The Origin of Natural Fractures in the Antrim Shale, Michigan*

Murray M. Matson[1]

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Abstract

The Antrim Shale of the Michigan Basin is black organic shale that was deposited in the Late Devonian. The Antrim is the primary unconventional gas target in Michigan and is ranked number thirteen in term of gas volume in the United States. The shale produces from a depth ranging from 300 to 1800 feet in an area of northern Michigan where the Antrim is naturally fractured. The natural gas produced is believed to be biogenic in origin, formed by the influx of fresh water bacteria into the organically rich shale. Fresh waters most likely enter the Antrim outcrop, located immediately north of production, during time of glaciation. Numerous studies have concentrated on the source and generation of natural gas in the Antrim but no theory has adequately explained the localized presents of natural fractures.

The Antrim Shale is present though out most of the Michigan Basin. Extensive drilling in all areas of the Basin has proven that only a several county area of northern Michigan was naturally fractured enough to sustain gas production. Currently the most accepted theories for this localized fracturing are (1) Paleozoic tectonics related to the Mid-Continent Rift or Grenville Front; (2) post glaciation rebound; (3) hydraulic pumping; and (4) frost wedging. The first two of the theories (1 & 2) fail to explain the fractures localization since most of the Michigan Basin has been tectonically active and covered by thick glacial ice. The other two theories (3 & 4) do not define a mechanism for propagating the fractures over 30 miles south from the Antrim subcrop.

Depositional models and cross sections indicate that localized Antrim fracturing in northern Michigan is the result of extensive leaching of the Detroit River Salt below the Antrim. Fresh waters, introduced during Pleistocene glaciation have dissolved the upper Detroit River salts over a four county area resulting in collapse of the overlying beds. The more brittle shales such as the Norwood and

Lachine Members of the Antrim were more intensely fractured during the collapse. Natural fractures have been enhanced by structural flexures but the primary fractures result from collapse. County-wide A1 Salt dissolution in SW Michigan is an example of this process.

References

Gardner, W.C., 1974, Middle Devonian Stratigraphy and Depositional Environments in the Michigan Basin: Michigan Basin Geological Society Special Paper, No. 1, 139 p.

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Traverse City, MI

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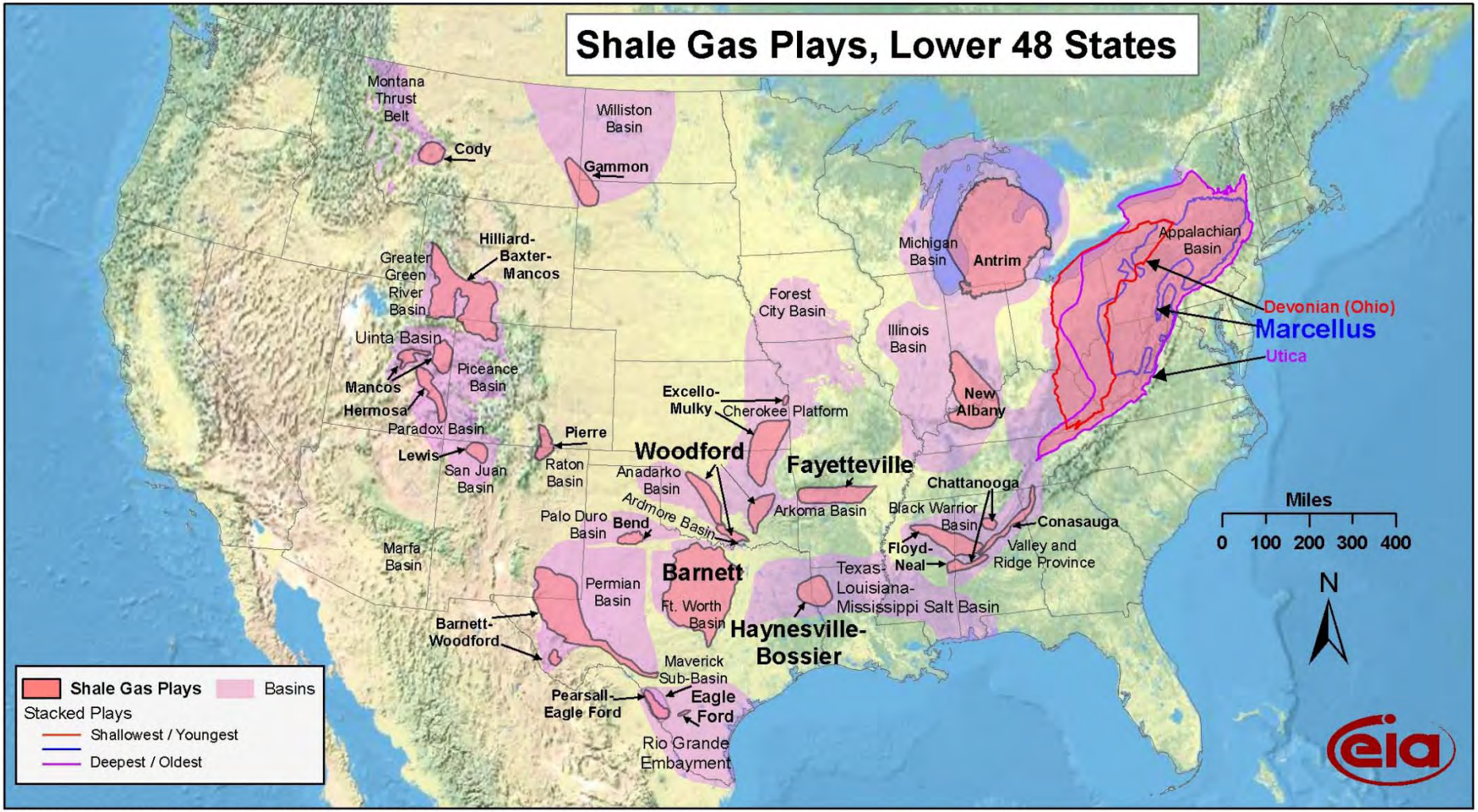


Source: Energy Information Administration based on data from various published studies.
Updated: March 10, 2010

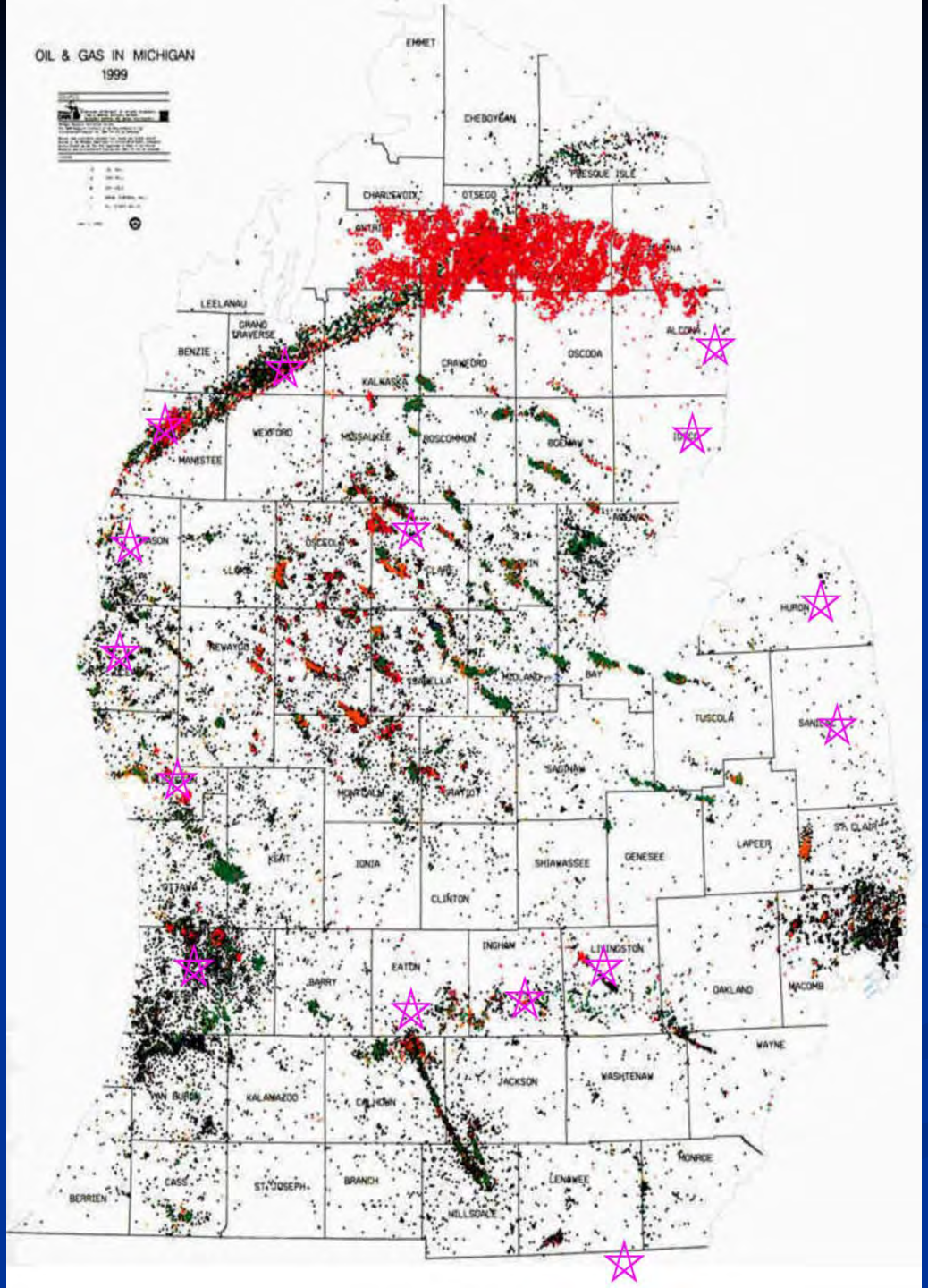
Important Components of Shale Plays

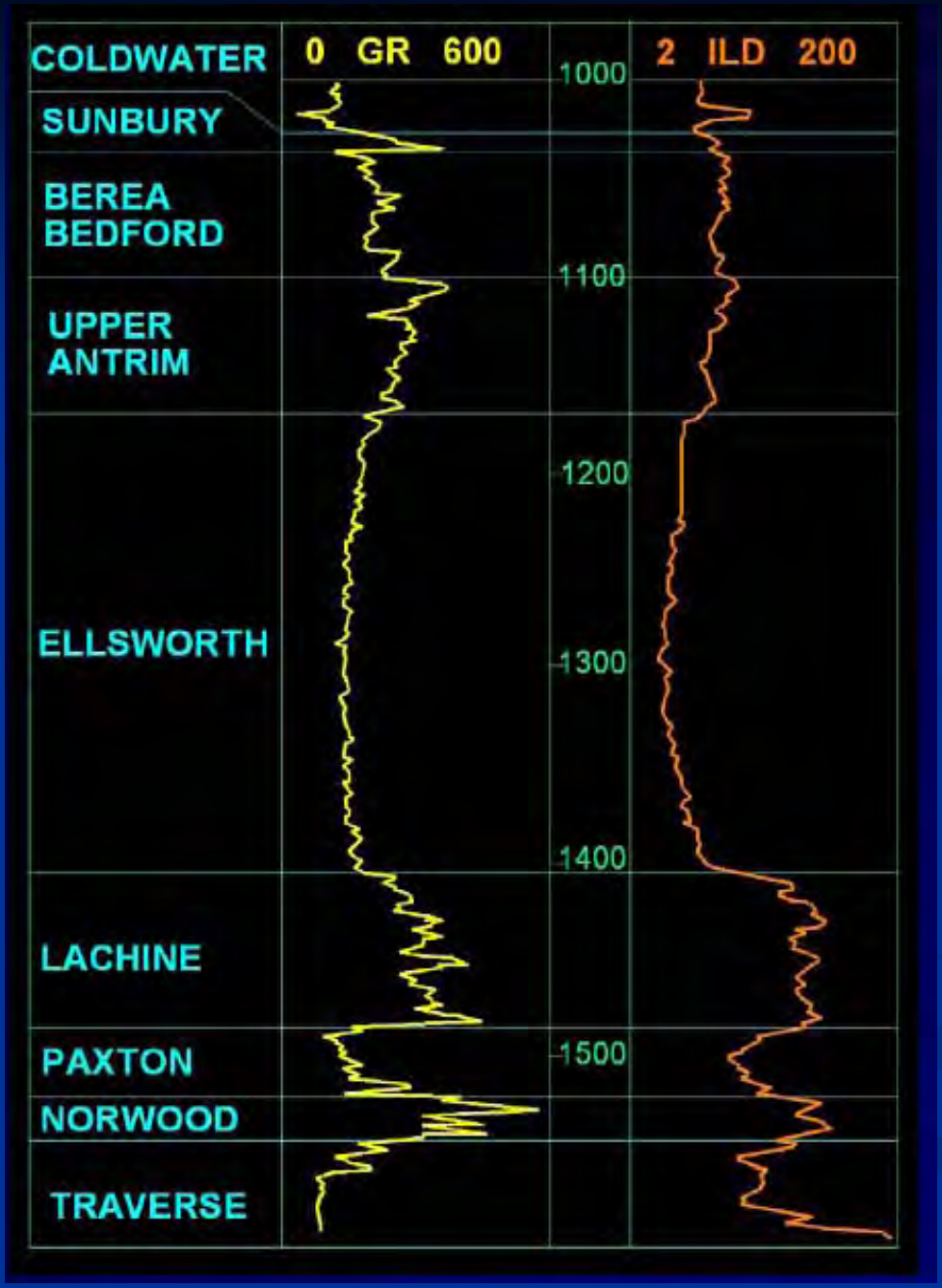
1) High Gas (organic) content.

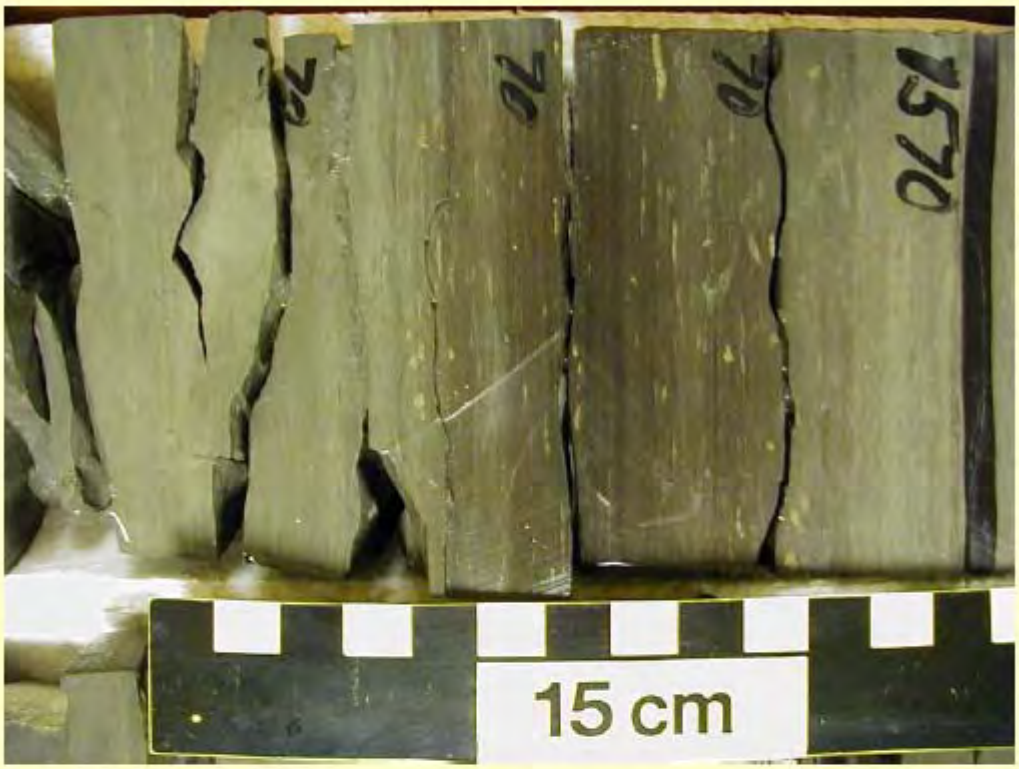
2) Brittle enough to be fraced efficiently.

3) Thick enough to have reserves and avoid fracing out of zone.

4)Existing natural fractures or porous interconnecting layers.


OIL & GAS IN MICHIGAN
1999
EMMET
CHEBOYGAN
PRESQUE ISLE
CHARLEVOIX
OTSEGO
ANTRIM
LEELANAU
GRAND TRAVERSE
BENZIE
CRAWFORD
OSCODA
ALCONA
KALKASKA
WEXFORD
MISSAUKEE
ROSCOMMON
OGEMAW
IOSCO
MANISTEE
MASON
OSCEOLA
LAKE
CLARE
GLADWIN
ARENAC
HURON
LOCKE
MIDLAND
BAY
TUSCOLA
SANILAC
SAGINAW
MONTCALM
GRATIOT
ST. CLAIR
KENT
IONIA
SHIAWASSEE
GENESEE
LAPEER
OTTAWA
CLINTON
INGHAM
LIVINGSTON
EATON
BARRY
OAKLAND
MACOMB
WAYNE
VAN BUREN
KALAMAZOO
CALHOUN
JACKSON
WASHTENAW
MONROE
BERRIEN
CASS
ST. JOSEPH
BRANCH
HILLSDALE
LENAWEE


COLDWATER
SUNBURY
BEREA
BEDFORD
UPPER
ANTRIM
ELLSWORTH
LACHINE
PAXTON
NORWOOD
TRAVERSE
0 GR 600
2 ILD 200
1000
1100
1200
1300
1400
1500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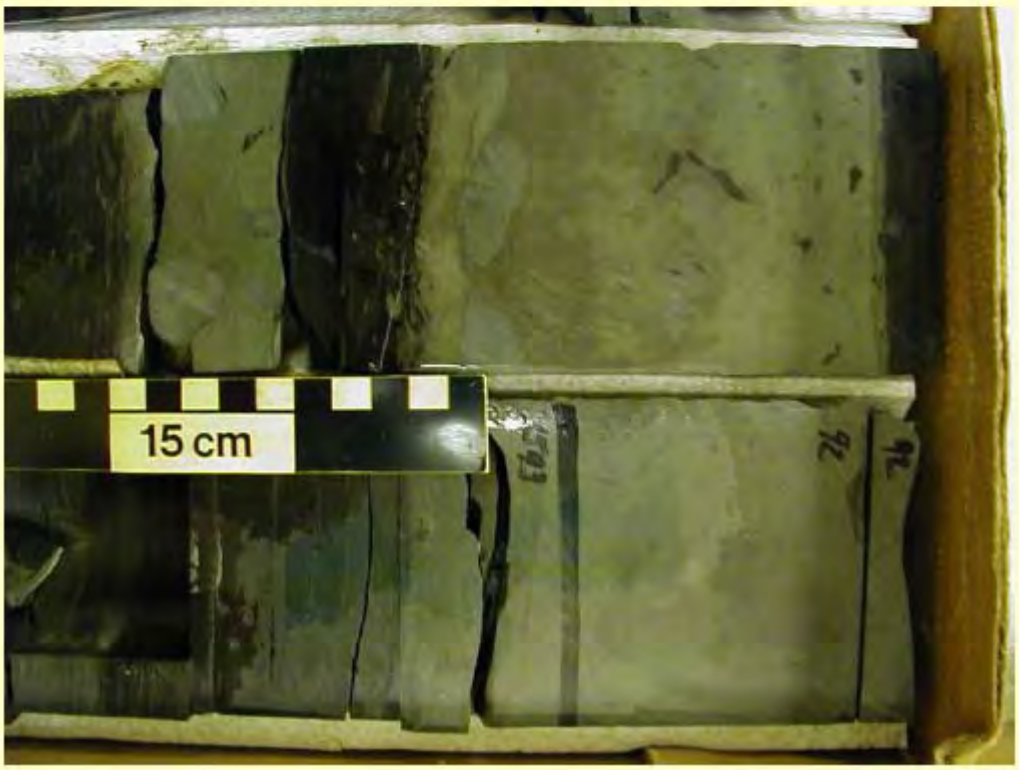
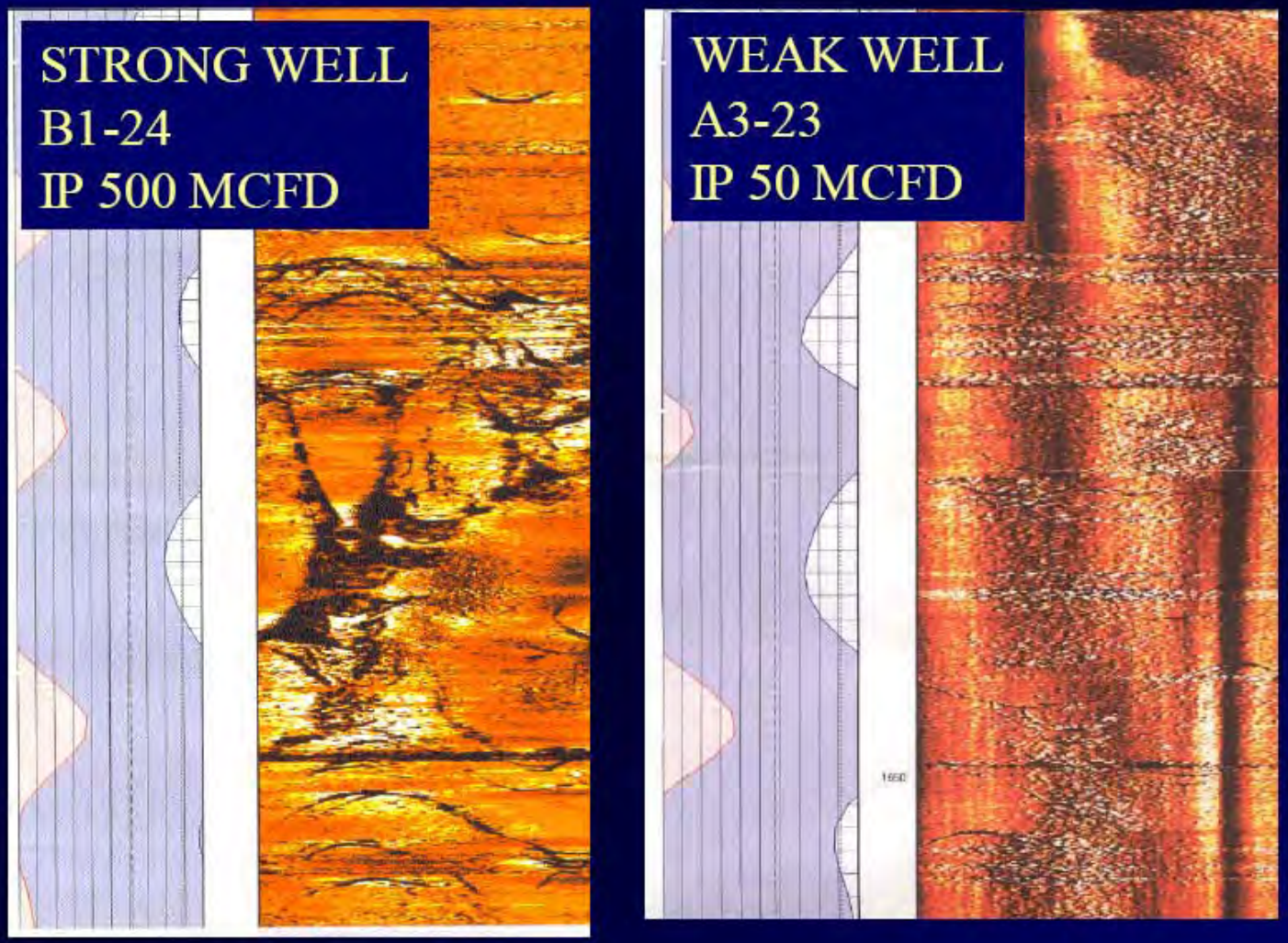
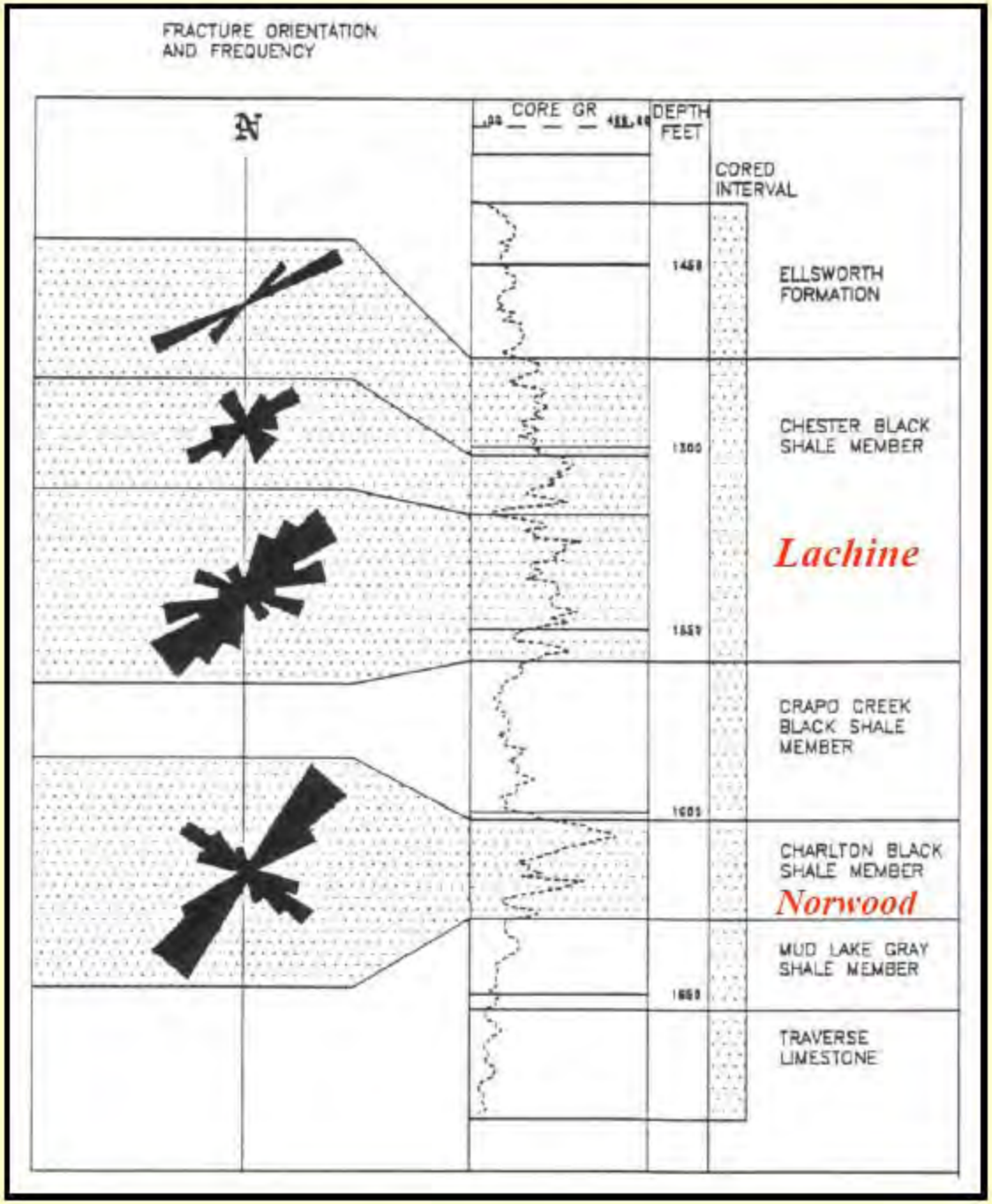

15 cm

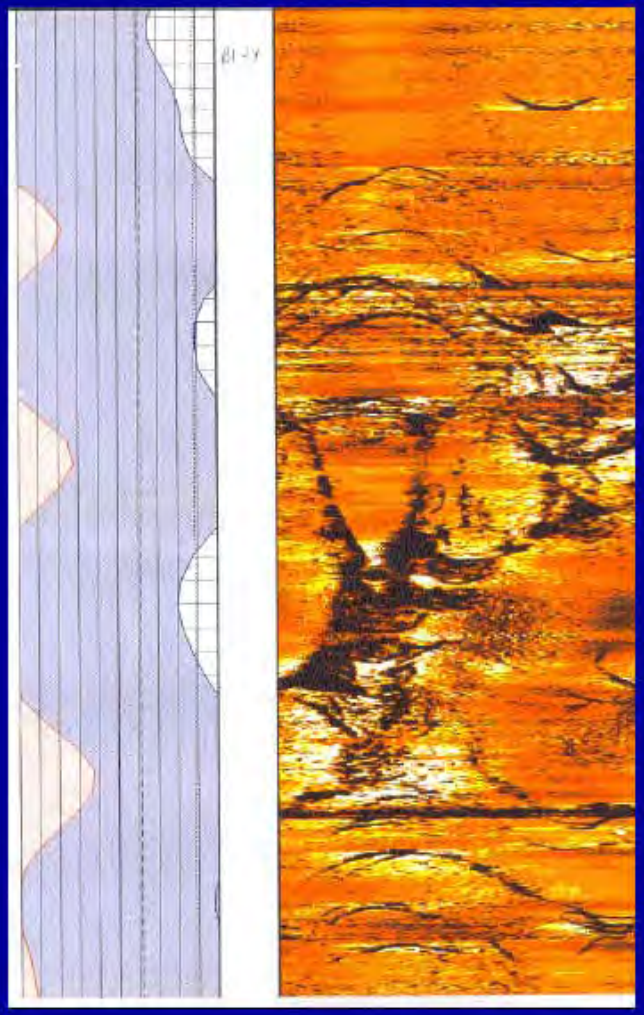

15 cm



Imaging Logs, MDC Big Wolf Lake Project
(CBIL, CAST, UBI Fracture I.D. Logs)


FRACTURE ORIENTATION
AND FREQUENCY
N
CORE GR
DEPTH
FEET
CORED
INTERVAL
1450
1500
1550
1600
1650
ELLSWORTH
FORMATION
CHESTER BLACK
SHALE MEMBER
Lachine
CRAPO CREEK
BLACK SHALE
MEMBER
CHARLTON BLACK
SHALE MEMBER
Norwood
MUD LAKE GRAY
SHALE MEMBER
TRAVERSE
LIMESTONE

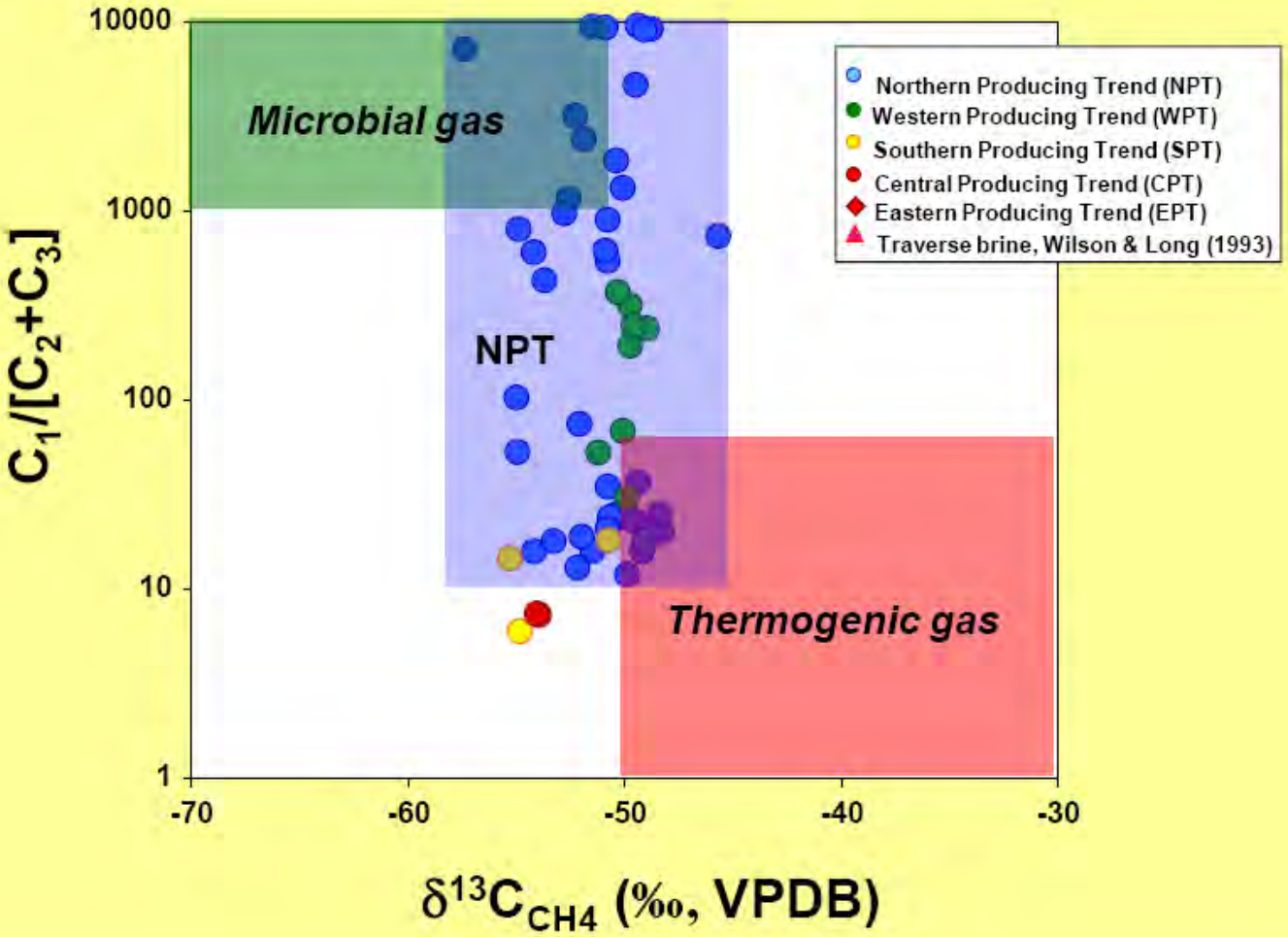
Whither the Fractures?

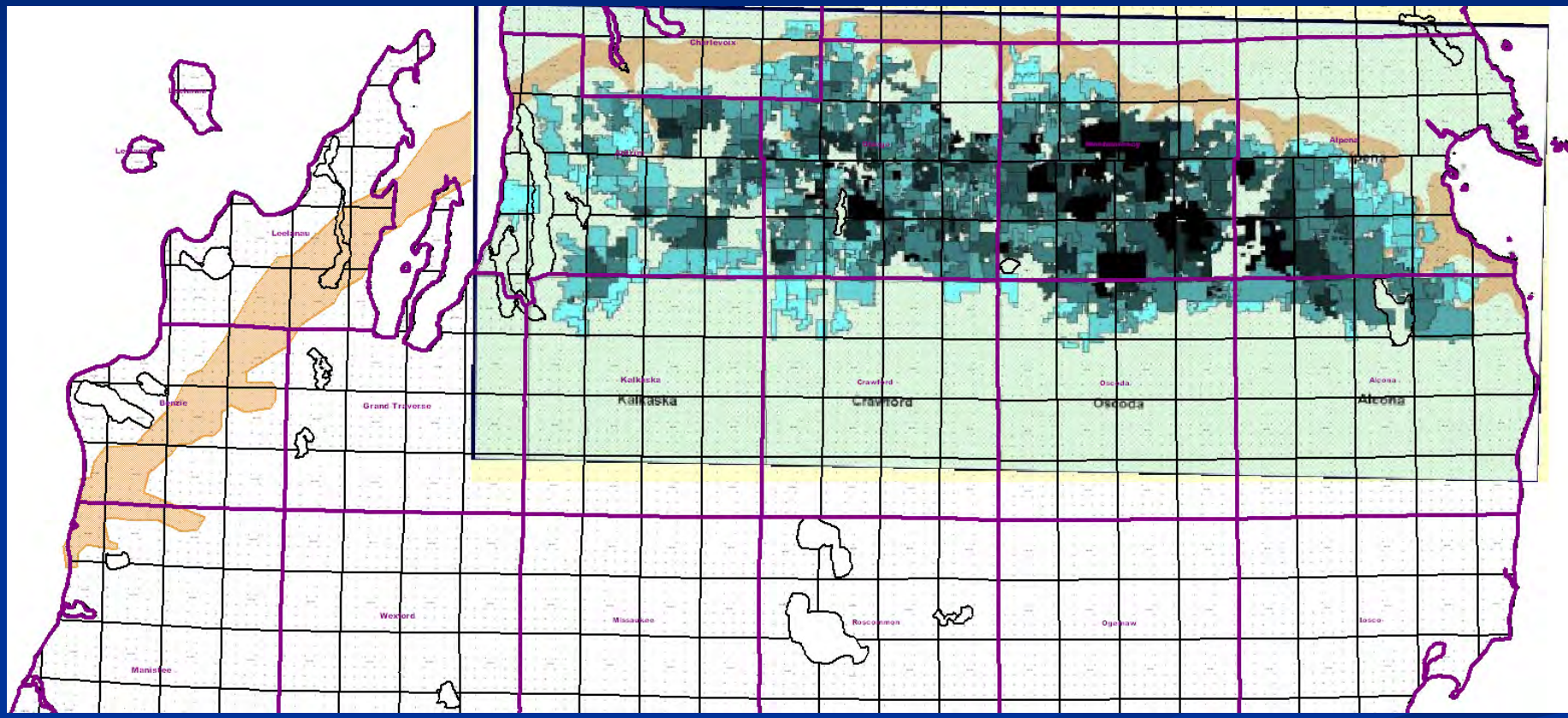


- Terrane Boundaries (NE-SW)(Grenville Front)
- Mid-Continent Rift (NW-SE)
- Paleozoic Tectonics (Chiefly NW-SE)
- Post-Glacial Isostatic Rebound (Enhanced Near Subcrop)
- Hydraulic Pumping
- Dissolution of underling Detroit River Salt

Antrim Shale Gas Composition

Martini

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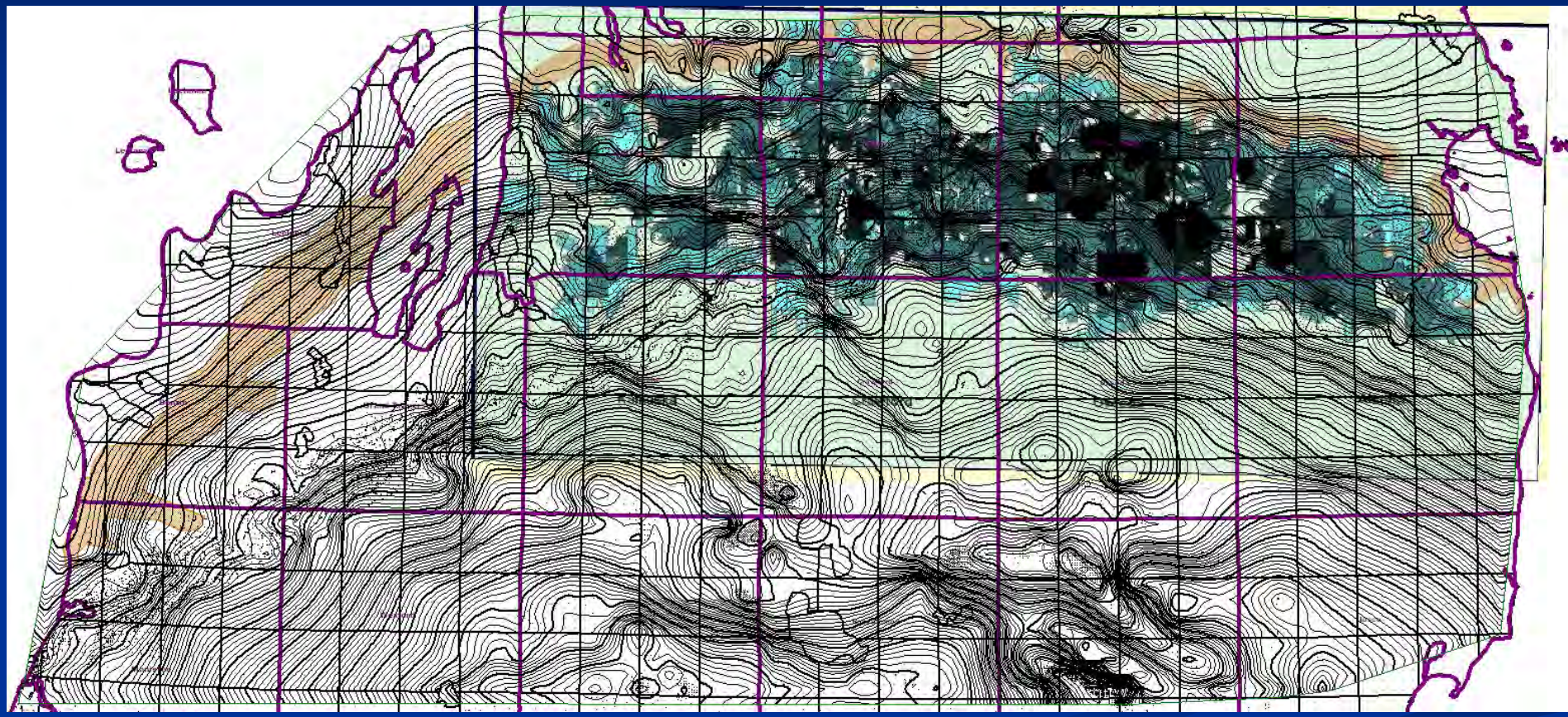
Leelanau
Benzie
Grand Traverse
Kalkaska
Crawford
Oscoda
Alcona
Wexford
Missaukee
Roscommon
Ogemaw
Iosco
Manistee

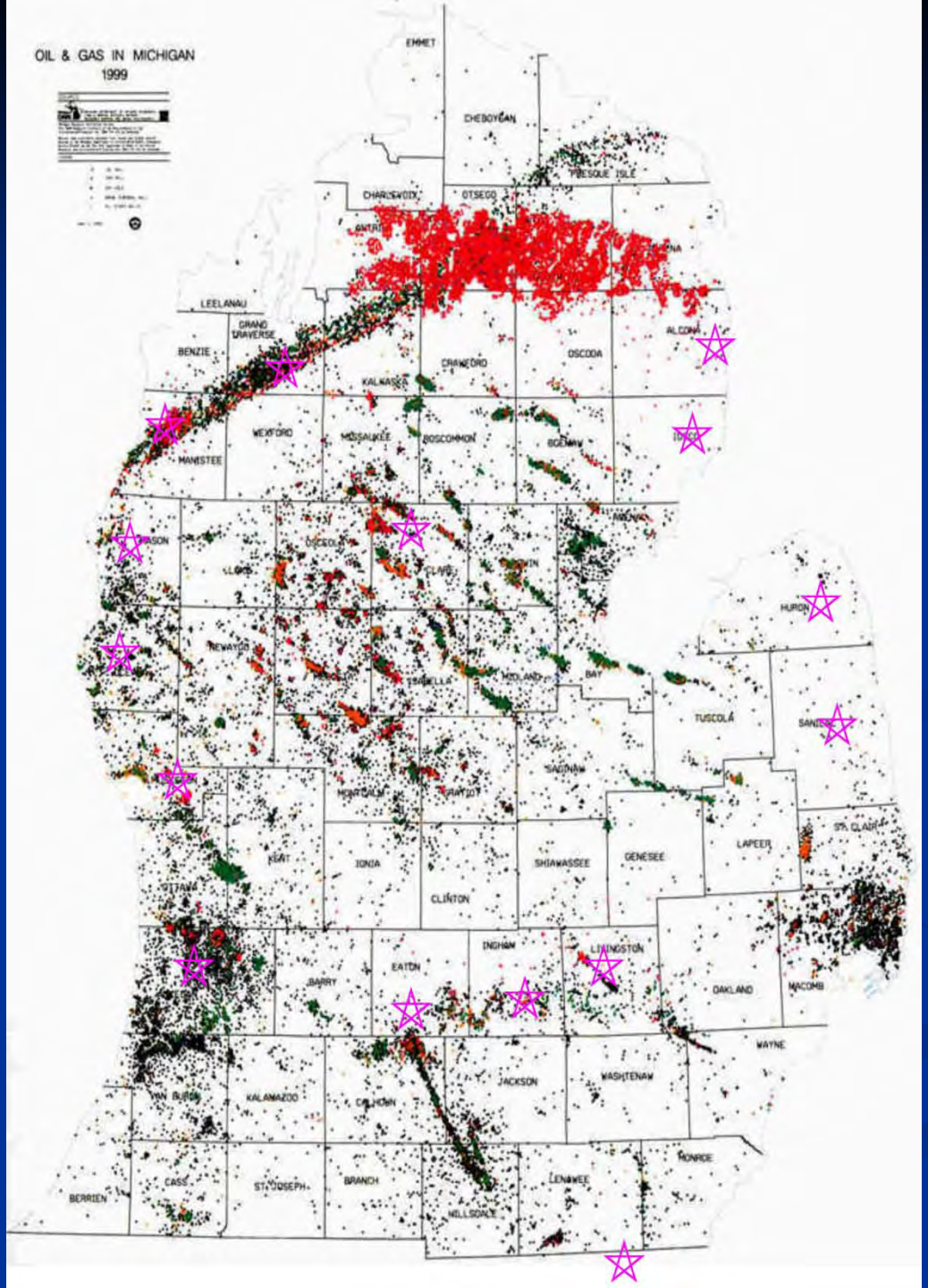
Origin of Natural Factures in Antrim

1) Dissolution of Upper Detroit River Salt and subsequent collapse of overlying strata.

2) Minor influence from tectonic deformation.

Traverse Lime Structure




OIL & GAS IN MICHIGAN
1999
EMMET
CHEBOYGAN
PRESQUE ISLE
CHARLEVOIX
OTSEGO
ANTRIM
LEELANAU
GRAND TRAVERSE
BENZIE
CRAWFORD
OSCODA
ALCONA
KALKASKA
WEXFORD
MISSAUKEE
ROSCOMMON
OGEMAW
IOSCO
MANISTEE
MASON
OSCEOLA
LAKE
CLARE
GLADWIN
ARENAC
HURON
LOCKE
MIDLAND
BAY
TUSCOLA
SANILAC
SAGINAW
MONTCALM
GRATIOT
ST. CLAIR
KENT
IONIA
SHIAWASSEE
GENESEE
LAPEER
OTTAWA
CLINTON
INGHAM
LIVINGSTON
EATON
BARRY
OAKLAND
MACOMB
WAYNE
VAN BUREN
KALAMAZOO
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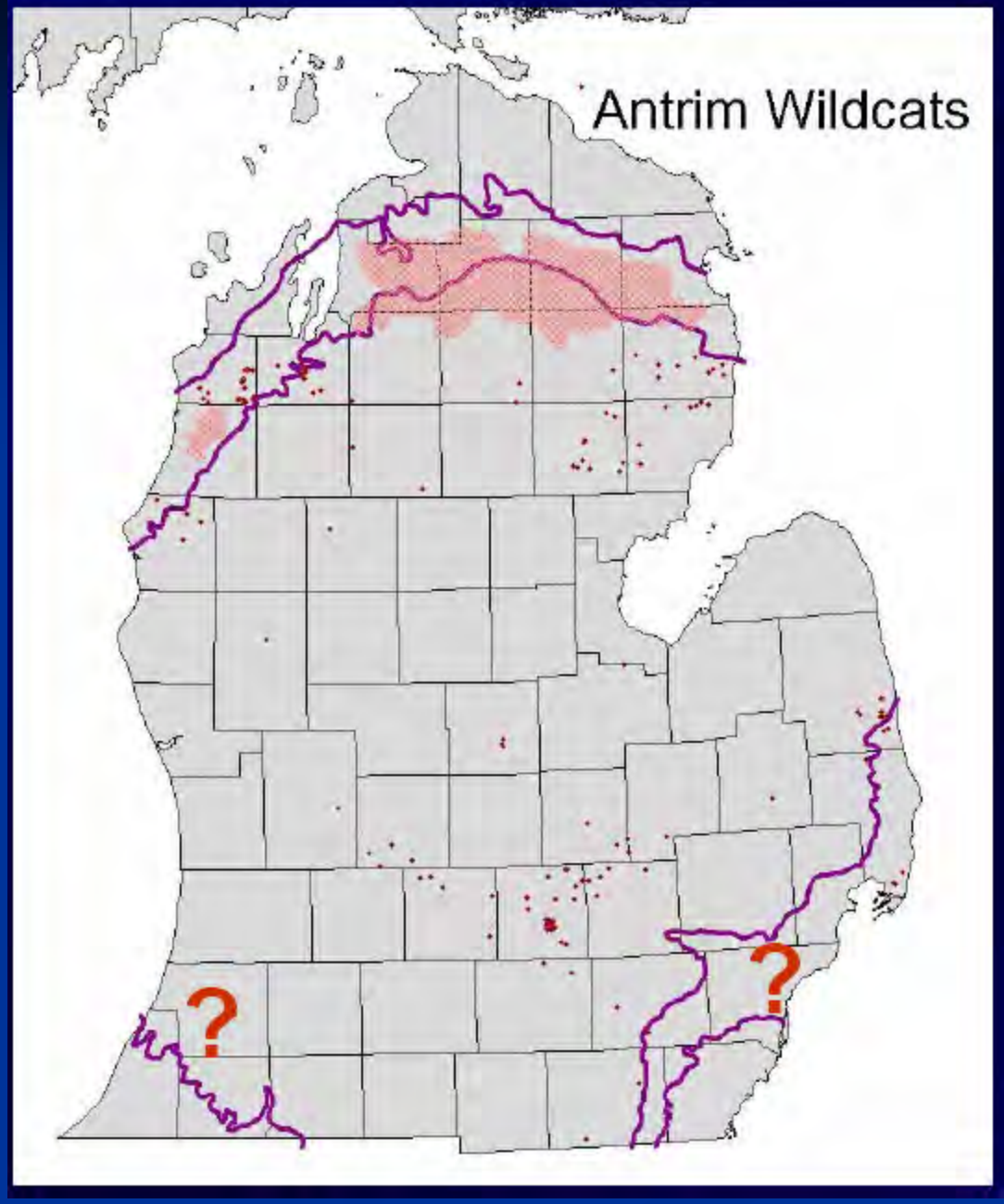
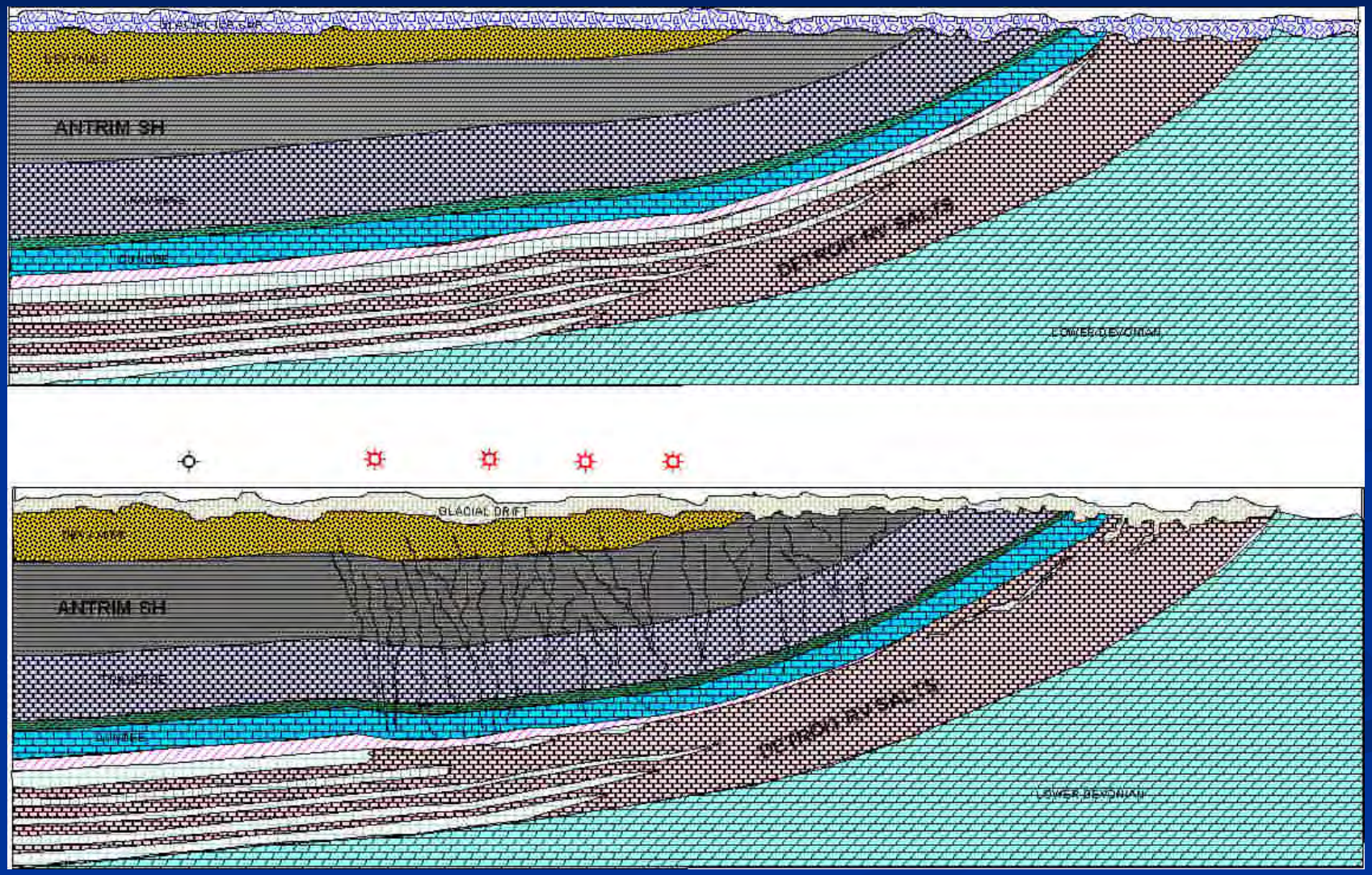
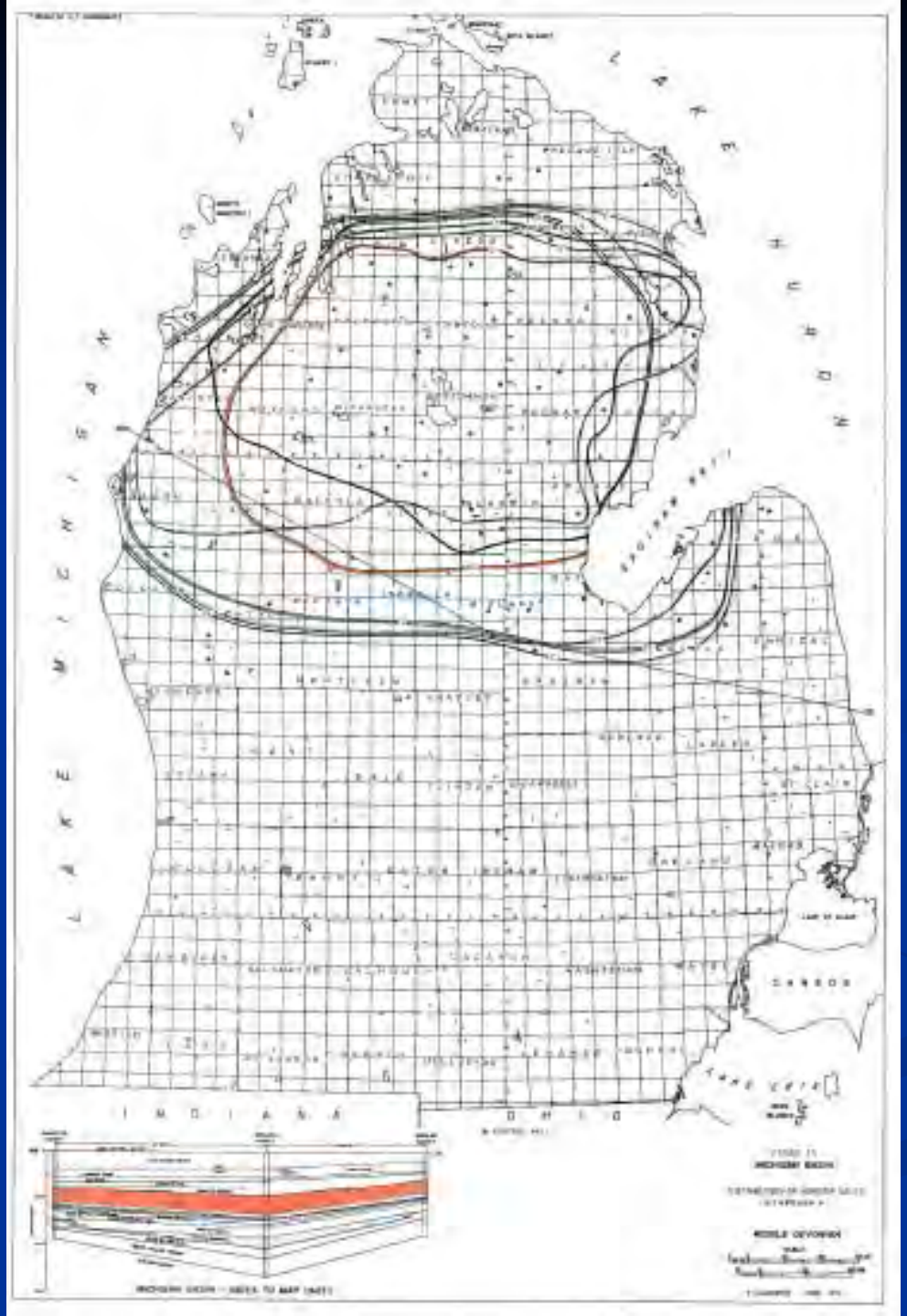
MONROE
BERRIEN
CASS
ST. JOSEPH
BRANCH
HILLSDALE
LENAWEE


Antrim Wildcats
?
?

DETROIT RIVER SALT COLAPSE MODEL





Detroit River Salts
A-H

Weston Gardner 1974

PN028546

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GARLAND 1
330 FSL 990 FEL/SE
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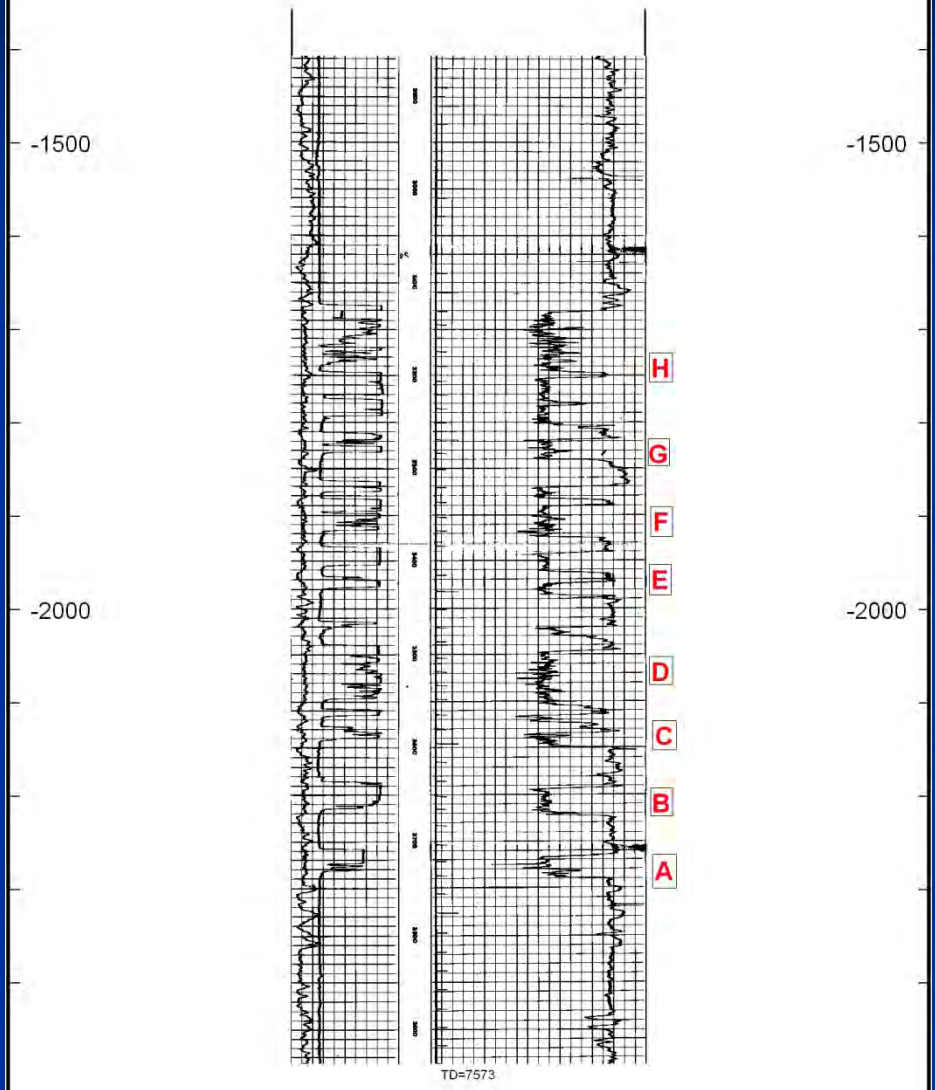
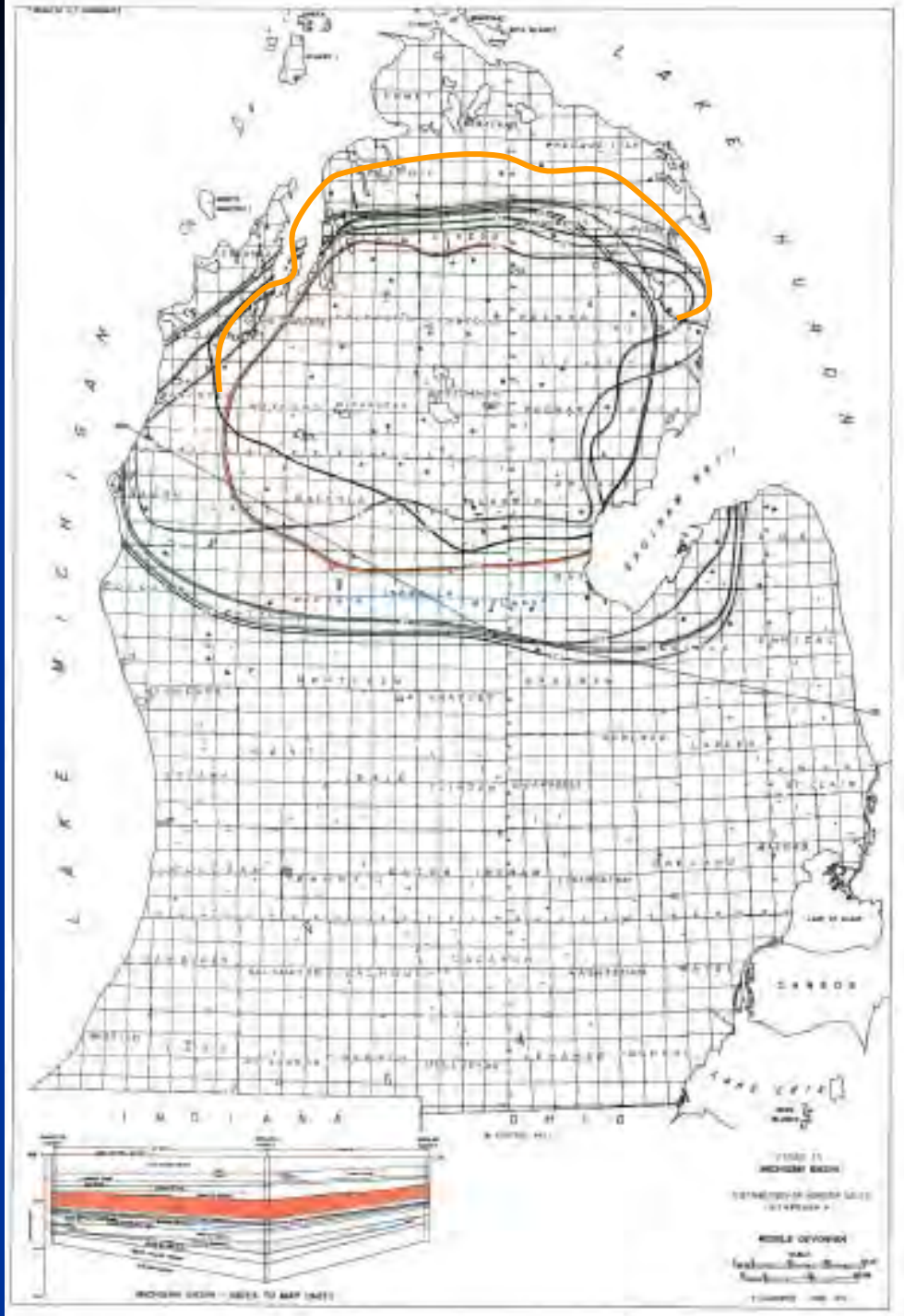
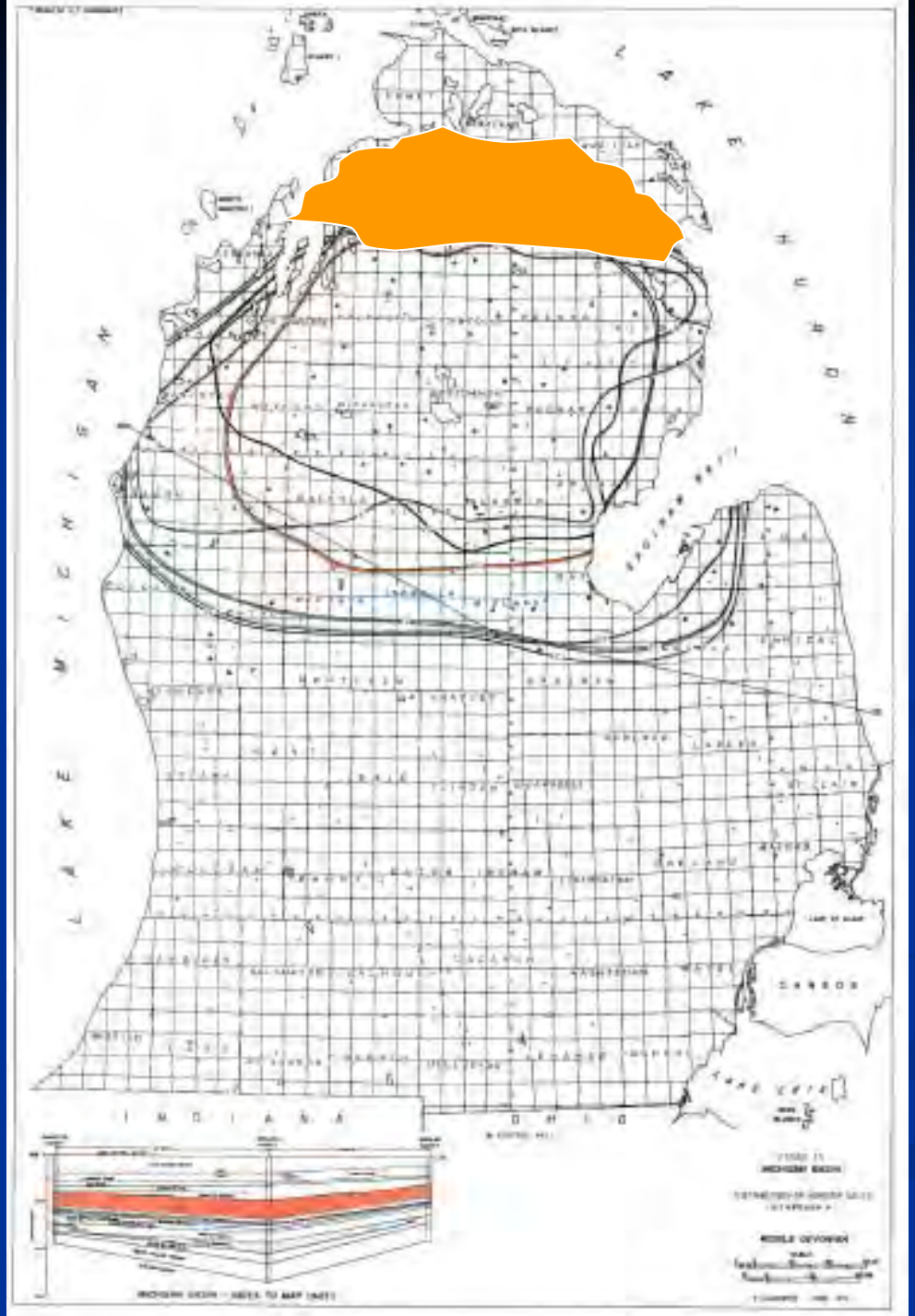



L A K E
M I C H I G A N
I N D I A N A
O H I O
CANADA
ONTARIO
MICHIGAN BASIN
MIDDLE DEVONIAN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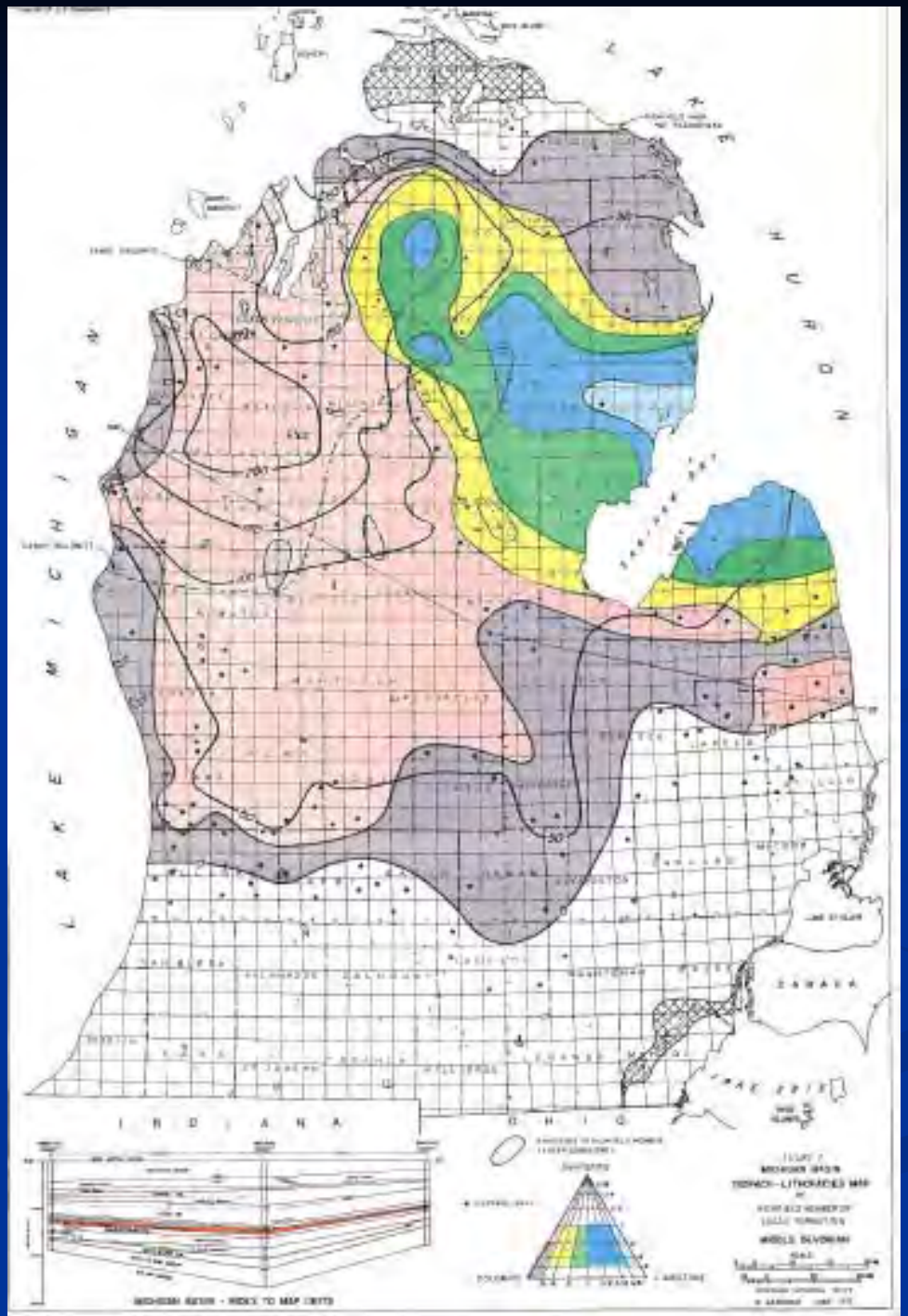
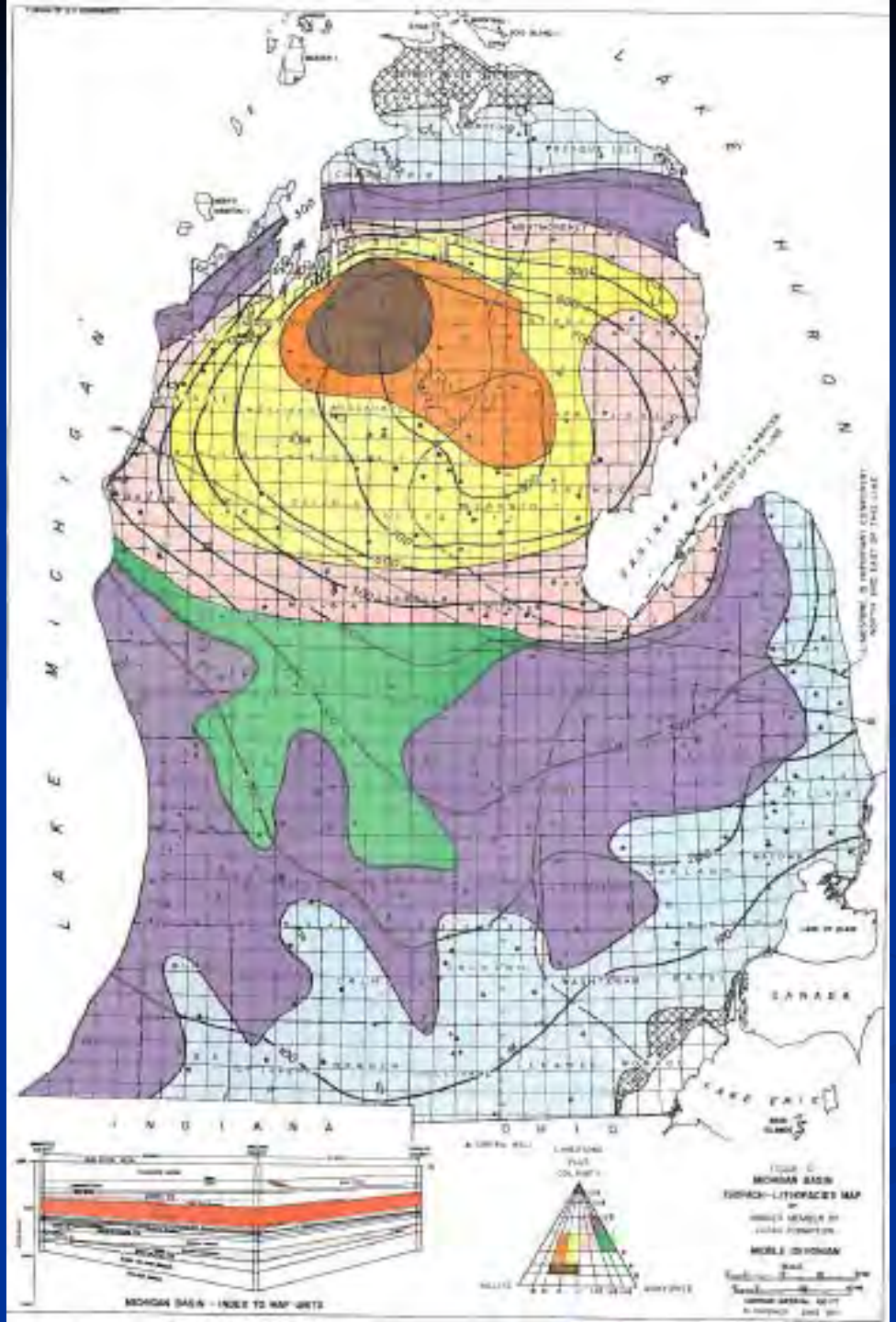
LAKE HURON
INDIANA
OHIO
CANADA



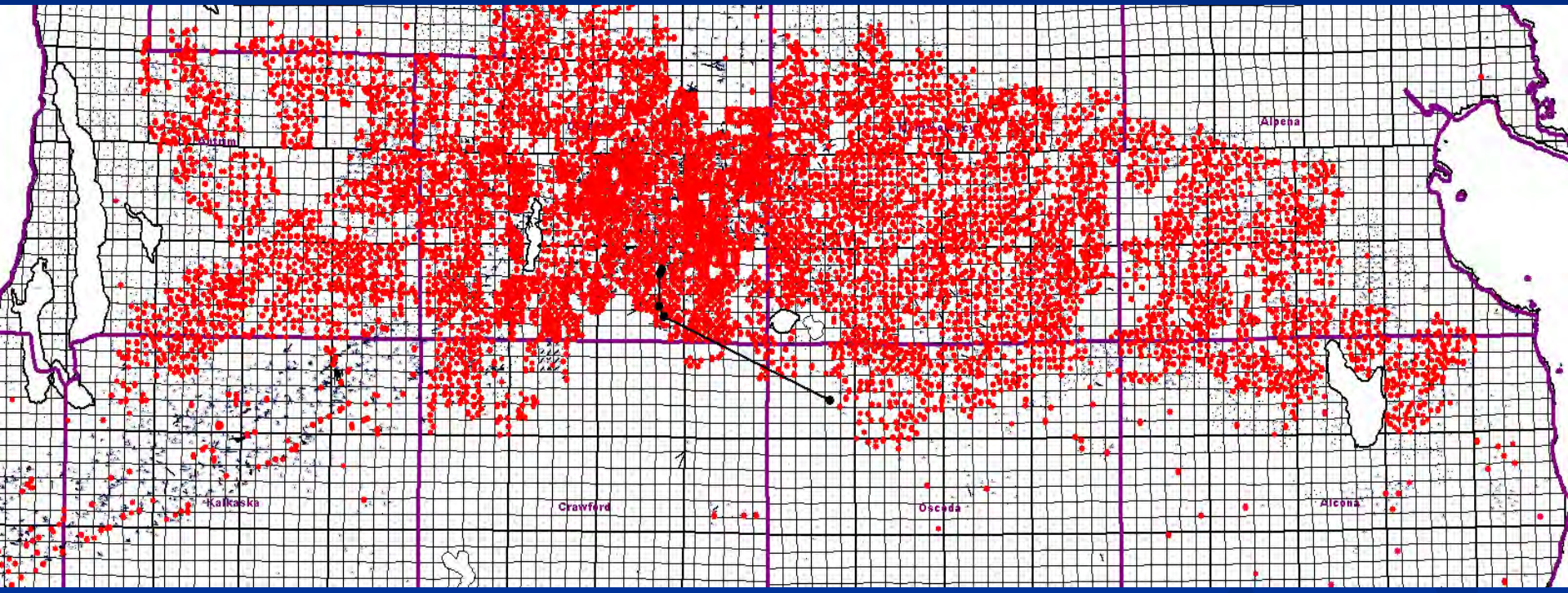
Richfield Deposition

Weston Gardner 1974

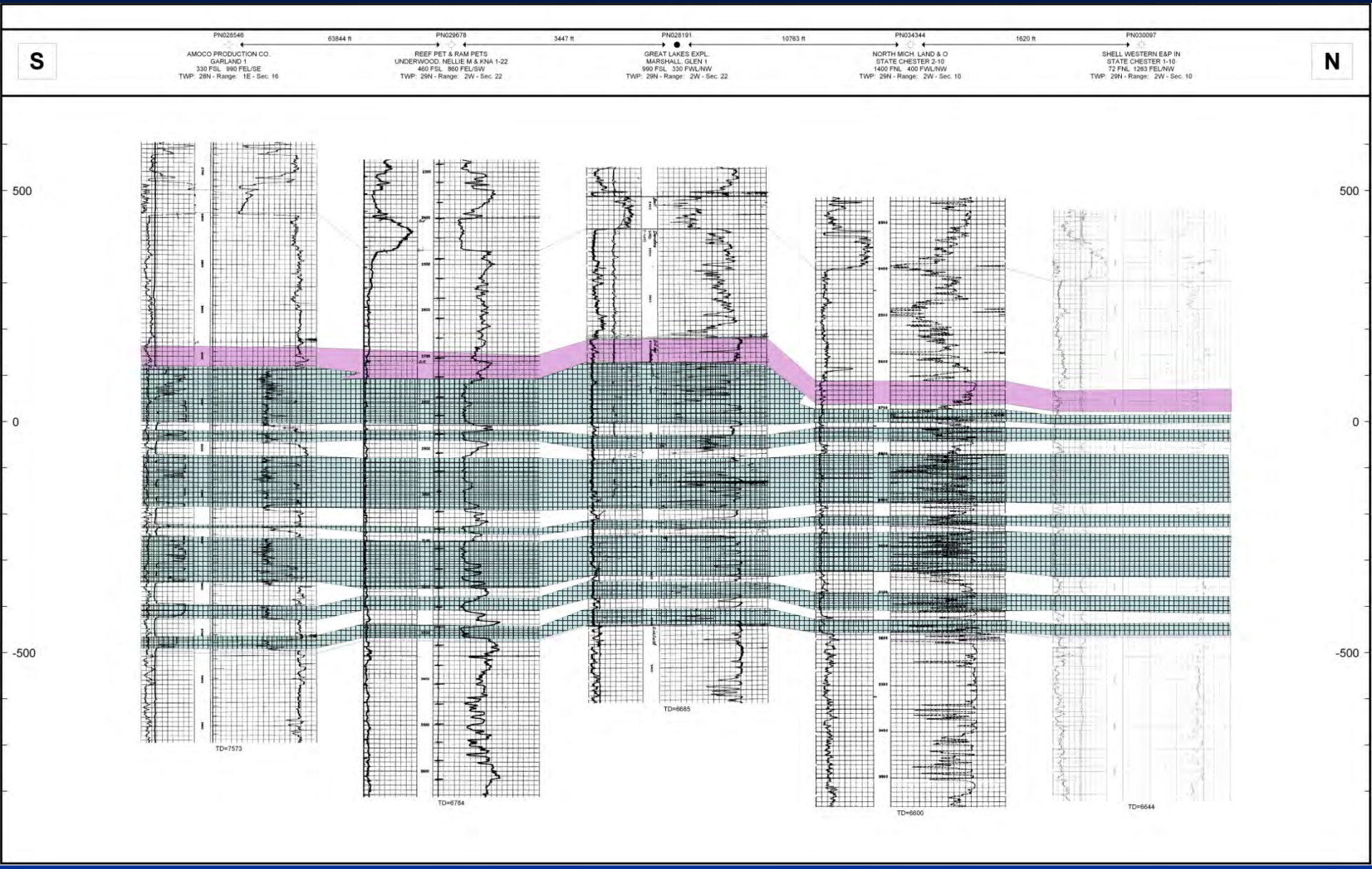


Detroit River Total Deposition

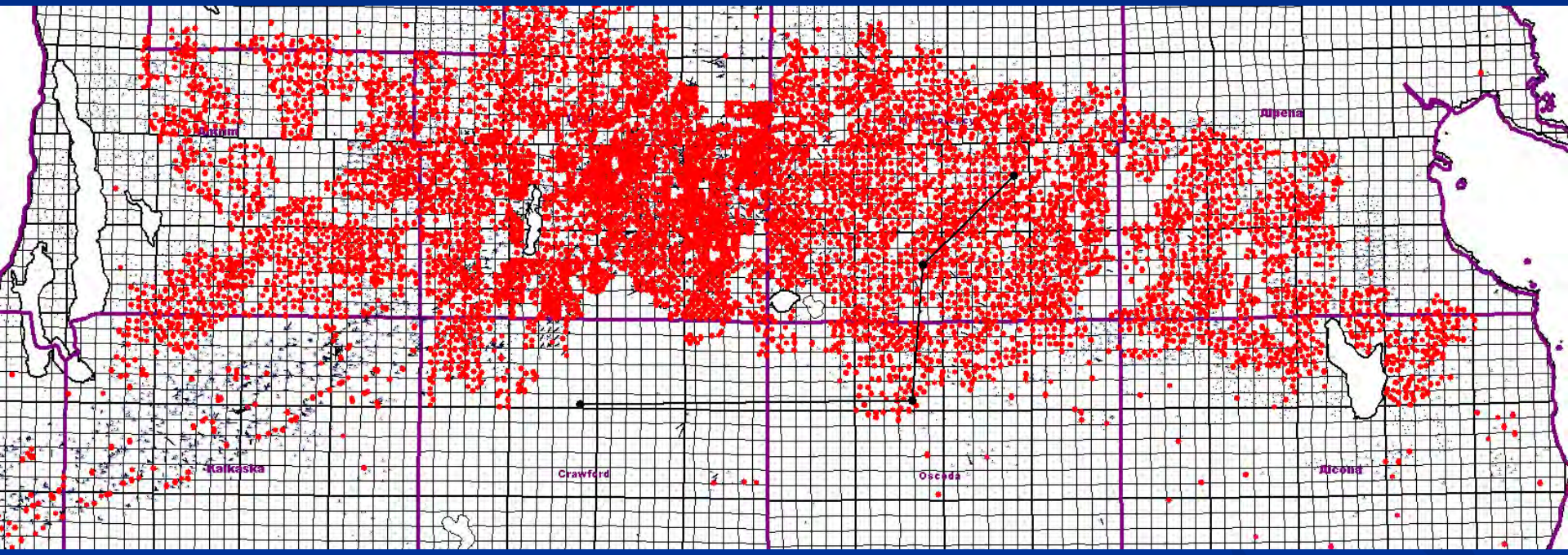
Weston Gardner 1974



Otsego N S


S
N
PN028546
AMOCO PRODUCTION CO.
GARLAND 1
330 FSL 990 FEL/SE
TWP: 28N - Range: 1E - Sec. 16
63844 ft
PN029678
REEF PET & RAM PETS
UNDERWOOD, NELLIE M & KNA 1-22
460 FSL 860 FEL/SW
TWP: 29N - Range: 2W - Sec. 22
3447 ft
PN028191
GREAT LAKES EXPL.
MARSHALL, GLEN 1
990 FSL 330 FWL/NW
TWP: 29N - Range: 2W - Sec. 22
10763 ft
PN034344
NORTH MICH. LAND & O
STATE CHESTER 2-10
1400 FNL 400 FWL/NW
TWP: 29N - Range: 2W - Sec. 10
1620 ft
PN030097
SHELL WESTERN E&P IN
STATE CHESTER 1-10
72 FNL 1263 FEL/NW
TWP: 29N - Range: 2W - Sec. 10
500
0
-500
TD=7573
TD=6784
TD=6685
TD=6600
TD=6644

Otsego N S



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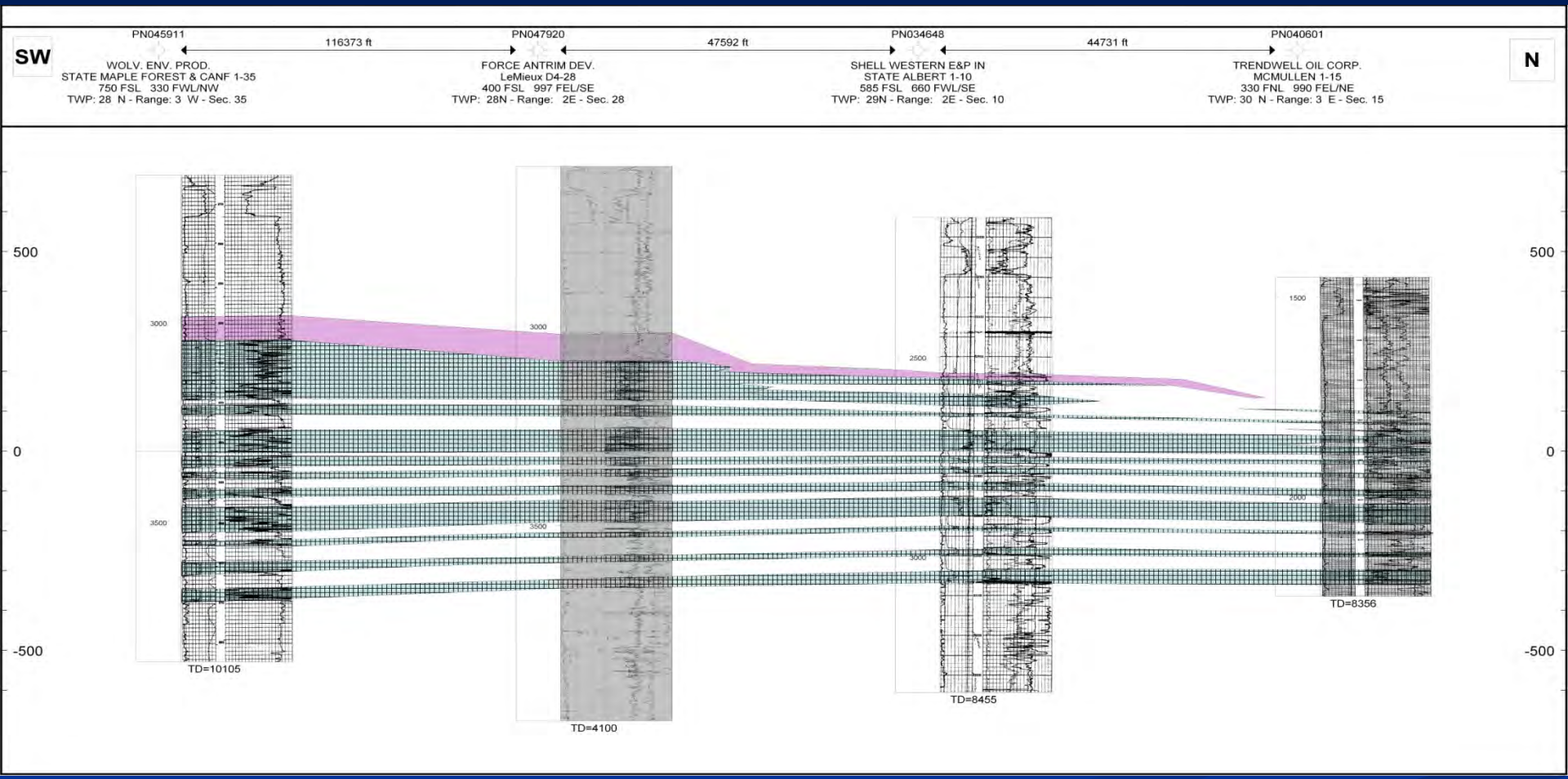

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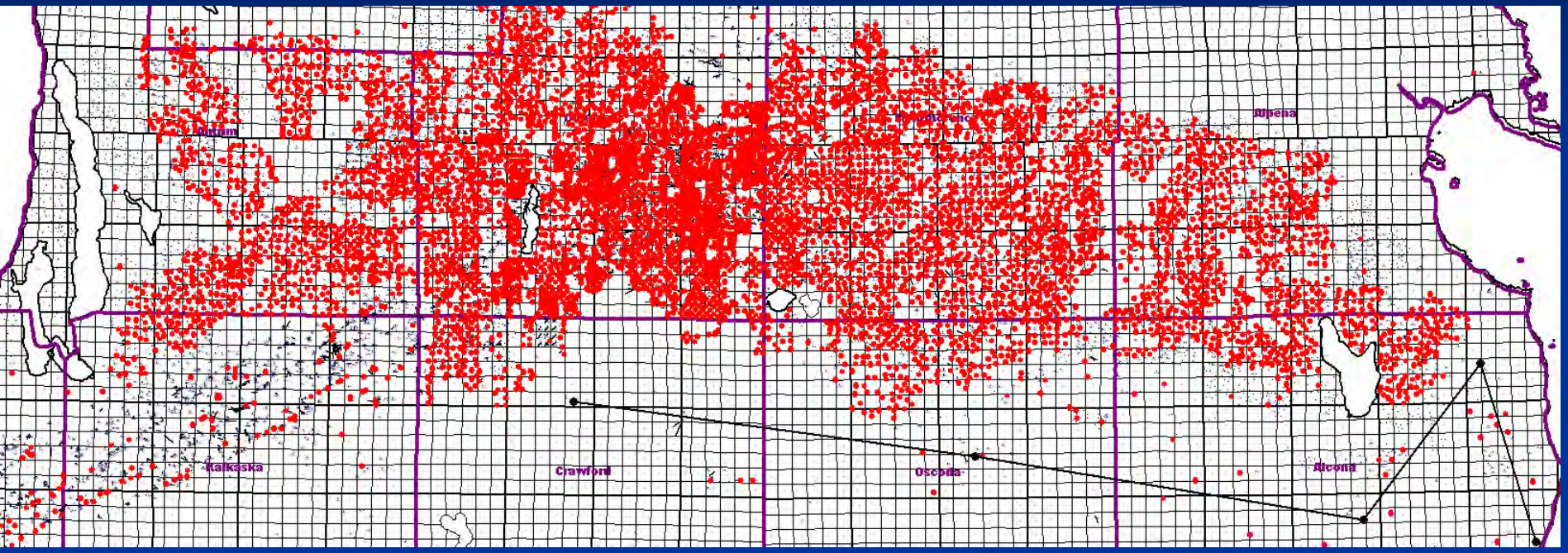
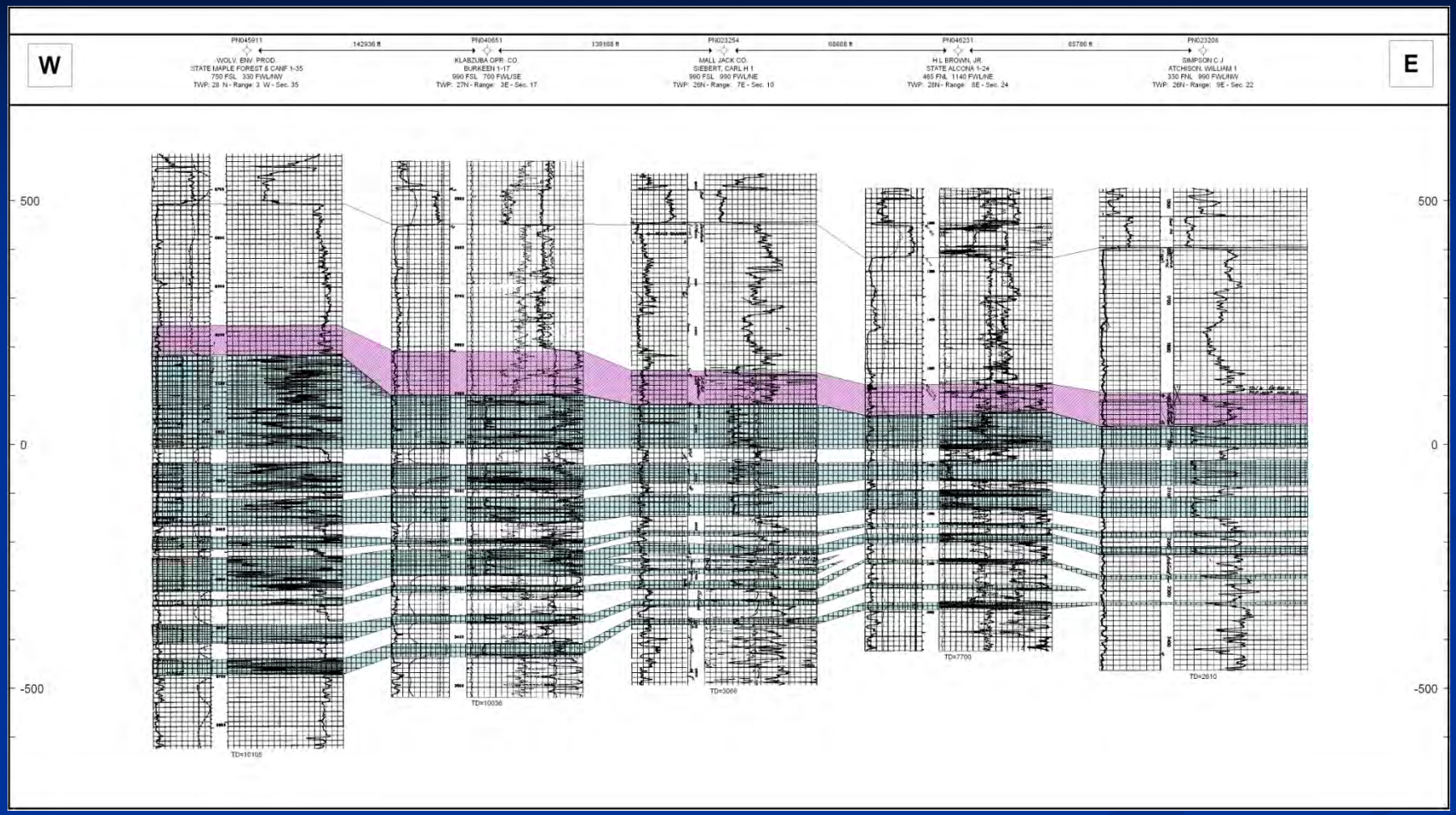


Alcona W E


W
E
PN045911
WOLV. ENV. PROD.
STATE MAPLE FOREST & CANF 1-35
750 FSL 330 FWL/NW
TWP: 28 N - Range: 3 W - Sec. 35
142936 ft
PN040851
KLABZUBA OPR. CO.
BURKEEN 1-17
990 FSL 700 FWL/SE
TWP: 27N - Range: 3E - Sec. 17
139168 ft
PN023254
SIEBERT, CARL H I
990 FSL 990 FWL/NE
TWP: 26N - Range: 7E - Sec. 10
68668 ft
PN046231
H L BROWN, JR.
STATE ALCONA 1-24
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TWP: 28N - Range: 8E - Sec. 24
65786 ft
PN023206
SIMPSON C J
ATCHISON, WILLIAM I
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0
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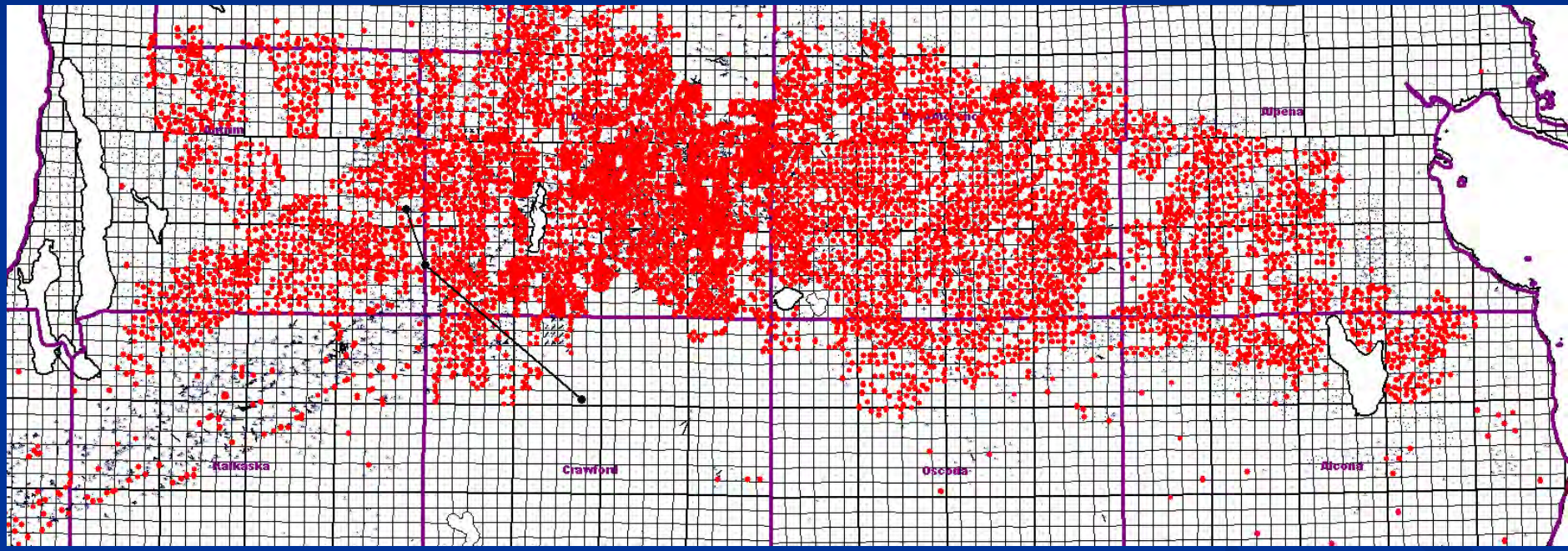
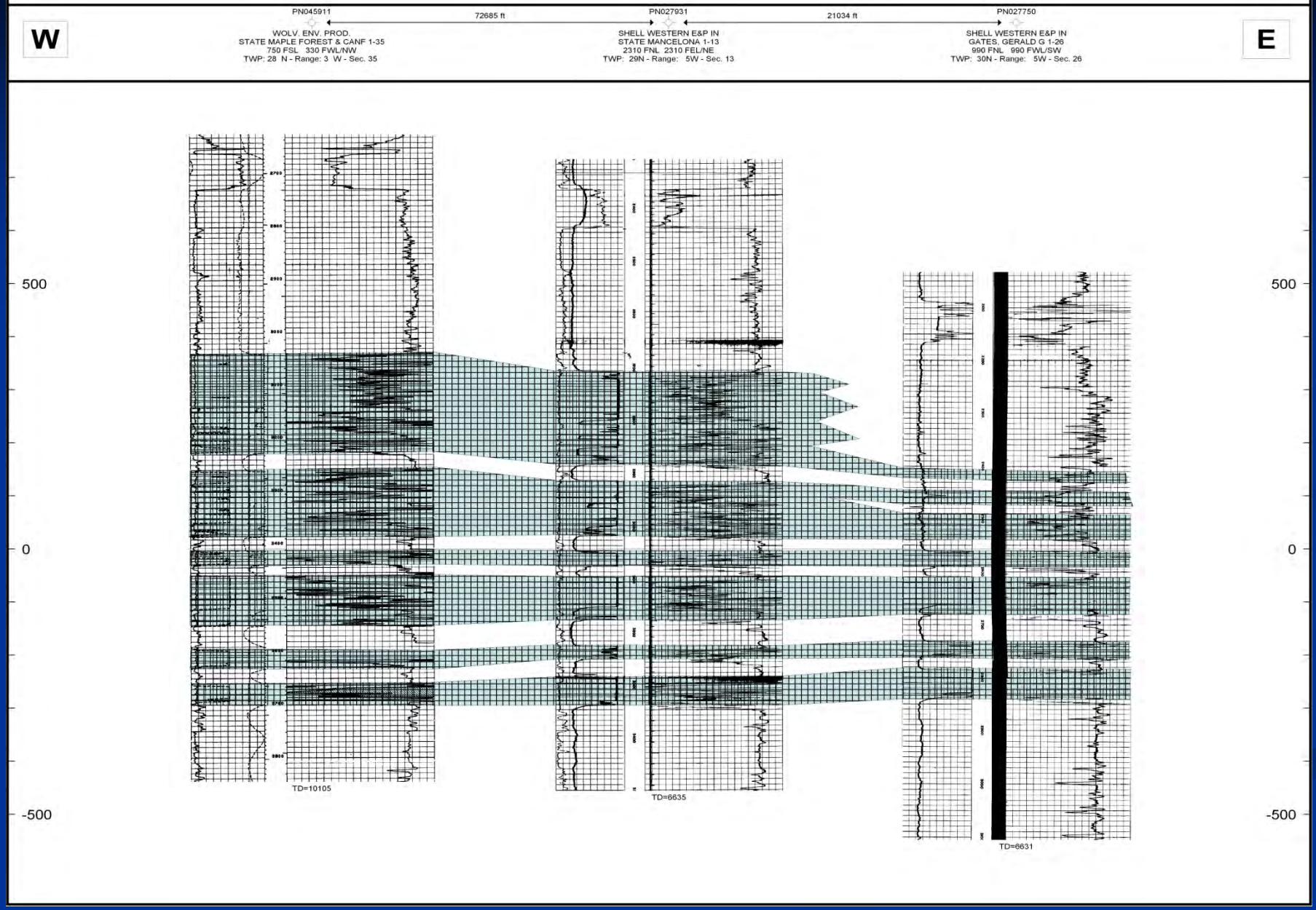
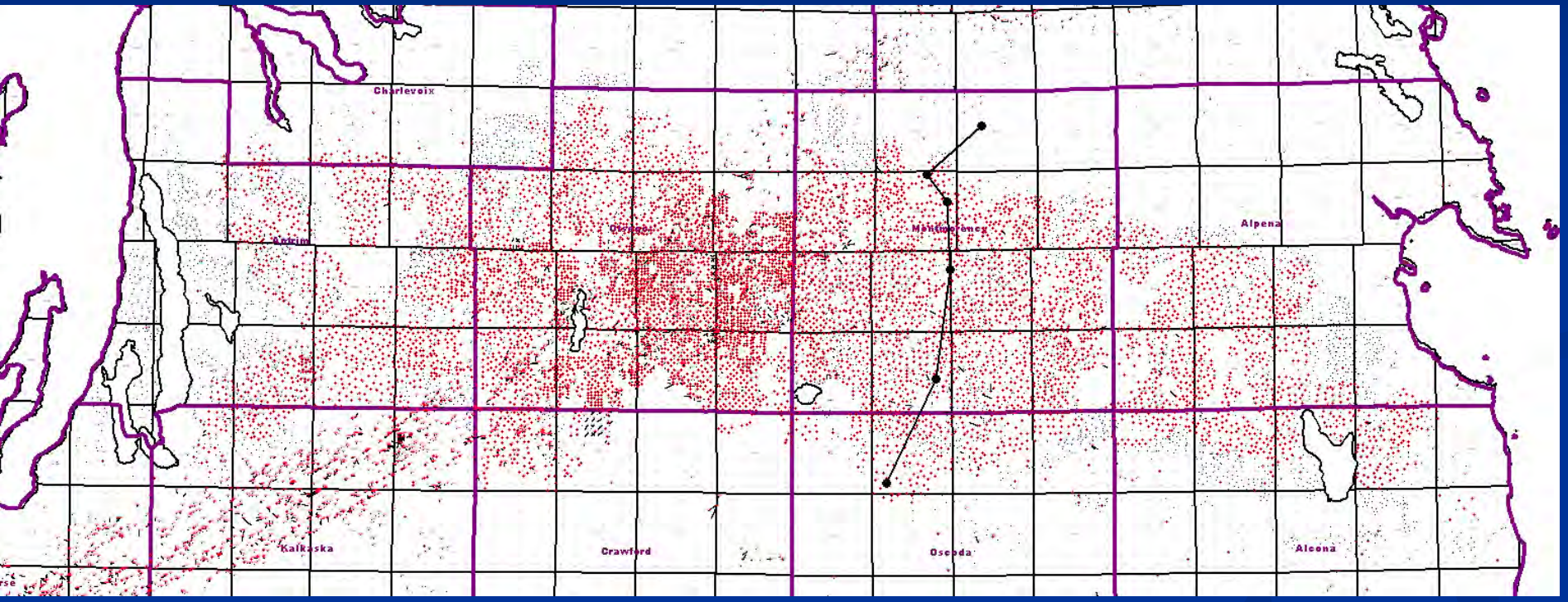
Alcona W E



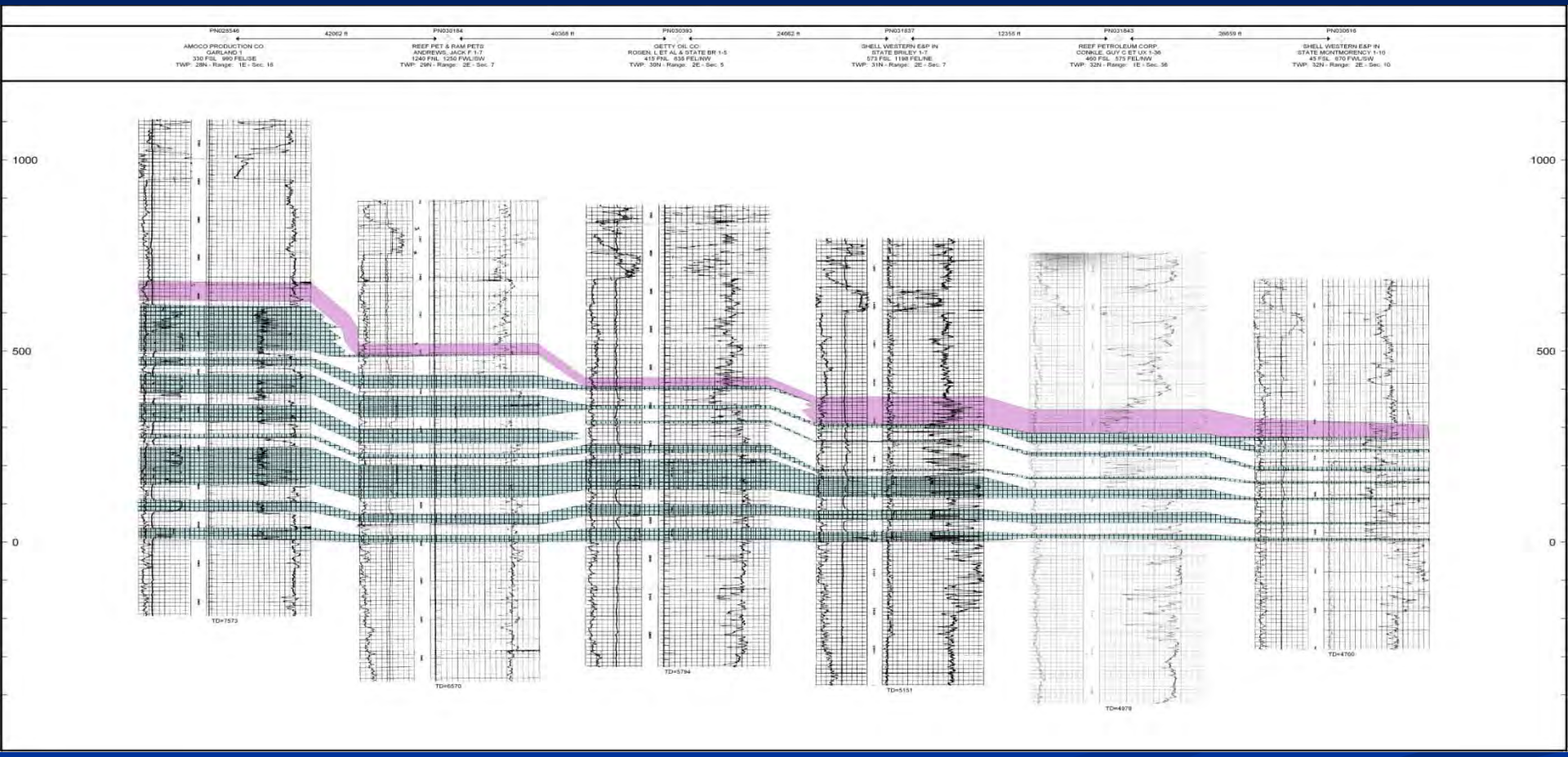
Grand Traverse W-E



Grand Traverse W-E

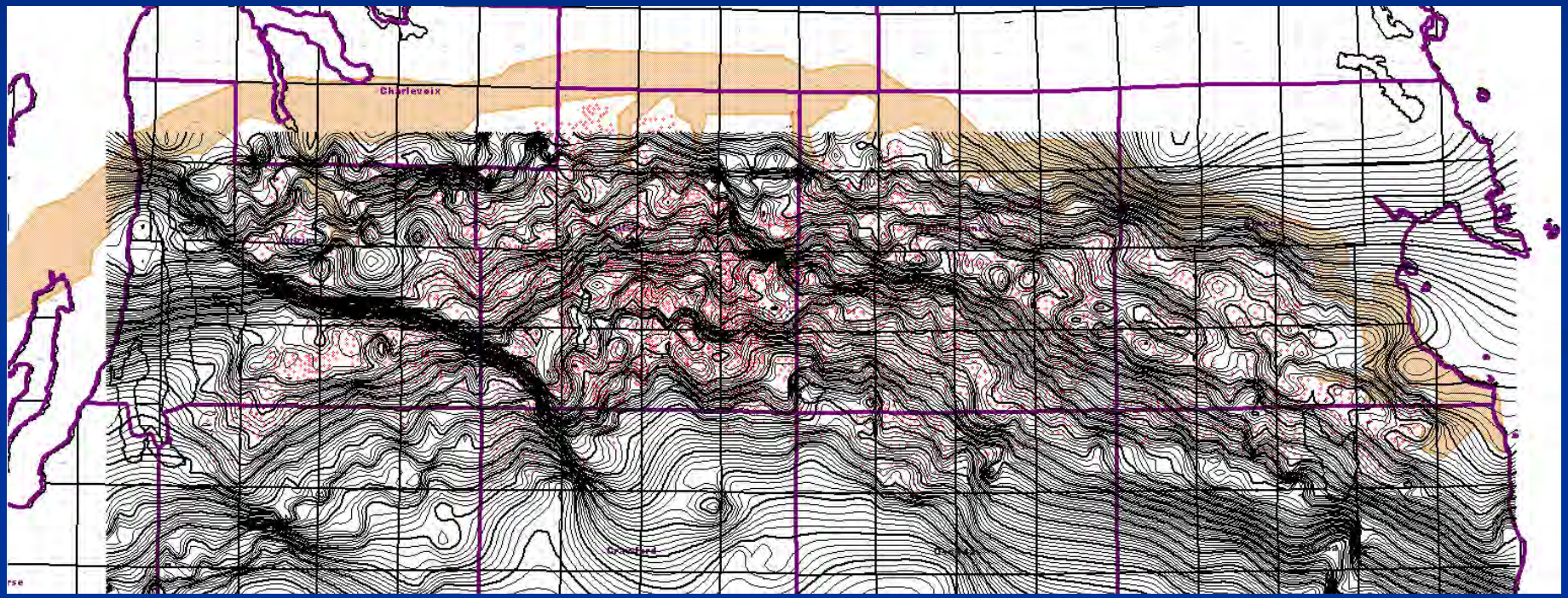


Montmorency N S Long

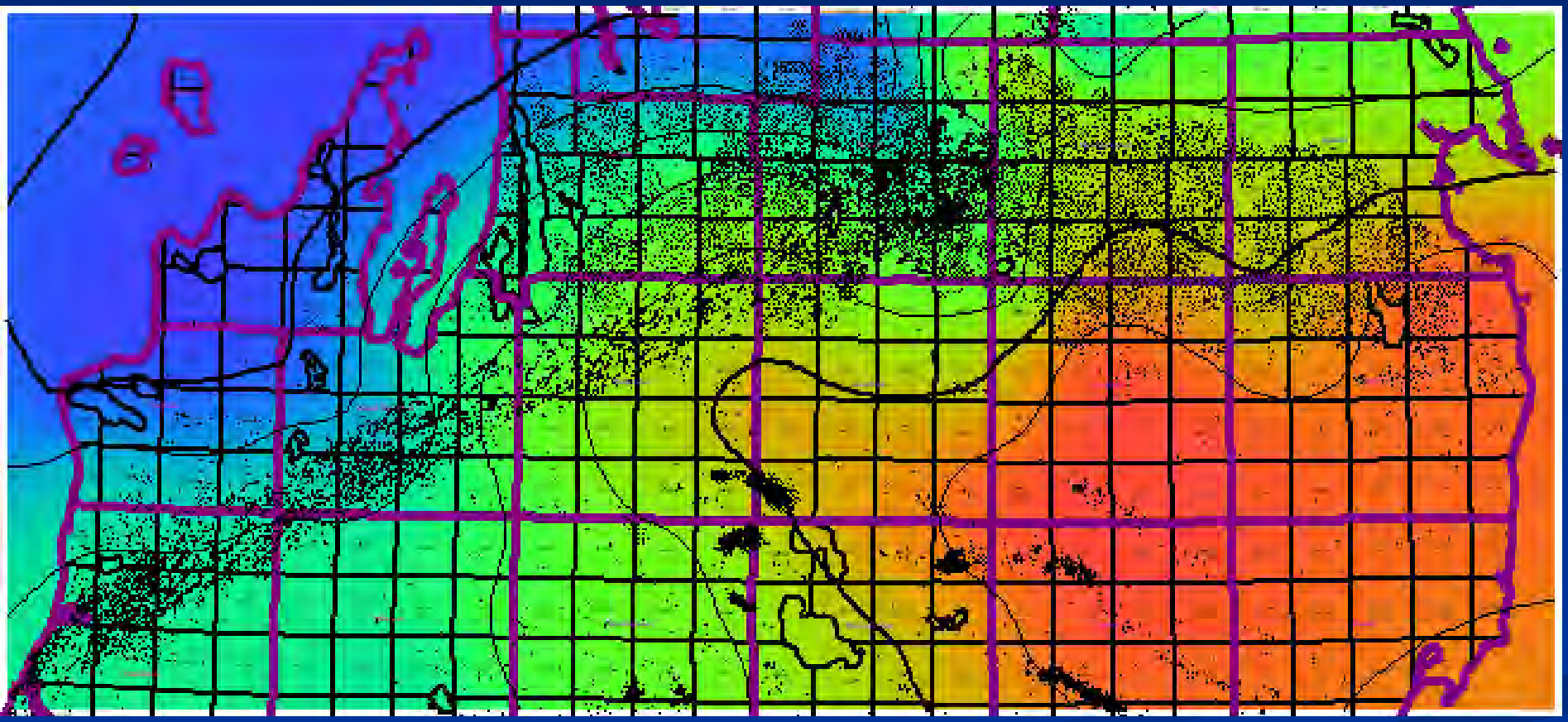


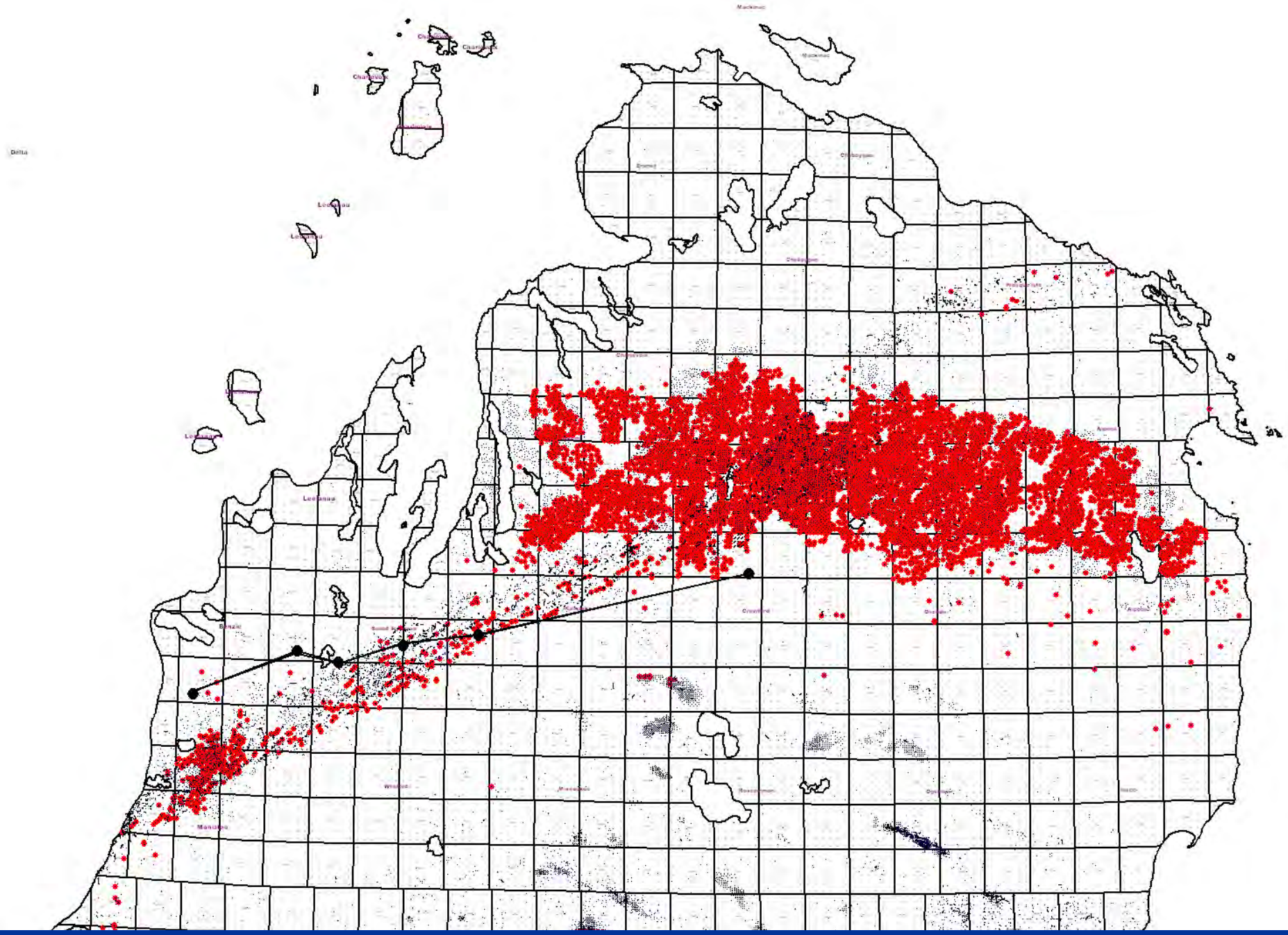
Montmorency N S Long

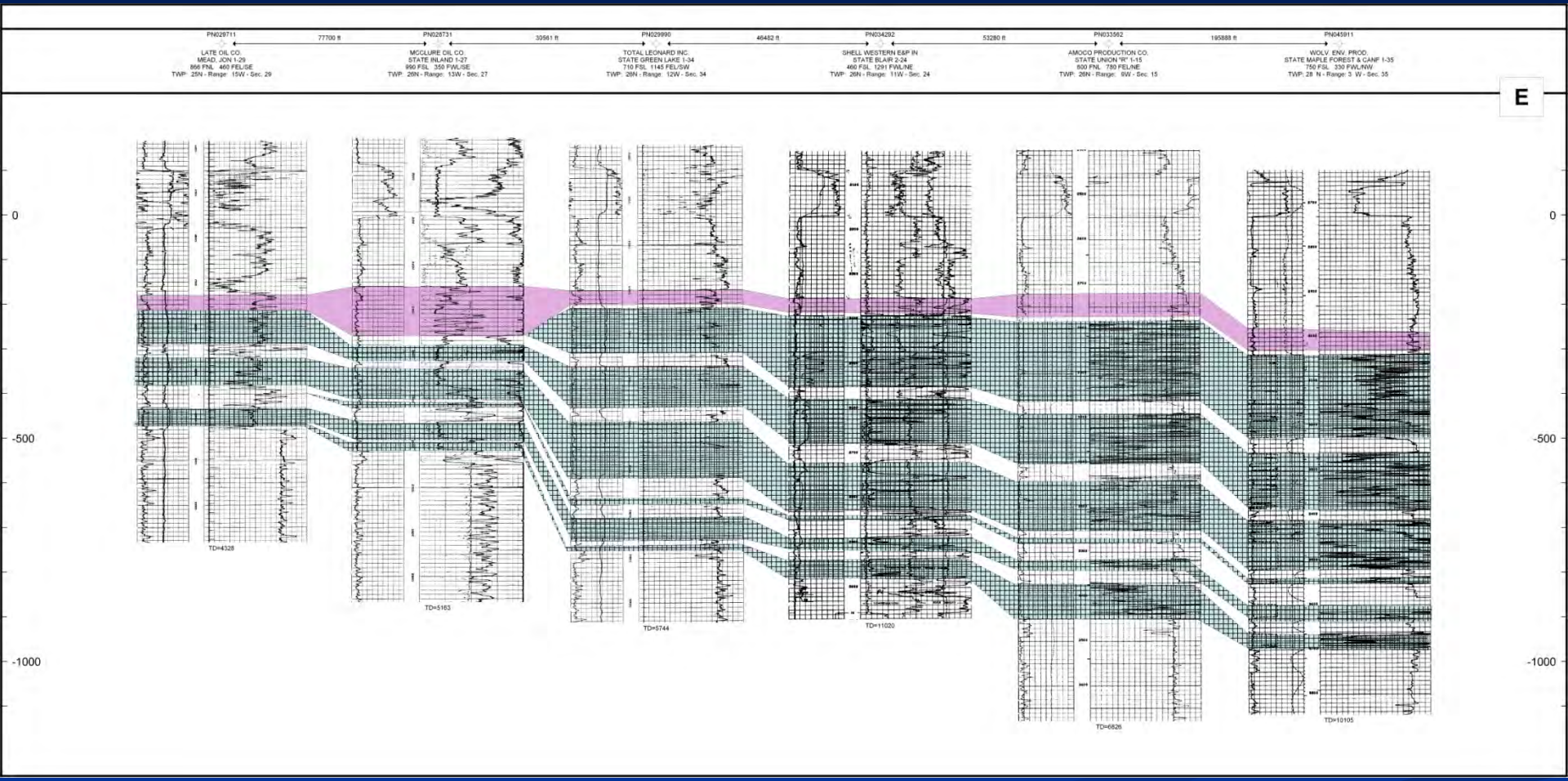
Traverse Lime Structure



Thickness of uppermost Detroit River Anhydrite






PN029711
77700 ft
PN029731
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46482 ft
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53280 ft
PN033562
195888 ft
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LATE OIL CO.
MEAD, JON 1-29
866 FNL 460 FEL/SE
TWP: 25N - Range: 15W - Sec. 29
MCCLURE OIL CO.
STATE INLAND 1-27
990 FSL 350 FWL/SE
TWP: 26N - Range: 13W - Sec. 27
TOTAL LEONARD INC.
STATE GREEN LAKE I-34
710 FSL 1145 FEL/SW
TWP: 26N - Range: 12W - Sec. 34
SHELL WESTERN E&P IN
STATE BLAIR 2-24
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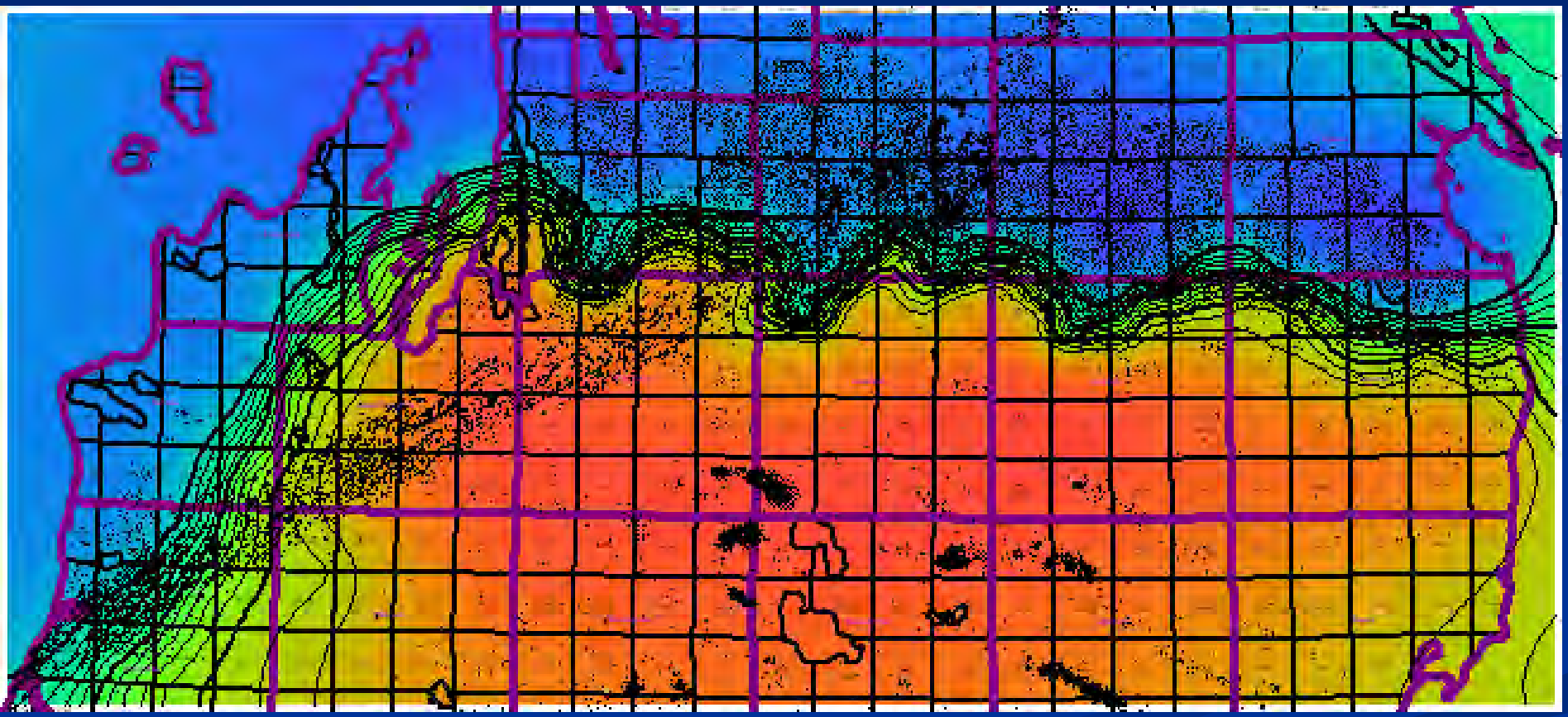
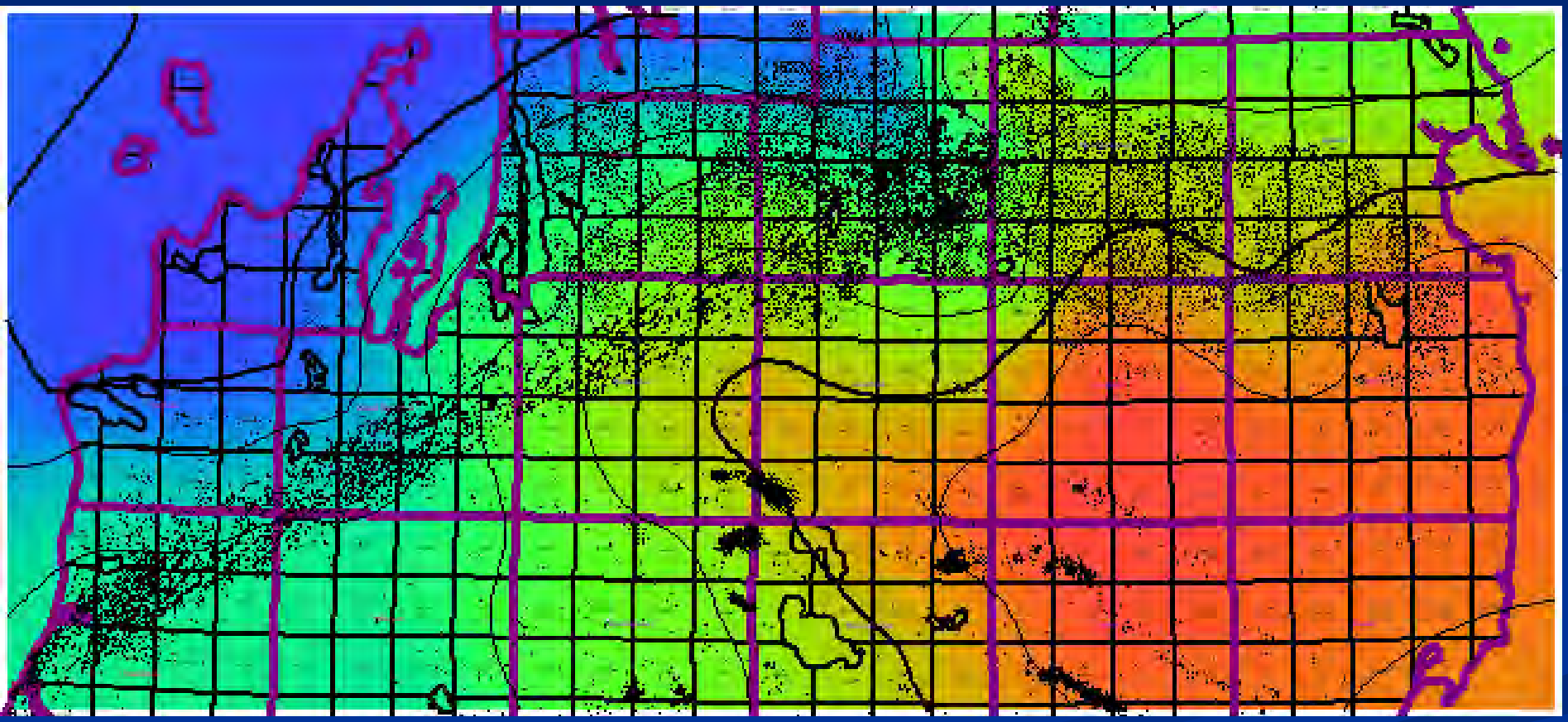
TWP: 26N - Range: 11W - Sec. 24
AMOCO PRODUCTION CO.
STATE UNION "R" I-15
800 FNL 780 FEL/NE
TWP: 26N - Range: 9W - Sec. 15
WOLV. ENV. PROD.
STATE MAPLE FOREST & CANF I-35
750 FSL 330 FWL/NW
TWP: 28 N - Range: 3 W - Sec. 35
E
0
-500
-1000
TD=4328
TD=5163
TD=5744
TD=11020
TD=6826
TD=10105

Manistee W E

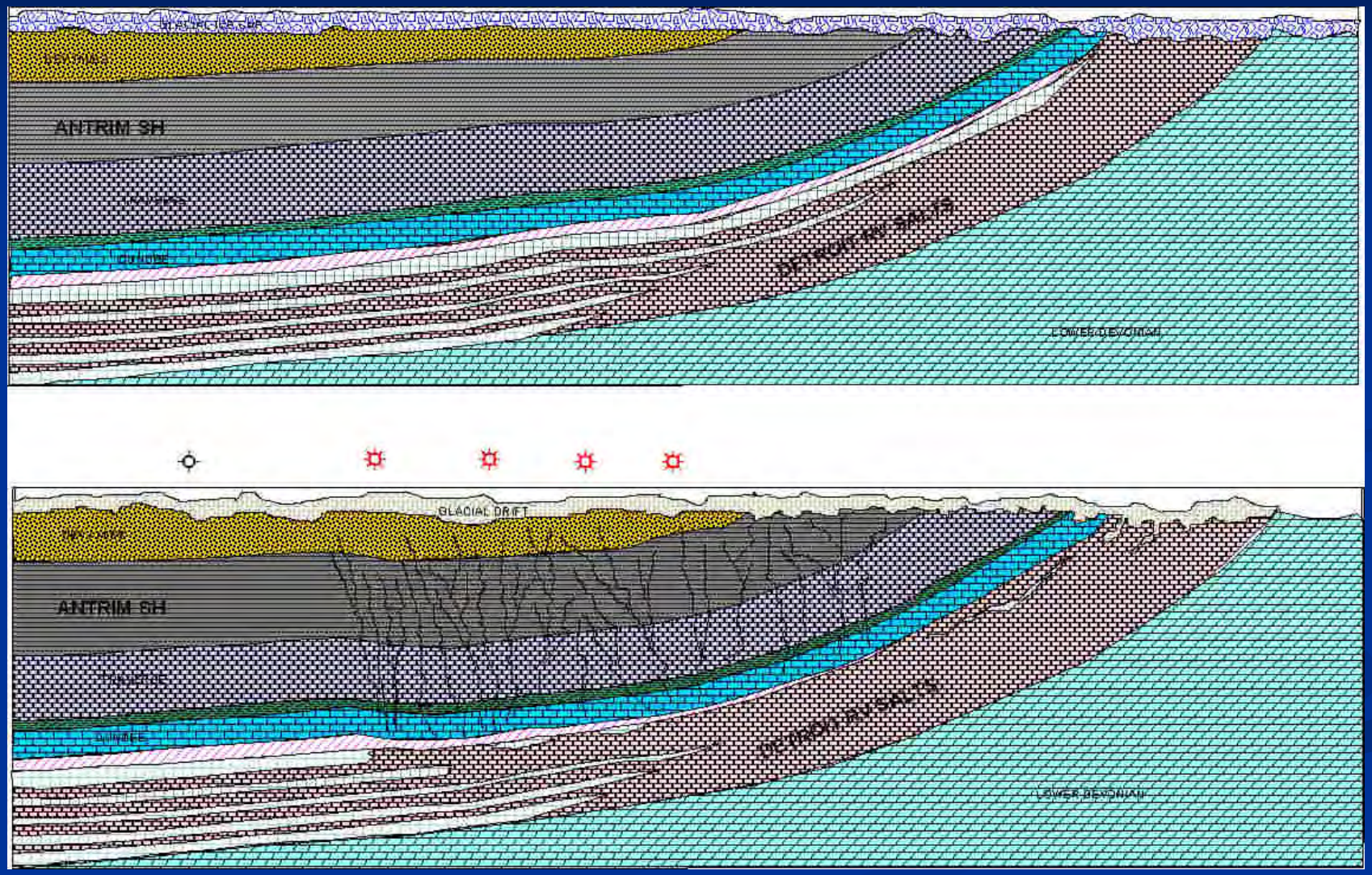
Thickness of the "H" Salt



Thickness of uppermost Detroit River Anhydrite



DETROIT RIVER SALT COLAPSE MODEL



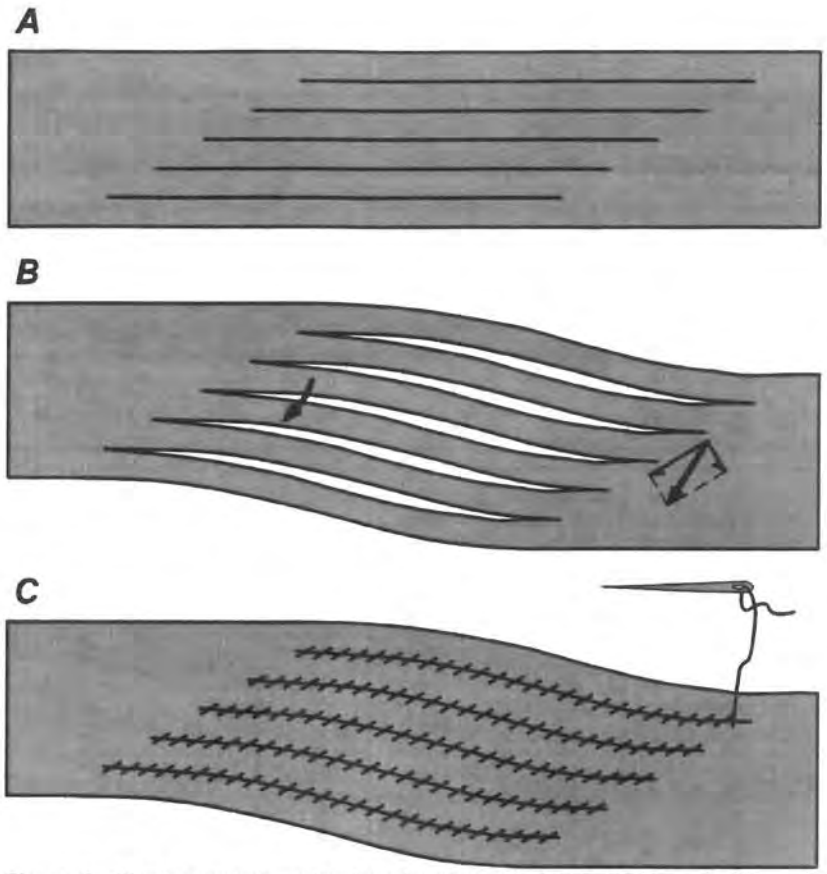


Figure 5. Displacement mechanics along en echelon fractures. *A*, En echelon fractures with intervening layers; *B*, combined dilation and shear displacement resulting from rock layers rotating away from adjacent substrates; *C*, fractures zone "repaired" with imaginary needle and thread. Both stitches and layers are under tension, thereby illustrating the origin of the tensile stress that causes fractures.

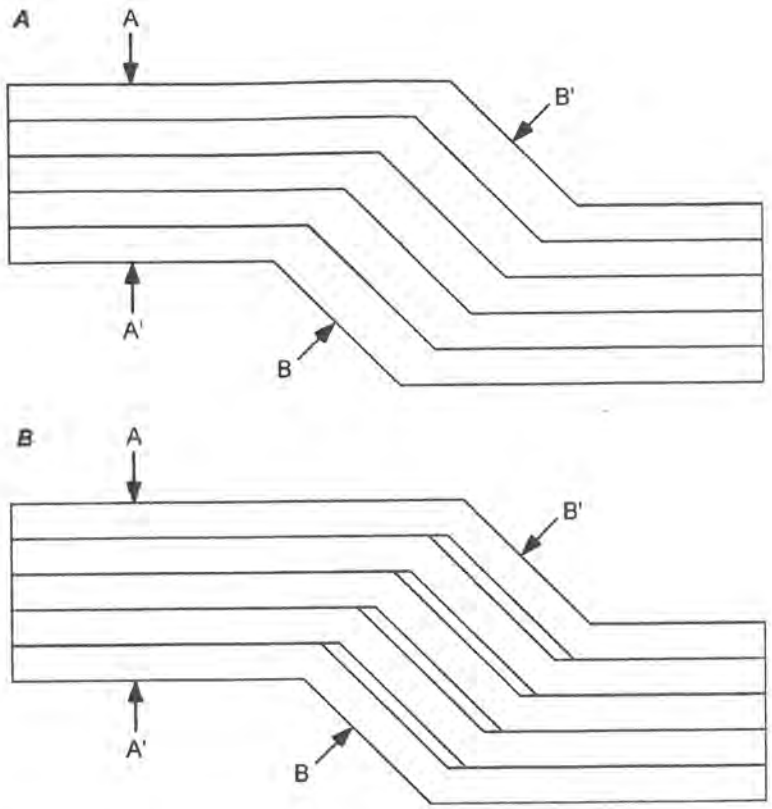
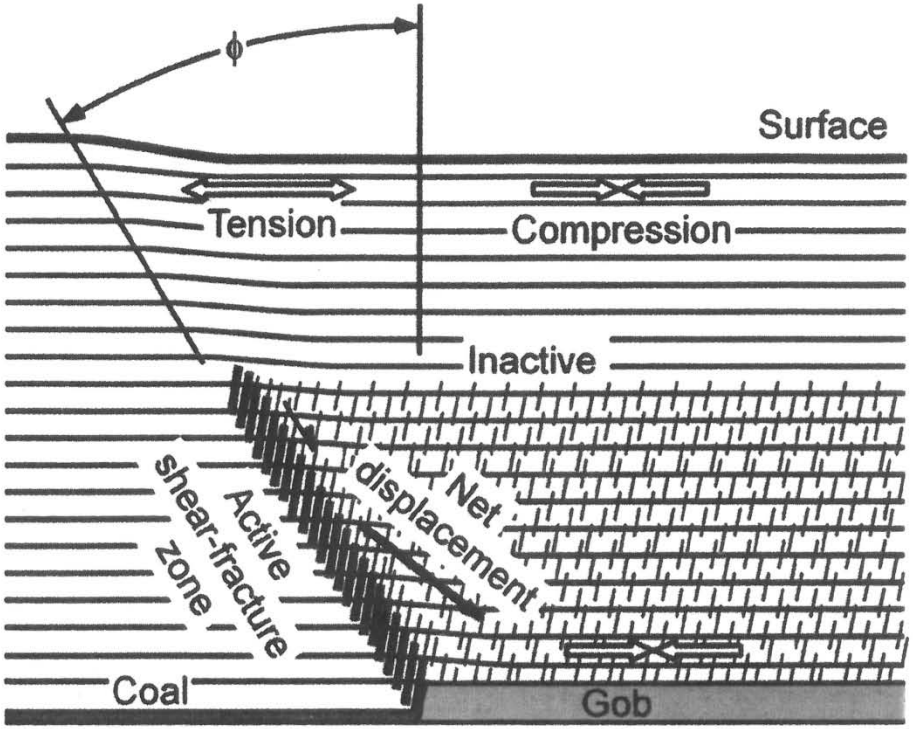


Figure 7. Representation of kink band, a familiar geologic structure. *A*, Dimension B-B' is increased with relative to original thickness A-A'. *B*, Geometry of deformation reduces high interlayer friction by separating layers within band, thus enabling deformation to take place.



B

Figure 8. Mining-induced fractures parallel to the face in longwall mines. *A*, Hard-rock mine, vertical vein (photo rotated 90° to approximate geometry of flat-dipping coal); *B*, proposed origin of fractures in coal mines as result of shear displacement along angle of draw.

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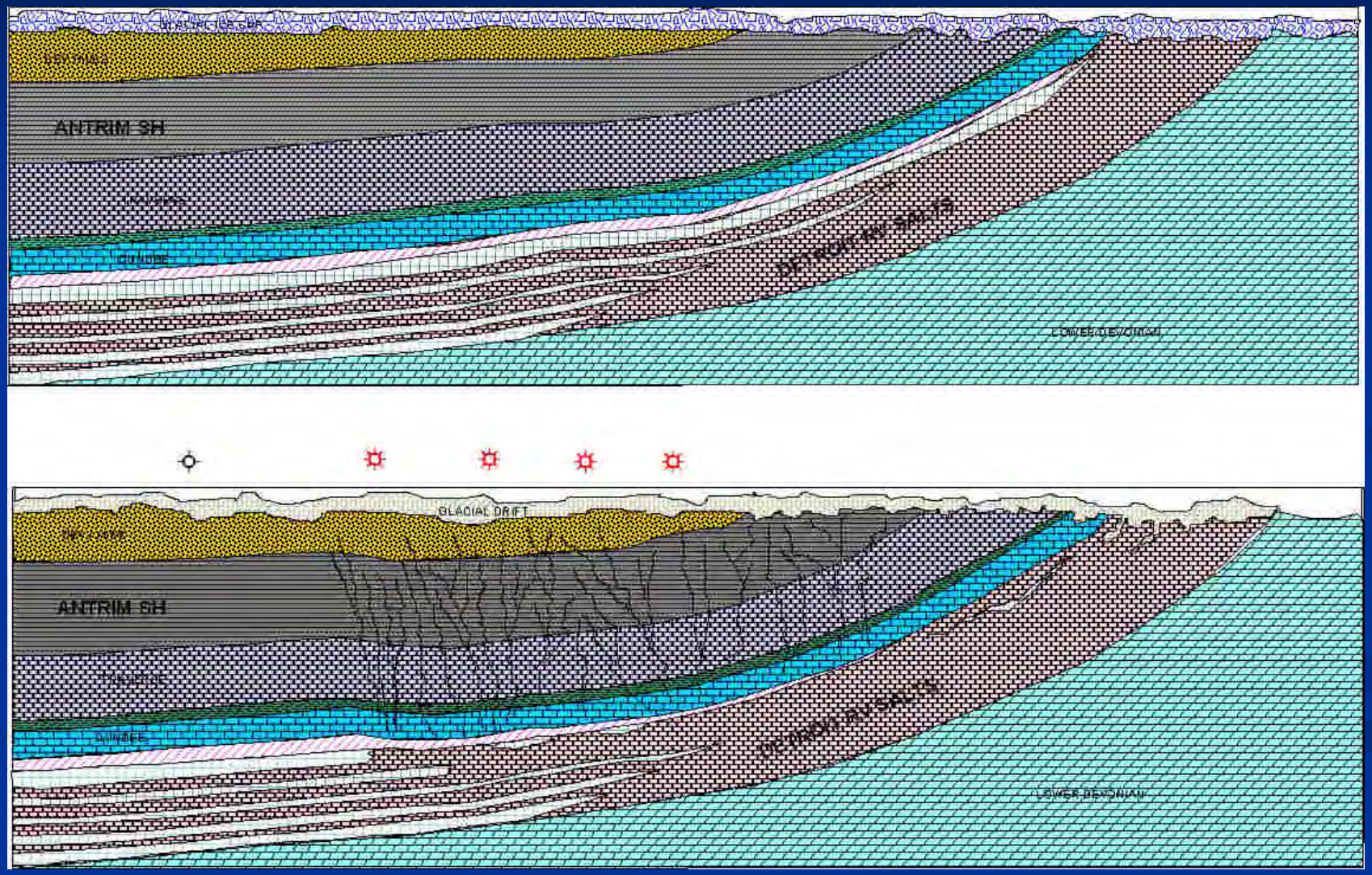

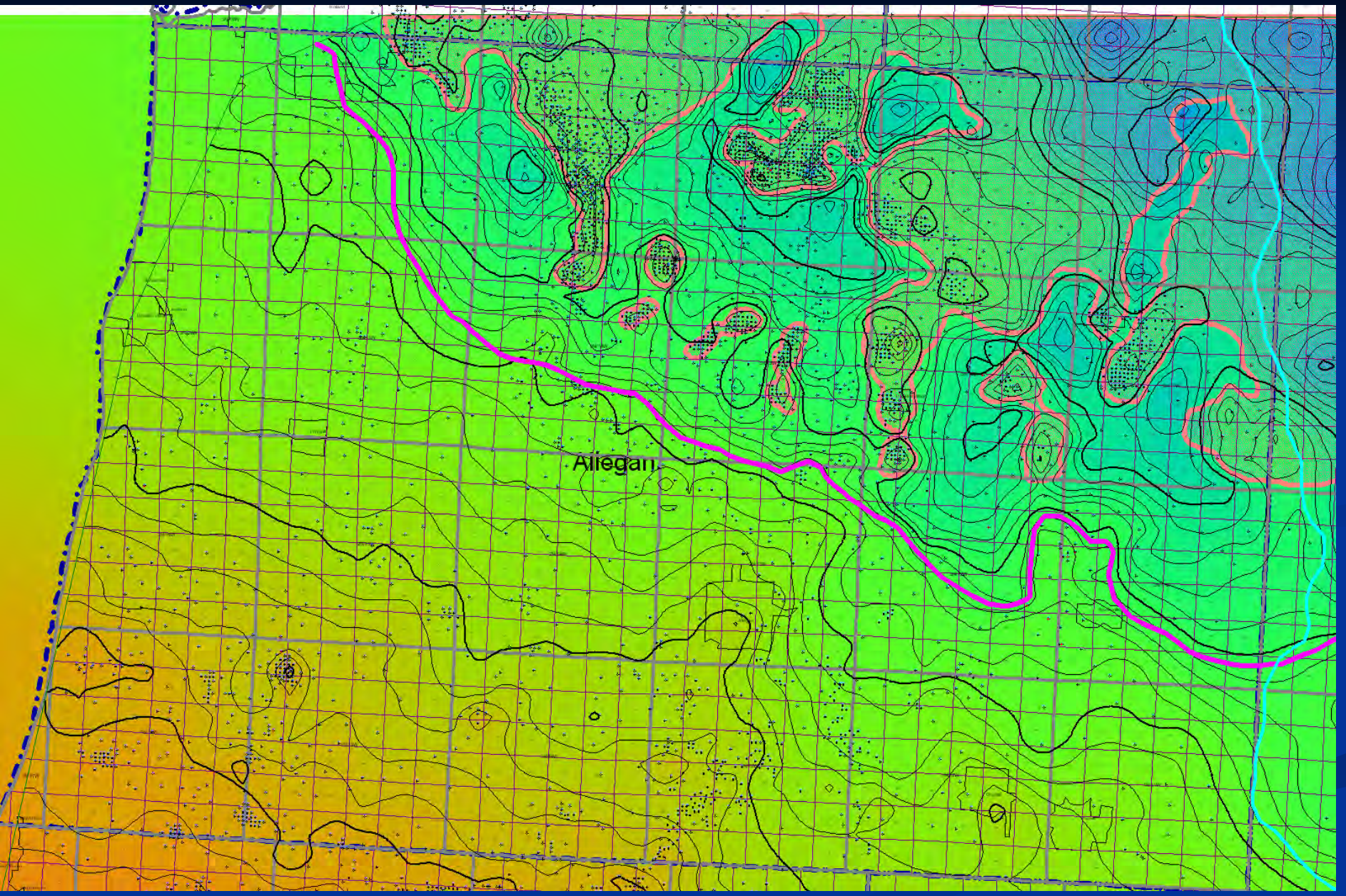
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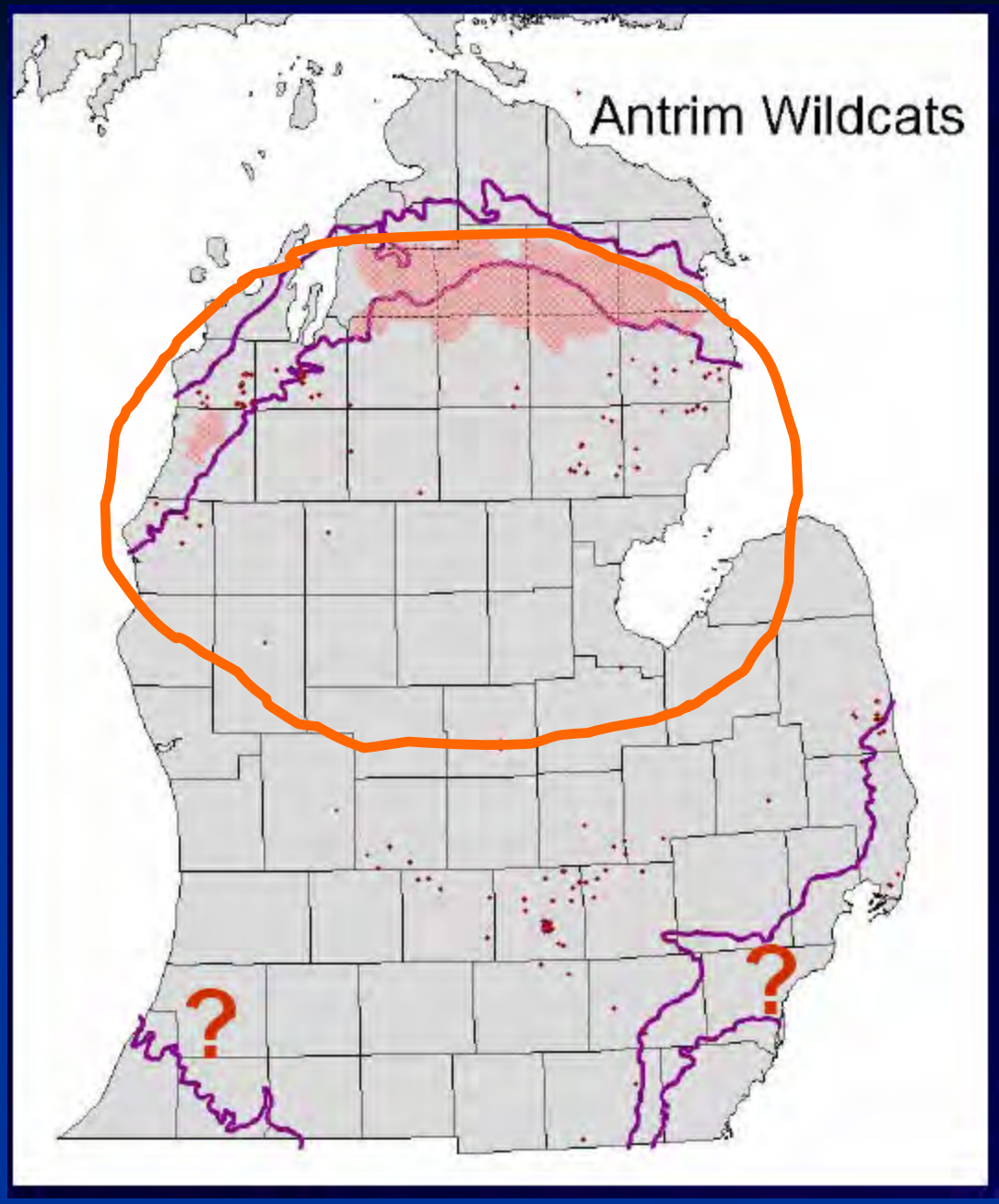
Conclusions

During periods of glaciation fresh water enter the Detroit River and leached the salts. The same fresh waters allowed for microbial gas development.

Subsequent collapse of the overlying formation fractured the more brittle rocks such as the Lachine and Norwood. Some thermogenic gas escaped upward into the Antrim. Difference in salt collapse resulted in some areas more fractured than others.

Further Antrim exploration is limited by few areas left unexplored that have Detroit River Salts close to possible fresh water sources (outcrops).


Antrim Wildcats
?
?

Thanks to:

West Bay Exploration

Wayne Goodman and Timothy Maness

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