Assessment of rock quality classification based on Principal Coordinates Analysis of conventional petrophysical and NMR data

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Abstract

This paper shows how principal coordinates analysis, PCO, can contribute to asses the correspondence between porosity, permeability and the ratio of moveable fluid over bound fluid volumes data and the rock quality classification of water saturated core plug samples.

The rock quality characterization of the samples from El Furrial field in eastern Venezuela is based on the determination of the Winland-Pittman equation of the port size. This characterization, taken from the literature, is based on NMR measurements of water saturated core plugs samples. The results show that a plot of the first and second PCO yields a characteristic horse shoe curve (2D), or a more accurate spiral curve (3D) by taking also the third PCO (3D) into account. The trajectory of these curves follows a continuous variation in the rock quality of the samples, from Megaporosity down to Nanoporosity. This procedure represents an easy, non-destructive way to obtain a rock quality classification based on conventional and NMR derived petrophysical variables and PCO.

Introduction

In recent years, the rock quality determination proposed by Winland and Pittman [Pittman, 1991] has been intensively used in petrophysical evaluations of Venezuelan reservoirs [Porras et al., 2001]. This procedure relies on the determination of the pore throat radius dominating the fluid flow, which is empirically related in the Winland-Pittman's equations to the porosity and permeability. Usually, the choice of the most suitable port size equation depends on the behavior of capillary pressure curve from the mercury injection. However, it is possible to obtain similar results without the need of mercury saturation and the consequently sample losses by using capillary pressure curves derived from the NMR T2 distributions obtained from water saturated core plug samples [Romero, Gomez, 2004], as the capillary pressure curve can be approximated by the accumulative T2 distributions.

Once the sample classification is done in terms of Megaporosity, Macroporosity, Mesoporosity and Microporosity, as shown in fig 1, a comparison of the shapes of their T2 distributions reveals a correspondence to the rock quality classes, figure 2. By applying a principal coordinates analysis to the data set containing permeability, porosity and NMR variables from the T2 distribution from 21 core samples measured at 100% and irreducible water saturation, it is possible to represent the data in a 3D-PCO space, where the samples are distributed regarding their rock quality classification.

Method

The data analyzed in this paper is from El Furrial field in eastern Venezuela [Gomez, 2003]. The equation chosen for the port size is the r_{25} [Romero, Gomez, 2004]:

$$\log r_{25} = 0.204 + 0.531 \cdot \log k + 0.350 \cdot \log \phi ,$$

where 25 means the mercury saturation in percents at which a continuous flow rate is reached during the fluid injection process. The input data for PCO has been chosen to be the porosity, the permeability and the ration of moveable fluid over bound fluid volume, which can be considered equivalent to the pore throat radius in the Winland-Pittman equation [Romero, Gomez, 2004].

The input data for the PCO analysis was performed with the PAST software package with the Morisita similarity index (Hammer et al., 2001). Any other option of multivariate analysis as principal components, non-metric multidimensional scaling, cluster or correspondence analysis did not yield as consistent as PCO. Although the PCO yields as many principal coordinates as number of samples used, no more than three principal coordinates are found to contain significant information for classification purposes.

Results

A first attempt to classify the samples using only permeability and porosity as input variables for PCO yielded as horse shoe curve by plotting the PCO-1 against the PCO-2 as shown in fig. 3. However, the sequence of the samples did not follow very well the underlying rock quality classes, specially the samples 224 and 625 with a very low permeability corresponding to the Microporosity class. This behavior can not be detected in a 2D plot as shown in figure 4.

A similar case occurs with the output of the PCO from accumulative T2 distributions, which behaves better than the standard T2 distribution for PCO classification purposes. Figure 5 shows how the trend, starting from the micro to macro and even megaporosity, is not followed by three samples 341, 418 and 461. This behavior is probably because these samples show a relatively low FFI (moveable fluid index) over BFI (bound fluid index) ratio, even having a T2 maximum higher than 100 ms.

Table 1 Input variables for PCO

Sample No.	Rock Quality Facies	Perm mD	Por %	FFI/BFI	T2max ms
102	Mega	1302.0	15.1	12.1	103.7
105	Macro	41.3	16.3	2.3	8.0
143	Meso	10.4	10.4	1.0	6.9
201	Mega	1290.0	19.8	13.0	83.4
224	Micro	0.4	8.4	0.3	2.2
256	Macro	22.2	12.6	1.7	6.0
309	Mega	953.0	17.1	6.4	103.7
320	Meso	8.6	10.3	0.6	53.7
333	Mega	171.0	18.6	3.9	62.2
341	Mega	709.0	16.6	5.2	200.3
406	Macro	241.0	19.6	5.1	83.3
408	Mega	354.0	18.7	5.7	94.6
418	Mega	588.0	19.1	4.8	173.0
423	Macro	21.9	14.2	2.7	53.7
461	Macro	34.0	16.1	2.1	268.3
524	Macro	178.0	16.6	3.5	62.2
621	Meso	9.7	13.9	1.8	16.7
625	Micro	0.1	11.3	0.3	0.9
660	Macro	44.9	8.9	1.3	2.3
681	Macro	43.7	13.4	3.1	22.3
685	Macro	31.6	14.5	3.2	25.9

By taking as data input the permeability, porosity and the ratio of FFI over BFI, the PCO analysis yield the results shown in figure 6. This result shows the smoothest transition in terms of rock quality for the whole sample set, beginning with the very low quality samples as 224, 625 and 320 and following a spiral curve up to the high quality ones like 102 and 201 with the highest FFI over BFI ratio. This approach honor three different rock properties: the pore space volume (porosity), pore space connectivity (permeability) and fluid distribution (movable and bound fluids). In the same way the Winland-Pittman equation relates the porosity and permeability to the pore throat radius, related to the capillarity pressure, which is highly responsible for the amount of movable and bound fluids.

Conclusions:

The principal coordinates analysis, PCO, can be used to asses the correspondence between Winland-Pittman rock quality classification of core plug samples and their conventional and NMR petrophysical data. The results show that only the first three PCO are significant. According to their rock quality classes, the samples are aligned along a horse shoe (2D) or spiral 3D curves yielded by PCO representations. This can be explained due to the fact that the PCO input data honor the pore space volume, the pore connectivity and the capillary forces on the fluids in the same way as the port size equation proposed by Winland-Pittman. The fact that the NMR variables, represented by the moveable and bound fluids, contribute significantly in the PCO corroborates the approach of using NMR instead of destructive mercury injection for port size determination purposes.

Acknowledgment

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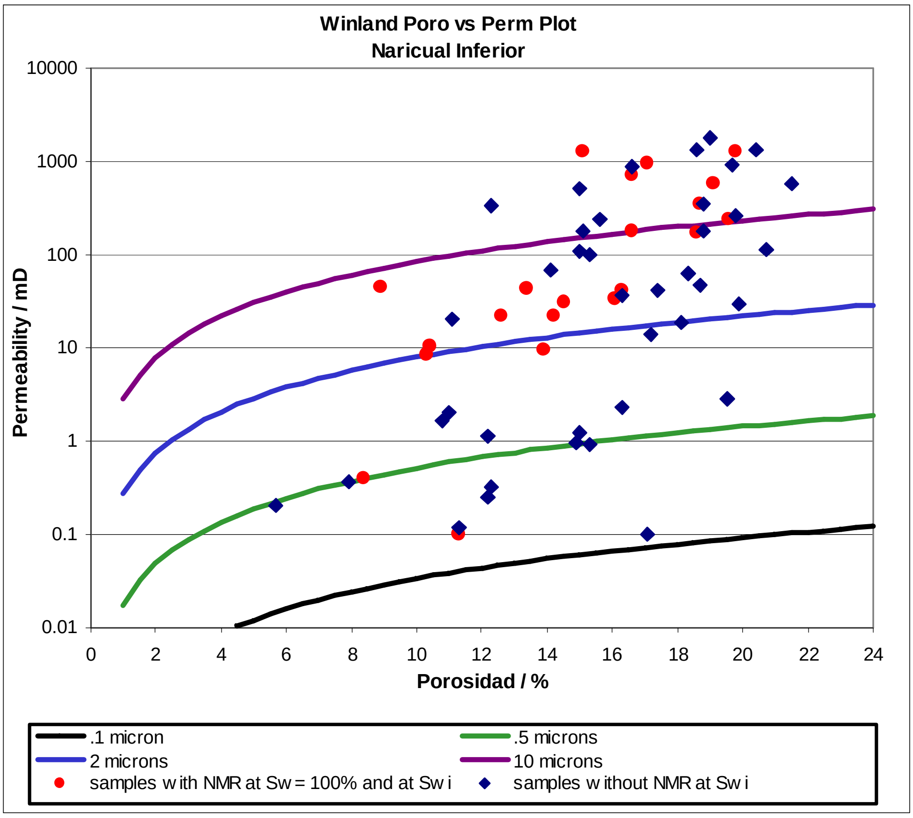

Figure 1 Rock quality ranges in a porosity-permeability crossplot

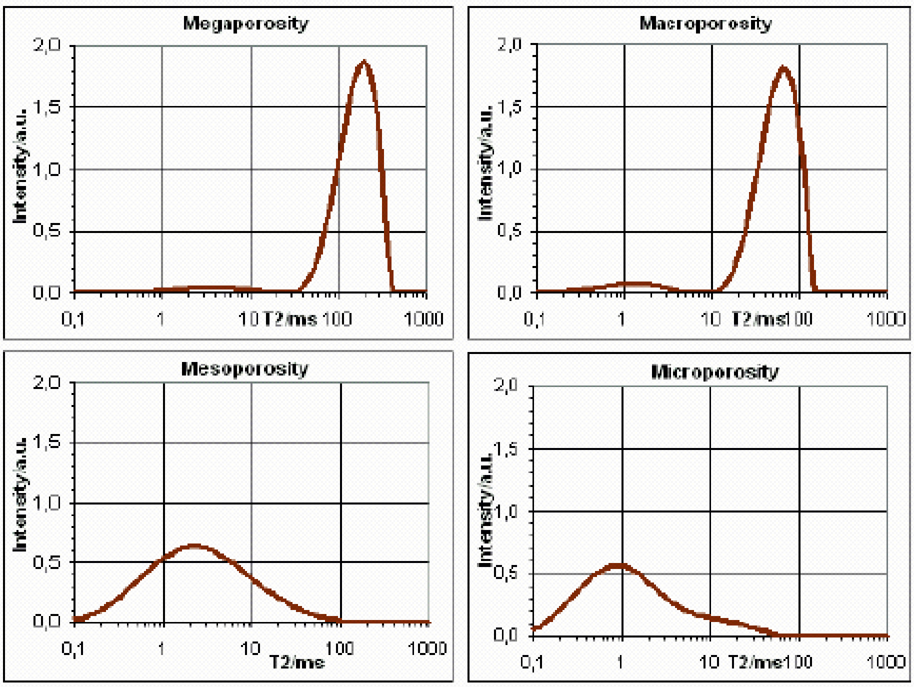

Figure 2 Typical T2 distributions of different rock quality samples

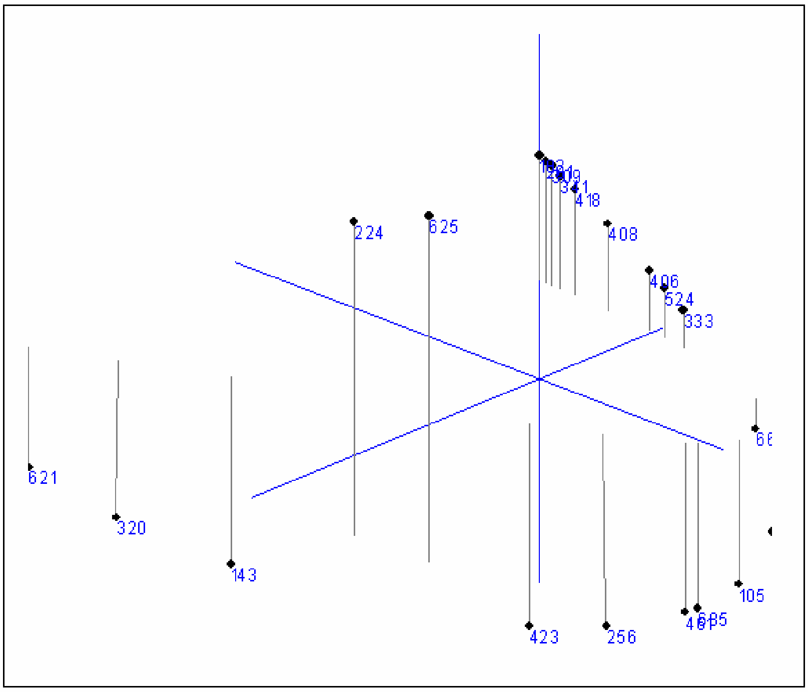

Figure 3 PCO of Porosity and Permeability

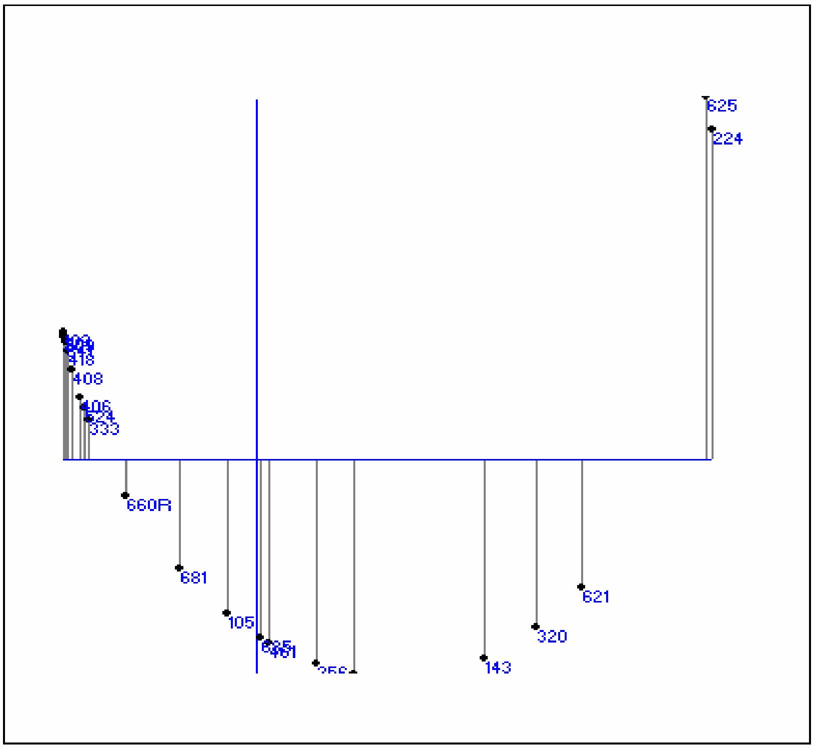

Figure 4 2D PCO of Porosity and Permeability

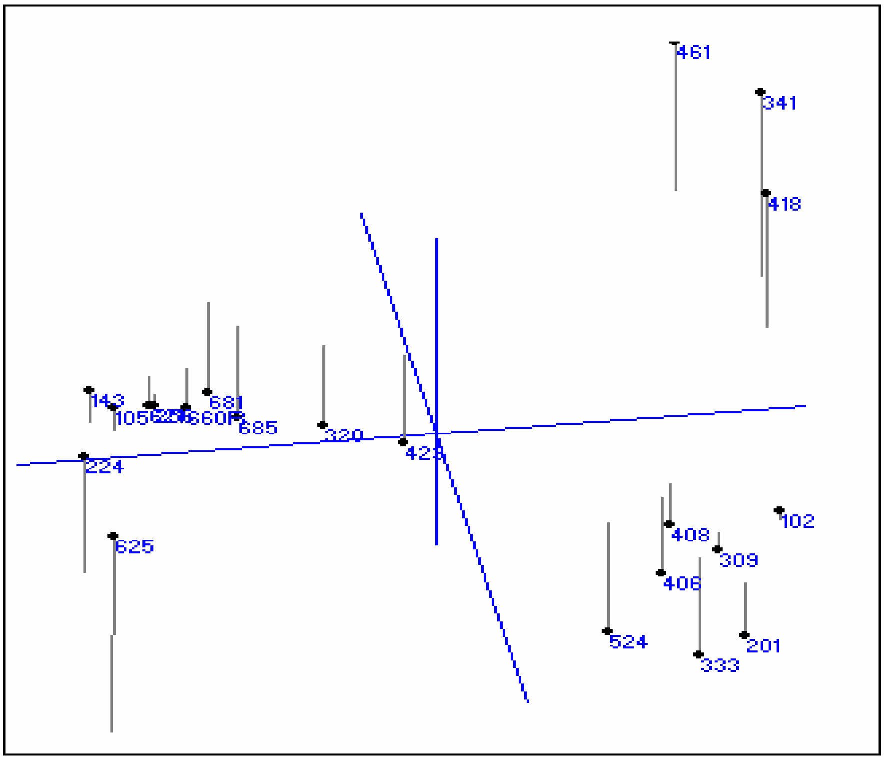

Figure 5 3D PCO of accumulative T2 distributions

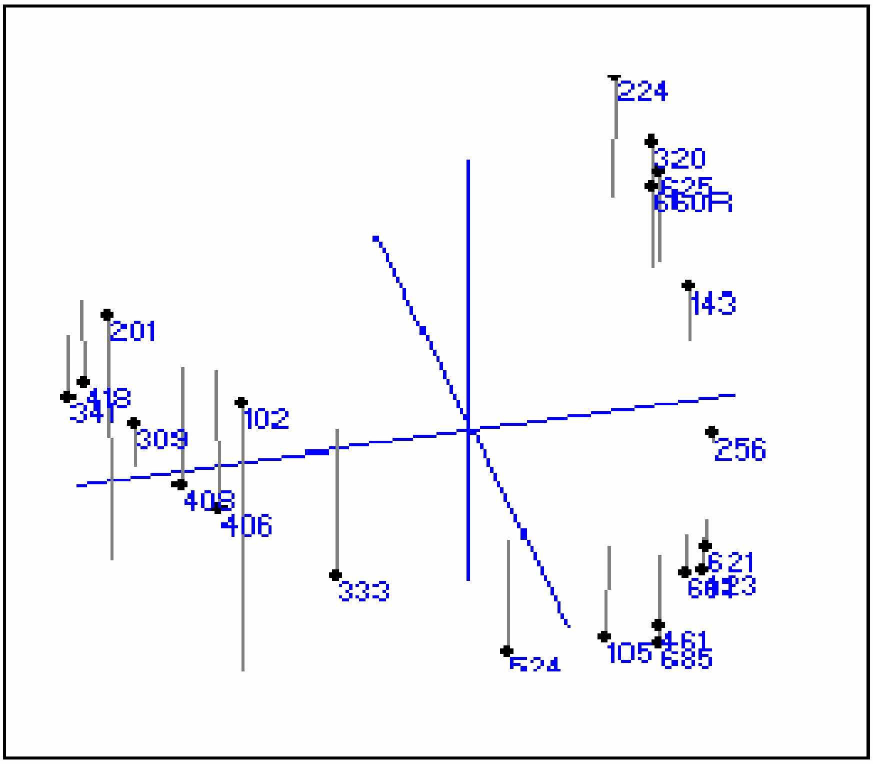

Figure 6 3D PCO of Poro, Perm and FFI/BFI