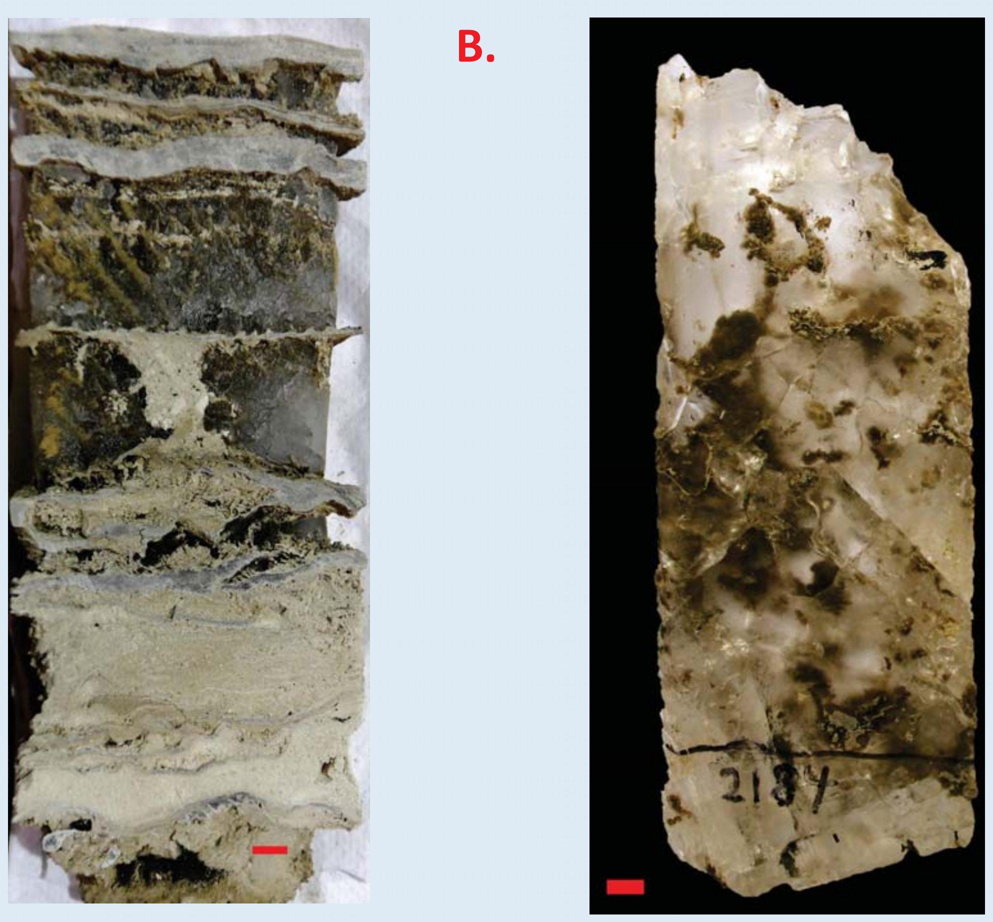


Figure 11: Selected core photographs from the B evaporite. Scale bars = 1 cm.
A.) Interbedded dolomite (microbially-laminated) and rock salt. 2121 ft. Willow Cavern #1, Washtenaw Co., MI.
B.) Coarsely crystalline rock salt. 2,184 ft. Consumers Power Brine Disposal Well #1-7 (PN: 00151), St. Clair Co., MI.

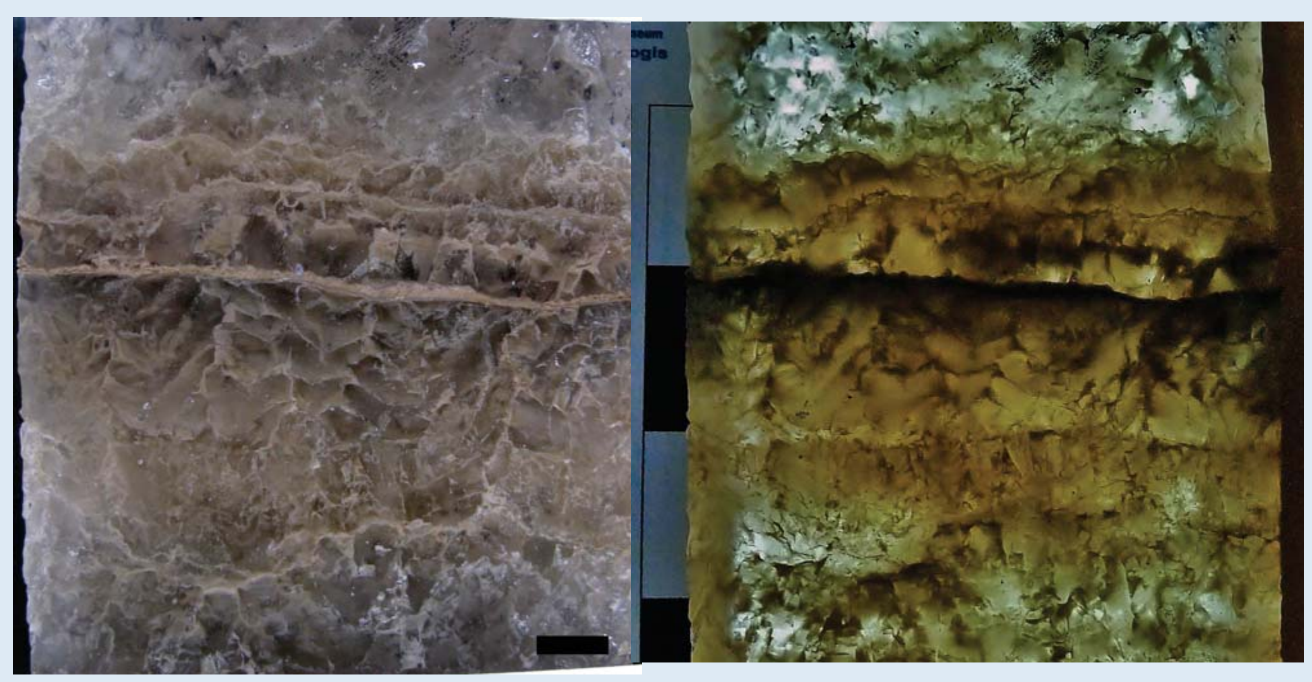


Figure 12: Two views of a sample of rock salt from the B Evaporite – under plane line and under transmitted fluorescent light. Note below the dark seam, the distinctive fabric of "Swallow-tail" crystals. This interval is interpreted as primary gypsum precipitants replaced with halite. Core photograph is from the Consumers Power Brine Disposal Well #1-7, St. Clair Co., MI at a depth of a 1,975 ft. Scale bar = 1 cm.

Figure 13: Core photograph from the upper C Unit with fracture cross-cutting, laminated carbonate mudstone and shaley carbonate mudstone with nodular anhydrite. Fracture is filled with a fibrous, reddish-brown Halite cement.

Salina D and E Units

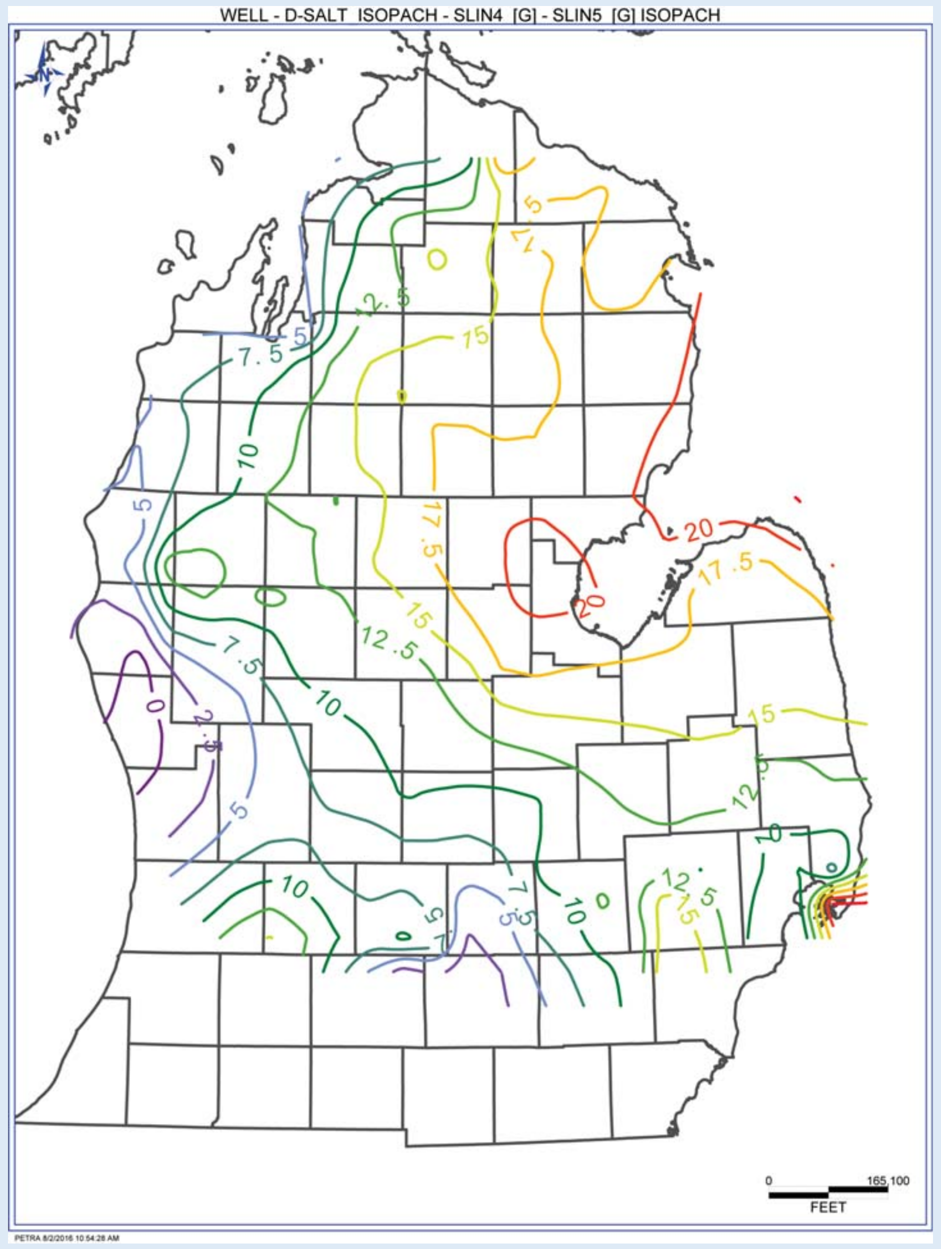


Figure 14: Isopach Map of the D Unit, which is the thinnest of the formally-defined Salina units. The depocenter is under the western shore of Saginaw Bay, where the formation exceeds 20 meters thick. Contour interval is 2.5 m (8 ft.).

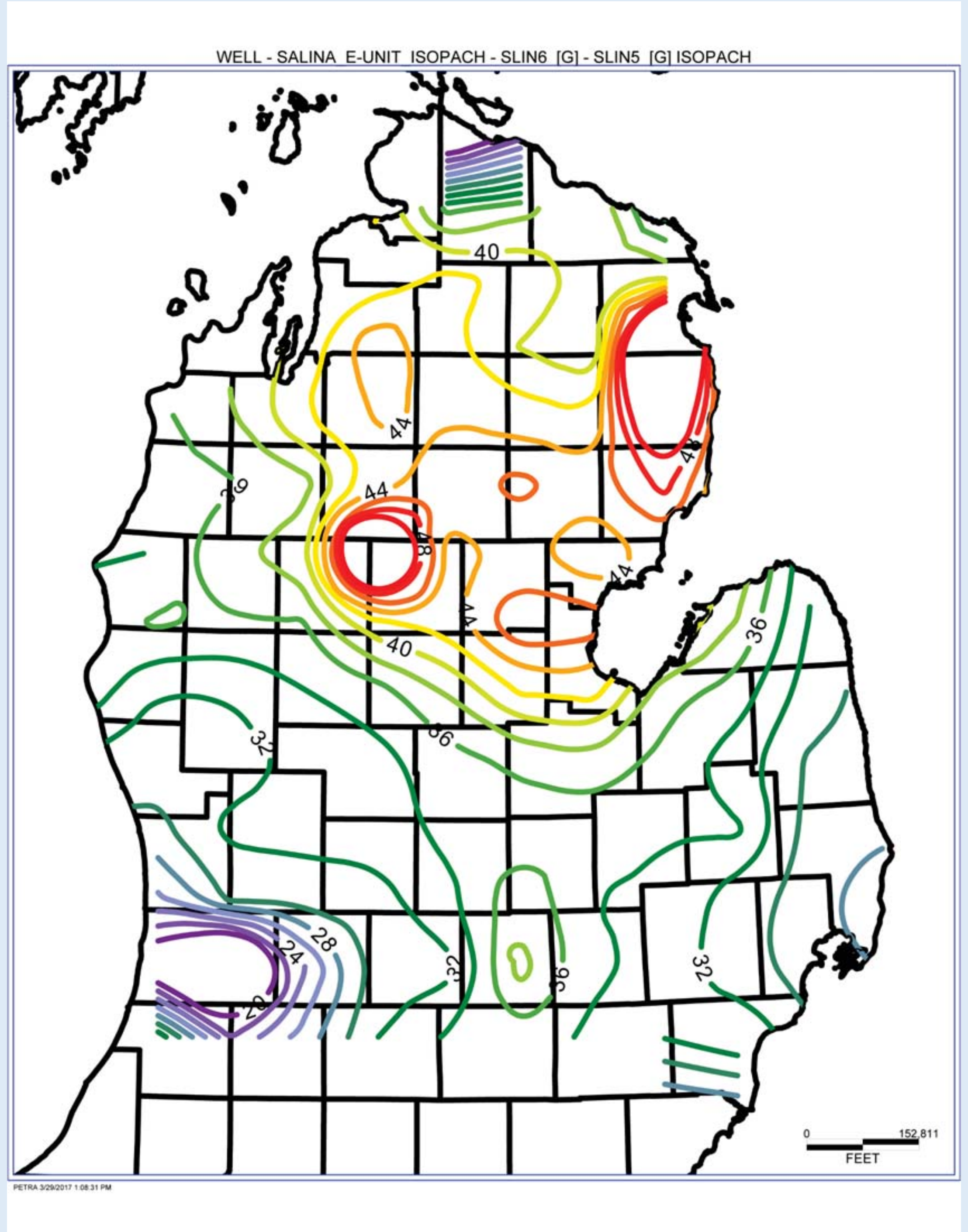


Figure 15 – The E Unit has a similar pattern to the C Unit, with the thickest accumulation in the northern central Lower Peninsula. Contour Interval = 2 m.

Figure 16: Dolomitic shale with anhydrite nodules in the Salina D Unit. The reddish-colored seam is a fracture lined with fibrous halite. Sample from the Willow Cavern #1 (Washtenaw Co.) from a depth of 1780 ft.

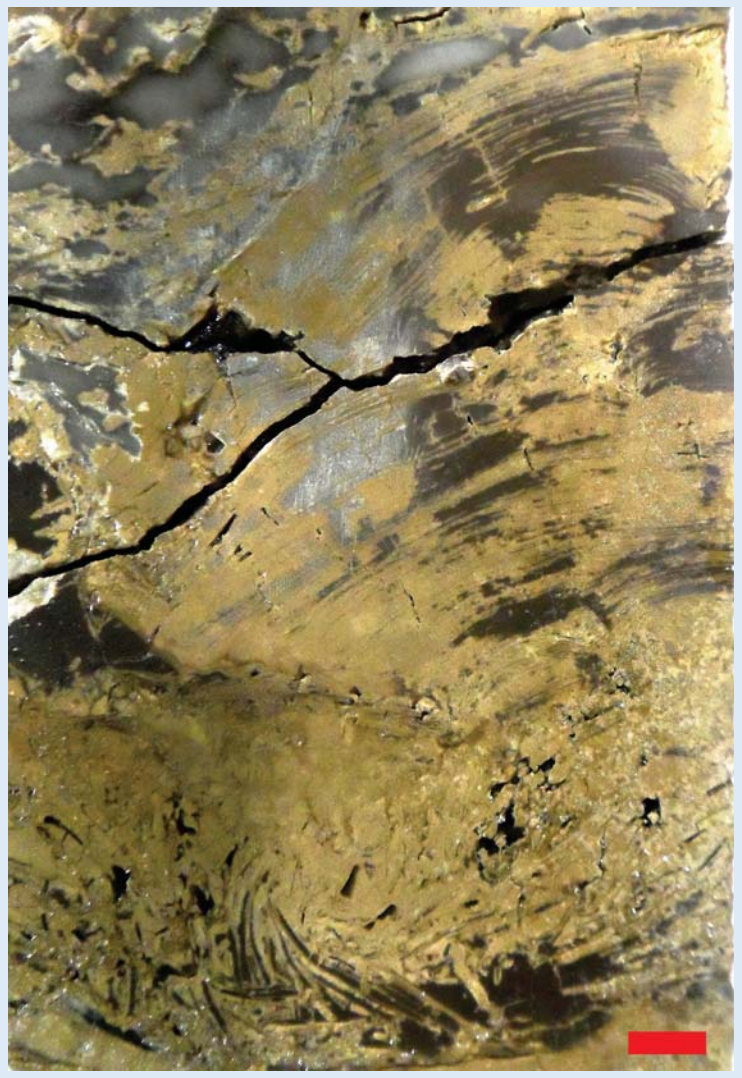


Figure 17: Domed stromatolite in the Salina D Unit. Note the disruption of the microbial laminations by growth of anhydrite nodules. Sample from the Willow Cavern #1 at 1757 ft. Scale bar = 1 cm.

Figure 18: Core photograph of the contact between the D Carbonate and the Upper D Salt. Core from the TB-7 test boring, Detroit International Bridge Crossing, Wayne Co. at a depth of 1252 ft. Scale bar = 1 cm.

Figure 19: Core sample from the Salina E Unit consisting of dolomitic carbonate mudstone and shaley carbonate mudstone with reddish brown salt filling secondary fractures and interbedded anhydrite nodules. Core from the TB-7 test boring, Detroit International Bridge Crossing, Wayne Co. at a depth of 1146 ft. Scale bar = 1 cm.

Figure 20: Selected Core intervals at the contact between the E and F Units. The upper E Unit consists of brecciated dolomudstones with fractures filled with secondary halite. Below this zone are dolomudstones with nodular anhydrites. Core interval from the TB-7 Detroit International Bridge Crossing, Wayne Co., MI.

Salina F and G Units

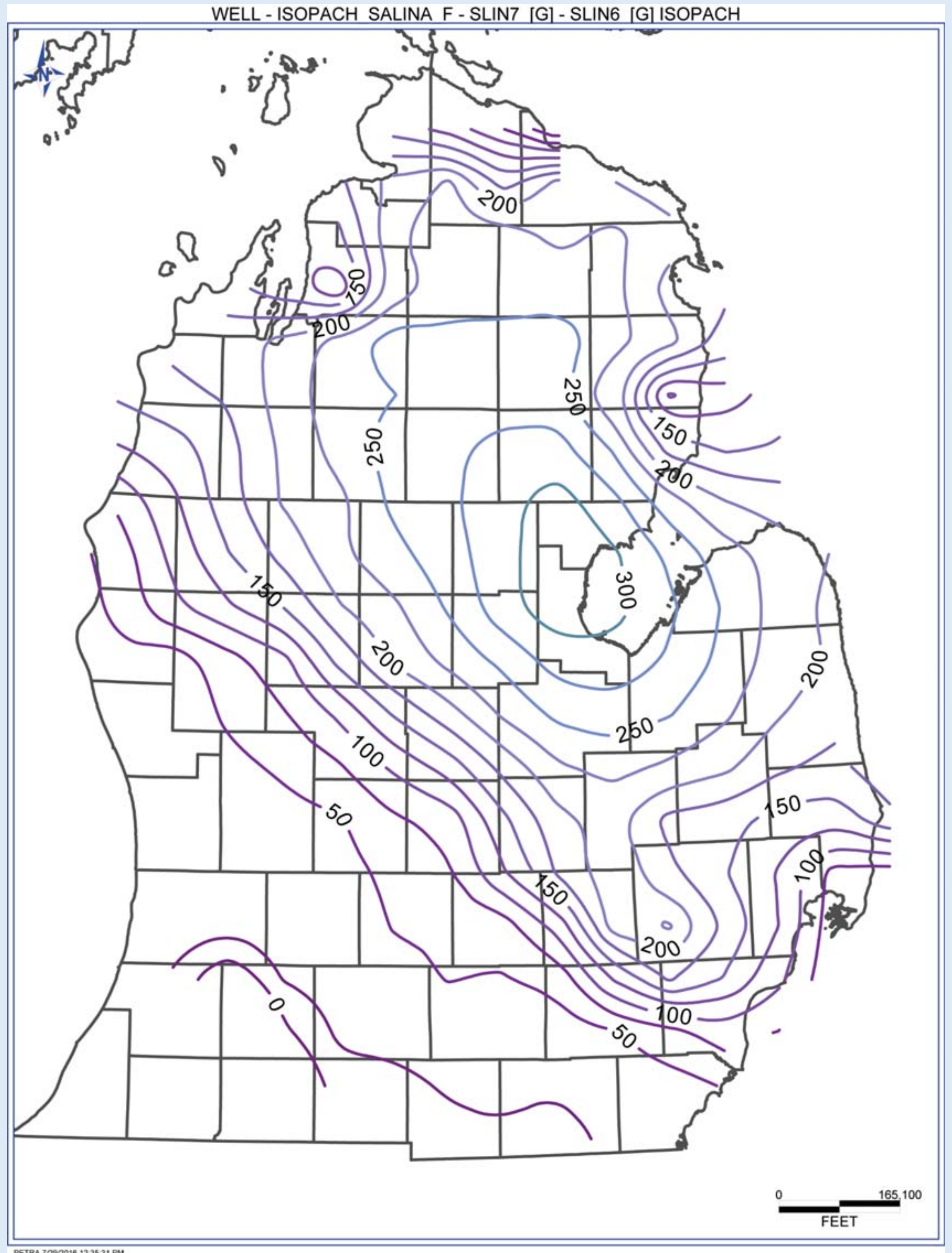


Figure 21: Isopach map for the Salina F Unit. Note the max depocenter was just west of Saginaw Bay. Contour interval = 50 m (164 ft)

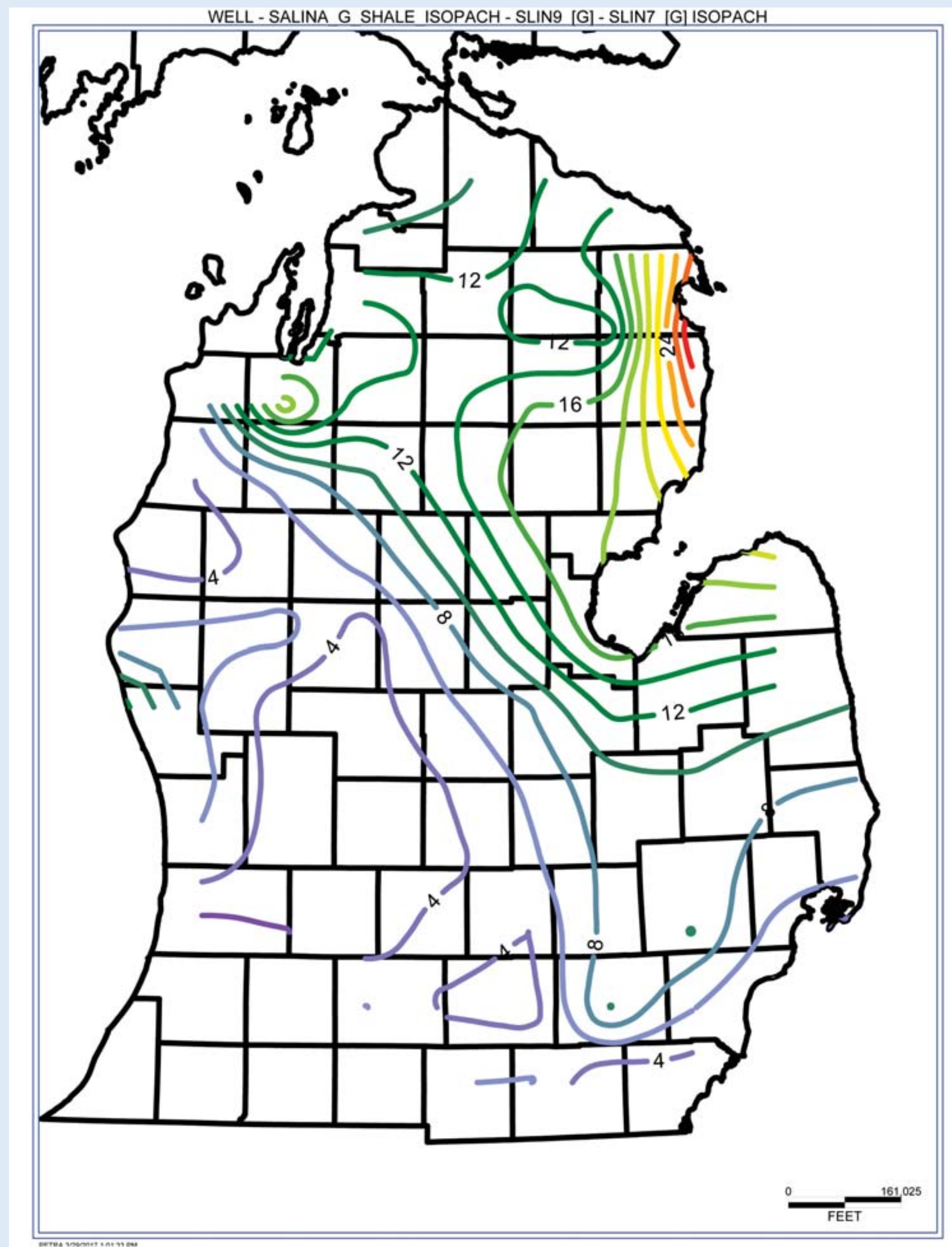


Figure 22 – Isopach map for the G Unit. Note the thickening of the G Shale towards the northeast. Contour interval = 2 m.

Figure 23: Selected Sample and Core Photographs from the F Unit. For all samples the scale bar is 2 cm.

A. Recrystallized rock salt with interbedded stringers of dolomite and anhydrite. 1,072 ft, Well TB-7, Detroit International Bridge Crossing, Wayne Co. MI.
B. Hand sample of coarsely recrystallized rock salt with thin-bedded anhydrite. Detroit Salt Mine, Wayne Co., MI.
C. Rock salt with interbedded dolomite and anhydrite. 1,124 ft., Well TB-7, Detroit International Bridge Crossing, Wayne Co. MI.
D. Coarsely-crystalline rock salt with dispersed organic matter. Lower interval consists of laminated and nodular anhydrite. 1,444 ft., Willow Cavern #1 (PN:26603), Washtenaw Co., MI.

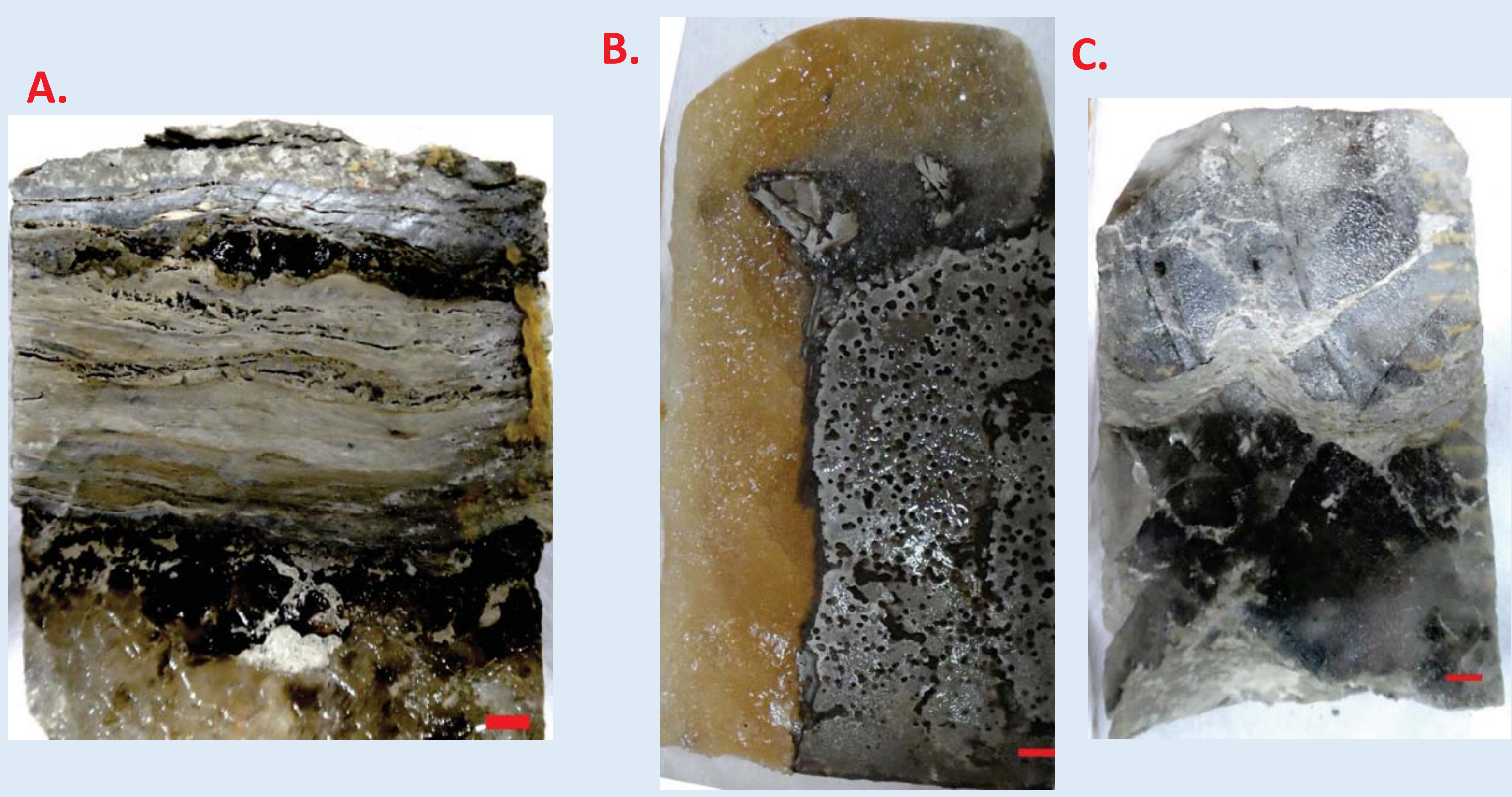


Figure 24– Selected Core Photographs of the F Unit from the Willow Cavern #1 (PN: 26603, Washtenaw Co., MI). For all samples, the scale bar = 1 cm.

A. Microbially-laminated dolomites overlying coarsely crystalline rock salt. Note the dark color of the disseminated organic matter in the salt. 1,477 ft.
B. Shaley dolomite with moldic porosity probably after halolites. Note the extensive fracture fill of secondary red halite. 1,492 ft.
C. Coarsely crystalline rock salt (in places preserving chevrons) with deformed microbially-laminated dolomite. 1,496 ft.

Figure 25: Contact of upper Pointe aux Chênes Formation with the Mackinac Breccia. The Salina Group outcrops in portions of the far southeastern Upper Peninsula in and around the town of St. Ignace. The Mackinac Breccia is interpreted as a collapse breccia from karsting of evaporites in the Salina.

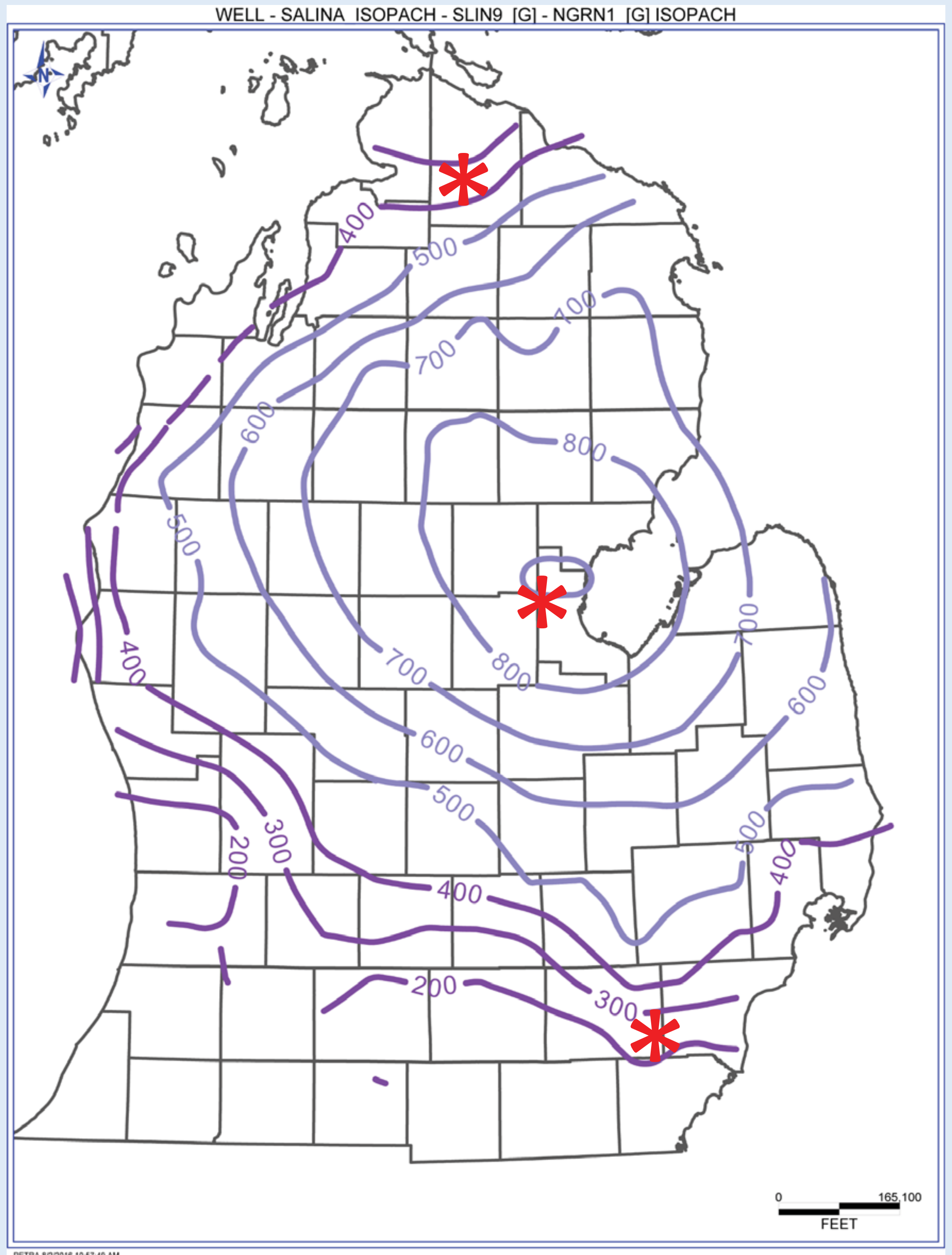
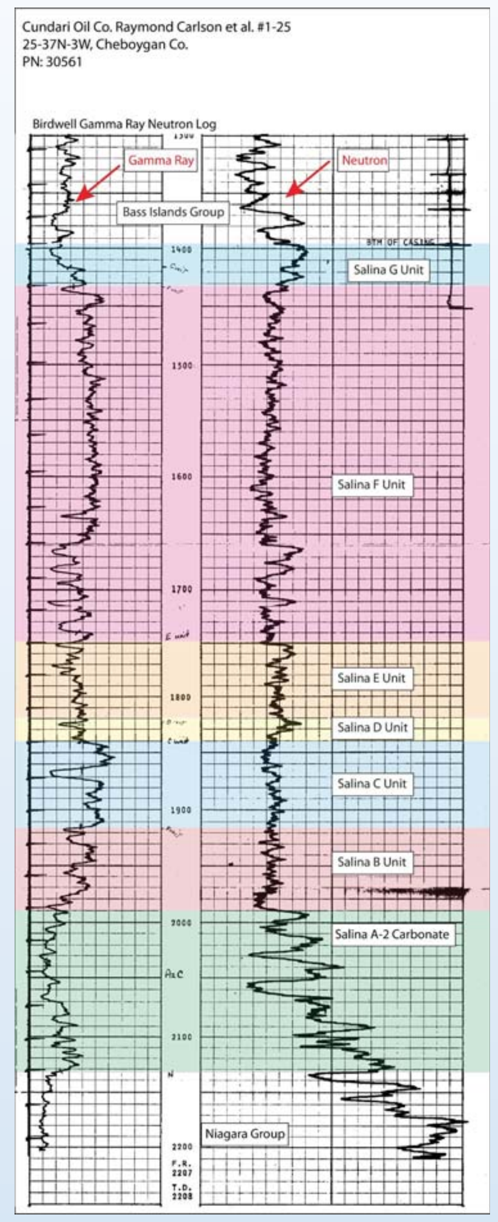
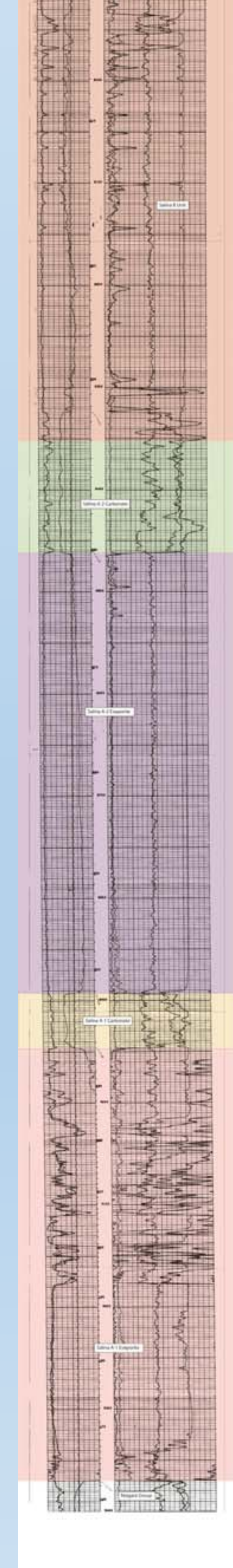


Figure 26: Isopach Map for the entire Salina Group. Note the maximum thickness is in the Saginaw Bay region. Position of the Willow Cavern #1 marked on the map. Symbols for the well locations are for the Willow Cavern #1 (Washtenaw County – southeastern Michigan), the Kielpinski #1-20 (northern Bay County, central eastern Michigan), and the Carlson et al. #1-25 (Cheboygan Co., northern Lower Peninsula) whose type logs are presented in the next figure.





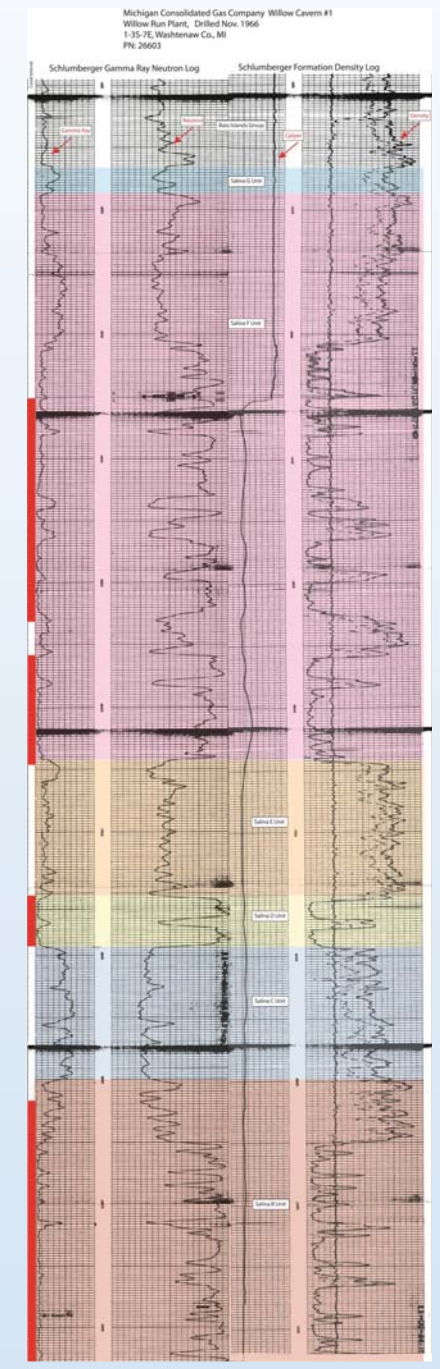


Figure 27: Type Logs for the Salina Group in the Lower Peninsula of Michigan. Formation nomenclature after Catacosinos et al. (2001).

Salina Unit	Thickness (ft)
G Shale	65
F Salt	1041
E Unit	164
D Salt	70
C shale	135
B Salt	517
A-2 Carbonate	109
A-2 Salt	432
A-1 Carbonate	54
A-1 Salt	423

Table 1 – Thicknesses of Salina units in the Kielpinski #1-20 well from northern Bay County. One of the few wells that penetrates the thickest Salina Group deposits.

Conclusions

- Salina Group has strong lithologic variability – complicated facies relationships – deserves a lot more attention.
- Ultimate Seal for lower Silurian reservoirs (Burnt Bluff Group, Niagara Group, Salina A-1 Unit)
- Significant Gas Storage Potential

Voice et al. 2017 References

Catacosinos, P. A., Harrison, W. B., III, Reynolds, R. F., Westjohn, D. B., and Wollensak, M. S., 2001, Stratigraphic Lexicon for Michigan, Bulletin, Geological Survey Division, Department of Environmental Quality and Michigan Basin Geological Society, Lansing, MI, v. 8, 56 p.

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