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POROSITY AND PERMEABILITY OF PALAEOCENE SANDS FROM THE NORTH SEA; A COMPARISON OF PLUG POROSITY AND IMAGE DERIVED POROSITY

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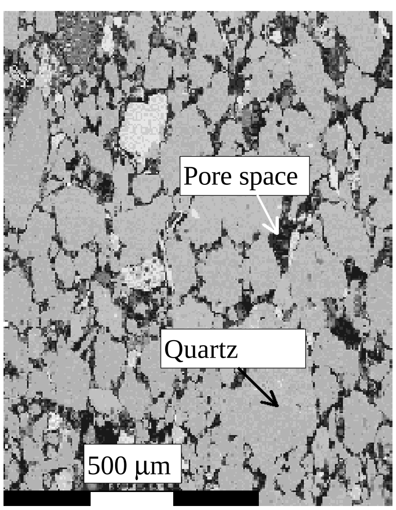
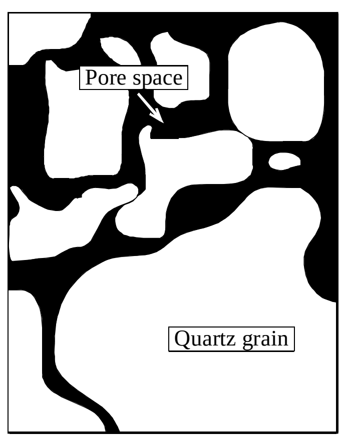
The relationship between porosity and permeability is traditionally used in the hydrocarbon industry to assist in flow prediction. For the Palaeocene sand reservoir discussed here this relationship is extremely poor. Consequently, image analysis has been used to try and understand the nature of the plug porosity-permeability plot.

The image analysis parameter considered is image porosity. The images used for the image analysis process are back scattered SEM images (Figure 1a), at two different magnifications (x30 and x150). Image porosity expresses the two-dimensional pore space seen within an image as a fraction of image area (Figure 1b). Plug porosity, by comparison, is the calculation of three-dimensional interconnected pore space by helium injection. Both of these porosities have been compared with a gas permeability measurement. The permeability and plug porosity measurements are made on the same plug and the image porosity measurement is made from an endtrim of each plug.

It should be noted that for the image porosity calculation the pores are not necessarily connected, and only pores greater than 13 μm^2 are counted. It is assumed that 13 images are representative of the entire plug. Forty-eight samples were studied.



(a)

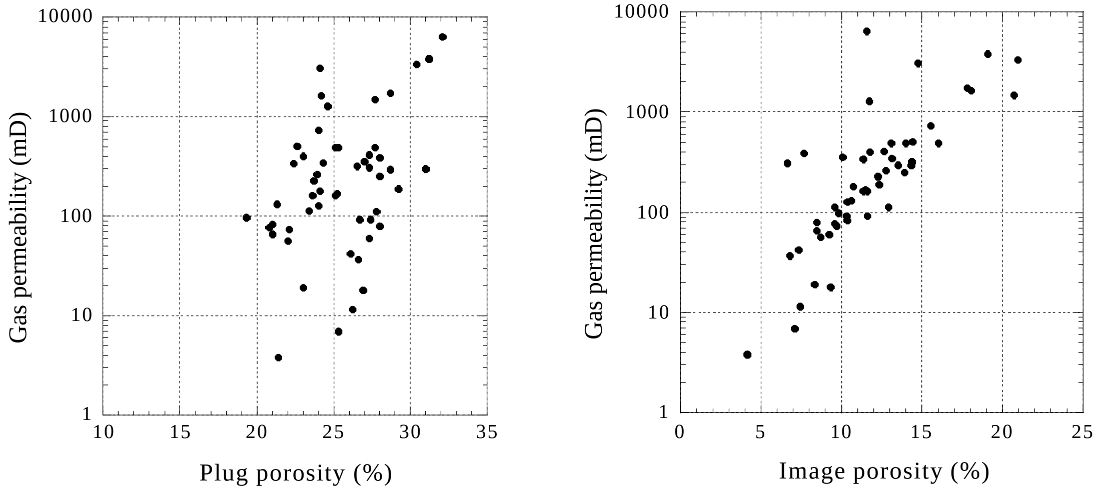


$$\text{Image porosity} = \frac{\text{Pore area}}{\text{Image area}}$$

(b)

Figure 1: (a) Low magnification image (x30) of a typical reservoir sandstone.
(b) A schematic of how image porosity is calculated.

Figures 2a and 2b show permeability cross plotted with plug porosity and image porosity respectively. The results show that image porosity has a better relationship with permeability for prediction purposes, and gives lower values than the plug porosity.



(a) (b)

Figure 2: (a) Gas permeability versus plug porosity. Correlation coefficient = 0.41.
(b) Gas permeability versus image porosity. Correlation coefficient = 0.73.

Three hypotheses are proposed to explain these observations:

Hypothesis I

Micro-porosity does not contribute to permeability.

To test whether micro-porosity is contributing to permeability the pores were split into a series of pore size ranges with range 1 consisting of the smallest pores through to range 7, the largest. The separate ranges are plotted against permeability. Figure 3 gives two examples at different ends of the permeability scale, and demonstrates how low permeability plugs are associated with many small pores and the high permeability plugs with large pores. Similar results are shown by all 48 samples.

Possible reasons why small pores do not contribute to fluid flow are turbulent flow effects, the Klinkenberg slip effect being small, and flow hindrance due to drag and friction.

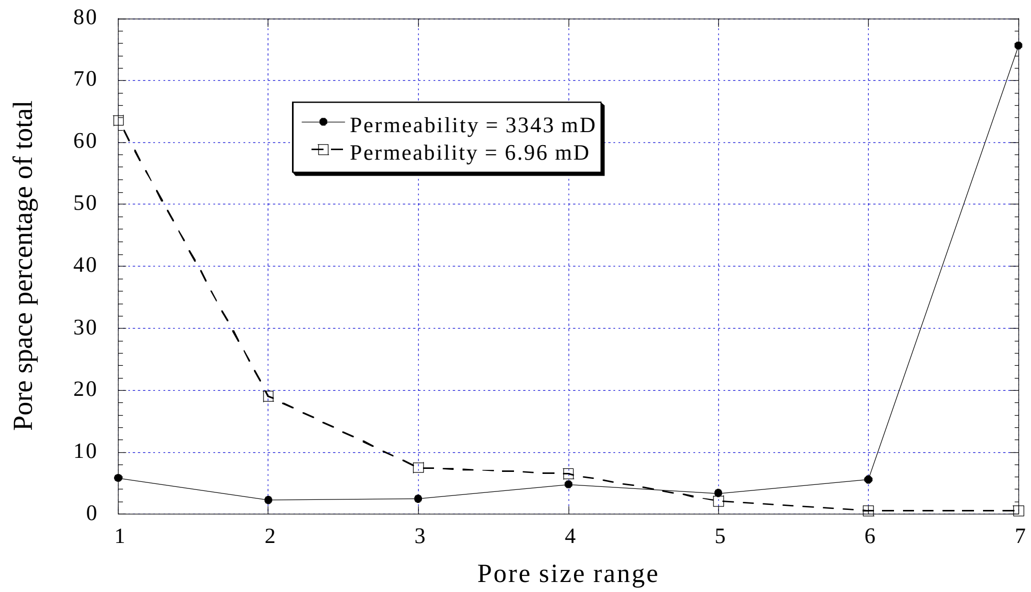


Figure 3: Percentage of total pore area for each pore size range, for a high permeability and low permeability plug.

Hypothesis II

Fixed orientation of the image porosity with respect to the permeability measurements helps constrain the relationship. i.e. Plug anisotropy is important.

The SEM images are always taken at right angles to the direction of permeability measurements and this may constrain the image porosity-permeability relationship. Cubic sandstone plugs were obtained from the same sandstone reservoir, and permeability measurements and image porosity calculations made on the same three orthogonal faces. The results were cross-plotted to see if there was any preference between direction of permeability measurement and the face the image porosity was calculated on. The results show that anisotropy of pore area is not significant in the relationship between permeability and image porosity. However, anisotropy in the distribution of the pores may prove to be significant.

Hypothesis III

The relationship between permeability and plug porosity is affected by the clay content.

To test the influence of clay content, the percentage of clay was measured in the images along with the percentage pore space. Figure 4 shows that the percent of total area covered by pores has a different trend from the plug porosity, but the percent of total area covered by pores and clay has the same trend as the plug porosity. However, the values of area pore plus clay are higher than the plug porosity. A logical explanation would be that not all of the clay is pore space. In the final curve, a third of the clay value has been subtracted and an improvement in the curve matching is seen. Figure 4 shows data from a single well. Similar results were seen for all other samples tested.

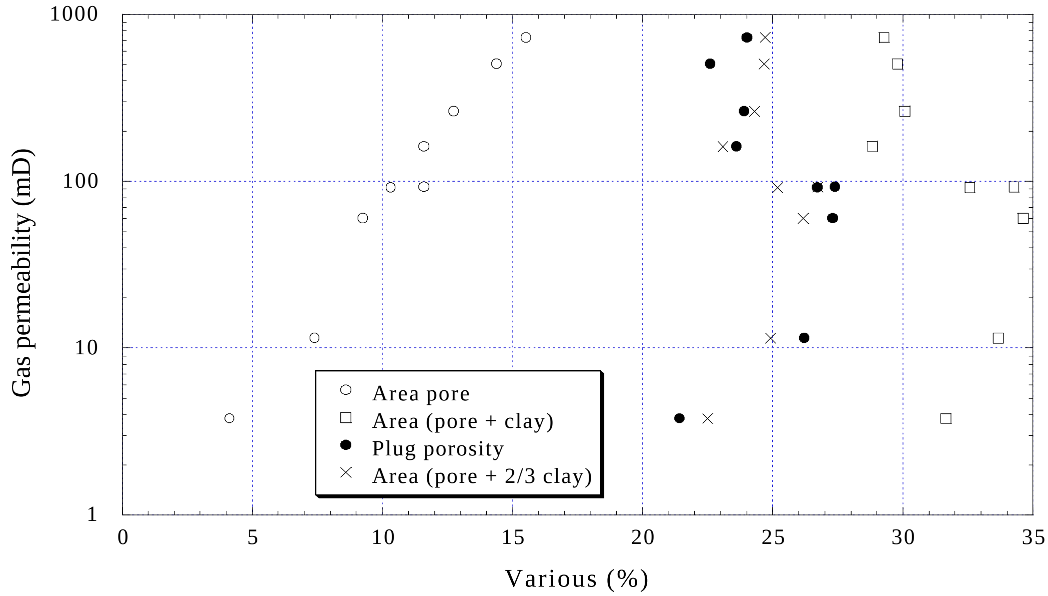


Figure 4: Image analysis parameters and plug porosity against permeability, for one Well.

Clay appears to be a major control in the relationship between the plug porosity and permeability. This understanding of the role of clay in plug porosity helps constrain the use of image analysis to predict plug porosity.

Conclusions

The third hypothesis gave the most interesting results - for this reservoir the plug porosity can be predicted from image measurements. Implications for further work include predicting the amount of clay down-hole and using this measure to constrain the plug porosity measure, so that porosity gives a better relationship with permeability for prediction purposes.