Geomechanics for Unconventionals Series:

Sand Volume per Unit of Lateral Length: Is There a Geomechanical Justification?

By Dr. Neal B. Nagel

Trial and error. It seems simple enough. In fact, it has a foundation in basic scientific study via the "Scientific Method". In essence, the scientific method relies on: 1) observation of the occurrence of something; 2) formulation of a hypothesis of why the event occurred; 3) development of a test of the hypothesis; and 4) execution of the test (and in true trial and error, revision of the hypothesis and execution of another test). First linked back to basic empirical evaluations by the Egyptians in the 16th century BC and more concretely to Aristotle in the 4th century BC, the scientific method is both a widely-accepted and well-known means to develop our understanding of physical phenomena.

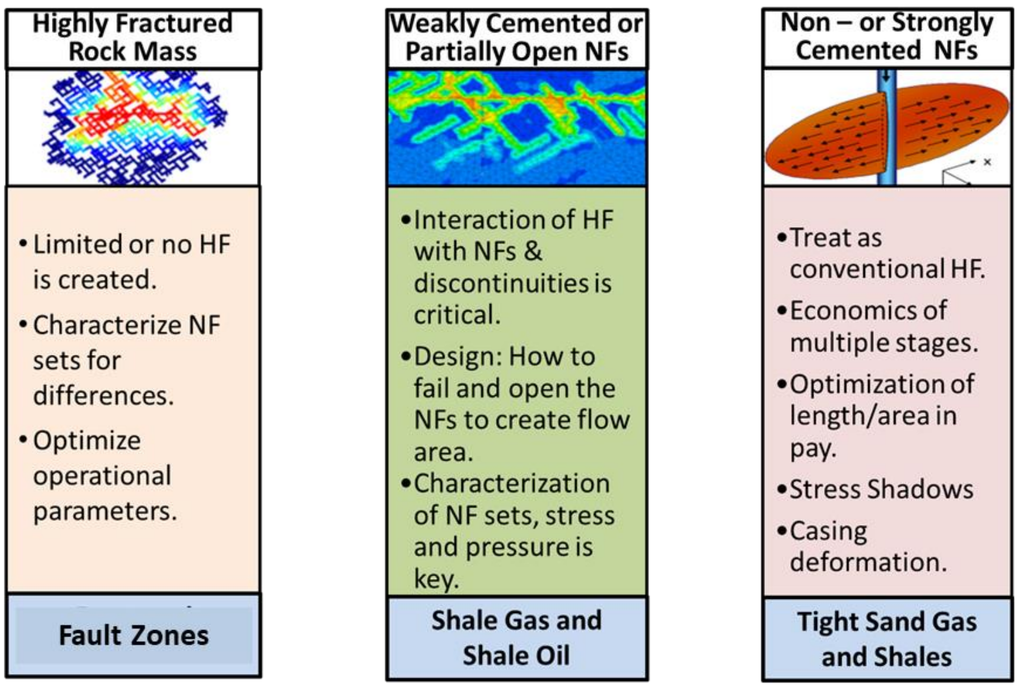
It is also widely known that the development of Unconventional plays has relied heavily on trial-and-error approaches – particularly in the area of completion (stimulation) design. But….does the trial-and-error approach commonly employed in the completion design for Unconventionals fully follow the scientific method? Have we observed something – like the increase in production with increased sand volume per unit length of lateral – then hypothesized why this may be and then tested the hypothesis?

It is human nature to take a multi-variate, complex problem and try to simplify it. However, as Albert Einstein is quoted to have said "Everything should be made as simple as possible, but not simpler." This exhortation from Einstein was to caution us as to the limitation of simplifications – like sand volume per unit length of lateral.

It has been reported that an operator recently pumped 4000lbs/ft of lateral. Was this a justified trial? And if successful (or, for that matter, not successful), why was it successful? In order to consider the significance of sand volume per unit length of lateral (SVULL) - and, in our case, the geomechanical significance – we have to first understand or define SVULL. As practiced, SVULL is simply the total volume pumped into a lateral divided by the length of the lateral (or, perhaps, the total stage length, which would be similar to total lateral length). However, SVULL is not about sand inside the lateral (obviously) but sand in the formation. Since the vast majority of completions are plug-and-perf with specific, potential entry points from the lateral to the formation, the entry points need to be considered. Would we, for example, expect the same production results from a lateral with 2000lbs/ft SVULL and one perforation cluster versus a lateral with 2000lbs/ft SVULL and five clusters per stage and 30 stages? Of course not. In the first case there is single fracture (at the wellbore) with LOTS of sand versus the second case with the potential for up to 150 fractures with 1/150th of the sand volume in each. So let's agree – as commonly used, SVULL can be (likely often is) misleading unless something is known about the number of entry points from the wellbore to the formation.

Commonly, when the SVULL value is increased, there is a commensurate increase in clean frac fluid volume AND an increase in the number of perforation clusters per stage. So, commonly, the increased production associated with an increase in SVULL *could* be (in whole or in part) related to the increase in the number of entry points from the wellbore. Consequently, it is important to understand that a change in SVULL value is commonly associated with other changes and not simply a change in total sand volume.

For those familiar with my published papers, invited presentations, and particularly the training courses in Geomechanics of Unconventionals, which I teach with my partner and wife Marisela Sanchez-Nagel, you will have seen our figure representing three fabric styles for completion design (Fig. 1).



HF=Hydraulic Fracture *NF=Natural Fractures/weakness planes*

Figure 1: Formation fabric styles in Unconventionals for Completion Design.

In the three fabric scenarios (styles), the impact on completion design changes markedly as does the expected production and monitoring results (i.e., microseismics). In the leftmost case, where the formation has significant flow capacity, the principal design goal would be to connect the wellbore to the (high capacity) formation. Hydraulic fractures (HFs) would be expected to be short and high conductivity (with the caveat that stress-dependent permeability changes are not expected). In the rightmost case, the rock is, euphemistically, "tombstone" – very low permeability with little influence of rock fabric wherein HF half-length is critical to increased production. Finally, the third fabric style exhibits considerable formation fabric – natural fractures, bedding planes, and other heterogeneities – that may contribute to an increase in effective permeability and/or drainage area OR may adversely impact HF propagation and potentially negatively impact production.

Consider for a moment the "tombstone" fabric style – a formation without the influence of natural fractures or bedding planes - where increasing HF half-length is critical to increasing production. If the reservoir formation we are fracturing is very low permeability (i.e., nanodarcy), then the drainage area (e.g., the distance of pressure change in the formation perpendicular to the HF face) from a given HF along a lateral is very limited. In fact, with very low permeability, this could be measured in inches. Given this case, would we expect an increase in production through reduced HF spacing (i.e., reduced cluster spacing assuming all clusters contribute)? Of course. So, if my sand volume per cluster stayed the same (again, assuming all clusters take an equal volume of frac fluid), yet the number of clusters along the lateral increased (and, by extension, the SVULL value) then we would expect production from the lateral to increase. Yet SVULL would not capture the physics involved – in essence it would be too simple AND misleading.

What if we used a more correct metric like sand volume per cluster (SVOC) instead of SVULL? And when using this metric, what if we see that production increases with SVOC?

Let's consider the tombstone fabric style again. IF production increases with SVOC (and, recall, an increase in SVOC is commensurate with an increase in frac fluid volume per cluster as well), this possibly suggests either we have an increase in HF half-length OR have improved the conductivity of the overall HF (recall most operators use slickwater, which *drops most sand in the wellbore* before ever getting to the perforations) by getting more proppant further along the HF (increasing the *effective* half-length of HF) or improving HF conductivity near-wellbore. IF this is the case, this should be readily apparent from proper simulation of the HF process (i.e., with calibrated stress inputs, etc.) with traditional bi-wing hydraulic fracture simulators….and readily provable.

What would our expectations be with increasing SVOC for the formation style with considerable fabric – wherein the formation has a significant number of natural fractures, bedding planes, and the like? When there is significant formation fabric, two things should be expected. First, HF half-length will be reduced. In the traditional bi-wing HF paradigm, this is easily shown by increasing fluid leakoff. The second effect would be increased drainage area, though this could be problematic. If frac fluid and proppant move into the formation fabric but because of damage or other issues does not increase production, drainage area would not increase. In fact, if factor one (reduced HF half-length) occurs and there is no additional production from the rock fabric (or…if production from the fabric is very limited in time) then the occurrence of formation fabric is a net negative to completion design!

If we have a case with increased production with increased SVOC and we know we have accessible, producible fabric, what does that mean (geomechanically)? We cannot exclude, as in the tombstone style case, the potential benefit of increased near-wellbore proppant conductivity or increased effective HF half-length. However, it is also possible that the production improvement is related to moving fluid further into the fabric (which reduces the effective stress on the fabric and increases shear stimulation) and/or moving proppant into the fabric. Particularly in the latter situation, this would be reflected in a sustained increase in drainage area.

There is another complication to the discussion. Because proppant transport is so poor with slickwater and because we rarely stimulate all clusters in a stage, one or two clusters tend to take the dominant amount of fluid. Mike Smith with NSI Technologies mentioned this during his excellent presentation at the SPE Geomechanics Technical Section networking meeting at the recent URTeC conference in Houston and a number of University studies have shown this. Figure 2 comes from a recent SPE paper on the evaluation of proppant placement in a horizontal lateral. As shown, there tends to be a dominant cluster within a given frac stage.

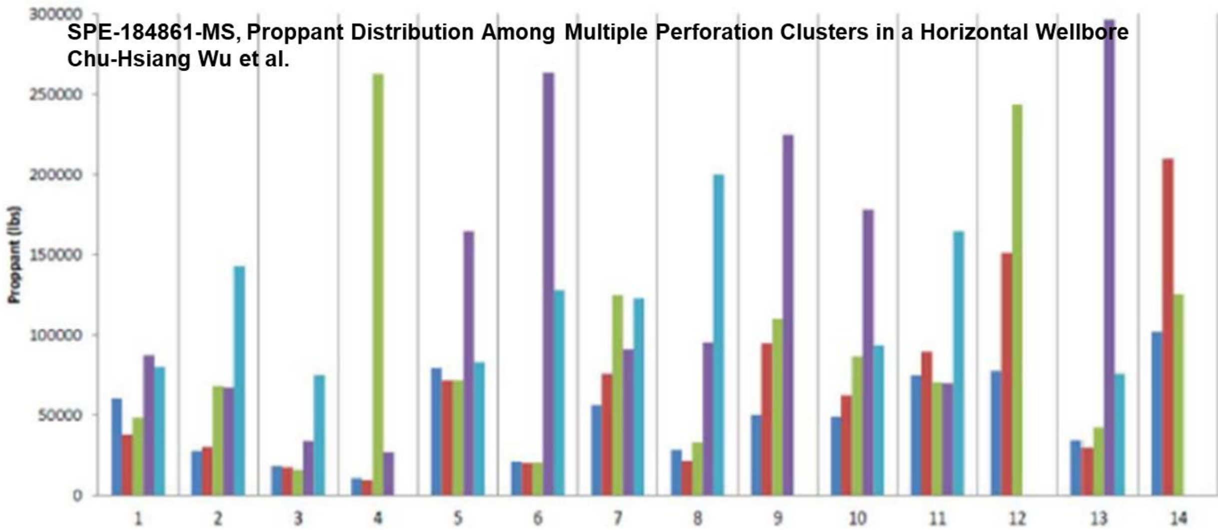


Figure 13—Field data published by Wheaton et al. (2016). Proppant distribution of 14 stimulation stages is presented. For each stage, the bars from left to right show the proppant placement from the toe cluster to the heel cluster. These results show a general trend of biased proppant distribution towards the heel-side clusters. In some cases, the heel cluster gets most of the proppant. In other cases, the second cluster from the heel gets most of the proppant.

Figure 2: Distribution of proppant in a horizontal lateral

What does this bit of a wrinkle – that our increased SVOC is largely influencing just one or two clusters - suggest? In the tombstone fabric style case, this would be reflected in a significant increase in effective HF half-length for the dominant cluster and/or a likely overkill in near-wellbore proppant conductivity for this dominant cluster. The increase in effective half-length should be readily provable and the overkill in near-wellbore conductivity would likely not increase production (and, given we see an increase in production, this suggests that it is not occurring).

In the case of a formation with considerable fabric, the large increase in frac fluid volume and proppant into a single, dominant cluster would more likely be reflected in a considerable increase in drainage area (and sustained production from that drainage area) only for that specific cluster. This could be proven with a high-quality PLT.

Circling back around to where we started, the industry is reporting significant production increases with increasing SVULL values. Why? What is YOUR hypothesis….

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