THE USE OF MTS (MULTIPLE TIP SIZE) PROBE PERMEAMETER METHOD IN CARBONATE ROCK

by

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ABSTRACT

The fundamental control in petrophysical properties of carbonate rock can be quite different from sandstone, therefore it needs different technique in permeability assessment. In this study we proposed a technique to assess permeability using probe permeameter for carbonate rock.

The technique applied Multiple Tip Size (MTS) probe permeameter which provides speedy, non destructively sampling at a significantly increased density. The key feature of the MTS is the use of different tip size. By using the MTS probe permeameter, the data can be screened to assess the appropriate data

I. INTRODUCTION

The probe permeameter is becoming increasingly important in reservoir characterization study, particularly in sandstone. However, the use of the probe permeameter data for characterizing the carbonate rock is very rare from recently published study. Since the fundamental control in petrophysical properties of carbonate rock can be quite different from sandstone, therefore it needs a different technique in permeability measurement. In this study, we proposed a sampling strategy for assessing permeability data with probe permeameter in carbonate rock. In sandstone, permeability is controlled by texture as primary depositional factor. In carbonate, however, the secondary diagenetic factors are more important. As a result carbonate rocks have very wide variation in pore system. Much or all of the original pore space is changed during diagenesis. New voids are created, and these in turn may be partly or completely filled. Therefore, carbonate rock has a different pore system with sandstone rock. The type of porosity in sandstone is intergranular and cemented; while in carbonate rock, the type of porosity is widely variable. Basically, two basic pore networks control the characteristics of pore system in carbonate rock: an interparticle pore network and a vuggy pore network. The effect of vugs on the petrophysical characteristics of the rocks is related to the type of interconnection. Vugs are interconnected in two general ways: unconnected vugs and connected vugs.

II. THE MULTIPLE TIP SIZE (MTS) PROBE PERMEAMETER METHOD

The probe permeameter used in this experiment was an unsteady state probe or pressure decay device (PDPK-200). The instrument measures the time rate of pressure decay as nitrogen flows to sample through the tip's probe (see Fig.1). Based on the Darcy Law, permeability is calculated as the ratio of gas flow rate to the pressure function and the geometric factor.

$$k = \frac{29392\ \mu PQi}{Gori(P1^2 - Pa^2}$$

The Geometric factor is supplied by Goggin's finite difference result that is a function of depth of investigation and the homogeneous flow assumption (see Fig.2). Several studies have been done to analyze the depth of investigation, it can be concluded that the depth of investigation depends on the inner tip's radius (it is about two times). Unfortunately, Goggin assumed homogeneous and isotropic media to determine the geometric factor. In the presence of heterogeneity or vugular pore, this condition might violate the geometric factor and the depth of investigation. In order to check the consistency of measurement, we proposed to measure permeability at different depth of investigation or tip size.

III. NUMERICAL MODELLING OF THE PROBE PERMEAMETER

The model was created to understand the tool response in a heterogeneous rock, such as a carbonate rock. Since the Goggin's geometric factor was obtained in homogeneous and isotropic condition that might be unsuitable for measurement in a heterogeneous carbonate rock. The model was created by using ECLIPSE-100 simulator.

In order to verify a base case model with Goggin's Model, a radial, homogeneous, isotropic, and single phase model has been developed. The model consists of

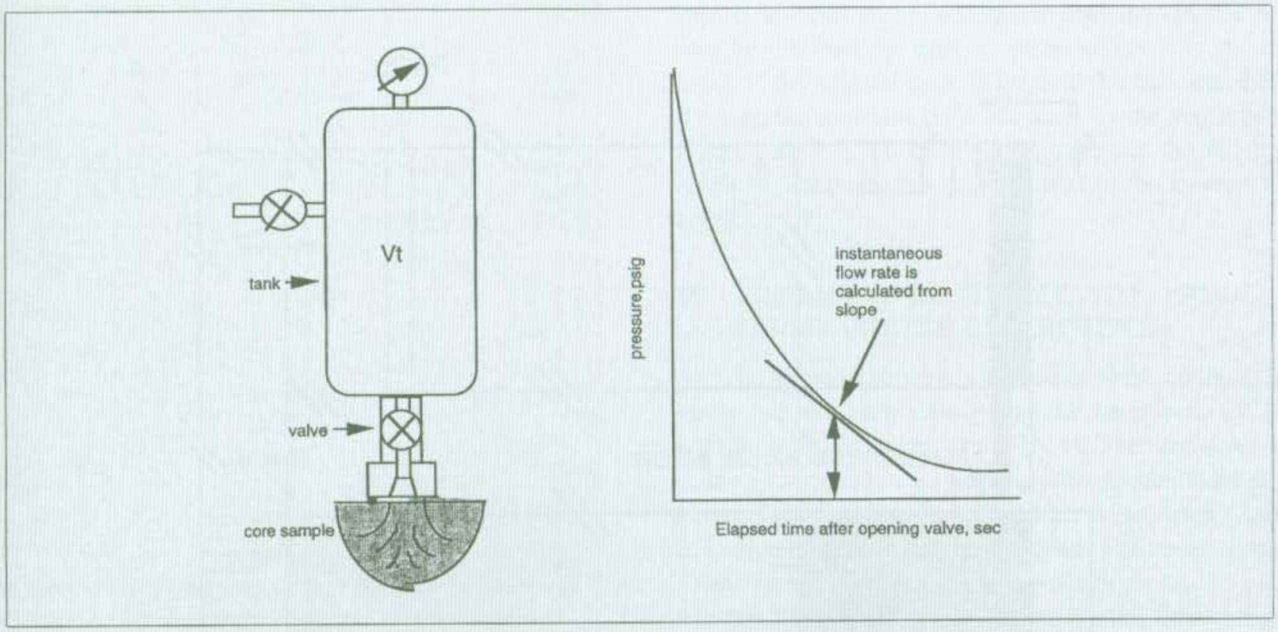

Figure 1
Principle of pressure-decay permeameter measurement. A tank is filled with a gas to some desired pressure, the valve is closed. After the probe tip is sealed against sample, the lower valve is opened and gas flow through the tip to the sample. The pressure of tank is recorded as a function of time

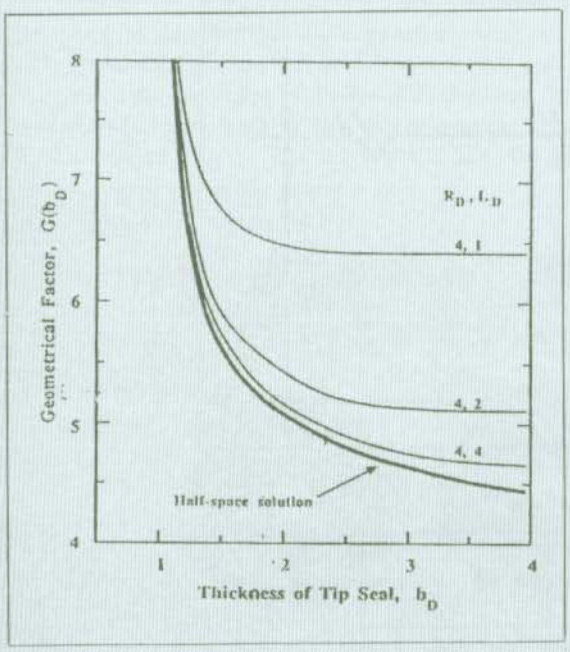

Figure 2
Plot of Gonggin's geometric factor versus bD (the ratio facktor of the outer diameter to the inner diameter of tip)

two "wells" which are "producer" and "injection" (see Fig.3). The model uses a core of 3.8 cm radius by 7.6 cm length. The core is surrounded by a very large volume with very high permeabilities and porosities. The function of the producer is to drain the gas, in order to keep constant pressure at 1 atm. The gas injection is through "injector" which is connected to blocks acting as a seal and an inner tip radius. The dimension of the model is 20 grid blocks in the vertical direction, and 21 grid blocks in the radial direction, with exponential increment, and a single (=90°) cell in the theta direction. The result shows the greatest agreement is obtained at the range 1 mD.

After verified the model, the sensitivity runs were done with the heterogeneous Cartesian model. Three scenarios of heterogeneous model were used in the sensitivity analysis.

1. A change of the vugular pore's diameter relative to the probe.
2. A change of the vugular pore's length relative to the probe.
3. A change of the vugular pore's distance relative to the probe.

The result shows that the probe measurements in a vugular carbonate (heterogeneous model) have different characteristics to the measurement in the sandstone (ho-

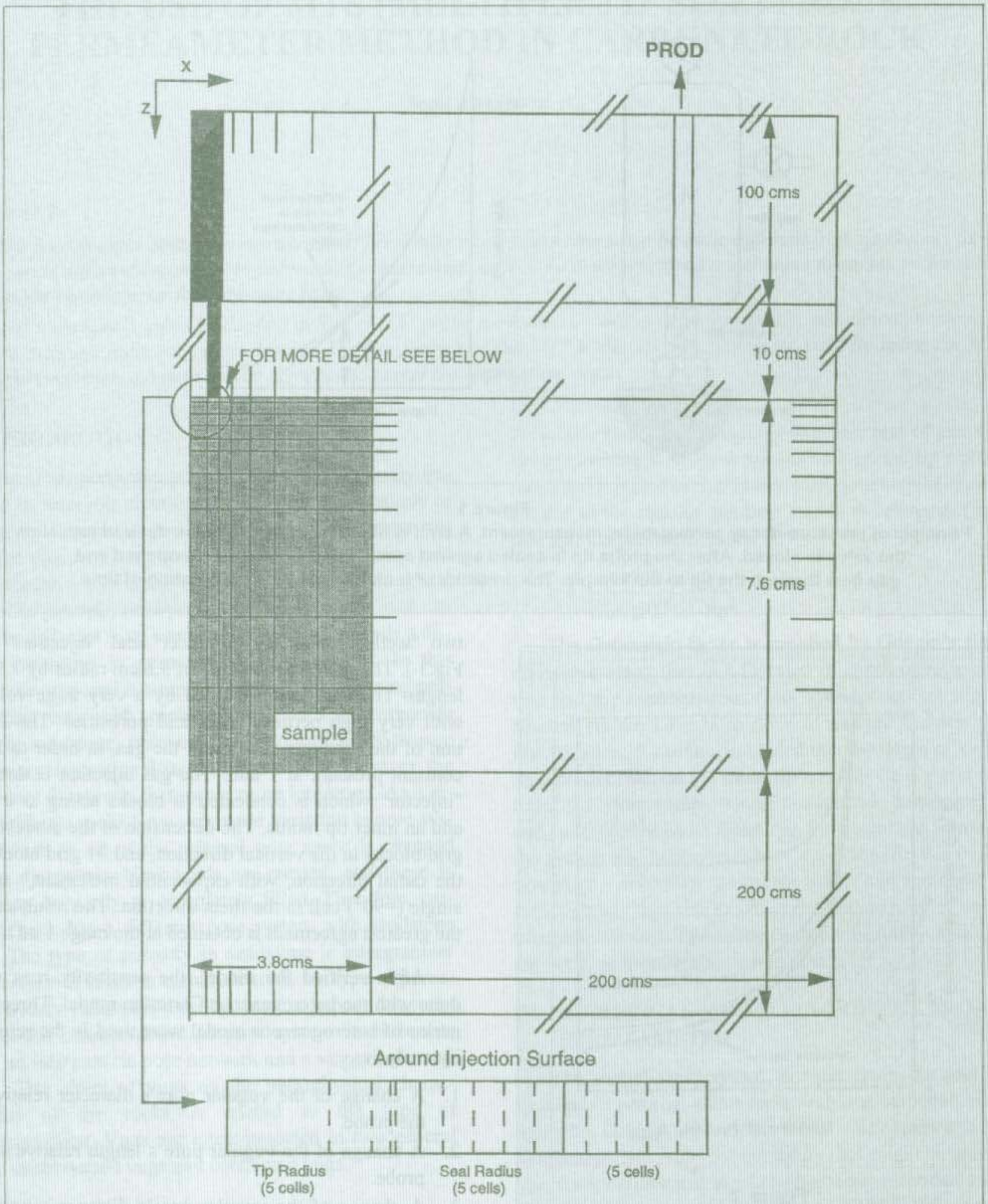

Figure 3
Showing Schematic of Model

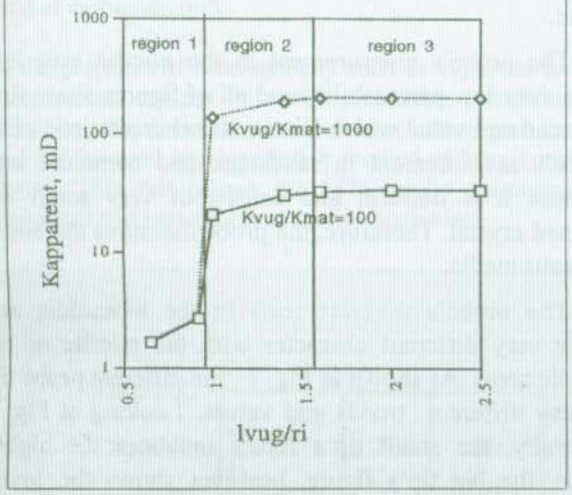

Figure 4
The sensitivity result shows that the tool response is effected by tip dimension and the characteristic of vugular pore system. In the region I (=the area with the vugular pore length within the tip radius), both of the figures indicate similar permeability value. The tool response is controlled by matrix permeability. In the region II (=the area with the vugular pore length between the seal's internal and external radii), both of the figures start to split. In the region II (= the area with the vugular pore lenght greater than the seal's external radii), the figures tend to stabilize and display the high apparent permeability indicates that the tool response is controlled by the vug permeability

mogeneous model). It is apparent from the sensitivity result, if the vug's pore is smaller than the tip, the probe will be effected by matrix permeability. On the other hand, if the vugular pore is big and the tip cannot cover the vug, the tool will be influenced by the vug's permeability (see Fig. 4). In this study, we use the sensitivity result to interprete the experimental probe measurement result.

IV. THE MULTIPLE TIP SIZE (MTS) PROBE PERMEAMETER EXPERIMENT.

The permeability measurements were conducted on sandstone and carbonate rock. The data were collected with three kinds of tips (see Fig. 5). The sandstone used in the experiment is an aeolian outcrop sandstone of the Permo/Triassic New Red Sandstone series from a quarry at Lochabriggs in southern Scotland. The result of measurements is displayed in Fig. 6 , which shows the plot of average permeability vs distance for the three kinds of tip. The trend of this figure for all of the tips is similar, as they are for the permeability values. However, the small tip has slightly lower value but it is consistent than the others.

The carbonate sample is a carbonate from the Carboniferous Honaker Trail formation, SouthEast Utah, USA. The sample can be divided into 3 pore types with different characteristic which are biomouldic, oomoldic, and micrite (see Fig. 7). The MTS probe permeameter results display different trends and values for the three tip sizes in biomoldic pore type. However in the oomoldic

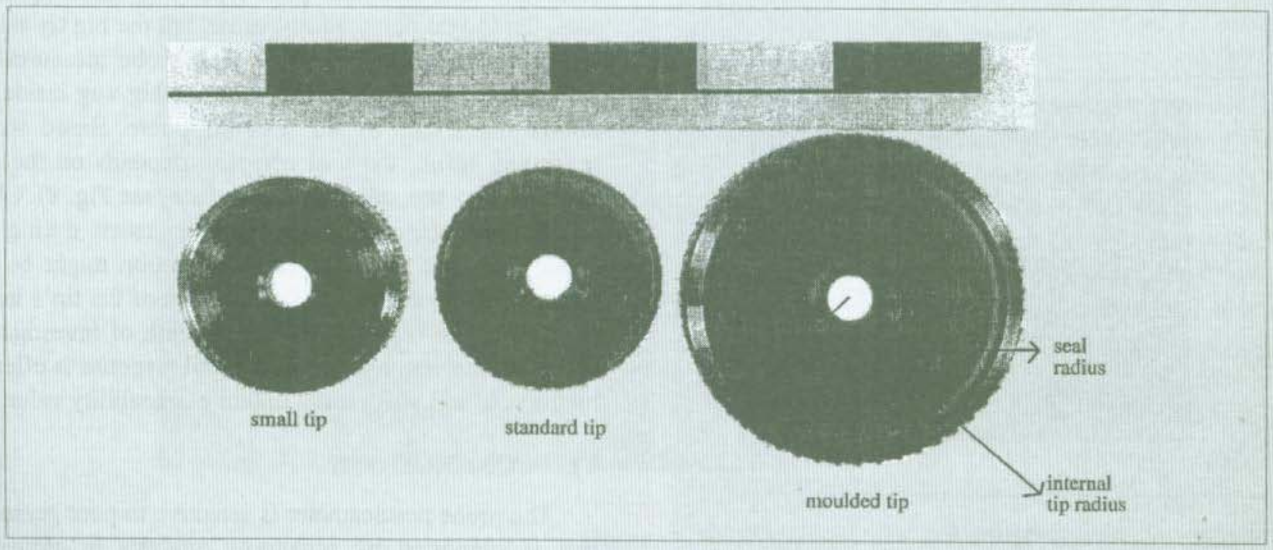

Figure 5
Varying probe tip sizes

pore type and micrite area, all the tips give similar trend and permeability value result.

V. DISCUSSION

The probe's measurement in the oomoldic area, as shown in Fig. 7 indicates similar value and trend for each tip size and it also represents relatively high permeability (100-1000 mD). The characteristic of measurement is similar with the characteristic probe response of sandstone. In these pore types, the probe's measurement result is quite accurate, since pore geometry is very uniform and homogeneous represent the condition which Goggin assumed for the modified Darcy equation. In this pore type, the vugular pores are connected, thus all of the tip's can cover the pores. These condition can be explained by the sensitivity result as shown in Fig. 4. Based on the sensitivity result, the probe will measure the effective isotropic permeability, if the vug's pore is within the tip's diameter and connected. Therefore, in the oomoldic pore type as well as in the sandstone all of the tip's measure the effective permeability and yield the similar trend and value.

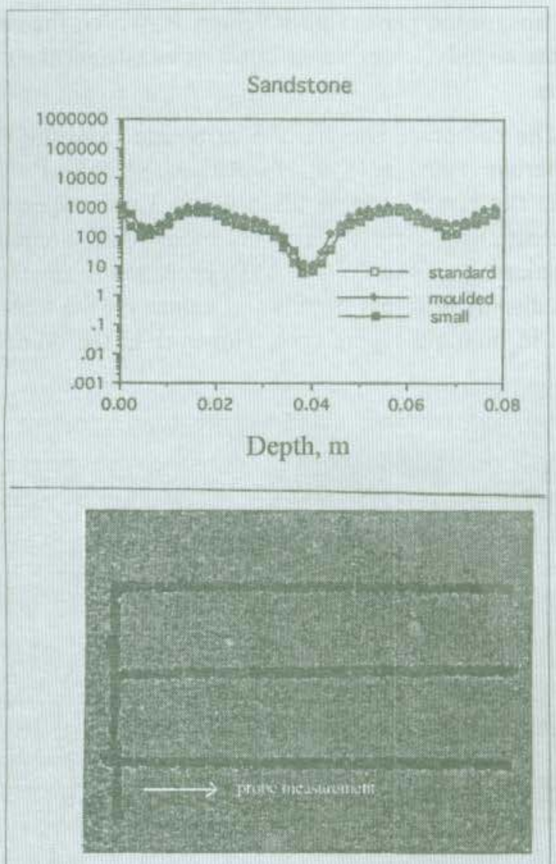

Figure 6
The probe measurement result for sandstone sample

The probe's measurement in the micrite area indicates very low permeability and all of figures show similar trend and value which is a similar characteristic of the probe's measurement in sandstone and oomoldic area, because it is uniform and consist of very small fine grained crystal. Therefore, the probe measures the homogeneous media.

The probe's measurements in the biomoldic area show very different character with the micrite or oomoldic areas. As shown in Fig. 7 , the different probe tips display different trends and values. Looking at Fig. 7, generally, the small tip's figure indicates the highest value, the big tip's figure, however shows the lowest value (as shown in the area 0-2.5 cm, 4-5 cm, and 6-7 cm). Except, in the area 3.5-5 cm, the big tip shows the highest value.. The big tip is big enough to cover the vug'' pore, the small tip, however, can not cover all the vug'' pore. Based on the sensitivity analysis result, the tool response depends on the size of vug relative to the size of tip (see Fig. 4). If the vug's size is small relative to the tip's inside radius, the tool response will be dominated by matrix permeability. Therefore, the big tip's presented the lowest value since the vug's pore size is within the tip inside radius. On the contrary, if the vug's size is bigger relative to the tip's inside radius, the tool will measure the vug's permeability. Because of that, the small tip indicates the highest permeability value.

The sample for the interval of 3.5-5 cm consists of biomoldic and oomoldic pore type. The small tip indicates the lowest permeability value, but the big tip shows the highest permeability value. The probe measures the porous and permeable media with the big vug inside the sample that's seen by CT scanning photo. Based on the sensitivity result, the tool response depends on the distance to vugs beneath the rock surface (see Fig. 8). Obviously, the distance of the vug is constant during the experiment, but the depth of investigation might be different which is defined as the function of the tip's inside radius. For the big tip, the deeper depth of investigation can reach the vug, as a result the tool response is effected by the void and will yield a higher permeability value.

VI. CONCLUSIONS

The probe permeameter is sensitive to pore geometry that is supported by sensitivity analysis in numerical model and the MTS probe permeameter experiment in sandstone and carbonate sample.

- The MTS probe permeameter should be used in carbonate rock to check the consistency of data and the pore type of carbonate rock.

- In the presence of heterogeneity such as vugs, the probe permeameter can not be used to determine permeability. However, the device is sensitive to effective pore throat and can be used as a qualitative method of "vug connectivity". This fact allows the MTS probe permeameter technique as a petrophysical tool for carbonate.

NOMENCLATURE

Go : Goggin geometric factor.
k : permeability, mD
Pa : ambient atmospheric pressure, psi.
P, Pi : pressure in the probe, psi.
Qi : the volumetric gas flow rate at this pressure, cm^3/sec.
ri : internal tip seal radius, cm.
m : gas viscosity, cp.

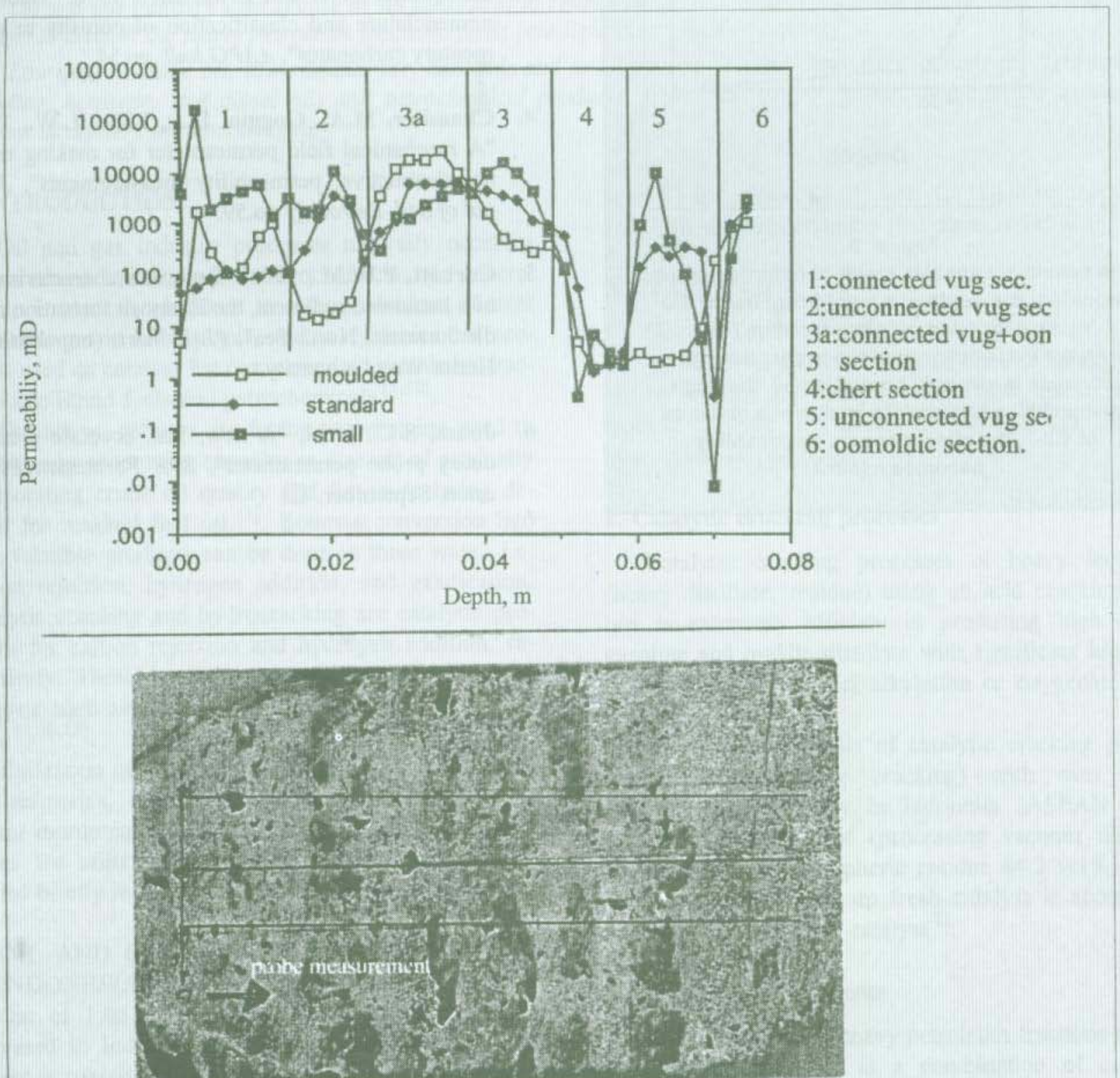

Figure 7
The proble measurement result for carbonate sample

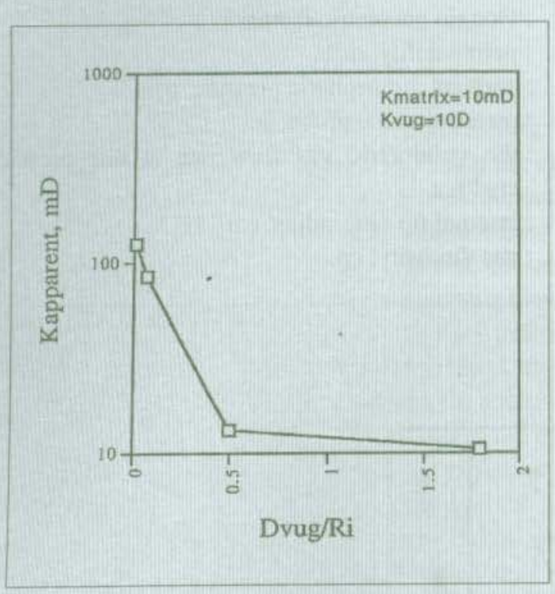

Figure 8
The sensitivity analisis result of heterogeneous model for the depth of a vug (Svug) below the tip as a function of internal radius (Ri). As the vug approaches the probe, the tool response is strongly controlled by the vug's permeability, but at a dimensionless distance of 1.8-2, the effect of vug's permeability becomes minimal

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