

Paleo-fluid Flows and Present Hydrodynamic Conditions Improved by Basin Modeling Integrating Salinity Transport

Xavier Guichet¹, Sylvie Wolf², and Pomuald Pandi¹

Search and Discovery Article #40530 (2010)

Posted April 30, 2010

*Adapted from oral presentation at AAPG International Conference, Rio de Janeiro, Brazil, November 15-18, 2009

¹Structural Geology, IFP, Rueil-Malmaison, France (xavier.guichet@ifp.fr)

²Applied Mathematics, IFP, Rueil-Malmaison, France

Abstract

Basin models are currently used to reproduce the present-day observed pressures in basins by modeling coupled processes such sedimentation, compaction, heat-flow and fluid flow. Measured pressures are consequences of the geological history of the basins and are related to an obvious estimate of the history of permeability fields. Permeability variations can be explained by geological, physical and chemical processes occurring in the course of the basin evolution. Moreover diagenetic phases have usually been associated with brine fluxes within basins.

The aim of our work is to calculate paleo-fluid flow which is then compared with fluid circulation assumptions proposed in geochemical studies to explain the main diagenesis stages identified in reservoirs. Therefore we developed a prototype for salinity transport based on Temis3D Software, which is a coupled numerical simulation program that evaluates pore pressure, porosity, overburden and other petroleum parameters through time. In our prototype, the salinity transport processes are calculated with an advection equation for a non-reactive solute such as salt. The heat and transport equations are coupled with the flow equation through the dependence of fluid density and of fluid viscosity on temperature and salinity. Equations are processed numerically by a finite-volume method on a square grid throughout the simulation of the basin evolution. For salinity transport, we require that groundwater along the halite bed maintain a salinity corresponding to saturation with respect to this mineral, and constant concentrations at surface are used in distinguishing marine and continental environments. Finally the integration of salinity transport through the geological history of the basins permits one to constrain the past evolution of a basin particularly in terms of paleosalinity and paleotemperature using fluid-inclusion data. As basin models try to reproduce through geological time coupled phenomena, they are dedicated tools to distinguish likely patterns of paleo-fluid flow for diagenetic models.

A simulation of the 200Ma geological history of the North Louisiana Salt Basin is presented and discussed.

Selected Bibliography

- Breit, G.N., compiler, 2002, Produced Water Database (provisional release): USGS <http://energy.cr.usgs.gov/prov/prodwat/> (accessed April 19, 2010)
- Dutton, S.P., and N.T. Diggs, , S. P., 1990, History of quartz cementation in the Lower Cretaceous Travis Peak Formation, east Texas: *Journal of Sedimentary Petrology*, v. 60, p. 191-202.
- Dutton, S.P., and L.S. Land, 1988, Cementation and burial history of low-permeability quartzite, Lower Cretaceous Travis Peak Formation, east Texas: *GSA Bulletin*, v. 100, p. 1271-1282.
- Hanor, J.S., 1988. Origin and migration of subsurface sedimentary brines: Society of Sedimentary Geology Short Course No. 21, Tulsa, 247 p.
- Hanor, J.S., 2007, Pre-production spatial variation in formation water salinity in a deepwater Gulf of Mexico field, *in* Water-Rock Interaction, Bullen and Wang, eds., Taylor and Francis Group, London, p. 505-508.
- Hanor, J.S., and McIntosh, J.C., 2006, Are secular variations in seawater chemistry reflected in the compositions of basinal brines?: *Journal of Geochemical Exploration*, v. 89, p. 153-156.
- Hanor, J.S., and J.C. McIntosh, 2007, Diverse origins and timing of formation of basinal brines in the Gulf of Mexico sedimentary basin: *Geofluids*, v. 7, p. 227-237.
- Harrison, W.J., and L.L. Summa, 1991, Paleohydrology of the Gulf of Mexico basin: *American Journal of Science*, v. 291, p. 109-176.
- Harvie, C.E., N. Moller, and J.H. Weare, 1984, The prediction of mineral solubilities in 125 natural waters: The Na-K-Mg-Ca-H-Cl-SO₄-OH-HCO₃-CO₃-H₂O-system to high ionic strengths at 25°C: *Geochim. Cosmochim. Acta*, v. 48(4), p. 723-751.
- Mancini, E.A., D.A. Goddard, J.A. Obid, and V.O. Ramirez, 2006, Characterization of Jurassic and Cretaceous facies and petroleum reservoirs in the interior salt basins, central and eastern Gulf coastal plain, *in* The Gulf Coast Mesozoic Sandstone Gas Province Symposium Volume: Tyler, East Texas Geological Society 2006 Symposium, p.11-1 to 11-27.
- Ranganathan, V., and Hanor, J.S., 1987. A numerical model for the formation of saline waters due to diffusion of dissolved NaCl in subsiding sedimentary basins with evaporites: *Journal of Hydrology*, v. 92, p. 97-120.
- Salvador, A., 1991, Origin and development of the Gulf of Mexico basin, *in* A. Salvador, ed., The Gulf of Mexico Basin, Volume J: The Geology of North America: Geological Society of America, p. 131–180.

Paleo-fluid Flows and Present Hydrodynamic Conditions Improved by Basin Modeling Integrating Salinity Transport

Xavier Guichet, Sylvie Wolf
Romuald Pandi
Structural Geology, IFP (France)





Outlines

- Salt Transport and Basin Modeling
- The Model for the origin and the transport of basinal brines
- Case study: North Louisiana Salt Basin
- Results and Discussion
- Conclusions



Salt Transport and Basin Modeling

- Basin modeling: two major aims
 - Overpressure assessment
 - Oil migration pathways
- Basin plumbing very important
 - stratigraphic geometries
 - petrophysical properties of rocks
- Overpressures and good understanding of sedimentation rate = estimate of permeabilities
- Without overpressures, a way for estimating flow velocities = use of tracers



Salt Transport and Basin Modeling

- Salinity like a geochemical tracer of fluid flows
 - Present day: salinity measurements
 - Past: fluid inclusion
- Salinity is also a key parameter for processes linked with geochemical reactions
 - salinity determines ionic strength, activity of chemical species
 - salinity has an indirect control on CO₂ solubility, for example



Model

■ Advection Law

$$\frac{\partial C}{\partial t} + \nabla(C \cdot \vec{V}) = q$$

■ Equilibrium Assumption

- groundwater along the evaporite bed maintains a salinity corresponding to saturation with respect to halite (Bethke, Basin 2)

Source law q (Buried Halite)

Salinity is calculated by polynomial function of the temperature
The polynomial based on Harvie-Moller model (1984)

■ Boundary Conditions (set of salinity along the basin surface)

- for each event, the user provides the salinity
- 35 g/L offshore, about 1 g/L onshore



Case Study: North Louisiana Salt Basin

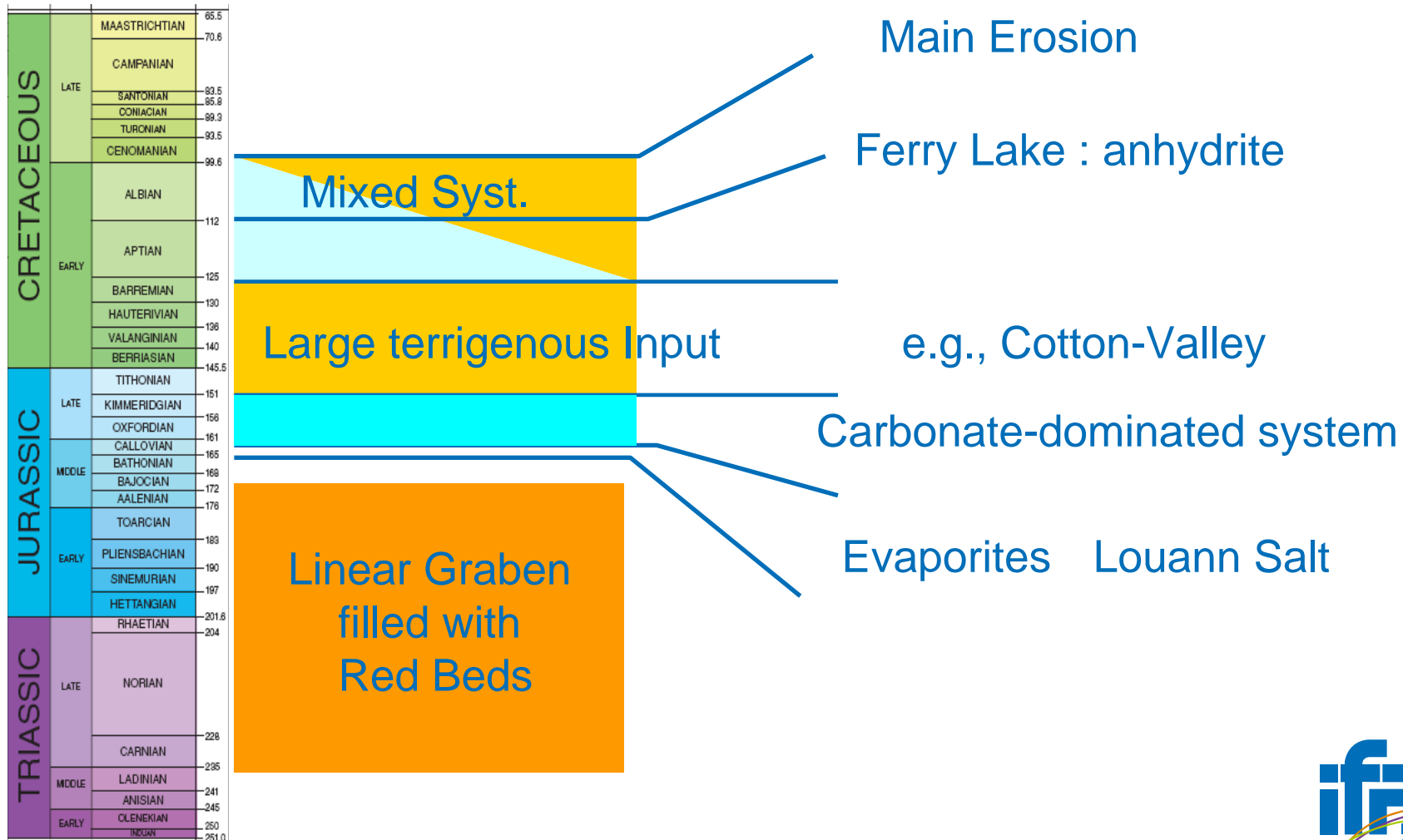
■ Numerous available data

- A. Salvador "*The geology of North America. Volume J : the Gulf of Mexico basin*", 1991
- Produced Water Data (USGS)
<http://energy.cr.usgs.gov/prov/prodwat/>

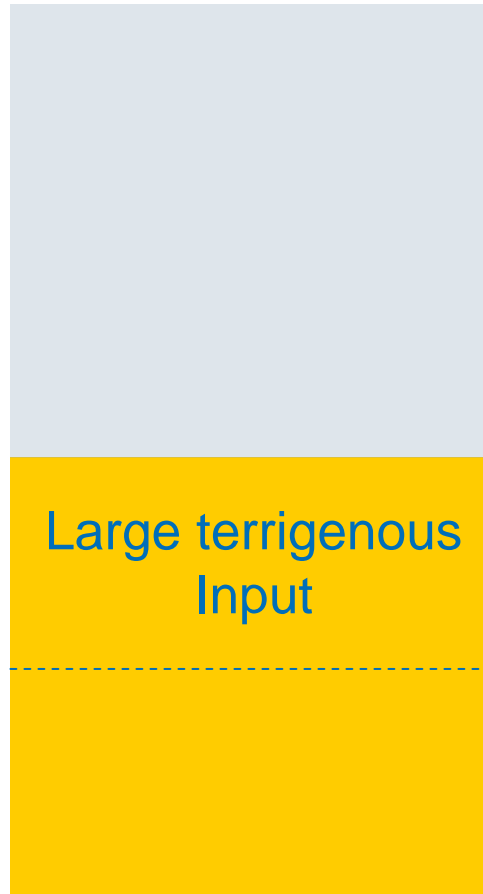
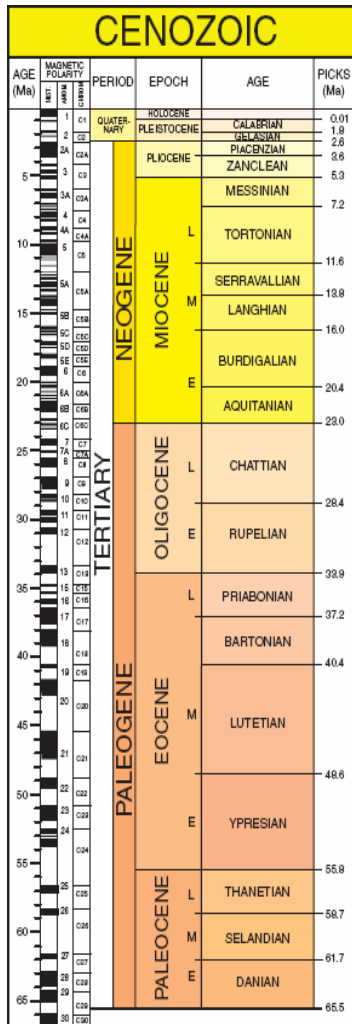
■ Studies of reference

- Basin Modeling
 - Harrison & Summa (1991)
 - E. Mancini (2006)
- Geochemical studies about the Origin and Transport of basinal Brines
 - J. Hanor (Baton Rouge, LSU)
- Thermal history
 - S. Dutton (BEG, UT Austin)

North Louisiana Salt Basin: Geologic history



North Louisiana Salt Basin: Geologic history

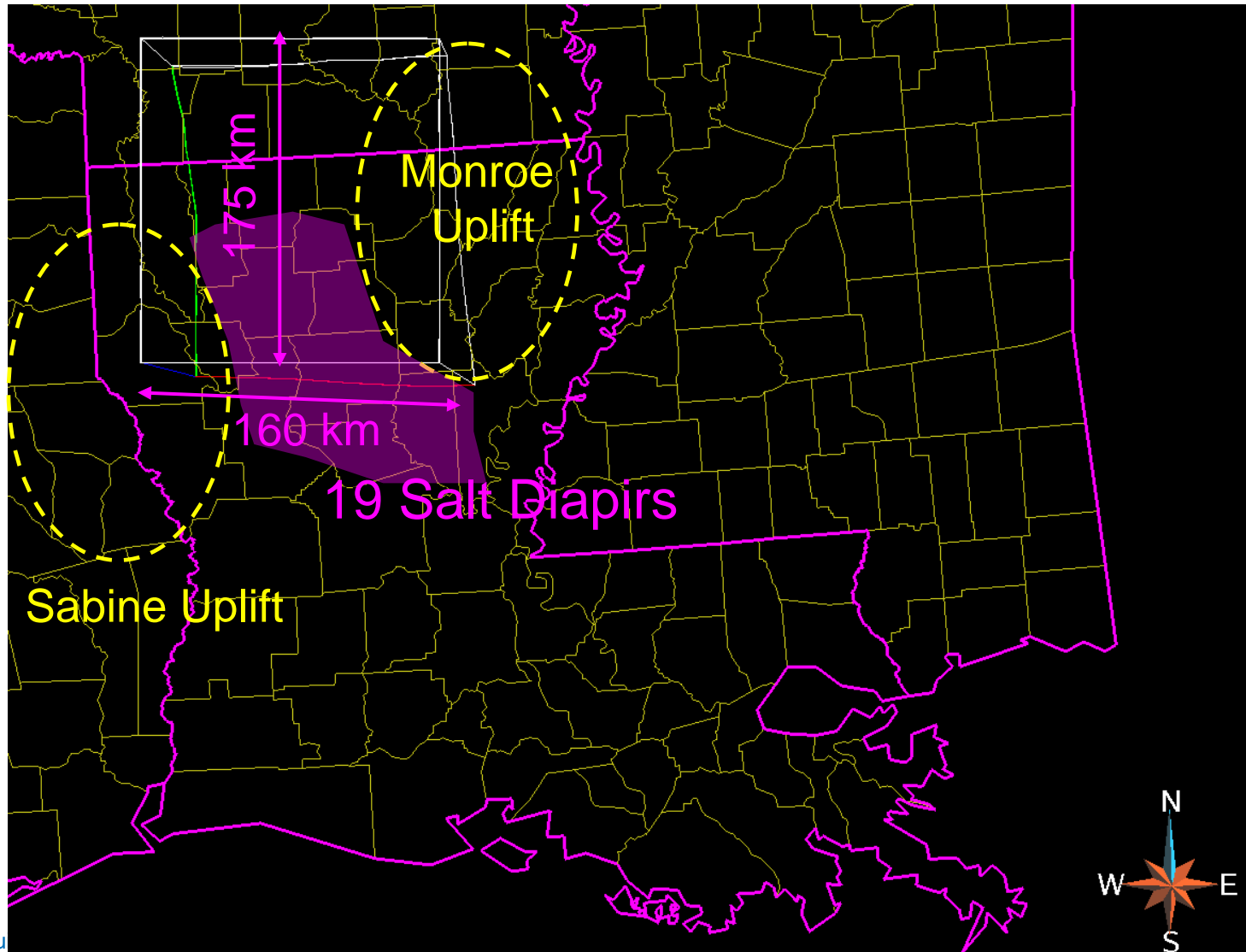


No deposit

Claiborne Fm.
(Cyclical transg. & regressive prograding events)

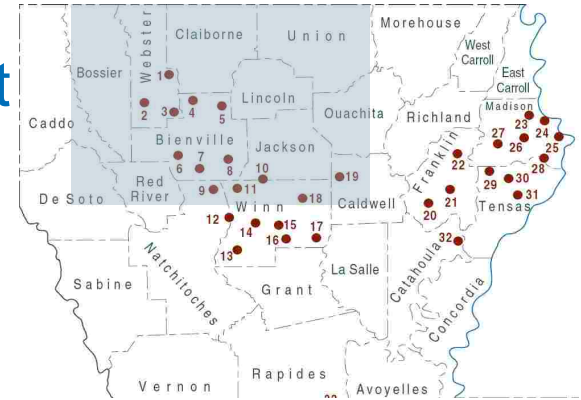
Wilcox Fm.
(Coarse clastic sediments)

NLSB Block overview

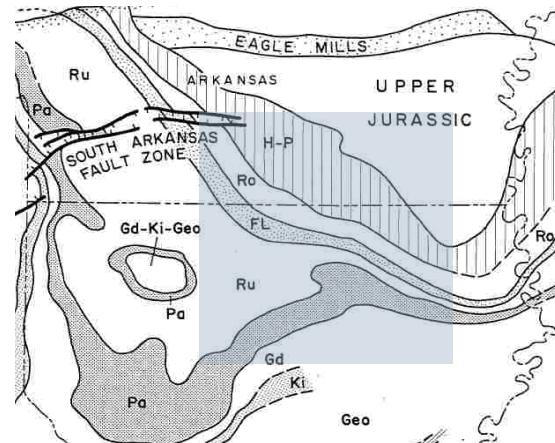


NLSB Block overview

Louann Salt Deposit
+
13 Salt Diapirs



Cenomanian Unconformity
(from Salvador (1991))

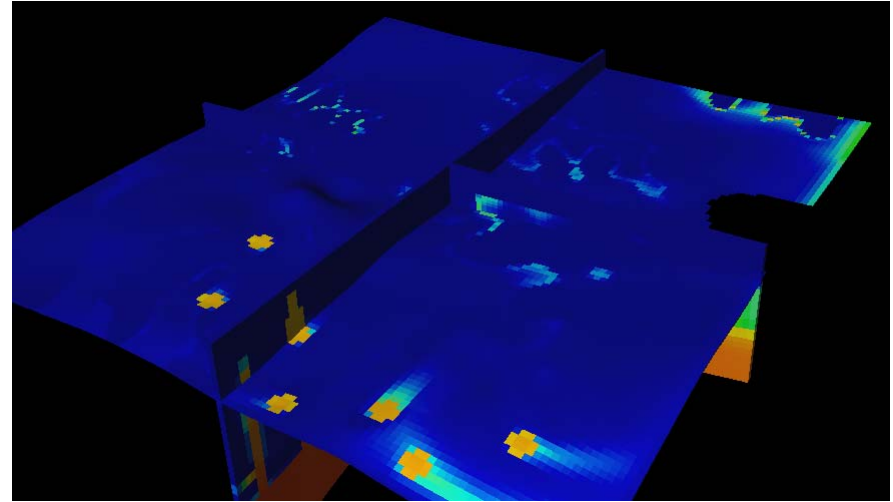


3D Block with 30 events, one erosion, and 10 lithologies

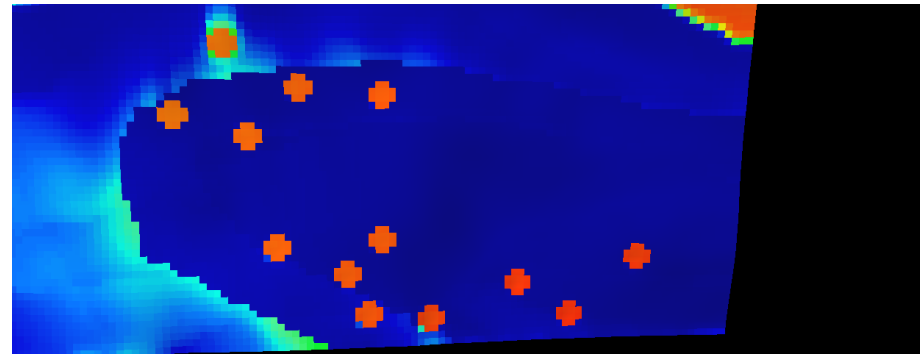
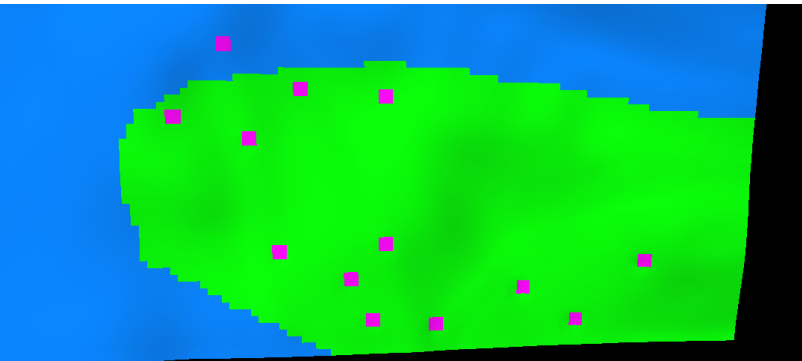


Simulation Results (general observations)

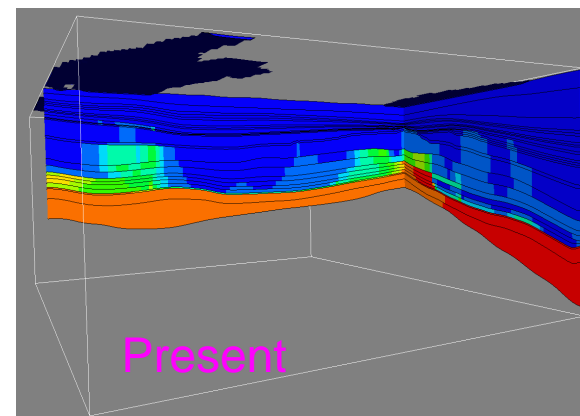
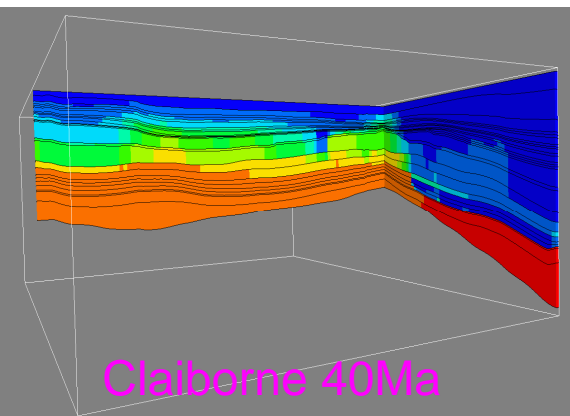
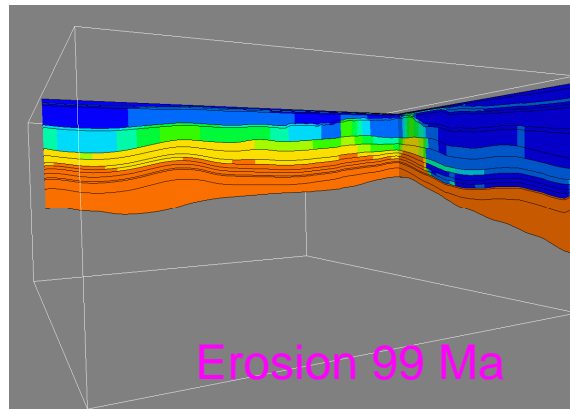
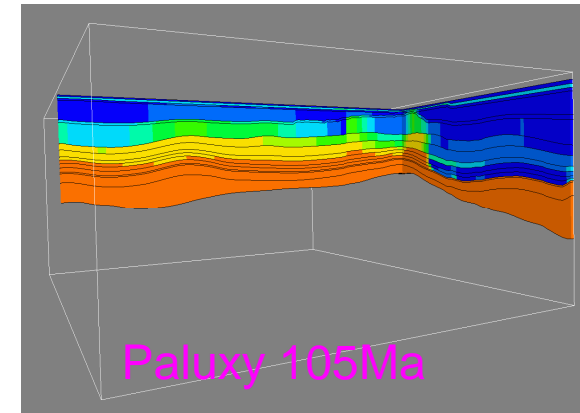
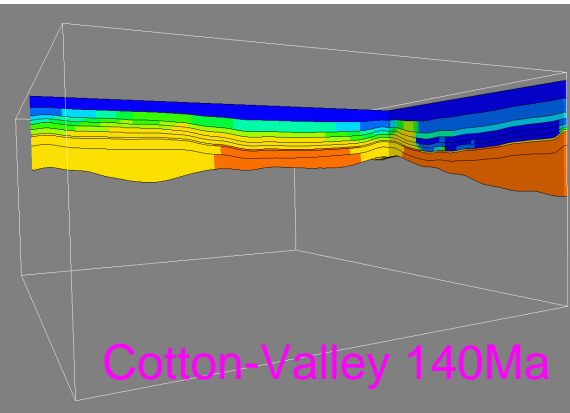
- Plumes around Diapirs



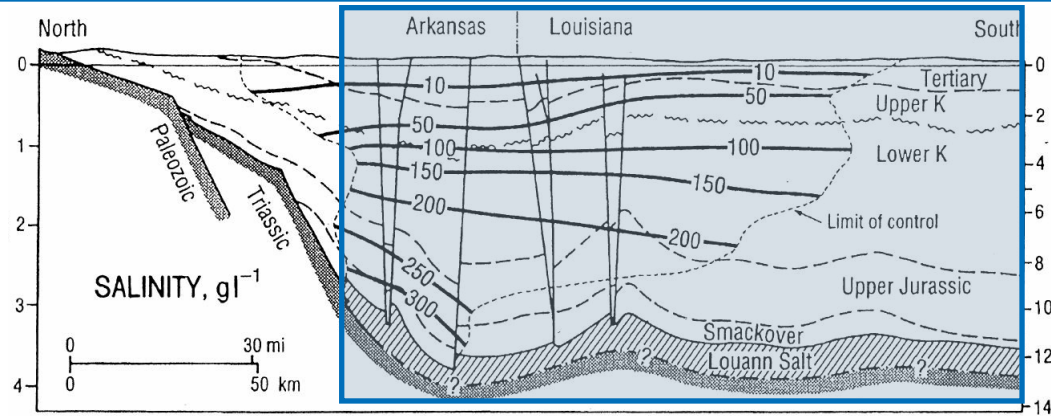
- Lithologies determine the extension of the salinity plumes



Salinity through time

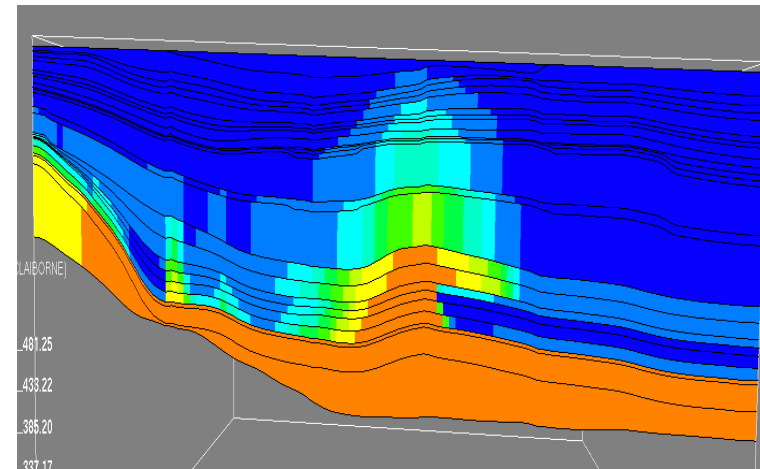
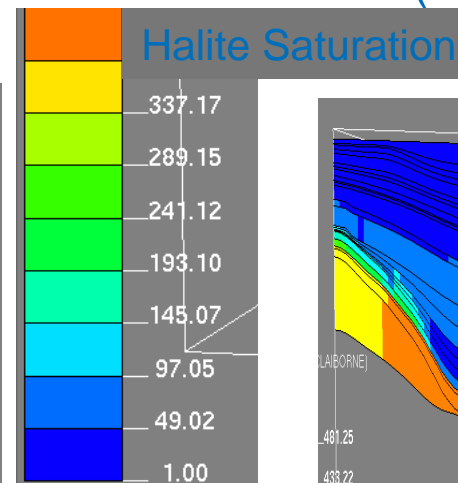
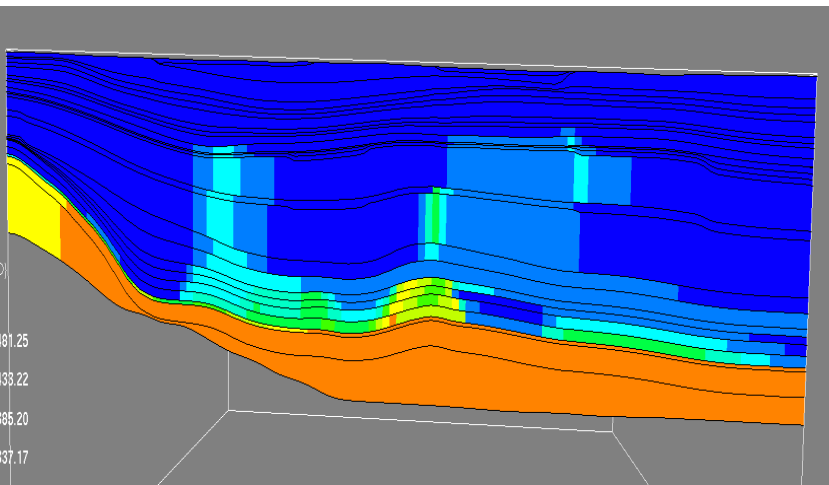


N-S Section West Border (Hanor and McIntosh, 2006)

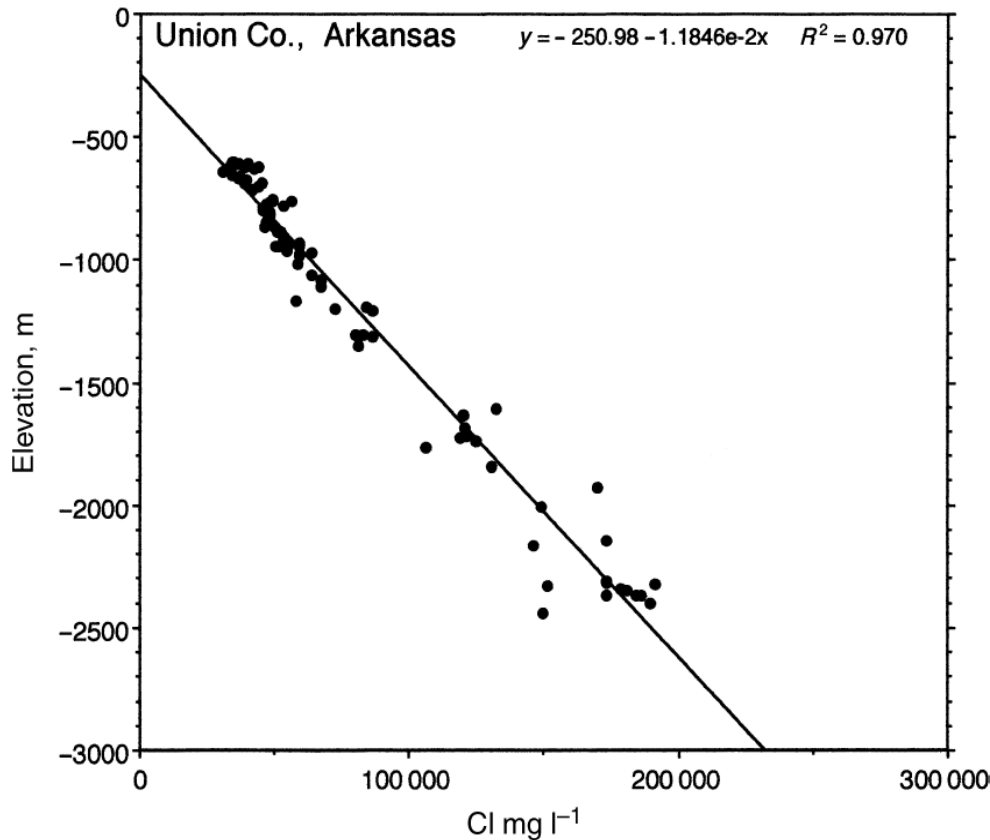


Present

Late Eocene
(when sedimentation stops)



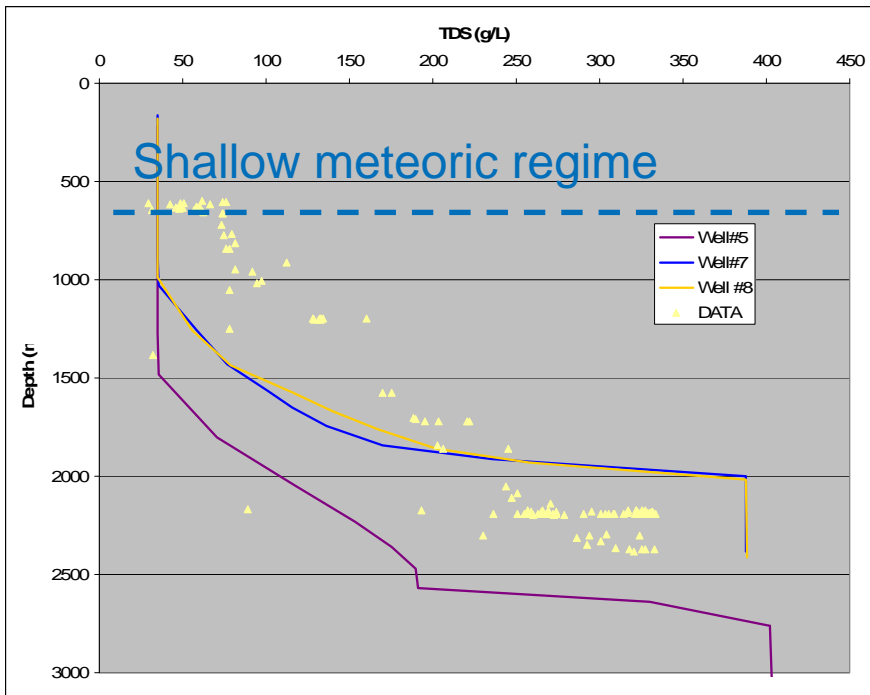
Union County (South Arkansas)



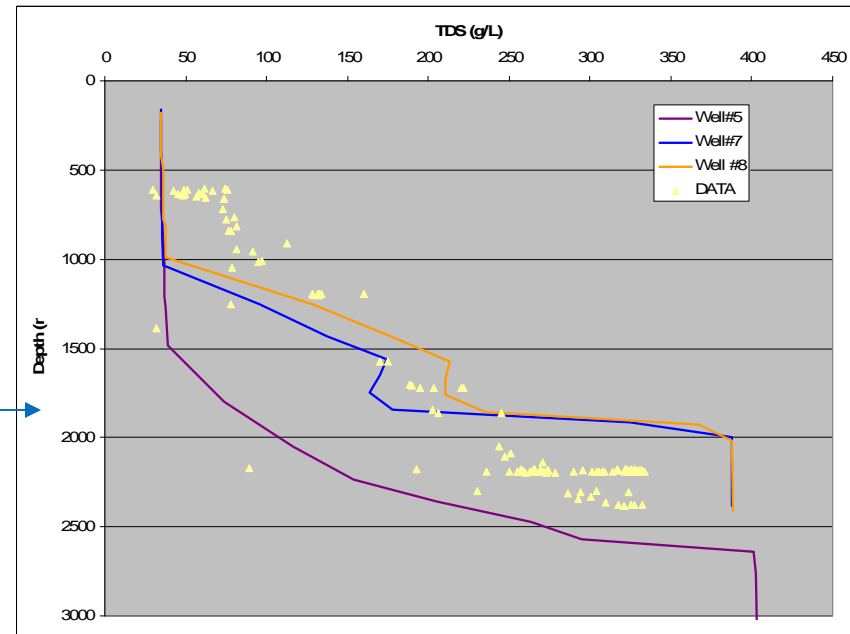
from Hanor and McIntosh (2007)

- Hanor (1984) suggested that the systematic linear increase in salinity represents an ongoing, steady-state mass transport of dissolved NaCl from evaporites at the base of the section to the base of the shallow meteoric regime.
- Numerical modeling by Ranganathan & Hanor (1987) showed that molecular and Soret diffusion are probably not rapid enough to account for the observed profile

Union County (South Arkansas)

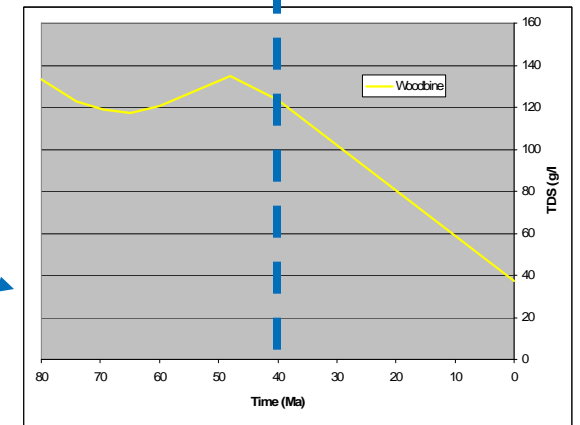
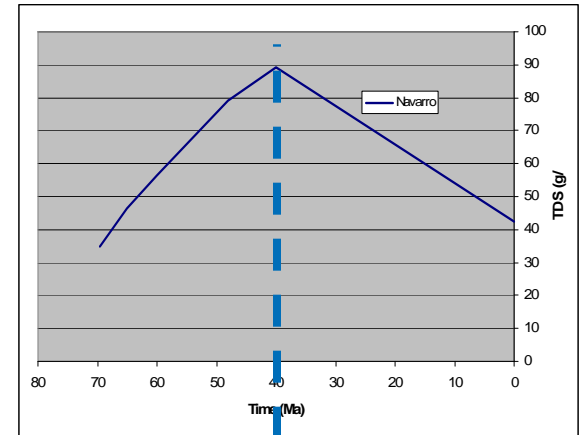
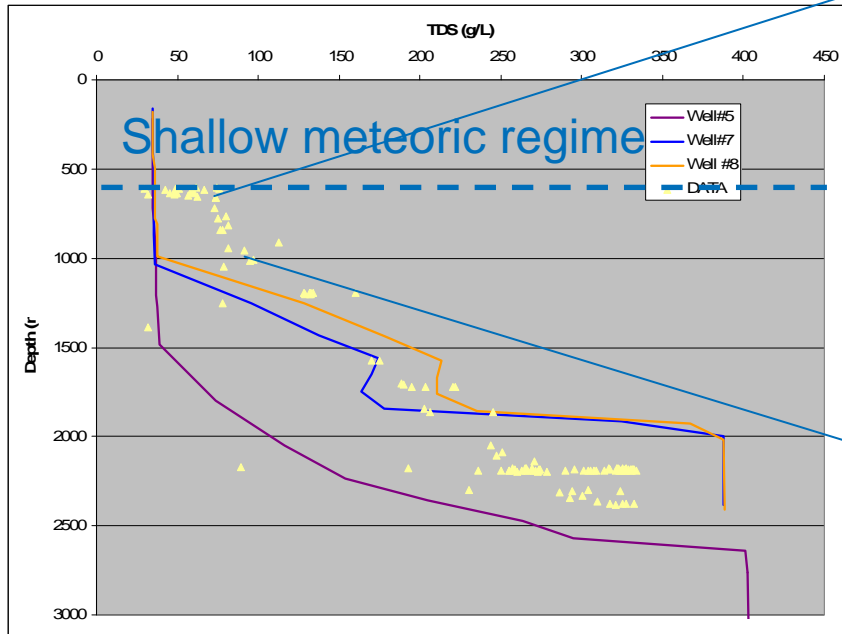


Assumption: halite was present with Ferry-Lake Fm. in the NE part of the block, but it has been eroded.



Union County (South Arkansas)

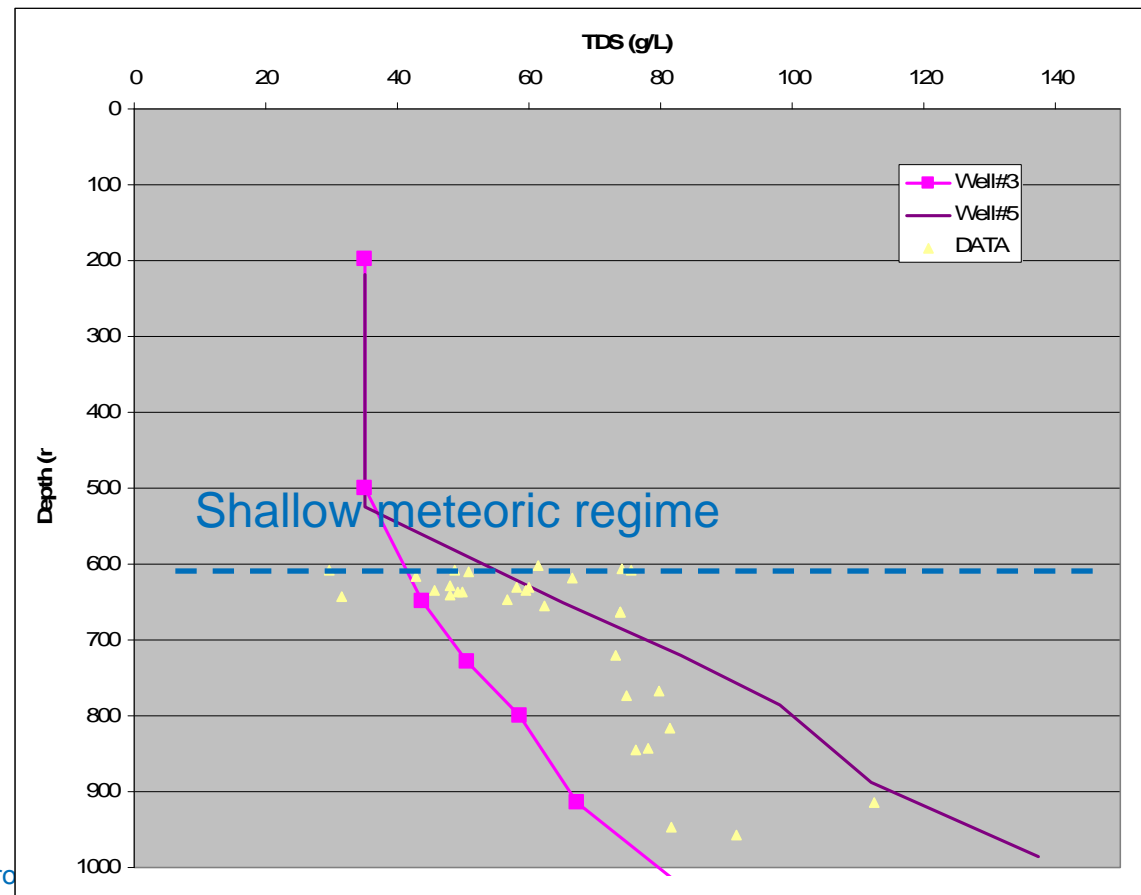
Salinity History



When sedimentation stops, dilution of brines with meteoric waters occurs.

Union County (South Arkansas)

- Ad-hoc permeability calibrations allow fit of the salinity trend and the contact between meteoric water and basinal brines





Conclusions

- We propose a new algorithm for 3D calculations including
 - halite dissolution
 - salinity transport by advection
- The algorithm gives us access to
 - salinity history
 - water mixing
- The new tool is relevant to assess present and paleo-fluid flows in basins with salinity contrasts
- Next steps
 - chemistry for evaporites
 - toward a simplified reactive transport at basin scales