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# What is Stimulated Reservoir Volume (SRV)?

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## Abstract

Ultra-low permeability shale reservoirs require a large fracture network to maximize well performance. Microseismic fracture mapping has shown that large fracture networks can be generated in many shale reservoirs. In conventional reservoirs and tight gas sands, single-plane fracture half-length and conductivity are the key drivers for stimulation performance. In shale reservoirs, where complex network structures in multiple planes are created, the concept of a single fracture half-length and conductivity are insufficient to describe stimulation performance. This is the reason for the concept of using stimulated reservoir volume as a correlation parameter for well performance. The size of the created fracture network can be approximated as the 3-D volume (Stimulated Reservoir Volume or SRV) of the microseismic event cloud. This paper briefly illustrates how the Stimulated Reservoir Volume (SRV) can be estimated from microseismic mapping data and is then related to total injected fluid volume and well performance. While the effectively producing network could be smaller by some proportion, it is assumed that created and effective network are directly related. However, SRV is not the only driver of well performance. Fracture spacing and conductivity within a given SRV are just as important and this paper illustrates how both SRV and fracture spacing for a given conductivity can affect production acceleration and ultimate recovery. The effect of fracture conductivity is discussed separately in a series of companion papers. Simulated production data is then compared with actual field results to demonstrate variability in well performance and how this concept can be used to improve completion design, and well spacing and placement strategies.

## Introduction

Fisher *et al*. (2002), Maxwell *et al*. (2002), and Fischer *et al*. (2004) were the first papers to discuss the creation of large fracture networks in the Barnett shale and show initial relationships between treatment size, network size and shape, and production response. Microseismic fracture mapping results indicated that the fracture network size was related to the stimulation treatment volume. **Figure 1** shows the relationship between treatment volume and fracture network size for five vertical Barnett wells, showing that large treatment sizes resulted in larger fracture networks. It was observed that as fracture network size and complexity increase, the volume of reservoir stimulated also increases. Fisher *et al*. (2004) detailed microseismic fracture mapping results for horizontal wells in the Barnett shale. This work illustrated that production is directly related to the reservoir volume stimulated during the fracture treatments. In vertical wells, larger treatments are the primary way to increase fracture network size and complexity. Horizontal well geometry provides other optimization opportunities. Longer laterals and more stimulation stages can also be used to increase fracture network size and stimulated reservoir volume. Mayerhofer *et al*. (2006) performed numerical reservoir simulations to understand the impact of fracture network properties such as SRV on well performance. The paper also showed that well performance can be related to very long effective fractures forming a network inside a very tight shale matrix of 100 nano-darcies or less.

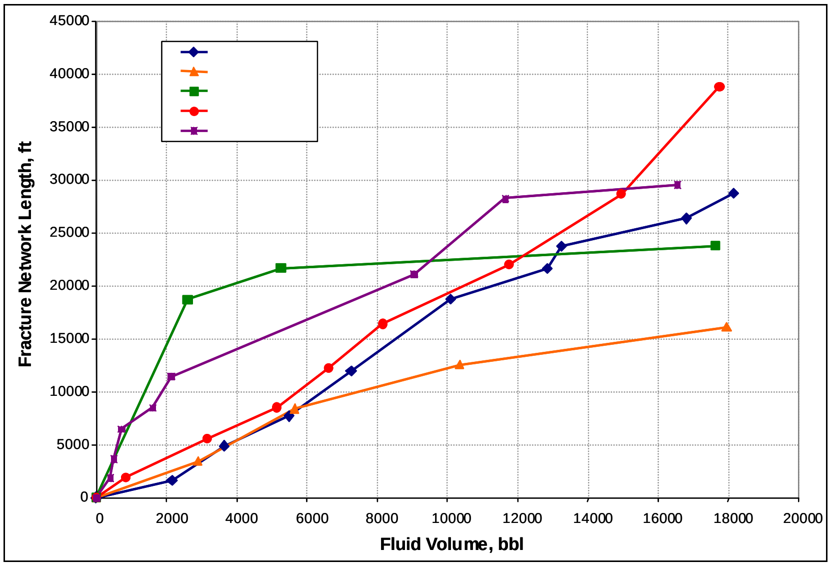

**Figure 1. Relationship of total fracture network length as a function of total job fluid volume pumped (SPE 77441)**

**Figure 2** illustrates the various types of fracture growth ranging from simple fractures to very complex fracture networks. Complex fracture networks are desirable in "super-tight" shale reservoirs since they maximize fracture surface contact area with the shale through both size and fracture density (spacing). Chances for creating large tensile fracture networks are increased by pre-existing healed or open natural fractures and favorable stress-field conditions such as a small difference in principal horizontal stresses. **Figure 3** shows an example of a complex fracture network in a vertical well measured with microseismic mapping. The figure illustrates the development of a large-scale network with two distinct, orthogonal fracture orientations. This paper aims to expand on the previous papers by discussing in more detail the concept of stimulated reservoir volume and its relationship with shale well performance.

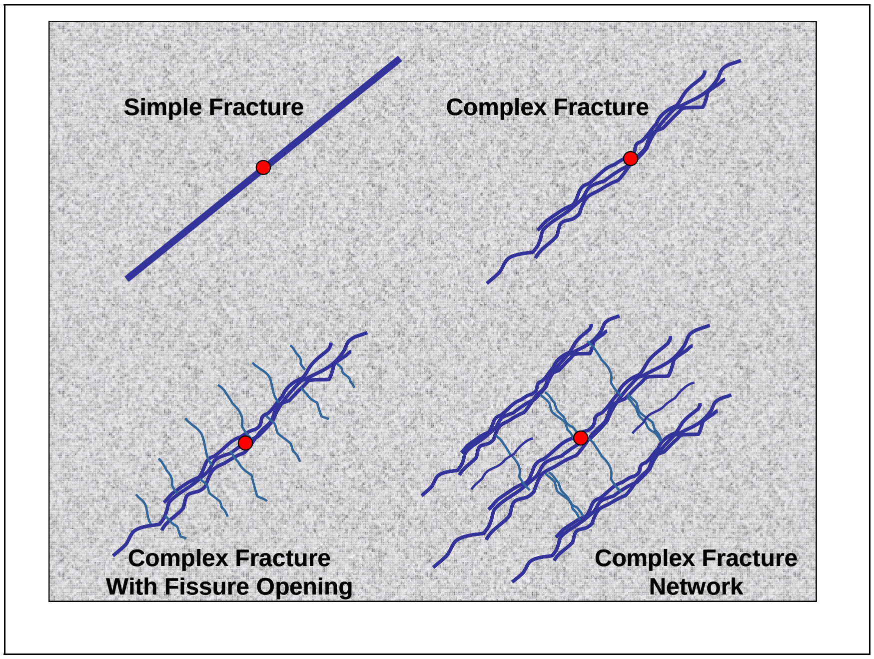

**Figure 2. Types of fracture growth (from SPE 114173)**

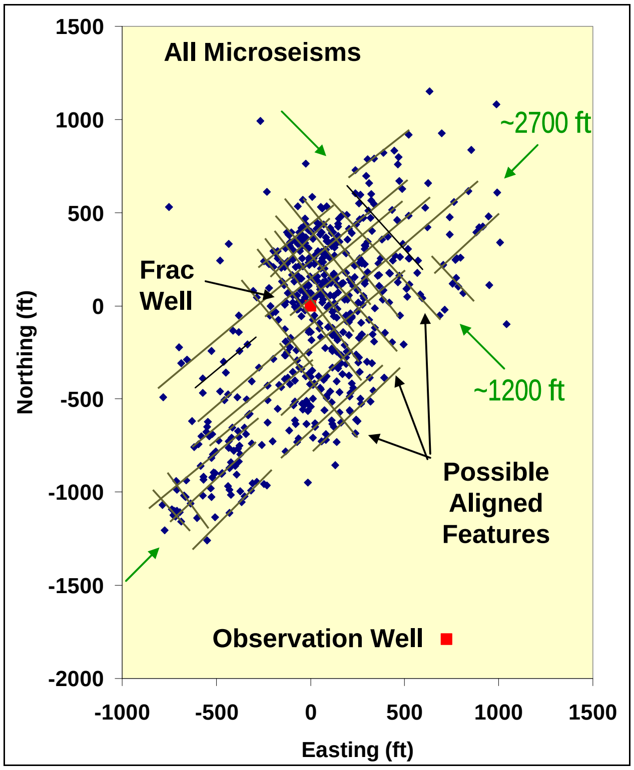

**Figure 3. Microseismic fracture mapping shows complex network growth in shales (SPE 114173)**

## Estimating Stimulated Reservoir Volume (SRV)

It has been well documented by Albright and Pearson (1982), Warpinski *et al.* (2001), and Rutledge *et al.* (2003) that microseismic events are mainly created as a result of shear slippages around the hydraulic fractures. The mechanisms include shear slippages induced by altered stresses near the tip of the fractures as well as shear slippages related to leakoff induced pore pressure changes. In conventional reservoirs with higher reservoir permeabilities and/or oil/water reservoirs, the microseismic event cloud can be fairly wide but may not be related to the generation of complex fracture networks. In this case most of the events may be related to pore pressure increase as a result of rapidly moving pressure transients in high permeability formations and/or reservoirs with fairly incompressible fluids. In “super-tight” shale reservoirs diffusivity related pore pressure changes cannot move very far from the actual fracture planes, unless natural fractures in alternate directions are opened and hydraulically enhanced as a network structure, thus serving as a conduit for fluid movement. This means that a large event cloud structure must be approximately equivalent to the actual fracture network size. Thus, the microseismic event cloud structure observed by microseismic fracture mapping provides a means to estimate the SRV in very tight reservoirs.

**Figure 4** shows an automated method using discrete bins to estimate SRV from microseismic mapping data in a horizontal well. Constant width bins (*e.g.*, 100 ft wide) are drawn in the principal fracture direction from the wellbore to the furthest event in the specific bin on both sides of the wellbore. The individual bin areas are then summed up to approximate the total stimulated reservoir area (SRA). The calculation of SRV (a 3-dimensional structure) also requires an estimate of the stimulated fracture network height in each discrete bin within the contacted shale section. This calculation is also performed within the selected bins and is performed by calculating the network height as the difference between the shallowest and deepest event within the specific bin and top and bottom of the shale section (**Figure 5**). While this method is not an analytically exact calculation, it does provide a fast automated method to approximate a very complex 3-dimensional structure, while honoring the contact with the actual shale section. The SRV is in this paper is specified in millions of cubic feet or acre-ft.

An important aspect of the SRV measurement is the proper setup of observation well or multiple observation wells to guarantee that the entire SRV can in fact be observed. The proper design of a microseismic mapping setup takes into account maximum observation distance to ensure that the entire SRV can be imaged. Microseismic moment magnitude versus distance plots (Zimmer *et al.* (2007)) can be used to ascertain if all events were within observable range or if the SRV could in fact be larger than imaged. Other issues that affect correlations between SRV and well performance include associated formation water production, and condensate yield, which becomes relevant in less mature shales close to the oil window.

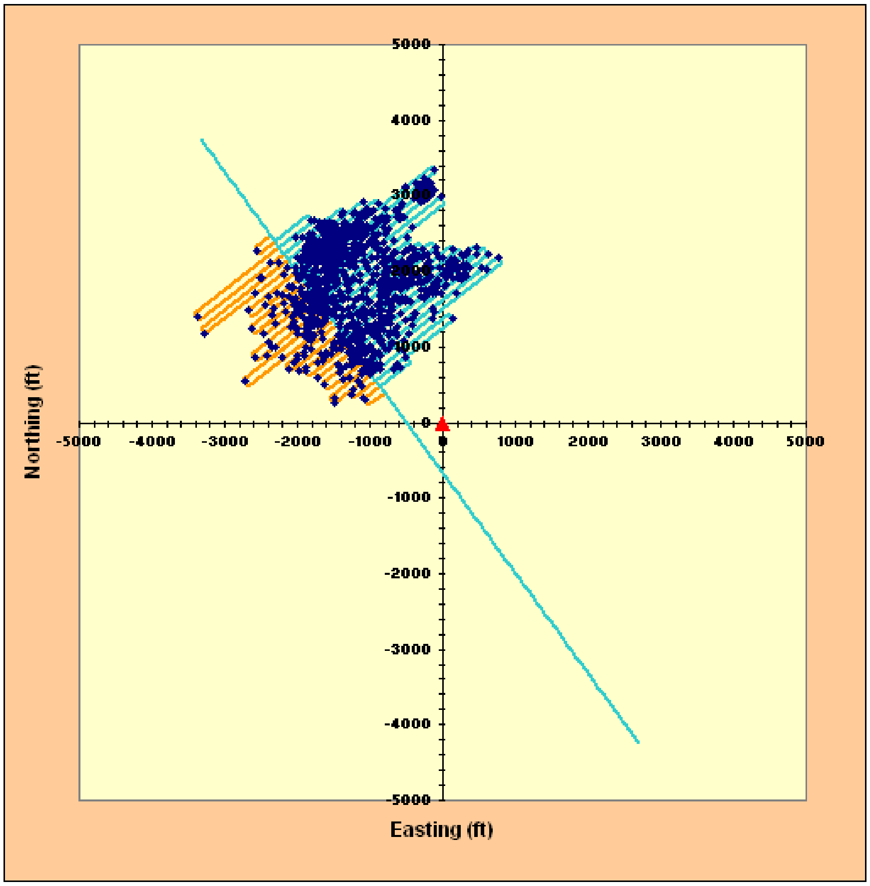

**Figure 4. Estimating SRA from microseismic mapping data**

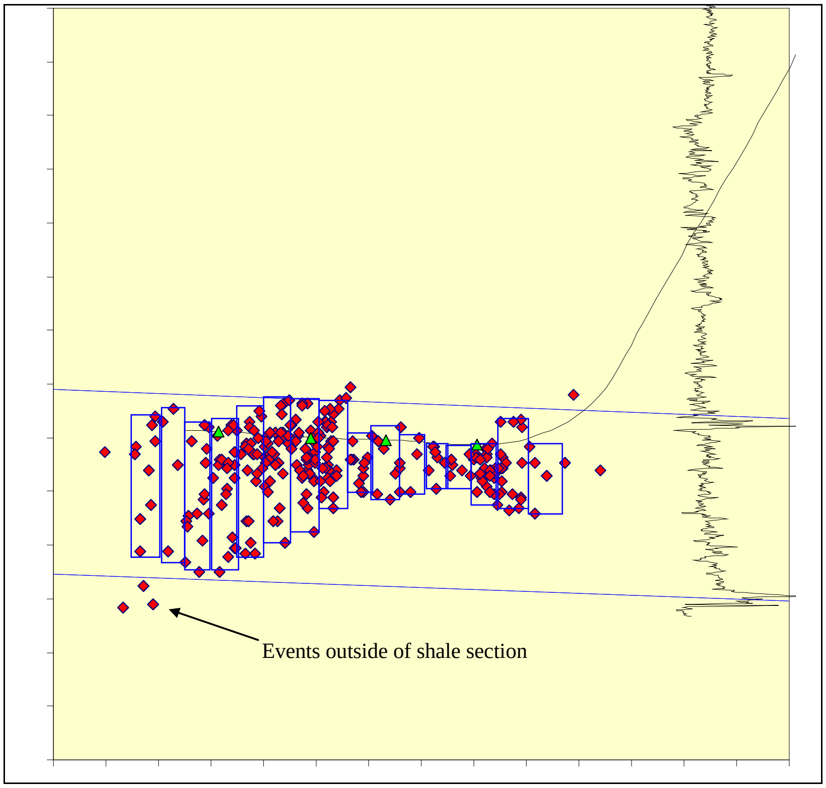

**Figure 5. Conceptual sketch of SRV height calculation**

## SRV and Fracture Spacing in Shales

It is important to note that the SRV is just the reservoir volume affected by the stimulation. It does not provide any details of the effectively producing fracture structure or spacing. Maxwell *et al*. (2006) introduced a concept that could eventually be used to characterize fracture density. In this approach "additional seismic signal characteristics allow investigation of the source of the mechanical deformation resulting in the microseisms. In particular, the seismic moment, a robust measure of the strength of an earthquake or microearthquake, can be used to quantify the seismic deformation." Besides this potential geophysical approach, reservoir modeling also provides an avenue to better evaluate the effectively producing network. The details of this approach will be described in the following section. As an introduction **Figure 6** shows an identical SRV with different fracture spacings (densities) and the effect of fracture spacing on the gas recovery factor. The SRV in this graph is about 2,000 x $10^6$ $ft^3$ (for h=300 ft). In contrast to conventional single fracture modeling using fracture half-length, the SRA (Stimulated Reservoir Area) dimensions are given by the total fracture network length ($2x_f$) and width ($x_n$). However, the key property for well production is really the total sum of all fracture network segments (linear feet) within the SRA, which is a strong function of fracture spacing (density).

Equation 1 shows the calculation of total fracture length, $L_{ftotal}$ for the entire SRV as a function of fracture network half-length $x_f$, width $x_n$ and fracture spacing $\Delta x_s$.

$$L_{ftotal} = \frac{4x_f x_n}{\Delta x_s} + 2x_f + x_n \text{ ......(1)}$$

**Figure 7** shows a plot of Eq. 1 on a log-log plot for the given SRV in Figure 6. The resulting curve forms an approximate straight-line on a log-log plot. As an example, reducing fracture spacing from 300 ft to 50 ft would result in a more than 5-fold increase in total fracture length (from 48,600 ft to 264,600 ft) and would accelerate the 3-year cumulative gas recovery by about the same multiplier. This illustrates the importance of viewing SRV in context with the potential fracture spacing. A dual porosity approach is not utilized at this point since the fracture spacing is still relatively sparse and the numerical approach better illustrates the linear flow patterns in a low permeability shale system.

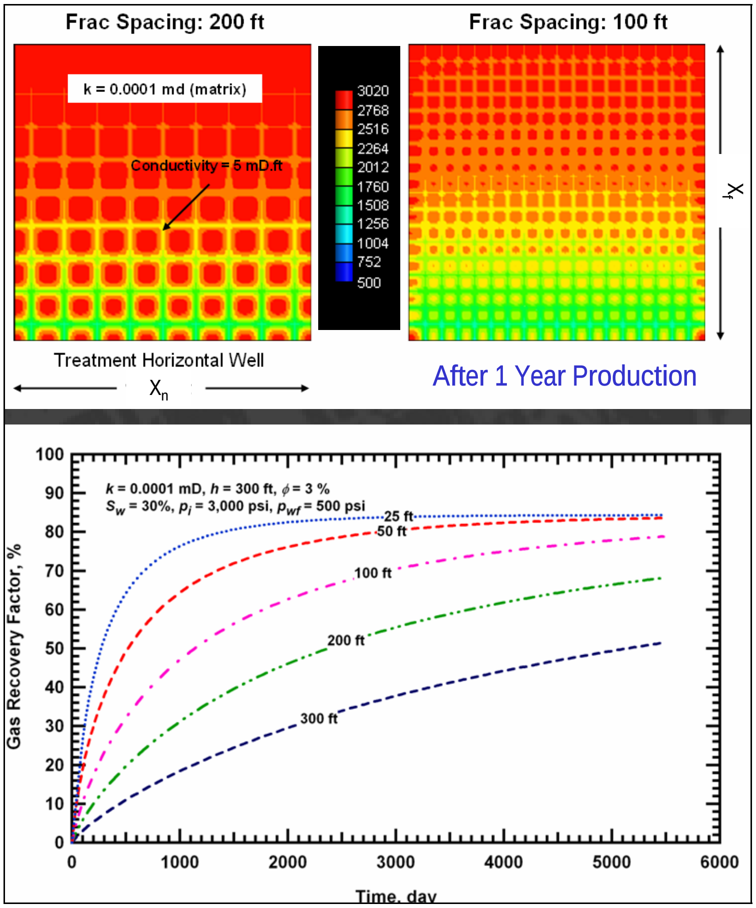

**Figure 6—Effect of fracture spacing ($\Delta x_s$) on well performance and recovery factor for SRV=2,000 x $10^6$ $ft^3$ (from SPE**

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