Developing a Method to Calculate Porosity, Permeability and Clay Content of Tuffaceous Reservoir Rocks Using MATLAB

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Abstract: *A method was developed to calculate porosity, permeability and clay content of tuffaceous reservoir rocks using scanning electron microscope photographs and MATLAB software language. Porosity values were calculated in the range of 11.6-23.7%. Permeability values were calculated in the range of 270-747 mD. Clay content values were calculated in the range of 76.3-88.4%.*

Keywords: *Porosity, permeability, clay content, tuffaceous rocks, MATLAB*

1. Introduction

Tuffs can sometimes produce hydrocarbons due to their fractures and cracks [1]. Porosity and permeability are two important parameters that define hydrocarbon-containing (gas-oil) reservoir rocks. Clay content negatively affects hydrocarbon production in a reservoir rock and can reduce production. Therefore, it is important to determine the clay content in the reservoir rock. Porosity is the storage capacity of the rock. The formula of the porosity is given in Equation 1.

$$Porosity\ (\%) = \frac{Volume\ of\ Voids}{Total\ Volume} x(100) \qquad (1)$$

Permeability is the rate of flow of fluid through the rock. It is expressed by Darcy's law which states that the rate of flow of a homogeneous fluid, in a porous medium is proportional to the pressure gradient and inversely proportional to the fluid viscosity. Darcy law is given in Equation 2.

$$\frac{q}{A} = -\frac{k}{\mu}\frac{dP}{dx} \qquad (2)$$

q: flow rate (cm^3/s)

$\frac{dP}{dx}$: pressure gradient (atm/cm)

μ: fluid viscosity (centipoise (cp))

k: permeability (darcy (D)) or (millidarcy (mD))

A: area (cm^2)

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The objective of the proposed study is to develop a method to calculate porosity, permeability and clay content of tuffaceous rocks using scanning electron microscope photographs and MATLAB software language.

2. Material and Methods

Scanning electron microscope photographs and MATLAB software language were used in this study.

3. MATLAB Application

3.1. Signing the Scanning Electron Microscope Photographs

Scanning electron microscope photographs were signed (Figure 1).

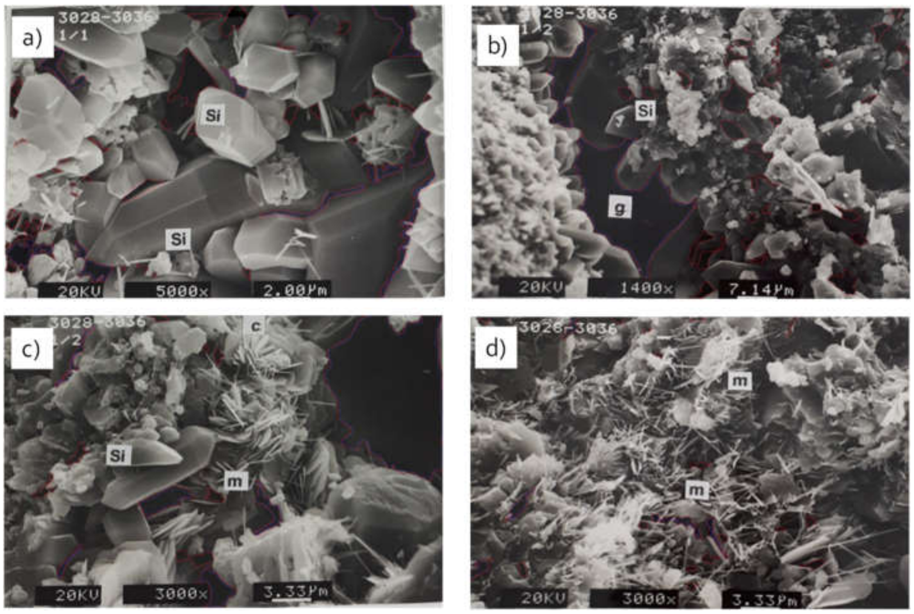

Figure 1. Signed scanning electron microscope photographs [1]

3.2. Defining and Uploading Scanning Electron Microscope Photographs to MATLAB

Scanning electron microscope photographs were defined and uploaded to MATLAB using imread command.

```
SEM_images=cell(1,4);
SEM_images{1}=imread('photograph1.jpg');
SEM_images{2}=imread('photograph2.jpg');
SEM_images{3}=imread('photograph3.jpg');
SEM_images{4}=imread('photograph4.jpg');
```

3.3. Performing Segmentation

The smallest unit of a digital image is called a pixel. Pixels create the images when combined with other pixels. The simplest thresholding methods replace each pixel in an image with a black pixel if the image intensity is less than a fixed value called the threshold, or a white pixel if the pixel intensity is greater than that threshold [2].

In this process, 150 was selected as the threshold value. This threshold value was found to effectively separate regions of interest corresponding to pores, solid matrix, and clay minerals.

A threshold value of 150 was used for segmentation of scanning electron microscope photographs. The thresholding process was applied to each of the scanning electron microscope photographs in the dataset. Pixels with intensity values greater than 150 are set to 1 (white) to represent pores or clay sections. Pixels with intensity values below 150 are set to 0 (black) to represent other material [2]. The code was given as follows.

```
threshold=150;
binary_images=cell(1,4);
for i==1:4
binary_images{i}=SEM_images{i}>threshold;
```

Segmentation was performed to distinguish different components of the geological sample.

3.4. Porosity, Permeability and Clay Content Calculation

Porosity, permeability and clay content matrices were defined as follows.

```
porosity=zeros(1,4);
permeability=zeros(1,4);
clay content=zeros(1,4);
```

3.4.1. Porosity calculation

The porosity of each scanning electron microscope photograph was calculated by dividing the total number of white pixels (representing pores or clay sections) by the total number of pixels in the photograph (numel(binary_images{i})).This ratio is then multiplied by 100 to express the porosity as a percentage. The code is given as follows.

```
for i=1:4
porosity(i)=sum(binary_images{i}(:))/numel(binary_images{i})*100;
```

3.4.2. Permeability calculation

The permeability was calculated based on connectivity analysis of the segmented image. The number of connected components (regions) in the binary image was calculated using bwconncomp function. Each connected component represents a separate pore or section of clay. The total number of connected components (connectivity.NumObjects) can be considered an estimate of permeability. The code is given as follows.

```
connectivity=bwconncomp(binary_images{i});

permeability(i)=connectivity.NumObjects;
```

3.4.3. Clay content calculation

Clay content was calculated as the complement of porosity. Since porosity represents the percentage of pores, subtracting porosity from 100 gives an estimate of the percentage of other materials, primarily clay. The code is given as follows.

```
clay _content(i)=100-porosity(i);
end
```

4. The Porosity, Permeability and Clay Content Results

The porosity values were given (Figure 2). Porosity values were found between 11.6% and 23.7%. According to the reservoir rock classification of Rider [3], the porosity of tuffaceous rocks is in the fair–very good class (Table 1).

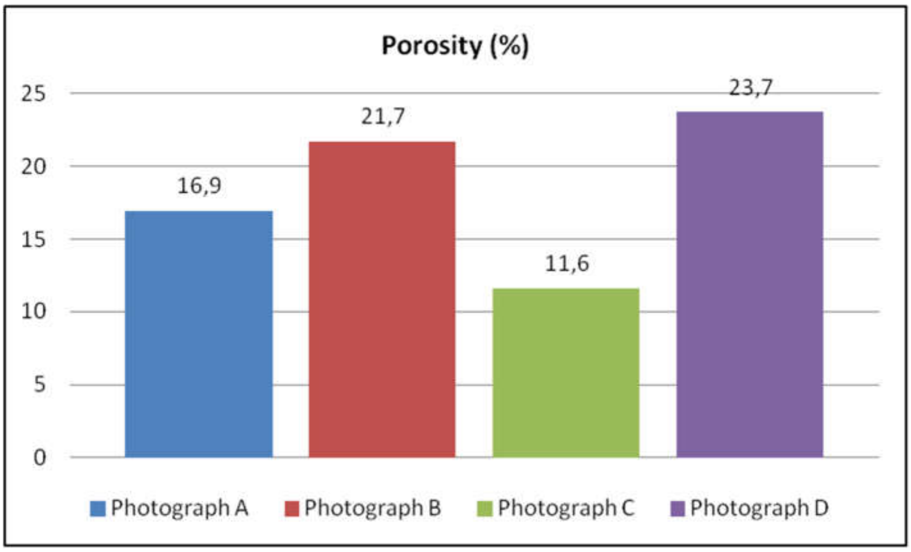

Figure 2. Porosity values (%)

The permeability values were given (Figure 3). Permeability values were found between 270 mD and 747 mD. According to reservoir rock classification of Rider [3], the permeability of tuffaceous rocks is in the very good class (Table 1).

Table 1. Reservoir Rock Classification of Rider [3]

Percentage Porosity (%)	Qualitative Description
0-5	Negligible
5-10	Poor
11-15	Fair
15-20	Good
20–30	Very good
>30	Excellent
Average Permeability Value (md)	Qualitative Description
<10.5	Poor
11-15	Fair
15-50	Moderate
50-250	Good
250-1000	Very good
>1000	Excellent

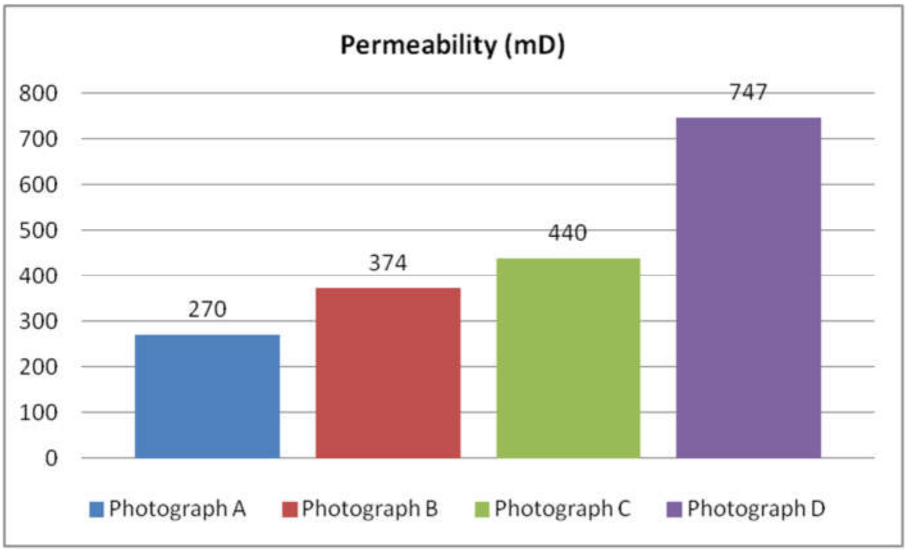

Figure 3. Permeability values (mD)

The Clay content values were given (Figure 4). The clay content values of tuffaceous rocks were found high between 76.3% and 88.4%.

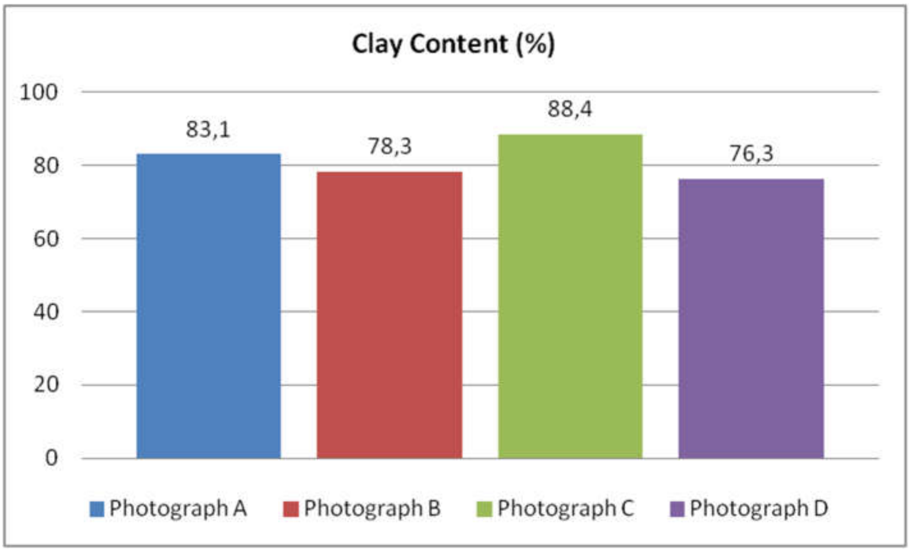

Figure 4. Clay content values (%)

5. Conclusions:

1. In this study, a method to calculate porosity, permeability and clay content of tuffaceous reservoir rocks have been successfully developed using scanning electron microscope photographs and MATLAB software language.

2. Porosity values were found between 11.6% and 23.7%. According to the reservoir rock classification of Rider [3], the porosity of tuffaceous reservoir rocks is in the fair–very good class.

3. Permeability values were found between 270 mD and 747 mD. According to reservoir rock classification of Rider [3], the permeability of tuffaceous reservoir rocks is in the very good class.

4. The clay content values of tuffaceous reservoir rocks were found high between 76.3% and 88.4%. The high clay content in this studied reservoir rock reduces porosity and permeability, negatively affecting hydrocarbon production.

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