Pore Pressure Estimation – A Drillers Point of View and Application to Basin Models*

Martin D. Matthews[1]

Search and Discovery Article #42044 (2017)**
Posted March 27, 2017

*Adapted from oral presentation given at AAPG Hedberg Conference, The Future of Basin and Petroleum Systems Modeling, Santa Barbara, California, April 3-8, 2016

[1]Consultant, Sanford, NC, USA (janicematt.matthews@gmail.com)

Abstract

Pore pressure estimation while drilling is extremely important. Accurate estimation not only affects the safety of the drilling operation it also affects the time and cost of drilling as well as the condition of the formation for testing and production. In cases of extreme overestimation, the mud pressure may destroy seal integrity. Accurate constraint on pore pressure is an important constraint on basin modeling.

In drilling, we attempt to constrain estimates of mud weight while drilling; to within at least one-half a pound of actual pore pressure and in many cases we are able to be within one eight of a pound. An extensive study of pore pressure estimation methodology was conducted and reported in DEA 119.

Many techniques were tested, including neural network and dimensional analysis techniques. The most accurate methodology is based on Terzaghi's compaction model. This involves an estimation of overburden and porosity as a function of depth from velocity, density, or resistivity logs. Using measured pore and facture pressures in sands, a calibration curve is developed and used to estimate pore pressure in the shales. The technique can be used on existing wells in the area to provide a continuous shale pore pressure curve. In real time, the procedure results in a cone of uncertainty that extends ahead of the bit. As drilling proceeds, the cone of uncertainty collapses at any given depth below the bit. These techniques can also be used to estimate pre-drill pore pressure from seismic data.

A unique 1.5D basin model was developed for pre-drill pore pressure prediction. It is not a flow model. There is no connection between control points. It is based on a full basin model that was simplified for pore pressure estimation. Creation of a model is similar to the 2D basin models we all have used. It begins with breaking out the section and creating a burial history profile at a control point (well or seismic). A conventional basin model needs to be populated with detailed estimates of rock properties such as compaction rates, initial porosity, organic content, permeability relationships, etc. In the 1.5D pore pressure basin model, the control points are scattered in map view and consist of pore pressure and porosity as a function of depth along with a burial history curve. This calibration data is provided by the analysis of well or seismic data as previously described. At each location, the modeler estimates the following initial information for each formation; initial porosity, compaction constant, specific area, effective lateral conduction, and effective hydrocarbon generation. Initial estimates consist of most likely and max/minimum values for each formation at each control point and the best fit values is then calculated using numerical techniques. The operator then attempts to modify the values for each formation at each control point such that three or four of the five factors have no or little variation between wells. These spatially simplified parameters do not represent the real world variations but are closely related to them. These values can be mapped and adjusted as geologic conditions suggest. The model is able to generate near correct pore pressures at any location within and adjacent to the control point space by interpolation or extrapolation. As new data is available by continued drilling or new seismic in the area, the model is easily updated. Run times are measured in minutes and simplification of parameters can be accomplished in tens of minutes.

It is suggested that the pore pressure estimates from this model as well as the parameters that produce these pressures can be used to constrain conventional basin models.

References Cited

Baldwin, B., and C.O. Butler, 1985, Compaction Curves: AAPG Bulletin, v. 69/4, p. 622-626.

Bowers, G.L., 1994, Pore pressure estimation from velocity data: accounting for overpressure mechanisms besides undercompaction: Proceedings of the 1994 IADC/SPE Drilling Conference, Dallas, Texas, p.515-530.

Bowers, G.L., 1999, State of the Art in Pore Pressure Estimation, DEA-119 Report No. 1.

Eaton, B.A, and T.L. Eaton, 1997, Fracture gradient prediction for the new generation: World Oil, v. 218/10, p. 93-100.

Eaton, B.A., 1972, The Effect of Overburden Stress on Geopressure Prediction from Well Logs: Journal of Petroleum Technology, v. 24/8, p. 929-934.

Finkbeiner, T., M. Zoback, P. Flemings, and B. Stump, 2001, Stress, pore pressure, and dynamically constrained hydrocarbon columns in the South Eugene Island 330 field, northern Gulf of Mexico, AAPG Bulletin, v. 85, p. 1007-1031.

Holbrook, P.W., D.A. Maggiori, and R. Hensley, 1995, Real-Time Pore Pressure and Fracture-Pressure Determination in All Sedimentary Lithologies: SPE Formation Evaluation, p. 215-222.

Matthews, M., W. Standifird, and C. Ikeocha, 2006, Proactive Prediction of Geopressure in Ultra High Temperature and High Pressure Environments: AADE-06-DF-HO-06.

Matthews, M., W. Standifird, and J. Jones, 2005, Estimating and Managing Geopressures Proactively, To boldly go where only the Russians have been before: World Oil, HPH/Deep Drill Technical Conference, April 7, 2005.

Matthews, W.R., and J. Kelly, 1967, How to predict formation pressure and fracture gradient: The Oil and Gas Journal, February 20, 1967, p. 92-106.

Terzaghi, K., 1973, Theoretical Soil Mechanics: New York, John Wiley & Sons, Inc.

Wyllie, M.R.J., A.R. Gregory, and G.H.F. Gardner, 1957, an experimental investigation of factors affecting elastic wave velocities in porous media: Geophysics, v. 23, p. 459-493.

Pore pressure estimation – A drillers point of view and application to Basin Models

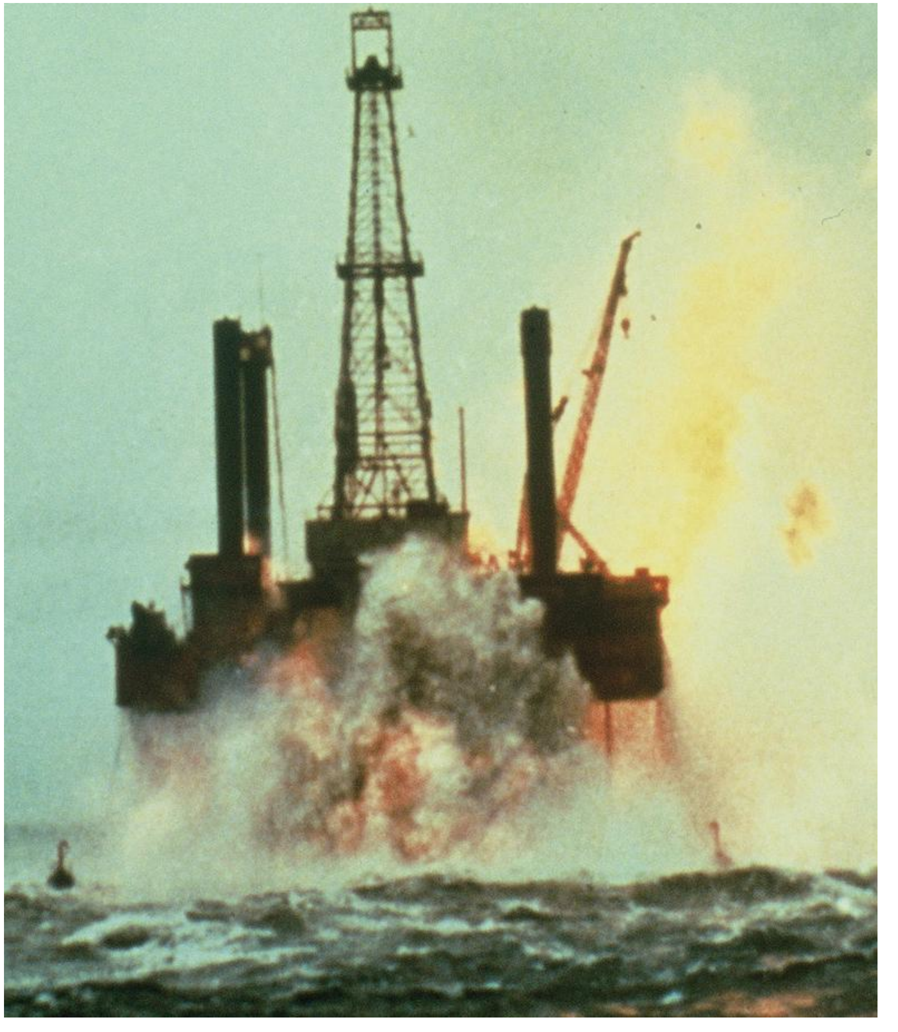
Martin D. Matthews
Consultant - 11 The Pointe Sanford N.C. 27332

Gulf R&D 1972 to the end - Extending their earlier numerical 1D Terzaghi compaction pore pressure models to 2D and later 3D we used to joke that by the time we had enough control on the models properties we would not need the models

The weakest links in basin modeling is not the science, or the code, but the lack of control on rock properties, lack of calibration points, and interpolation between these points.

Drillers live in a static pore pressure world

Interested in pressures NOW and ahead of the bit

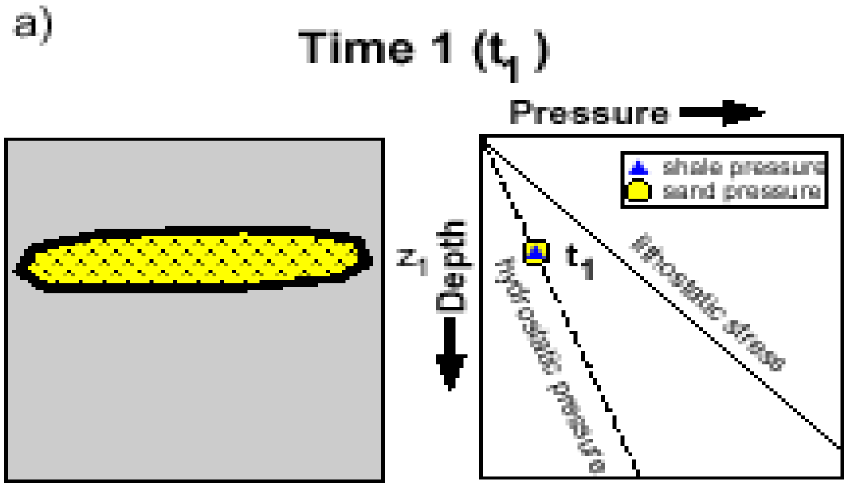


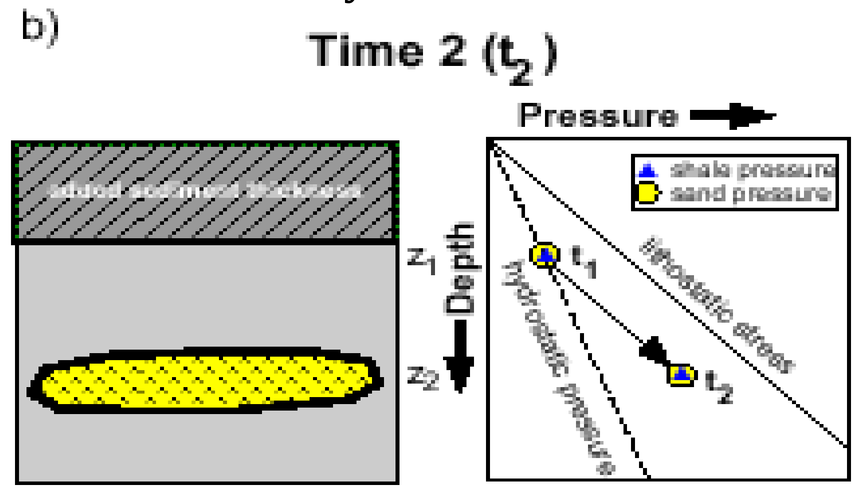
Sands and Shales

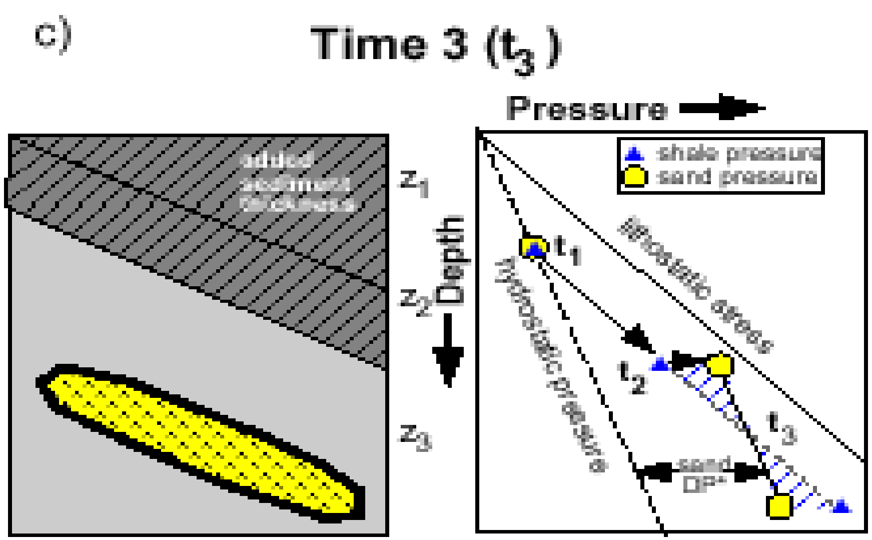
- **The world can be divided into high permeable rocks (Sands, pressure is measured) and low permeable rocks (Shales pressure cannot be measured only estimated)**
- **Sands and shales are assumed in pressure equilibrium for calibration (not necessarily correct)**

Sand pressure
The Centroid Model

Within interconnected sands the pressure gradient is controlled by the density of the fluids in them







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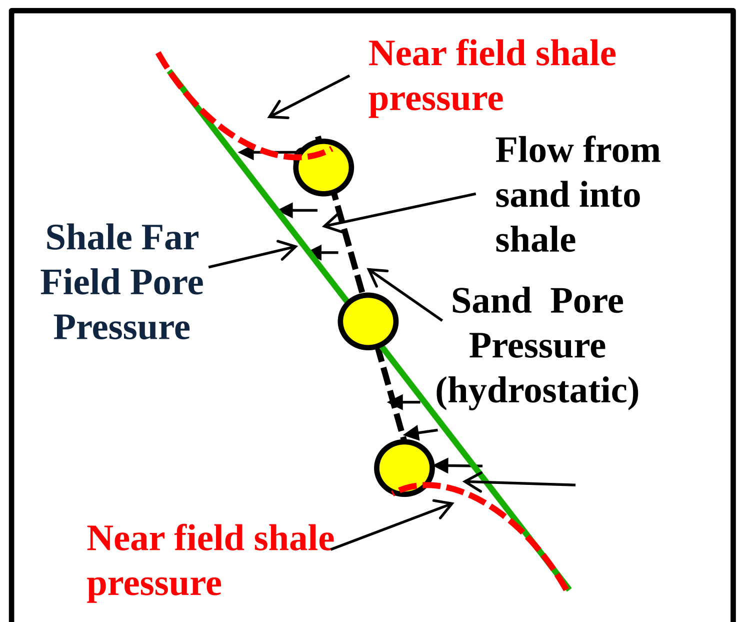
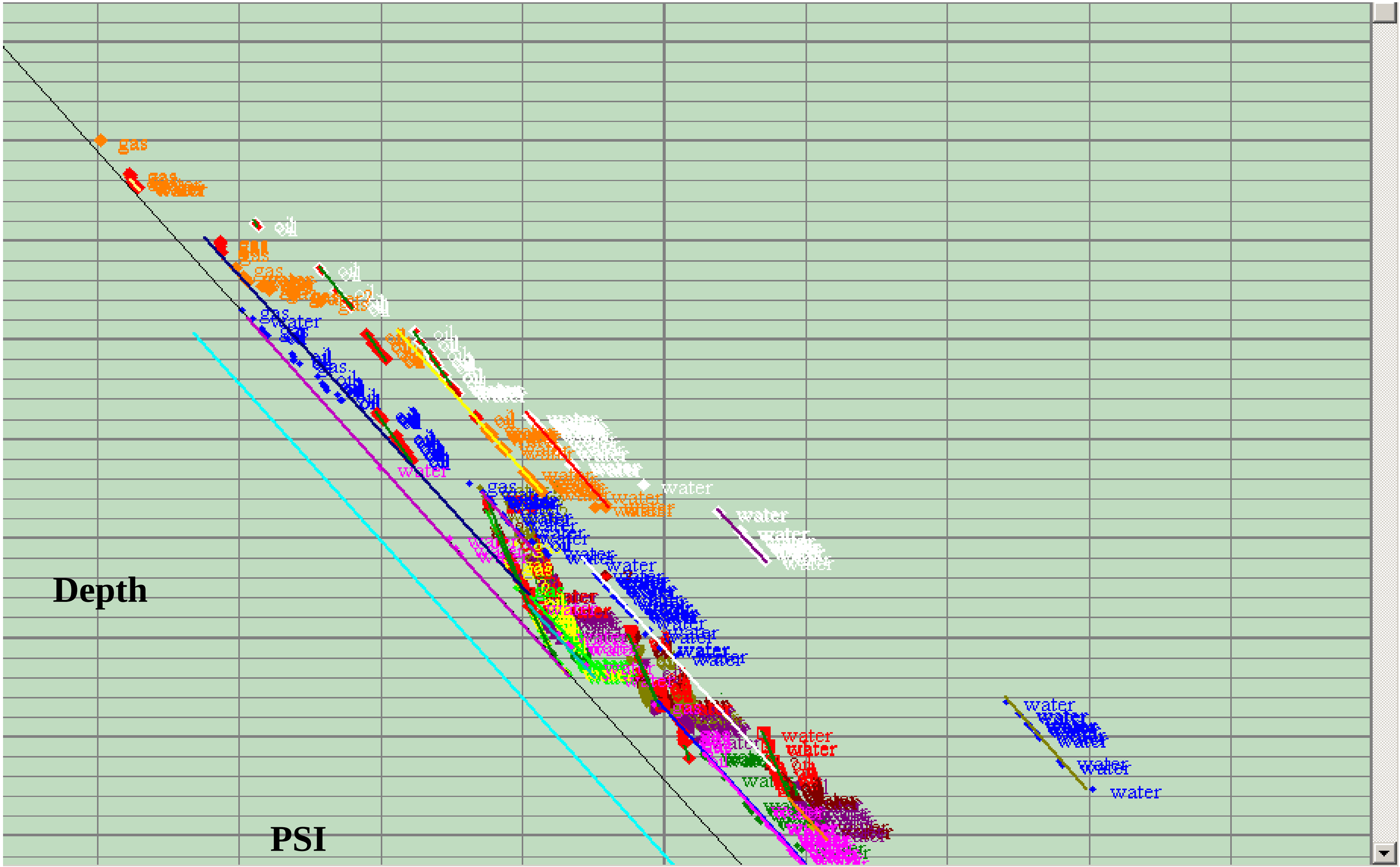
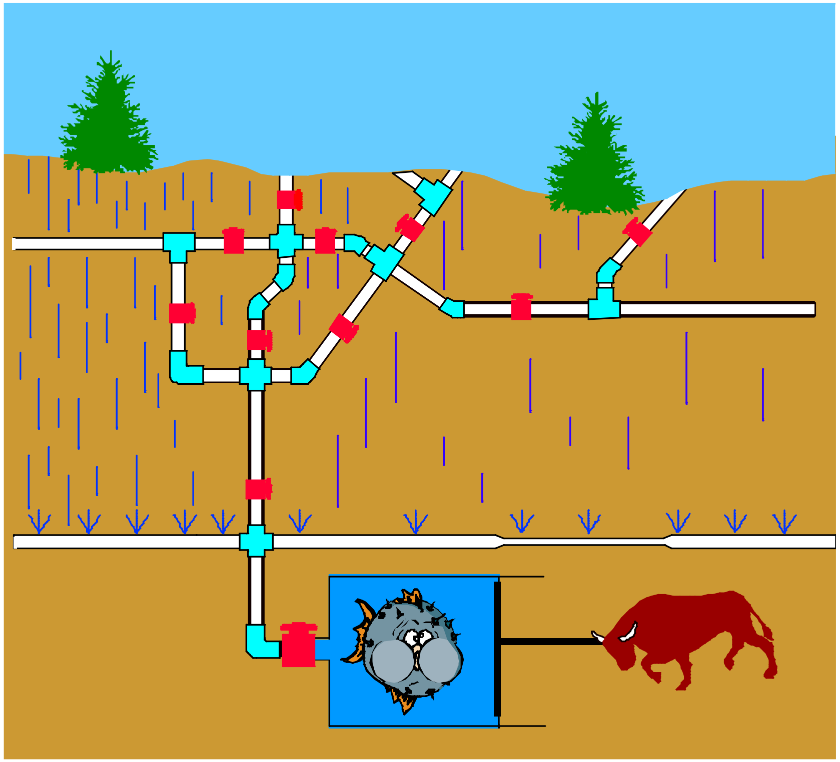




Pressures measure in a single field, colors represent separate wells

Origin of Shale Pressures

- **Restricted flow**
- Organic Phase Change - Fluid Expansion
- Mineral Diagenesis
- Tectonics



Goal – Safe efficient well

Unlike sands you can’t measure pressure in a shale.

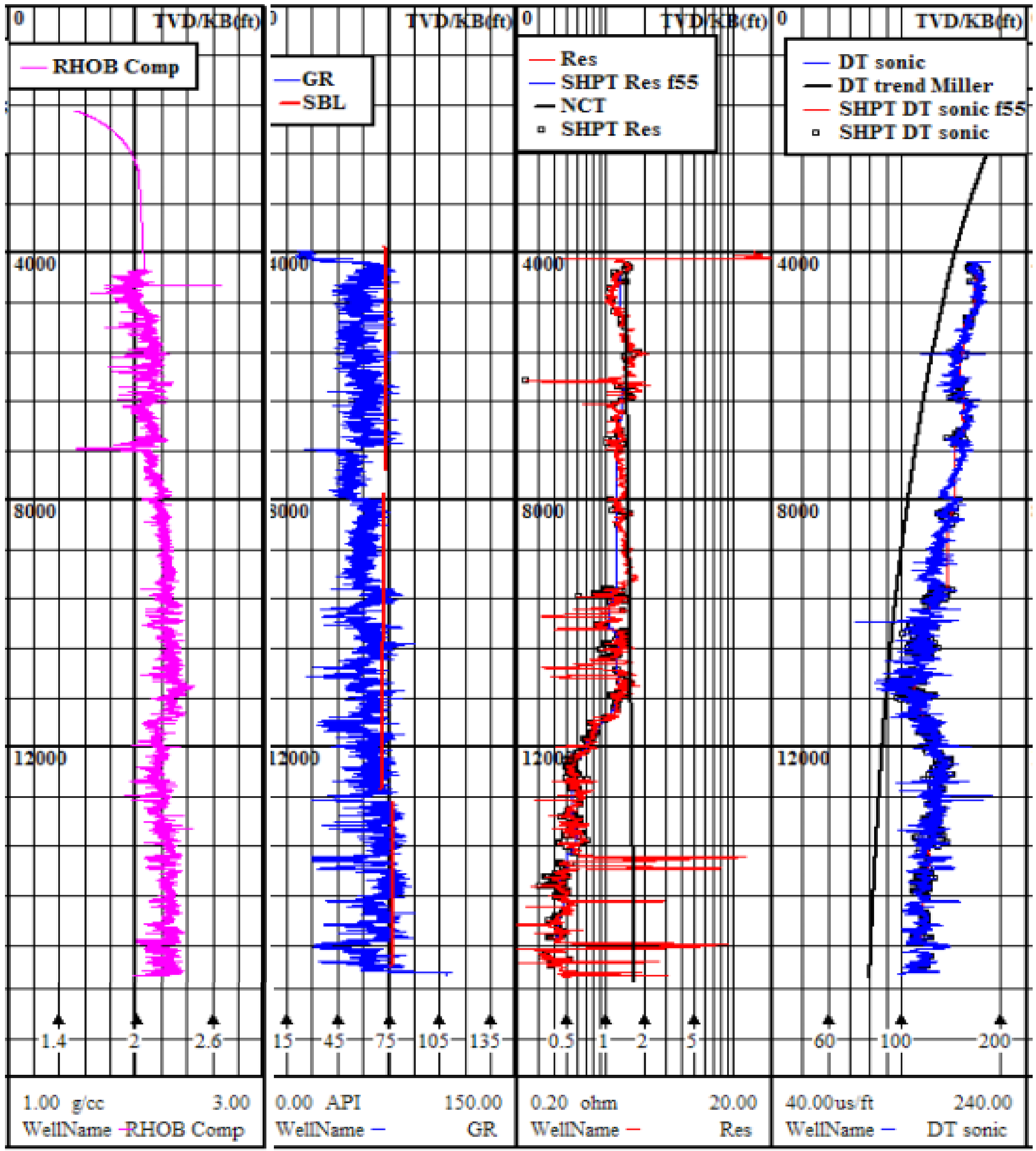
Assumptions in Pore Pressure Estimation in Shales

- Total Stress = effective stress + pore pressure
- Porosity is a proxy for effective stress
- Velocity is a function of effective stress
- Under hydrostatic pore pressure gradients, rocks compact in a smooth, continuous, curve

Interpretation is a Science based Art

Shale pressure estimation

We are estimating effective stress (velocity) or its proxy pore volume (resistivity) indirectly in shales and looking for deviations from a "normal" compaction curve



Pressure Calibration

Measurements

(In sands)

DSTs

LOTs

Inference while drilling

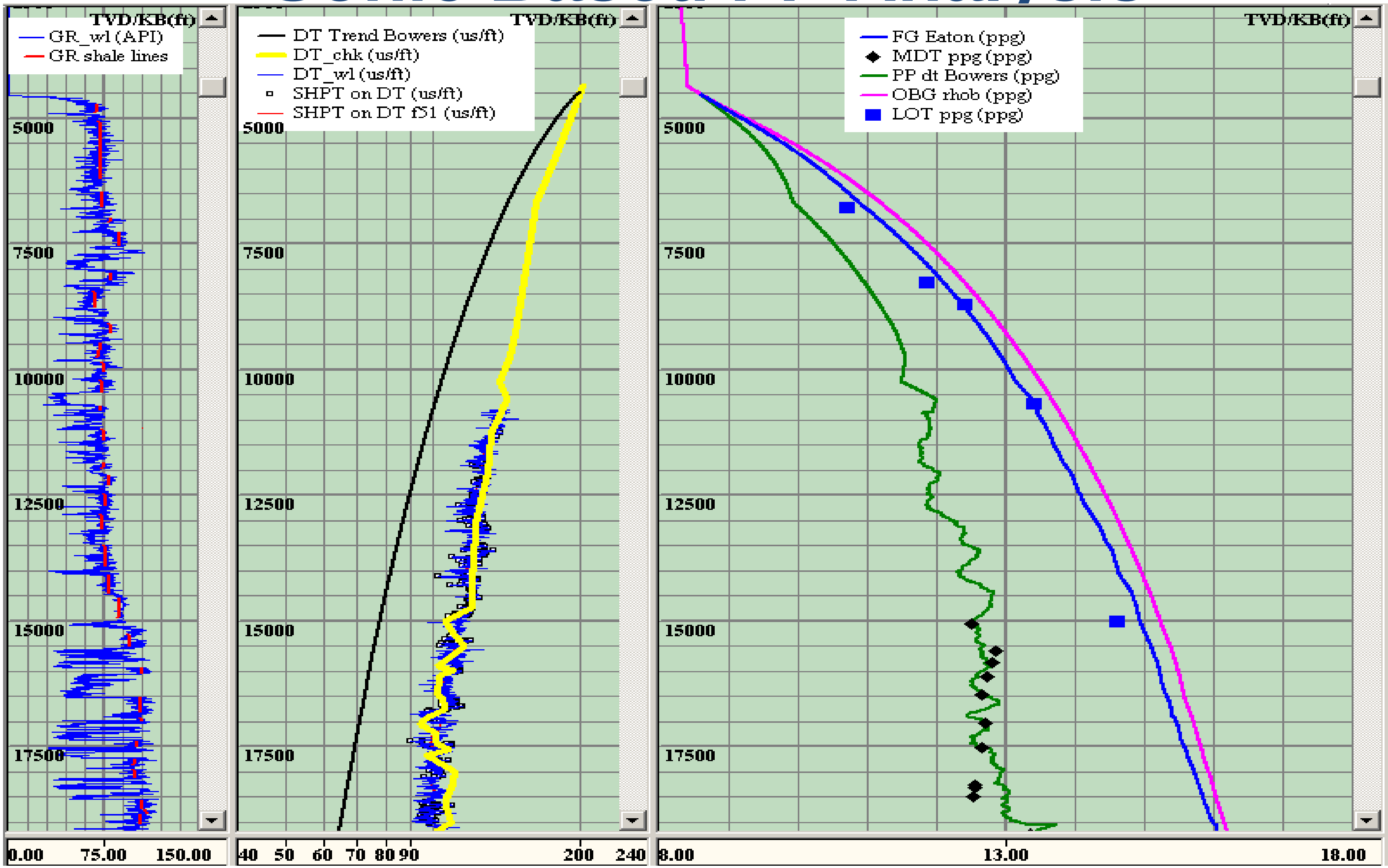
Increase in

- Mud weight and kicks
- Rate of penetration
- Gas
- Splintery shale cuttings
- volume of shale
- flowline temperature
- chlorides
- <u>shale travel time(MWD)</u>

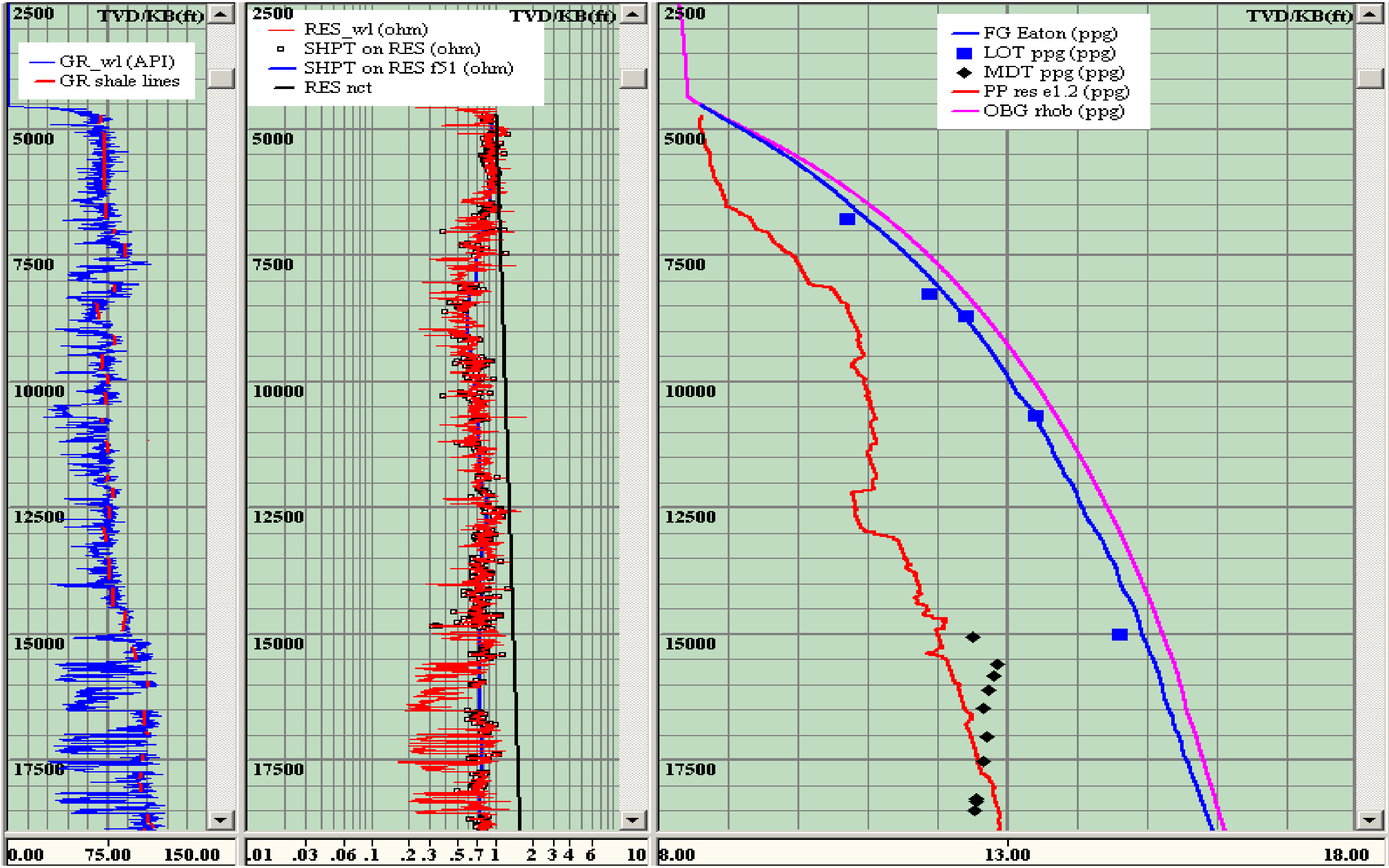
Decrease in

- d-exponent
- shale density
- <u>resistivity (MWD)</u>

Sonic Based PP Analysis



Resistivity Based PP Analysis

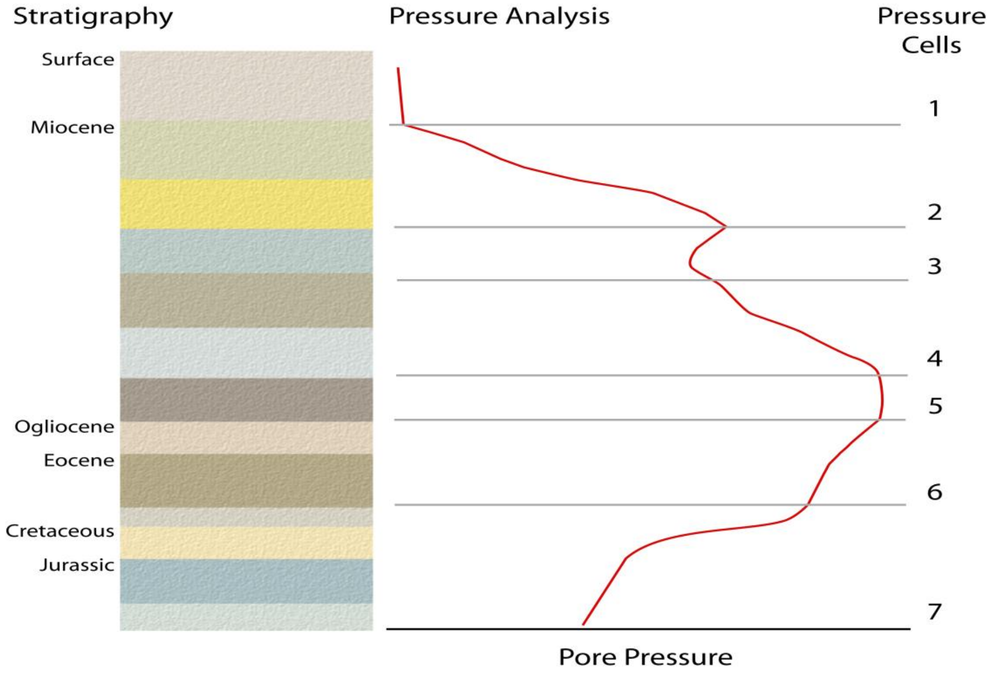


Basin modelers live in a dynamic word

Interested in paleo pressures and fluid movement

Identification of "Pressure Cells"

- **Stratigraphic section divided into intervals with approximately uniform compaction behavior**
- **Pressure patterns vary laterally with rock properties, but are distinct with respect to the overlying and underlying units**

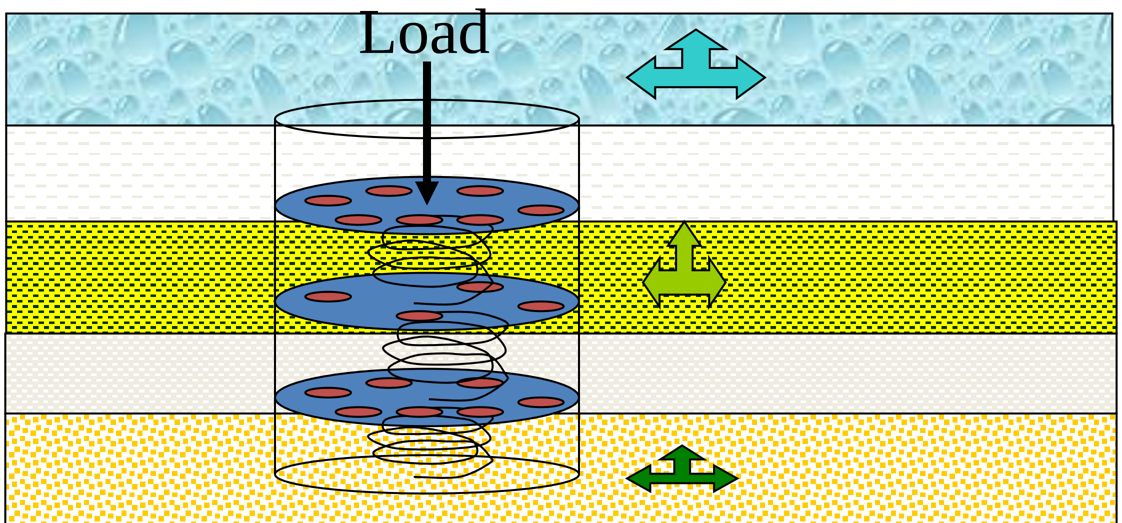


Basin Modeling Parameters

<u>Temperature</u>

Surf Temp

Geothermal Gradient



<u>Geometry</u>

Water Depth

Ages

Thickness

Lithology

Initial Porosity | **Compaction Constant** | **Specific Area** | **Effective Lateral Conduction** | **Effective Hydrocarbon Generation**

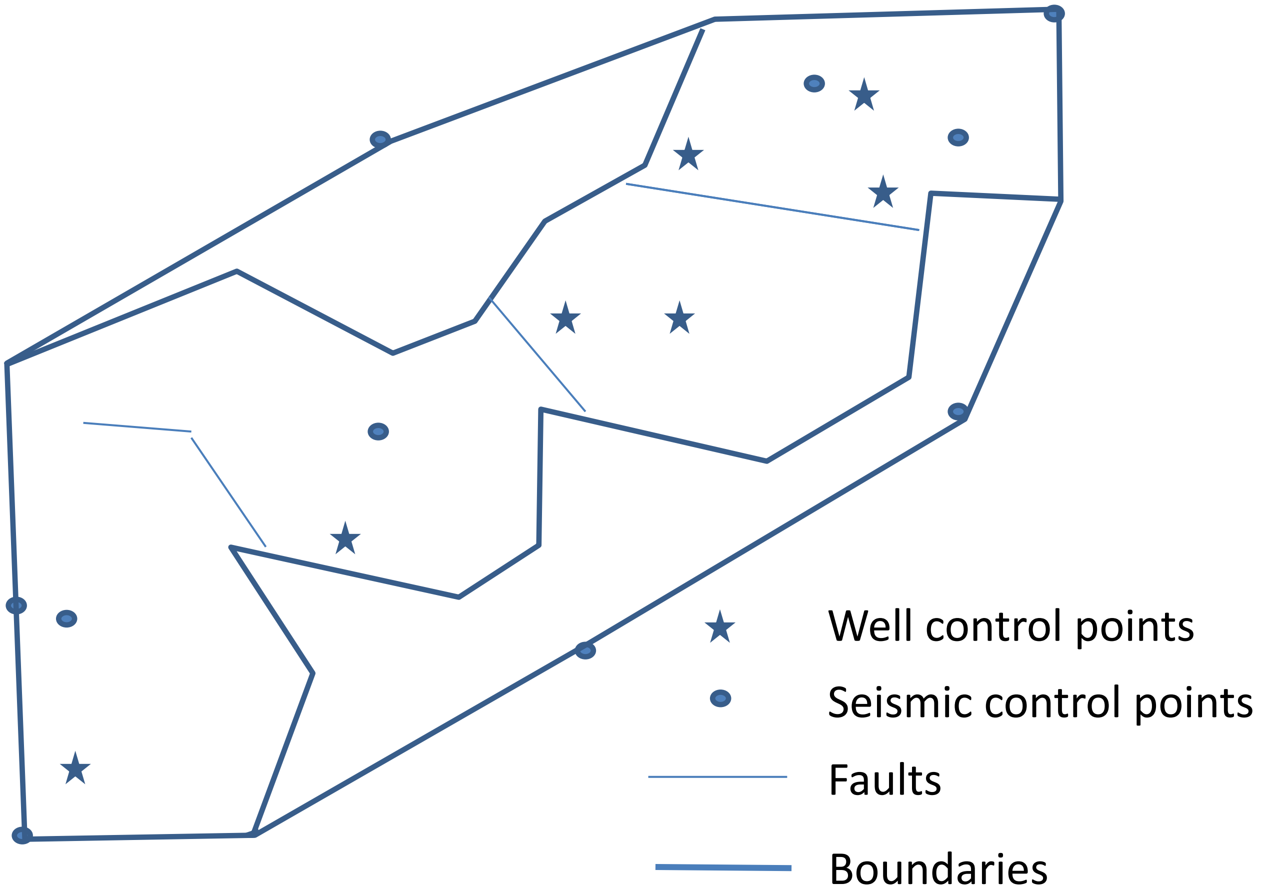
Lithology | **Fluid Flow** | **Unloading**

<u>Data at Calibration Points (Wells)</u>

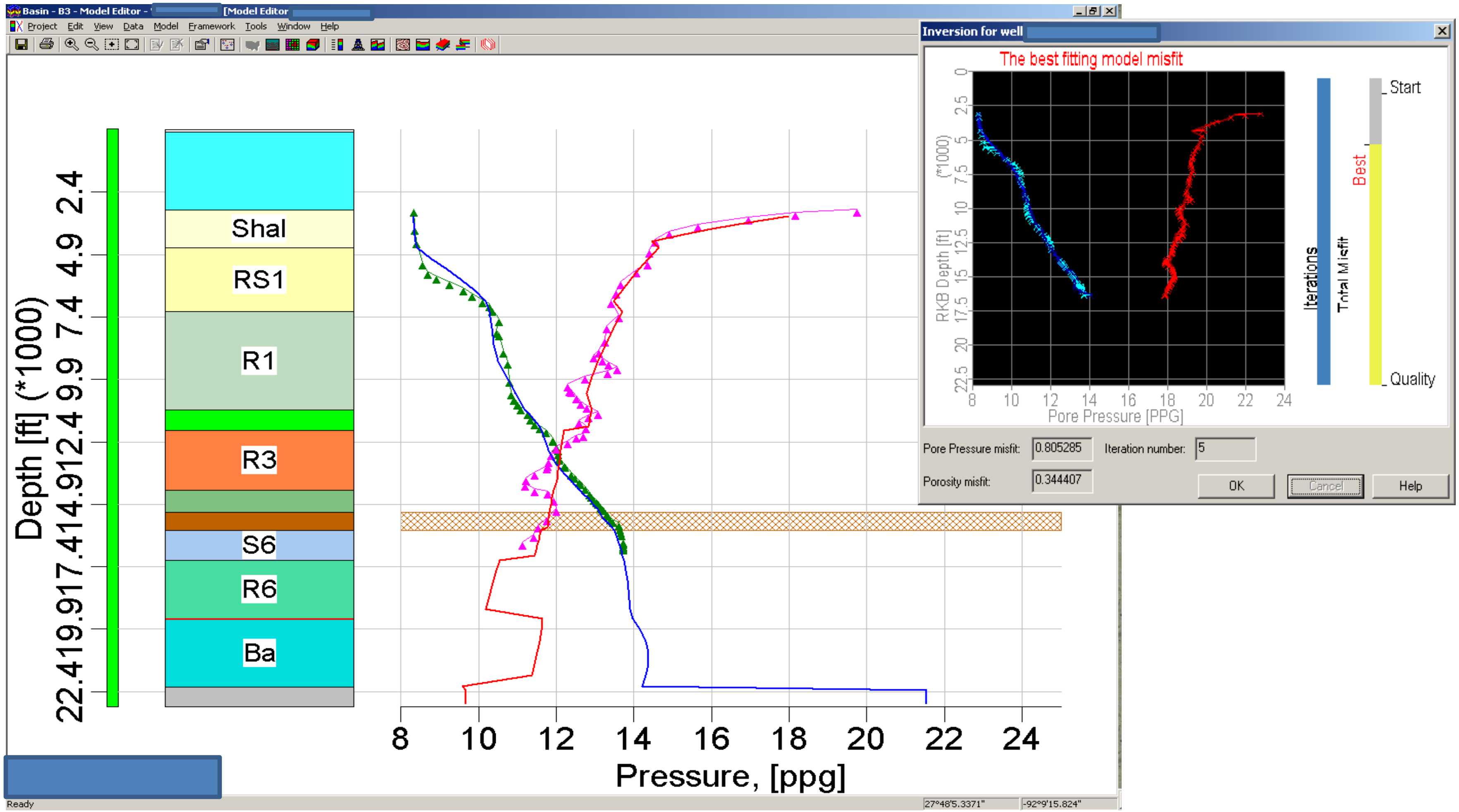
Definitive Porosity **Thickness**

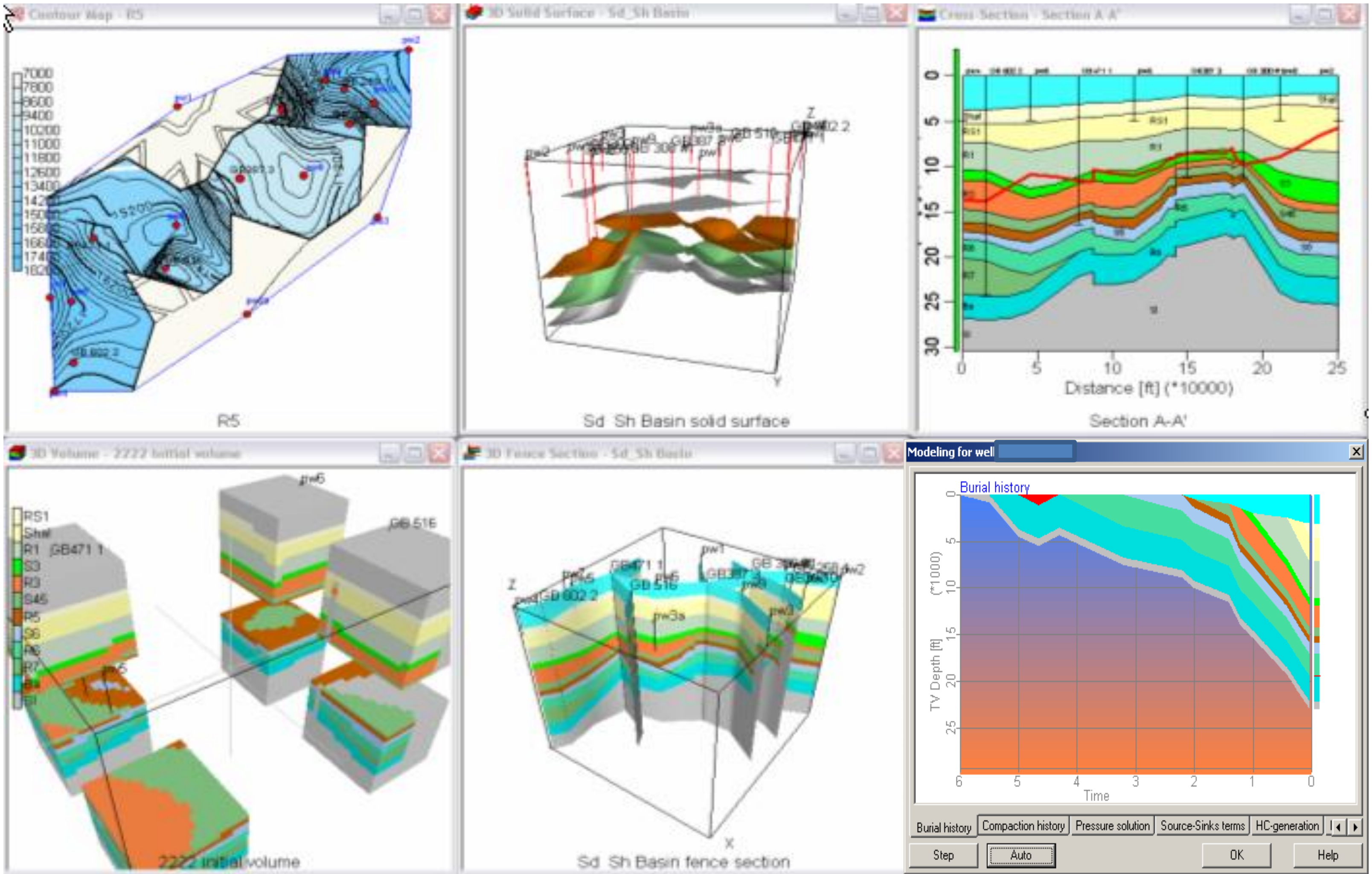
Definitive Pore Pressure

Map view of the area of interest



Fit the parameters to the control (por perm Thick) at each well





R5
Sd Sh Basin solid surface
Distance [ft] (*10000)
Section A-A'
RS1
Shal
R1
S3
R3
S45
R5
S6
R6
R7
S8
GB471 1
GB 516
pw5
2222 initial volume
Sd Sh Basin fence section
Modeling for well
Burial history
TV Depth [ft] (*1000)
Time
Burial history
Compaction history
Pressure solution
Source-Sinks terms
HC-generation
Step
Auto
OK
Help

Using the model for pre-drill pressure prediction

- Iterate for the best fit at each well
- Simplify parameters to as constant values as possible for each horizon leaving only 1 or at most 2 independent variables
- Solve the model at points of interest
- Runs in minutes

Using the model as control for Conventional Basin Models

- **Use as pressure/ porosity evolution control directly**
- **Adjust the parameters to achieve something more reasonable with respect to rock properties in the area, maintaining the pore pressure /porosity prediction as control**
- **Transfer these interpolated rock property to the conventional basin models as a first guess**

Numerical models are best used as Intelligence amplifiers allowing us to ask

What If?

A special thanks to all the pore pressure engineers I was privileged to work with