



Results from a Collaborative Study on DFIT Interpretation

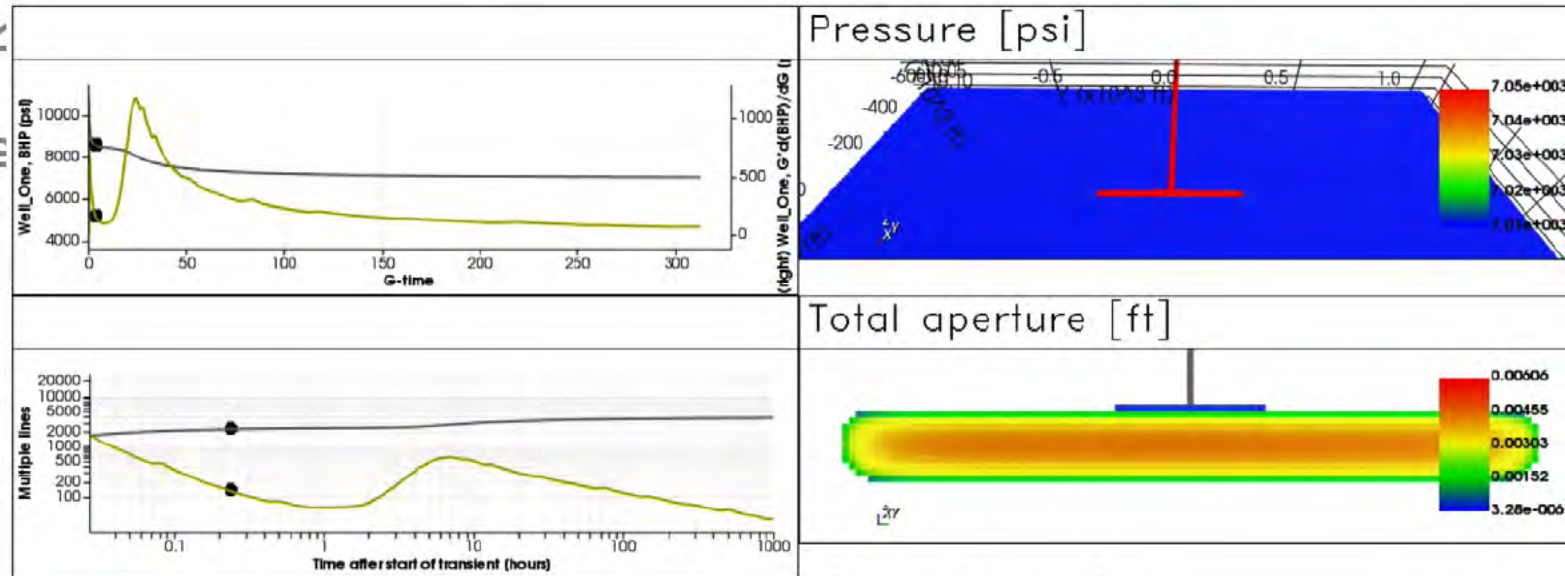
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What is a DFIT (Diagnostic Injection Test)

A short duration, small volume fracturing operation where a small amount (5-300 bbls) of clear water is pumped until fracture initiation. The is shut-in, allowing the well's pressure to fall-off naturally over the course of the test. The data is analyzed to estimate the fracture length and conductivity.



0 y, 0 d, 0 h, 18 m, 0 s

- Motivation: Recently published results indicate problems with existing interpretation techniques (McClure et al., 2016; Jung et al., 2016; McClure, 2017).
- Goal was to design a step-by-step DFIT analysis procedure, looking at stress, permeability, and pressure estimation.
- Combine insights from modeling with a diverse dataset and the experience and expertise of the participants.
- Use a modeling tool that integrates multiphase flow in the reservoir with fracture propagation and



URTeC: 123

A Collaborative Study on DFIT Interpretation: Integrating Modeling, Field Data, and Analytical Techniques

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- Utica/Point Pleasant gas shale DFIT
- Overall setting is described by Cipolla et al. (2018)
- These results (and much more) are summarized in an URTeC paper (McClure et al., 2019); and a follow up paper at ATCE (Fowler et al., 2019).

- G-time is a function of shut-in time. It is similar to square root of shut-in time.
- Under ideal conditions, dP/dG should be constant prior to closure. This is because:

$$\frac{dP}{dG} = \frac{dP}{dV} \frac{dV}{dG}$$

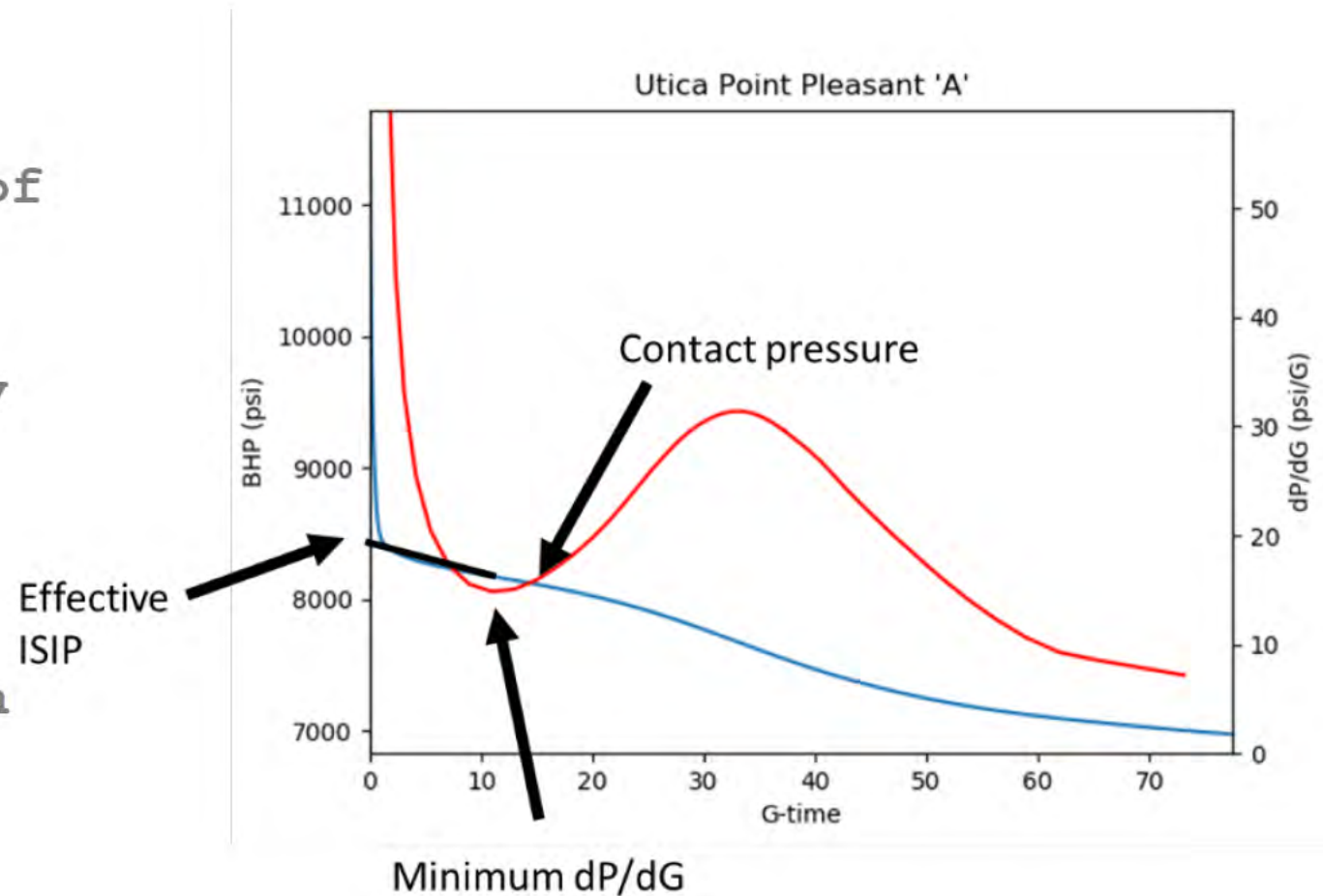
$\frac{dV}{dG}$ is the leakoff rate with respect to G-time. It is constant (prior to closure) as long as Carter leakoff is valid.

Specifically: $\frac{dV}{dG} = \frac{\pi}{2} AC_L \sqrt{t_e}$ (Nolte, 1979).

$\frac{dP}{dV}$ is the system stiffness, equal to $\frac{1}{C_w + \frac{A}{S_f} + V_f c_{fl}}$ (McClure et al.,

- More commonly, people plot $G \cdot dP/dG$. We find that plots of dP/dG are more useful.
- In real data, there is rarely a constant dP/dG , as is predicted by theory.
- dP/dG starts high, drops to a minimum, rises up to a maximum, and then asymptotically approaches

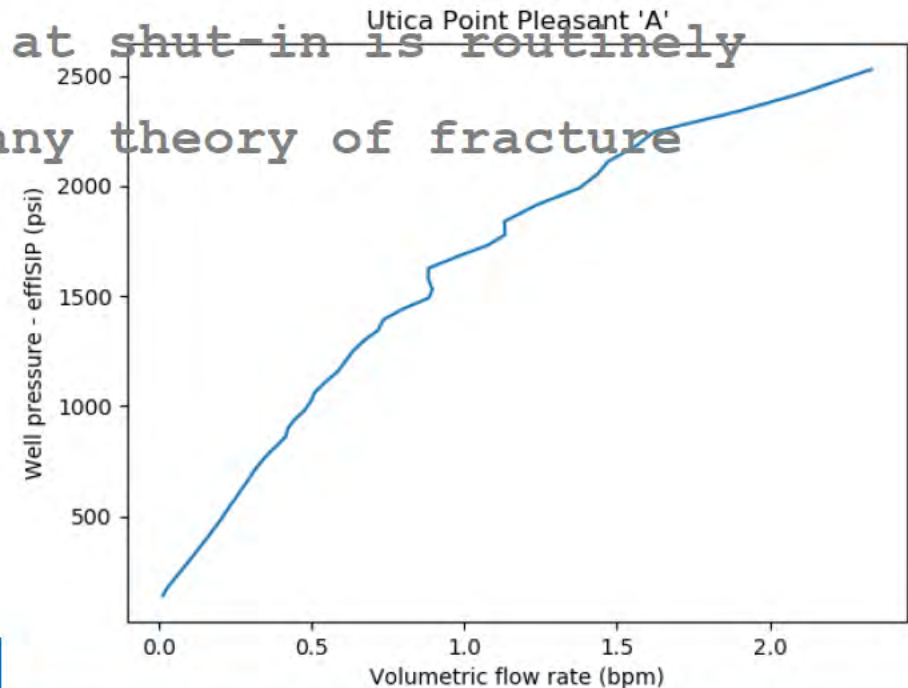
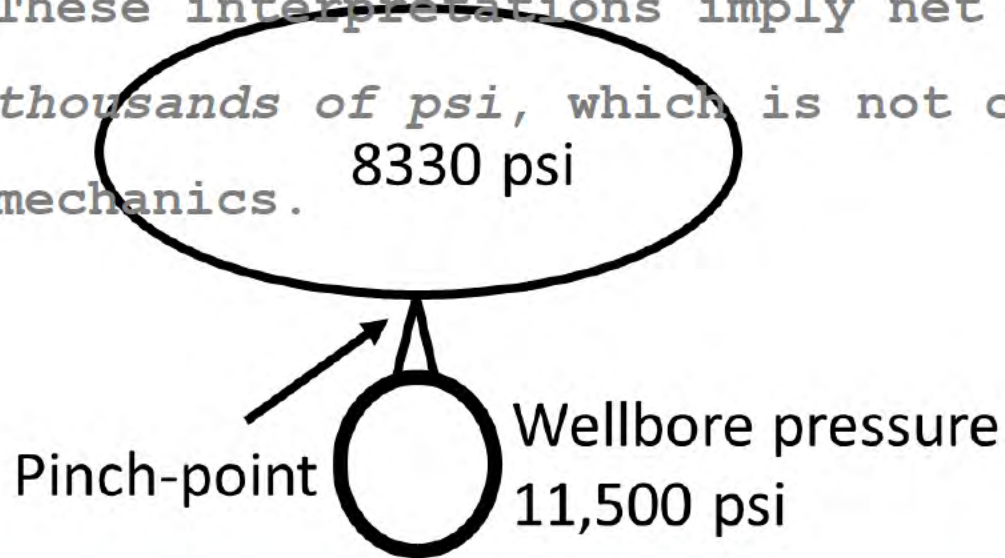
zero. Most field DFITs (in



Near-wellbore tortuosity

- The high early dP/dG is caused by near-wellbore tortuosity. A pinchpoint develops between the well and the far-field fracture, creating a large ΔP .
- This is sometimes recognized in the literature. But more often, it's diagnosed as 'tip-extension' or 'pressure-dependent permeability'.

These interpretations imply net pressure at shut-in is routinely *thousands of psi*, which is not constant any theory of fracture mechanics.



- We propose to retire the term "closure pressure." A review of the literature indicates that it is rarely defined explicitly, and authors use all kinds of subtly different assumptions regarding what it means. This imprecision has led to confusion in the literature.
- Shmin is what actually matters. How can we find Shmin? When the

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(e)



(f)



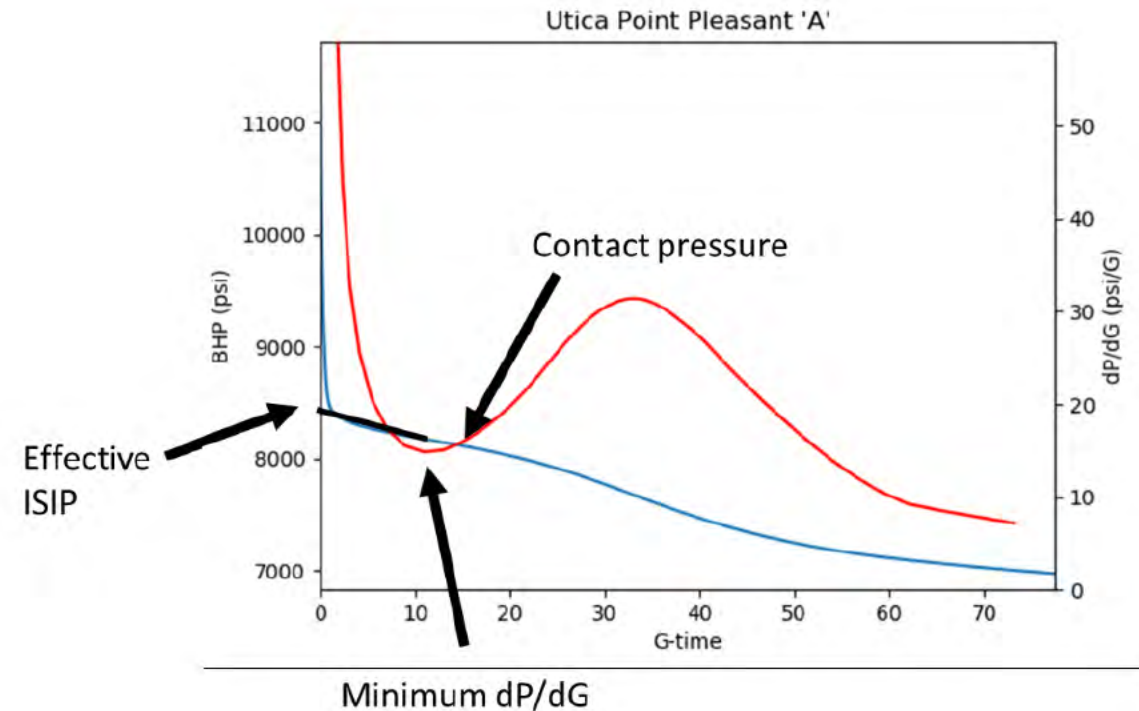
Gale et al. (2018)

- As the fracture walls contact, stiffness increases, and so the magnitude of the derivative increases.

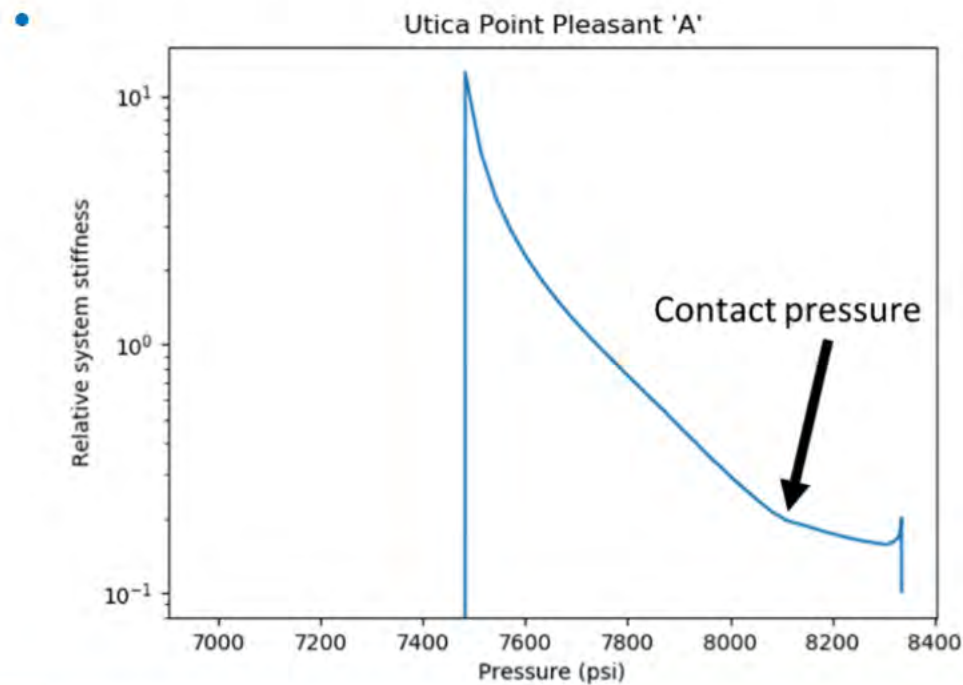
- $$\frac{1}{C_w + \frac{A}{S_f} + V_f C_{fl}}$$

- Conventional O&G interpretation is that the derivative increase is caused by 'height recession' or 'closure of transverse fractures'.

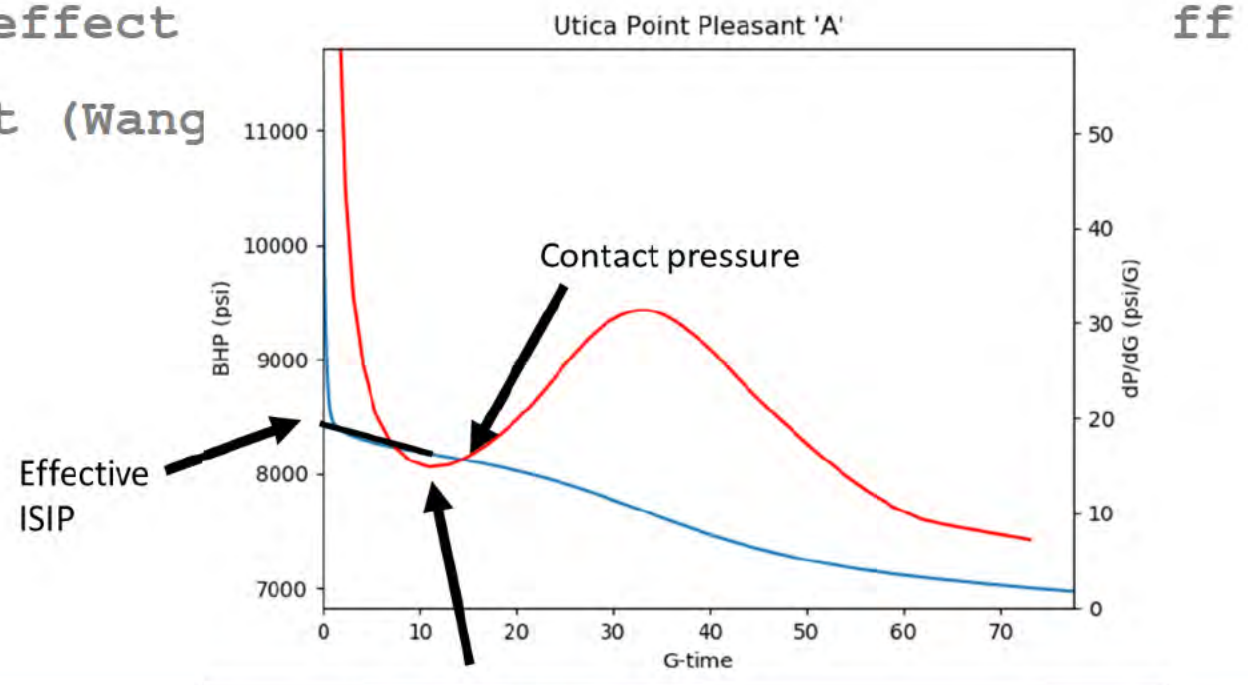
Modeling suggests that these are, at



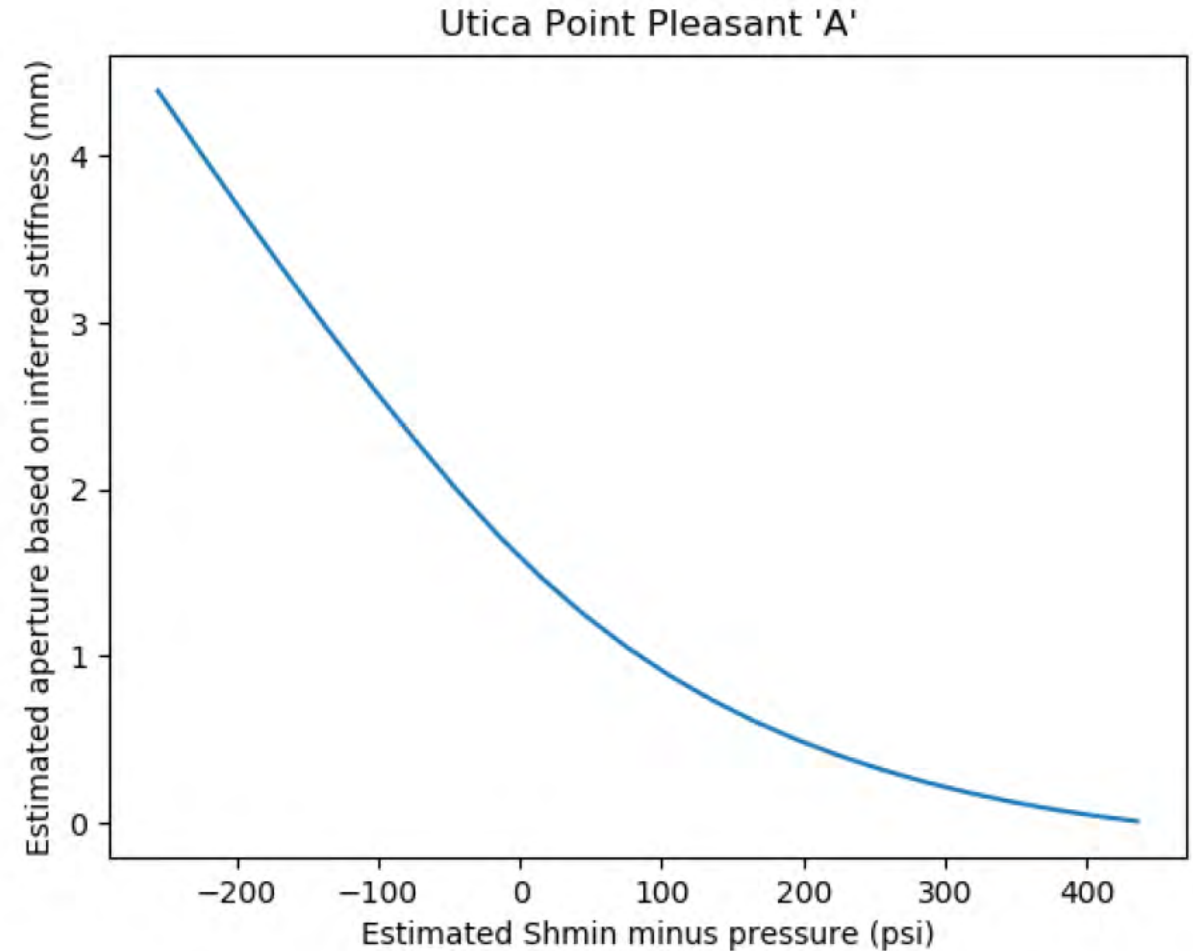
- Contact is most easily identified in a dP/dG plot - not a $G*dP/dG$ plot (which turns out to not be very useful).
- dP/dG peaks because of decreasing leakoff rate due to deviation from Carter leakoff (McClure, 2017).



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lot (Wang



We show how to estimate the average aperture at contact. It varies from 500-2000 microns. This is representative of the macroscopic roughness of in-situ fractures. Also, this is why we've away from the prior definition (from McClure et al., 2016), of calling this 'closure'.

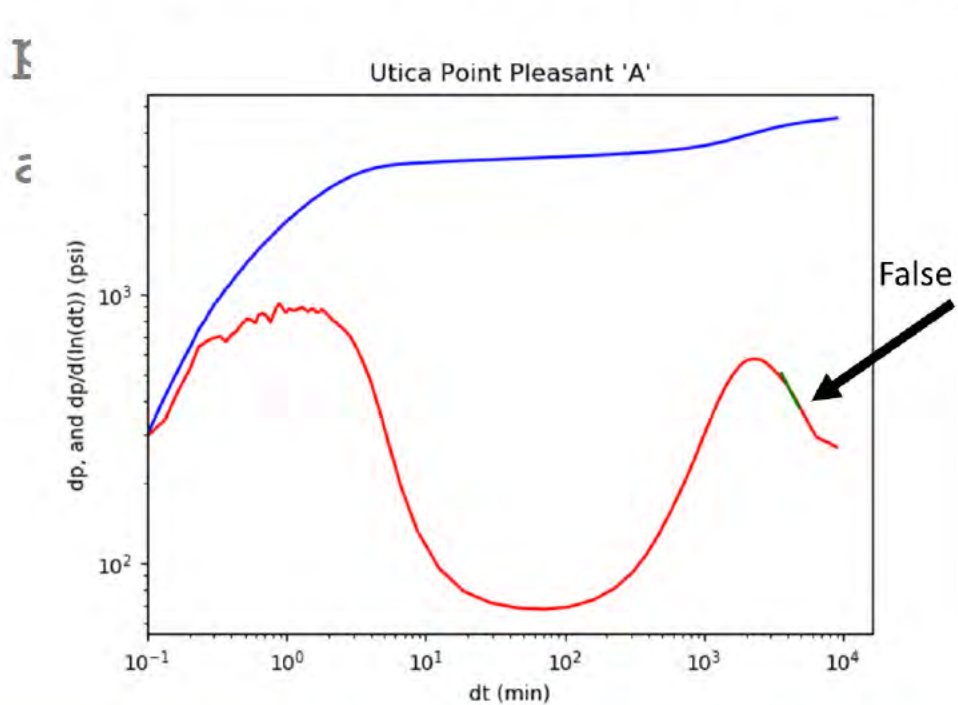


- We derive new equations for estimating permeability from dP/dG , from a newly developed h-function method accounting for deviation from Carter leakoff, and from 'after-closure' analysis. Common literature equations (Valko and Economides, 1999) did not account for wellbore storage or effect of leakoff on geometry.

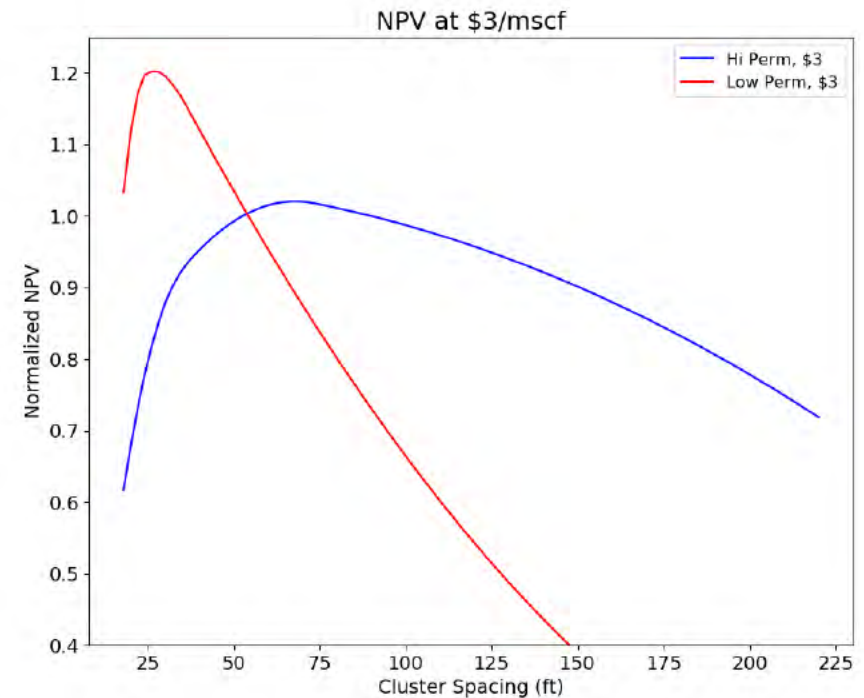
$$C_L(\text{radial}) = -\frac{dP}{dG} \frac{C_w + \frac{16R_f^3}{3E'}}{\frac{\pi^2}{2} R_f^2 \sqrt{t_e}} \quad h(\Delta t) = \int_0^{\Delta t + t_e/2} \frac{(P(\tau) - P_{res})}{d\tau} \sqrt{\Delta t + t_e/2 - \tau} d\tau$$

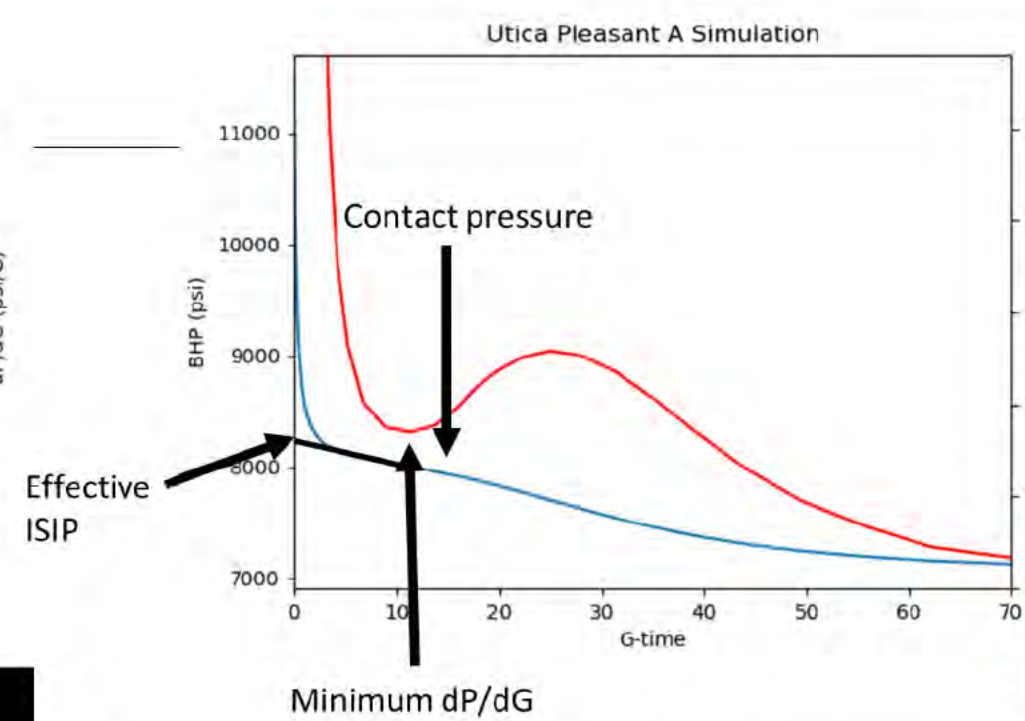
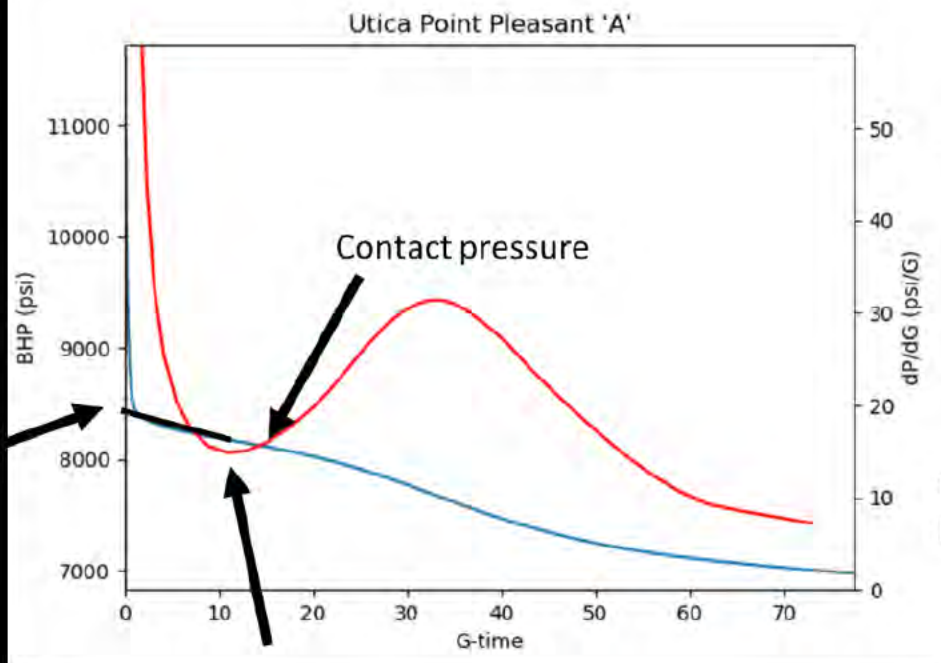
$$V_{inj} = C_w(P(\Delta t) - P_{w,init}) + \frac{A}{S_f} (P(\Delta t) - Shmin) + 2AC_L\sqrt{t_e}g(\Delta t)$$

Simulations show that in gas shale (not oil), the viscosity contrast causes an apparent radial flow at late time. If used in a permeability estimation, it greatly overestimates

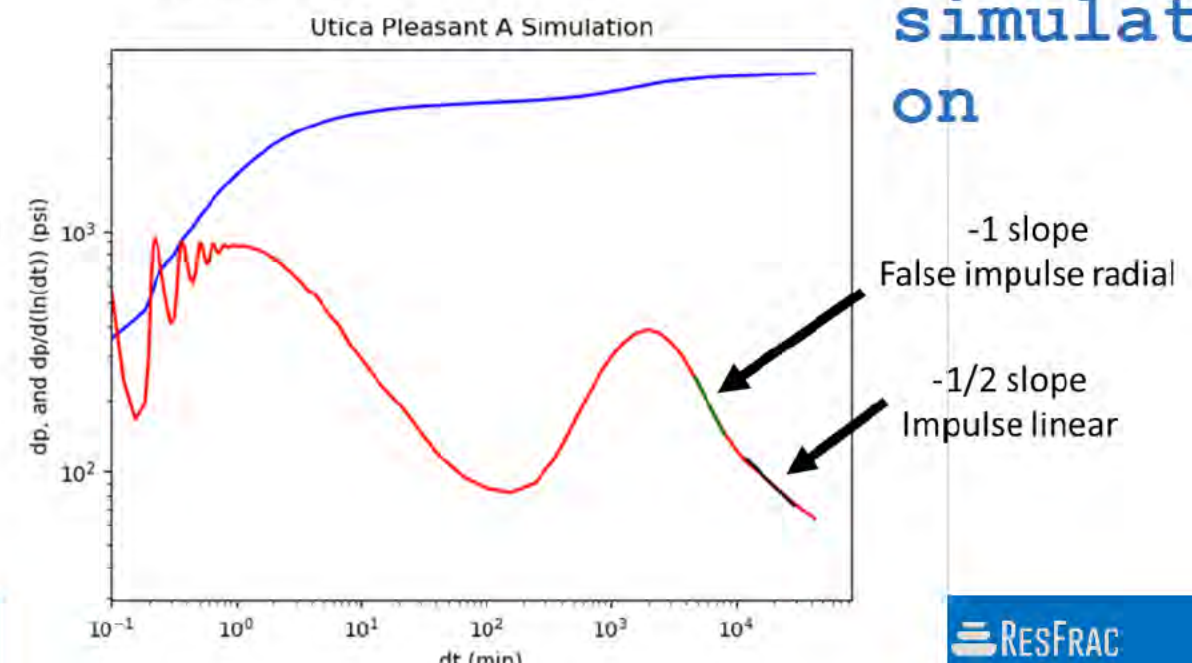
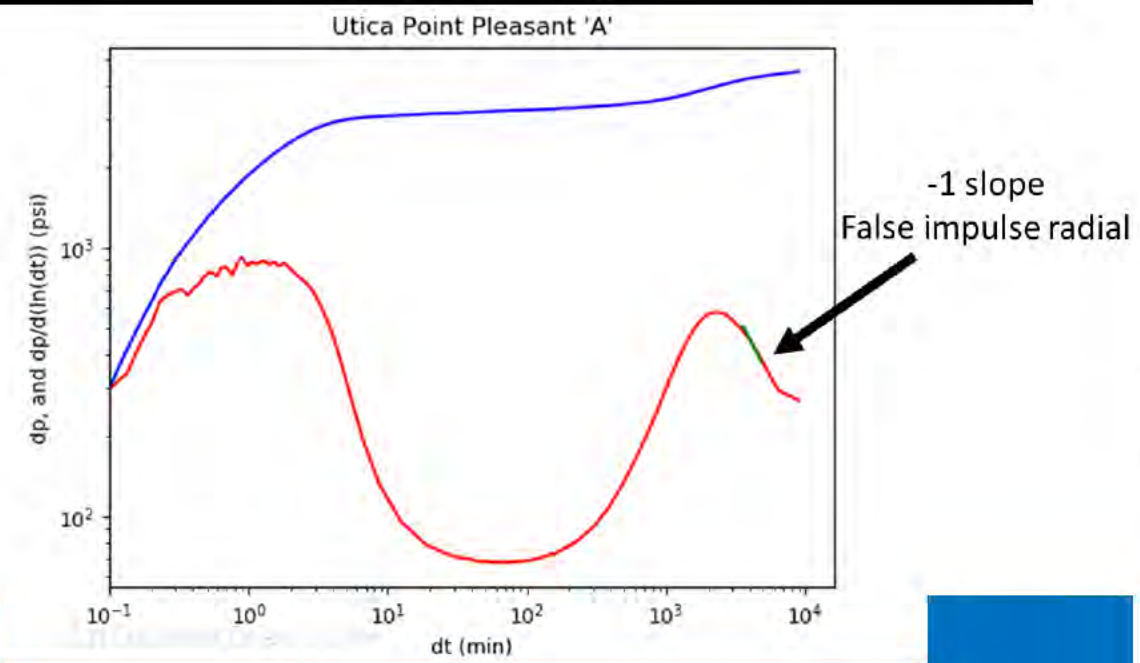


0x). If thi
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False impulse radial

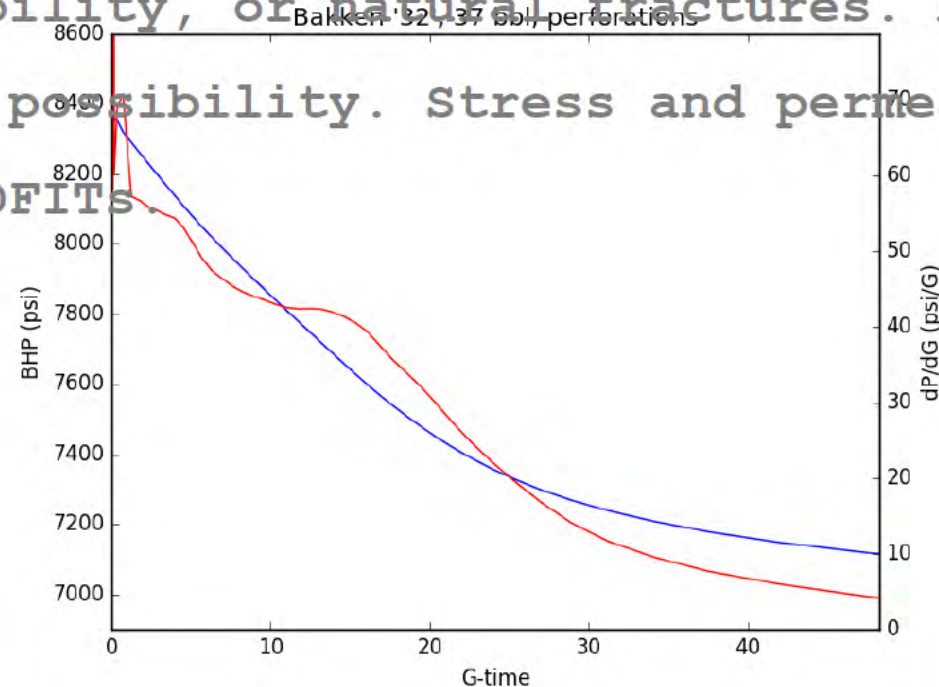




Comparison with simulation



- Not all DFITs show indication of contact. The below DFIT has monotonically decreasing dP/dG. Contact is supposed to cause dP/dG to increase. How to interpret?
- Simulations suggest a variety of processes can cause this. "Instant closure" causes this shape, and can be caused by prior injection into the interval, high permeability, or natural fractures. Excessive near-wellbore tortuosity is another possibility. Stress and permeability cannot be estimated from these DFITs.



- The chain-rule decomposition provides a powerful framework for understanding DFIT transients.
- The 'baseline' interpretation is that curves in dP/dG are caused by near-wellbore tortuosity and the effect of the contacting of the fracture walls.
- Contact pressure can be used to estimate Sh_{min} . Contact apparently begins with average aperture of 0.5-2 mm, a manifestation of the roughness of real fractures.
- We derive new equations for calculating permeability. Account for deviation from Carter leakoff, wellbore storage, and leakoff effect on fracture size. Also, rely on an accurate stress estimate.
- False radial in gas shale DFITs causes a huge overestimate of permeability. This leads to substantially suboptimal designs.

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