Petrophysics and Pore Pressure: Pitfalls and Perfection*

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Conclusion

- The world of petrophysics is fraught with danger.
- A simple awareness of the pitfalls that can occur have been highlighted.
- Do not use wireline logs in isolation.
- Ensure that all petrophysical logs are fully reviewed and prepared before use.
- Undertake a fully integrated pore pressure evaluation, calibrated to operational events; pressure measurements should be robust and defensible.
- The software allows the collation and display of these data types, along with the wireline logs, captured within a simple-to-follow workflow.

The impact of using poorly prepared and/or reviewed petrophysical data will result in a potential environmental calamity.

Selected References

Barker, J.W., and T.D. Wood, 1997, Estimating shallow below mudline deepwater Gulf of Mexico fracture gradients: Proceedings of the AADE Houston Chapter Annual Technical Meeting.

Bellotti, P., and R.E. Gerard, 1976, Instantaneous log indicates porosity and pore pressure: World Oil, (10/1976), p. 90-94.

Bellotti, P., and D. Giacca, 1978, Seismic data can detect overpressures in deep drilling: Oil & Gas Journal, v. 76, (8/21/1978), p. 47-52.

Bellotti, P., and D. Giacca, 1978, Pressure evaluation improves drilling programs: Oil & Gas Journal, v. 76, (9/11/1978), p. 76-78, 83-85.

Bellotti, P., D. Raffaele, and G. Diego, 1979. Deep drilling in Po Valley: Planning criteria and field results: Society of Petroleum Engineers of AIME (4/1979), 15 p.

Daines, Stephen R., 1980, The prediction of fracture pressures for wildcat wells: Society of Petroleum Engineers of AIME (9/1980), 11p.

Eaton, B.A., 1969, Fracture gradient prediction and its applications in oilfield operations: Journal of Petroleum Technology, p. 1353–1360.

Eaton, B.A., 1997, Fracture gradient prediction for the new generation: World Oil, (October 1997), p. 93–100).

Gardner, G.H.F., L.W. Gardner, and A.R. Gregory, 1974, Formation velocity and density—the diagnostic basics for stratigraphic traps: Geophysics, v. 39, p. 770–780.

Greenberg, M.L., and J.P. Castagna, 1992, Shear-wave velocity estimation in porous rocks: Theoretical formulation, preliminary verification and applications: Geophysical Prospecting, v. 40, p. 195-209.

Lindseth, R.O., 1979, Synthetic sonic logs – A process for stratigraphic interpretation:
Geophysics, v. 44, p. 3-26.

Matthews, W.R., 1984, How to calculate pore pressures, gradients from well logs for the U.S. West Coast: Oil & Gas Journal, v. 82, (10/1/1984), p. 132, 133, 136-137.

Matthews, W.R., and John Kelly, 1967, How to predict formation pressure and fracture gradient: Oil& Gas Journal, Reprint (2/20/1967), 7 p.

Matthews, W.R., R.T. McClendon, and C.R, Soucek, 1972, How to predict formation pressures of Cretaceous - Jurassic age sediments – Mississippi: Society of Petroleum Engineers of AIME, SPE Paper 3895, p. 137-144.

Raymer, L.L., Hunt, E.R., and Gardner, J.S., 1980, An improved sonic transit time-to-porosity transform: SPWLA Twenty-First Annual Logging Symposium Transactions, Lafayette, Louisiana, p. 1-12.

Petrophysics and Pore Pressure: Pitfalls and Perfection

AAPG Geoscience Technology Workshop
Singapore
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Objective

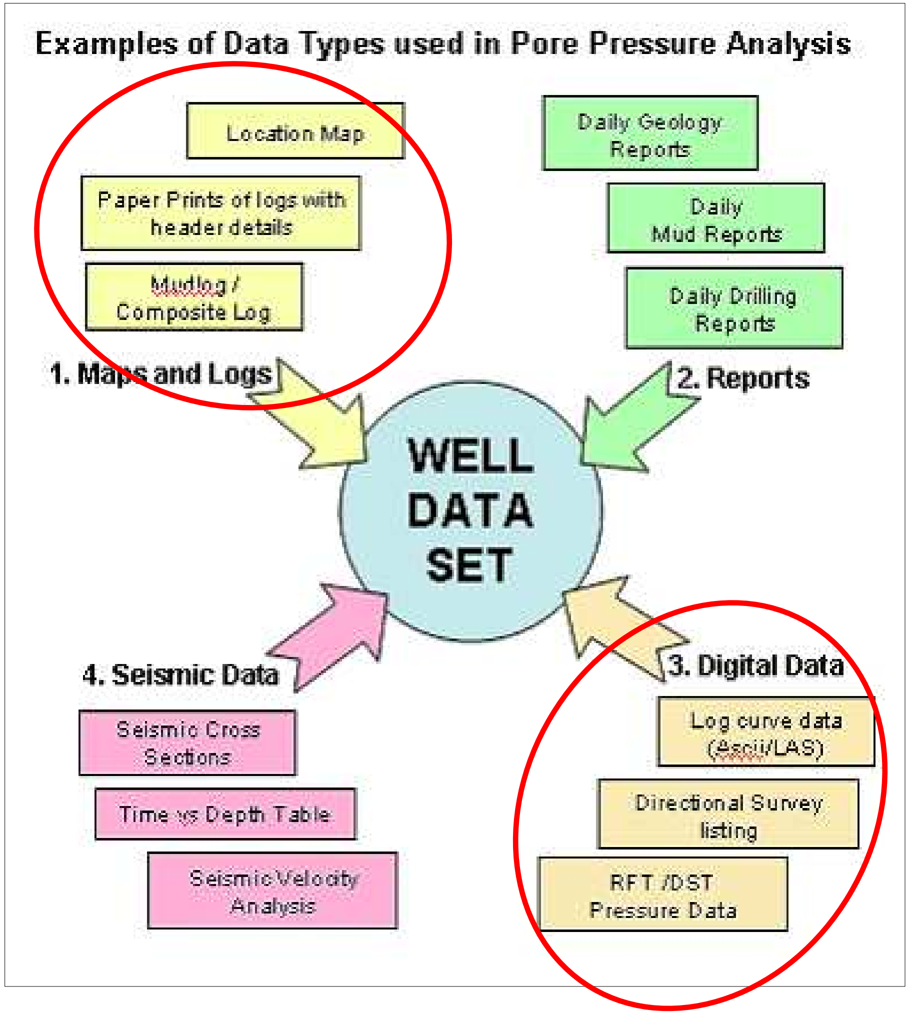
- Often the petrophysical data we use can be uncalibrated and poorly QC'ed.
- There can be an impact drilling a well using poorly constrained data when calculating pore pressures?

Objective

- This presentation will:
  - Demonstrate common petrophysical pitfalls
  - Present a workflow that results in a creditable (‘perfect’) pore pressure prediction.

Pore Pressure Prediction

- A good prediction of pore pressure requires integrated data from:
  - Geophysics
  - Geology
  - Petrophysics
  - Drilling



Log Quality Control Log Header Information

- A comprehensive log header should document:
  - Logs run
  - Mud type and properties in the well
  - Bottom hole temperatures
  - Casing shoe depths
  - Environmental corrections applied.
- Digital databases are frequently presented without adequate log acquisition information and potential interpretation errors may result

Log Header Information	Purpose
Tool Types	Environmental Corrections.
Casing points	Identify potential gaps, poor data.
Drill and Log TD	Identify depth discrepancies.
Bottom Hole Temperature (BHT)	Environmental Corrections & estimation of formation temperature.
Mud Type	Environmental Corrections & expected log types, Potassium in mud.
Mud Weight	Environmental Corrections.
Mud resistivities	Environmental corrections, R_w from SP.
List of Logs acquired	Identification of available curves.
Engineers remarks	Warning of problems acquiring logs.

Log Quality Control Depth Control

- Depth is the most important measurement made in logging; however logs can be off-depth for several reasons:
  - Incorrect log offset adjustments can be applied by logging engineer
  - Successive runs in a well may not be correctly depth matched
  - Tool sticking can cause apparent tool movement due to cable stretch – see tension logs.
  - Problems are often restricted to pad tools, for example Density and Neutron logs.
  - Hence GR for first run non-pad tool usually used as reference log.

Environmental Corrections

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- All logging companies publish chart-books of log environmental corrections
- Logging tools are calibrated to work in a particular environment
- The further you get away from this environment the greater the need to apply an environmental correction to the resultant log curves
- Sometimes environmental corrections are applied at the well site, computer centre post processed before delivery to the client or done by the client/consultant sometime later
- Understanding what has or has not been corrected for can often be a challenge, especially on older data where all curve history has been lost
- In such circumstances it's better not to correct than over-correct. Unless a correction is obviously required
- A main motive for environmental correcting data is to try and standardise curves and then perhaps your interpretation parameters.

Wireline data – Mineralogy & Lithology

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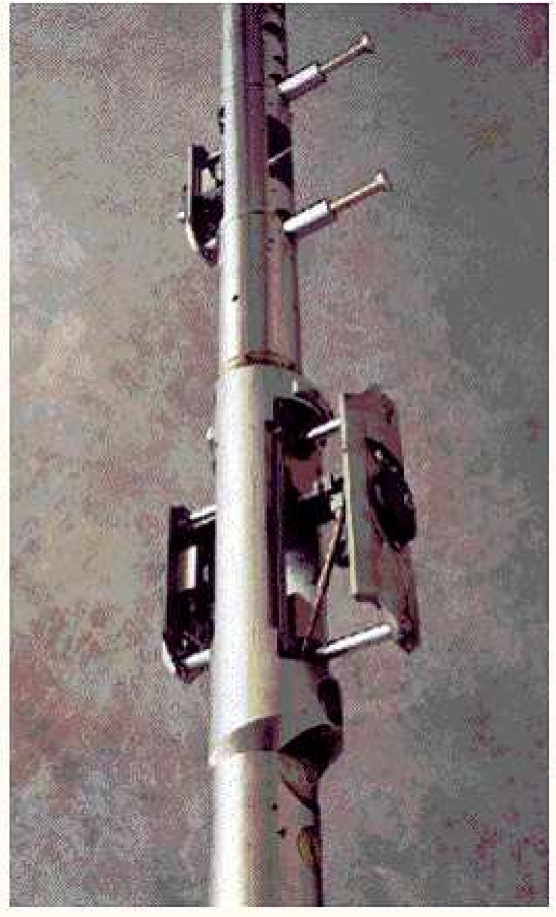
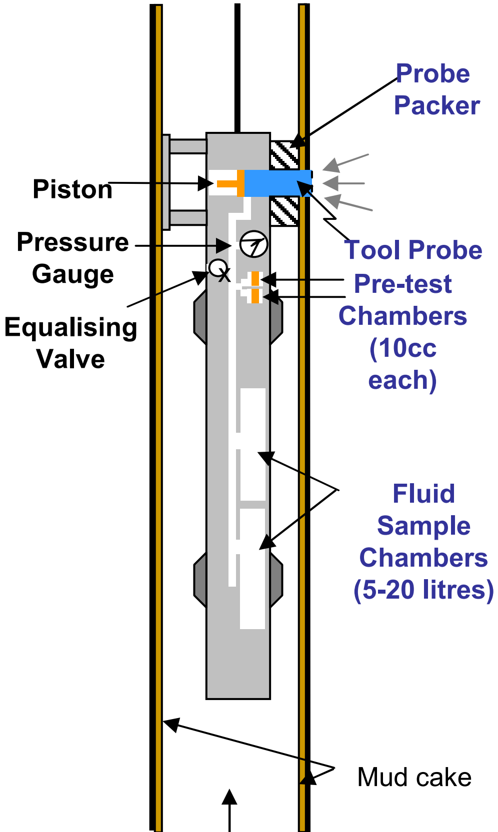
- Mica
  - Affects Gamma Ray
  - Plugs Formation Tester tool
- Coal
  - Affects Resistivity & Sonic tools
  - Can cause shoulder bed effects on thin sands
- Carbonaceous material
  - Affects the density tools
- Volcanics
  - Affects neutron tools & imaging tools (magnetometer)
  - May look like clay
  - May look like sand
- Pyrite
  - Affects resistivity tools (highly conductive)
  - Affects density – small percentage has a large effect leading to incorrect porosity
- Siderite
  - Affects the density tool leading to incorrect porosity
- Carbonate cemented sandstone
  - Affects the density tool leading to incorrect porosity
- Thin bed effects
  - Sandstone - shale sequence on GR can appear as "homogeneous" siltstone

Wireline – Formation Tester

MDT



- The purpose of the tool is to obtain formation pressures and to sample formation fluids:
    - A retractable probe is sealed, using a rubber packer, against the borehole wall.
    - A pressure draw-down is applied at the probe and formation fluid flows through probe into the tool.
    - The pressure measured by the tool will equilibrate to formation pressure if the formation is sufficiently permeable and the wait time long enough.



Wireline – Formation Tester

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- Depth control on the Formation Pressure Tester measurements is important:
  - Always run a Gamma ray log for correlation and depth control
  - Use of Image data to pick points in thin heterogeneous sand
- Ensure that the Formation Pressure Tester includes a header that includes:
  - All pressures
  - Times and duration of tests
  - Set pressure
  - Basic observations such as:
    - Tight
    - Poor seal
    - Seal failed
    - Tool failed

- Important Considerations Formation Pressure Tester
  - If the pressure returns to the higher 'mud' pressure it is likely the packer is not sealing against the formation.
  - In tight formation (low permeability) the pressure of the mud filtrate may not be dissipated within the formation, leading to pressure readings intermediate between mud and formation pressures. This effect is 'supercharging'.
  - Pressure / sampling points should be selected from in-gauge hole, avoiding washouts ensure a bad hole flag is run prior to picking pressure points
  - Measurements should be taken going from shallow to deep to avoid gauge hysteresis

Preparation for Interpretation

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- Talk to the rest of the team
  - Stratigraphy – Tops: Geologist / Geophysicist.
  - Mineralogy & Petrology: Geologist.
  - Expected pressures & reservoir fluids: Reservoir Engineer.
  - Drilling events (losses, kicks etc): Drilling engineer or end of well reports.
- Assemble Well Header Data
  - Contractor and Dates logged.
  - Logs run and intervals logged.
  - TD Logger and Driller.
  - Logging problems noted (variable tension, cycle skipping etc).
  - Bottom Hole Temperature (BHT).
  - Mud Type (OB, WB, KCL) and Weight.
  - Mud resistivities.
- QC logs
- Examine all data:
  - Shows.
  - Lithology log/cuttings description.
  - Core data and photographs.
  - Test and fluid sample data.
  - Offset logs etc.
- Make environmental corrections
  - Gamma Ray
  - Density – borehole correction in large holes.
  - Neutron – care needed depending on corrections applied at well-site.
  - Resistivity – depending on tool type and mud properties.
- Pre-calculate
  - Formation Temperature log.
  - Determine Lithology flags (coals, calcite stringers, anhydrite, salt).
  - Washouts flags.

Wireline Data: Summary

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- Are the tools appropriate for the mud system?
- Has a thorough quality control and quality assurance been undertaken of all the log data (depth, splicing, formation pressure data, drilling data)
- Have the appropriate environmental corrections been made?
- Has all the header information been collated and utilised effectively?
- Have adverse hole conditions been identified and accounted for:
- Has all off-set data been incorporated into the model?
- Are there ‘exotic’ minerals / lithologies present in the well bore and have these mineral properties been adopted in the analysis

Pre Processing Data

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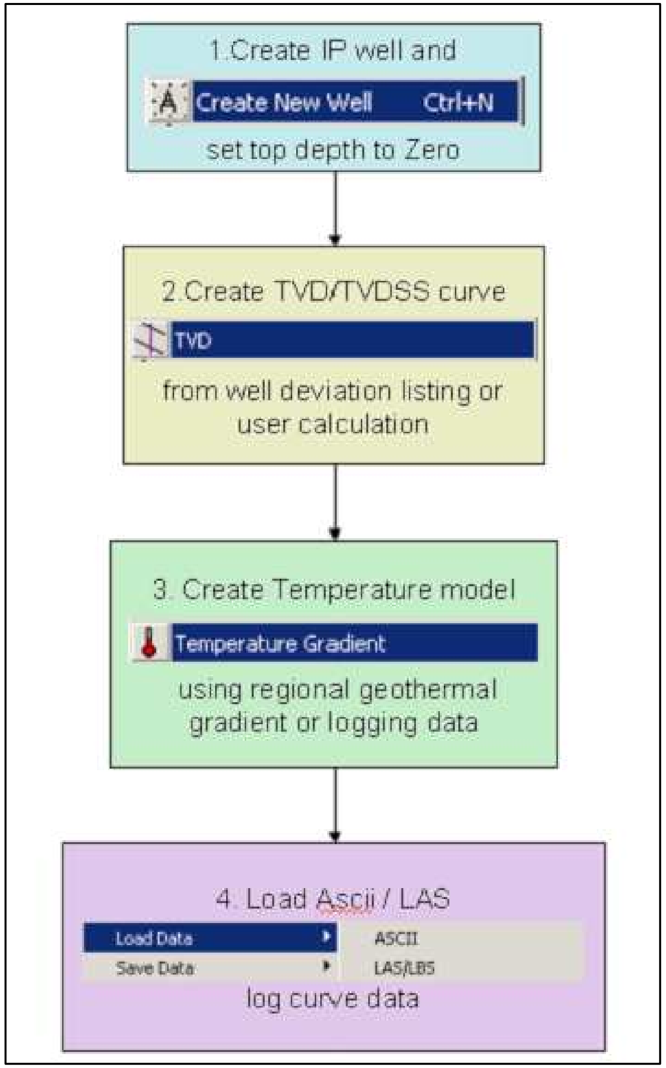
When data compilation is complete, the following 'Preparation workflow'

(Refer to right)

should be followed before proceeding to the

Pore Pressure evaluation modules



The Pore Pressure Work Flow

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- ***Pore Pressure Calculation*** modules comprise the following three tools:
  1. Density Estimation
  2. Overburden Gradient Calculation
  3. Calculate:
     - Pore Pressure Gradient
     - Fracture Pressure Gradient
- These tools can be used to evaluate the subsurface pressures encountered within a well.
- Based on conventional log curves, drilling information and seismic data input. They enable the user to model:
  - Overburden (OB)
  - Pore Pressure (PP)
  - Fracture Pressure (FP)
- It can be used as a pre-drill (predictive) and while-drilling (real-time) tool, as well as for post-drilling analysis to update and refine OB, PP and FP models.

1. Density Estimation

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- First Module Provides the user with a means to generate a density curve from sonic log data
- When density log information is not available it is often estimated from P-wave velocity (Vp) using an empirical relationship.
- A number of authors have published density-sonic transit time algorithms e.g. Gardner, Bellotti et al or Lindseth

- Density
  - The Density Log should track the Sonic or Neutron log in sands and limestone.
  - Affected in washed out or rugose holes due to lack of pad contact.
  - Check the Caliper and density correction ($\Delta\rho b$) curves. $\Delta\rho b$ should be less than 0.05 gm/cc; if larger the density log is likely to be unusable.
- Sonic
  - Compressional Sonic log should track the other porosity logs
  - Cycle skipping is a common problem; slower velocity can occur in washed out hole.
- Shear Sonic
  - Shear logs have a slower velocity than the compressional sonic but the two logs normally track each
- A quality control check can be made by using a Vs v Vp plot with reference to a Greenberg-Castagna sand and mud line overlay.

2. Overburden Gradient Calculation

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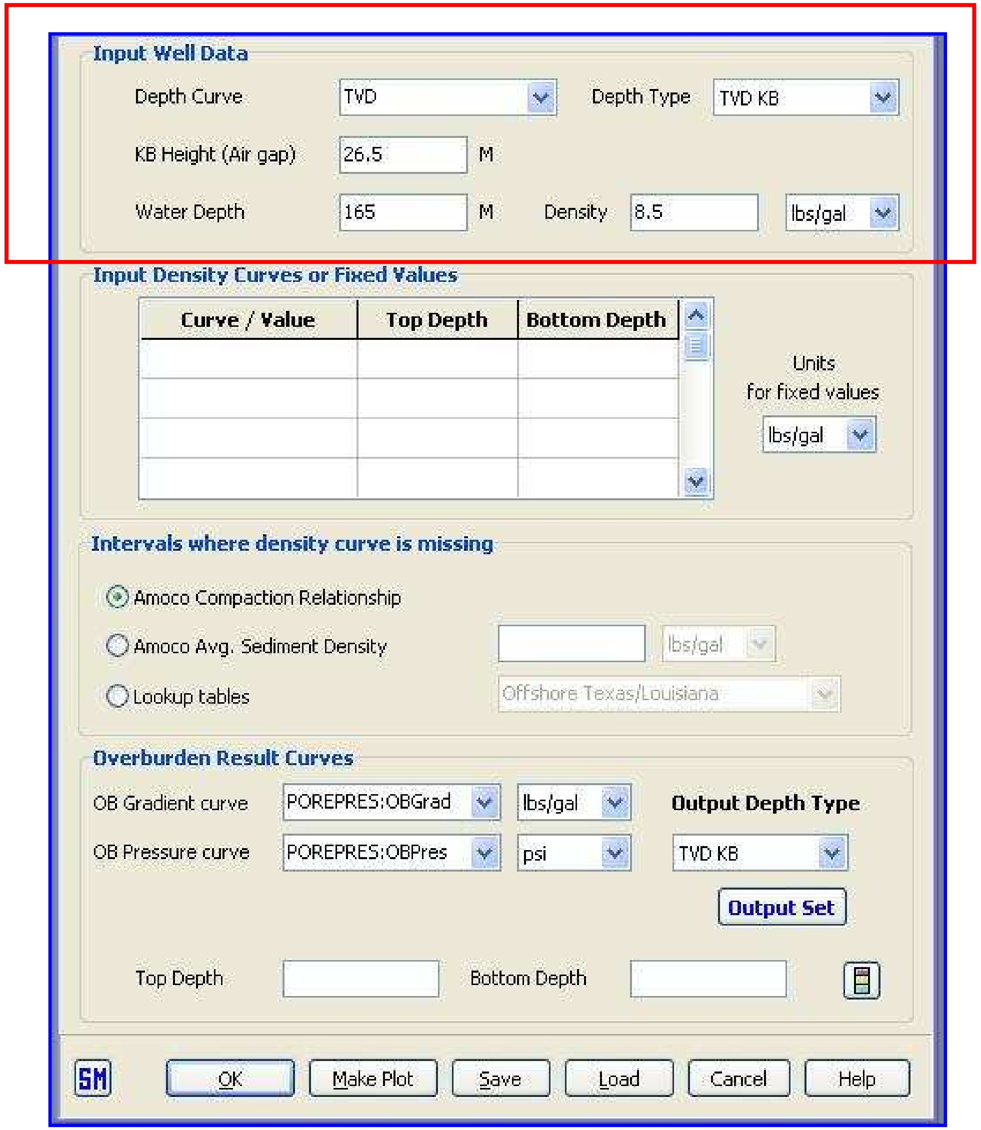
Header Information

- The second module within the Pore Pressure Calculation suite calculates :
  - Instantaneous average Overburden Gradient (OBG) &
  - Overburden Pressure (OBP) curves
- These are calculated relative to the 'reference depth' datum :
  - KB (TVD KB) ,
  - Mean Sea Level (TVDSS)
  - TVD Sea Bed.



3. Pore and Fracture Pressure Gradients

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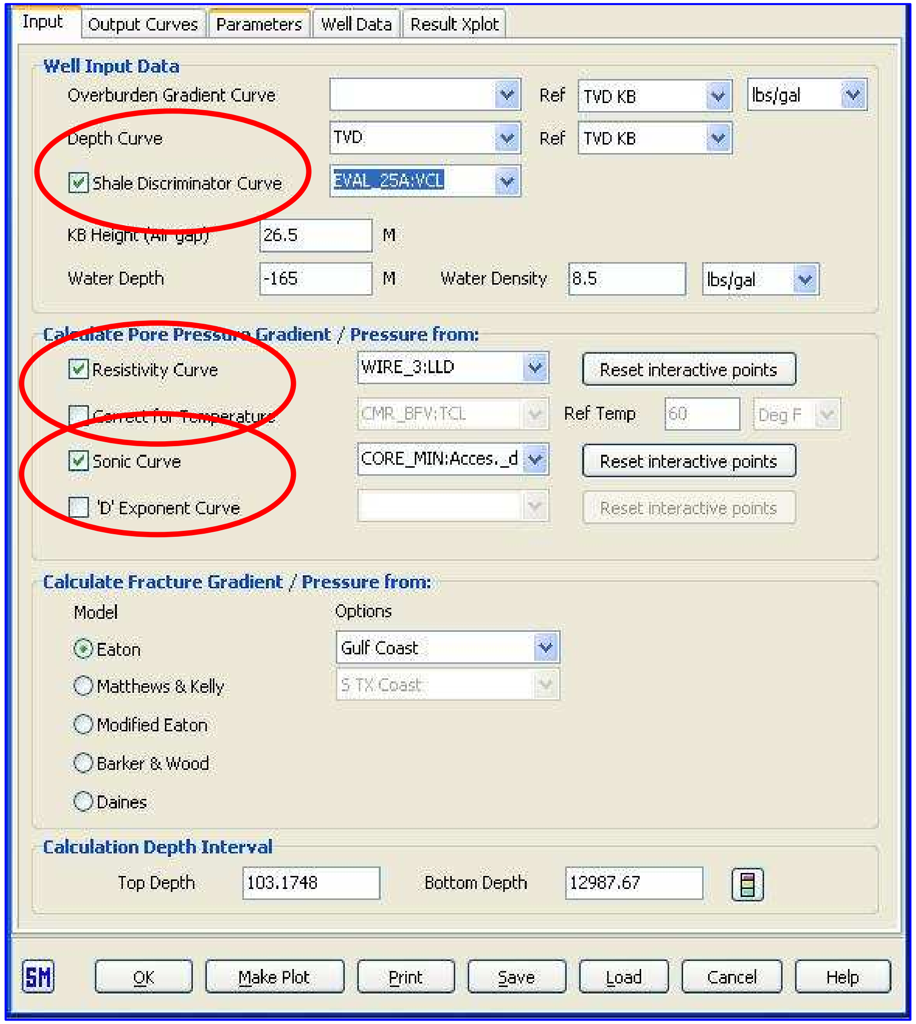
- The final module provides the user with the methodologies to generate Pore Pressure and Fracture Pressure gradient models for the study well, based on the analysis of input log curves and additional drilling information
- Five Fracture Gradient models are implemented in IP. These are:
    - Eaton
    - Matthews & Kelly
    - Modified Eaton
    - Barker & Wood
    - Daines



Shale Discriminator Curve

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- Using Gamma Ray
  - In a sand / shale sequence the GR log normally responds to lithology change; however An elevated Gamma Ray can result from a number of situations:
    - Uranium enriched mineral sands
    - Volcanic ash
    - Phosphates – fossil shell fragments.
  - Note GR readings decrease in large diameter hole or if run through casing.
- When calculating Vsh ensure:
  - All log data is reviewed including the density – neutron logs
  - Mud log cutting descriptions are integrated
  - Core and / or sidewall core data are included in the review

Resistivity Curve

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- Pore Pressure from Resistivity has a number of limitations which must be considered during an evaluation:
  - Variations in Cation Exchange Capacity (**CEC**) affect the normal shale compaction trend line
  - Formation temperature and fluid salinity effects are significant, especially at shallow depths
  - The methodology becomes less accurate at deep burial depths where porosity is low
- Induction Resistivity
  - There are induction limitations when run in saline mud and resistive formations and works best in low resistivity formations
- Laterolog Resistivity
  - Problems with the Deep Laterolog can occur below thick resistive beds and works best in resistive formations
- Microlaterolog Resistivity
  - Microlaterolog Resistivity logs should track deeper reading Resistivity logs, except where mud filtrate invasion occurs.
  - If poor pad contact occurs then the tool will respond to the mud resistivity rather than formation resistivity.

Velocity Data – Sonic Curve

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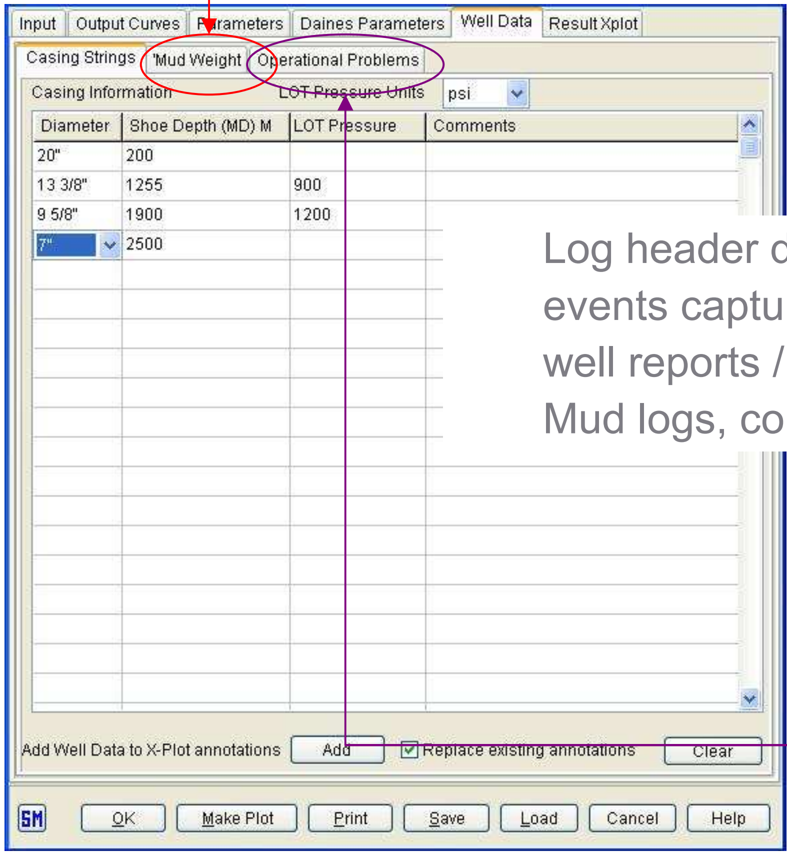
- Ensure that calculated interval velocities are similar to the anticipated rock velocities
- Whilst generic velocity guidelines exist, consider local variations based on:
  - Age
  - Anisotropy
  - Stress orientation
- If possible ensure that enough velocity functions are present to ensure verification of any spatial variation

3. Pore and Fracture Pressure Gradients

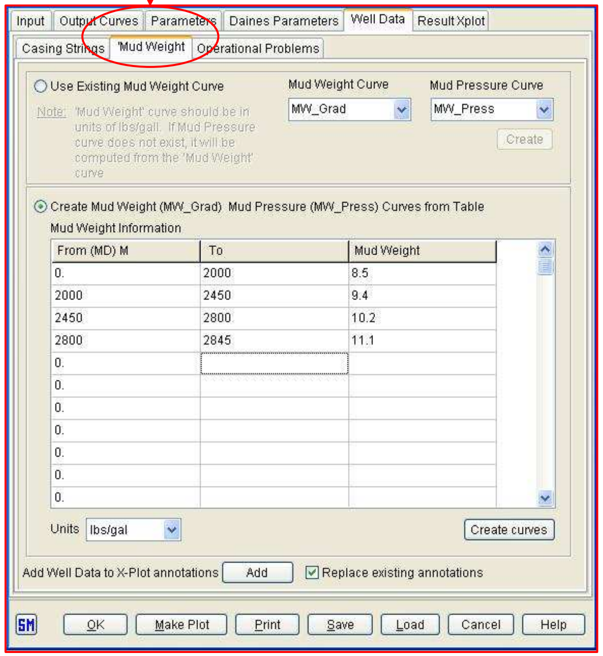
- Beware of the fracture gradient methodologies because:
  - The computations consider over-simplistic geologic / tectonic models
  - They introduce additional unknowns

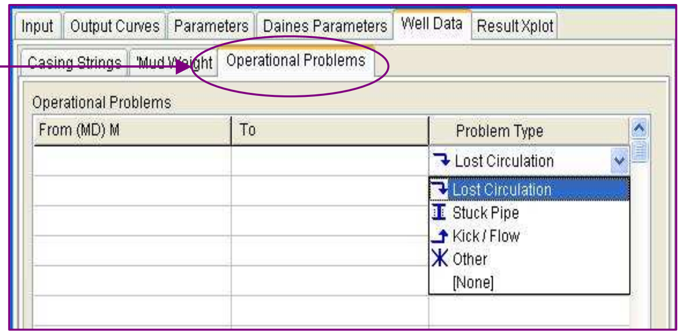
- Ensure that consideration is given to other critical factors such as:
  - Well trajectory,
  - Nature of the formation being tested
  - Knowledge of the in-situ stresses on a local as well as a regional scale

3. Pore and Fracture Pressure Gradients

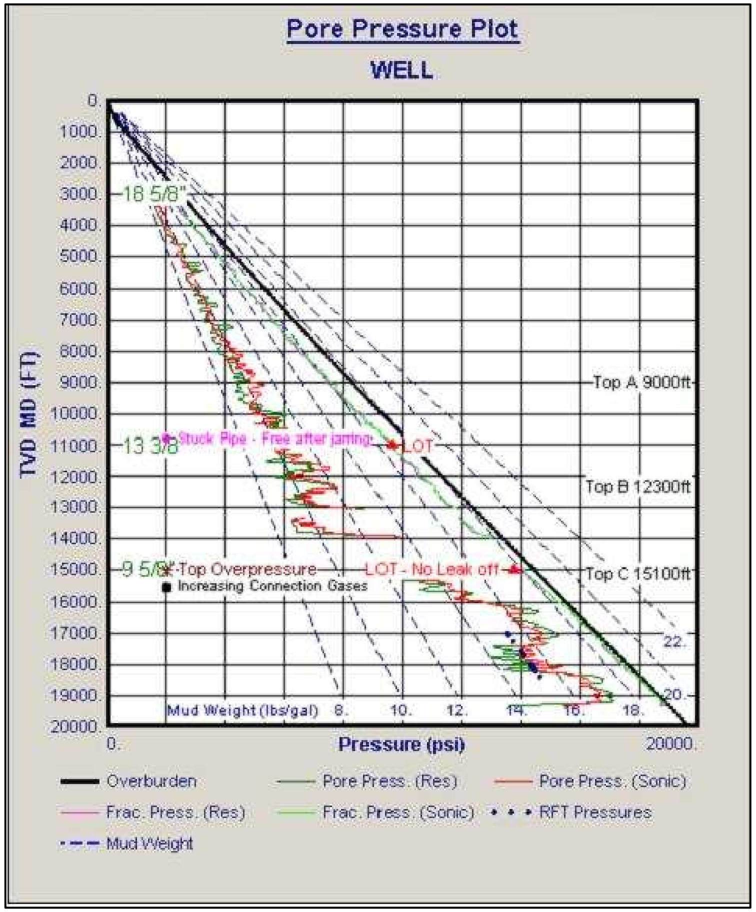


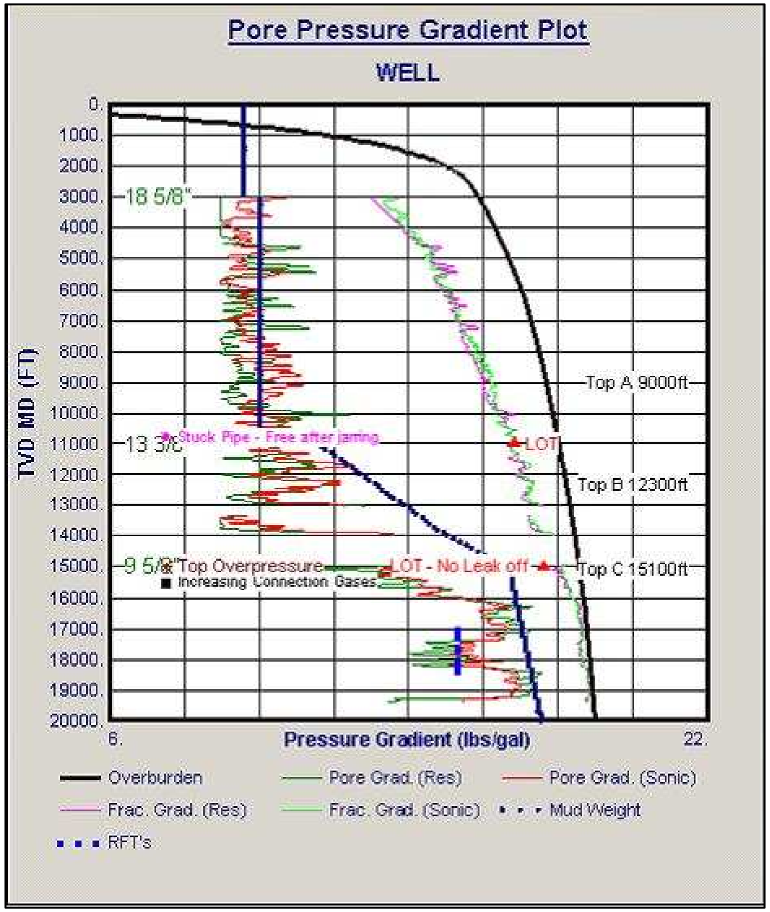
Log header data and drilling events captured from end of well reports / DDR / DGR Mud logs, composite logs





3. Pore and Fracture Pressure Gradients





Model Initiation

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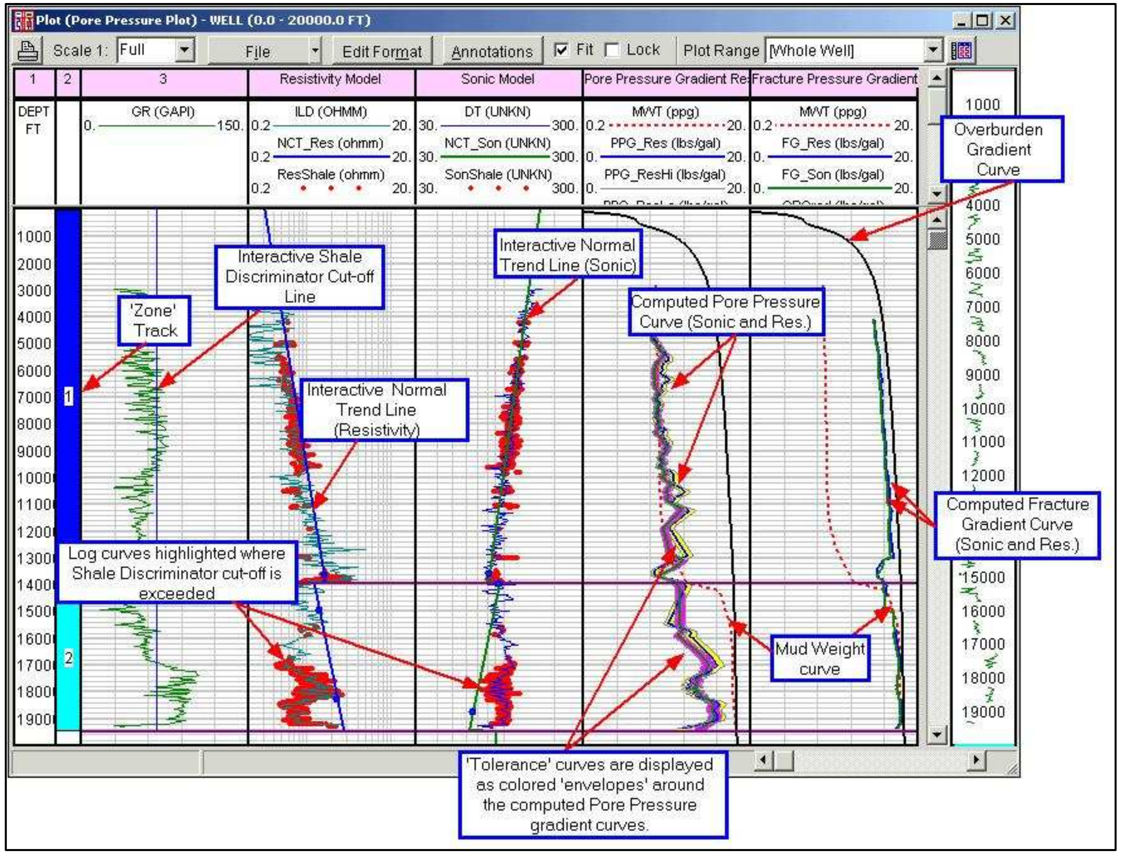
- The module is initiated when the following data are entered:
  - Input curves
  - Leak Off Test data
  - Mud Weight
  - Output curve options
  - Pore and Fracture Gradient models selected
- Interactive Log Plot



Conclusions

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- A simple awareness of the Pitfalls that can occur have been highlighted
- Do not use wireline logs in isolation
- Ensure that all petrophysical logs are fully reviewed and prepared before use
- Undertake a fully integrated pore pressure evaluation, calibrated to operational events and pressure measurements should be robust and defensible.
- The software allows the collation and display of these data types, along with the wireline logs, captured within a simple-to-follow workflow.

The impact of using poorly prepared and /or reviewed petrophysical data will result in a potential environmental calamity

Thank you

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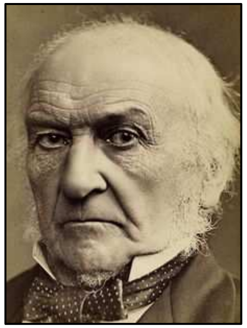
Benjamin Disraeli (21 Dec 1804-19 Apr 1881)

William Gladstone (29 Dec1809-19 May 1898)



“The difference between a misfortune and a calamity is this”:

If Gladstone fell into the Thames, it would be a misfortune.
But if someone dragged him out again, that would be a calamity”