**Relationship among porosity, permeability, electrical and elastic properties**

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**Summary**

Electrical resistivity is usually easier to measure in the laboratory and *in-situ* than permeability. Therefore, a method of combination between permeability and electrical resistivity might be used to define the fluid flow of reservoir rocks from resistivity data. However, estimating permeability from resistivity has been a problem examined by different authors. Furthermore, neither electrical nor elastic data seldom allow us to accurately quantify the hydrocarbon saturation. Hence, a combination of elastic and electrical properties could offer a powerful means of solving the problem of hydrocarbon saturation production. The objective of this study is to experimentally and theoretically revise the relations among the electrical properties, porosity, permeability, and elastic wave velocity. A data set of laboratory measured petrophysical properties, electrical properties and elastic properties of glauconitic greensand from the North Sea Nini Field was used for this study. A linear relationship between laboratory measured electrical properties and permeability could be established if the diagenesis of greensand is known. By combing Archie’s relation and Kozeny’s equation, the greensand diagenesis may be described by the specific surface area of pores. A linear relationship between laboratory measured electrical and elastic properties could be established if the effect of micro structure of greensand is known. Rock physics modeling results show that quartz cementation has a larger effect on elastic properties than electrical properties, while berthierine cementation has a similar effect on elastic and electrical properties. Self-consistent modeling results show that pore aspect ratios are more sensitive for electrical properties than elastic properties.

**Introduction**

Electrical resistivity is commonly used types of to define the hydrocarbon saturation of reservoir rocks. A method of combination between permeability and electrical resistivity may be used to define the fluid flow of reservoir rocks. Even though both resistivity and permeability strongly depend on porosity, no rigorous relationship between permeability and resistivity has yet found (Gomez, 2009). Estimating permeability from resistivity has been a problem examined by different authors, including Archie (1942), who showed an average trend of formation factor versus permeability for sandstones, but recognized that the scatter was too large to establish a definite relation between the two properties.

Like electrical resistivity, sonic velocities is also one of the most common collected types of geophysical well logging data used in hydrocarbon investigations. However, neither electrical nor elastic data seldom allow us to accurately quantify the hydrocarbon saturation. Therefore, a combination of elastic and electrical properties could offer a powerful means of solving the problem. In the case of common reservoir rocks resistivity strongly depends on

![Figure 1: (a) BSE image of a cemented greensand (Hossain et al. 2011). (b) Cemented greensand model shows micro crystalline quartz cement (QC) on quartz (Q) grains and berthierine (B) cementation within large pores. (c) Glauconite (G) grain of greensand with complex pore structure (Hossain et al. 2009).](image-url)
porosity, pore geometry and saturation (Archie 1942) while the elastic properties depend on porosity (Mavko 1980, Murphy 1984), saturation history (Mavko and Mukerji 1995), pore geometry (Mavko 1980; Mavko and Nur 1978), mineralogy and fluids types (Mavko et al. 2009). However, elastic and electric methods can contribute in different ways to characterizing rock properties.

The objective of this study is to experimentally and theoretically revise the relations among the electrical properties, porosity, permeability, and elastic wave velocity. Laboratory measured data from the North Sea greensand was used. Greensand is composed of a mixture of quartz and micro-porous glauconite grains. (Figure 1). Diagenesis of greensand can be described by microcrystalline quartz cement and pore-filling berthierine cement. Petrophysical models and rock physics models were used to describe the effect of micro structure of greensand on elastic and electrical properties.

Method

A laboratory measured core data set of 16 greensand samples from the Nini field of the North Sea was used for this study. Helium porosity and Klinkenberg permeability data were obtained from Hossain et al. 2011 while resistivity and elastic wave velocity data were obtained from Hossain et al. 2012.

A physical relationship between permeability and resistivity may be explained by combining Archie’s equation (Archie, 1942) and Kozeny’s equation (Kozeny 1927). The ratio of the pore fluid resistivity of, $R_w$ to bulk resistivity of the fully saturated rock, $R_o$ is known as 1 over the formation factor, $F$ (Archie 1942). Archie’s law is an empirical relation relating the formation factor and cementation factor, $m$ to the porosity, and a factor correcting for conducting minerals, $a$ in brine saturated reservoir rock:

$$F = \frac{a}{\phi^m} \quad (1)$$

The relationship among porosity ($\phi$), permeability ($k$) and specific surface area of bulk volume ($S$) may be written by using Kozeny’s equation (Kozeny 1927) as:

$$k = c \frac{\phi^3}{S^2} \quad (2)$$

where, $c$ is Kozeny’s factor and the relationship between permeability and formation factor can be expressed as:

$$k = c \left( \frac{a}{F} \right)^{3/m} \frac{1}{S^2} \quad (3)$$

Worthington (1997) revisited the relationship between formation factor and permeability by Archie and showed how formation factor $F$ decreases as permeability increases according to the following relation:

$$k = \left( \frac{b}{F} \right)^{1/c} \quad (4)$$

Results and discussion

Electrical properties of greensands are higher than those for consolidated sandstone, unconsolidated sandstone, average sands, shaley sands and clear granular rock (Figure 2). These higher electrical properties of greensand are related to the micro-porosity within glauconite and pore-filling berthierine cementation of greensand.

![Figure 2: (a) Comparison of greensand formation factor with different types of rocks.](image)
Relationship among porosity, permeability, electrical and elastic properties

For this data set, I defined $m$ is equal to 1.9, $a$ is equal to 1.67 and $c$ is close to 0.21 for porosity 0.27 to 0.42 so in equation (3) only specific surface area of pore is the controlling factor for relationship between permeability and formation factor (Figure 3c).

The relationship between resistivity and elastic wave velocity is not linear; indeed, the data exhibit an approximate quadric trend (Figure 4a). Note that the expression could be linear if I the three highest elastic velocity bearing greensand from the lower Ty Formation are omitted. By combining a rock physics soft-sand and stiff-sand model (Mavko et al. 2009) with the Archie equation (Archie 1942) the scatter could be described. The modeling shows that micro crystalline quartz cement has a larger effect on elastic properties and a smaller effect on electrical properties. In contrast berthierine cementation has a simultaneous effect on elastic and electrical properties and berthierine cementation is mainly responsible for higher elastic and electrical properties (Figure 5b).

Using self-consistent modeling with grain aspect ratio 1, and pore aspect ratio between 0.2 and 0.1, the laboratory measured resistivity data fall into this theoretical range (Figure 5a). Whereas, using self-consistent modeling with grain aspect ratio 1, and pore aspect ratio between 0.05 and 0.3, the laboratory measured elastic velocity data fall into this theoretical range (Figure 5b). Self-consistent modeling

![Figure 3:](image-url)
Results show that pore aspect ratios are more sensitive to electrical properties than elastic properties.

Conclusions

A linear relationship between laboratory measured electrical and elastic properties could be established if the diageneis of greensand is known. Rock physics modeling results show that quartz cementation has a larger effect on elastic properties than on electrical properties, while berthierine cementation has a simultaneous effect on elastic and electrical properties.
EDITED REFERENCES

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REFERENCES


