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Effect of Glauconite on the Elastic Properties, Porosity, and Permeability of Reservoirs Rocks

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1. ABSTRACT

We report measurements on glauconitic rocks as a function of pressure. Glauconite is an iron rich variety of clay that can be found as individual pellets, composite grains, and intergranular cement. Identifying glauconite in the subsurface is important for depositional environment interpretation, stratigraphic correlation, dating, tracing of unconformities, geochemical exploration in marine environments, and reservoir quality prediction in glauconitic sandstones.

In order to identify, track, and characterize glauconitic sandstones from seismic data, it is important to relate the elastic properties of glauconitic sandstone to their physical properties, most important among which are mineralogy, porosity, and rock texture. To this end, this paper presents laboratory measurements of ultrasonic velocities, porosity and permeability of glauconitic rocks from the Caballos Formation, Putumayo and Upper Magdalena Basins (Colombia). To differentiate between glauconite bearing and non-glauconite bearing rocks, we compare their physical and acoustic properties.

Based on this laboratory data, we have established that, at the same porosity, quartz-sandstones containing glauconite have lower permeability and lower velocity than sandstones without glauconite. Association of calcite with the glauconite further reduces permeability by about two orders of magnitude, decreases porosity, and, significantly increases velocity and acoustic impedance.

Probably the most exciting and practically meaningful result is that the quality of reservoir rock (specifically, permeability) can be discriminated not only by porosity but also by acoustic impedance (Ip). This seismic attribute (Ip) is a reliable reservoir quality discriminator. High Ip corresponds to non-reservoir rocks (calcareous-glauconitic sandstones, glauconitic wackestones and quartz-siltstones), while low Ip indicates reservoir-quality sandstones.

Thus, within the sandstones of reservoir quality, intermediate values of Ip (10-11 Mrayls), indicate very good reservoir-quality rocks (quartz-sandstones); and values of Ip

below 10 Mrayls correspond to moderate quality reservoir rocks (glauconitic sandstones).

We also measured elastic moduli of pure glauconite on a powdered sample prepared from commercially available glauconite of the Cap Mountain Formation, Texas. Glauconite dry moduli values are: bulk modulus = 15 GPa, and shear modulus = 10 GPa.

2. INTRODUCTION

Identifying glauconite in the subsurface is important for depositional environment interpretation, stratigraphic correlation, dating, tracing of unconformities, and geochemical exploration for source and reservoir rocks (Srivastava, 1986). A number of commercial hydrocarbon reservoirs are glauconitic sandstones, found globally, for example in Colombia, Ecuador, Peru, Venezuela, Australia, Eastern China, North Sea, Unites States, Canada, Saudi Arabia and Ireland.

Although glauconite tends to exist as grains and as such is part of the rock framework, under moderate overburden pressure, these grains are easily compacted (Figure 1) and may form a pseudomatrix that occludes the original primary porosity. This behavior is in contrast to that observed in clay minerals. This problem, and the fact that there are no published studies about the elastic properties of glauconite and glauconitic sandstones, motivated this research to understand their rock physics properties.

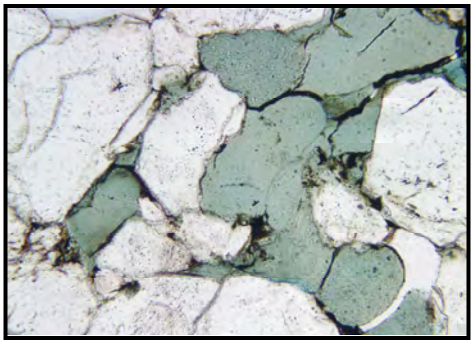


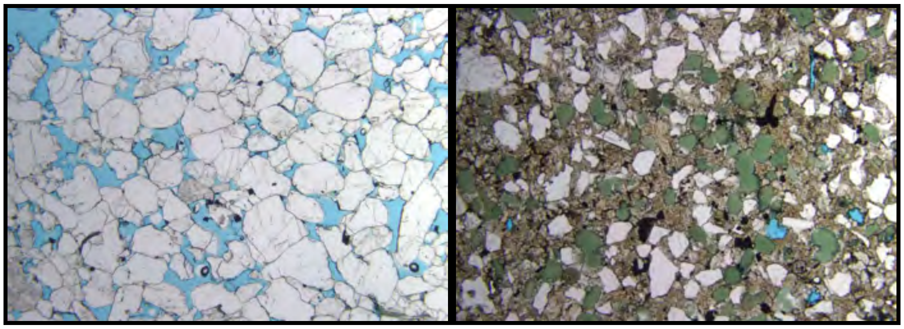
Figure 1. Optical image of a glauconitic sandstone (made at 20X magnification) showing formation of a pseudomatrix that occludes the original primary porosity

3. DATA

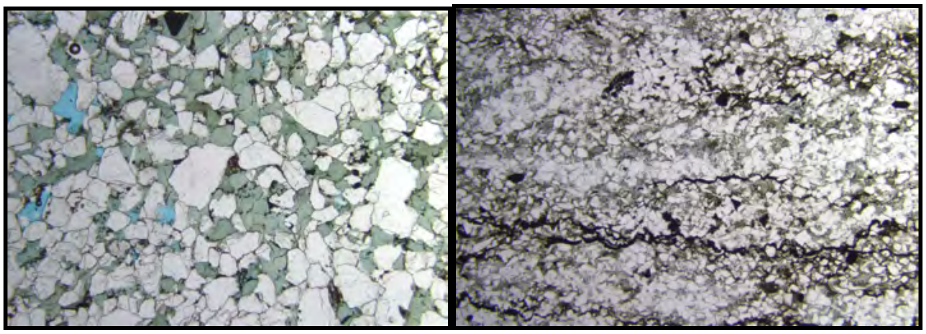
A total of thirty-four plugs from two nearby wells were analyzed for density, porosity, permeability, ultrasonic velocities and optical and XRD mineralogy. Based on thin section description and XRD analysis, the samples were classified into five categories: twelve quartz-sandstones, seven sandstones with carbonates and glauconite, five sandstones with glauconite (content of glauconite between 10 and 60 %), four siltstones and six samples with only glauconite and carbonates. A lithological code was given: 1=quartz-sandstones, 2=calcareous-glauconitic sandstones, 3=glauconitic sandstones, 4=quartz-siltstones and 5=glauconitic wackestones. Typical optical images of thin sections for all lithologies (1 - 5) are shown here (Figure 2).

The measurements made in this study include: Density and porosity from Helium porosimeter.

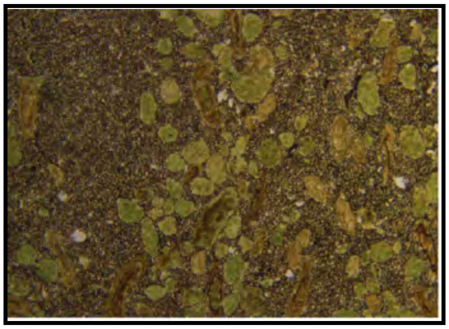
Klinkenberg-corrected air permeability. Ultrasonic P- and S-wave velocities under pressure to 40 MPa.



Lithology 1= quartz-sandstones Lithology 2= calcareous-glauconitic sandstones



Lithology 3 = glauconitic sandstones Lithology 4 = quartz-siltstones



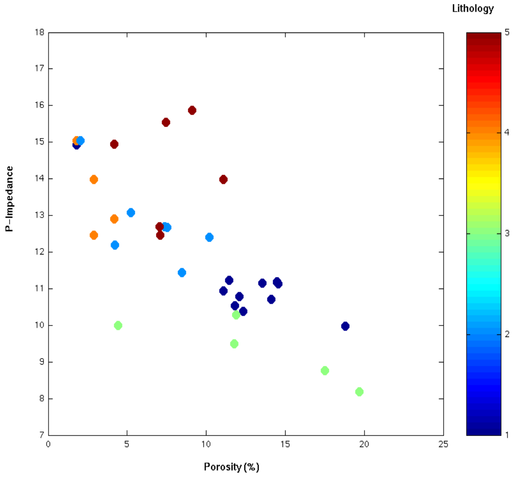
Lithology 5 = glauconitic wackstones

Figure 2. Optical images of different lithologies at 4X magnification. In the images, glauconite grains are green colored. The pore space is masked by blue-dye epoxy, and quartz and occasional feldspar grains are white.

4. RESULTS

In Figures 3, 5, and 7, the color code assigned to each sample is according to the lithology: dark blue=quartz-sandstones (lithology 1); light blue=calcareous-glauconitic sandstones (lithology 2); green=glauconitic sandstones (lithology 3); orange=quartz-siltstones (lithology 4), and; red=glauconitic wackestones (lithology 5). In Figure 4, the color code assigned to each sample is according to the permeability (mD), while in Figure 6 is according to the values of P-impedance (given in Mrays. 1 Mray=10^6 Kg/m^3. m/s)

The plot of porosity versus P-impedance (=velocity x density) discriminated by lithology (Figure 3), shows two trends. An upper trend is shown by the quartz-sandstones (lithology 1), the calcareous-glauconitic sandstones (lithology 2), the quartz-siltstones (lithology 4), and the glauconitic wackestones (lithology 5). The glauconitic sandstones (lithology 3) fall on a lower trend. At same porosity values as the lithology 1 sandstones, the glauconitic sandstones (lithology 3) have lower P-impedance. The same cross plot, discriminated now by permeability (Figure 4), shows two clouds: samples with higher values of permeability (lithologies 1 and 3), and samples with lower permeability (lithologies 2, 4 and 5).



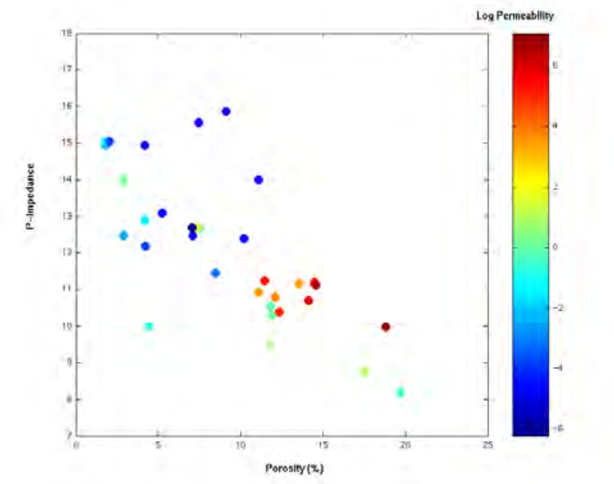


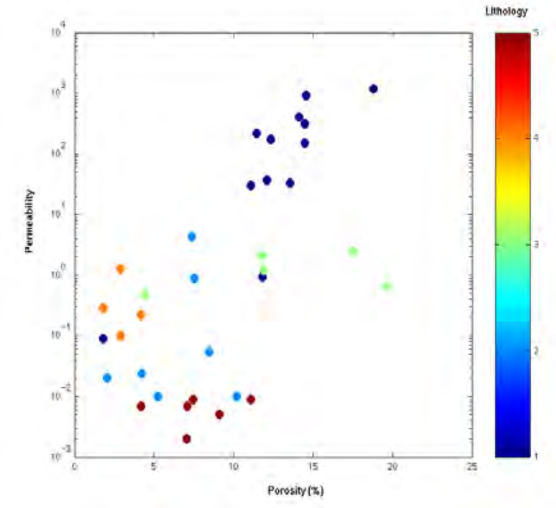
Figure 3 (left). Crossplot of porosity versus acoustic impedance discriminated by lithology. The color bar on the right shows colors assigned to the lithologies defined in the study.

Figure 4 (right). Plot of porosity versus acoustic impedance, discriminated by permeability.

Figures 5 and 6 show the relation between porosity and permeability, discriminated by lithology (Figure 5) and by acoustic impedance (Figure 6). Figure 5 shows that quartz-sandstones (lithology 1), have the best reservoir properties, high permeability and high porosity. The presence of glauconite in quartz-sandstones (lithology 3), reduces the permeability in samples of similar porosity, and as a result, deteriorates the reservoir quality. Also, the presence of calcareous cement in the sandstones (lithology 2) drastically reduces the reservoir quality. As it would be expected, the very fine-grained rocks; glauconitic wackestones (lithology 5), and quartz-siltstones (lithology 4), show very poor quality reservoir properties.

The same cross plot discriminated by P-impedance (Figure 6), shows that this seismic attribute (Ip) is a reliable reservoir quality discriminator. High Ip corresponds to non-reservoir rocks (calcareous-glauconitic sandstones, glauconitic wackestones and quartz-siltstones), while low Ip indicates reservoir-quality sandstones.

In fact, within the reservoir-quality sandstones, intermediate values of Ip (10-11 Mrayls), indicates very good quality rocks (quartz-sandstones); and values of Ip below 10, corresponds to moderate reservoir rocks (glauconitic sandstones).



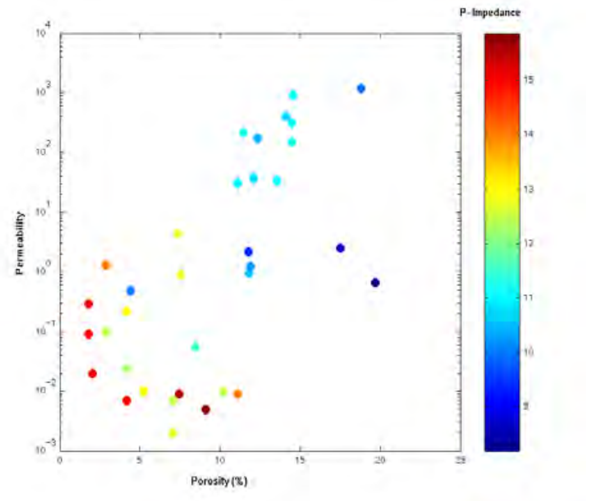


Figure 5 (left). Cross plot of porosity versus permeability, discriminated by lithology. The color bar on the right shows colors assigned to the lithologies defined in the study.

Figure 6 (right). Plot of porosity versus permeability, discriminated by P-impedance.

Finally, the combination of P-impedance versus Poisson's ratio (Figure 7) shows that the samples can be discriminated by lithology. Quartz-sandstones and glauconitic sandstones (lithologies 1 and 3) show relatively low impedance and low Poisson's ratio. In contrast, quartz-siltstones, calcareous-glauconitic sandstones and glauconitic wackestones (lithologies 2, 4 and 5), exhibit higher values of impedance and Poisson's ratio

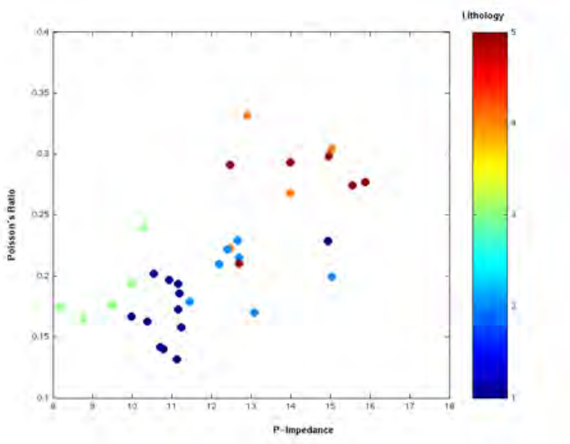


Figure 7. Cross plot of acoustic impedance versus Poisson's ratio, discriminated by lithology. The color bar on the right shows colors assigned to the lithologies defined in the study.

6. CONCLUSIONS

1. In this study, the attributes of porosity, acoustic impedance and Poisson's ratio are used to describe the quality of a glauconitic reservoir.

2. P-impedance (Ip) is the most reliable elastic property to discriminate reservoir quality. High Ip (above 12 Mrayls) corresponds to non-reservoir quality rocks, while low Ip (below 12 Mrayls) indicates reservoir-quality sandstones.

3. Within the reservoir-quality sandstones, intermediate values of Ip (10-11 Mrayls) indicate very good quality reservoir rocks (quartz-sandstones); and values of Ip below 10 Mrayls, corresponds to moderate quality reservoir rocks (glauconitic sandstones).

4. At same porosity, the presence of glauconite reduces permeability, velocity and P-impedance in quartz-sandstones.

5. Additional presence of carbonates with glauconite further reduces permeability; it also decreases porosity.

6. At same porosity, glauconitic sandstones show lower velocity and P-impedance, than all other lithologies investigated here. Additional presence of carbonates increases velocity and P-impedance.

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