Spatial Variations in Salinity to Determine Fluid Flow Pathways and Reservoir Compartmentalization in a Deepwater Gulf of Mexico Field*

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Abstract

In this study, we used well data to estimate the spatial distribution of pore water salinity in a deepwater salt withdrawal minibasin located on the upper slope of the Gulf of Mexico. Using a dual conductance model (Revil et al., 1998), we computed pore water salinity from digital gamma ray, deep resistivity and density porosity well logs. In addition, a correction for hydrocarbons in the pore space was applied (Waxman and Smits, 1968). Pore water salinity estimates from logs were calibrated against core data and well head salinity samples. Two-dimensional seismic data was used to correlate salinity distribution to salt structures and faults.

Within the study area, two hydrologic zones were identified: (1) a shallow hydrostatically pressured zone with near seawater salinity (35 g/L), and (2) a deeper, overpressured zone with variable pore water salinities ranging from 80 g/L to more than 200 g/L. The boundary between the two zones is around 7500 ft SSTVD. A middle hydrostatically pressured zone with hypersaline pore waters that has been documented in other Gulf of Mexico fields (e.g. Bruno and Hanor, 2003) was not observed here. Movement of pore fluids in the study area are driven by: (1) down dip migration of dense brine fluids from salt structures, and (2) up dip brine migration along fault planes and salt structures into shallower sediments driven by overpressure. Vertical compartmentalization of reservoirs was evident by the difference in pore fluid salinity between sands and adjacent shales. Sands that exhibited fresher pore waters than adjacent shales were interpreted to be the result of sediment dewatering during

overpressure generation, whereas shallower sands with higher salinities than adjacent shales suggest down dip migration of saline fluids from salt structures.

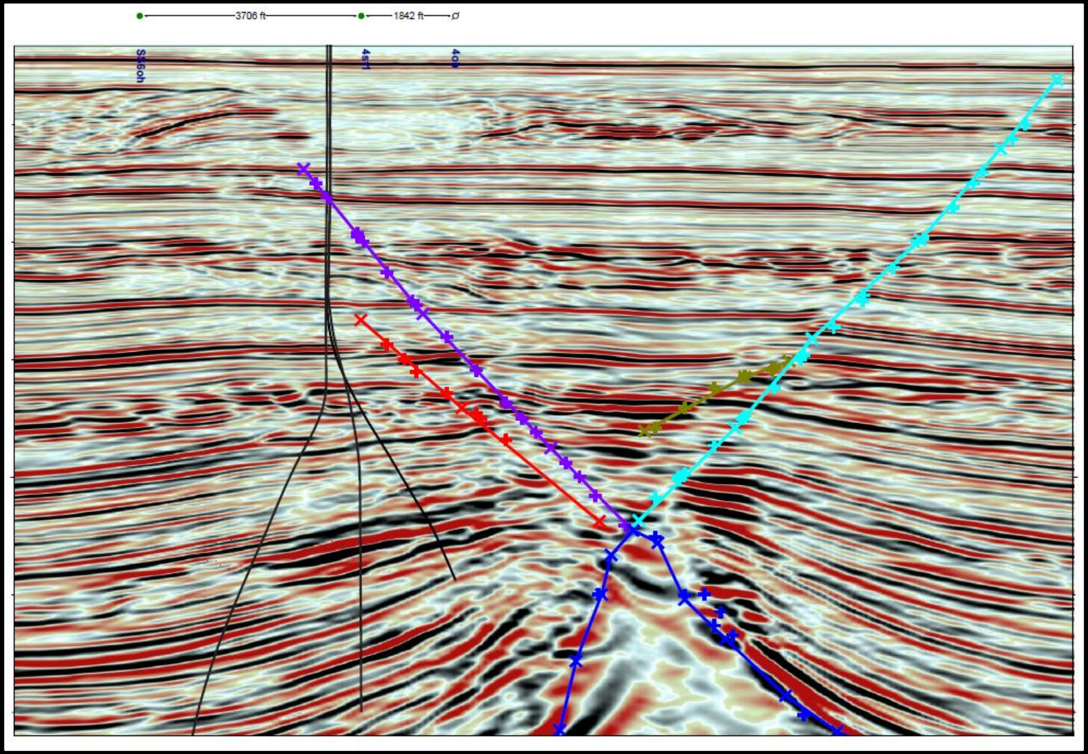
References Cited

Bruno, R.S., and J.S. Hanor, 2003, Large-scale fluid migration driven by salt dissolution, Bay Marchand dome, offshore Louisiana: Gulf Coast of Geological Societies Transactions, v. 53, p. 97-107.

Revil, A., L.M. Cathles, S. Losh, and J.A. Nunn, 1998, Electrical conductivity in shaly sands with geophysical applications: J. Geophys. Res., v. 103, p. 23,925–23,936.

Waxman, M.H., and L.J.M. Smits, 1968, Electrical conduction in oil-bearing sands: Society of Petroleum Engineers Journal, v. 8, p. 107-122.

Spatial Variation in Salinity to Determine Fluid Flow Pathways and Reservoir Compartmentalization in a Deepwater Gulf of Mexico Field



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Outline

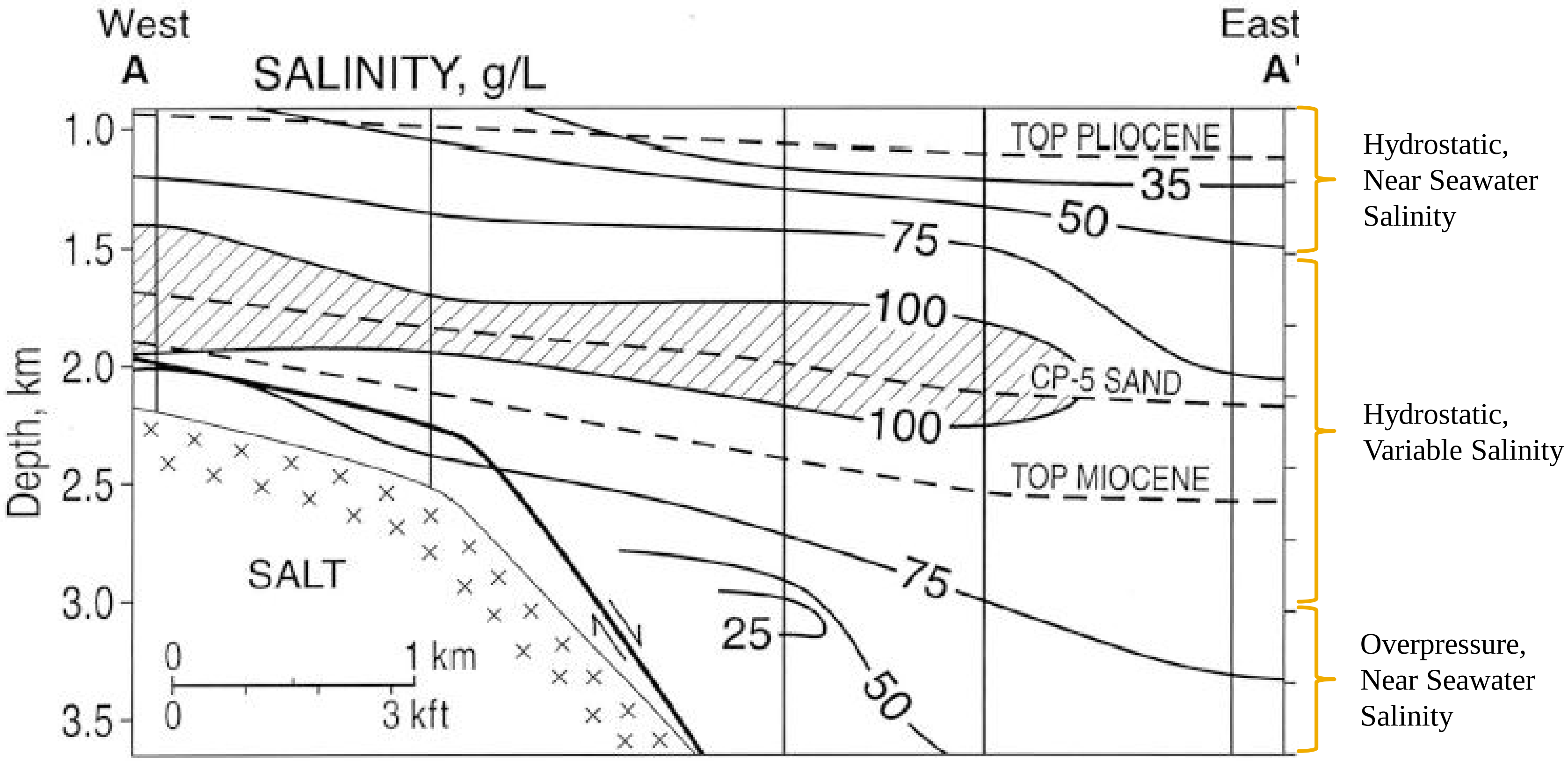
- Purpose
- Previous Studies
- Study Area
- Methods
- Results
- Discussion

Purpose

- Estimate pore water salinity from well data in a salt withdrawal minibasin
- Use spatial variations in salinity to infer fluid flow pathways and compartmentalization of reservoirs
- Compare results to hydrologic regimes found elsewhere in the Gulf of Mexico
- Correlate spatial variations in salinity to mechanisms of solute transport

Previous Work

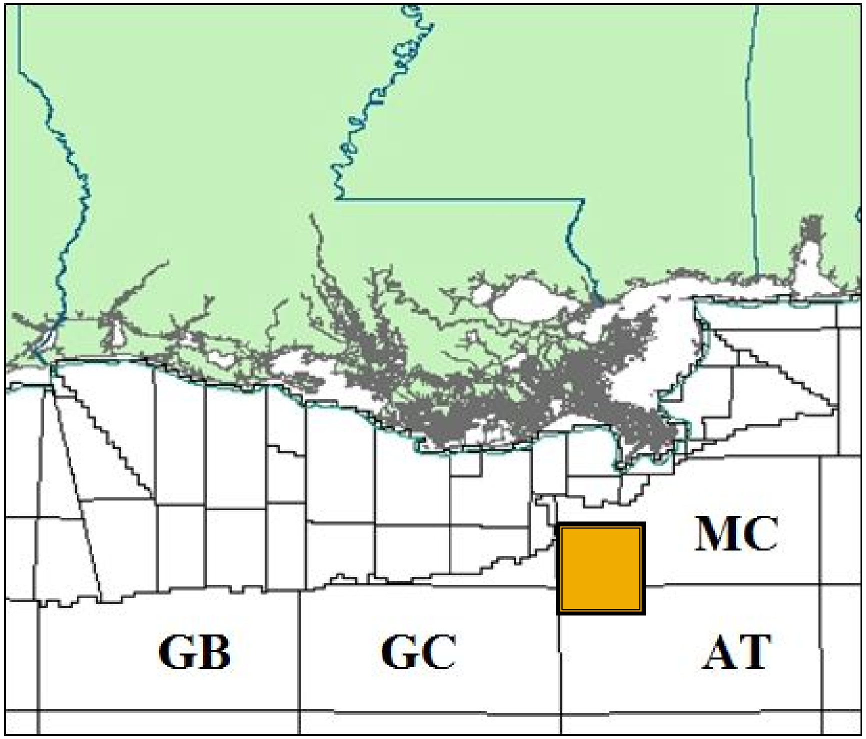
- Dissolution and migration of pore fluids around salt structure onshore and coastal Louisiana (SP log analysis – Sands only)

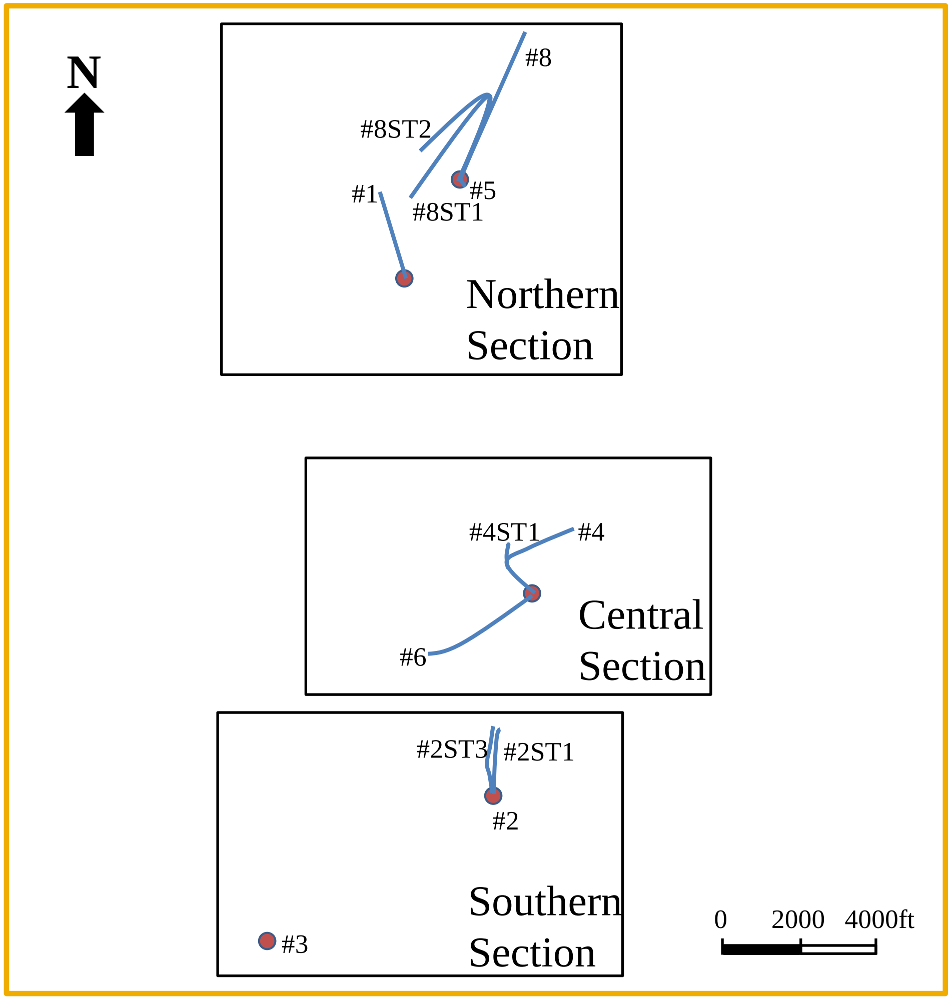


(from Bruno and Hanor 2003)

Study Area

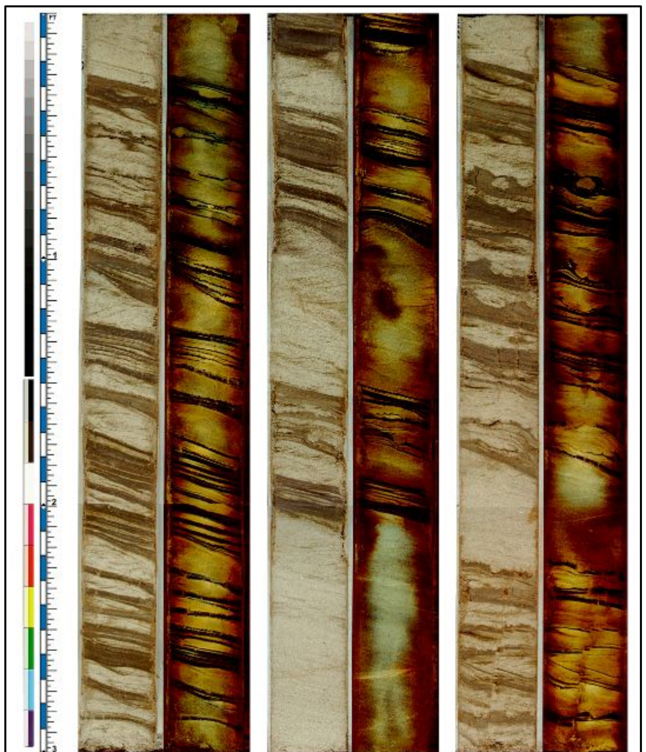
- Mississippi Canyon
- 12 wells
- Located in deepwater (~ 3000' of water)
- Hydrocarbon producing field

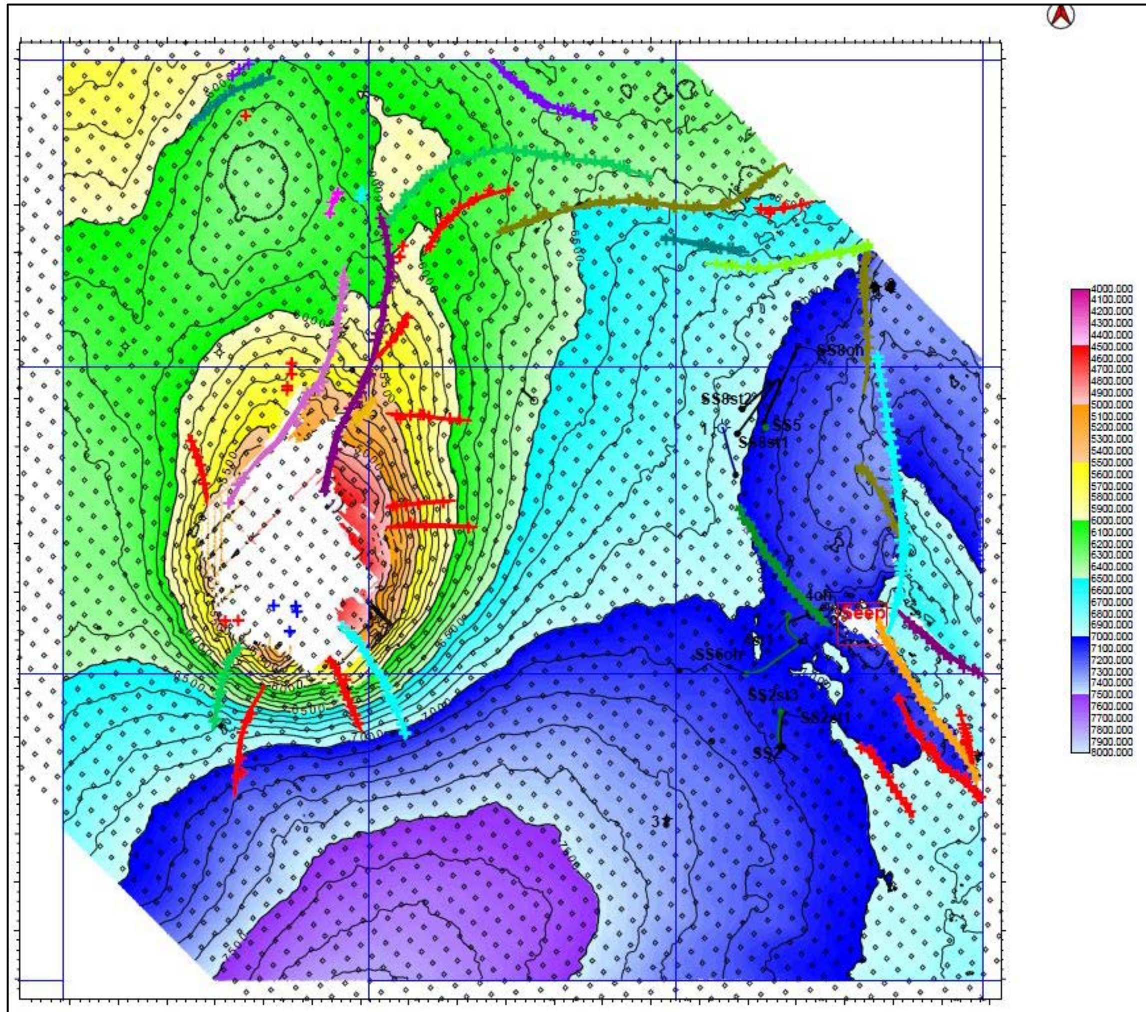




Salt withdrawal minibasin

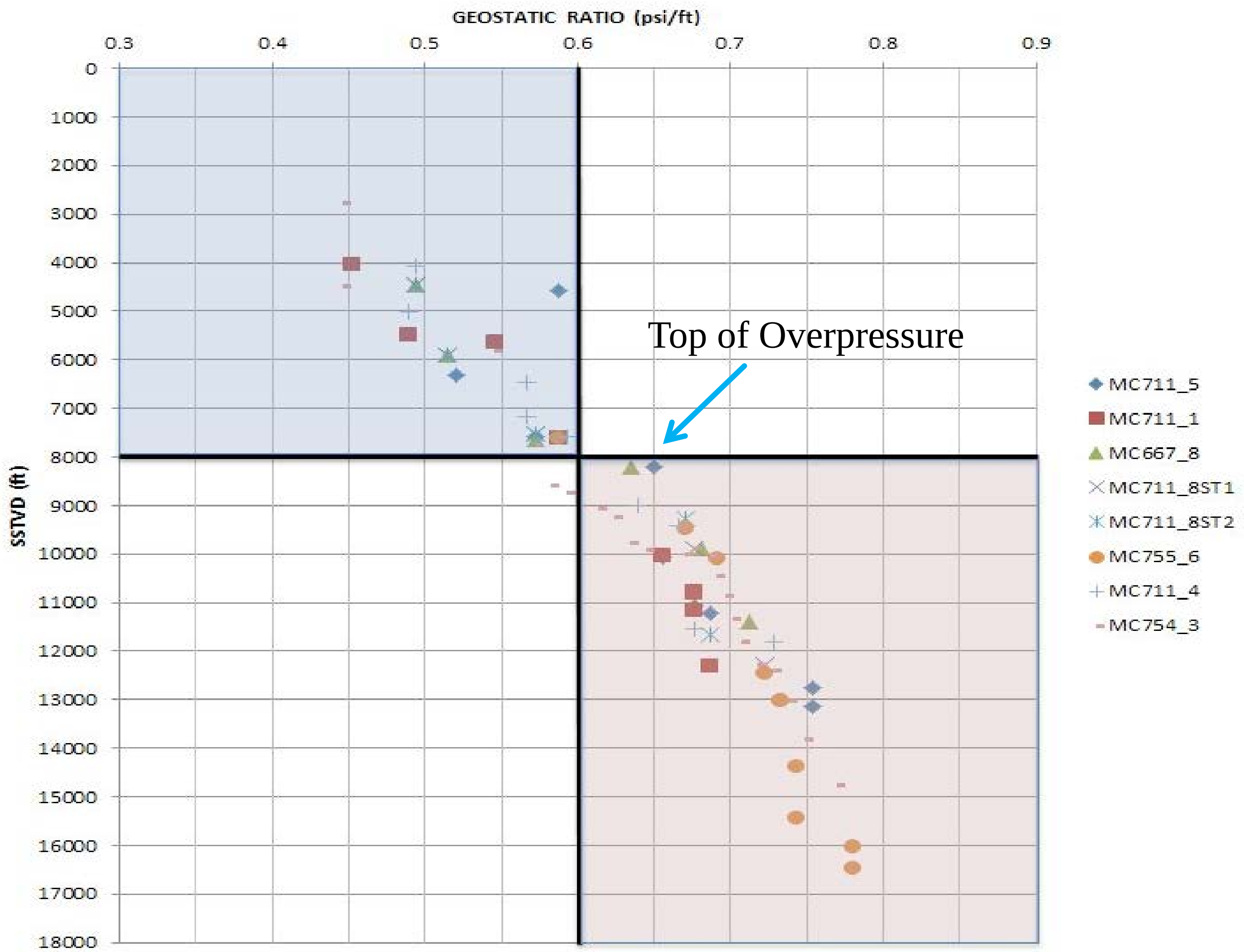
- Pliocene – Pleistocene Turbidites
  - Depositional Channels
  - Levee and Overbank Deposits





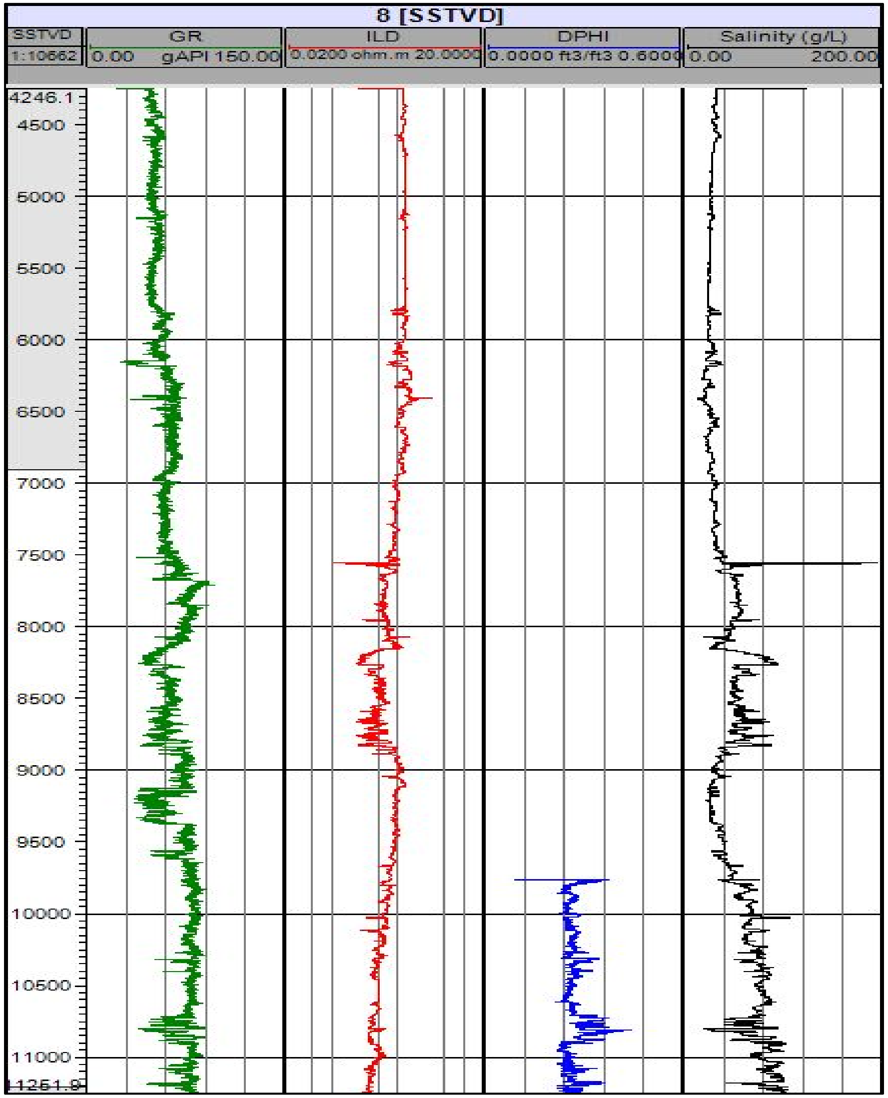
(courtesy of Clark Walraven)

Methods - Fluid Pressure from Mud Weight



Methods - Revil et al. 1998

- Utilizes three well logs to estimate salinity for both sand and shale
  - Gamma Ray (GR)
    - Distinguishes between lithologies
    - Determines clay volume
  - Deep Resistivity (ILD)
    - Determines bulk resistivity of sediment and pore fluid
  - Density Porosity (DPHI)
    - Determines porosity of sediment
    - Where DPHI is not present the use of a porosity curve was necessary
- Corrected for presence of hydrocarbons (Waxman and Smits, 1968)
- Results calibrated with produced water salinities



Methods - Revil et al. 1998

- Dual conductance model
- CEC determined from cores

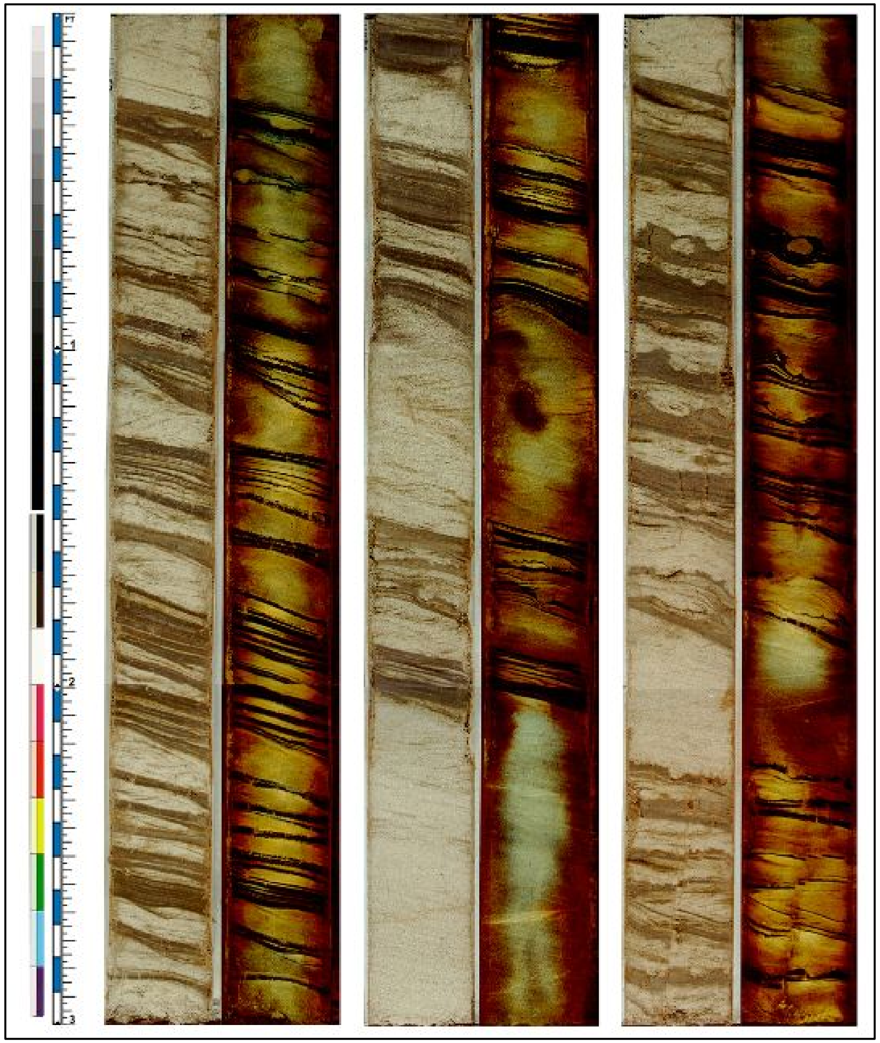
	MINERALOGY OF WHOLE ROCK SAMPLE (WEIGHT %)							MINERALOGY OF CLAY FRACTION (RELATIVE %)			
Depth (ft)	Qtz	Ksp	Plag	Cal	Dol	Pyr	Clay	Ill/Smec*	Ill&Mica	Kaol	Chl
11,451.8	65	10	15	0	1	1	8	61	26	9	3
11,465.4	65	10	16	1	1	0	8	64	24	8	4
11,467.8	68	8	16	0	1	0	8	62	27	7	5
11,468.5	71	8	14	0	1	0	5	69	20	7	5
11,781.5	56	11	17	0	1	1	14	58	30	7	5
11,807.3	77	7	7	1	0	1	8	60	24	10	7
11,821.3	73	10	13	0	0	0	5	55	29	9	7
Min:	56	7	7	0	0	0	5	55	20	7	3
Max:	77	11	17	1	1	1	14	69	30	10	7
Avg:	68	9	14	0	1	1	8	61	26	8	5

*Mixed-layer illite/smectite contains 75-80% smectite layer

KEY:

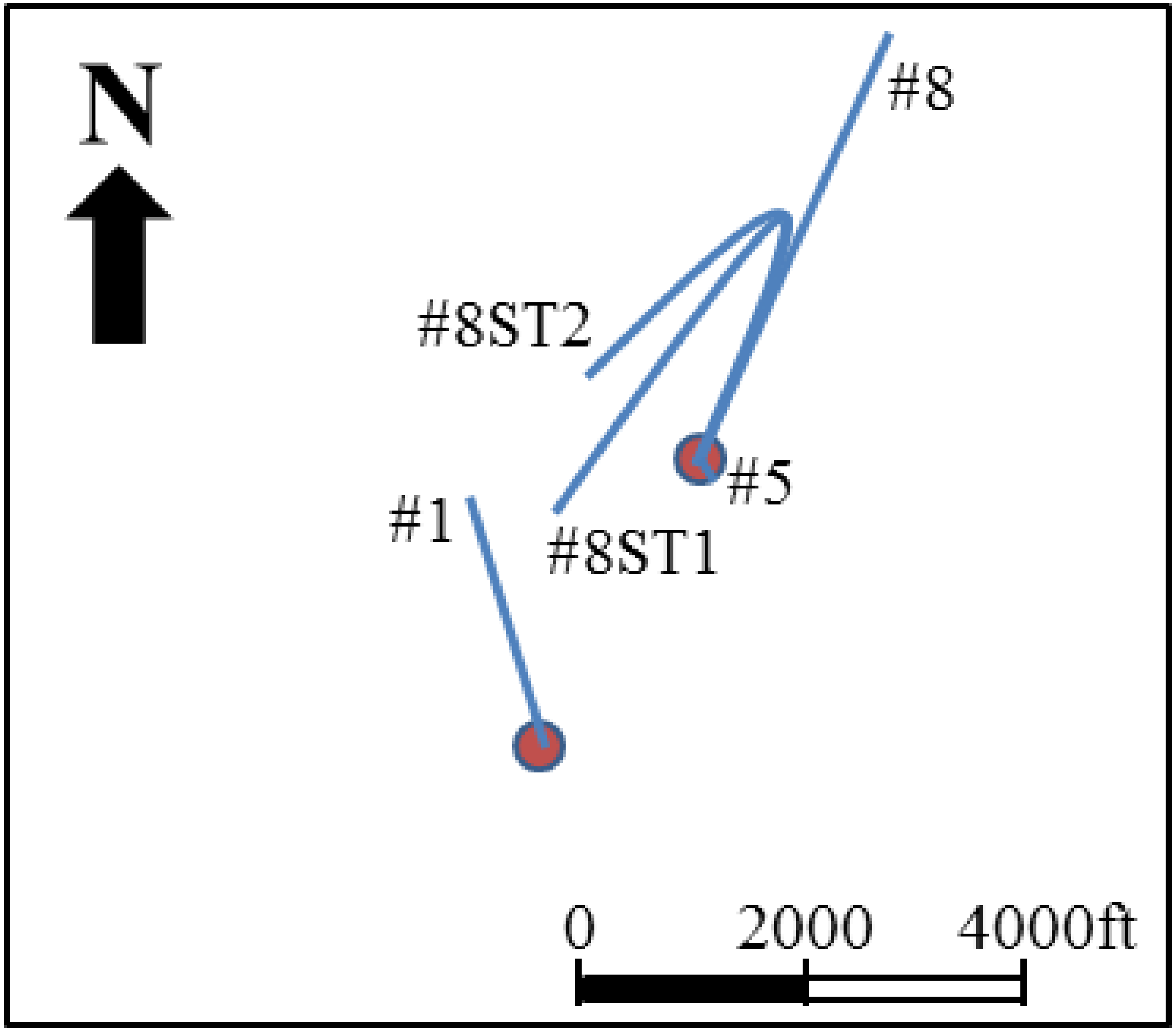
Qtz = Quartz
Ksp = K-feldspar
Plag = Plagioclase
Cal = Calcite
Dol = Dolomite
Pyr = Pyrite
Clay = Total Clay
Ill/Smec = Mixed-layer Illite/Smectite
Ill&Mica = Illite and Mica
Kaol = Kaolinite
Chl = Chlorite

(courtesy of Core Laboratories)



(courtesy of Core Laboratories)

Northern Section Results

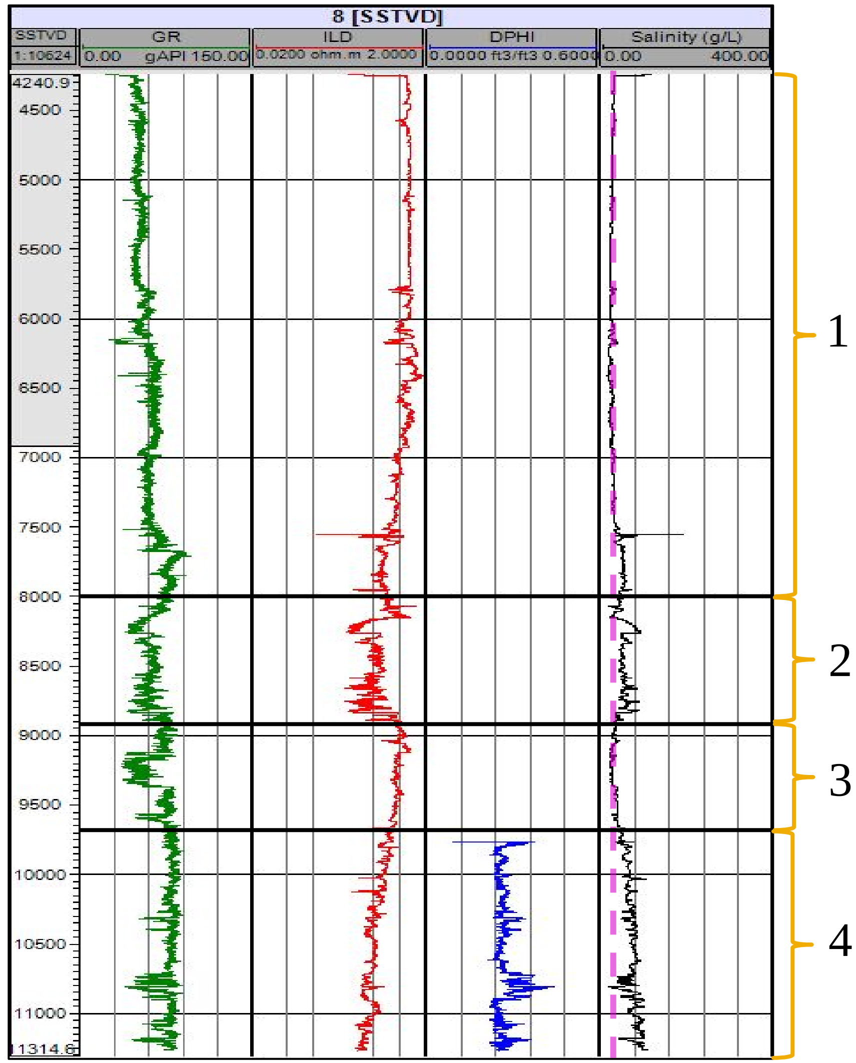


Northern Section Salinity Profile

- Hydropressured regime
  - ~ 35 g/L (Normal marine salinity)

<u>Onset of Overpressure</u> →

- Overpressured regime
  - ~ 35 g/L - 110 g/L
  - High salinity zone
  - Salinity reversal
  - Increase in salinity with depth



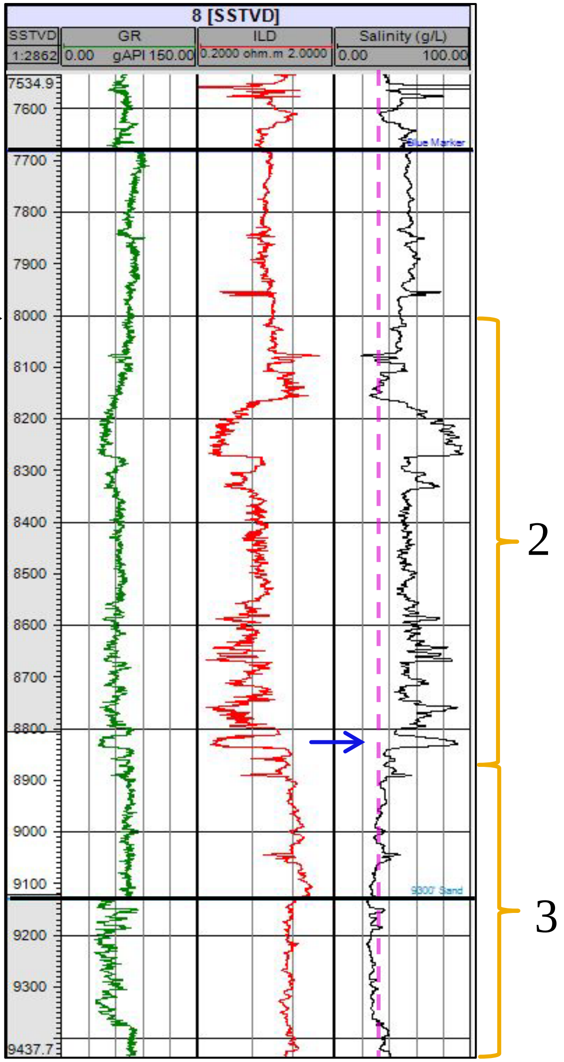
Northern Section Salinity Responses

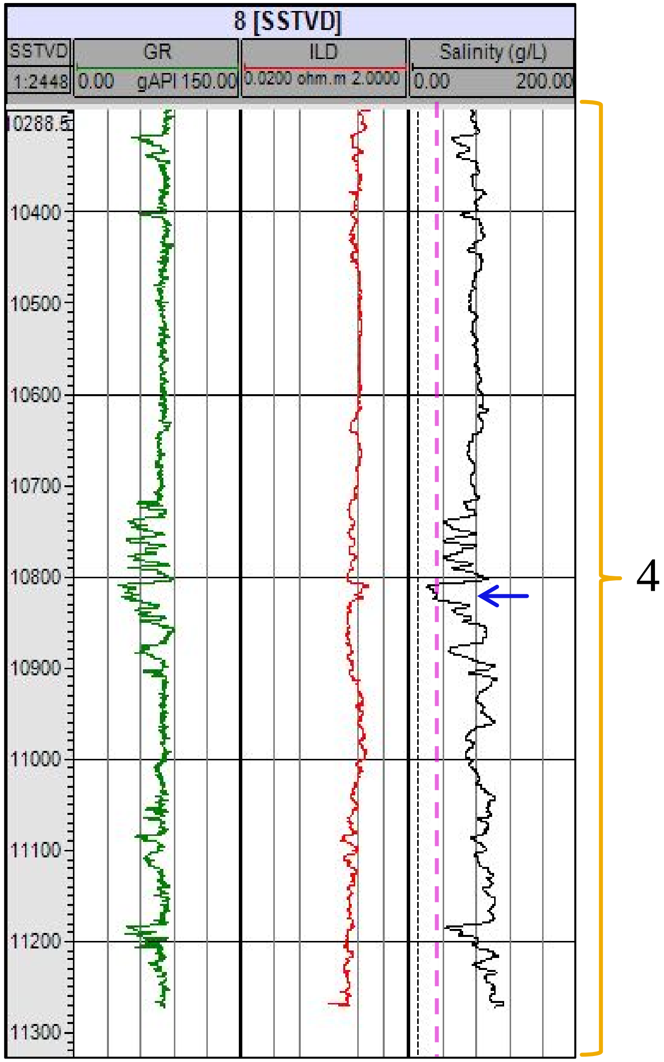
Blue Marker

<u>Onset of Overpressure</u>

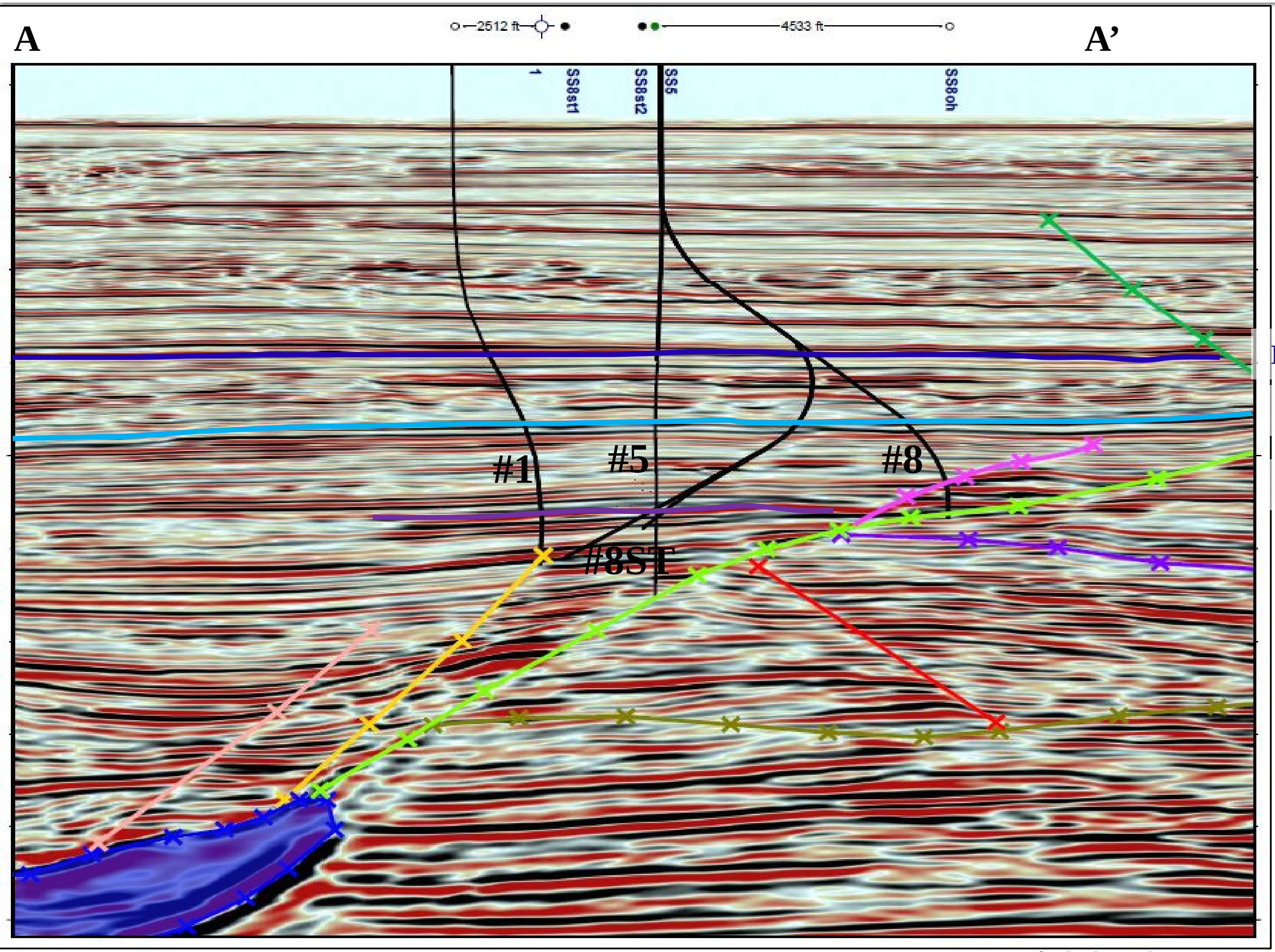
- Overpressure Regime
  - 3 compartments of varying salinity

9300’ sand





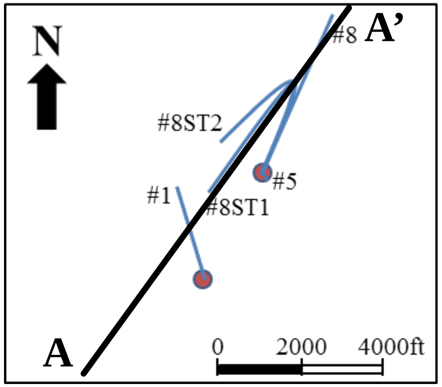
Northern Section Seismic Profile



Blue Marker

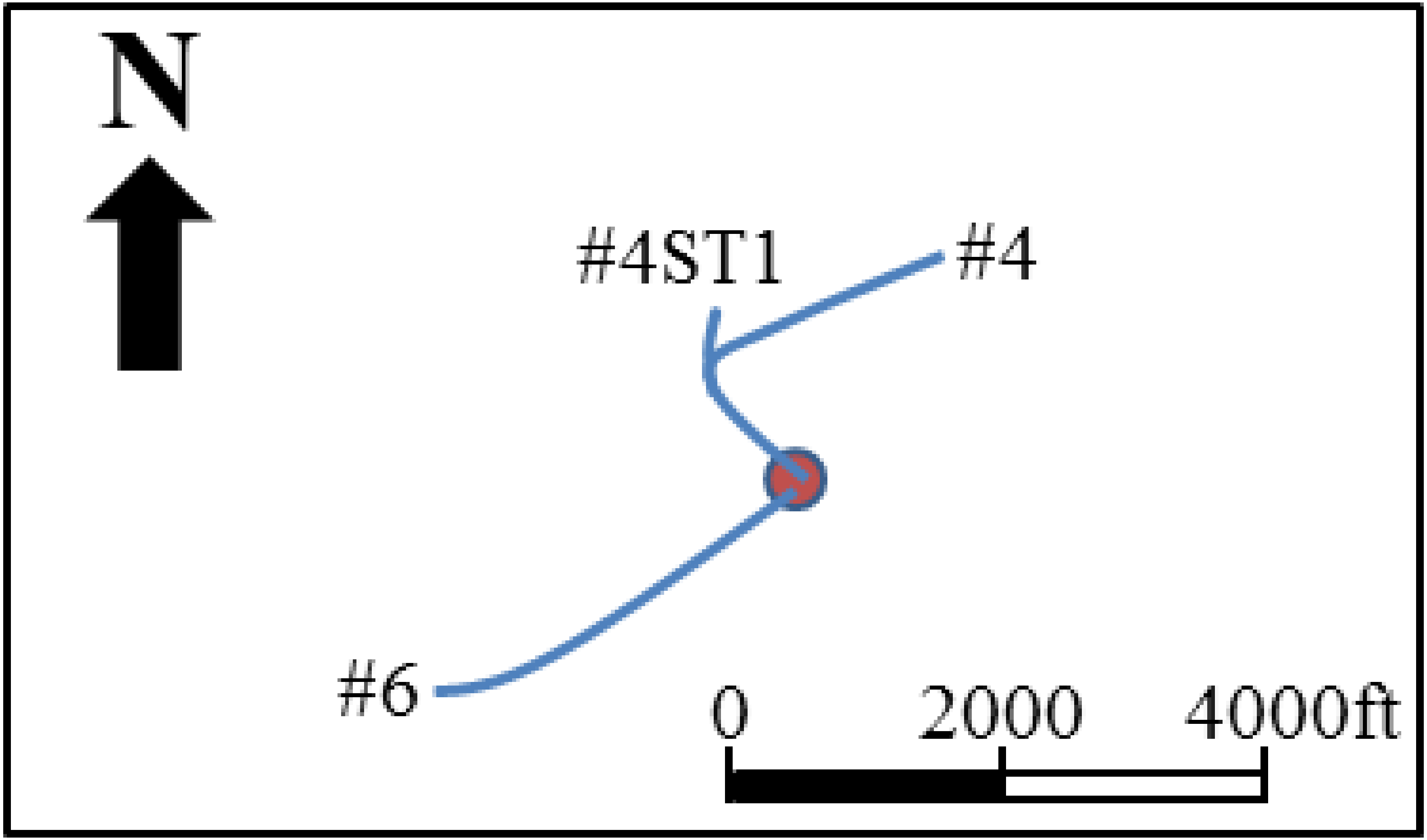
9300' Sand

B Sand



(courtesy of Clark Walraven)

Central Section Results

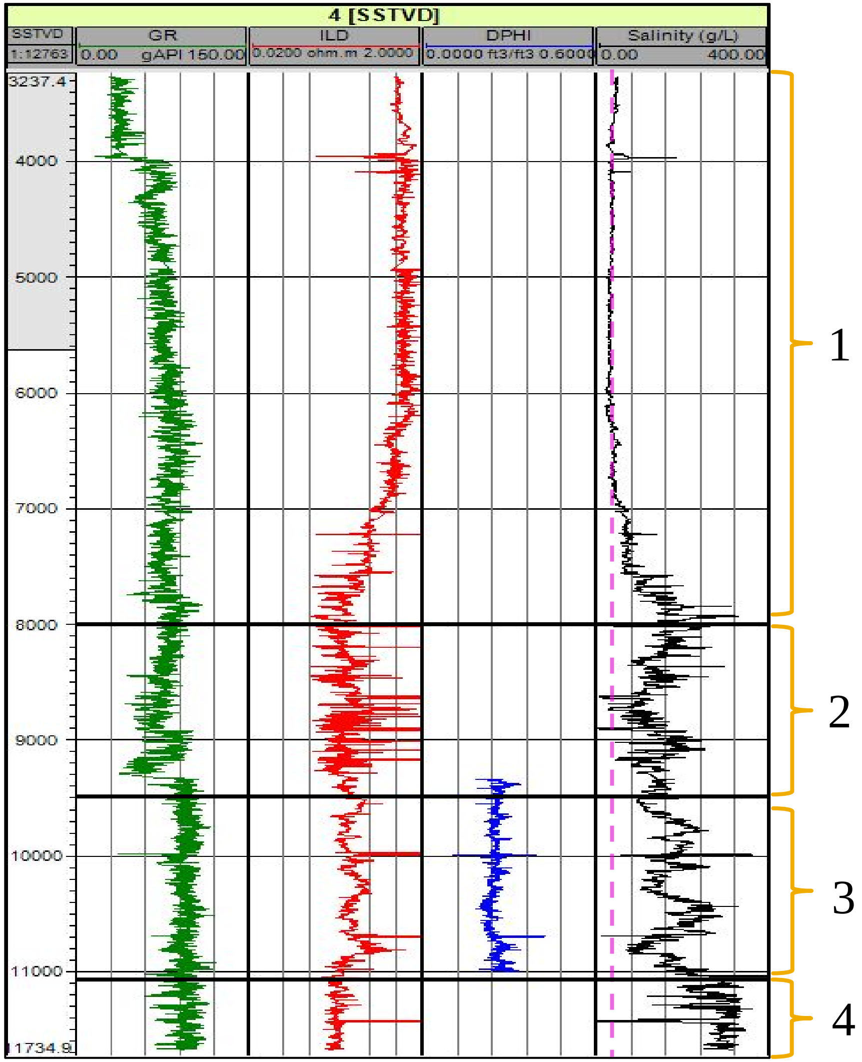


Central Section Salinity Profiles

- Hydropressured regime
  - ~ 35 g/L – 160 g/L
  - Increase in salinity with depth

Onset of Overpressure →

- Overpressured regime
  - ~ 80 g/L - 350 g/L
  - Highest salinities near base of #4 well
  - Increase in salinity with depth



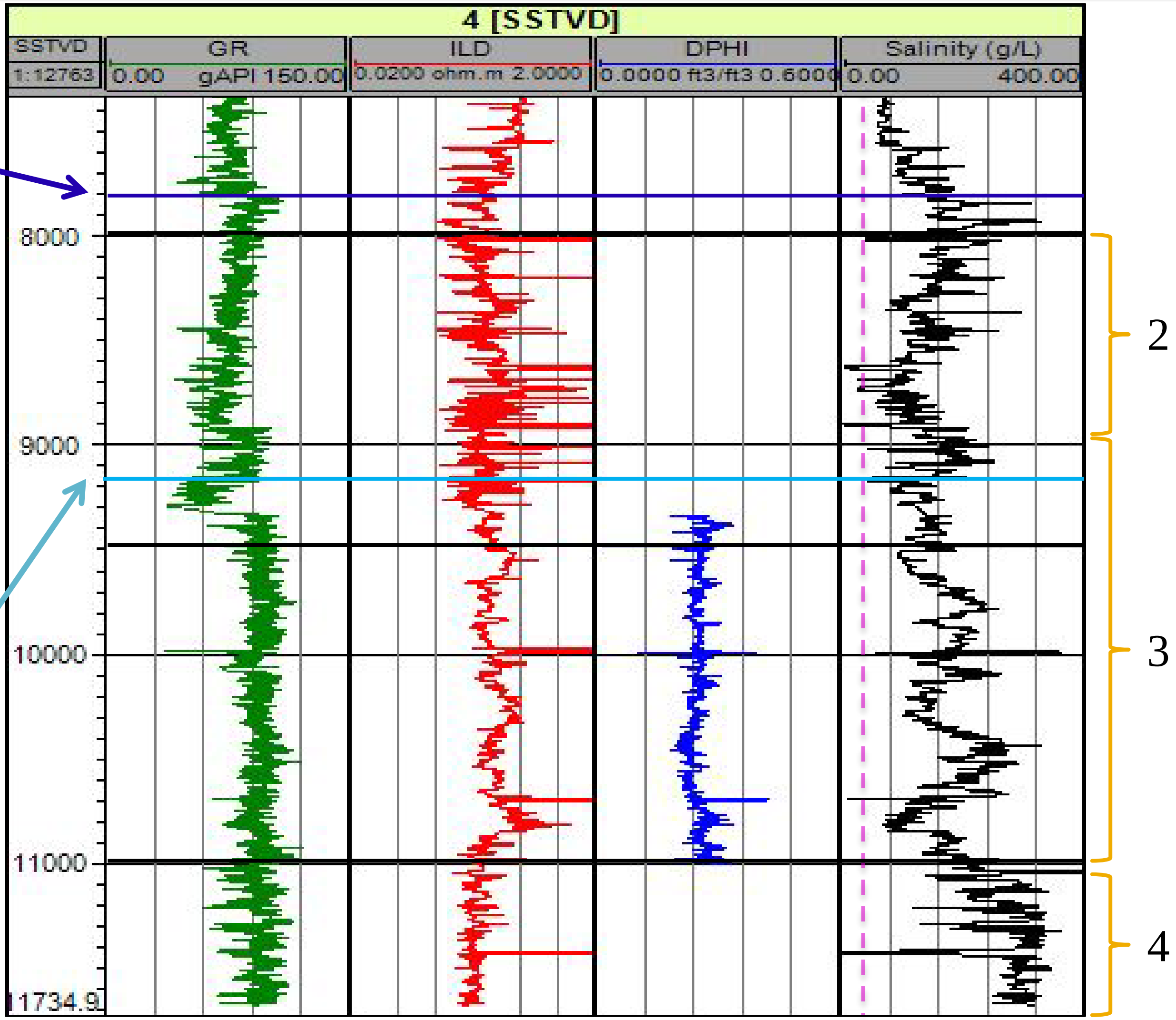
Central Section Salinity Responses

Blue Marker

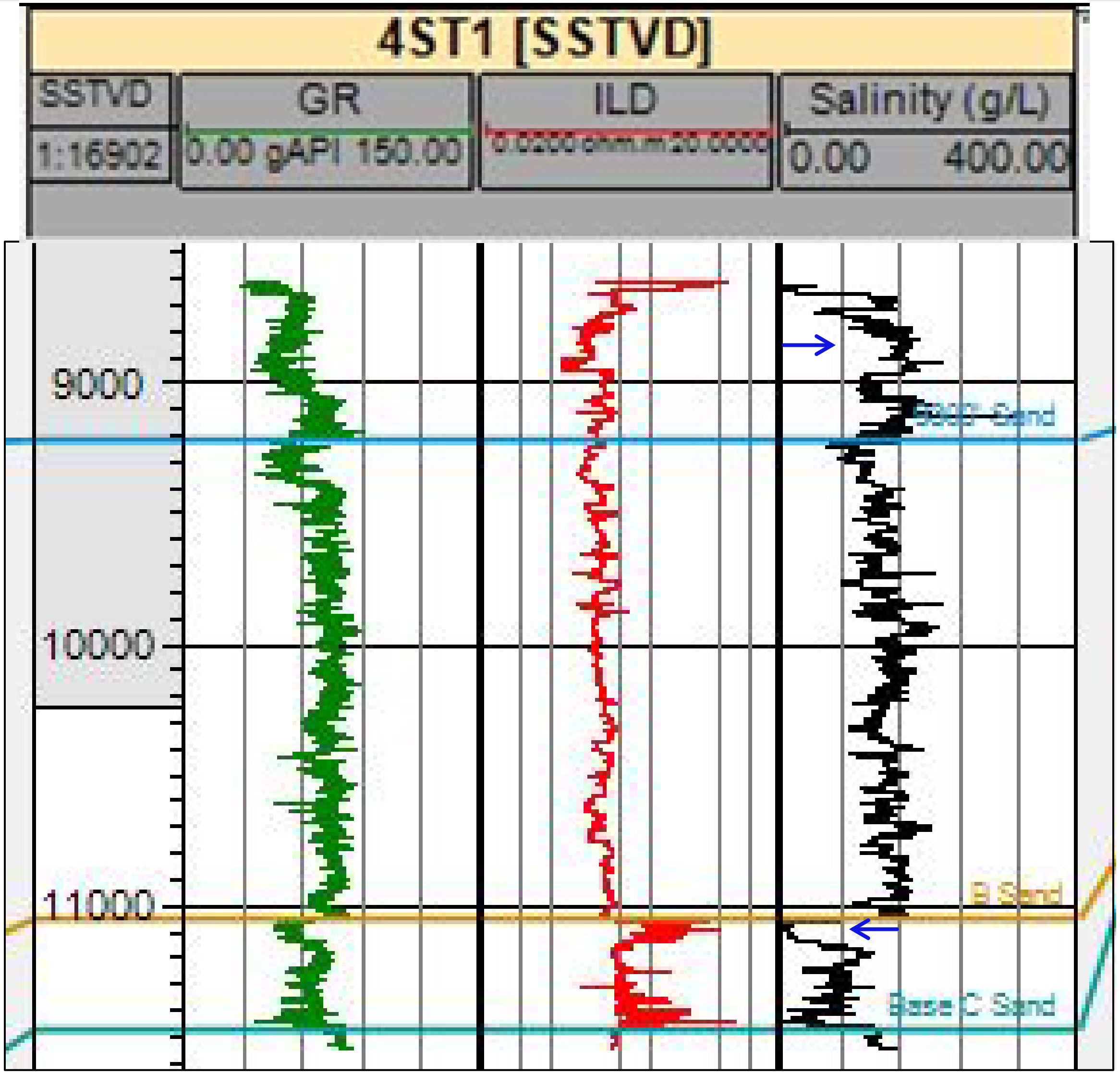
<u>Onset of Overpressure</u>

- Overpressured regime
  - 3 compartments of varying salinity
  - Compartment 3 may be subdivided into more compartments due to complex faulting near salt structure

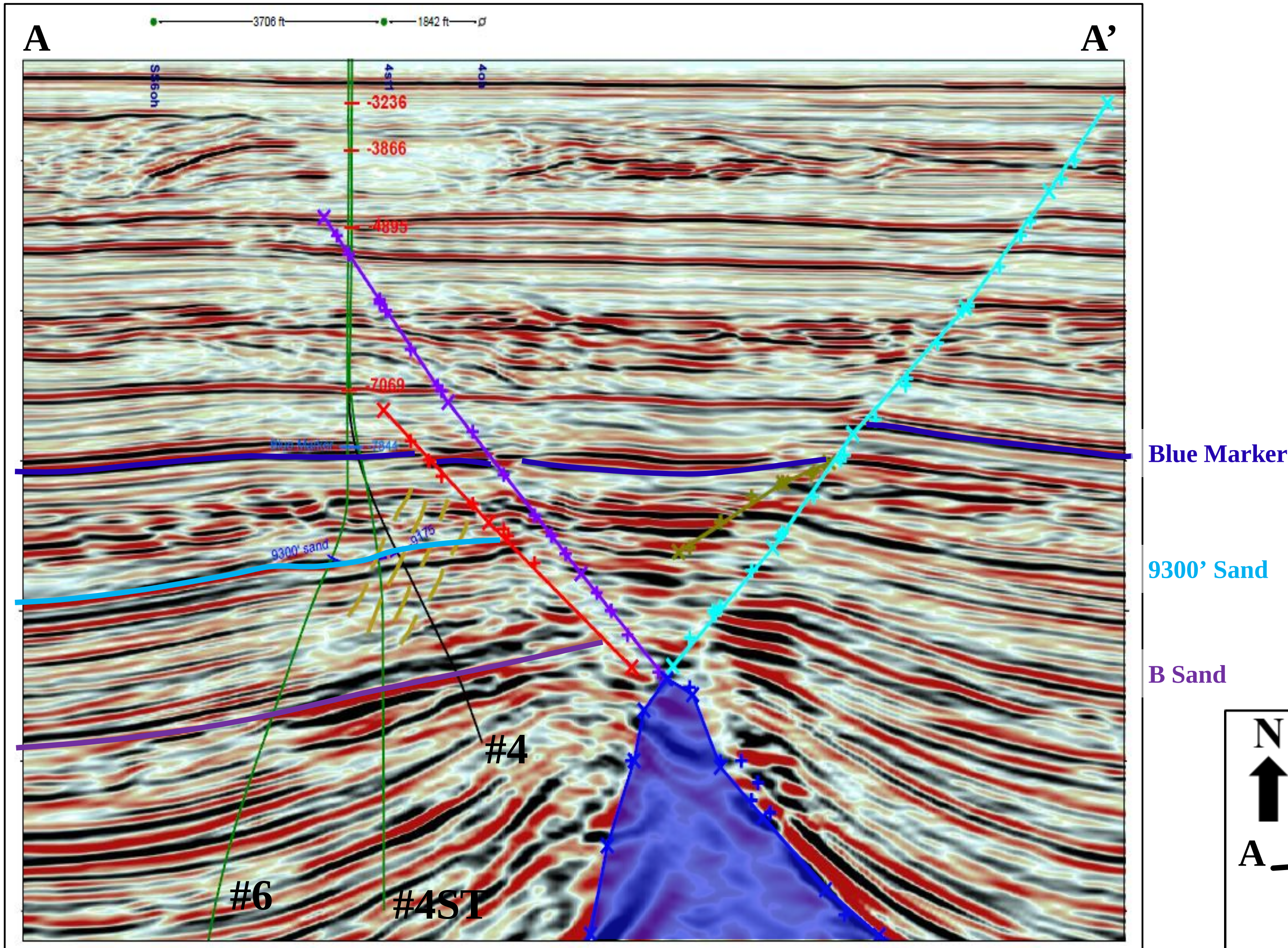
9300' sand

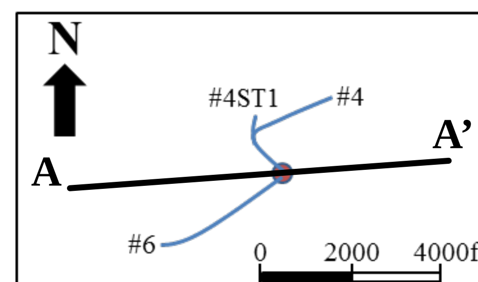


Salinity in Sand/Shale



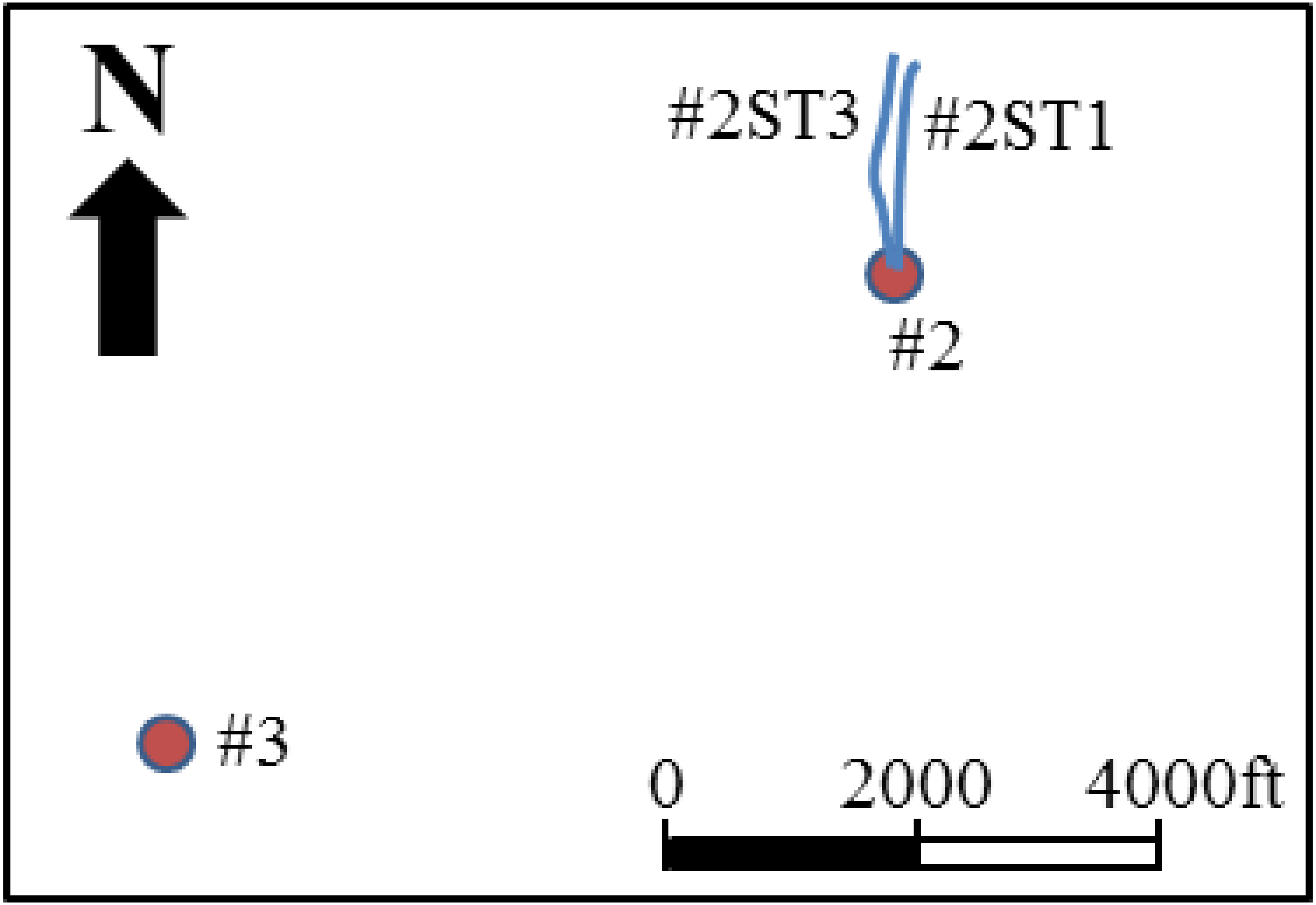
Central Section Seismic Profile





(courtesy of Clark Walraven)

Southern Section Results

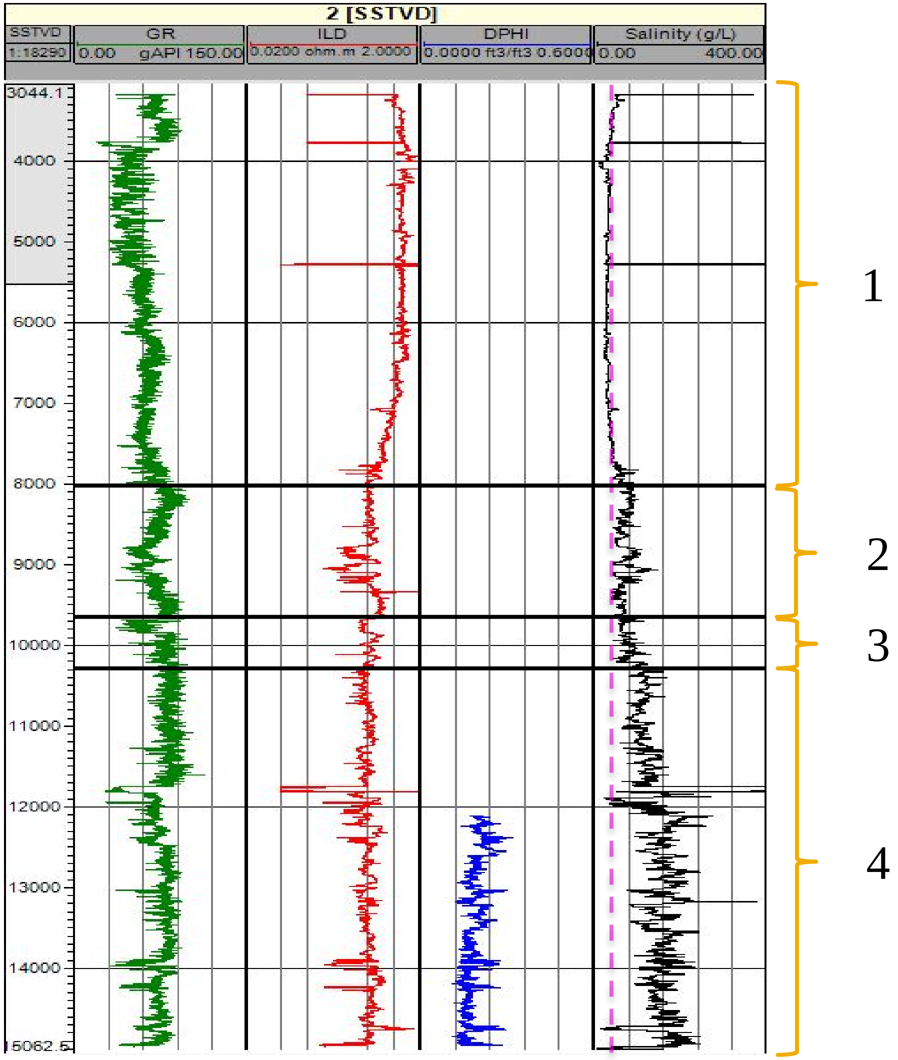


Southern Section Salinity Profile

- Hydropressured regime
  - ~ 35 g/L – 70 g/L
  - Increase in salinity with depth

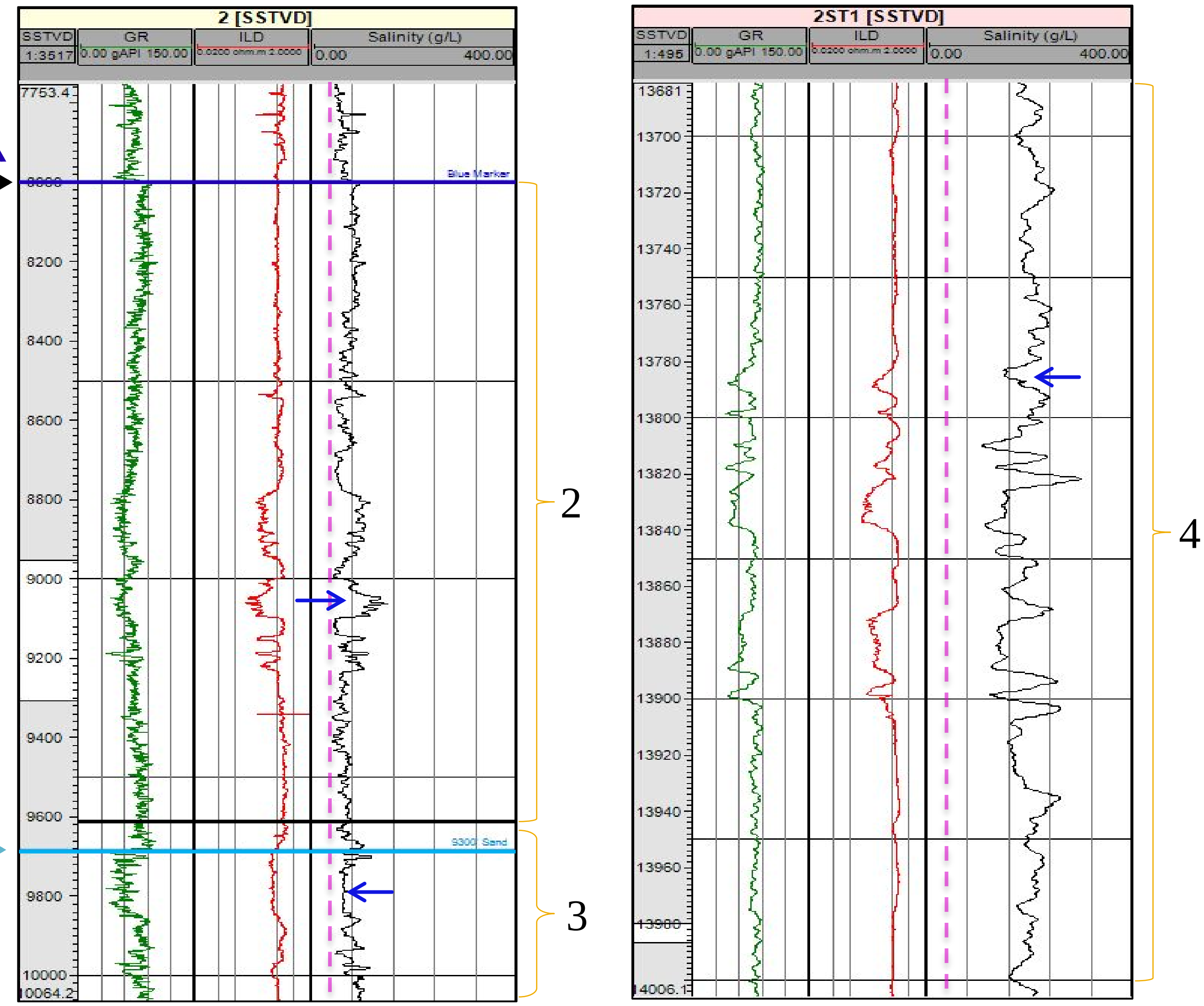
Onset of Overpressure →

- Overpressured regime
  - ~ 70 g/L – 240 g/L
  - High salinity zone
  - Increase of salinity with depth

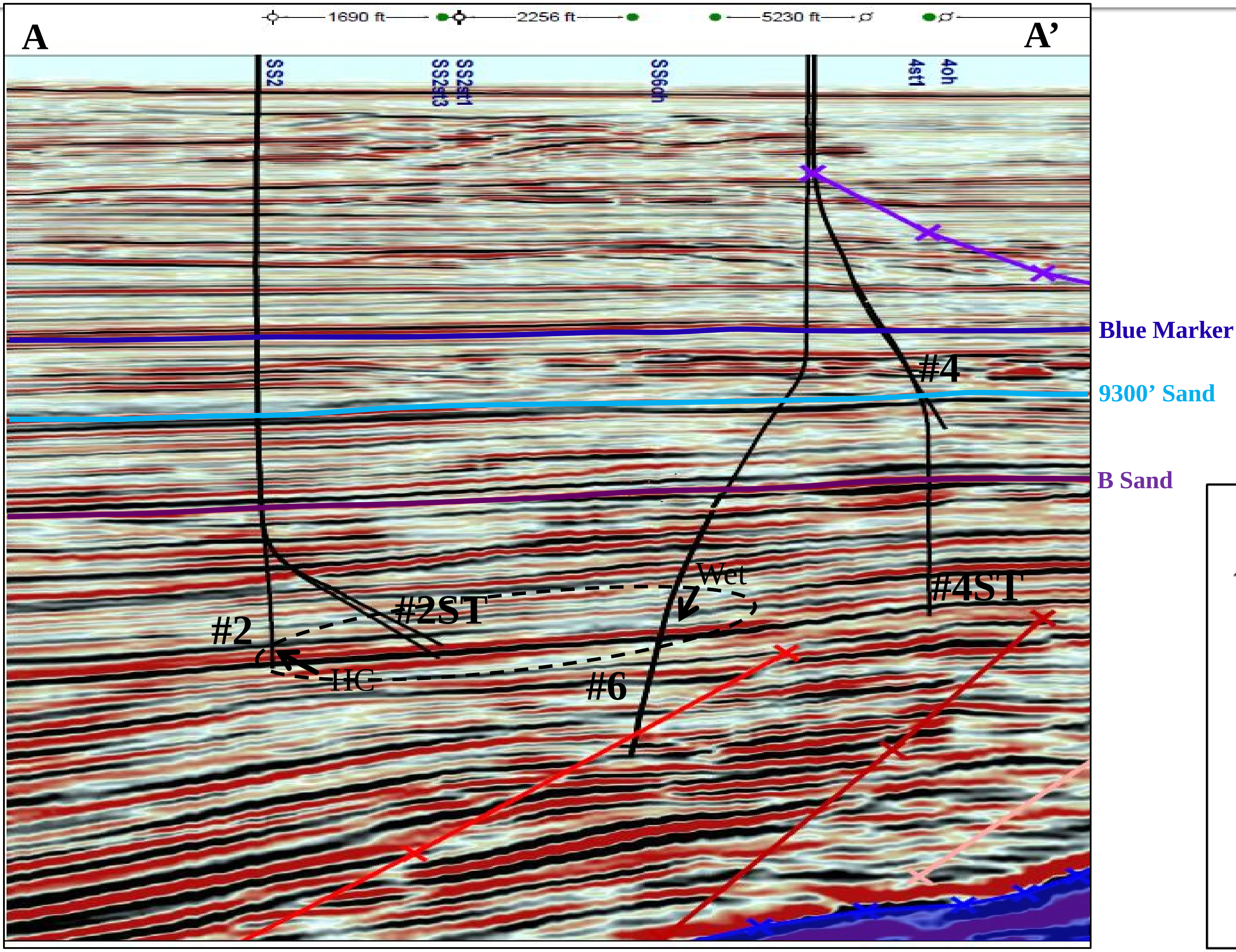


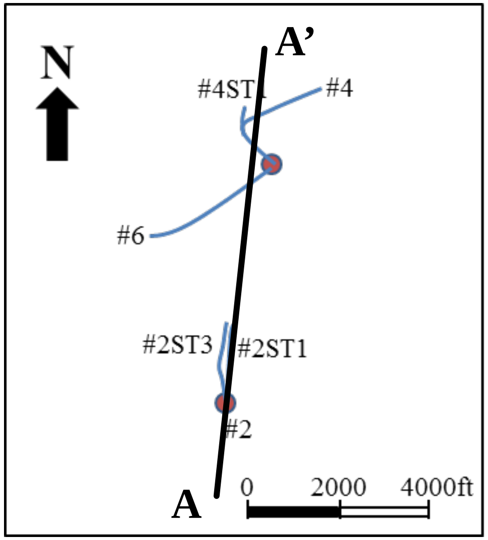
Southern Section Salinity Responses

- Overpressured regime
  - Two salinity responses versus depth



Southern Section Seismic Profile





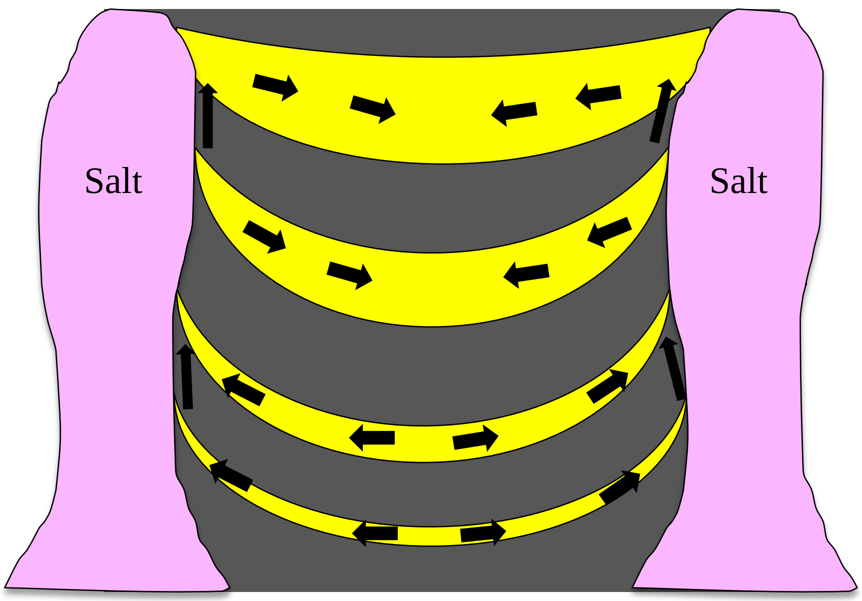
(courtesy of Clark Walraven)

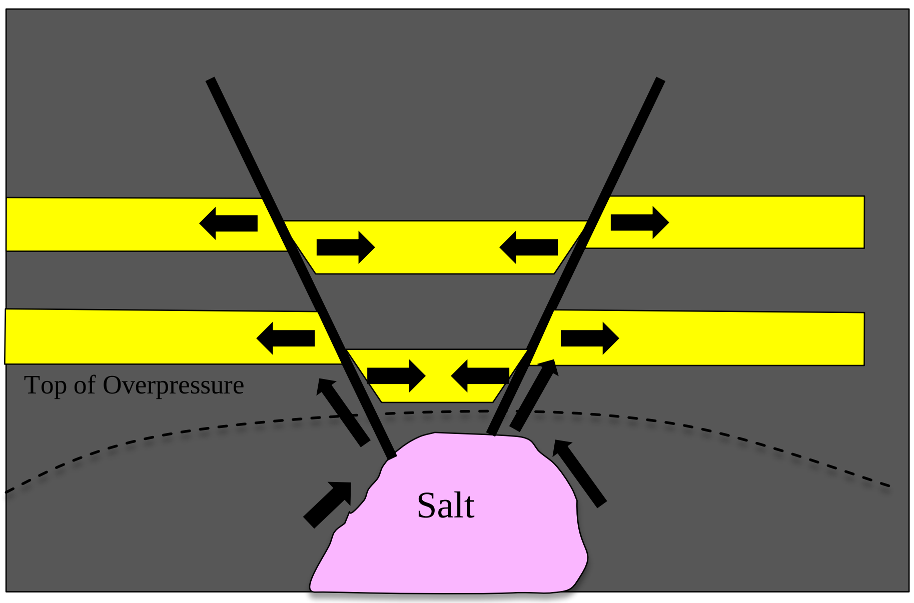
Discussion of Results

- Hydrogeologic regimes recognized
  - Hydropressured Regime
    - Approximately normal marine salinity with an increase near the top of overpressure
  - Overpressured Regime
    - Upper Section
      - Higher salinity
      - salinity of sands $>$ shales
    - Middle Section
      - Salinity reversal in Northern Section (no flow zone?)
      - Complex in Central Section
    - Lower Section
      - Much higher salinity increasing with depth
      - salinity of sands $<$ shales

Solute transport mechanisms

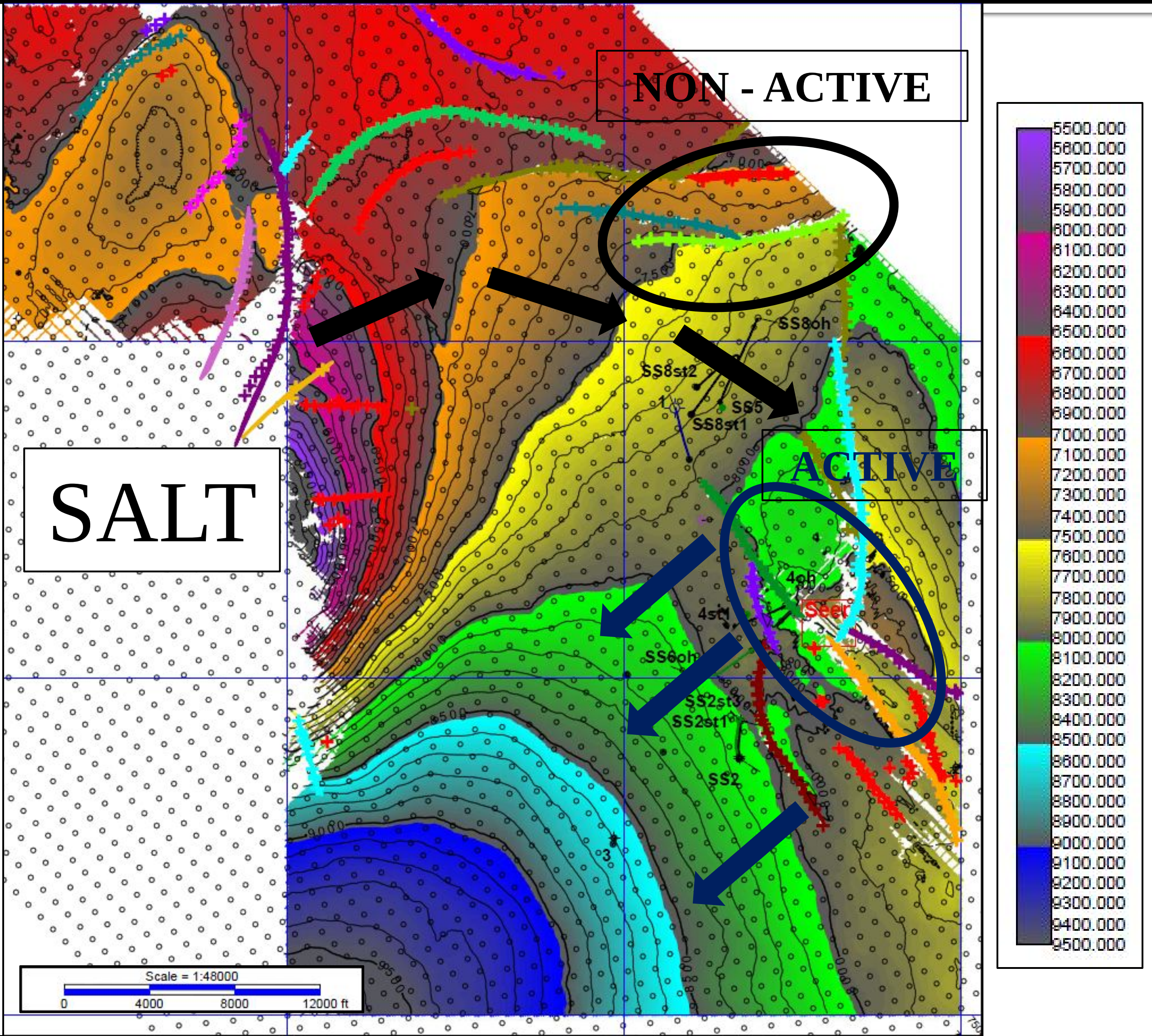
- Compaction driven advection
- Density driven flow
- Shale Dewatering
- Flow along faults and flanks of salt structure





Shallow Zone Migration Pathways

- Two Sources
  - Dissolution of salt from Western structure
  - Dissolution of salt from Eastern structure
- Pathways
  - Down dip density flow
  - Pressure driven flow along salt flanks and fault planes
  - Faults considered as active conduits are located nearest Central Section of the study area
  - Faults to the North are considered non active due to complexity of migration pathways via numerous fault planes



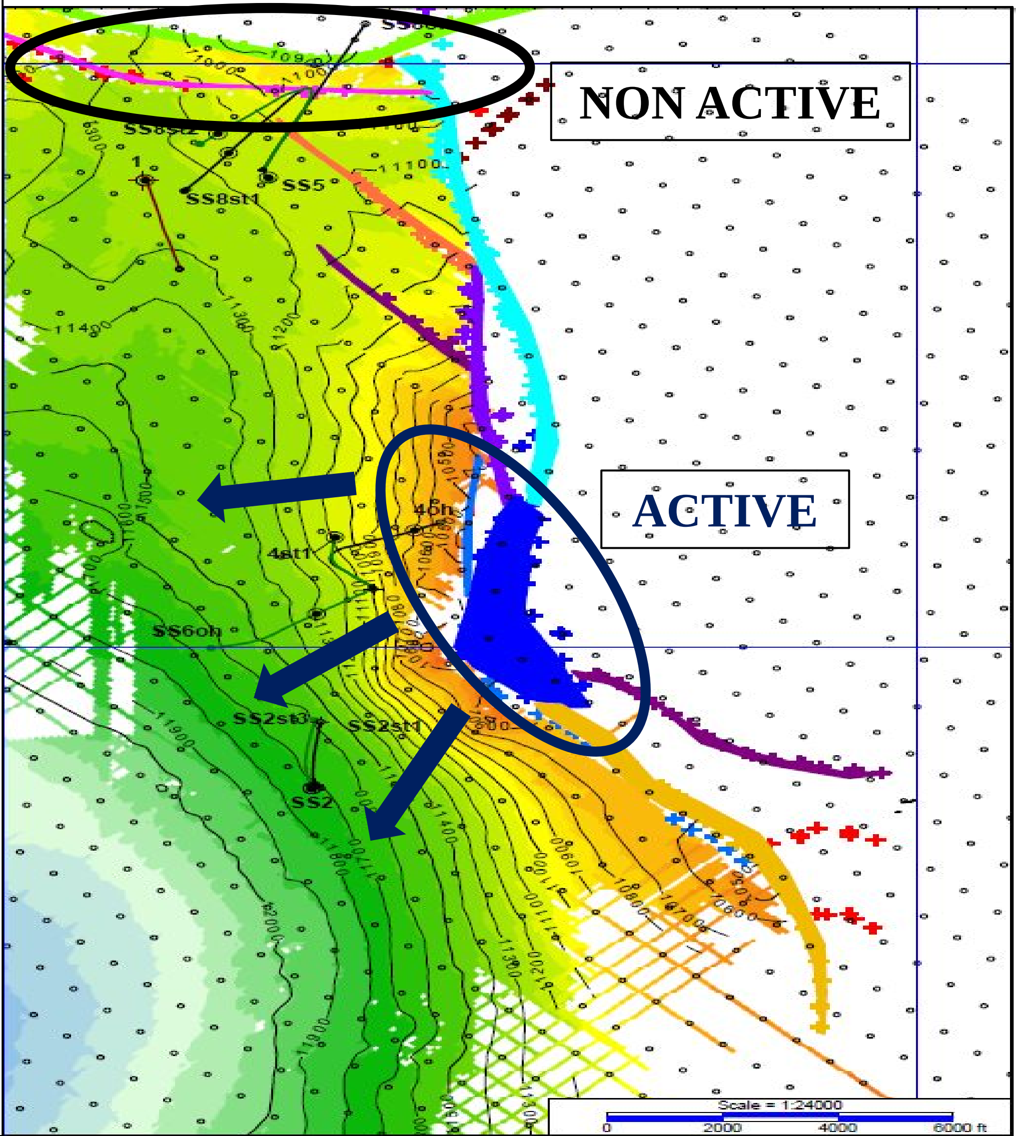
(courtesy of Clark Walraven)

Deeper Section Migration Pathways

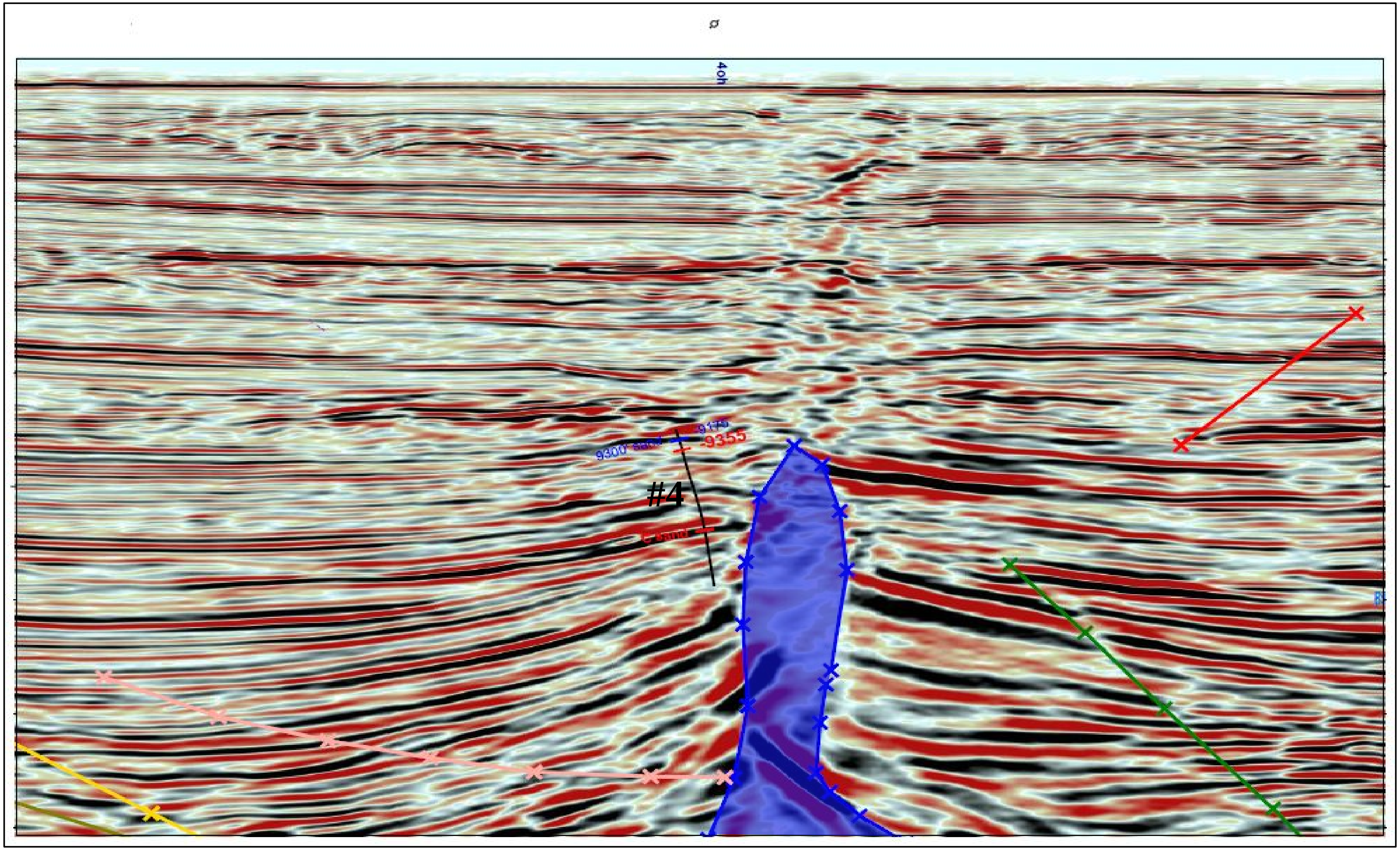
- Two Sources
  - Dissolution of salt from Eastern structure
  - Clay dehydration and expulsion into adjacent sands

- Pathways
  - Pressure driven flow along salt flank and fault planes
  - Faults considered as active conduits are located nearest Central Section of the study area
  - Faults to the North are considered non active

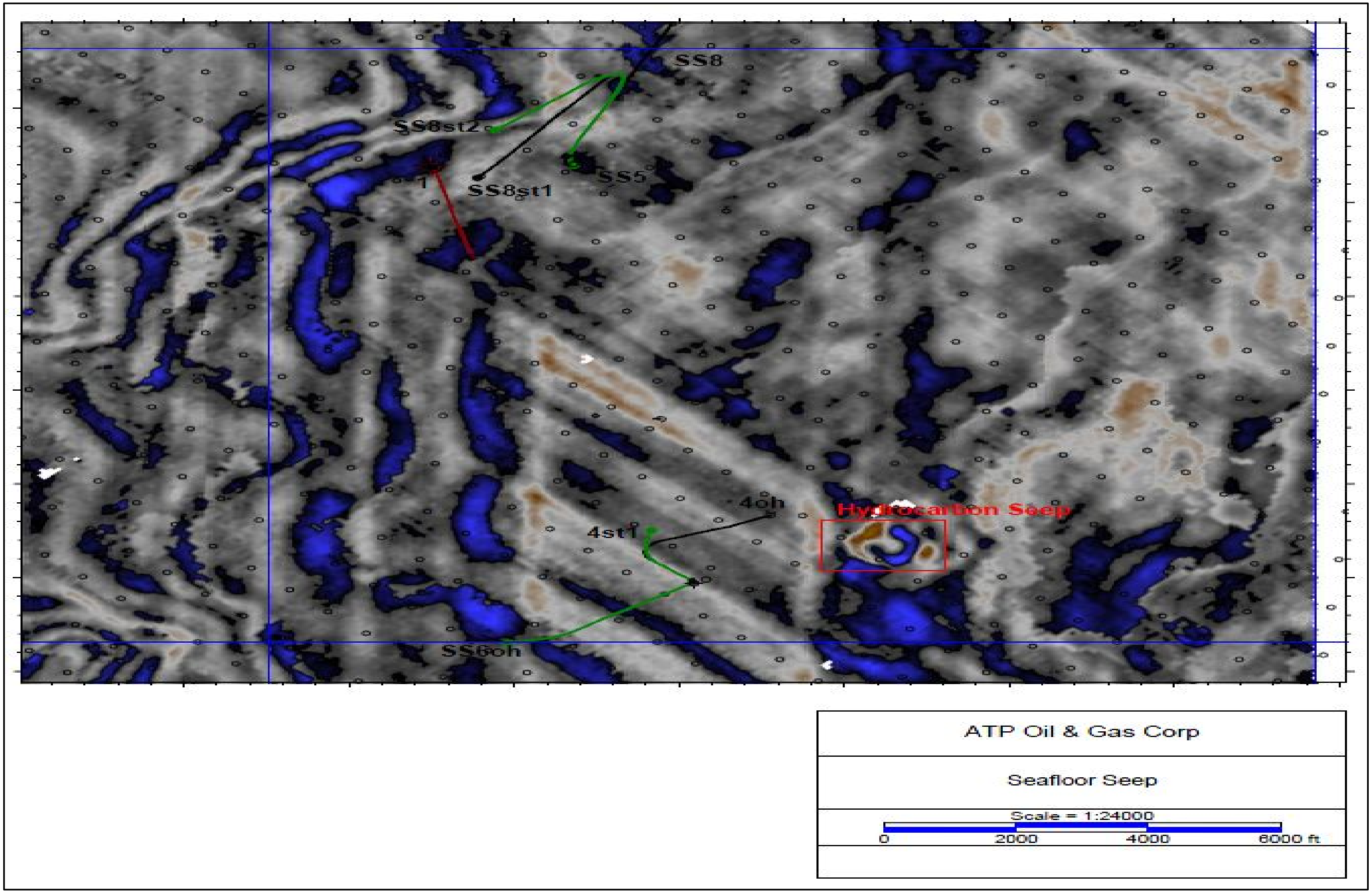
(courtesy of Clark Walraven)



Active Migration of Fluids



Active Migration of Fluids



Conclusions

- Some hydrologic regimes recognized onshore/near shore are also found in deepwater GOM
  - Variations in fluid flow pathways within study area
- Vertical compartmentalization of reservoirs within the study area illustrates the complex hydrogeology of the Gulf of Mexico
  - The presence of shallow brines above fresher water sands
- The driving mechanisms for fluid flow within the study area include:
  - Pressure driven flow of overpressured fluids into shallower sediments via salt flanks and faults
  - Density driven downdip migration of saline fluids derived from salt dissolution

Acknowledgments

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- Steve Sears
- Andre Revil