Presented to BHP Billiton

Primer of CSG Testing:
Some considerations and examples

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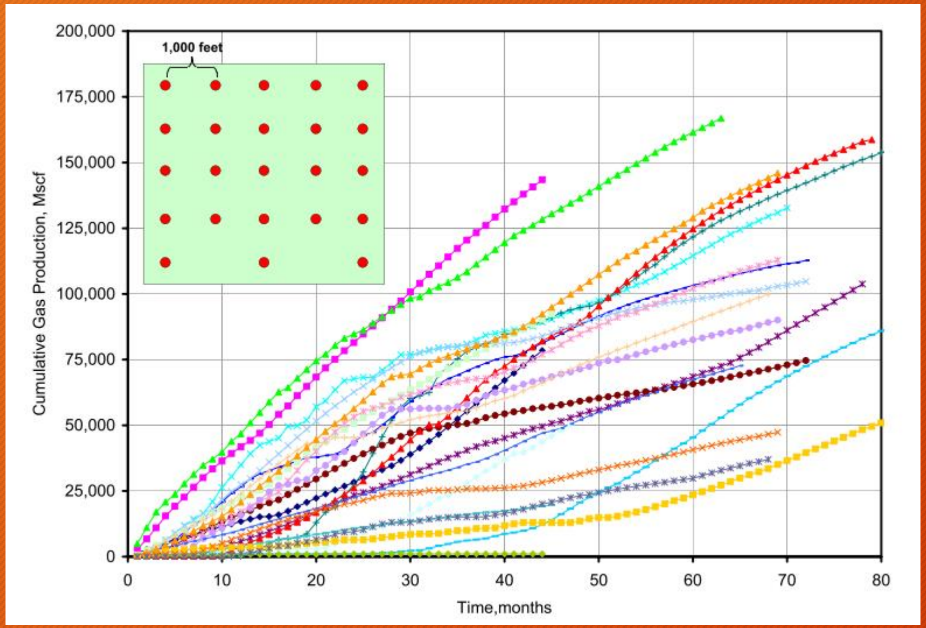
Some Introductory Comments

- DST
  - DST give good estimate of Pi, but many analysts consider them to provide poor estimates of permeability.
- Flow and Buildup Tests (FBU)
  - Single phase tests are easy analyzed. However, FBU in CSG/CBM wells can result in multiphase flow complicating the analysis.
  - In single phase flow, can provide more reliable estimates of permeability when compared to DST and Injection tests (discussed later in this presentation)
- Injection Tests (IFT)
  - Can be a useful alternative to FBU. Results in single phase test which is less complicated to analyze.
  - Can "stress" coals leading to pessimistic estimates of permeability.

Permeability Distribution in Coals

Potential Pressure Test Well Distribution?



Development plans should incorporate:
Regular shut-in pressure data;
Both flow & buildups should be analyzed for kh/skin;
Material balance modeling of shut-in pressures

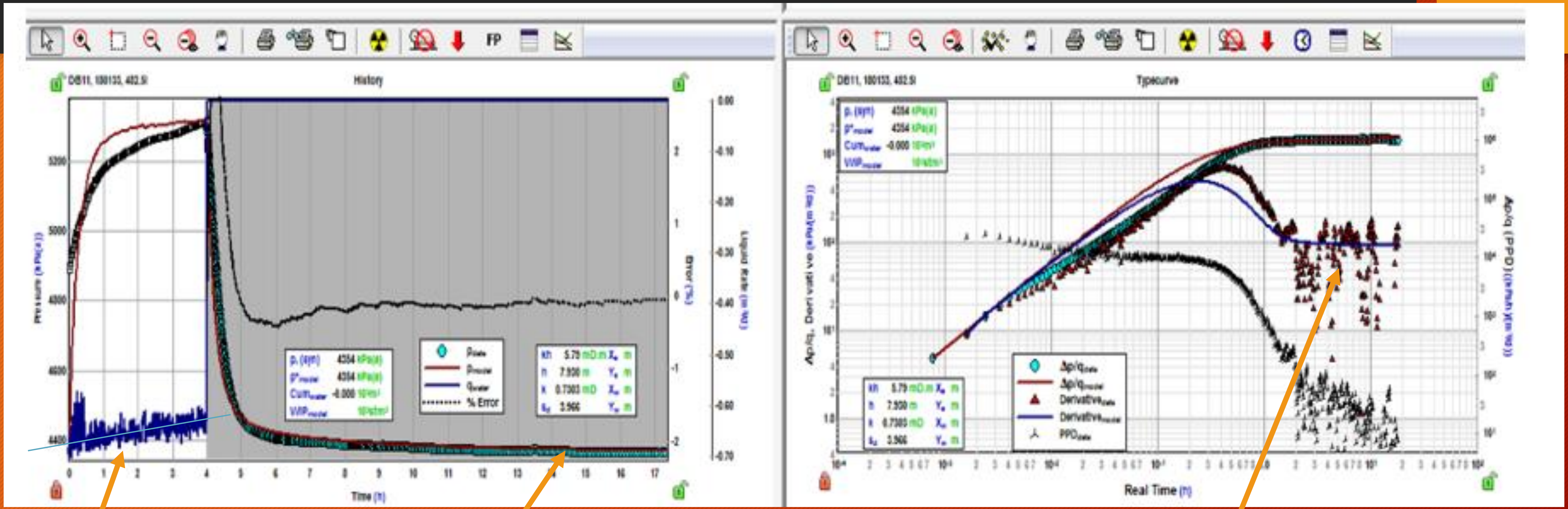
Local well performance variations in a group of 23 wells from the Black Warrior Basin. Differences were attributed to local changes in cleat and natural-fracture permeability

Fracture During Injection

- Of course, you have to watch that you do not inject over the formation fracture pressure. If fracture occurs during the injection period, it will complicate the analysis. I have personally found that pre/post fracture tests are easier to evaluate than analyzing actual fracture tests such as DFITs etc. The fracture point can be estimated from the Closure pressure (Pc) using known/estimated values of Poissons Ratio, Overburden and Pore Pressure:
-
- You may be aware that BHP Billiton CSG group (Don McMillon) uses the following:
- $Pc = (v/(1 - v)) * \text{Overburden Pressure} - \text{Pore Pressure}$
- $v = 0.25$ for coal
- Overburden Pressure = 1.08 psi/foot
- Pore Pressure = 0.433 psi/foot

Illawara Coals

Sample Injection Test -

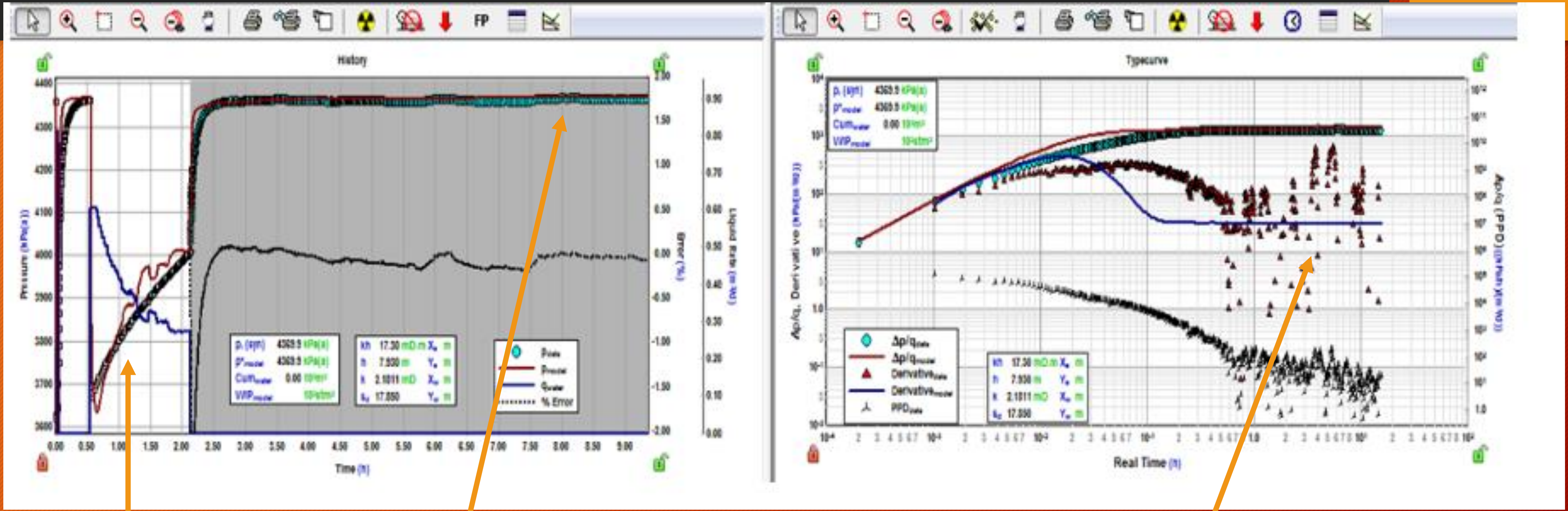


A good estimate of Pi or Pr

Smooth the rates, and analyze the injection period

This data is actually collapsing. Stable pressures on cartesian plot lead to derivative values of zero which cannot be plotted on a log-log plot

Sample Flow and Buildup Test



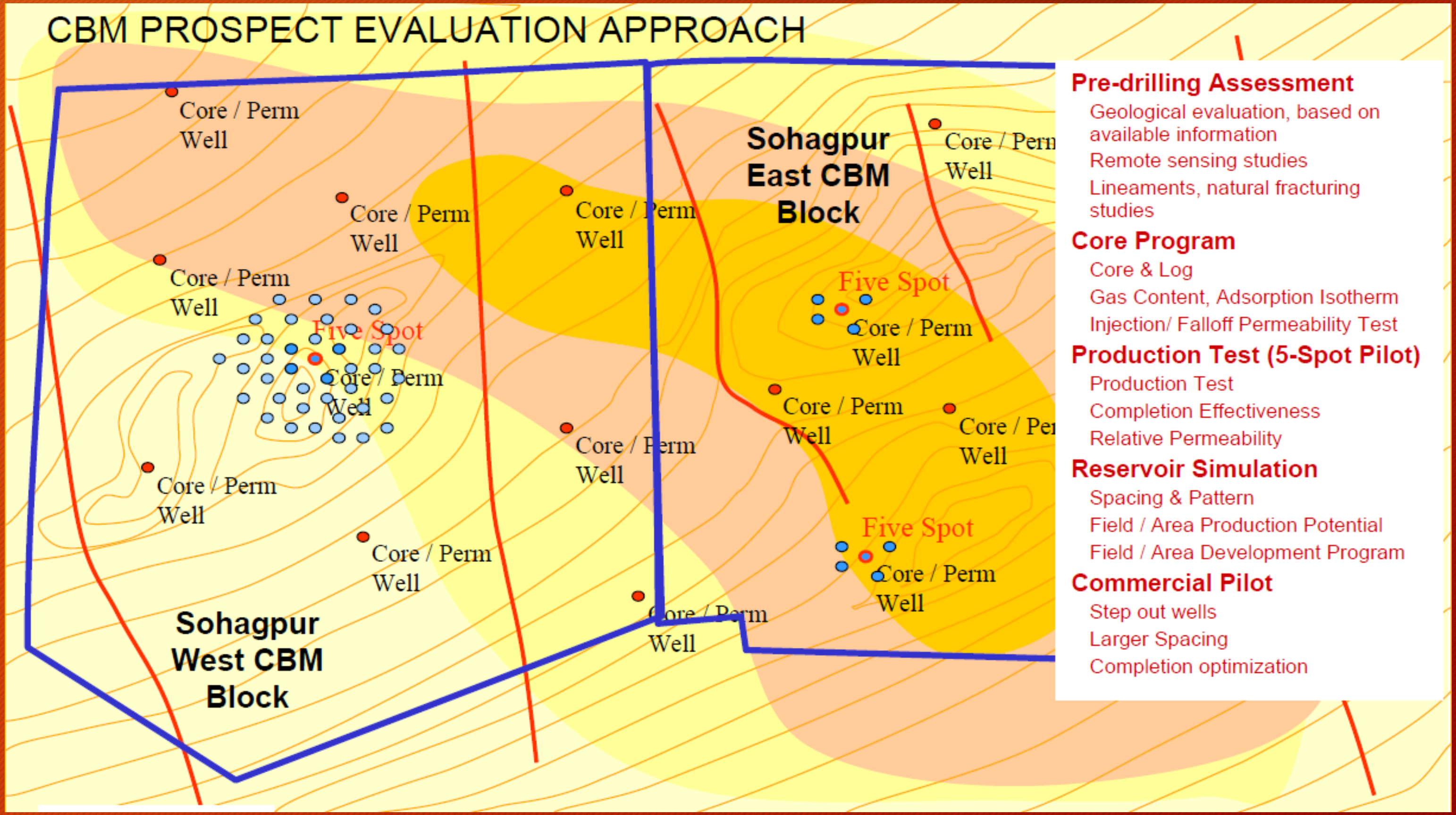
A good estimate of Pi or Pr

This data is actually collapsing. Stable pressures on cartesian plot lead to derivative values of zero which cannot be plotted on a log-log plot

An analysis can be performed on drawdown

Permeability Distribution in Coals

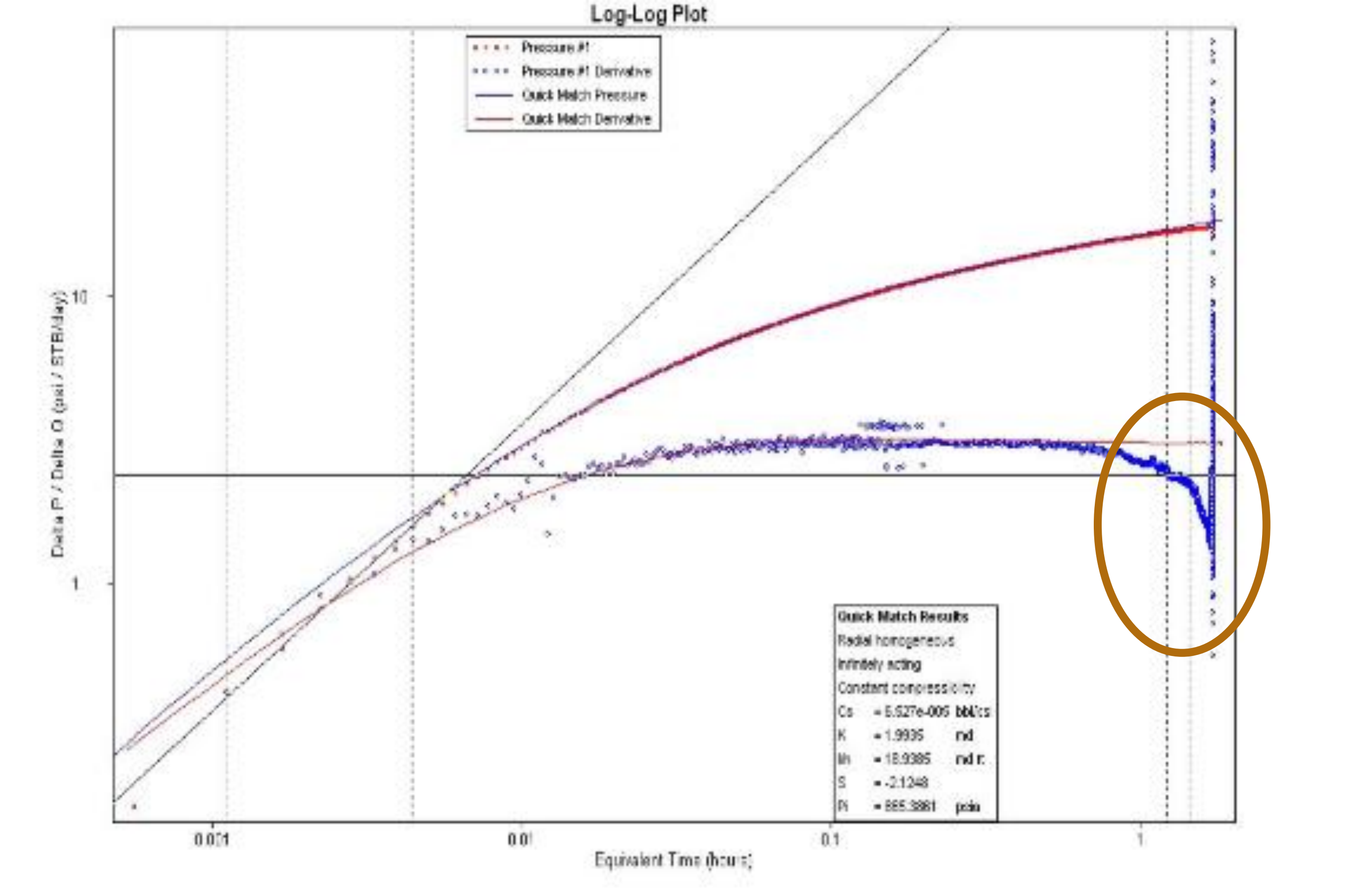
- Example demonstrating a range of permeability, core, and production test locations throughout project area. Example drawn from Sohagpur Block in India



Analyzing Injection Period

- Trying to maintain a relatively constant injection rate can simplify the analysis. Although well testers tend to say that we analyze the fall-off portion of the test, there is no reason why we can also analyze the injection period.
- Given that modern test packages such as Fekete Welltest or Kappa Saphir handle superposition excpility, you can treat the injection period just like a fall-off or drawdown. Attempting to keep a relatively constant rate during the injection period will reduce noise in derivative analysis of the injection period.

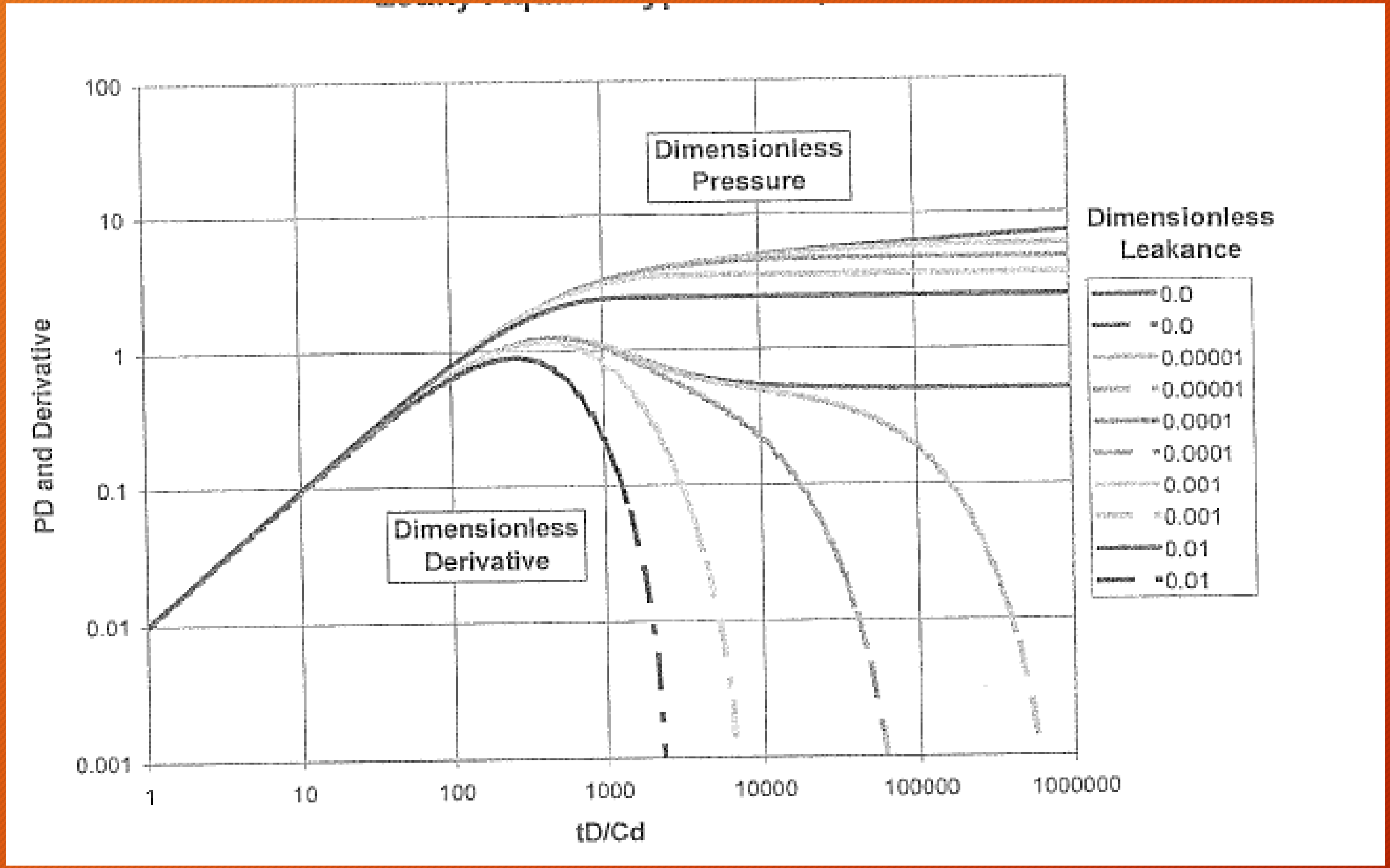
Late-time effects on Injection tests



This late time data is can be due to:

A) Pressure Stabilization
B) Multiphase Effects
C) Leaky Aquifer

Leaky Aquifers



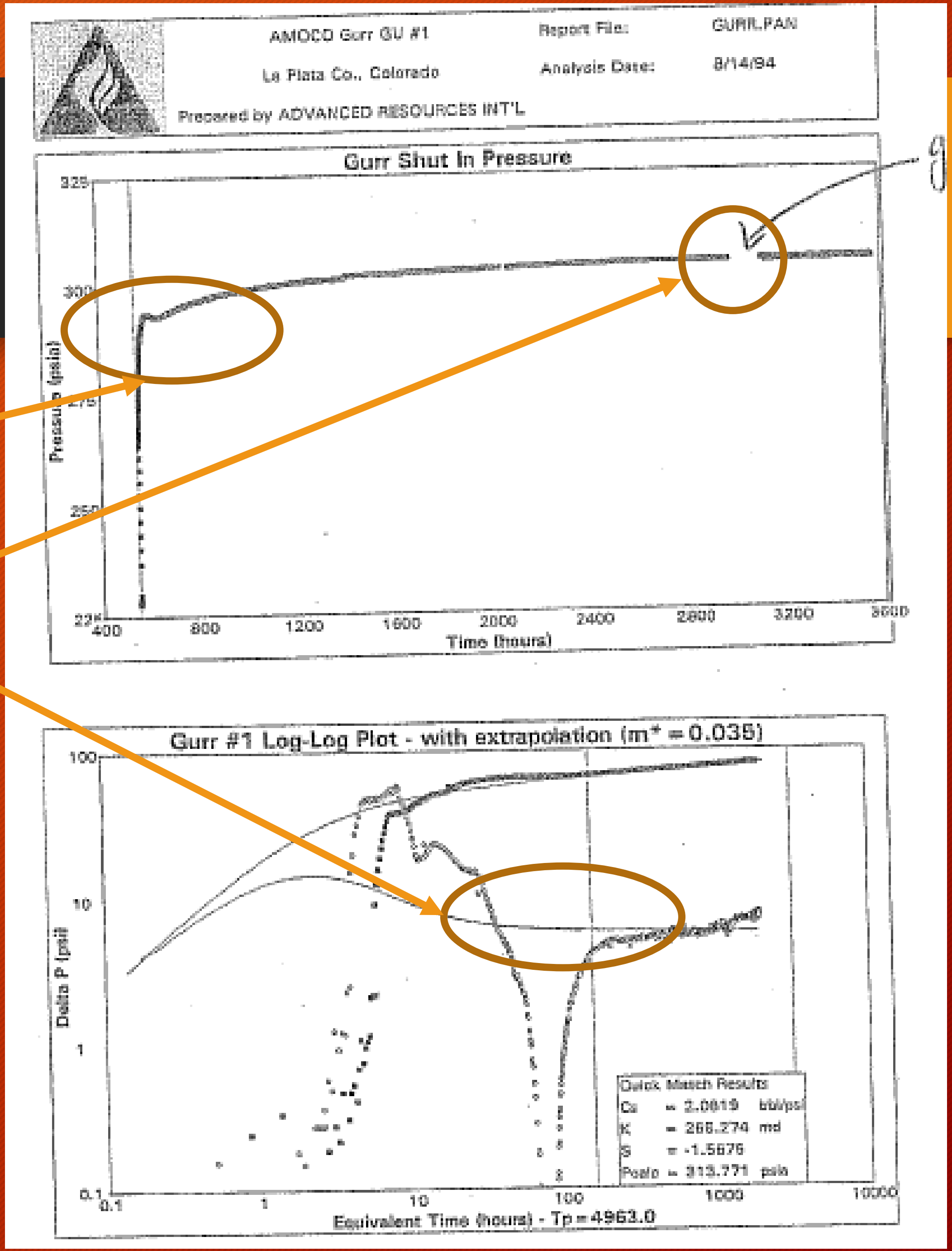
In many cases, the test zone can be connected to other strata. This can lead to a leaky aquifer response similar to pressure support. This has been seen in the Warrior Basin of USA, with a larger number of CSG/CBM projects

Leaky aquifer can be difficult to distinguish from generic pressure stabilization during the fall-off period.

San Juan Basin CSG Test

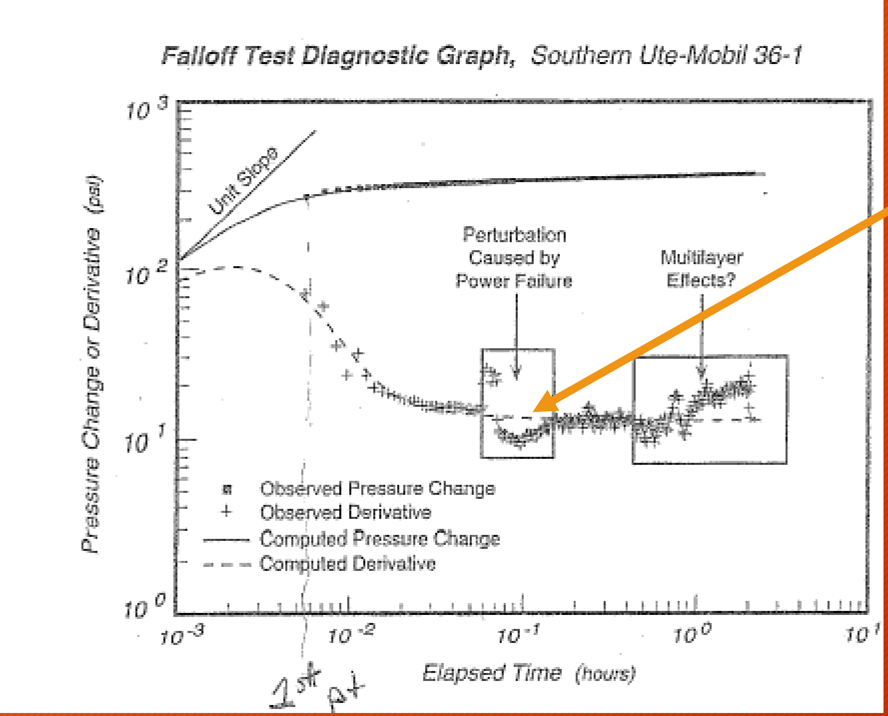
Watch for phase redistribution and/or other wellbore effects.

Take effort to review operations for anything that may affect the pressure derivative interpretation



Dual Porosity / Other observations

- Although is considered a naturally fractured medium it is extremely rate to observe the classic Warren and Root, or any real dual porosity character on pressure derivatives or semi-log plots.

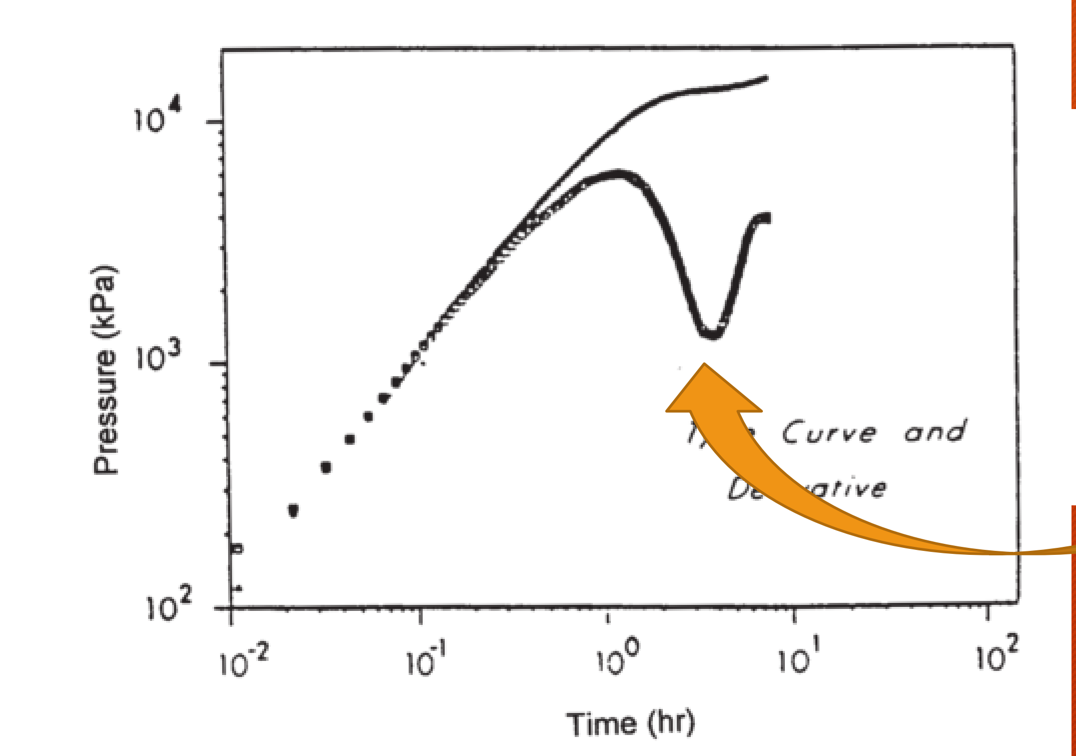


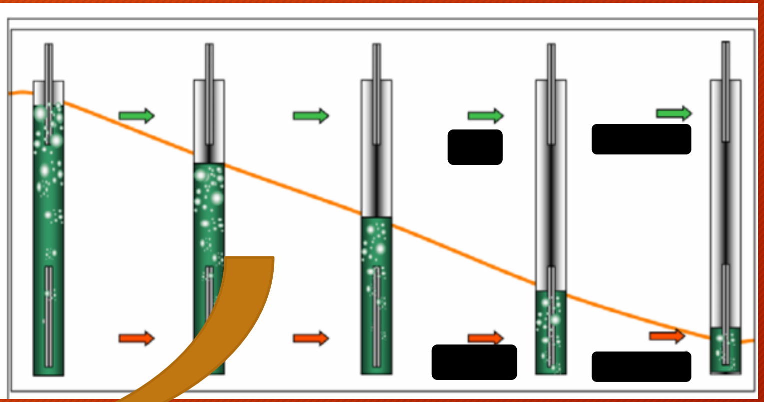
Some testers would have called this dual porosity

I would have called this nothing more than radial flow. Very limited late-time data to call it Multilayer effects

Dual porosity or other?

Liquid moving past recorders signature is very reminiscent of dual porosity one might expect in CBM reservoirs



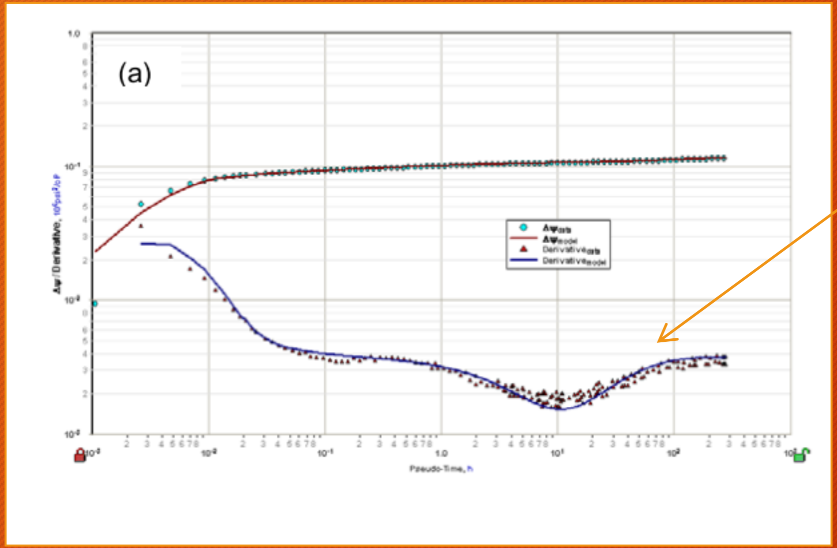


Upper Gauge

Lower Gauge

Dual porosity or other?

- Is this really CBM dual porosity behaviour?
- Example from Canadian Horseshoe CBM (Dry coals)



Dual porosity?
Smoothing?
Filtering?
How confident are we in the interpretation?

Clarkson, C. R. (2008)

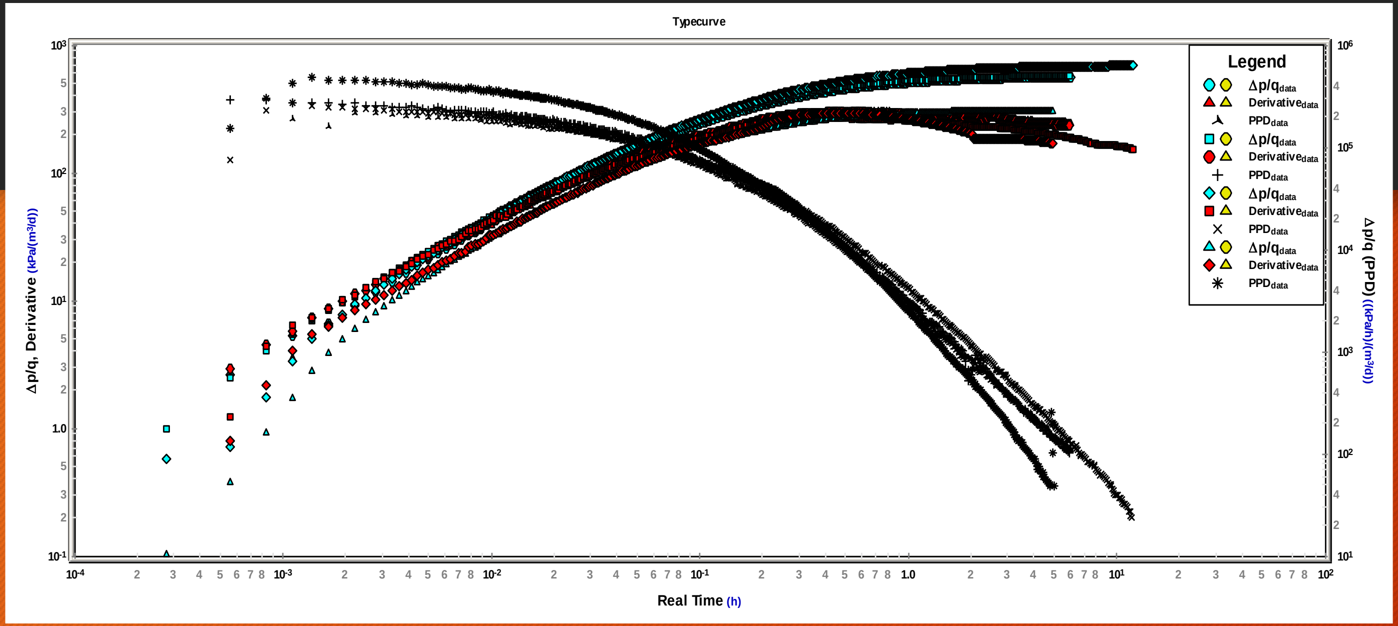
China CSG: Single Phase Flow-Buildup DST's

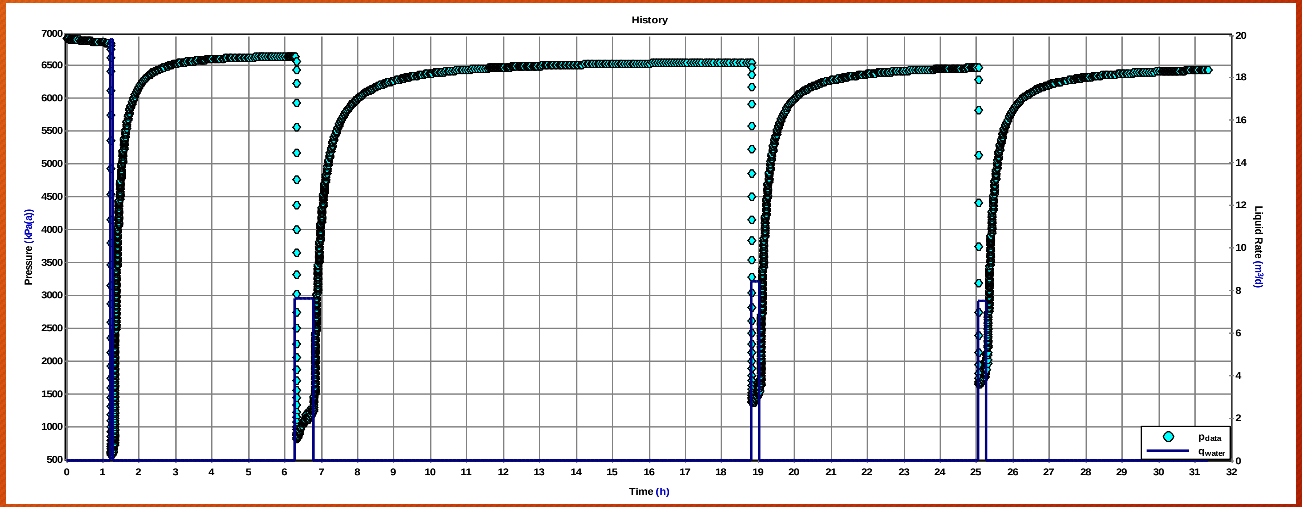
In China, we executed single phase DST flow / buildup tests using the following operations:

- *Cushion to keep BHP > Desorption Pressure (required understanding of Isotherm and gas saturation).*
- *Test duration based on expected low k of Dajing region*
- *Wellbore storage calculated assuming downhole shutin*
- *Ran commercial software simulation to find optimum design*

The main advantages of using downhole shut-in are the minimization of both wellbore storage effects and/or duration of afterflow.

China CSG dst #1





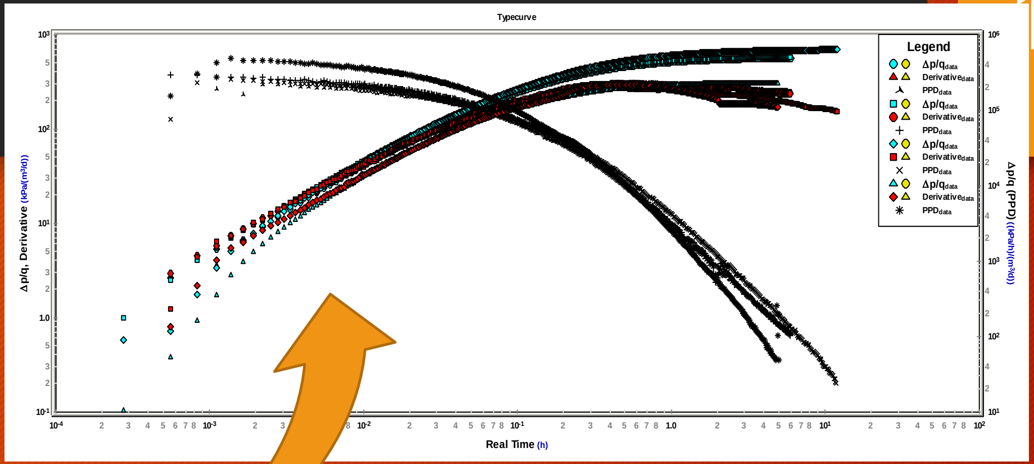
CSG does not exclusively require DFIT or IFO

Conventional DST with proper test design will provide reliable results.

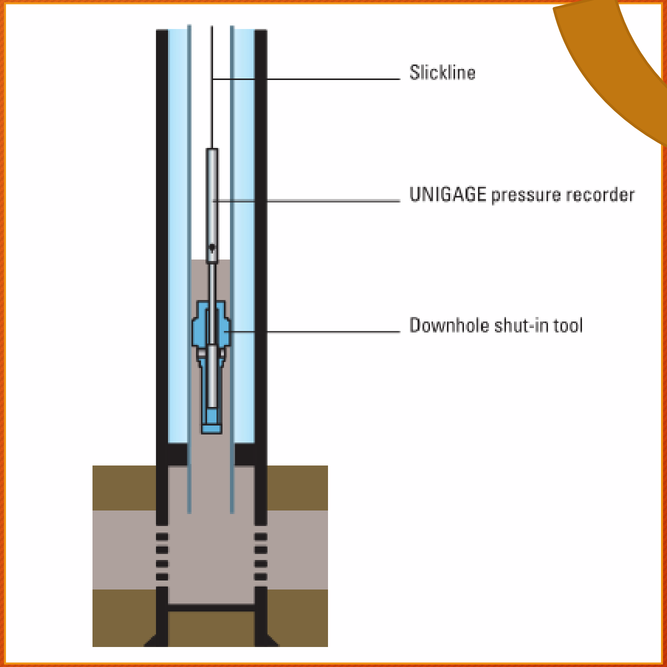
These examples are from Dajing Basin & incorporated downhole shut-in

China CSG dst #2

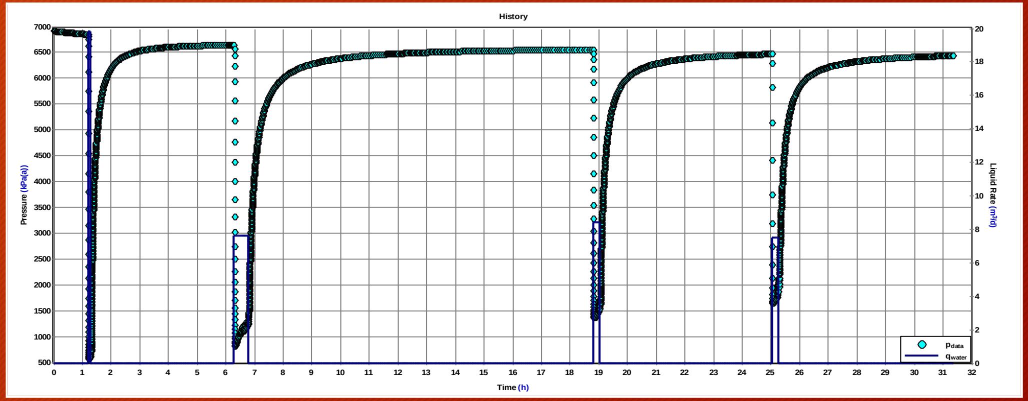
3. Analysis: Repeatable results



2. Execution with downhole shut-in



2. Data Collection: Quality pressure & rate measurement



Another Example

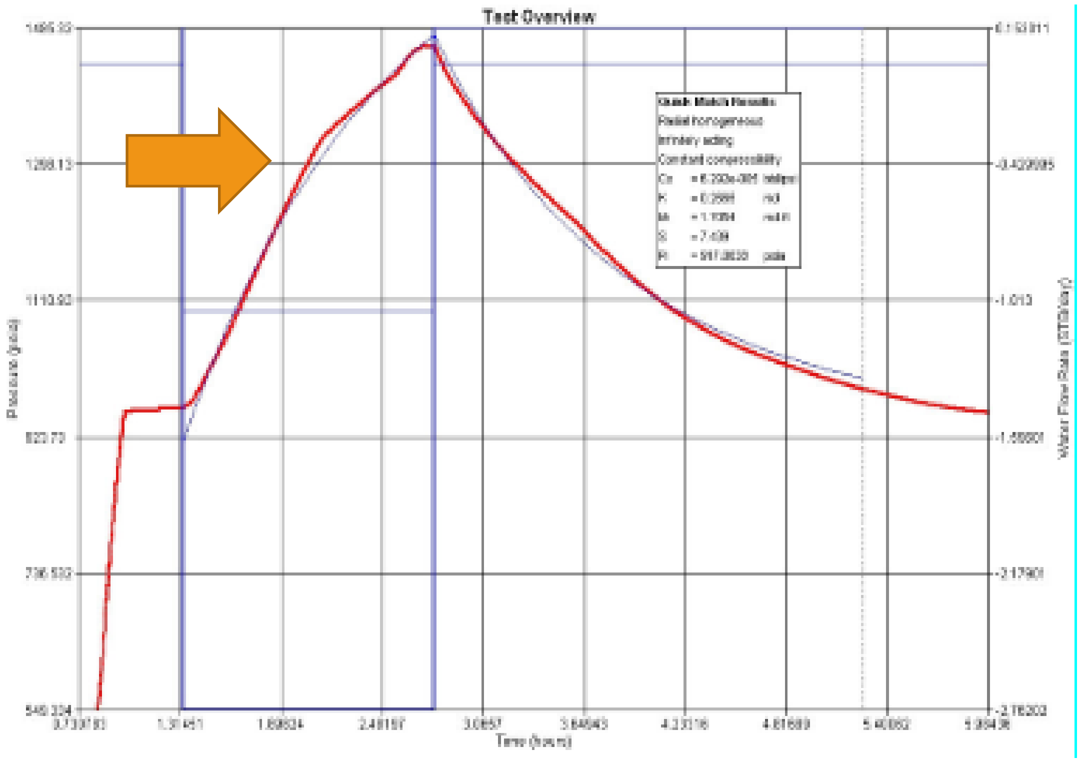
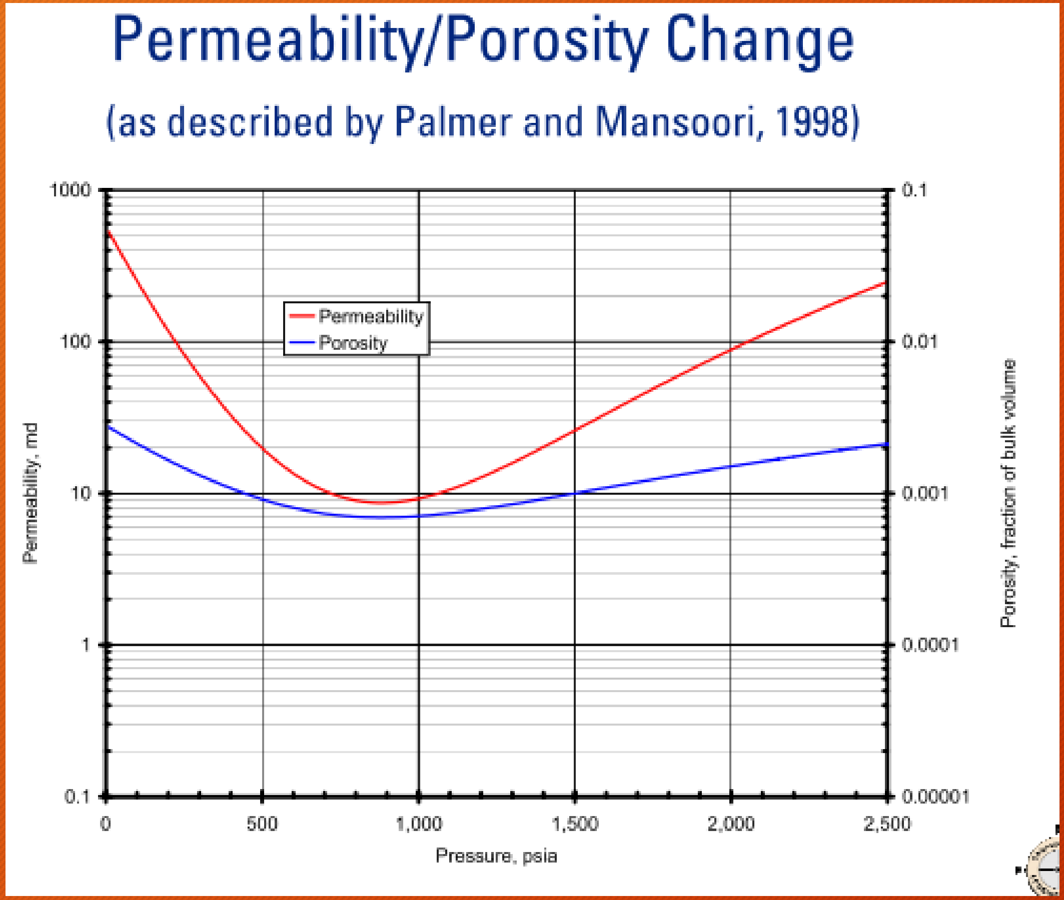


Fig. 7 - Test Result overview using quick match results

In this data set, the both the injection period and fall-off period can be analyzed.

The operator maintained a relatively constant injection.

Permeability Results & Matrix Shrinkage/Growth

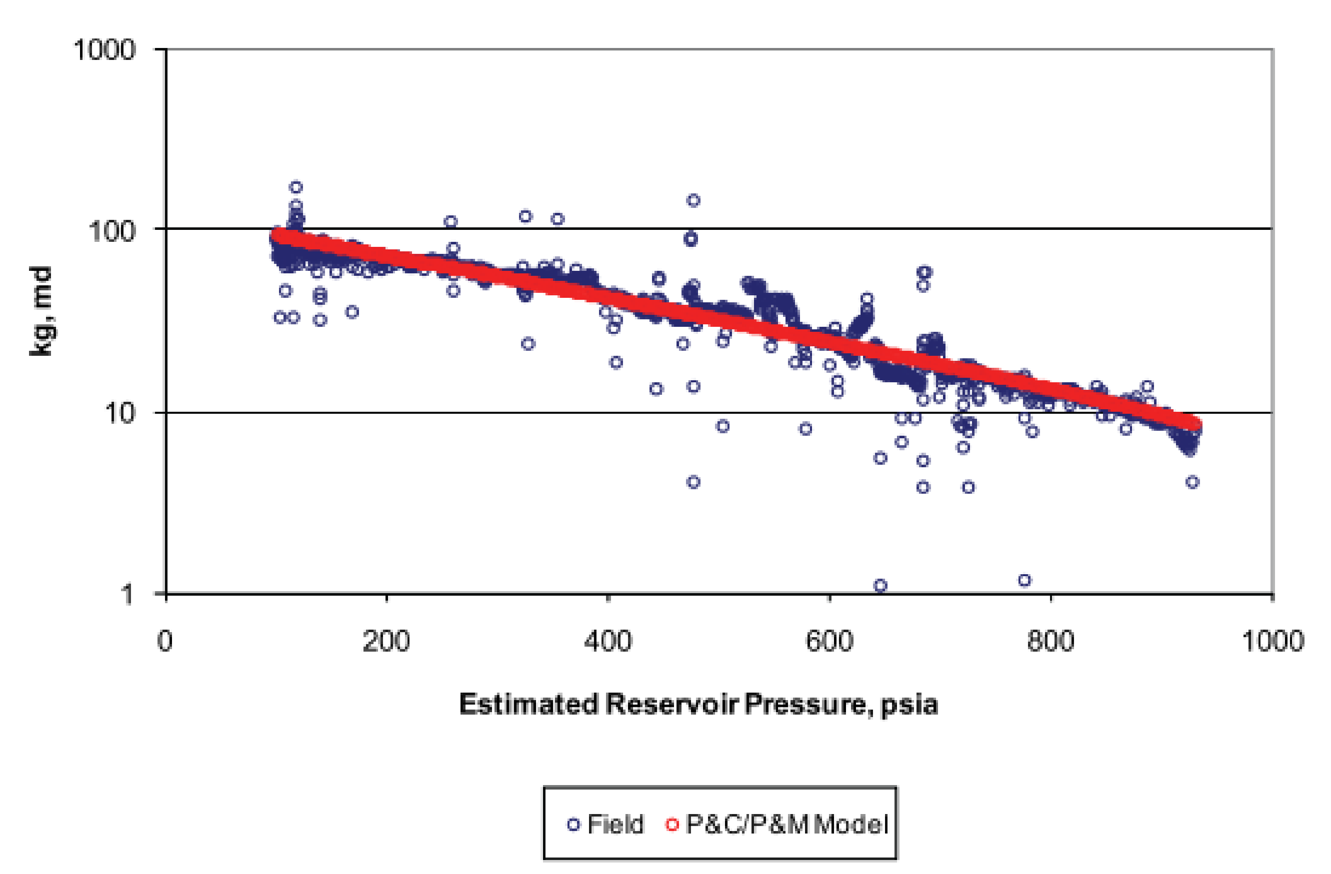


As coals dehydrate (i.e. water is removed during production) coal permeability can increase significantly due to coal shrinkage (although pressure reduction during production tends to close coal cleats).

When making long-term production forecasts in various simulation tools, you may want to ensure some permeability growth to avoid making overly low performance predictions.

Although a well known phenomena, there is often limited data available to judge the magnitude of its effect. In the absence of laboratory data, periodic buildup tests on the same well may illustrate the effect by calculating increasing permeability results.

Matrix Shrinkage – San Juan Basin Example



Example of permeability growth with decreasing reservoir pressure (increased production).

Permeability increased from 10 to 100 md.

Other Permeability Considerations

- Coal is also very mallable (plastic deformation), and is sensitive to stress. It is possible that injection testing can lead to pressure on coal cleats and result in <u>temporary</u> lower permeability results.
- In Canadian Mannville coals, we have seen PTA perms of 1 md (from injection tests) while performance / production based permeability was as high as 10 md.

Derivative Interpretation

- Generally, pressure derivative interpretation for CSG is similar to conventional tests.
- During the fall-off, as pressure stabilizes, you may see a downward trend in the derivative. In my opinion, the downward trend has no physical meaning, and is just an artifact of the lack of pressure change in the raw data. Some analysts attempt to assign constant pressure boundaries and so on. Multiphase effects can also cause similar behavoir - the implication is that at the end of the test, gas may evolve depending on your gas saturation levels and so on.
- Once pressure is stablized, you can get a good estimate of Pr, but the estimate of permeability can be difficult due to the chaotic nature of the derivative. Since derivatives are plotted on a log-log scale, the derivative goes "bannas' when the pressure data stops changing - this make look like radial flow, but most likely is not

Comparison of IFT an FBU

Table 2. Permeability Comparison

Example	FBU (mD)	IFT (mD)	Difference (%)	Ratio	Reference
Zone A	45.91	57.44	-25%	0.80	Figs 11, 12
Zone B	28.73	23.61	18%	1.22	Figs 13, 14
Zone C	60.49	129.92	-115%	0.47	Figs 15, 16

Table 3. Skin Comparison

Example	FBU	IFT	Ratio	Reference
Zone A	9.97	79.73	0.12	Figs 11, 12
Zone B	6.51	42.53	0.15	Figs 13, 14
Zone C	8.00	19.30	0.41	Figs 15, 16

Quality of data can even influence these permeability differences

In this raw data, injection tests showed formation damage 10x those values estimated from flow and buildup tests. Were coals stressed?

However, flow and buildup tests are potentially complicated by multiphase flow tests.

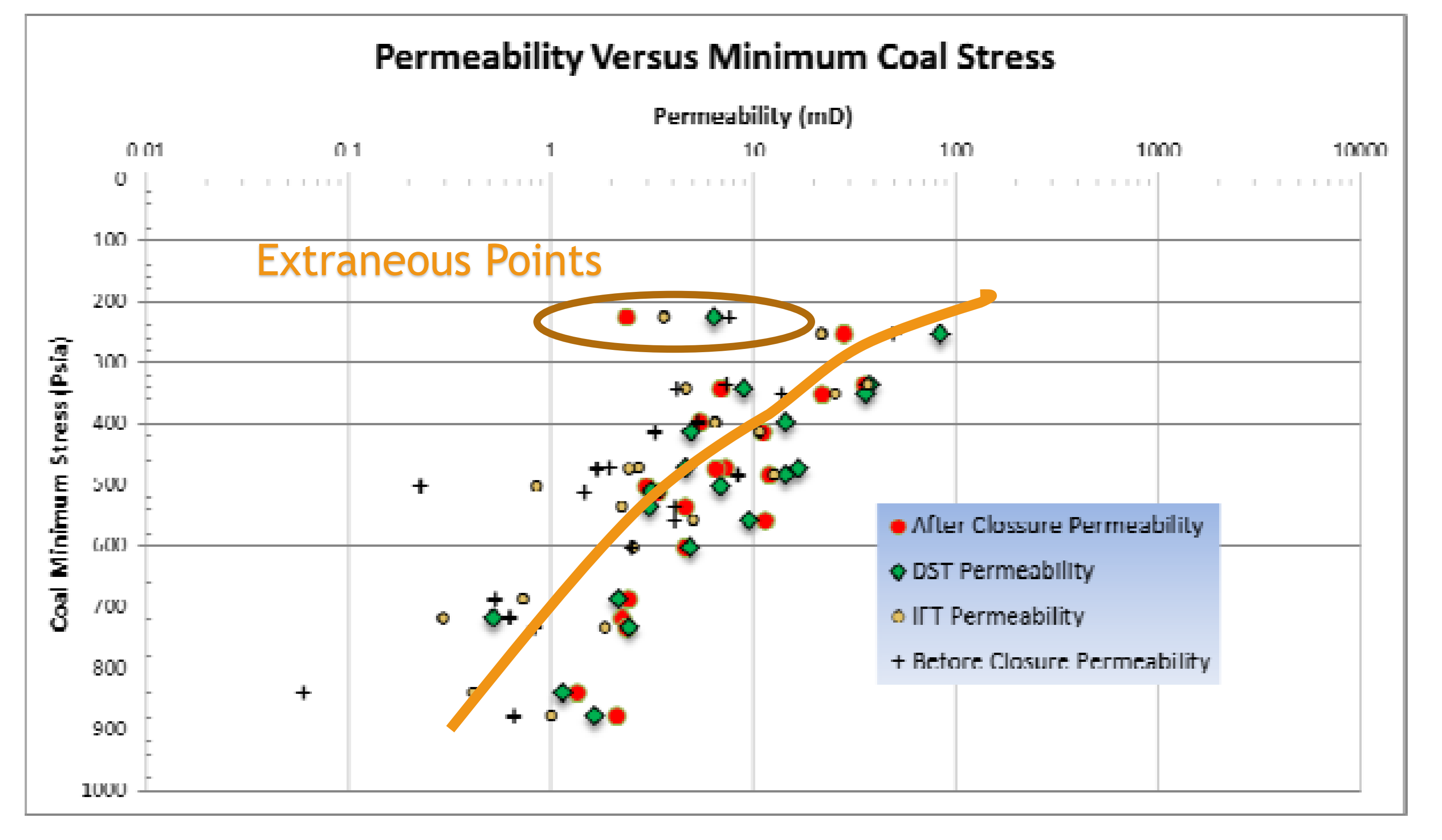
If a good match can be achieved with high skin and high perm, it is possible the same match can be achieved with lower skin and lower perm. Be prepared to try different combos!

Final Comments on Stressed Coals

- Even pressure pulses generated from running tools downhole can distort the natural coal stress around the wellbore region. As suggested above, these pressure pulses have the capacity to distort the wellbore natural static stress and generate fluid load up into the coals, which in turn, causes changes in the total compressibility around the wellbore.
- Although these disturbances have moderate radius of influence, they are enough to influence injection tests results.. In other words, if this is overlooked, the testing results could be compromised or misleading. To minimize the pressure pulses effect, the operator should condition the drilling or completion fluids before the test to reduce the viscosity as much as possible and run the testing tool slowly. DST,

Correlating and Vetting Coal Perms

- The above observations means that multiple sources of permeability evaluation may need to be used to generate a representative estimate of permeability.
- For instance, correlating permeability from DST, Production Tests, DFITs against both permeability depth, or stress.

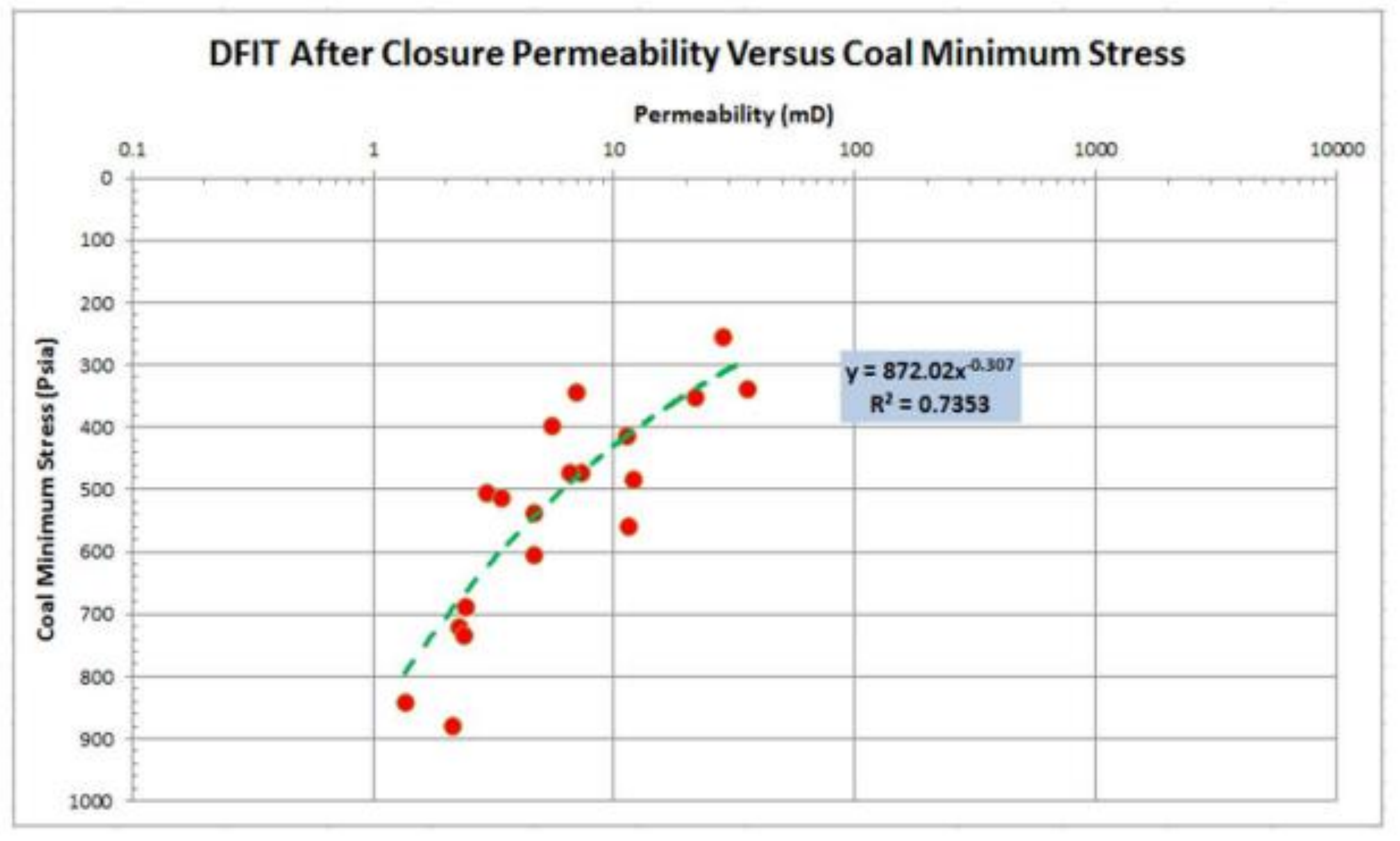


We should see a trend of decreasing perm as a function of downhole stress.

This should help in establishing permeability trends across the field, and with depth.

It may also be a good tool for removing extraneous points.

Other correlations



In addition to permeability vs stress, permeability vs depth correlations can also be established.

Reservoir Management

- DST / IFT/ FBU data should be done on more than development wells.
- PDHGs will be installed on all production wells. This will allow accurate estimation of on-going reservoir pressure (which helps us evaluate current state of coal de-watering/desorption).
- Observation wells should be included in the development plan. We can use interference testing methods to evaluate directional permeability, gas saturation (where are we on the isotherm), and more.

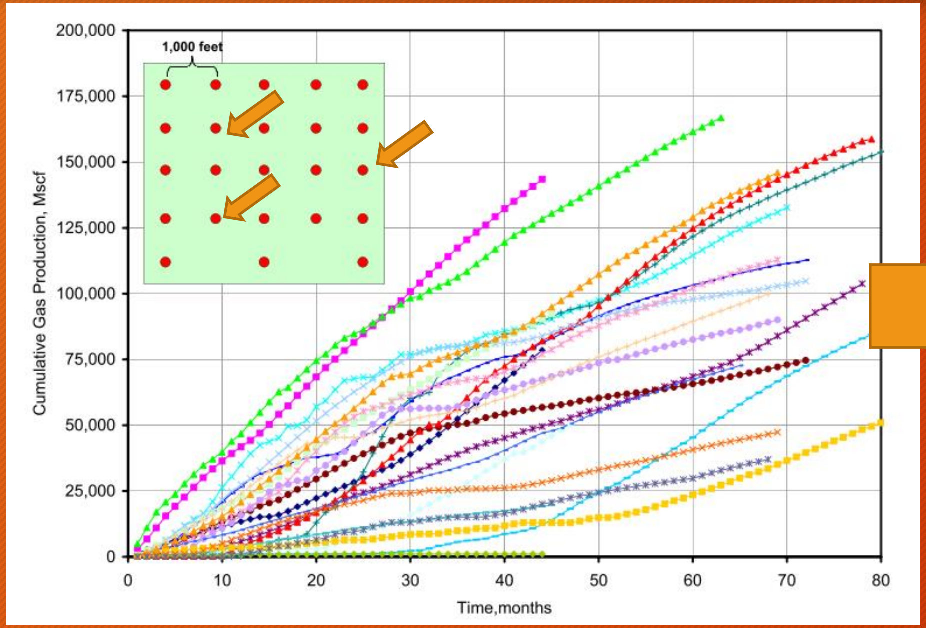
Reservoir Management

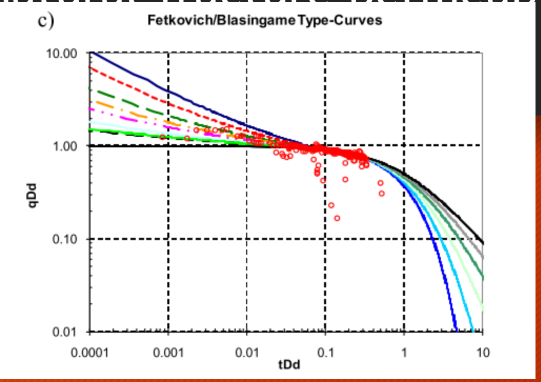
- Downhole gauges will help estimate fluid level column in wellbore. Are we drawing the well down 50% or 75%? Is the flowing bottomhole pressure less than the desorption point?
    - I have seen wells with liquid operating at flowing BHP > coal desorption pressure.
    - This means the well will never produce gas
- The automatic level controlling the downhole pressure data can be fed back to a programmable logic controller which varies the pump speed as appropriate.
- Production should be monitored on a real-time basis.

Reservoir Management

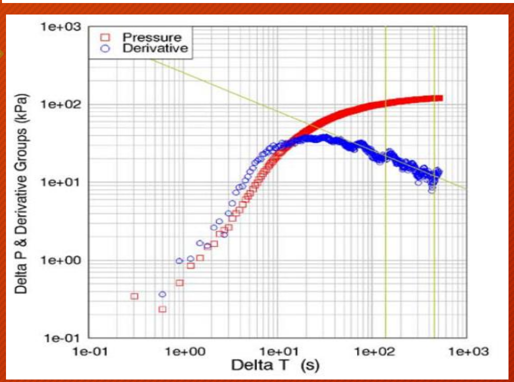
- Local well performance variations in a group of 23 wells from the Black Warrior Basin. Differences were attributed to local changes in cleat and natural-fracture permeability

Potential Pressure Test Well Distribution?



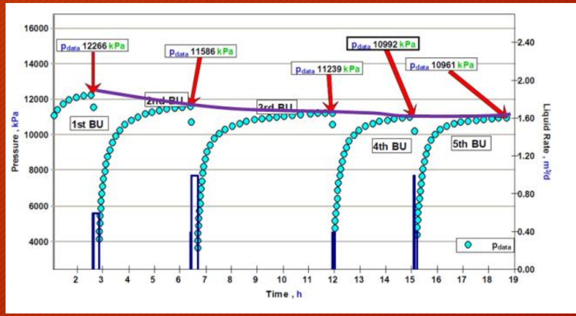


Rate analysis of production periods (Blasingame, NPI, FMB)



Pressure analysis of shut-in data (Traditional derivative analysis)

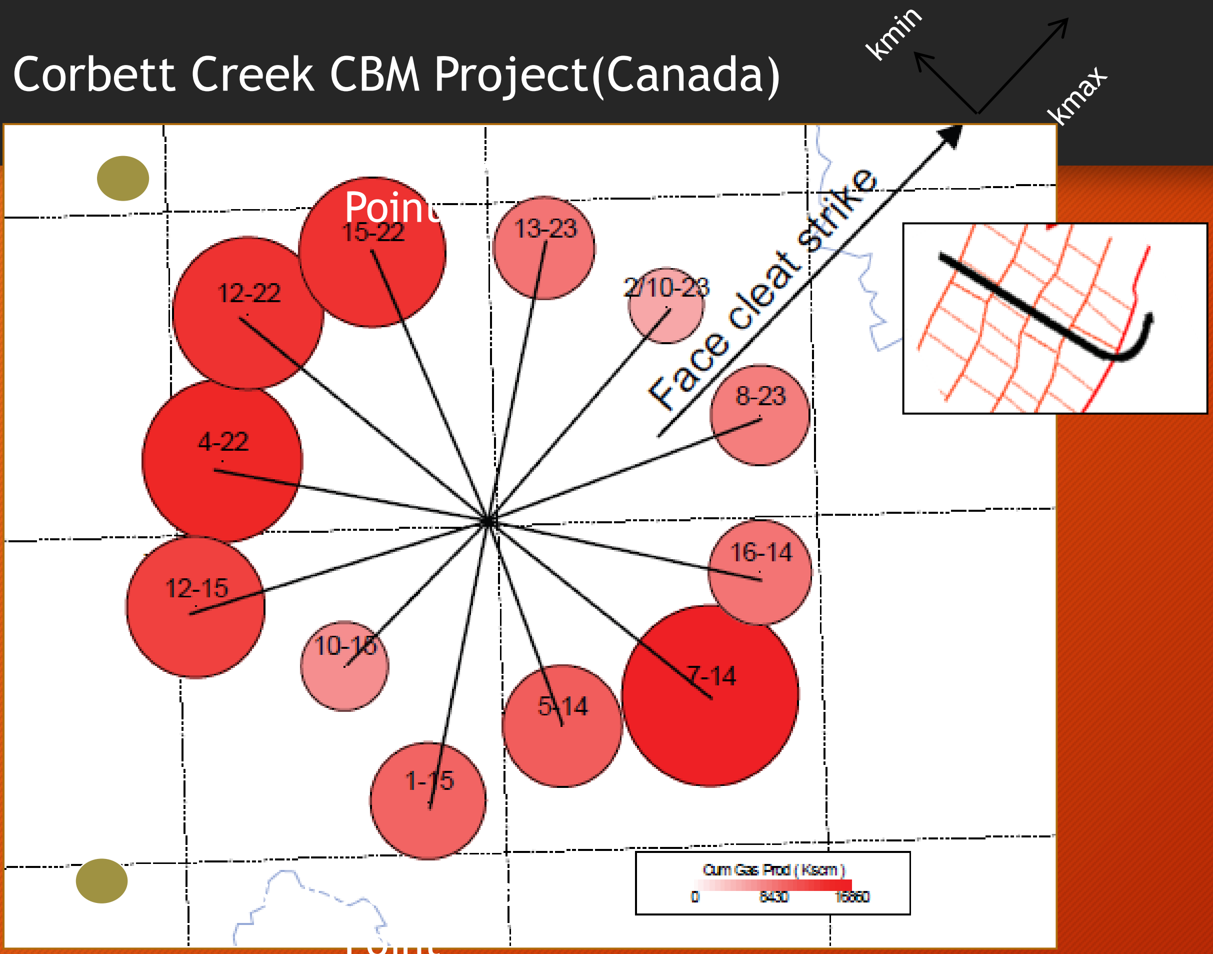
Development plans should incorporate:
Regular shut-in pressure data;
Both flow & buildups should be analyzed for kh/skin;
Material balance modeling of shut-in pressures



Material balance analysis of shut-in data. Any shut-in period should be analysed.

Reservoir Management

Corbett Creek CBM Project(Canada)

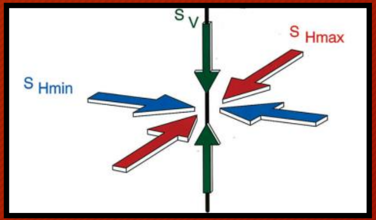


Numeric values represent well names in Cdn nomenclature

Pressure and production data was monitored from a series of Hz wells to help characterize cleat orientation

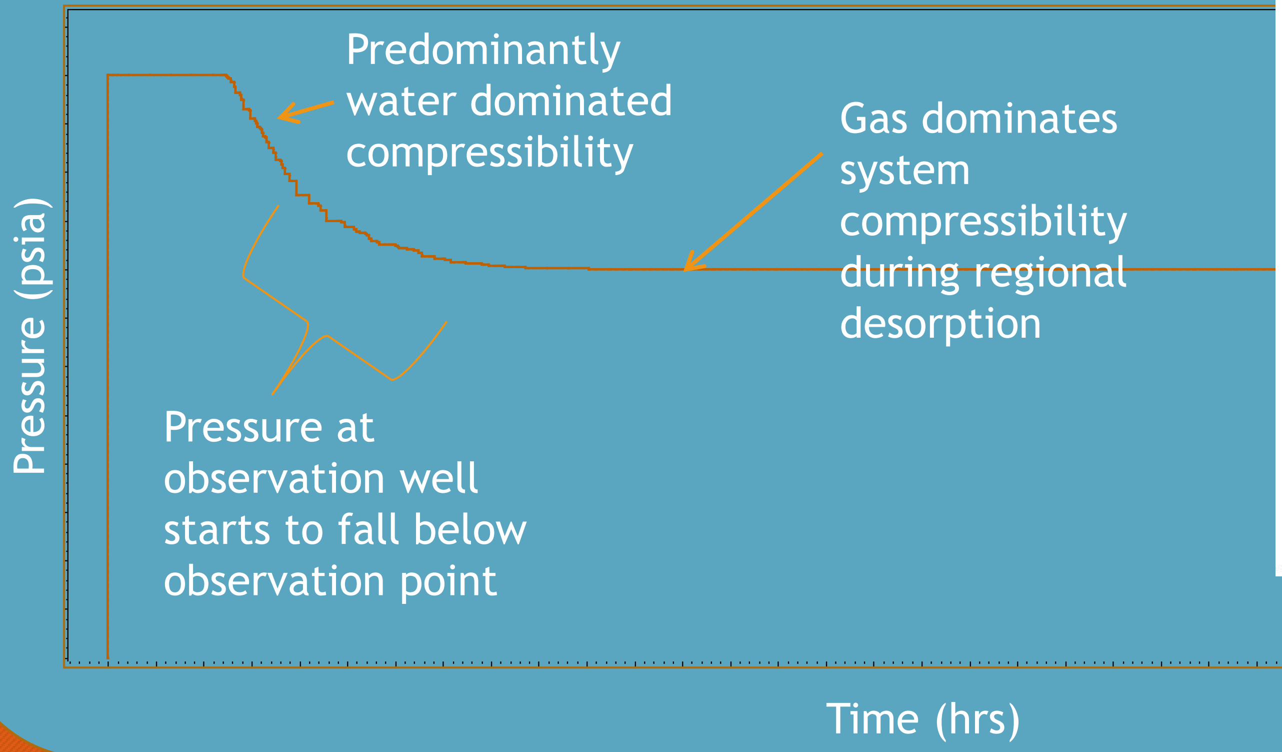
Measured pressure and rate data was supplemented with select pressure observation points

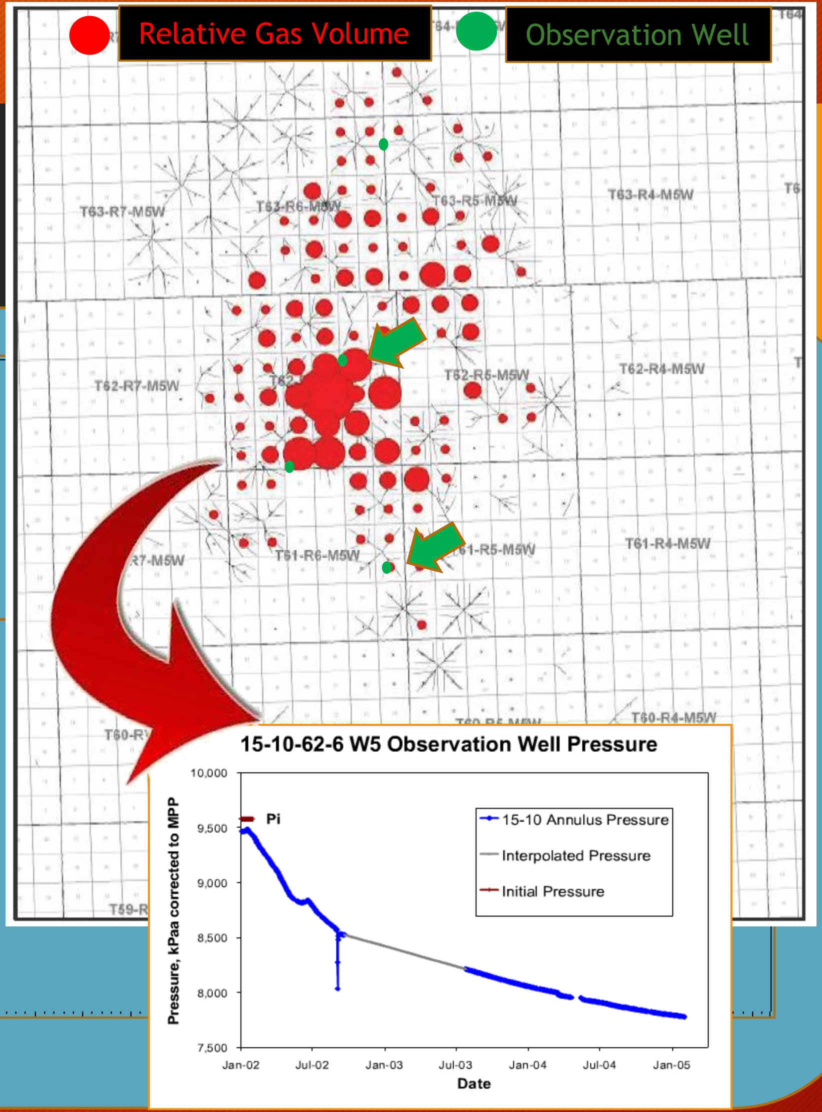
Analysis can be supplemented by core samples and image logs.



Reservoir Management

Corbett Creek CBM Project(Canada)



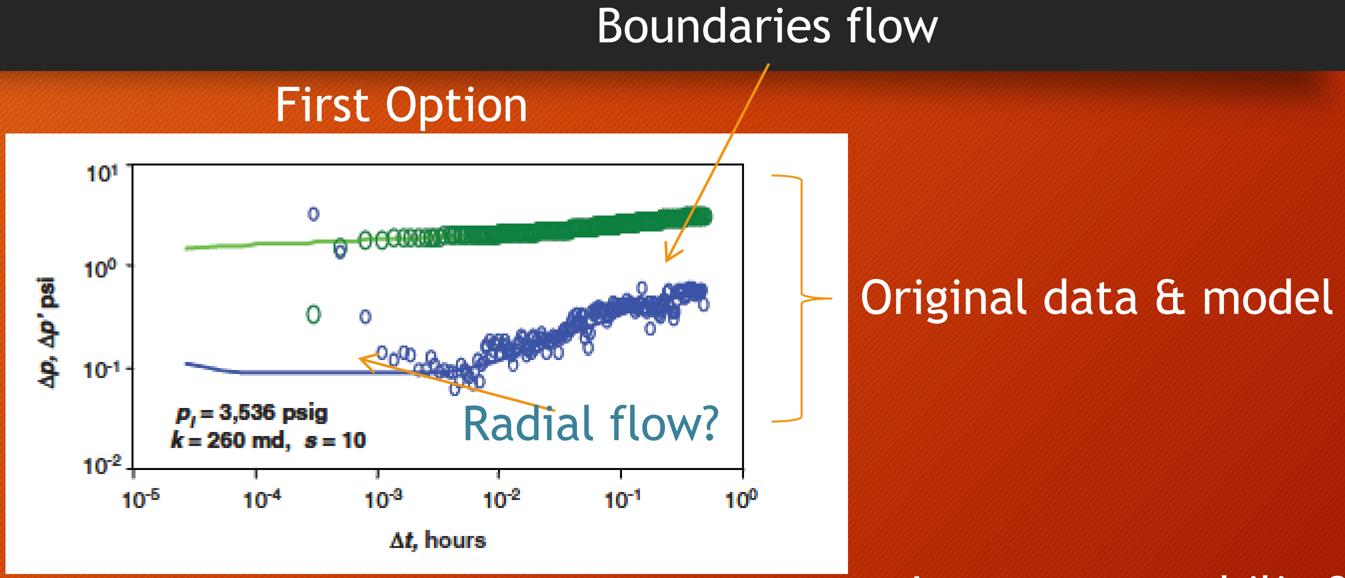


<u>On-going observation wells can be used to help determine if field development area has passed desorption point</u>. Corbett Creek Mannville CBM (Canada) project implemented a series of test wells to observe regional pressure response during development. How much of the reservoir is at 100% gas saturation? When will we reach gas production?

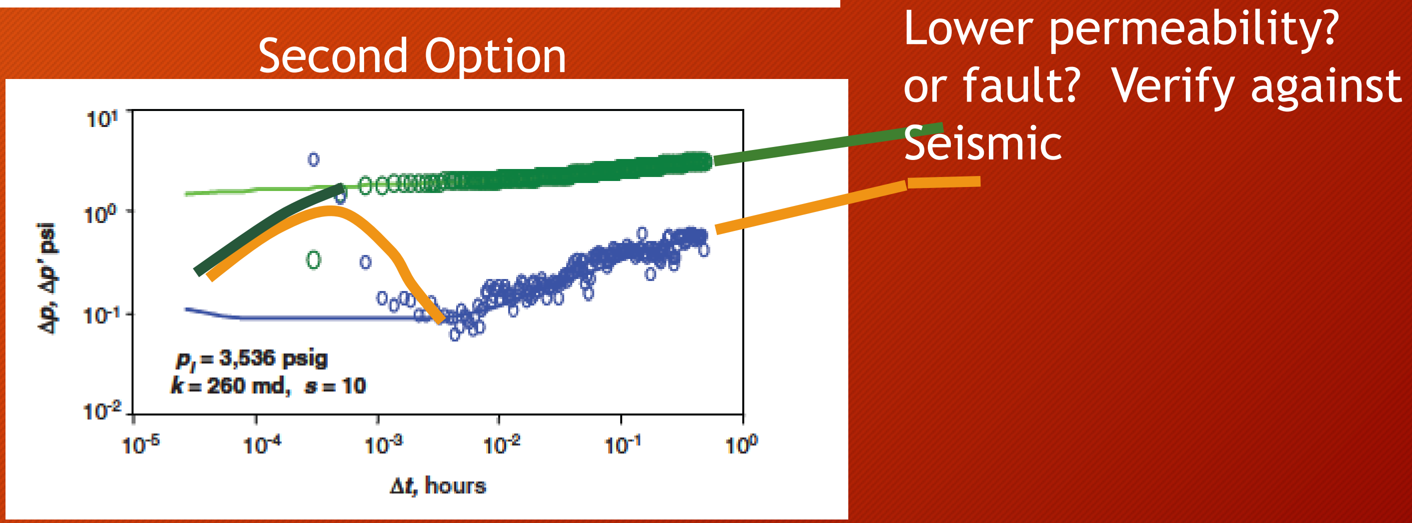
Integrate other data sources

Malaysian work incorporated seismic data which indicated that the well was in close proximity to intersecting faults.

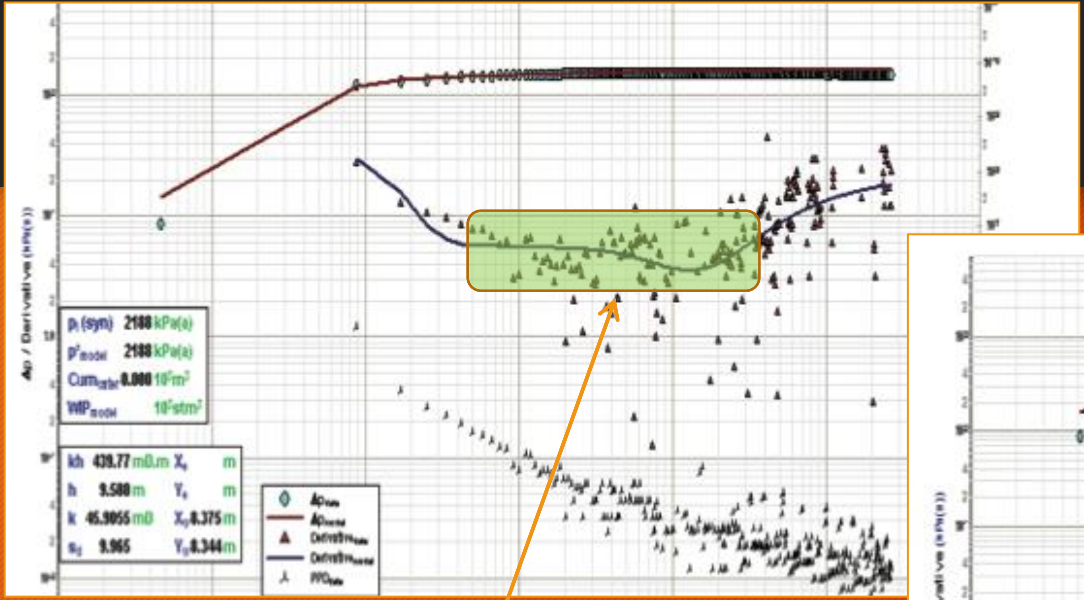
First Option

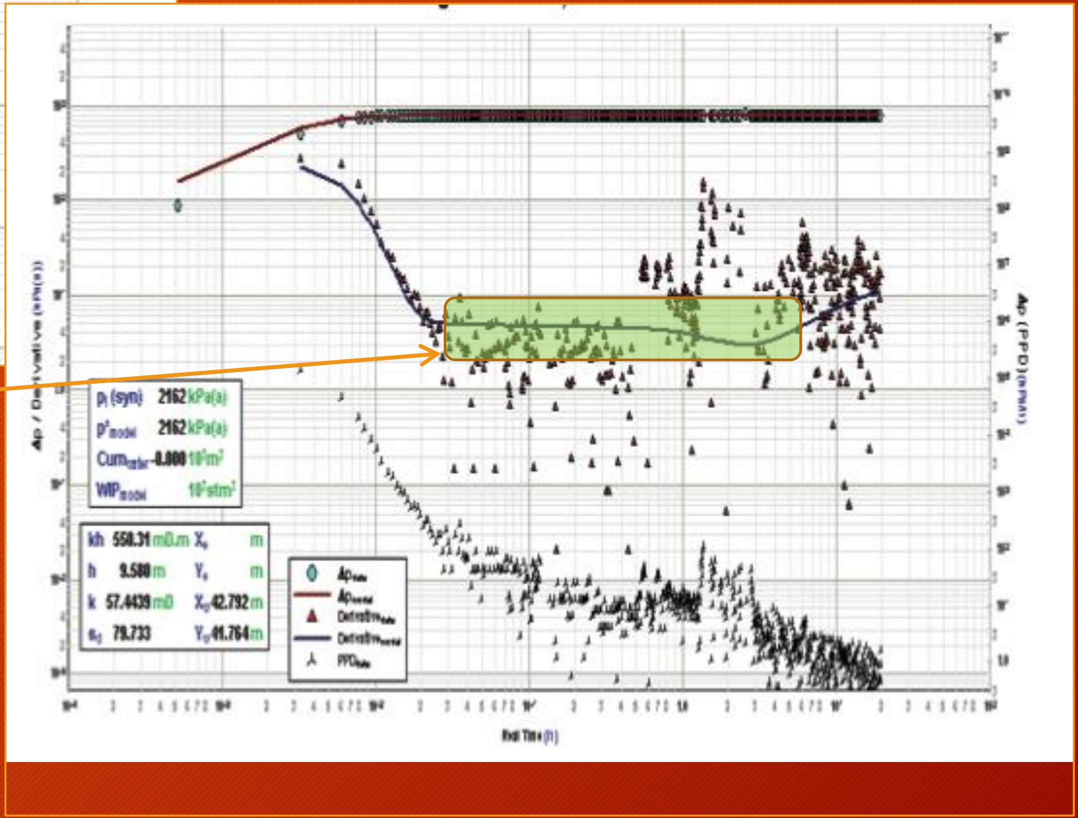


Second Option



Recognize uncertainty in pta



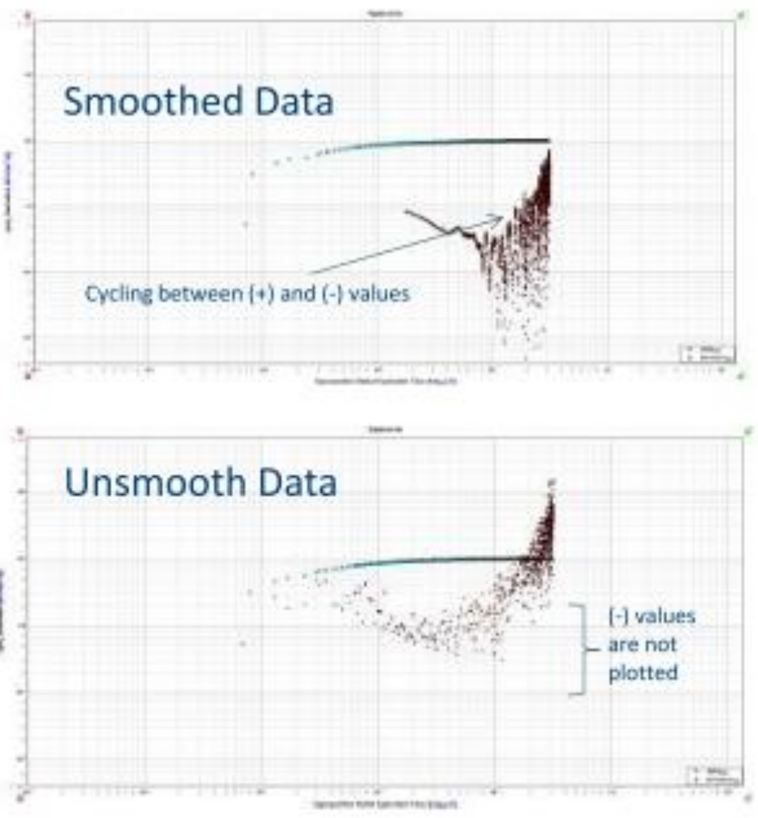


Permeability in these examples could potentially range by a factor of 10.

Reliability in PTA improves with repeatability.

PTA should be regular part of reservoir management plan.

Uncertainty and Software



The [redacted] data, unfiltered, is quite erratic. The graphic (left) shows the pressure derivative increasing in the late-time.

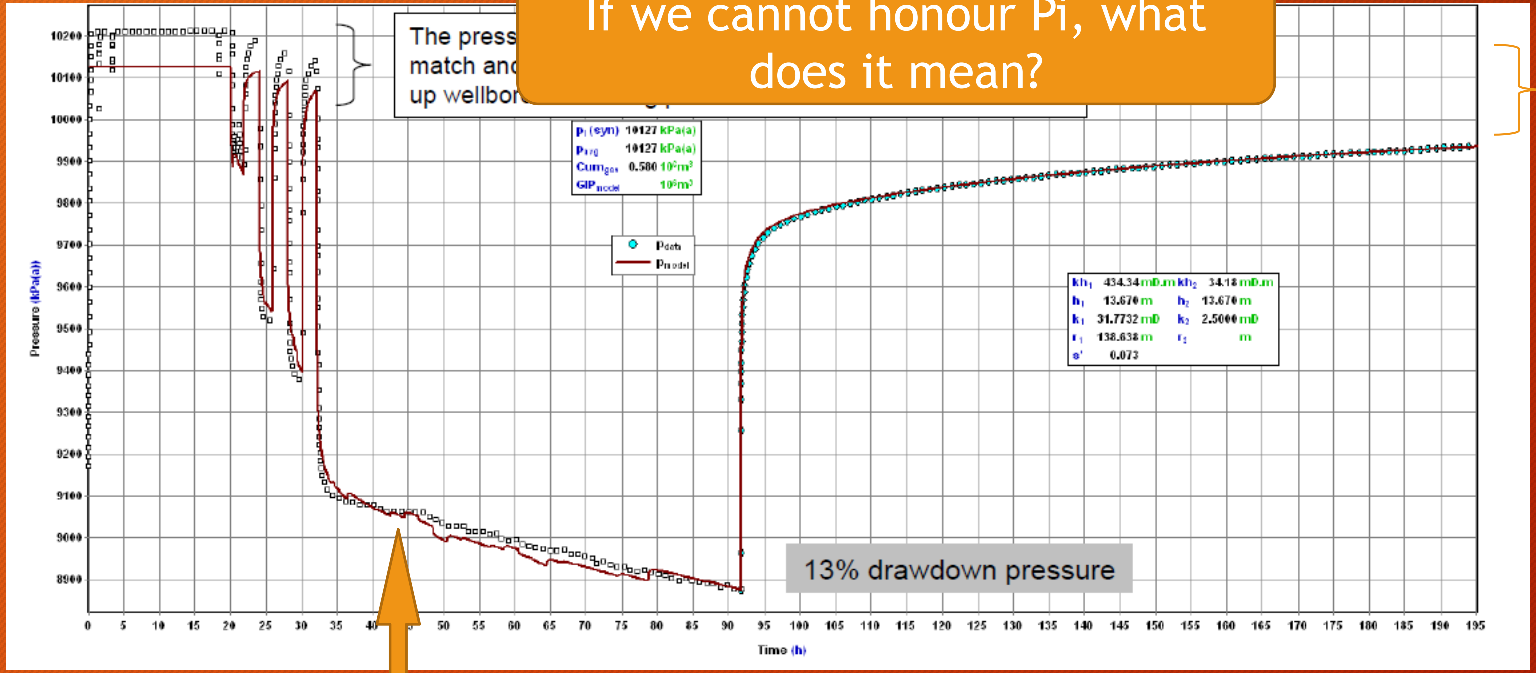
However, the cyclic nature of the breaks suggest that the derivative is alternating between very large and very small (negative) values.

Cyclic behaviour tends to suggest lack of resolution of pressure buildup data, and/or decreasing pressure points.

Automatic filtering in Commercial packages has a Significant impact on interpretation

Why initial reservoir pressure?

Work with all data! Any pressure-rate data can be potentially analyzed

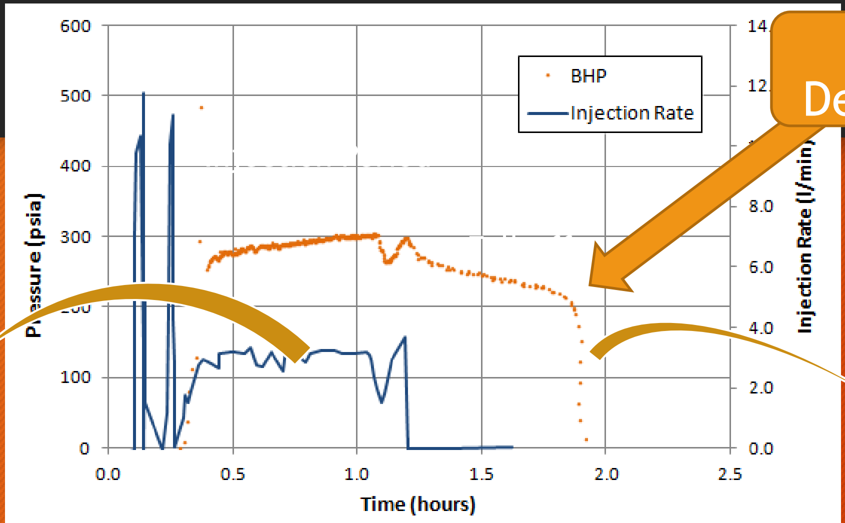


If we cannot honour Pi, what does it mean?

Limited reservoir? Permeability decreasing away from wellbore ?

Production period can be analysed as well.
Linear trend may suggest PSS or limited reservoir

IFO Test failure: Indonesian csg



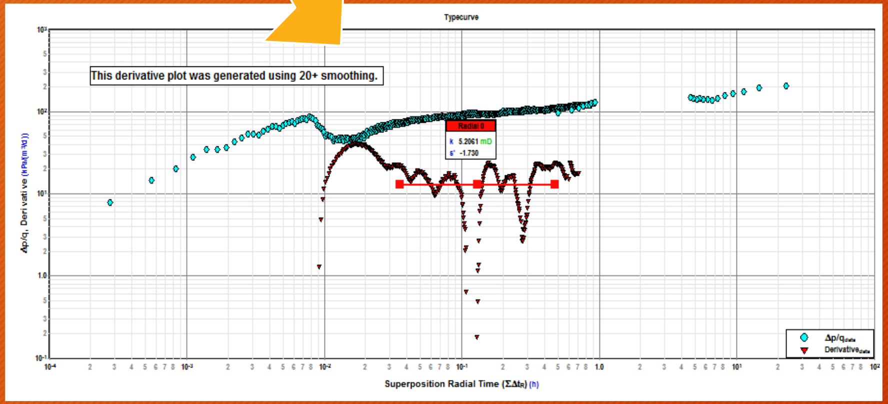
Leak! Developed

What impact would a leak have on PTA analysis?

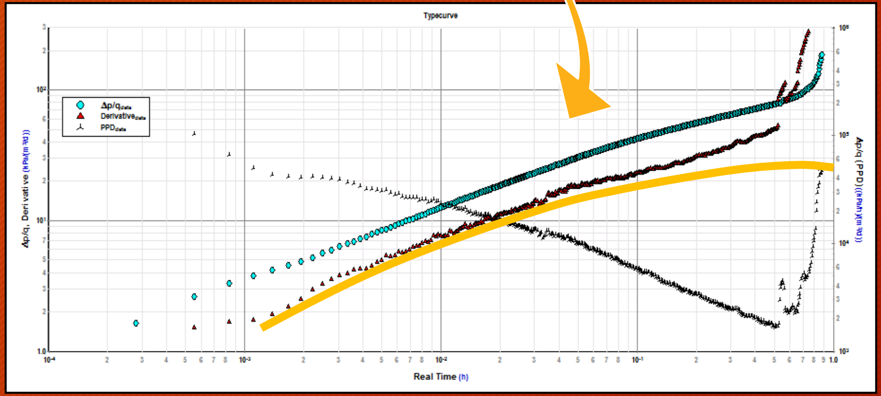
Rate of pressure decline is not stabilising?

Even bad data can be used. We can still estimate a rough estimate knowing the late time data is bad

Analyse Injection



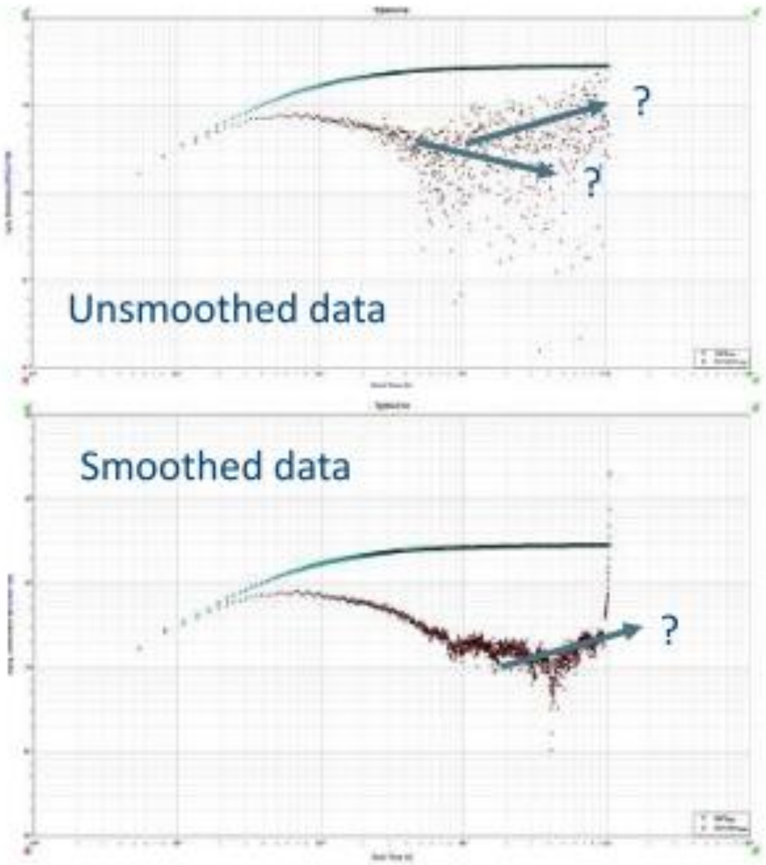
Analyse Buildup



Actual

Ideal

Recognize the impact of software GUNNEDAH CSG Example



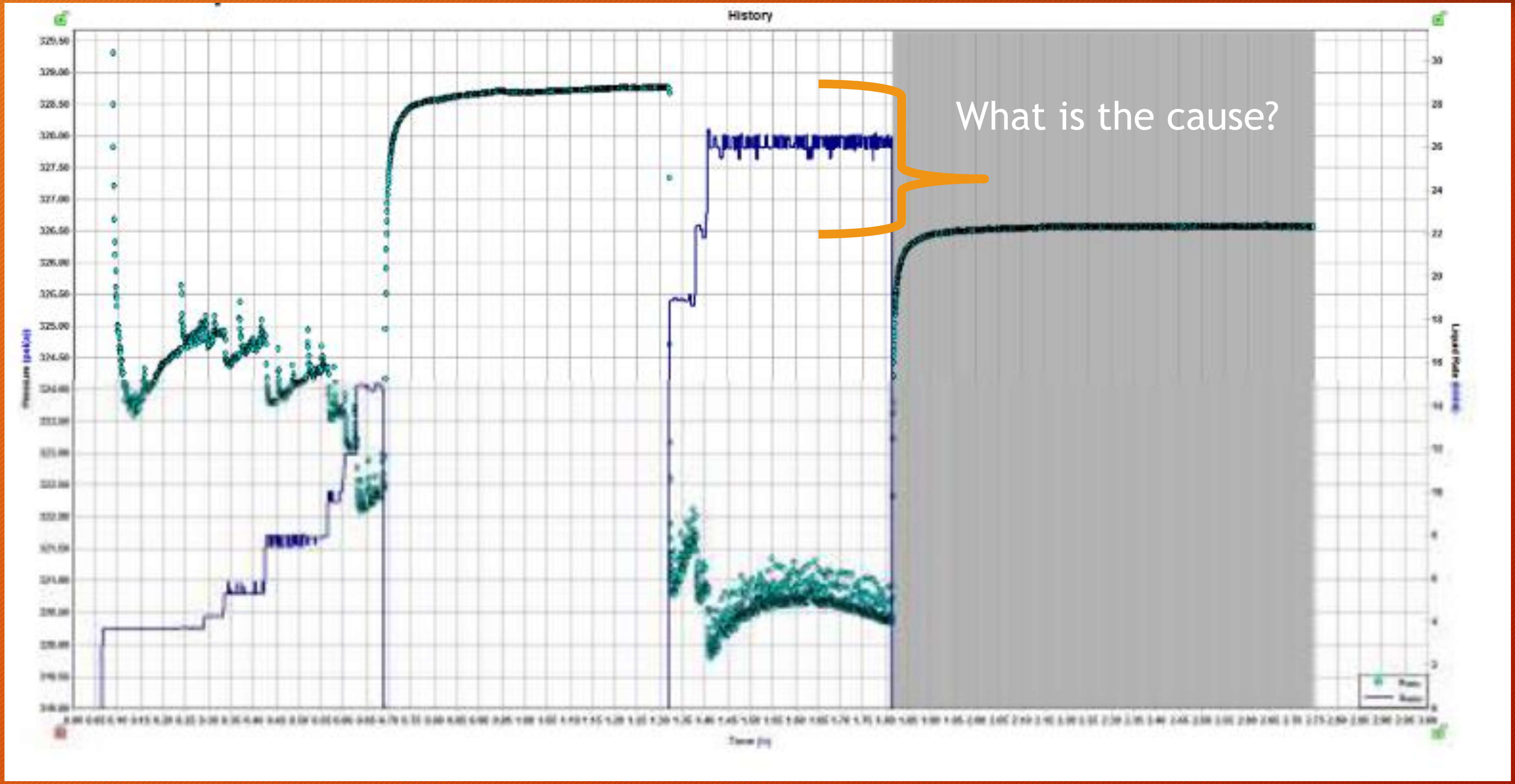
The well data does require a substantial amount of smoothing (after filtering) to create a suitable derivative for interpretation.

In addition to smoothing, negative values are not plotted on a logarithm scale, effectively adding another layer of filtering.

The combined effects of the aforementioned could be giving the appearance of a false radial flow.

Automatic filtering in Commercial packages has a Significant impact on interpretation

Supercharging: GUNNEDAH CSG Example



Loss of pressure may be other phenomena than depletion.

Supercharging can often occur in CSG Wells leading to overly optimistic pressures in the initial BU.

The supercharging effect can be reduced/removed with subsequent flow periods.