Reservoir Quality Prediction in Sandstones through Rock Microcharacterisation*

Alberto Consonni[1], Francesca Golfetto[1], Andrea Ortenzi[1], and Monica Arduini[1]

Search and Discovery Article #40845 (2011)
Posted December 12, 2011

*Adapted from extended abstract prepared in conjunction with oral presentation at AAPG International Conference and Exhibition, Milan, Italy, October 23-26, 2011

[1] Eni E&P, Via Emilia 1, I-20097 San Donato Milanese (MI), Italy (andrea.ortenzi@eni.com)

Abstract

The siliciclastic sediments (sand and sandstones) represent most of the hydrocarbon bearing reservoirs. They are composed of fragments (clasts), chiefly silicates, coming from the weathering and erosion of pre-existing rocks. The reconstruction of the depositional model of such sediments, along with the rock microcharacterisation, is aimed at the prediction of the areal distribution, continuity and quality of siliciclastic sedimentary bodies.

The Reservoir Quality Prediction (RQP) of a sandstone reservoir is a fundamental activity aimed at the delivery of maps that may be used for the evaluation at the level of play/leads/prospects and, more in general, for the ranking of the different zones of an exploration area/concession. This provides a significant contribution to the exploration activity from basin to prospect scale. The reservoir quality of a siliciclastic sediment that will become a sandstone, is basically determined by:

- The vertical (thickness) and horizontal (areal) dimension of the sand body; this is directly linked to the energy of the environment of deposition and influences the presence and amount of sand deposited in each point of the basin;

- The initial depositional petrographic characteristics (such as grain-size, sorting and the presence of detrital clays in the pore space) and the original composition of the sediment in terms of type of grains (quartz, feldspars, lithic grains, etc.); both features are determined by the energy of deposition and, for composition, by the source-area of the sediments;

- The changes in the pressure/temperature regimes undergone by the sediments during burial; these changes induce, besides the reduction of porosity due to mechanical compaction, cementation/dissolution phenomena that will produce the final poro-perm characteristics of the sandstone reservoir. All these phenomena are grouped under the definition of diagenesis. Diagenesis is directly influenced by the primary sediment features and is thus controlled by lithology, pressure, temperature, pore fluids type, grain size, and amount of fluid flow.

The RQP is the result of two parallel work-flows that deliver quantitative data. In particular:

1) The sedimentological work-flow delivers the thickness and areal distribution of the reservoir;

2) The petrographic work-flow, called Rock Microcharacterisation at Eni, delivers the vertical and horizontal distribution of the diagenetic events that affected the reservoir.

The integration of the output from the above approaches produces, as final deliverable, the reservoir quality maps at the required scale. The two work-flows are not stand-alone and they require a strict integration with biostratigraphy, especially for the correlations, seismic for the areal distribution of the facies and PSM (Petroleum System Modeling) for the 3D burial and thermal evolution of the area of interest.

In the subsequent work-flow description, the focus is on the Rock Microcharacterisation, as the sedimentological work-flow is already sound and is the object of other papers. In the perspective of the RQP, the main output of the sedimentological workflow is, as already outlined before, the isopach (thickness) and distribution maps of a given facies/facies association. In the Rock Microcharacterisation work-flow, the innovative part is represented by the Reservoir Efficiency Index (e-rei).

Rock Microcharacterisation

The petrographic work-flow is called, at Eni, Rock Microcharacterisation and it is aimed to provide an objective classification of each facies of siliciclastic reservoirs based on the Reservoir Efficiency Index (e-rei). The input data derive from both a quantitative analysis at the optical microscope and from a quantitative pore network characterisation at the scanning electron microscope. The result of these quantitative analyses allows the evaluation/assessment of tens of significant variables and a Rock Microcharacterisation spreadsheet is obtained. In order to make the interpretation of this vast amount of data easy and effective, the variables are combined and normalised into a unique e-rei, that varies from 0 (no efficiency) to 1(maximum efficiency). This index takes into account all the compositional and pore network aspects crucial for the quality of the system and is calculated for each sample. As samples statistically represent facies, the e-rei is used to characterise the reservoir quality of the different recognised sedimentological facies. The e-rei is based on the computation of three indexes, in turn calculated on a set of specific Rock Microcharacterisation variables and corrected through specific modifiers. The three indexes are called:

- **Clast Index**, which is mostly related to the depositional variables, such as total unstable grains, detrital matrix presence, grain-size and sorting;
- **Filling Index**, which is based on the amount and behaviour of the cements;
- **Pore Dimension Index**, based on the relative proportion of pore size.

Clast Index

The first index is calculated on the grains type and on the amount of detrital matrix. The grains are classified following their stability. The constituents are subdivided into three categories (see ternary diagram in Figure 4):

MSCS - mechanically and chemically stable: e.g. quartz.
MSCU - mechanically stable and chemically unstable: e.g. feldspars, white mica, etc.
MUCS/U - mechanically unstable and chemically stable/unstable: e.g. argillaceous lithic fragments.

The choice to use the stability of grains is mainly due to the observation that the compaction of sediments is influenced by the amount of mechanically unstable grains, and that the dissolution/precipitation phenomena are closely linked to the amount of chemically unstable grains. The Index is calculated on the amount of the total unstable grains (MSCU plus MUCS/U) and of the detrital matrix. Then it is modified to consider the grain-size and the sorting. It is apparent that, given a composition, the efficiency will be higher in coarser-grained sediments due to the expected larger dimension of pore-throats. It is less easy to evaluate the influence of sorting on the pore network efficiency. It is assumed that, going to worse sorting, the efficiency is affected.

The detrital matrix sometimes may have some microporosity, generally due to a partial or total reorganisation or recrystallisation, that greatly influences the porosity of the sediment. In this case it is preferable to consider the matrix as a microporous authigenesis and place it in the Filling Index.

Filling Index

The filling index is calculated on the relative amount of the cements that fill the pore space (see ternary diagram in Figure 5). It was observed that the important thing is, besides the mineralogy of the cement, the way in which the cement fills the pore space that is:

- Partially, called partially occlusive behaviour;
- Completely, the so-called occlusive behaviour;
- With a micro-porous texture, typical of the clay minerals.

Specific cements, such as filamentous illite (Figure 1), may have a distinct influence on reservoir quality and where considered stand-alone. The Index is calculated on the amount of partly occlusive, occlusive, microporous and illite authigenesis.

Pore Dimension Index

The Pore Dimension Index is calculated on images obtained at the Scanning Electron Microscope used in the Back-Scattered mode. The Index is calculated on the relative amount of pores that have a certain dimension in terms of maximum diameter (see ternary diagram in Figure 6). The three main categories are:

- Pores of less than 25 microns; this is the category of micro-pores, associated with small pore-throats; the 25 microns threshold is used in order to stay above the limit of digitalisation of the pores, which is normally of 3 to 5 microns;
- Pores between 25 and 100 microns, associated with small to intermediate pore-throats;
- Pores above 100 microns, associated with large pore-throats.

The Reservoir Efficiency Index (e-rei)

The average value of the three indexes is the Reservoir Efficiency Index. A further correction is applied to the index in order to take into account the effect of porosity, as the same index may result for samples with different porosity. The porosity correction is designed for a strong correction in the 0% to 20% region, and for a very low to nul correction above 20% for samples without microporosity. For samples with microporosity the correction is more effective and follows the second line. Laboratory porosity is generally used but, if it is not available, the porosity value directly measured on the samples through image analysis is utilised.

Conclusions

Rock Microcharacterisation provides the quantitative data on which the e-rei is calculated. The e-rei is an index which takes into account all the petrographic variables that really influence fluid flow. In this sense it is independent from any local geological setting, as the e-rei is dependent mainly on depositional parameters and the diagenetic evolution.

The e-rei has demonstrated to be well correlated to permeability over the whole permeability range (Figure 3). A e-rei value 0 corresponds to 0 permeability, while a value of 1 is never reached and corresponds to values around 10 Darcies or more, which is reasonable, since all reservoirs underwent at least mechanical compaction.

The e-rei, calculated on the sedimentary facies, may be extended to the non-drilled areas on the basis of geological considerations on the depth of burial and on the nature of the sediments, driven by the sedimentological model. In this sense it is the best way to distribute the expected porosity and permeability in a play-fairway analysis.

Due to the fact that the e-rei is independent from the geological setting, it may also be used as a proxi for the porosity and permeability for plays or prospects that belong to very different basins or even counties. The strength of the e-rei lies in the fact that a quartzose sandstone with similar depositional characteristics in terms of grain-size and sorting and similar depositional setting will end up with a similar porosity and permeability, and its burial and thermal histories are also similar.

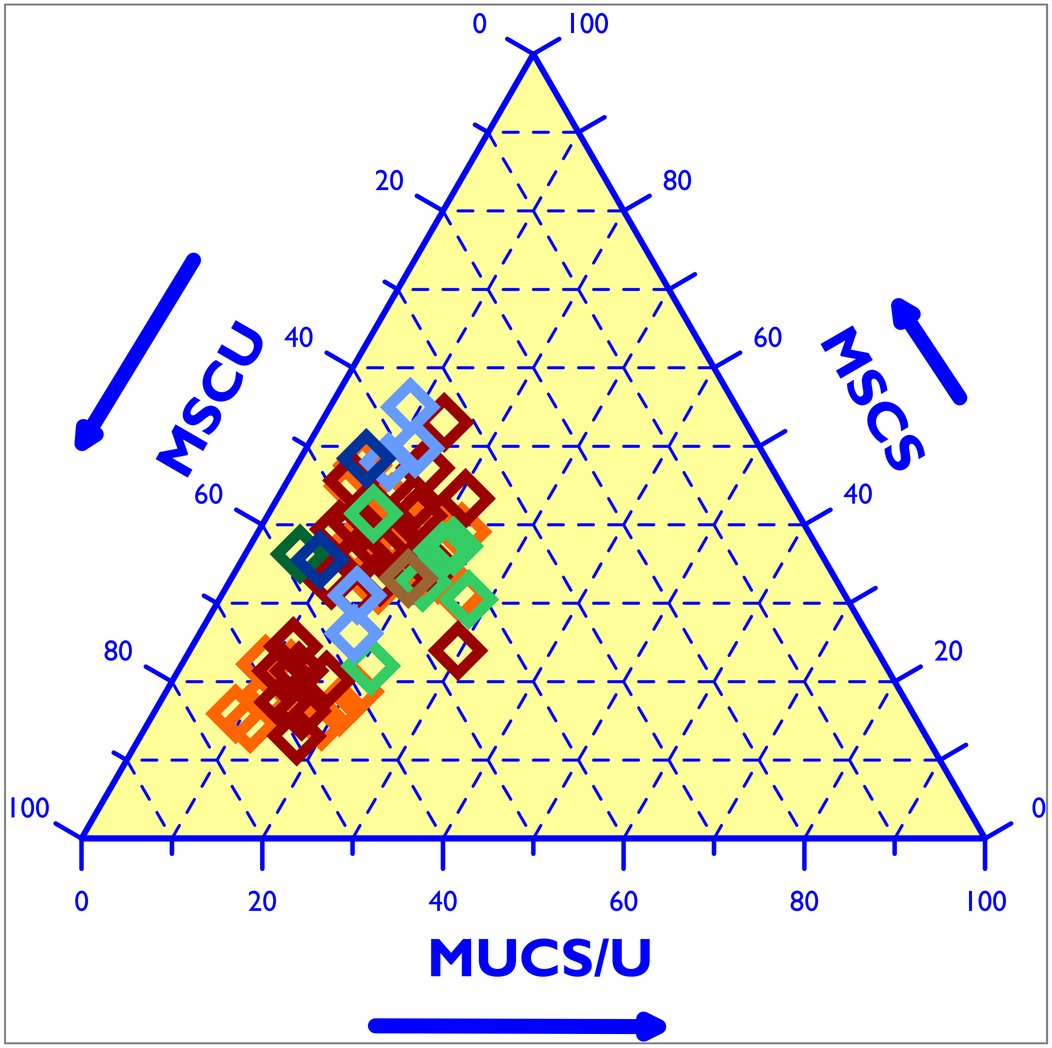

Figure 1. An example of a sandstone with filamentous illite covering grains. This type of clay texture has a high impact on permeability and is difficult to quantify (Scanning Electron Microscope).

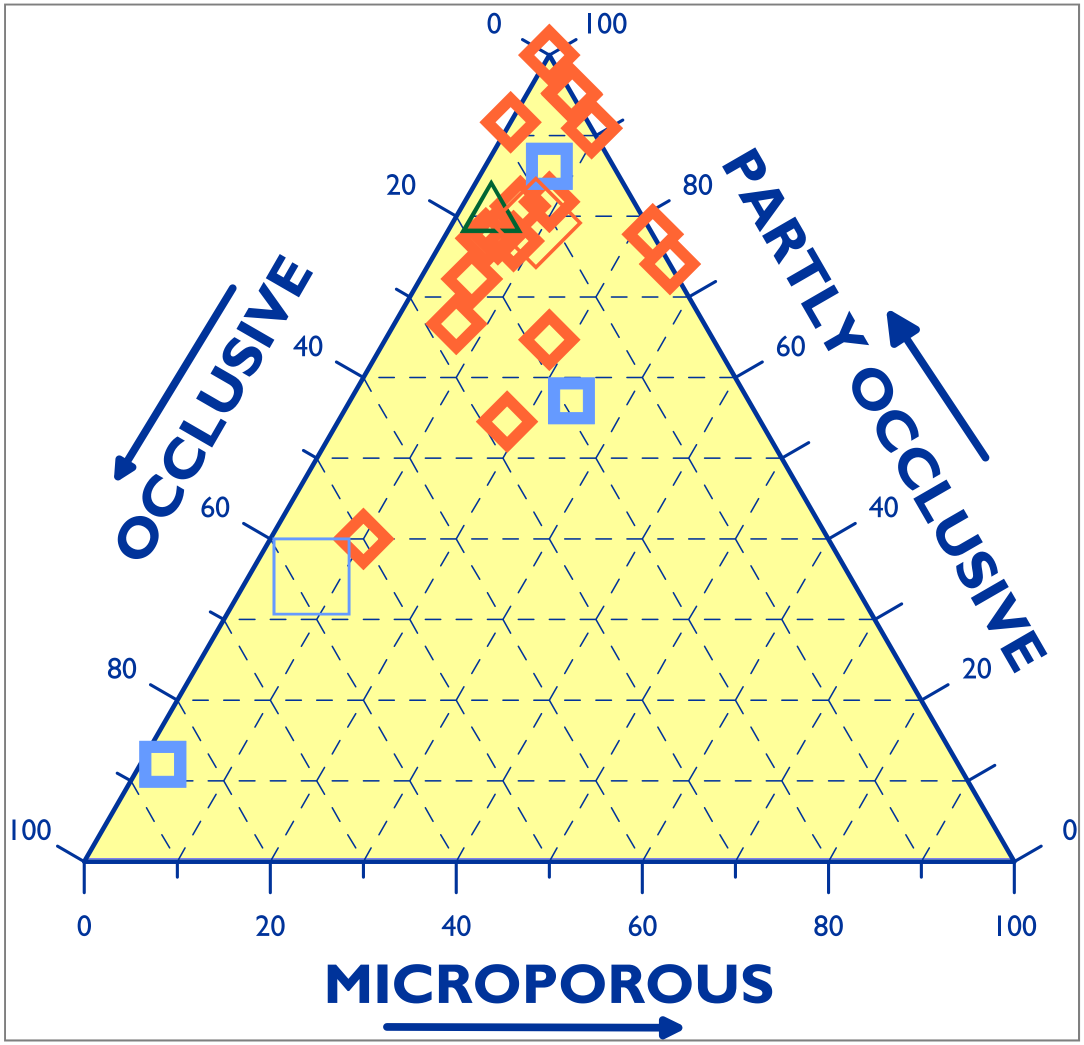

Figure 2. Porosity correction curves. The samples used for calibration are in yellow. The magenta line represents the correction for purely microporous samples.

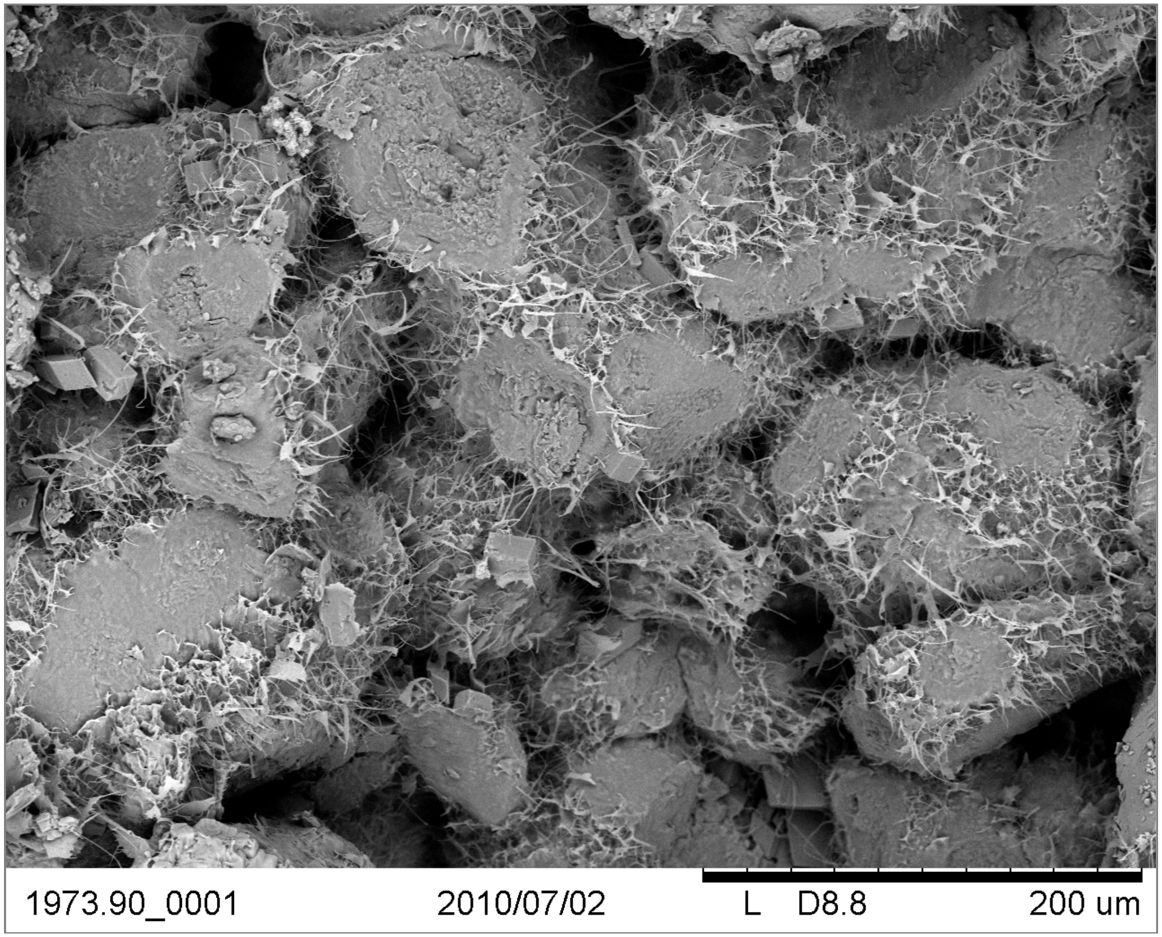

Figure 3. The correlation of e-rei with permeability is good (R=0.84) over the entire permeability range. The data-set utilised is of around 1000 samples. The horizontal permeability is obtained in ambient conditions from plugs. The magenta squares represent the average permeability value for each e-rei class. The yellow triangles represent the geometric mean of permeability for each e-rei class.

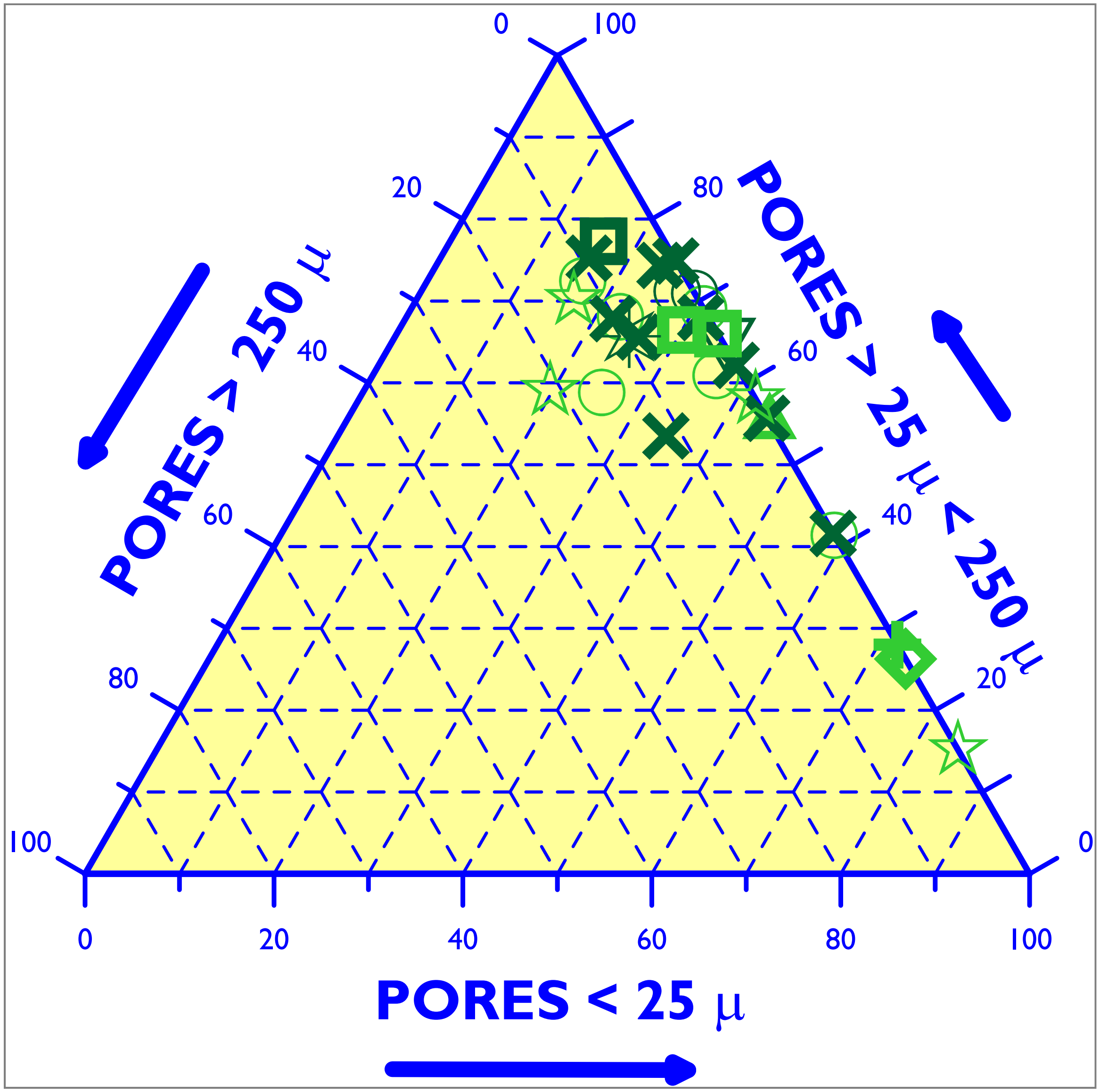

Figure 4. Ternary diagram used to calculate the Clast Dimension Index.

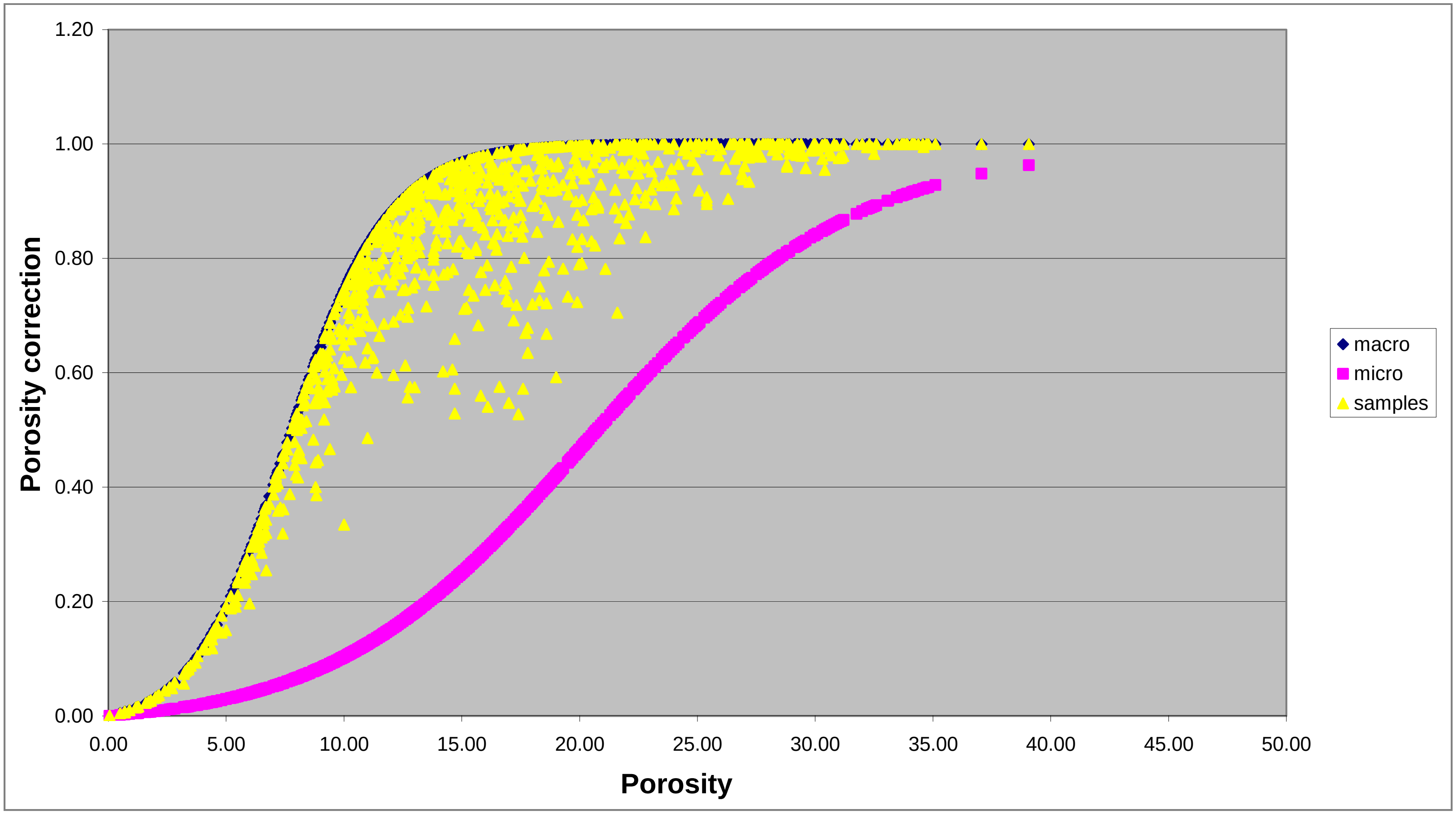

Figure 5. Ternary diagram used to calculate the Filling Dimension Index.

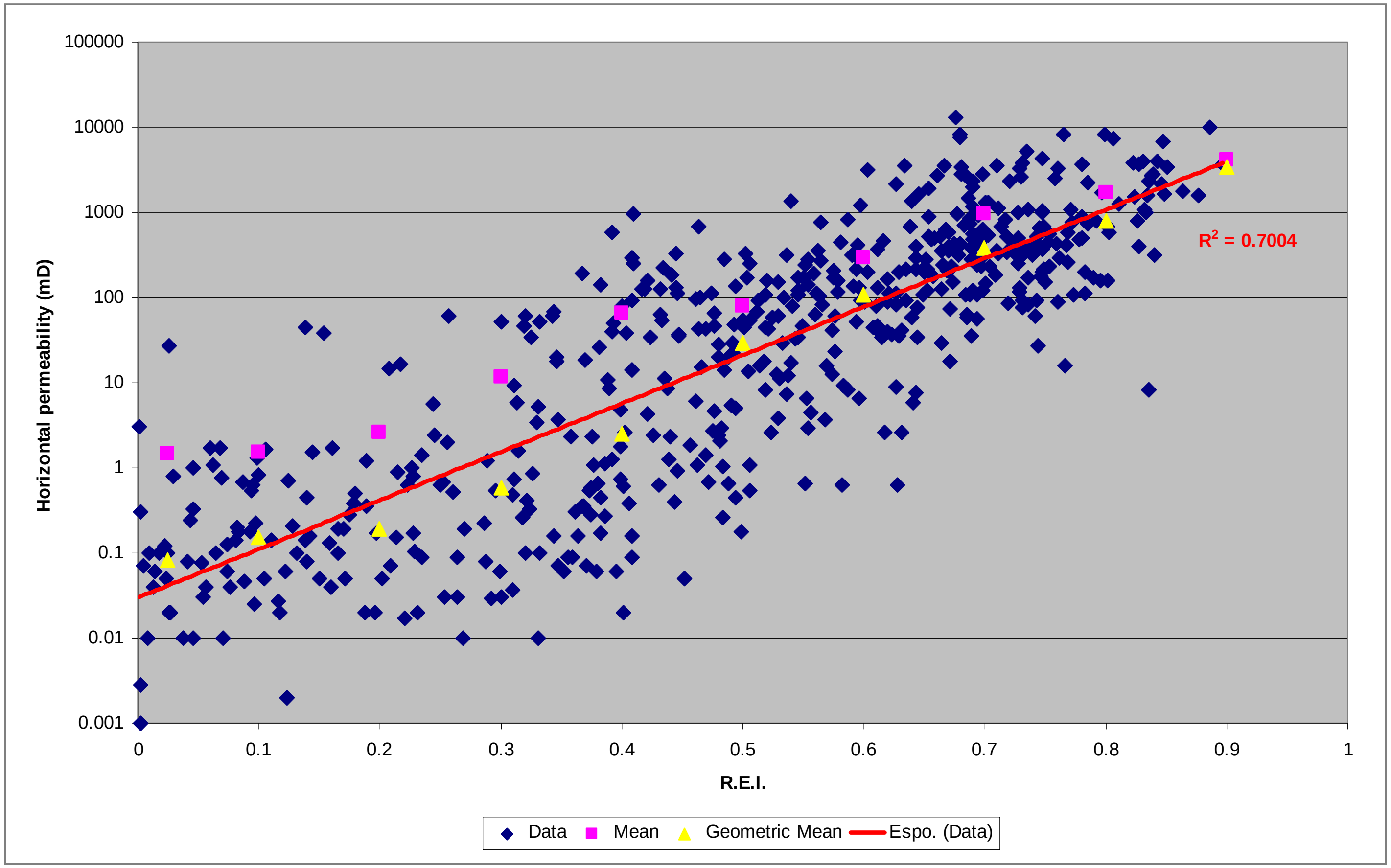

Figure 6. Ternary diagram used to calculate the Pore Dimension Index.