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Geological Setting of the Vaca Muerta Fm, Neuquen Basin - A World class Shale Play

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SUMMARY

The Vaca Muerta Formation, the main proven source rock in the Neuquen basin, has become, in the last two years, a unit that promises an enormous potential as a Non-Conventional Shale Gas and Oil resource play. This unit shows a high geological complexity related, primarily, to its large size and extension. The aim of this work is to characterize the geological features of Vaca Muerta Fm., as an example of a shale play, in order to understand and define the productivity of this type of shale resources.

Introduction

The Vaca Muerta Formation, the main proven source rock in the Neuquen basin, has become, in the last two years, a unit that promises an enormous potential as a Non-Conventional Shale Gas and Oil resource play. This unit shows a high geological complexity related, primarily, to its large size and extension. The aim of this work is to characterize the geological features of Vaca Muerta Fm., as an example of a shale play, in order to understand and define the productivity of this type of shale resources.

Geological Description: The Vaca Muerta Formation

The Vaca Muerta Formation, (Weaver 1931) belongs to the Neuquén Basin, located between latitude of 36° and 40° S, in the west part of Argentina, covering most of Neuquén Province, western part of Rio Negro Province, La Pampa Province and southwest portion of Mendoza Province. The basin is limited to the east by the Sierra Pintada range, to the south by the Somun Curá massif, and to the west by the Andean volcanic arc.

A large sedimentary record, from Late Triassic to Cenozoic, has been preserved in this basin, involving continental and marine siliciclastic, carbonate and evaporitic deposits covering an area of more than 140.000 km².

During late Jurassic to early Cretaceous (Middle Tithonian - Lower Berrasian), Vaca Muerta Fm. shales were deposited in a semi restricted basin with connection with the pacific ocean from north, and with several and isolated entrances from west side. These marine units consist mainly of dark bituminous shales, developed in a mix system of clastic and carbonatic variable proportions, with low percentage of clay minerals. Along the basin, Vaca Muerta presents thicknesses which range from 50 to more than 500 meters. This huge variance of the thickness was strongly controlled by the space of accommodation during the sedimentation period, causing the rock physics and reservoir characteristics of the unit to be extremely heterogeneous.

Figure 1 Geological setting for the Vaca Muerta (VM) Formation. On the lower left, a facies map of the Lower/Mid Tithonian (after Legarreta and Uliana, 1991). On the right, a thermal maturity (%Ro) map of the Neuquen Basin, showing the shale oil and shale gas areas (after Askenazi, et al., 2013).

Understanding Shale Petrophysical Properties:

Vaca Muerta Fm. has been, for far, the most prolific source rock of Argentina. Nowadays, it is treated as an unconventional reservoir. In this kind of reservoirs, the hydrocarbon accumulation are not established by the flotability of hydrocarbons related to the water table, neither Darcy's law can be applied as it is usually applied on the conventional reservoirs. It is therefore reasonable to assume that these types of accumulations have large continuity, at a regional scale and are totally independent of the classical concept of "trap", either structural or stratigraphic.

These plays involve, mainly, a fine grained matrix with different proportions of clays, sandstones and carbonates. They present very low permeabilities values and they need massive hydraulic stimulation in order to produce hydrocarbons. These rock-types act as source, trap and reservoir at the same time. Usually shale reservoirs, in order to be economically doable, must group a certain amount of pre-requisites, such as:

- Organic Content (>2% COT for shale Gas and it may vary for shale Oil),
- Thermal Maturity (>0,7 Ro%),
- Thickness (>30 m) and areal extension,
- Adsorption capacity (mainly in Shale Gas),
- Frackability (shale content less than 40% of clays),
- Overpressure
- Depth
- Surface facilities

The efficiency of Vaca Muerta Formation as a source rock is proven in almost all the basin (Cruz et. al., 1996; Cruz et. al., 2002). It presents a type II kerogen corresponding to a marine environment (Villar & Talukdar, 1994; Villar et. al., 1998; Scasso et. al., 2005; Villar et. al., 2006) which is oil and gas prone. The organic matter is described as 100% amorphous material with scarce traces of terrigenous material. It is extremely homogeneous on the lower and upper sections throughout the whole basin where this information is available.

Along the basin, the Total Organic Carbon (TOC) values of the unit vary from 1 to 12%, with a tendency of increment towards the base of this formation (Villar et. al., 1998; Uliana et. al., 1999; Stinco et. al., 2003). The lower part of the unit (first 30 to 40 meters) shows TOC values between 3.5 to 7%, whereas the upper part has values ranging from 2 to 4%. What is remarkable from the upper section is that there is an empirical relationship between the total thickness and the thickness with TOC greater than 2%. In some areas this relationship is almost 1 to 1, as it can be found in the central-east part of the basin. In contrast, in the western part of the basin where the total thickness of the Vaca Muerta Fm. can be greater than 550 meters, the net pay thickness (using the 2% of TOC as cutoff) can be of 200 to 250 meters.

Regarding thermal maturity, it is possible to say that the vitrine reflectance index (%Ro) indicates the maximum temperature on which the source rock was exposed and allows to define the type of hydrocarbon this source rock has generated. A wide range of Ro values were found, with the lowest value been 0.5% (immature Ro) and highest values up to 3% (gas window generation) (Villar & Talukdar, 1994; Villar et. al., 1998; Uliana et. al., 1999; Veiga et. al., 2001). Using this maturity index, the unit can be divided into 3 different regions, concerning the hydrocarbon expected: the shale oil region (0.7 to 1.2% of Ro values), the wet gas region (1.2 a 1.35%) and the dry gas region (1.35 a 3.2% Ro). This division is not only important to determine the type of fluid that is expected, but also to define the completion strategy.

The petrophysical analysis of the Vaca Muerta Fm, based on well log data, showed porosities that ranges from 4% to 12% along the basin. If the unit is vertically analysed, the lower part of it has porosities within 8 to 12%, whereas in the middle and upper parts these porosities varies from 4 to 8%. This wide range may be associated to the organic content of the unit (TOC), which also varies in the same way as porosities; TOC is higher in lower parts of the unit. This "organoporosity" is generated during burial and maturation of the organic material.

The mechanical properties of a shale reservoir are strongly controlled by its geological characteristics. Quartz, carbonate and clay contents control significantly the elastic parameters of a rock, and constrain how efficient a hydraulic fracture will be. Two main parameters, used in order to measure how "hard" and how "deformable" rock will be, are the Young's Modulus and Poisson's ratio.

According to Britt and Schoeffler (2009), for a shale rock to be a potential reservoir, they must have Young modulus greater than 3.5×10^6 psi, and low values of Poisson's ratio (less than 0.25). Lab measurements of these mechanical properties made on the Vaca Muerta Fm., confirm this statement above in order to become a "frackable" shale reservoir.

Shales with high percentage of quartz and carbonate have a tendency of been more fragile and "frackable", which will provide a better environment for developing dendritic shaped fracture patterns during the completion stages. On the other hand, shales with high amount of clays are more likely to behave ductilely, preventing a successful fracture configuration. In the industry, the cutoff value of 40% of clays is assumed in order to decide when a shale is "frackable" or not. The results from the DRX analysis over Vaca Muerta Fm., have showed very low clay content, i.e.: between 5 and 30% (mainly illite and intrabeded). Quartz and carbonate content vary according with vertical and lateral position within the basin. Quartz is likely to be more abundant at the bottom part of Vaca Muerta, whereas carbonate increments towards the top. On distal areas, there is almost the same proportion of quartz and carbonates.

Although it is not a fundamental feature for the success of this kind of plays, overpressure is desirable to improve productivity. This can be confirmed by the performance of the wells drilled along the basin for the Vaca Muerta Fm., where the best ones are related to high pressure gradients zones (between 0.85 and 1.1 psi/ft). This overpressure is generated by the maturation processes of the organic matter.

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