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Influence of rock microstructure on its electrical properties: an analysis using x-ray microcomputed tomography

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Abstract

Precise understanding of rock properties on a subsurface formation is one of the most important factors in petrophysic and hydrogeology studies. For decades, electrical resistivity has been extensively analysed, as it has essential capability to evaluate rock formation. The liquid content and water conductivity used as key parameters to measure the resistivity value of a rock formation. However, few explanation about the rock microstructure influences its resistivity level. The objective of this research is to investigate this fundamental relationship. We found that pores and grains distribution, which is micrometer sizes, are the deciding factors for fluid accommodation, as well as the results deduced from electrical measurement devices are also depend on these parameters.

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Keywords: microstructure, x-ray microcomputed tomography,electrical resistivity, formation factor, conductivity

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1. Introduction

Electrical properties are essential factors to evaluate rock formation. These are also used in induced polarization, resistivity, and electromagnetic methods of mineral explorations [1-4]. The nature and amount of pore saturated (water, other fluids, steam, and other gases [5]), temperature and pressure are among several important factors in measuring the electrical properties [6]. In calculating hydrocarbon in place, resistivity measurement is a crucial part [7]. Herrick also expressed the same view, he mentioned that the correlation between the hydrocarbon saturation of reservoir rocks to their bulk electrical conductivity is a fundamental part in log analysis [8]. In 1942, Archie, introduced a quantitative empirical relationship between resistivity and hydrocarbon saturation [9]. The formation factor is a constant of proportionality that describes the presence of the rock matrix and is a function of porosity and pore geometry and a unit less entity as it's a ratio between those two resistivity values.

In the last decades, attempts also have been made to evaluate the relationship that exists between the rock formation factor and porosity in determining value of its electrical properties, such as in clay [10], particle shape and effect of cementation [11], secondary porosity, laminations, and thin beds [12]. However, there is no clear explanation about how the rock microstructure would influences its electrical properties. The authors believe that a clear understanding of this complex relationship is important to be solved, as electrical properties is a key parameter in subsurface measurements. Thus, we conducted research on various types of rocks are including sandstone, limestone, and carbonate rocks by using high resolution micro computed tomography image. Their microstructure and electrical properties differences were then analysed.

2. Experimental Methodology

2.1 Sample preparation

We selected five outcrop rock samples with various types of heterogeneity (two sandstones, two limestones, and one carbonate rocks). The samples dimensions were range from 50mm to 95mm lengths and ~38mm diameters. The carbonate rock has the largest porosity, 18%. Meanwhile the lowest porosity is Tofo limestone, 3.1%. Please refer to Table 1 for the chemical and physical properties.

Table 1. Physical and chemical properties of the porous media investigated.

Porous Medium	Porosity (%)	Resistivity, (Ωm)
Barea sandstone	17.60	2.86
Bentheimer sandstone	16.00	2.97
Rordal Chalk limestone	5.27	1.26
Tofo limestone	3.10	0.73
Savonnier carbonate	18.10	3.77

2.2 Image acquisition and processing

The five outcrop samples imaged at a high resolution of ~$(4\mu m)^3$ using x-ray micro computed tomography in a dry state (Xradia Versa XRM500T). The acquisition images were processed using Avizo Fire 9.1 (iVec lab, CSIRO and Pawsey science groups, Kensington, WA, Australia) cropped, then filtered by a non-local means edge preserving filter [13,14]. These grey-scale filtered images segmented by applying iThreshold. The 3D segmented images were then analysed to measure porosity, pore distribution, and grain size distribution [16,17,18,19,20,21,22].

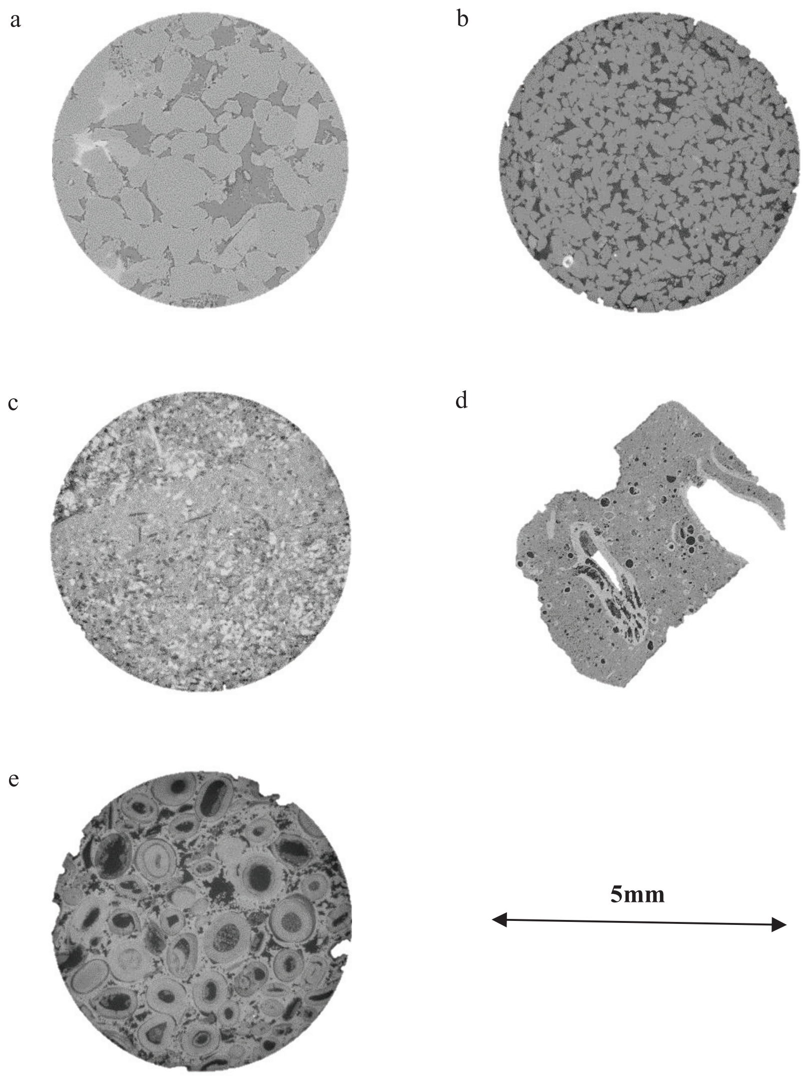

Fig. 1. Five selected samples. A to E are the raw image of Berea sandstone, Bentheimer sandstone, Tofu limestone, and Rordal chalk limestone, and Sovenier carbonate consecutively.

2.3 Formation factor measurement

The saturated resistivity tests were carried out at room temperature, 25 ^{o}C. The tests facilities are set as shown in Figure 2. The saturated liquid is 5% NaCl brine and its resistivity is 0.16 OHM-M. The formation factor is the ratio between resistivity of brine saturated rock and resistivity of brine [9]. These saturated samples were tested for different electric frequencies from low ~1 KHz to high ~ 66.6 KHz. A non-linear equation for each sample related to frequency and formation factor is built. Electrical conductivity of rock related to its porosity and brine saturation. The rock formation factor is the resistivity of bine saturated rock with brine's resistivity. The equation reads [9]:

$$F = \frac{R_0}{R_w} = \frac{a}{\emptyset^m} \tag{1}$$

Where;

- F = formation factor
- R_o = resistivity of brine saturated rock
- R_w = resistivity of brine
- a = constant
- ∅ = porosity
- m = cementation exponent

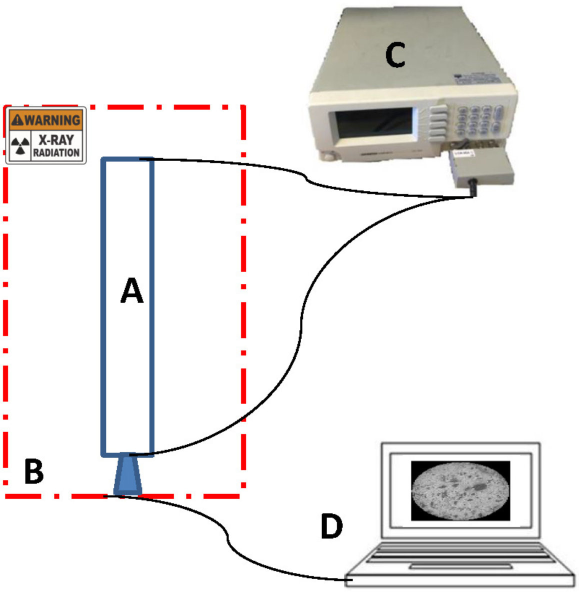

Fig. 2. Experimental setup for formation factor measurements that used in this research study. A is core holder, B is the microCT, C is ISO-tech Lcr819 instrument, and D is the computer for data processing.

3. Results and discussion

3.1. Grain and pore size distribution effects

Grain size distribution influences rate of porosity and permeability of the rock formation. With increasing in well sorting and fineness during sedimentation process, then it can creates more pore spaces and higher distribution in the formation. This will increase the chances of hydrocarbon present into the formation, which creates a higher resistivity value.

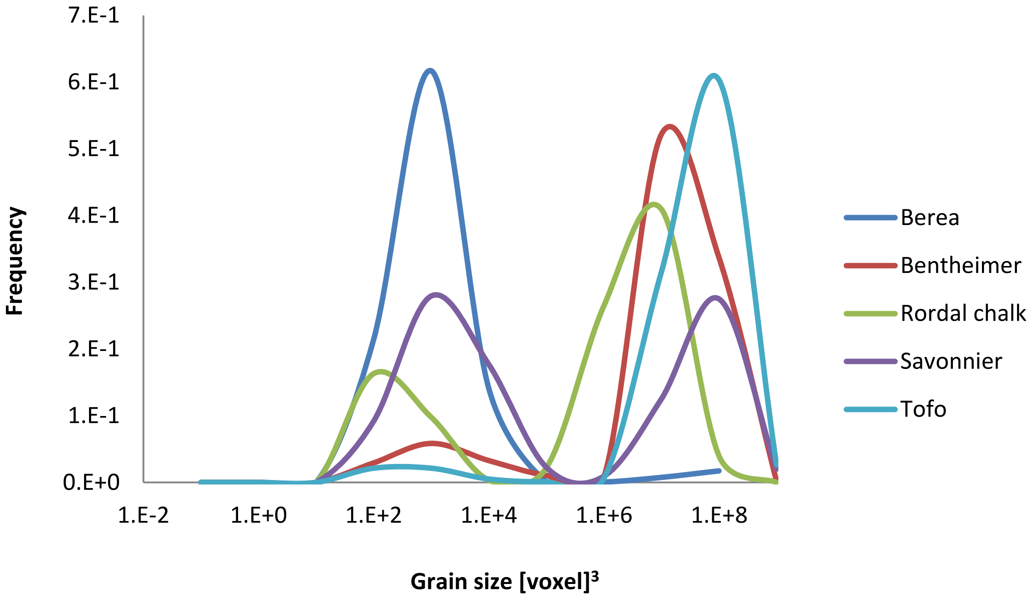

Fig. 3. Grain size distribution of the five selected samples

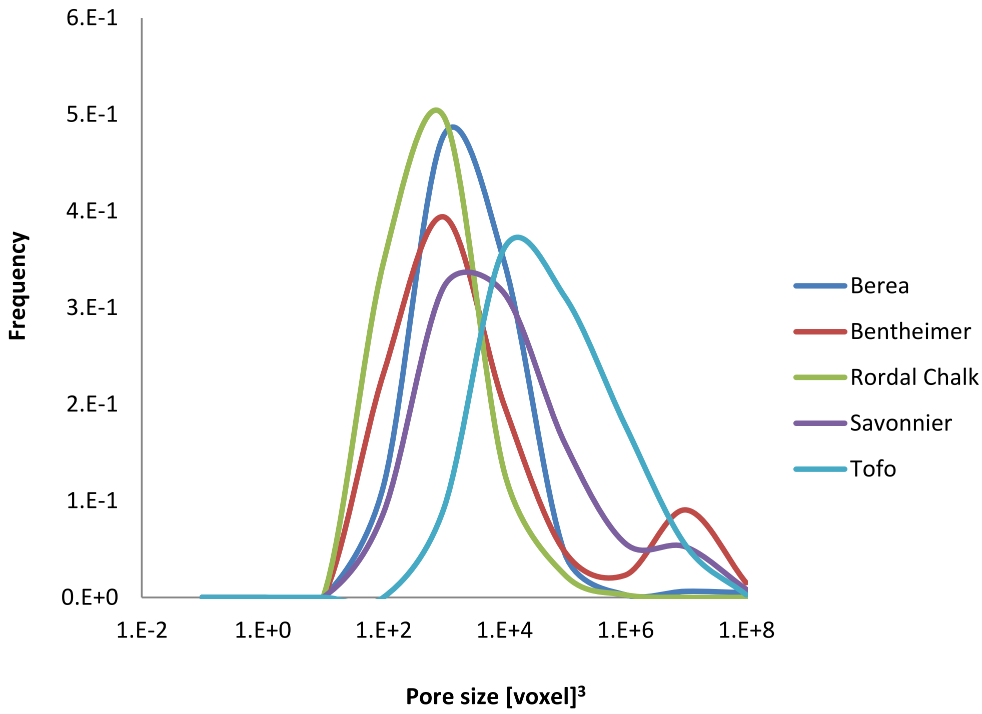

Fig. 4. Pore size distribution of the five selected samples

3.2 Formation factor

The formation factor value is significantly dropped in a range of frequency 0 to ~20 KHz, then became constant at the higher frequency (Figure 5). The constant values occurred as the rocks have no conductive solids and minerals in them. It is consistent with Sethi explanation that formation factor of the conductive rocks is known to be as apparent formation factor whose affect is dampened by the presence of minerals [15]. The result of presence different minerals either conductive or nonconductive, various value of porosities, are affected the resistivity, as saturation water depends on the pore size distribution and matrix alignment. Rordal Chalk and Tofo limestones have lowest formation factor values less than 10, as they have much smaller pores. While the carbonate rock with highest porosity, has much higher formation factor, above 30. Micro structure that has strong influence on porosity, tortuosity, and cementation factor, also create different values of the formation factor for each rock samples (Figure 6).

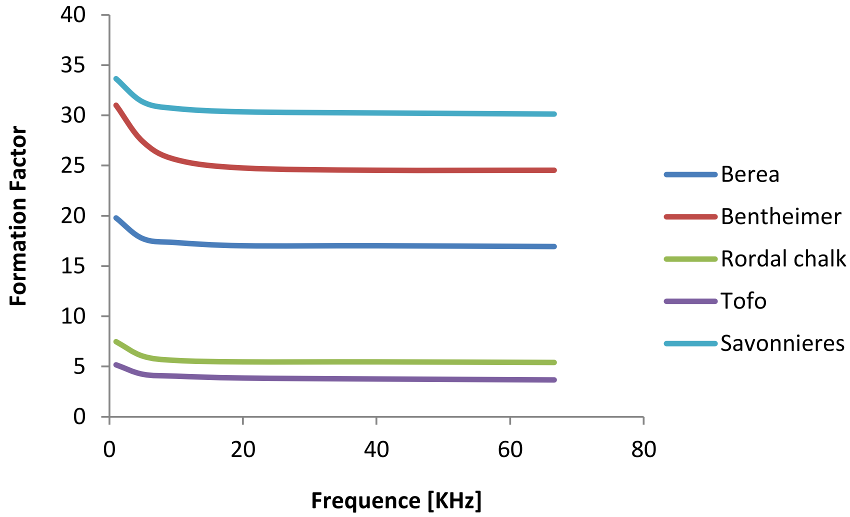

Fig. 5. Formation factor vs frequency of the five selected samples.

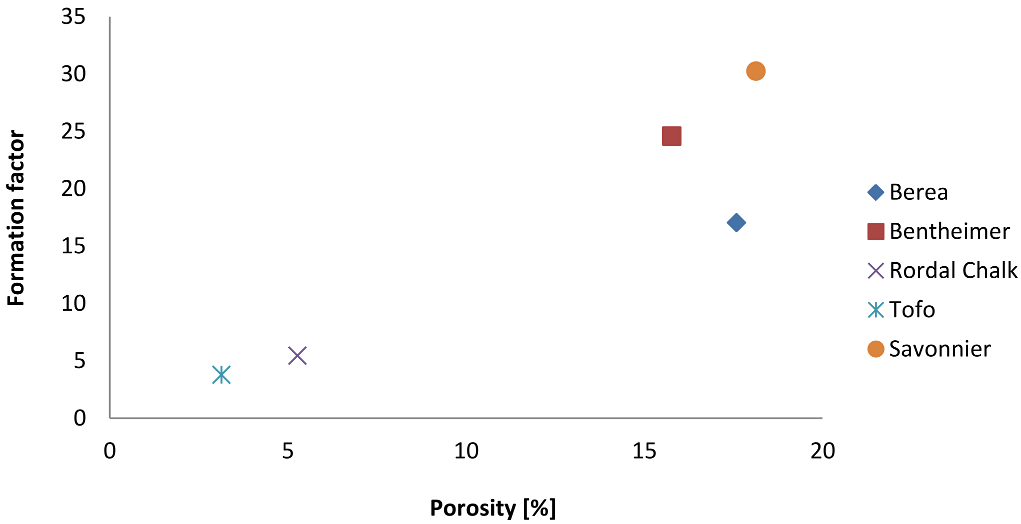

Fig. 6. Formation factor vs porosity of the five selected samples.

4. Conclusions

Pores and grains distribution are the deciding factor for fluid accommodation. The results deduced from electrical measurement devices also depend on these parameters. Formation factor gives an idea of the porosity and saturation of water, where the values are strongly influenced by microstructure of materials.

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