The Late Cretaceous Niobrara Formation in the south-central South Dakota (USA): a correlation study using porosity and gamma ray logs

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Abstract

The Niobrara Formation is a Petroleum System in a developing petroleum resource play. It is present over most of the Rocky Mountain region until the Great Plains, and has many prospective areas for oil and gas production. As a petroleum system it is a self-sourced system, which reservoir and source rocks compose the same stratigraphic unit. The Niobrara Formation occurs in South Dakota, but different geological contexts such as different stress regime, natural fracturing, burial depth and diagenetic processes in the area of the Rocky Mountain region has led to different configurations than those found in South Dakota. In the eastern extension of the Niobrara Formation that includes South Dakota, the reservoir consists mainly of low permeability chalks, shales and siltstones. The petroleum production and available data in the Niobrara Formation is greater in the Rocky Mountain region than in South Dakota, even though both areas were parts of the same western interior seaway in the Cretaceous period.

Porosity is a critical parameter for petroleum production, and accurate porosity information is needed to adequately evaluate the Niobrara Formation in South Dakota. This work aims to present the results of porosity well logs analysis from the Niobrara Formation mostly in South Dakota that supported a lithostatigraphic correlation to better understand this Formation in that region. Well logs that were already available were used to observe the spatial distribution of porosity across the study area. Scanned images from well logs in the State of South Dakota that are already available by the SGDS – South Dakota Geological Survey were used to acquire needed information about porosity and lithology. It was also used density logs to reach porosity values. Statistical analyses were applied to image porosity spatial distribution. Porosity values in the Niobrara Formation range from 30% over 40% but can be severely dropped to an average 6%. As the greater porosity values it's related to the chalk intervals and the smaller ranges of porosity were due to intervals made of chalky-shale

Introduction

The Niobrara Formation received this name after Meek and Hayden 1861 due to the extensive chalky outcrops along the Missouri River across the Niobrara River (Stach, 1972). As a petroleum system is a developing play, being present over most of the Rocky Mountain Region with many areas productive in oil and gas (Sonnenberg, 2011).

The organic matter content ranges from 2 to 8% in the source rocks (Landon *et al.,* 2012). The Niobrara Formation also can be understood as an unconventional petroleum system due to the source and reservoir that are contained in the same unit (Sonnenberg, 2011). The unit is thermally mature in the deeper, western part of its extent, in Laramide Basins of the Rocky Mountain region (id Sonnenberg, 2011).

Niobrara Formation occurs in the entire northern Rocky Mountain region and through the Great Plains and these areas were part of the North American Seaway then the depositional setting is much closer to shallow marine environments (Longman et al., 1998). However the production of oil and gas in South Dakota is concentrated by the Pennsylvanian Minnelusa Formation thus the Niobrara Formation hasn't perspectives oil and gas production (Gries, 1964).

Method

The acquired data was provided by the South Dakota Geological Survey (SDGS) using scanned well log images in theTIFF format. Then the images were converted to .LAS files with the software *NeuraScanner NeuraLog*® granted from the *South Dakota School of Mines and Technology* to be manipulated on the softwares of geological and geophysical interpretations.

The .LAS files were displayed using the software TIBICO SPOTFIRE® (2016) which was developed and qualified to manage and storage of all sort of data, including geological and geophysical data, provided by IES Brazil Company. The geoscience data is manipulated by the plug-in called *Ruths* ® created in Houston to give support to the oil and gas industry and its information. All these softwares allow the user to acess the data from wherever they are once the data is located in a central storage system.

Gamma ray and porosity density logs were used due to the high confidence of gamma ray logs in geological interpretation and the good response of chalky shales inthe Niobrara Formation.

The first step was the calculation of the IGR (Index of Gamma Ray) which means the response of the clay contente, from the GR (gamma ray) maximum and minimum compared to the clay content at each GR interval:

$$IGR = \frac{GR - GR\,min}{GR\,max - GR\,min}$$

The volume of clays can be calculated from the IGR value using the special formula for Cretaceous, the Larianov relationship (Asquith e Krygowski, 2004):

$$Vshale = 0.33\,(2^{(2.1\,IGR)} - 1)$$

The last correction applied were based on the *Wyllie et al.* (1956) relationship to calculate the density porosity affected by the clay content,

$$\phi = \text{Vshale}\ (\rho ma - \rho shale) \div (\rho ma - \rho liq)$$

Considering the limestone matrix density ρma = 2.6 g/cm^3, the fluid density ρliq = 1.1 g/cm^3, which considers the drilling fluid as the main fluid and the mean shale density $\rho shale$ = 2.4 g/cm^3 (Rider, 2002). All these corrections were performed with the software *TIBCO SPOTFIRE*® (2016) that allows the easy input of the formulas and parameters.

Results

Two correlations were presented based on gamma ray and porosity density logs. Gamma ray logs are essential for distinguishing the lithologies.

The first stratigraphic correlation is based on the informations of tops and bottoms provided by the SGDS. This correlation identified three cycles of chalk and two cycles of marls with greater expression than the chalks.

The second correlation is based on the interpretations from the log curves after corrections, which aimed to identify more chalky cycles. The second correlation was guided in the interpretations of gamma ray and corrected porosity values with four cycles of chalks and five cycles of marls. But chalks show way more volume compared to the marls in this case.

Discussion and Conclusions

Both correlations confirm the stratigraphic models for the regional setting for the Niobrara Formation and the western cretaceous basin, from east to west.

The greater numbers of cycles that can be recognized confirm that the petrophysical corrections allow greater vision to the log profiles.

The more effective presence of chalks is due to the corrections of the clay content highlighting the carbonates and their potential to be reservoirs. The repetition of marls and chalks makes greater potential of source-reservoir system stored in the same unit.

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