URTeC: 1503

Imaging a Two-lateral Zipper Frac With a Surface Microseismic Array in Vaca Muerta, Argentina

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This paper was prepared for presentation at the Latin America Unconventional Resources Technology Conference held online on 16-18 November 2020.

Abstract

Two horizontal wells were completed in Vaca Muerta Formation, Neuquén Basin, Argentina in June 2019. The hydraulic fracture treatments were monitored with a large surface microseismic array. The data acquired present several interesting observations about the results of the frac'ing and the interaction of the treatment with a nearby, previously completed producing well. This paper discusses the monitoring and the results achieved.

Introduction

Lindero Atravesado field is located in the central part of Neuquén Basin, Argentina, in a geological region known as the "engulfment" (see Figure 1). To date more than 250 conventional and unconventional wells have been drilled in the field. Exploration and development activity in this particular field began in the late 60's, with the first wells targeting Sierras Blancas and Quintuco formations.

The development of conventional oil and gas reservoirs in these formations began in the eastern sector of the field, moving lately towards the western sector. In 2000, the first deep well to Lajas and Punta Rosada tight gas sands was drilled and fractured in the eastern sector (Martínez et al., 2005). The encouraging results from this well led to the development of these unconventional reservoirs over the period of 2012 to 2018.

In 2012 the first two vertical exploratory wells were drilled to test the Vaca Muerta Formation as an unconventional shale oil reservoir. Logging, coring and microseismic monitoring of the hydraulic fracturing were done in both wells. A detailed reservoir characterization of the formation was carried out with these data as input to an integrated workflow centered on the simultaneous inversion of a 3D seismic dataset.

The results of the initial vertical wells and the detailed reservoir study led to the drilling of two horizontal wells in 2018. The wells were placed in the northern part of the field where the total organic carbon content and porosity seemed to be the most promising. Both wells were targeted to the lower part of Vaca Muerta Formation, at a depth where the proportion of organic matter, carbonates and silica favored both oil storage and successful hydraulic fracturing, informally known as *"the kitchen"*.

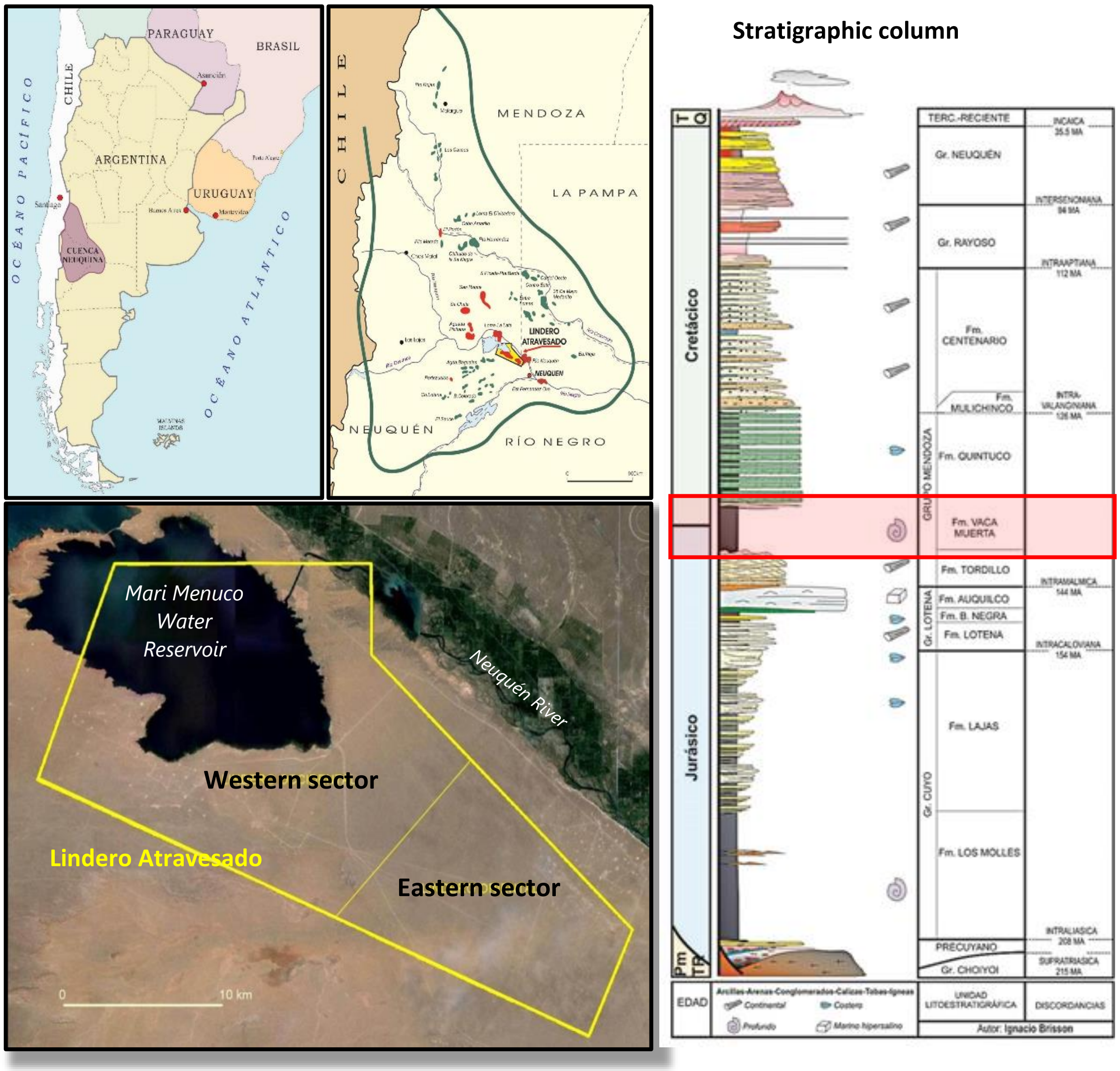

Figure 1. Location of Lindero Atravesado field in Neuquén Basin of Argentina along with a local stratigraphic section.

These first two horizontal wells, A and B, peaked with a production of more than 1500 barrels/day. As a result, a development program consisting of four horizontal wells was carried out in 2019 kicking off the "factory-mode" development of the block. Microseismic was used to monitor the completion of two of these wells, C and D, that were 2500m parallel laterals at a 250m spacing with a total of 66 stages of hydraulic fracturing (Figure 2).

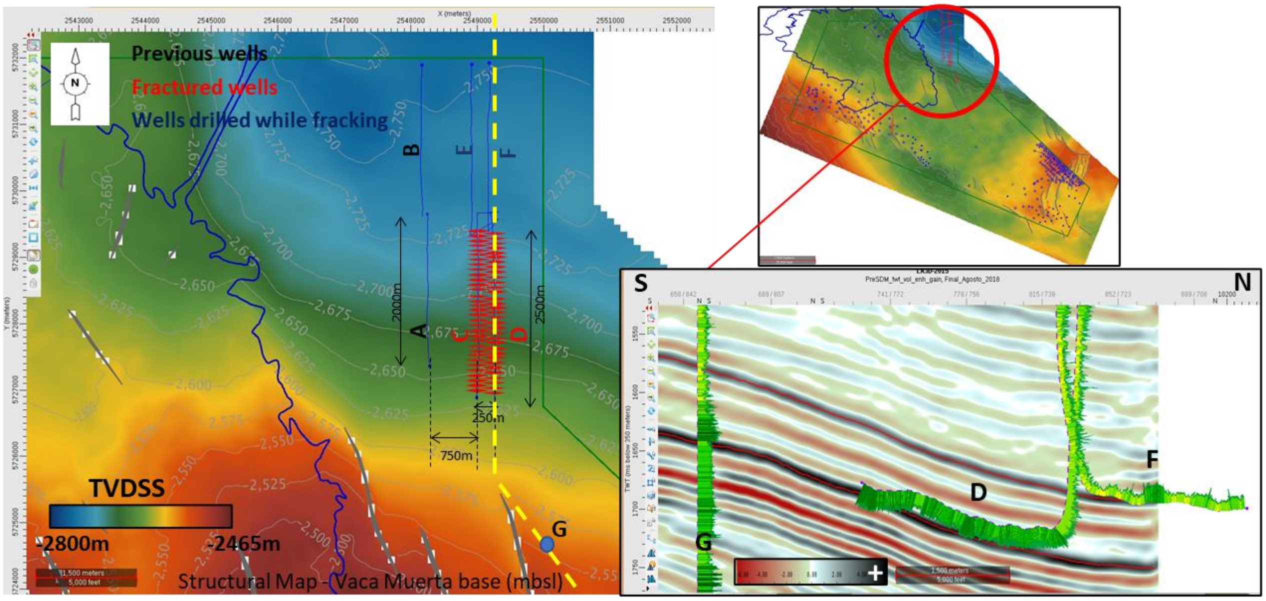

Figure 2. Structure map on the base of Vaca Muerta formation in the northern area of the Lindero Atravesado field, with the position of previous wells A and B, and the monitored C and D wells shown. Red hatch marks on the wells represent treatment stage locations. The S-N seismic section shows the laterals D and F.

Geological Setting

The Vaca Muerta formation, located in the Neuquén Basin, is a marine source rock deposited during early Thitonian – early Valanginian (Weaver, 1931). It is composed mainly of fine grained siliciclastic and carbonaceous materials, with high organic carbon content and some isolated pockets of sandstone and limestone. The formation has been studied and drilled as an unconventional shale play in different parts of the basin since 2010. Producible reserves are estimated to be more than 300Tcf of gas and 16 Bbbl of oil. Today's Vaca Muerta oil and gas production represents 21% and 25% respectively of Argentine total production (Secretaría de Energía de la Nación, 2020).

The sedimentary environment in Lindero Atravesado field varies from deep basin to ramp (Mitchum y Uliana, 1985; Legarreta y Uliana, 1991). The Vaca Muerta formation has a mean thickness of 150 m over the field. The 20 m thick lower part represents the first marine transgression bounded by a maximum flooding surface (MFS); this lower layer has very high TOC and GR values. A succession of prograding-agrading sequences associated with changes in sea level lie above the MFS. The most representative lithologies are mixed matrix fangolites, with a minor contribution of limestones. Mineralogically, silica content is around 50%, clay minerals (mainly illite and illite-smectite) are less than 30% and the rest are carbonates. Maximum TOC in the area is ~5%. Vitrinite reflectance values range from 0.9 to 1.1% indicating some variation in thermal maturity inside the block (González et al., 2016).

Theory and Methods

The microseismic monitoring data were acquired with a surface array consisting of 2,345 stations spread over 18 arms as depicted in Figure 3. The asymmetric layout was the result of the nearby river. Cable and cableless receiver systems were employed on both sides of a main road crossing the star array. Station spacing along the arms was 25m, and each station had a 25m long,12 geophone linear array evenly spaced along the arm. Both monitored wells had an average depth over the treatment interval of 2669m subsea. Microseismic data were recorded with 2ms of sampling rate from 6/04/2016 to 06/23/2019.

Proprietary processing tools were applied to condition the data, estimate hypocenters for the microseisms detected and to estimate the focal mechanism for each event.

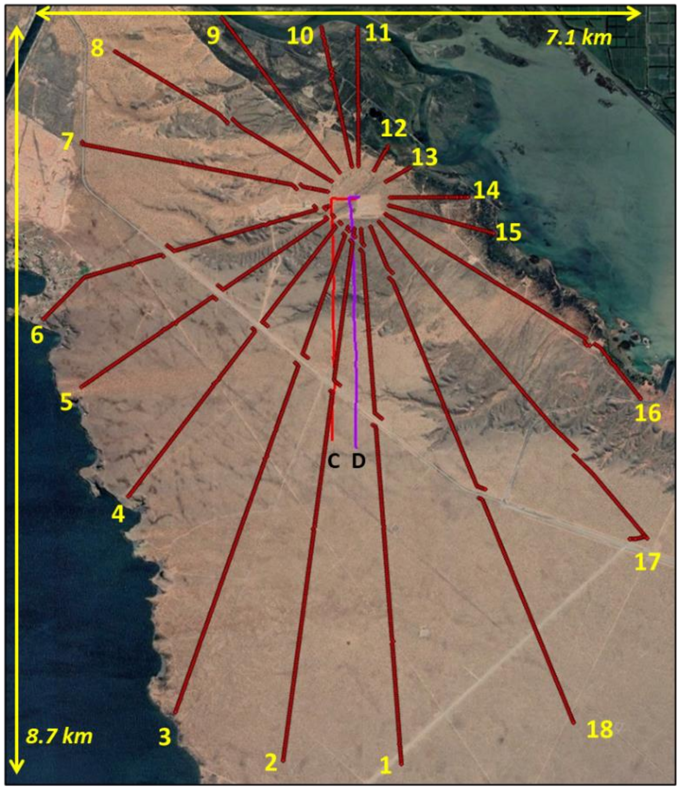

Figure 3. Layout of surface microseismic surface array, with the monitored laterals in red and purple.

The estimated magnitude, azimuth and dip of the frac events were used to replace each event with a planar representation of the fracture centered on the hypocenter. Taken together, these planar elements form a discrete fracture network (DFN) that describes the total stimulated reservoir volume (SRV) in a geologically insightful manner. The DFN for this project is pictured in Figure 5.

A mass balance approach was applied to estimate the proppant distribution within the DFN in a 30 m x 30 m grid. The volume of proppant pumped for each stage is algorithmically mapped into the DFN associated with that stage from the wellbore outward until the amount of proppant is exhausted (Oda, 1985). Figure 5B and Figure 6 illustrates the relationship of the total to the propped SRV.

Observations

The number of observed microseismic events during the treatment was very different for each well, according to the injection. In well C, with more fluid volume and less proppant injected, a total of 4999 events were detected, whereas in well D, with less fluid volume and more proppant injected, just 1940 events were mapped (

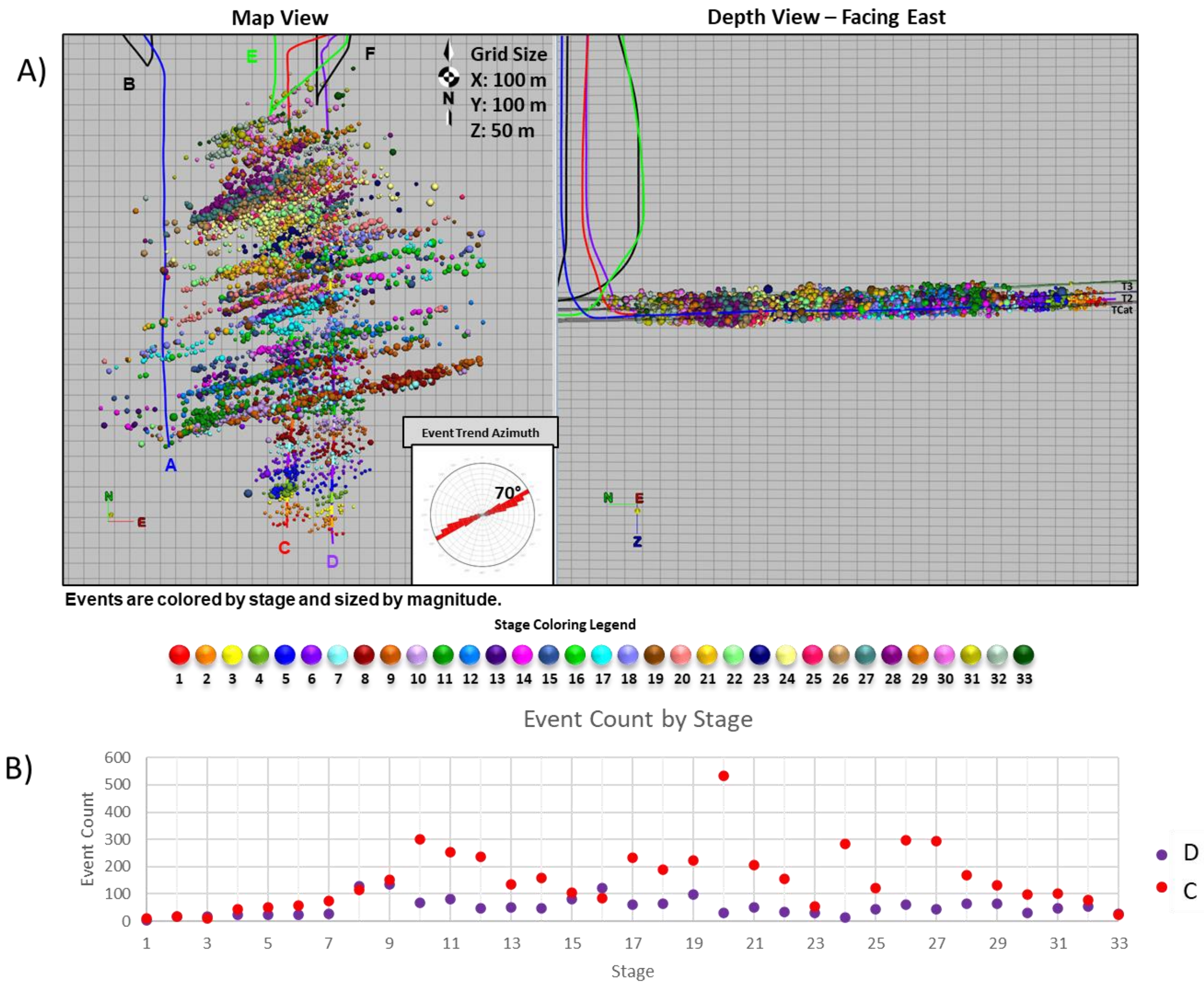

Figure 4). The frac treatment of C and D wells produced fractures with a mean half-length of 545m and a height of 120m, while propped half-length of 110m and total height of 50m were obtained after mass balance approach (Figure 5B).

Inversion for the full moment tensors of the principally dip-slip events determined an estimate of the maximum horizontal stress (SHmax) direction to be 82°, which agrees with local and regional measurements (Heidbach et al., 2016). There exists a large population of oblique-slip events that tend to strike at 70°. These are thought to represent a set of pre-existing fractures being excited by the treatment, that are hardly detected in the conventional seismic image. The stress regime is indicated to be dip-slip with the vertical stress being the largest principal stress and the stress ratio estimated to be 0.56.

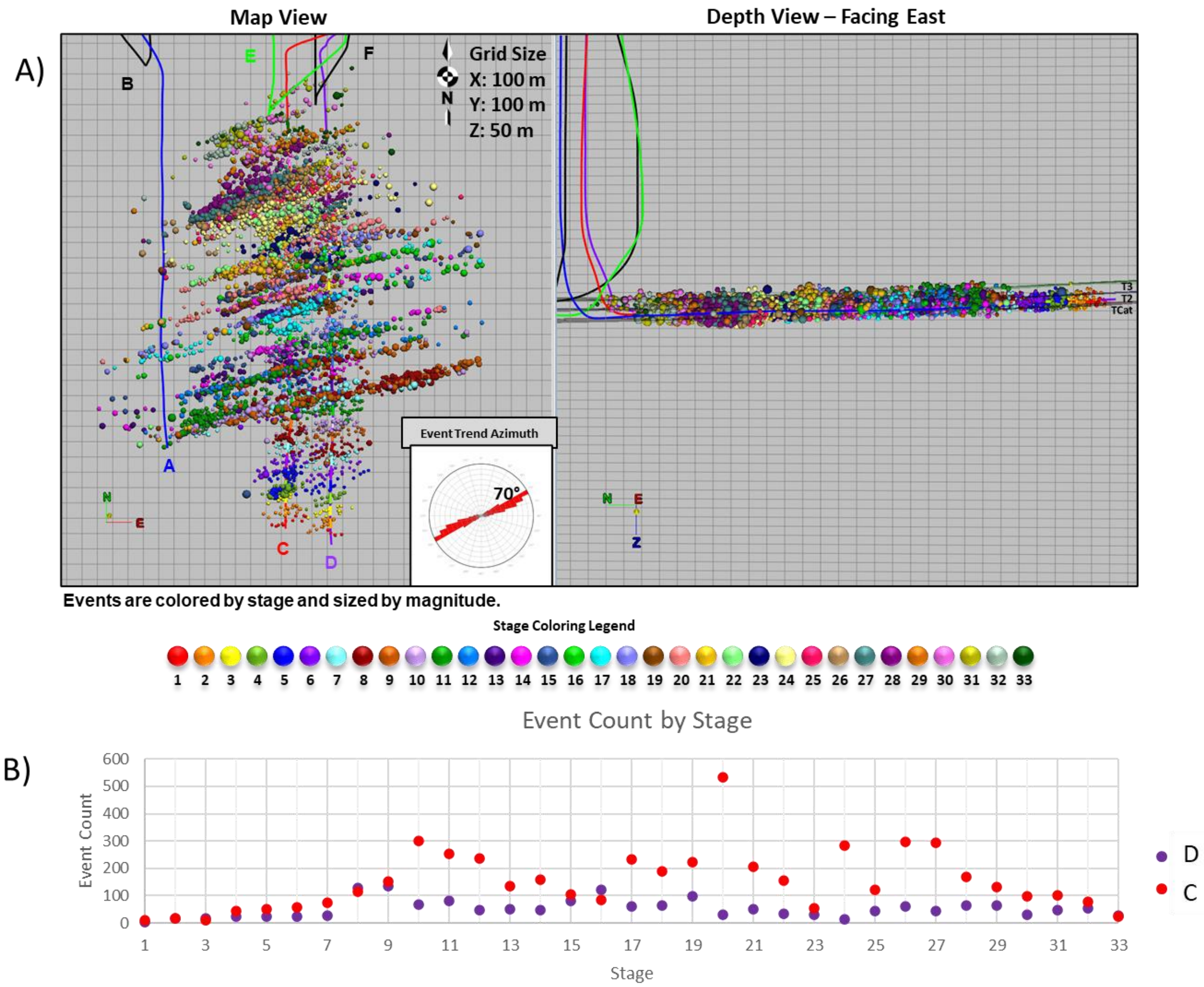

Figure 4. A) Microseismic event hypocenter locations for the treatment of wells C and D. Events are colored by stage and sized by magnitude. The rose diagram insert shows the overall average azimuthal trend of the locations. B) Number of events per stage in both wells.

A very strong fracture driven interaction (FDI) was observed between the treated wells and well A located 750m to the west. Well A had been on production for approximately 7 months prior to the completion of the wells C and D and was on production when the treatment began. When the treatment of wells C and D advanced to the point that the stage location was on strike with the dominant fracture direction extended to well A, the nature of the fractures changed dramatically as seen in Figure 5A. The fracture half lengths became much larger and extended to the primary well while remaining reasonably symmetric about the treatment wells.

Interestingly, pressure in the primary well, still on production, dropped. The well A was shut in for the duration of the treatment at approximately the point indicated by the red arrow in Figure 5. As treatment proceeded toward the heel of the wells, the fractures become less symmetric, showing a bias toward the primary well A to the west.

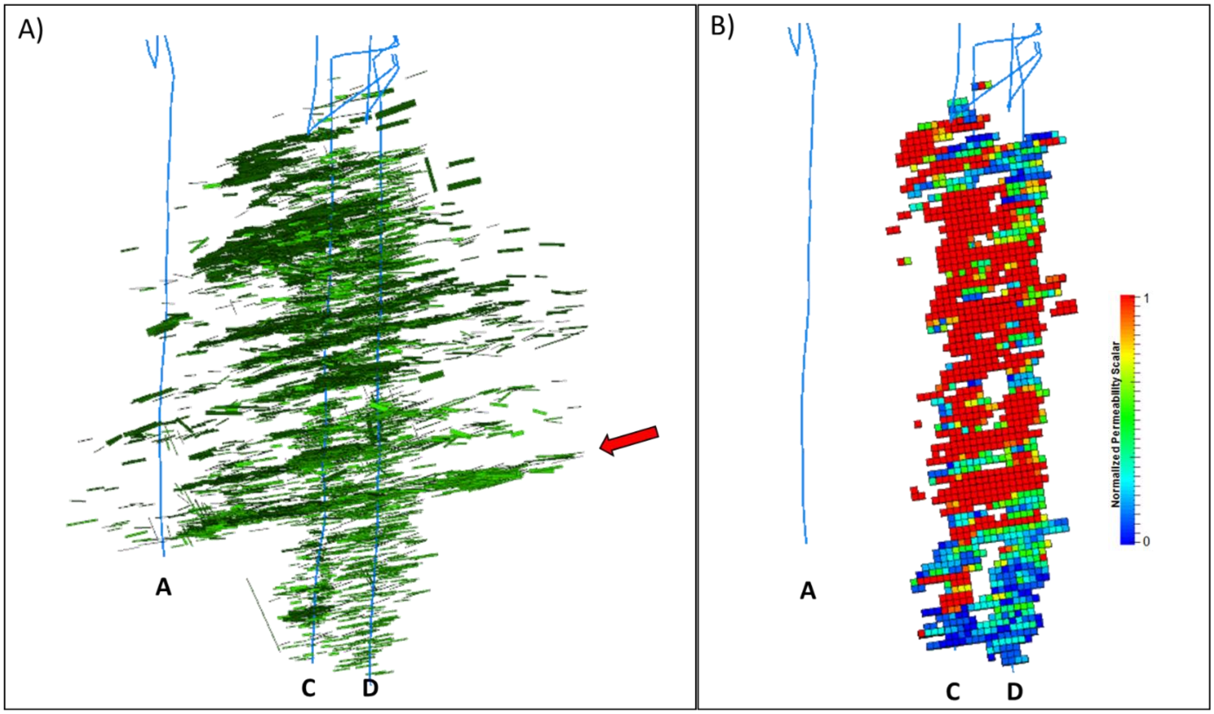

Figure 5. A) Total DFN for treatment of C and D. Note the effect on the SRV of well A which was producing at the time of treatment. The red arrow indicates the timing of the shutting in of well A during the treatment. B) Propped volume colored by a relative permeability factor.

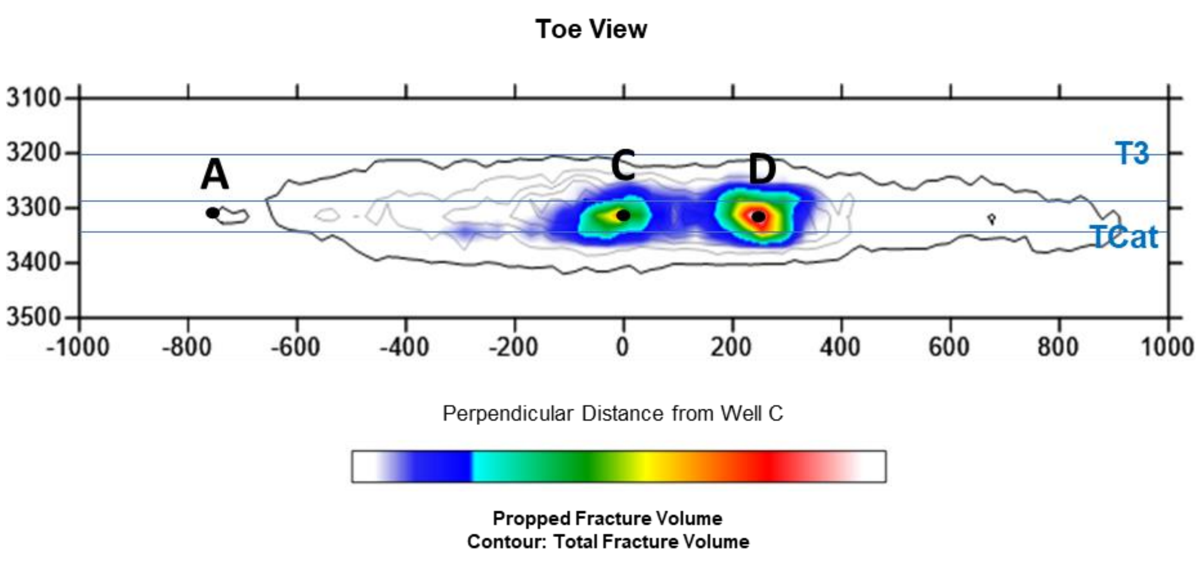

Figure 6. Gunbarrel view from the toe (south) of the total SRV (black contours) and propped SRV (color contours) of the treated wells C and D.

Conclusions

Monitoring the treatment of wells C and D with a large surface array proved very insightful for the completion of these Vaca Muerta wells and was judged a success. The limited height growth indicates that vertical well interference could be controlled allowing for multi-level development. Lateral interference is being evaluated currently with the aid of these results to determine the optimum distance between parallel laterals. The strong FDI observed between the primary and secondary wells indicates that some form of mitigation should be practiced in order to minimize this effect in future development. Shorter fractures with more stages per well are being considered in this regard.

Acknowledgments

The authors would like to thank Pan American Energy and YPF for permission to publish this work.

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