# Permeability prediction from MICP and NMR data using an electro-kinetic approach

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## INTRODUCTION

Permeability is the key reservoir parameter in any reservoir assessment. However, it is an extremely difficult parameter to obtain. The measurements are expensive, suffer from sampling and experimental uncertainties, and are carried out at a scale that is unrepresentative of the gross fluid flow in the reservoir.

Clearly, it is in our interest to obtain a reliable method for predicting permeability from downhole measurements. No downhole measurement can access permeability directly. However, several techniques have been used to infer permeability from downhole tools.

Poroperm crossplots (Tiab & Donaldson, 1996),
Principal component analysis (Lee & Datta-Gupta, 1999),
Cloud transforms (Al Qassab et al., 2000),
Fuzzy logic (Cuddy & Glover, 2002),
Neural networks (Helle *et al*., 2001),
Genetic algorithms (Cuddy & Glover, 2002),
Empirically determined "laws" (e.g., Berg, 1970).

All of these methods either rely on mathematical pattern recognition, a simplifying assumption, or calibration to a data set from a different formation in a different field which is often not even the same lithology.

The NMR tool is often feted as having the ability to provide directly downhole permeability measurements. However, this claim is misleading. The current method (Timur-Coates equation (Coates et al., 1991) is simply another empirically-derived relationship. However, the NMR tool has the potential of providing the distribution of grain sizes or pore sizes within the rock by inverting the $T_2$ relaxation time spectrum for use in other methods.

Here we introduce a new permeability prediction equation. Unlike some of the other equations, it does not depend upon calibration to an empirical data set. Instead, it is derived from the consideration of the electro-kinetic link between fluid flow and electrical flow that occurs in a porous medium. The method was originally described in an unpublished discussion paper by André Revil, Paul Glover, Philippe Pezard and M. Zamora. Consequently, we call the new model the RGPZ model.

This paper has two goals; (i) to validate the RGPZ model and to compare its results with those from other common permeability prediction models, and (ii) to ascertain the optimal method for obtaining the relevant mean grain size from either MICP (laboratory) or NMR (downhole) data.

## THE PREDICTION EQUATION

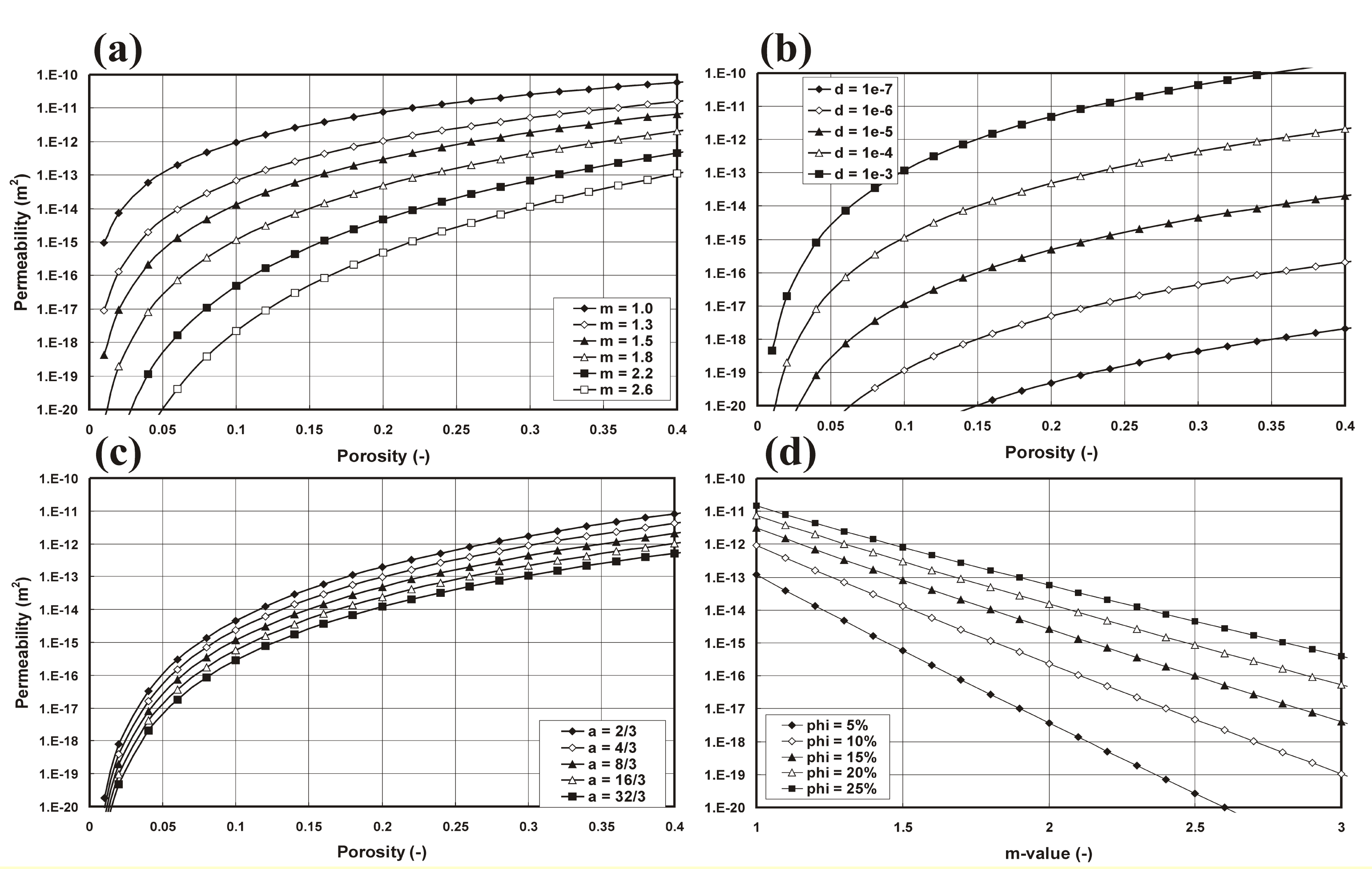
$$K_{RGPZ} \qquad \frac{d^2 \quad {}^{3m}}{4am^2}$$

where:

$d$ is a measure of the mean diameter of the grains (m)
is the fractional porosity (-)
$m$ is the cementation exponent (-)
$a$ is a constant thought to be equal to 8/3
$K_{RGPZ}$ is the predicted permeability ($m^2$)

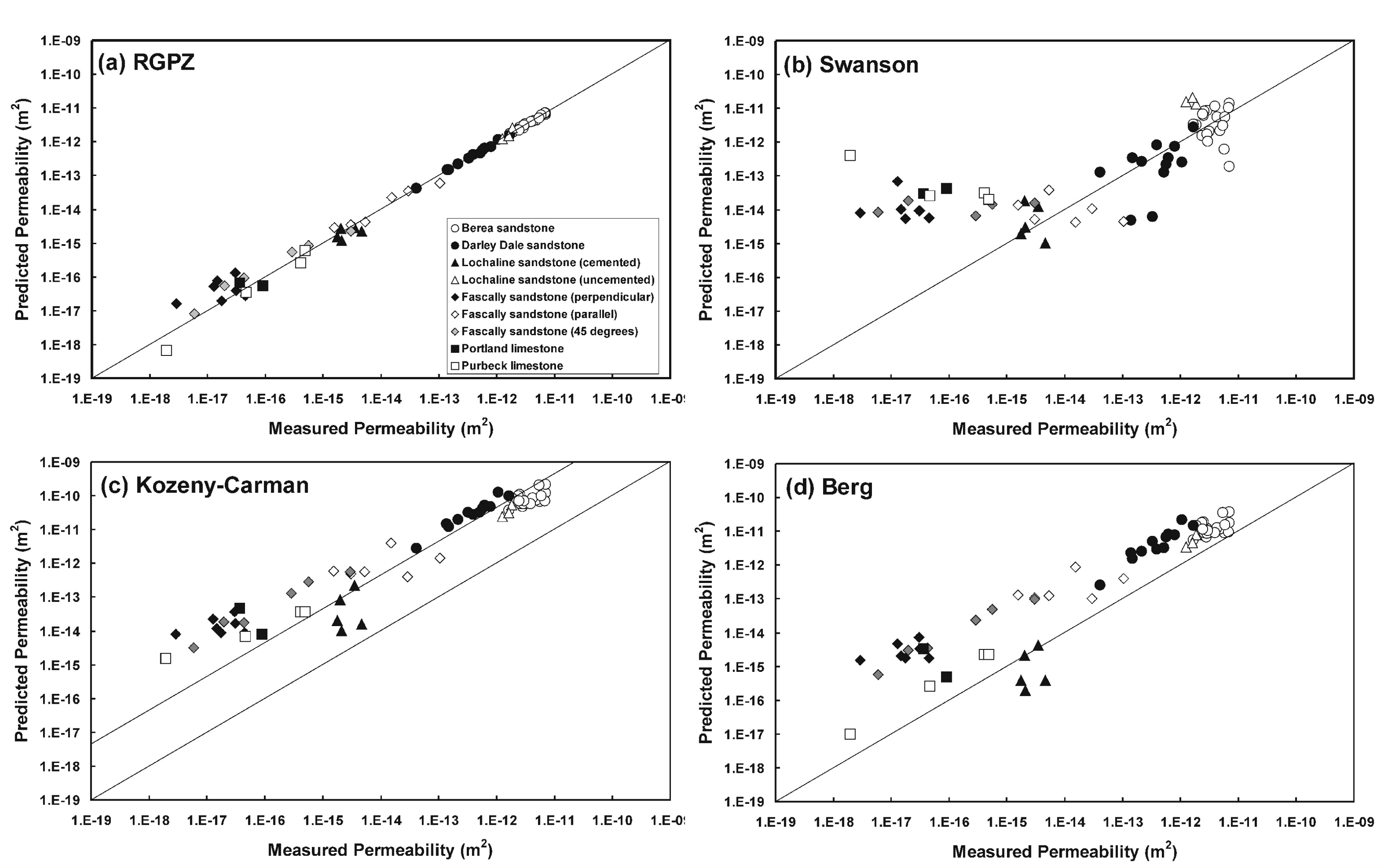
It involves the solution of the Bruggemann-Hanai-Sen equation with the restriction of grain coatings after Kostek (1992) and the comparison of the result with the relationship between hydraulic permeability and length scale using a relationship derived from electro-kinetic theory.

## PROPERTIES OF THE EQUATION



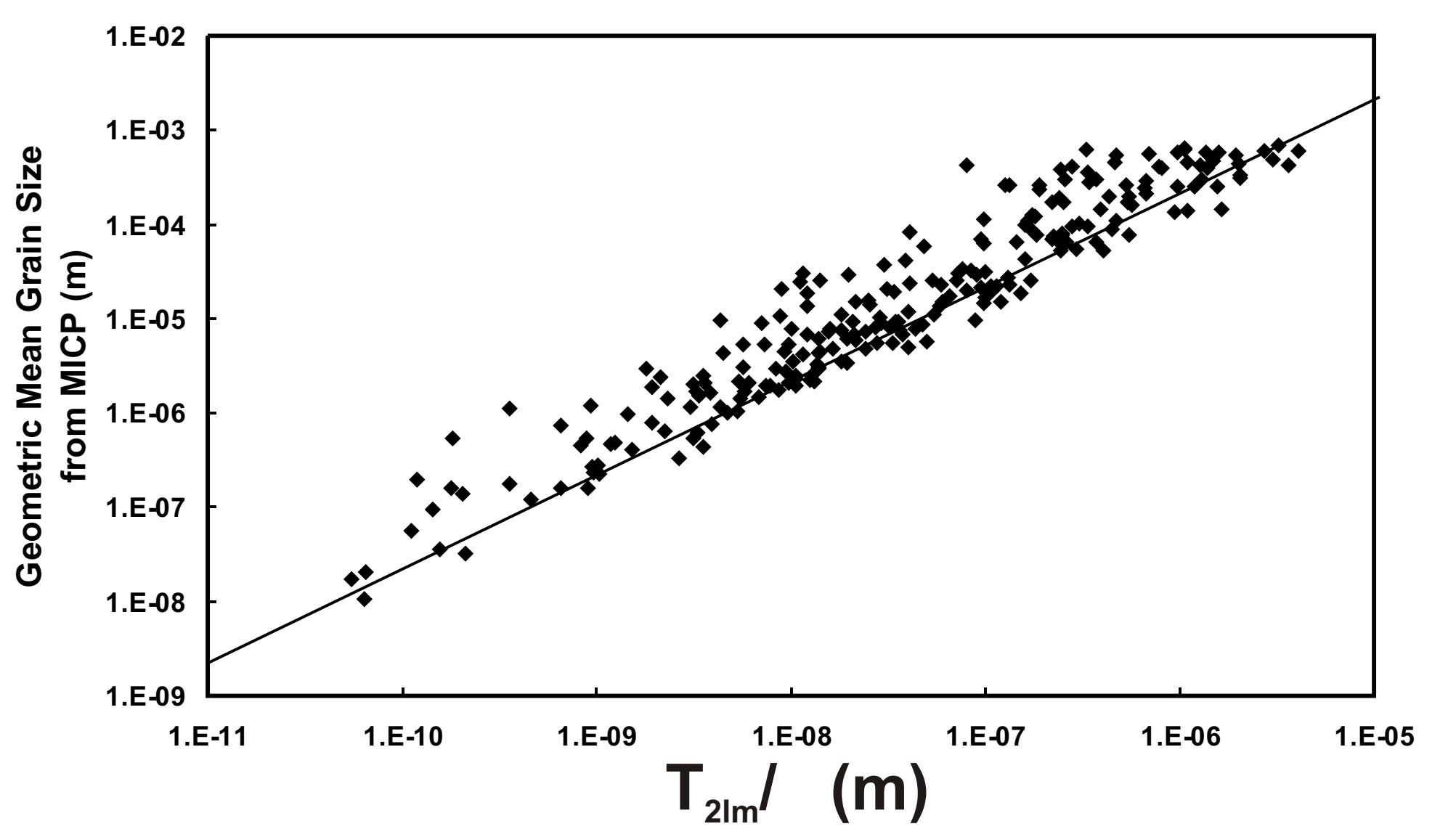
The equation has a variation as a function of porosity that is commonly seen in rocks (a to c). Furthermore, variation with cementation exponent and grain size are consistent with those recognised in the literature. The sensitivity to variations in the value of a is small, reducing the impact of using an erroneous value.

## PREDICTION POWER OF 4 DIFFERENT MODELS



Predicted permeability as a function of measured permeability for the RGPZ model, two grain size-based empirical models (Kozeny-Carman's and Berg's) and Swanson's MICP model. The RGPZ model has the best performance followed by the MICP-based model, which is good for high permeabilities.

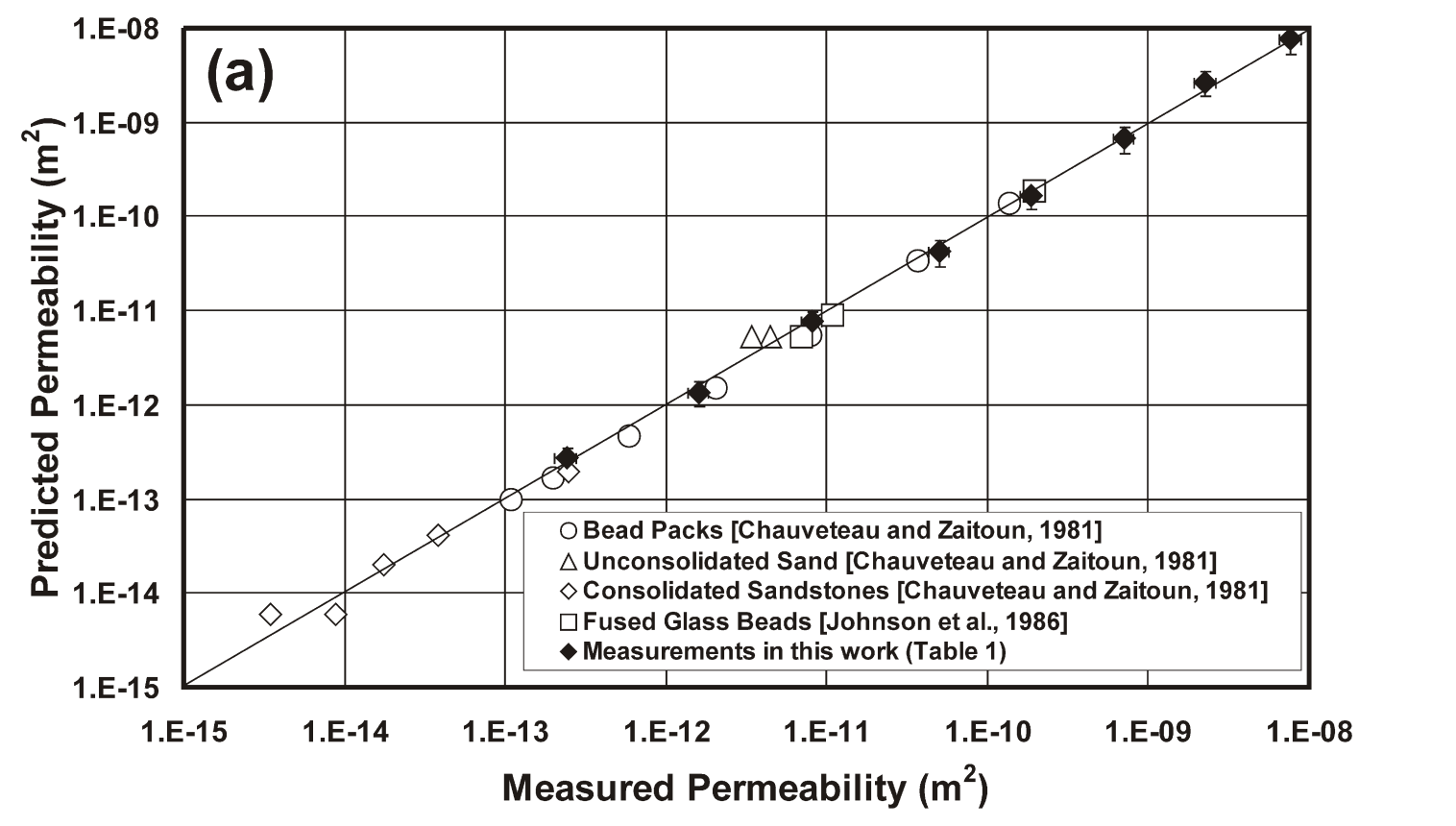
## NMR RELAXATION TIME & GRAIN SIZE

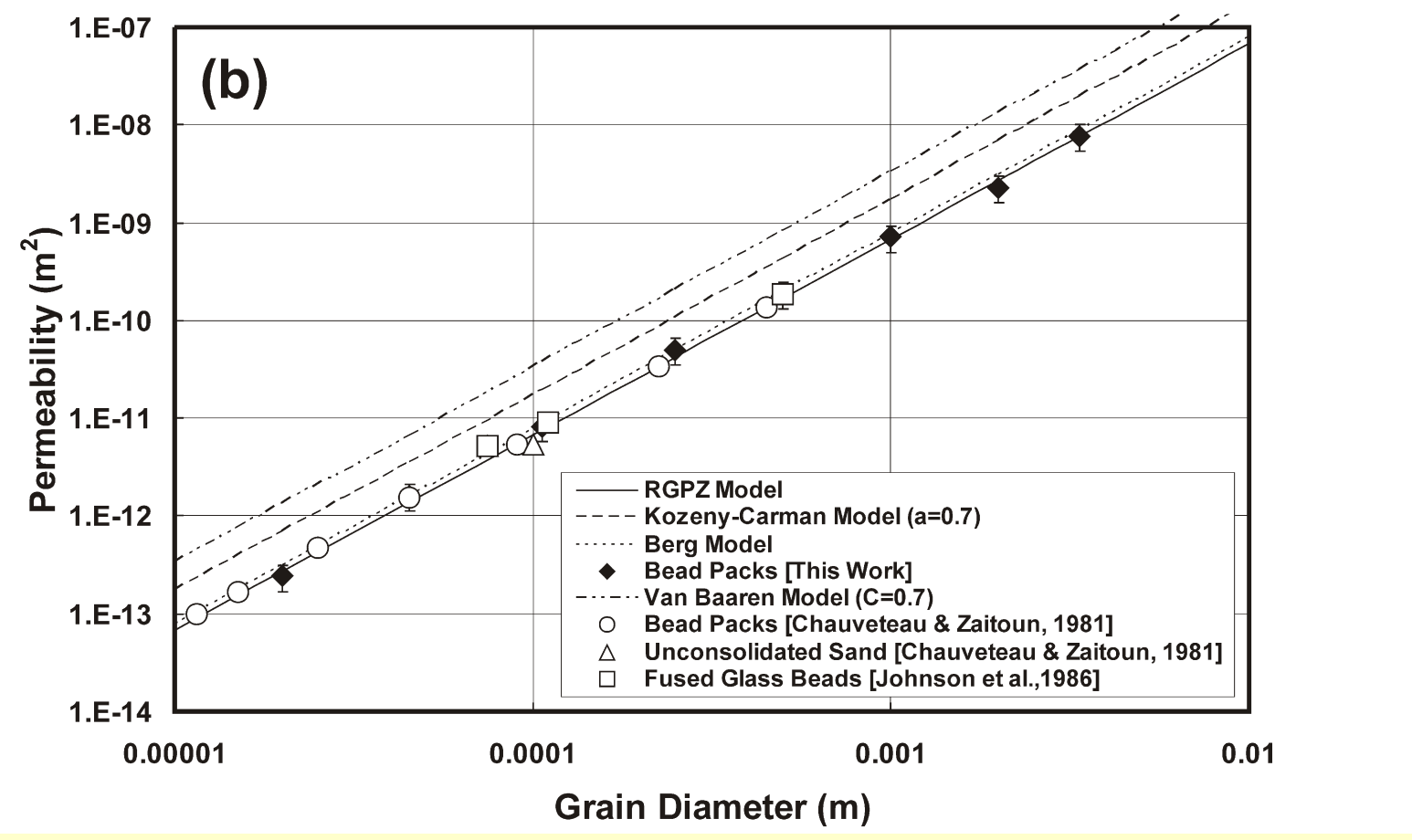


The relationship between the T2 relaxation time and the geometric mean grain size that allows the RGPZ model (and other models) to be used with NMR data.

## VALIDATION

Comparison of the predicted permeability with the measured permeability for a range of rocks, sands and bead-packs

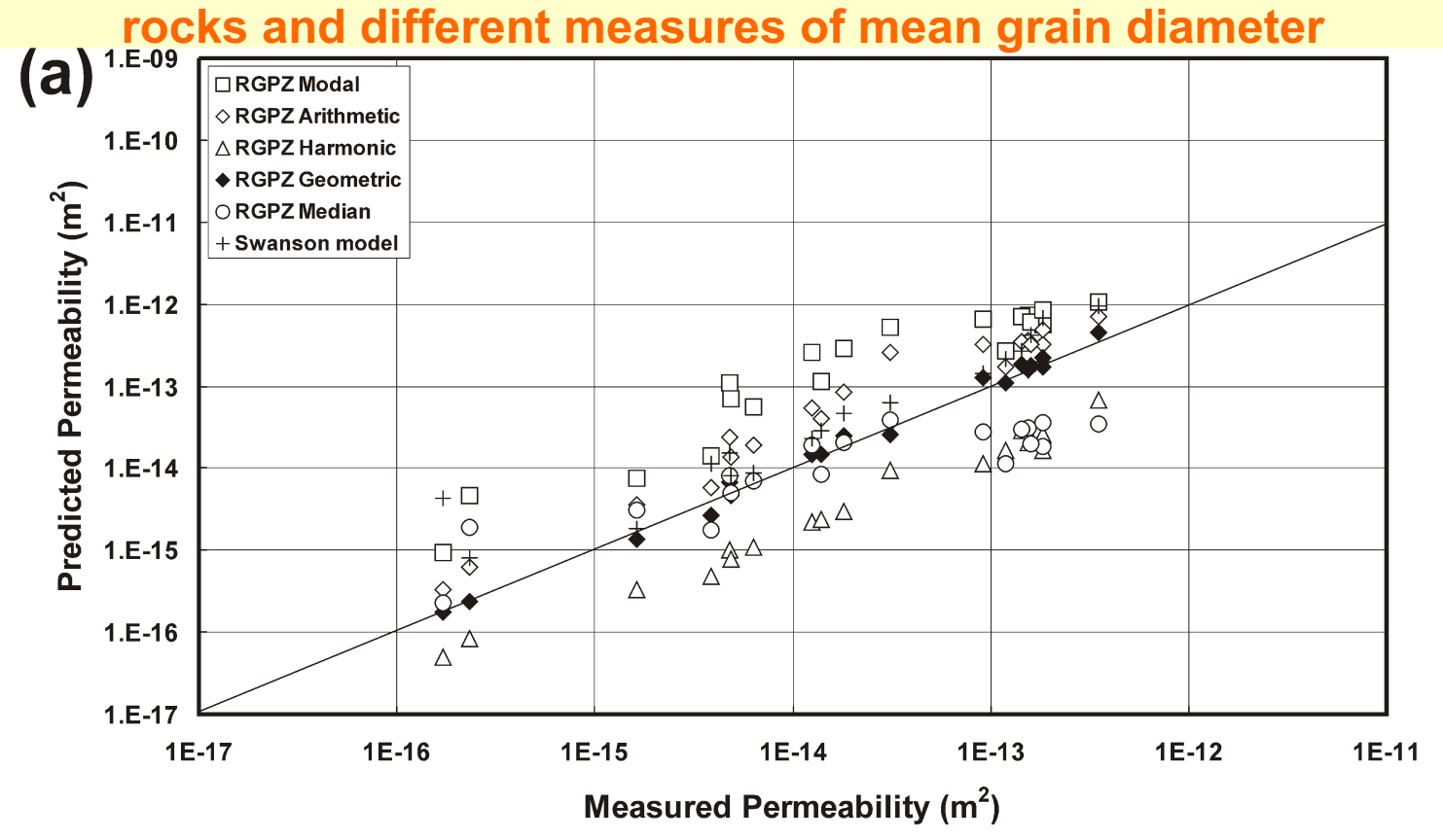


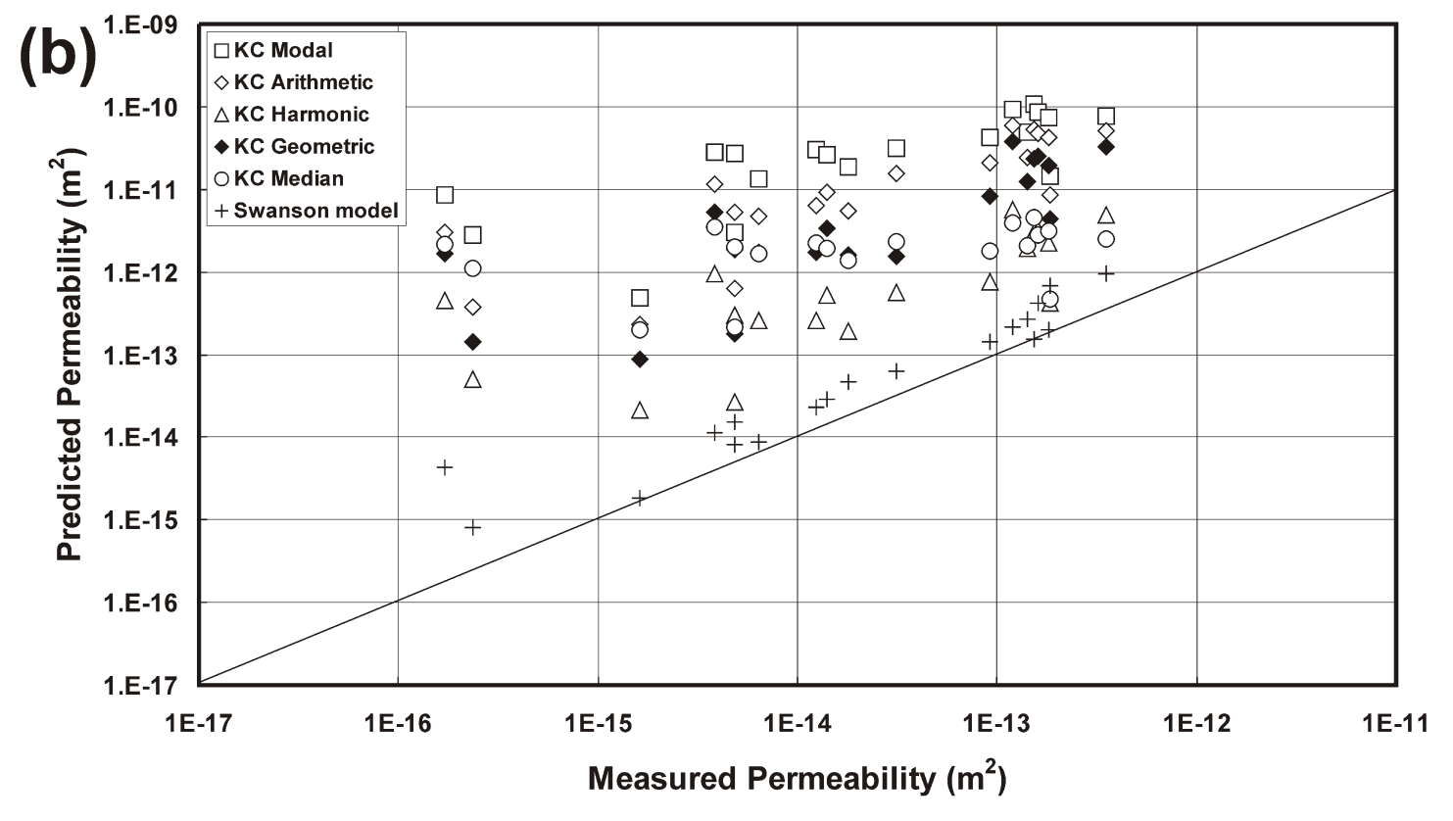


Comparison of the predicted permeability with the measured permeability as a function of grain diameter for the new model and 3 other models (Kozeny-Carman, Berg, van Baaren)

## CHOICE OF MEAN DIAMETER

Variation of predicted permeabilities using the RGPZ model as a function of measured permeabilities for a set of reservoir rocks and different measures of mean grain diameter

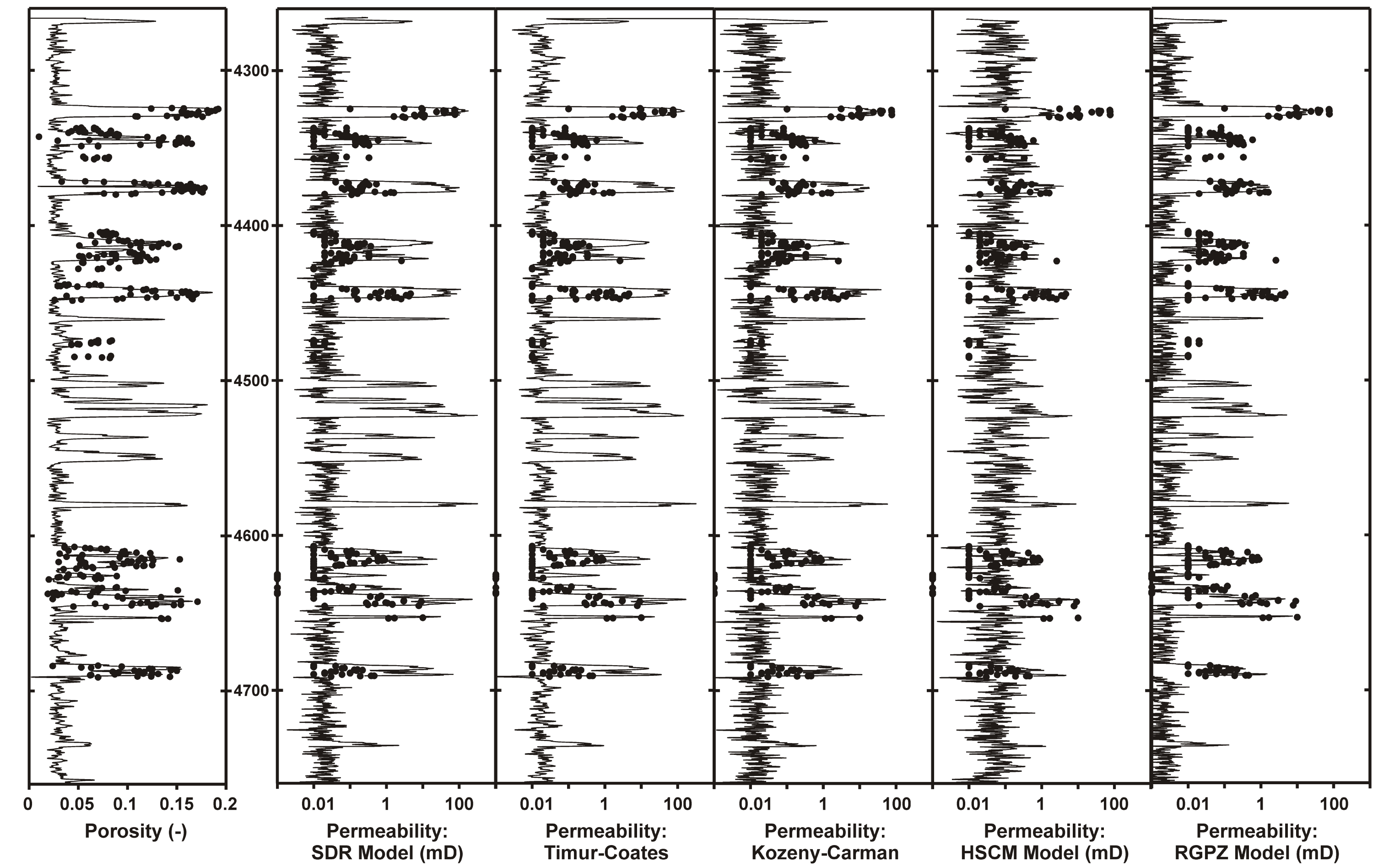




Variation of predicted permeabilities using the Kozeny-Carman model as a function of measured permeabilities for a set of reservoir rocks and different measures of mean grain diameter

## PREDICTION OF PERMEABILITY FROM NMR DATA

Variation of predicted permeabilities using the RGPZ model and 4 other models using NMR data obtained from well logs, and their comparison with permeabilities measured on cores. The RGPZ model gives the best fit to the data.



## LIMITATIONS

Although the RGPZ model seems to provide good predictions for the experimental and downhole data, it is important that its limitations are made clear.

1. Although the RGPZ model is not empirical, but derived analytically from electro-kinetic considerations, its application requires knowledge of a characteristic grain size.

2. If the RGPZ equation is used with downhole NMR data, the required characteristic grain size can currently only be obtained by employing an empirical procedure relating grain size to the $T_2$ relaxation time.

3. The *F* and *m* values used in the equation should be derived from saline water bearing rock to minimize perturbation of the results by surface conduction.

4. The value of *F* should be significantly greater than unity. This constraint means that the RGPZ equation should not be used in low porosity fractured rocks.

5. The RGPZ equation is not valid in the limit that becomes near to 1 (i.e. 100% porosity), which amounts to a trivial restriction of the model.

6. The RGPZ equation relies on the assumption that O'Konski's equation can be used for non-spherical grains providing the grain radius therein is taken as an equivalent or characteristic grain radius. This is valid providing the range of grain radii in the target rock is bigger than the average difference between the smallest radius and the largest radius of each particle. This is true for almost all sedimentary rocks.

## SUMMARY

A new model for predicting the permeability of porous media is proposed. The model is derived analytically from considerations of electro-kinetic processes.

The model has been tested on fused and unfused bead packs, unconsolidated sands and a wide range of rock types as well as downhole data. The model provides a better fit to measured data than all the other models tested providing that a geometric mean grain size is used.

The model may be used to predict permeability from NMR data, but relies then on an empirical calibration of grain size to NMR T2 relaxation time.

The derivation of the equation is simple but lengthly.
A copy of it can be obtained from the lead author.

For additional information, please contact:
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