

# **IMPACT OF CLAY MINERAL ATTRIBUTES IN ESTIMATING DAMAGE IN CARBONATE ROCKS**

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## **ABSTRACT**

The impact of clay migration on impairing reservoir permeability is a well-known problem. A critical component of attempting to minimize this damage is to perform accurate characterization of the clay morphology and distribution. The objective of this work was to apply techniques of clay imaging to develop a qualitative estimate of the potential for clay damage in low-permeability carbonate formations.

The first step in clay characterization consisted of applying x-ray diffraction (XRD) to estimate clay type and abundance. From this analysis, it was determined that the samples contained different amounts of kaolinite and illite. Furthermore, calcium silicates were identified as components of the grain structure of the matrix.

The next step was to extend the characterization by quantifying clay size, location and distribution using electron probe microanalysis (EPMA). This analysis provides compositional analysis of grains and clay minerals. Selection of key elements from XRD analysis provides information to perform elemental mapping images and therefore determine the distribution and location of clays.

This work shows the clay size, location, and distributions have a significant impact on the impairment of permeability. Therefore, proper characterization is essential in estimating potential clay damage in carbonate reservoirs.

## **Introduction**

Clay migration damage reduces reservoir permeability<sup>1</sup>. The process of clay migration damage involves movement of clay minerals within the low-permeability carbonate reservoir pore structure; as a result, migration damage is dependant on the sizes of both clay minerals and pore restrictions. This study will attempt to characterize the clay mineralogy and other characteristics such as size, distribution, and location within the pore geometry of the reservoir rock. This study also provides an analysis of the pore geometry by mercury (Hg) porosimetry. Together clay mineralogy and pore geometry give a better understanding of clay mineral migration damage. Understanding the complex pore geometry of carbonate reservoirs is the key to improved reservoir characterization. Reservoir characterization is the result of data integration from several sources of information, such as wirelines logs, core analysis, production tests, well tests and seismic. Recent advances in reservoir characterization have revealed the importance of mineralogical attributes that occur microscopically or at the pore level.

## **Experimental Work**

Four low-permeability carbonate reservoir samples were selected to evaluate the effect of clay minerals and their geometry on permeability. In this study, methods were applied for detailed characterization of migration damage. Characterization starts with the rock mineralogy identification using X-ray diffraction. XRD gives the clay type and abundance<sup>2</sup>. After the preliminary XRD analysis of clay minerals, polished sections of the carbonate sample are subject to the SX-100 latest-generation CAMECA EPMA<sup>3</sup>. This

analysis provides compositional analysis of clay minerals. Also, backscattered images and X-Ray maps are produced from this instrument, and from these images, clay physical distribution is deduced using the key elements of Al, Si, K, Na, Ca and Mg, to map the distribution and location of these elements and thus identify the distribution of the clays<sup>4</sup>. Figure 1 illustrates the elemental mapping analysis for identifying layers of kaolinite and illite. BSE provides valuable information due to their sensitivity to atomic number variations and the high resolution of BSE images, approximately 1000 Å. The resolution of X-Ray maps is about 2 microns. Additional tests included Hg porosimetry<sup>5</sup> to characterize pore geometry and critical velocity core flood tests to identify changes in permeability due to clay migration. This pore geometry sizer operates at 33,000 psi pressure and defines pore structures in terms of capillary radii.

### Results and Discussion

All four core plug samples are low permeability carbonate rocks; i.e., pore throat sizes equal or less than 2 µm. These samples were chosen for their differences in porosity type as well as their varying clay mineral content. Pore type varied from micro-fractures in Plug 4 to a scattered heterogeneous pore type with no fractures or vugs in Plug 12 to. Vuggy type pores in Plug 24. Clay minerals were present in plugs 4, 19, and 24, but not in plug 12. Figure 2 shows two back-scattered images; Plug 4 exhibits a fracture with illite bridge while in Plug 24 the clay particles favor the calcium silicate surface rather than the calcite matrix.

Average mean hydraulic radius, AMHR, is the pore throat radius that controls or connects the flow of fluids inside the reservoir<sup>6</sup>. This concept is a good tool to characterize pore geometry and permeability profile. Four samples were submitted to the Hg pore size test; plugs 4, 12, 19 and 24, respectively. Figure 3 and Table 1 is an example of the results for this test on Plug 24. Starting with plug 4, intrusion was not successful indicating lower permeability of the order of 0.011 md. The maximum pressure introduced was 33,000 psi. From imaging it was clear that this sample was subject to clay damage and blocking of porosity by the illite and kaolinite.

Plug 12 had a 100% successful intrusion, but since no clays had been detected, the image characterization was not performed. Plug 19 had also 100% successful mercury intrusion. The mercury pore distribution shows the majority (about 98%) of pore network in a pore throat range slightly larger than the size of clays. From core flood tests, it was observed that the initial permeability reduction was caused by an accumulation of illite clay particles within the pore network. These particles would have been removed due to the increase of the velocity of the flood; therefore causing permeability to recover. Plug 24 had a 100% successful mercury intrusion. The illite/smectite clays were large enough to block smaller pores including pore throats. As a result the core flood showed significant impairment due to the clay migration and when increasing flood velocity, a slight permeability recovery was noticed.

### Conclusions

The clay mineral amount and type are not the only cut-off parameters in characterizing formation damage, but other physical parameters such as clay composition, size, location and distribution must be taken into account. These parameters will give a better understanding of formation damage. In order to investigate such parameters the electron microprobe together with the XRD analysis enable a more complete mineralogical. Understanding the complex pore geometry within the different lithofacies is the key to

improved reservoir characterization. Mineralogical characterization at the pore level reveals the existence of different types of clay minerals that would have an impact on permeability and fluid flow.

#### References

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#### Appendix

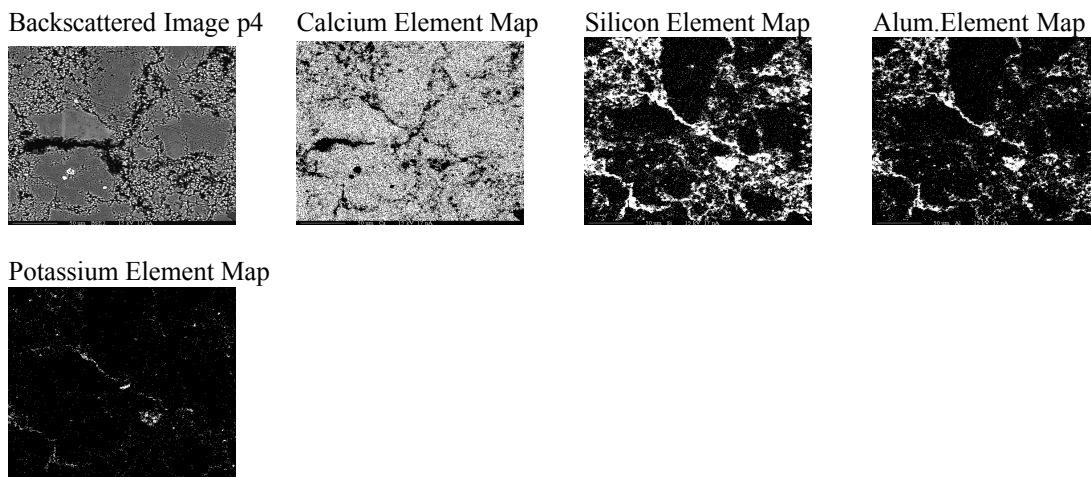


Figure 1. Plug 4 elemental clay mapping shows layers of kaolinite/illite, key elements Si, Al, and K.

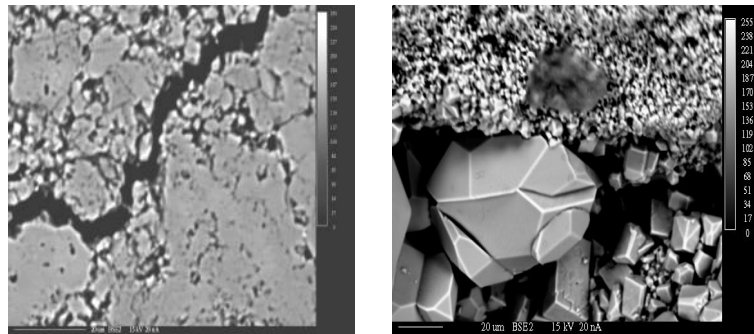


Figure 2. Backscattered images for a fracture with illite bridge in plug 4 (left) and a clay particle favors calcium silicate surface rather than the calcite in Plug 24 (right)

Table 1. Mercury scan data for Plug 24-pore size distribution in Angstrom

$$D = \frac{2.133 \cdot 10^6}{P}$$

Range Interpolated Intrusion Data	Mean Pressure Psia	Pore Diameter A°	Hg cum. Vol. cc	% Vol. Intruded For each Interval	Cumulative Surface Area m <sup>2</sup> /g
Range 1 (Largest)	3.56	>599,270	0.0004	0.000	0
Range 2	20.272	105,229-599,270	0.0148	14.286	0.002
Range 3	147	16,000-105,229	0.0398	24.802	0.008
Range 4	164.094	10,000-16,000	0.0423	2.780	0.013
Range 5	328.188	3,000-10,000	0.0761	33.510	0.156
Range 6	1066.611	1,000-3,000	0.087	10.860	0.283
Range 7	2844.296	500-1,000	0.0941	7.060	0.485
Range 8	5688.592	250-500	0.0955	1.390	0.576
Range 9	12189.84	100-250	0.1006	5.100	1.131
Range 10 (Smallest)	31930	0-67	0.1008	0.213	1.158
				100	

Mercury Pore Diameter Distribution

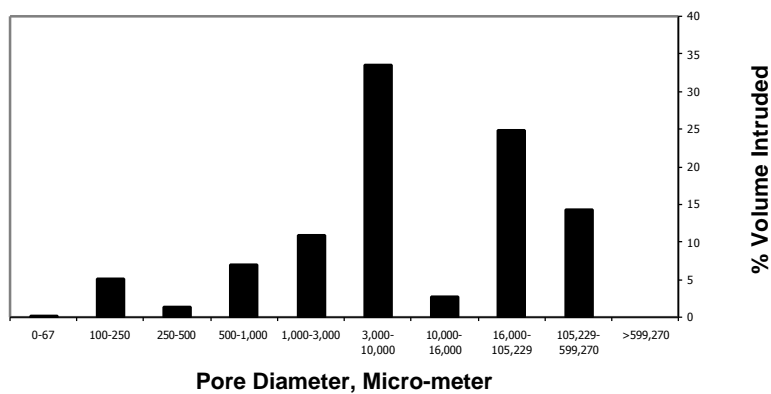


Figure 3. Pore size distribution for Plug 24 from Mercury porosimeter.