# NMR T1-T2 Map of Different Hydrogen Contents of Bakken Formation

Seyedalireza Khatibi, Mehdi Ostadhassan, Azadeh Aghajanpour, and Rehan Ali Mohammed

***Abstract*—The development of shale reservoirs has interpreted as a milestone in the energy equation. This issue led to organic-rich oil-producing mudrocks to be studied extensively during the last decade. Shale reservoirs properties such as pore size, organic matter, wettability, clay content and mineralogy would limit the application of the conventional methods for characterizing such reservoirs.**

**Nuclear Magnetic Resonance (NMR) relaxation method is a crucial technique for evaluating shales rocks, both core and log scale. Utilizing NMR tool to measure relaxation times (ranging from 0.1–1 ms) provides a way to understand small pore sizes (nano-meter scale) and also to investigate different proton populations using 2D T1–T2 maps.**

**We took some samples from upper and lower Bakken formation with different maturity levels. Then, the position of each proton population such as hydroxyls from the clay, water, kerogen, and hydrocarbon was detected in samples. Results showed, in a T1–T2 map, the position of these signatures do not overlap and also shows the movability of each portion as well.**

***Index Terms*—Nuclear Magnetic Resonance (NMR), shale reservoirs, proton populations, T1-T2 map.**

## I. Introduction

The fully characterization of gas shales still remained a challenge, since it cannot be performed by means of conventional petrophysical techniques, and new techniques are required for characterizing shale reservoirs. Even for porosity and permeability as basic properties, special methodologies are required. Standard measurement of pore sizes as well as advanced microscopic techniques such as SEM have shown the existence of very small pores [1]-[4].

NMR is a versatile technique used previously to study soluble and insoluble hydrocarbon mixtures, such as kerogen [5]-[9], bitumen [10], [11], petroleum [12], [13], and asphaltenes [13]-[15]. Reference [16] used the T1/T2 ratio to differentiate between moveable and non-moveable fluids in both conventional and unconventional reservoirs. In Smectites having sheet-like pores, NMR instrument can detect and quantify the interlayer water content [3].

It should be noted, simple 1D NMR are not sufficient due to complex porous media [17]. There is also a potential overlapping of the signals of different Hydrogen (H) populations. Multidimensional NMR techniques improve the separation of the different proton contributions [8]-[18]. In this study, T1–T2 map was used in conjunction with geochemical data to characterize hydrogen content in pore spaces of two samples from upper and lower Bakken. The hydrogen population were distinguished straightforward in 2D T1-T2 map. Interestingly, presence of hydrocarbon which was detected in NMR in one of the wells in this study, was also seen in UV image.

Manuscript received March 8, 2018; revised May, 20, 2018.

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## II. Data and Samples

For this study, samples were chosen from the upper and lower members of the Bakken Formation and analyzed with Rock-Eval and also NMR. The Bakken Formation is an organic rich shale, mudstone and sandstone that was deposited during the Late Devonian and Early Mississippian Periods [19]. It is located in the Williston Basin, which is an elliptical shaped depression located in the western portion of North Dakota, northeastern region of Montana and extends into parts of Saskatchewan and Manitoba [20]. The lower and upper members contain Type-I and Type-II organic matter that originated from marine algae. The total organic carbon (TOC) has a maximum of 30% and 20% in the upper and lower members, respectively [21].

(a)

(b)

Fig. 1. Photo of raw samples for Well No. 1 (a) and Well No. 2 (b).

doi: 10.18178/ijcea.2018.9.3.705

Fig. 1 shows raw sample chips used for this study, Table I also presents sample properties from Rock-Eval. No special sample preparation but routine was carried out.

TABLE I: PROPERTIES OF SAMPLES USED IN THIS STUDY FROM UPPER BAKKEN (U.B) AND LOWER BAKKEN (L.B)

| Well No. | Sample depth (ft) | TOC (wt%) | Ro (%) | $T_{max}$ (°C) |
|---|---|---|---|---|
| **1** | 8326 (U.B) | 16.27 | 0.54 | 428 |
| **2** | 10555 (L.B) | 13.26 | 0.86 | 449 |

## III. NMR MEASUREMENT

Organic-rich oil-producing mudrocks has become a major exploration target, thus understanding pore network of such fine grained rocks is crucial for optimizing and designing expenses of production. NMR relaxation methods are considered as key techniques for evaluating oil-producing mudrocks, from both cores and logging data. Fig. 2 shows pore system in a shale rock from [2]. Recently, NMR is being widespread for characterizing of shale oil and shale gas reservoirs by showing producible zones in log scale and pore size distribution in core scale. T1 and T2 are longitudinal and transverse relaxtion times of H nuclei in rock which can be measured and used for fluid typing and pore size [16]-[22]. It can also help in finding the contribution of Bitumen, Kerogen, Bound water, moveable water and hydrocarbon by 2D T1-T2 map or using ratios of T1/T2.

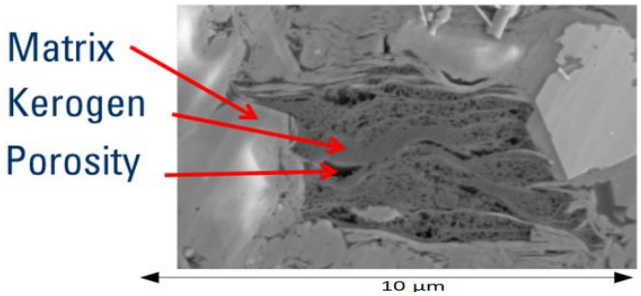



Fig. 2. Pore system in a shale rock sample from [2].

High Frequency NMR measures all hydrogen present in water, oil and solid organics. T1 and T2 relaxation times are physical properties of a sample and are related to mobility of molecules, so they can be used to differentiate liquids from solid, and also talk about mobilty. If T1 and T2 will be measured simultaneously, T1-T2 map will be resulted which provid hydrogen intensity map. The different Hydrogen contents in the T1–T2 map can be associated with the origins stated in Table II.

We used a modified CPMG (Carr-Purcell Meiboom-Gill) sequence in which inter-echo time increased gradually up to 100 µs or more to catch very short and very long relaxation times [23]. 2D T1-T2 maps were then determined using an inversion recovery sequence. Fig. 3 shows T1-T2 map for two samples in this study from Bakken Formation. As it can be seen, the map is a very efficient way to separate the contributions from the different compartments containing hydrogen molecules.

TABLE II: ORIGIN OF DIFFERENT HYDROGEN CONTENT IN NMR

| Hydrogen content | Origin |
|---|---|
| **Hydroxyls** | OH part of the clay structure or at the edges of clay platelets; it is always below 0.1 ms, and needs appropriate NMR instruments |
| **kerogen** | Based on the maturity, it can overlap with hydroxyls. It is best detected in dry samples since their hydrogen index is quite low compared to water |
| **Water** | It is located close to the line T1/T2 ~2 |
| **Methane** | It can easily be separated on T1/T2~10 |

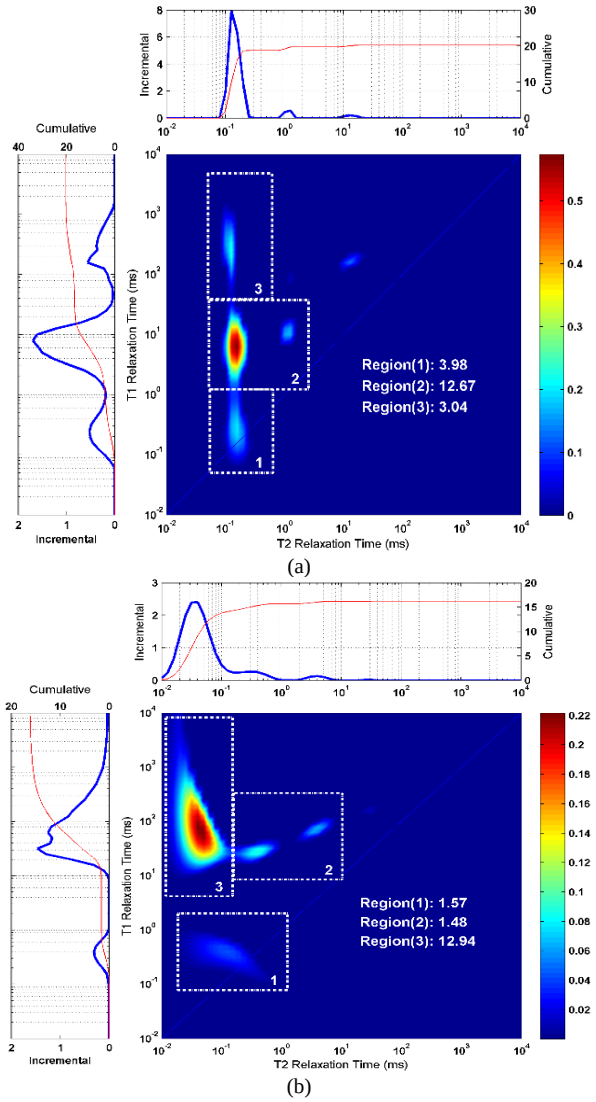



Fig. 3. T1-T2 map for: (a) Well No. 1 Upper Bakken, (b) Well No. 2 Lower Bakken. Hydrogen fraction for different regions are also shown.

## IV. RESULTS AND DISCUSSION

Analyzing the core samples from which the organic matter

was isolated showed hydroxyls from the clay are characterized with 0.01<T2<0.1 ms and 10<T1/T2<100 and/or spread over a wide T1 range, as region 3 in Well No. 2. Kerogen showed itself with 10<T1/T2<100, as in Region 2 and 3 in Well No. 1. It should be noted, in the gas window, organic matter cannot be distinguished, due to low maturity which leads to overlapping of Kerogen signal with the hydroxyl signal. Methane showed itself with T1/T2∼10, as in Region 4 and 2 in Well No. 1 and Well No. 2, respectively. By changing pore size, it moves towards higher T1 and T2 values, as in Region 2 in Well No. 2. Water showed itself with T1/T2∼2, as in Region 1 in both Well No. 1 and Well No. 2. Moreover, the T1 axis can roughly represents the proton rotational mobility [3]-[24]. The mobility is small for large T1/T2 ratios, whereas for solid protons, it corresponds to reduced molecular mobility. Low viscosity fluids have T1/T2=1 (like water), but high viscosity fluids have T1/T2 >100 (like Bitumen).

Reference [3] and [24] proposed typical T1-T2 map, which distinguishes between different hydrogen content based on their location in T1-T2 map, Fig. 4.

Interestingly, Photomicrographs of Well No. 2 under UV light (fluorescence) showed presence of HC, Fig. 5.

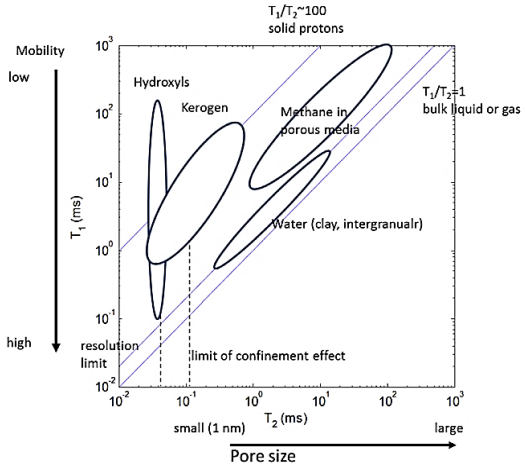
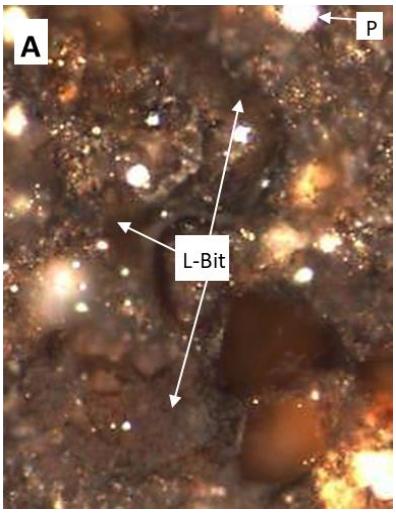
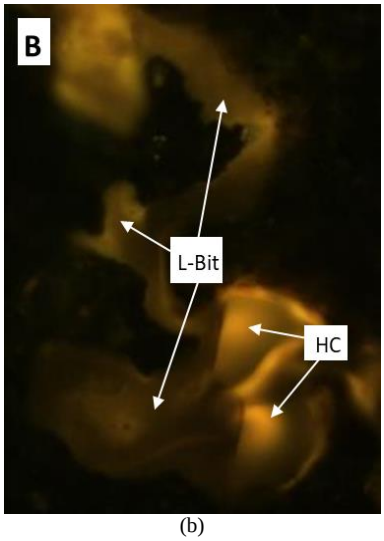



Fig. 4. T1-T2 map proposed by [3] to find each hydrogen content based on location.




(a)




(b)

Fig. 5. (a) Low-reflecting bitumen (L-Bit) for Well No. 2 (b) the same view as in (a) but under UV light. Note the dull-yellow fluorescence color of the generated hydrocarbon (HC) filling the cavities. P is also showing Pyrite.

## V. Conclusion

In this study, we had two samples from upper and lower Bakken formations. We used NMR T1-T2 map to distinguish between different Hydrogen contents in unconventional shale reservoirs as hydroxyls from the clay structure, kerogen, water and methane, since signals are not overlaping.

Estimation of the fluid properties in shales is challenging, and even using advance methods such as NMR needs more experimental work to develop a reliable correlations. This issue would be better performed by understanding the shale system fully. NMR method, might be a benefical tool to help us in this way.

## Acknowledgment

Authors thanks Core Laboratories in Houston for their helps and valuable advices to improve the paper quality.

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