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PORE SIZE AND GEOMETRY OF RESERVOIR ROCKS USED AS KEY FACTOR FOR DRILLING AND COMPLETION FLUID DESIGN OF OIL WELLS

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Abstract

The initial poor well productivity in many cases is a result of the lack of control for fluid loss and the invasion during drilling and completion operations. Rock formation attributes like pore geometry within the rock should be considered as a key factor in the design and selection of reservoir drilling and completion fluids with capabilities to control the fluid loss and the invasion effectively.

Drilling and completion engineers as well as related professionals need to have a better understanding of sizes and shapes within the reservoir pore system in order to formulate optimum fluids to minimize the formation damage. The size and shape of pores, pore geometry, is usually determined using direct visual methods like petro graphic thin section analysis and scanning electron microscopy (SEM). The Mercury injection porosimetry has also been used as an indirect method to get the pores' size.

Limitations of pore geometry SEM measurements have been revised and applied in both synthetic and real formation samples with the usage of fundamental concepts, methods and available data of pores. The digital image processing and analysis are presented as an applied technology tool used to enhance the pore system interpretation, as soon as images were obtained through conventional SEM practice. Concepts like pore throat, body, connectivity and 2D to 3D analysis were discussed in detail to make the actual pore geometry information more accessible and useful to drilling and completion fluid design teams.

Introduction

Reservoirs drilling fluids or Drill-In fluids have become widely used in recent years due to their relationship with higher levels of well productivity. Properties of these fluids have been studied mainly from the perspective of rheological and filtration tests performed extensively in the lab in a trial and error approach.

Filtration testing using paper or synthetic ceramic media is an approximate way to evaluate bridging materials in order to control possible fluid losses. This approximation introduces an error in fluid design that will be critical if there is not a good matching with representative rock pore geometry, piece of information not available in most cases, and introducing the use of field rules of thumb, like the calculation of the square root of permeability to get pore geometry "risky" values.

Formation attributes from any candidate well come usually as a geological-petro physical report from offset well cores, with little or no mention to formation pore geometry. Sometimes mercury porosimetry is presented, somehow its interpretation is not simple, and data provided is an indirect pore size distribution technique. Pressure is measured and pore aperture radii and general pore size are calculated from it. There is no information of pore shape.

Direct visual methods, on the other hand, give no representative quantitative but rather qualitative information of pore sizes and shapes. This limitation can be solved after appropriated sample preparation and observation through SEM in BSE (Backscattered Electron) detection mode followed by digital image processing and analysis of two dimensional images.

Stereology has been defined (Russ, 1991) as the study of the three-dimensional structure as revealed in two-dimensional images, usually of sections through it. Stereometry is, therefore, the measurement of these structures. In Stereology we are forced by the very nature of the measurement process to sample the 3-D structure, and the extent to which our samples reveal the “truth” about what is there is fundamentally a statistical problem. In our case, two-dimensional images are representative sections through a 3-D structure of a rock. This is almost always shown as a plane, because it makes the mathematical analysis simpler and corresponds in most cases to the way actual sections are prepared (by cutting, grinding, etc). These images show pore geometry clearly differentiated from the clastic grain arrangement or fabric as geologists call it. More accurate measurement of pore bodies and throats and how they are connected will be the input to optimum selection of seal properties on any working fluid proposal.

Pore Geometry Fundamentals (Precompaction Geometry-Packing)

Two principal sedimentary characteristics, which affect the packing, are the shape of grains and their geometric arrangement. Almost all theoretical and experimental studies of packing have used spherical particles or points in space. The principles are well understood and for geologists interested in sediments, have been presented at length by Graton and Fraser (1935), who dealt with the regular packing of spheres and progressed, to more irregular, random packing arrangements. Naturally, there is criticism of using spheres as model grains.

There are two types of layers, which are stable against the force of gravity acting alone; they are the square and simple rhombic (Figures 1A-B), and there are three simple ways of stacking square layers one on top of another (Figures 2A-F). Because two of the three ways of staking square layers are identical to, but differently oriented from, two of the three ways of staking simple rhombic layers, there are six fundamental regular arrangements. Two of these six arrangements repeat as to form (grain volume, porosity) but differ in symmetry and hence in tortuosity and permeability.

In addition, the six packing types can be characterized in terms of coordination numbers and the number of other grains touched by an arbitrarily chosen central grain. Coordination numbers, which are common in crystallographic terminology, are almost impossible to derive for compacted sediments and rocks. Their packing must be described in other less precise terms, partly because the packing of natural grains is seldom regular to any appreciable extent and partly because of cementation.

The porosity of regular packing configurations is fixed and directly related to the geometric arrangement of the pack. Because the sorting of grains of the six types of packing is regular, the sorting of their pores is also regular. Graton and Fraser (1935) made extensive determinations of the geometry of the pore space, including serial sections of the pores in the regular packs (Figures 3A-B).

Figure 1: Plan View of two types of regular packing layers. A simple square layer and B simple rhombic layer

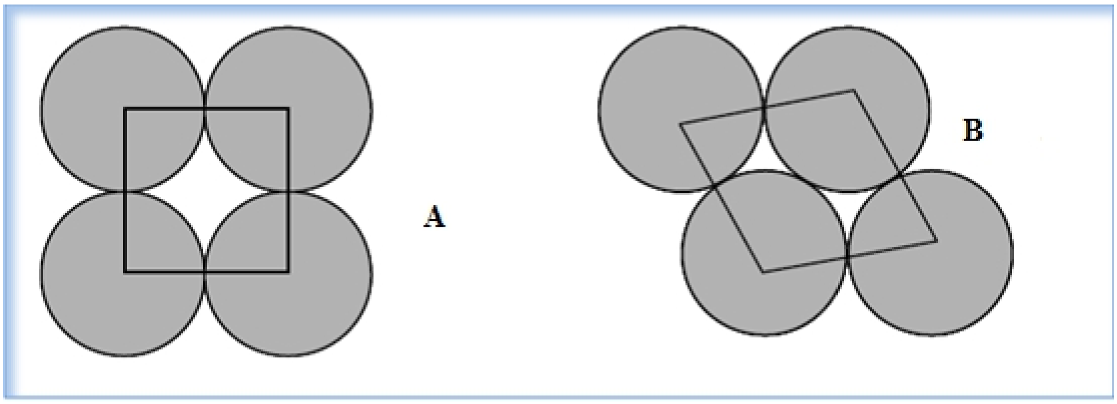
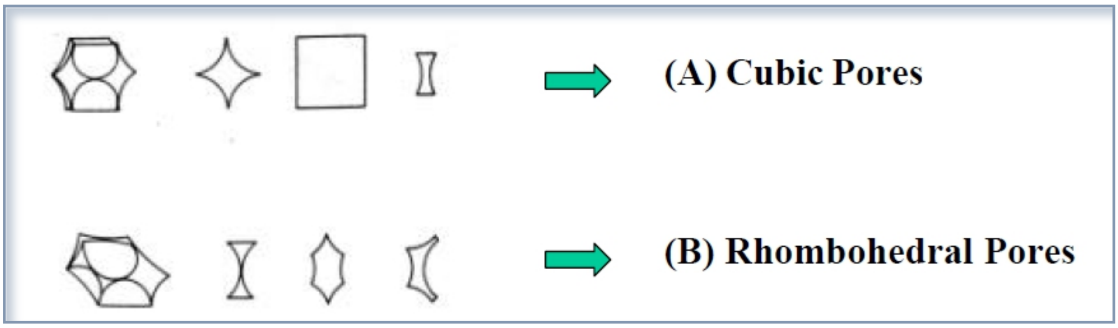


Figure 2: Six regular pack configurations of uniform spheres. Cases A-C are arrangements of square layers, Cases D-F represents similar offset of stacks of rhombic spheres.



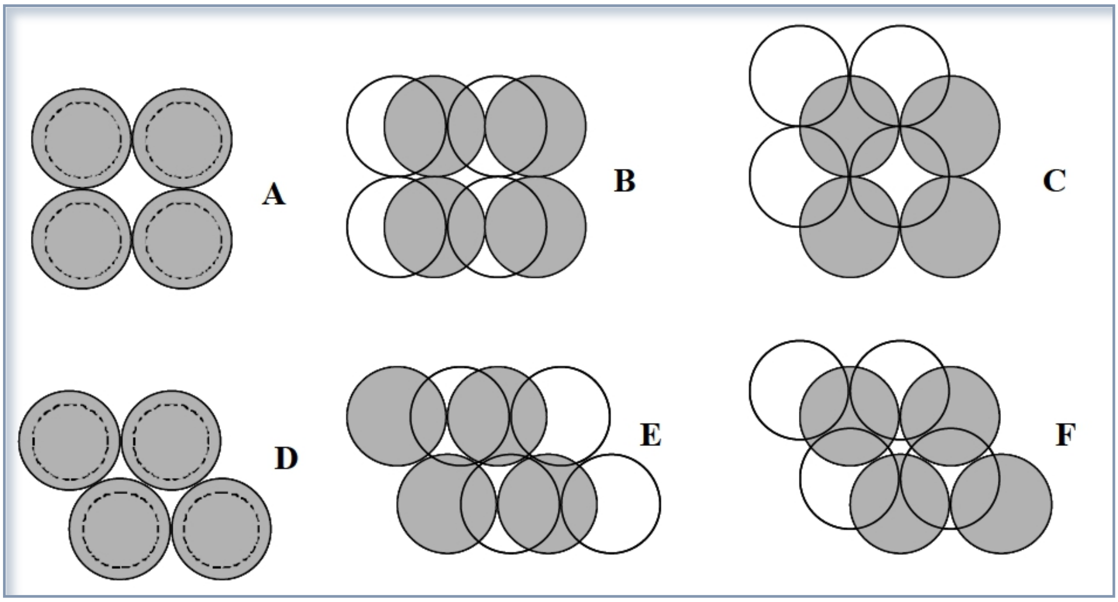


Figure 3: Geometry of pore space in cubic and rhombohedral packing, seen as though the solid spheres were removed. Right – hand figures represent different cross sections.

It is clear that the space in rhombohedral packs is not only less (25.9% porosity versus 47.6% for cubic packs), but the geometry of the pore space is markedly different. In rhombohedral packs there is less grain surface area exposed to wetting fluids and the capillary pressure and surface tension for the whole pack are higher. All of these characteristics affect the subsequent compactive forces as they relate to solution of the grains under pressure and the maintenance of pore pressure.

Packing heterogeneities

Small-scale packing heterogeneities have been investigated by Morrow (1971) in terms of the distribution of pore sizes, which is indicative of grain size heterogeneities in sediments without clay or cement. Packing heterogeneities occurs where there are variations in particle size or packing in different areas of the rock. Capillary pressure drainage curves can be used to characterize packing heterogeneities in rock, because the slope of the curve reflects the pore size distribution of porous sand. In addition, larger interconnected pores tend to drain faster than smaller ones (Figure 4A).

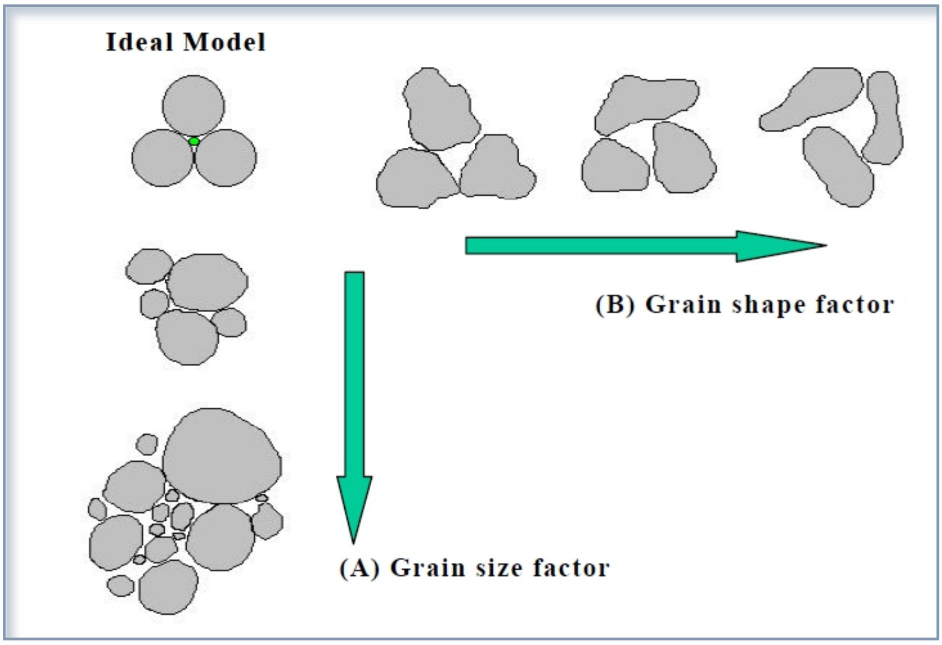


Figure 4: Effect of random packing heterogeneities (A) Size, (B) Shape.

Random packing of irregular grains

The shape of sedimentary grains is probably never spherical, not even in politic sands, and these irregularities in shape should result in a larger possible range of grain percentages in sediments, because irregular grains theoretically may be packed either more tightly or more loosely than regular packed spheres. The shape of marine sand grains is reported to be fairly uniformly disk shaped and may be packed more tightly to the third dimension, with flat sides together, which would allow for higher grain volume percentage. The grain volume percentage for beach sand does not differ widely from that on spherical grains (Figure 4B).

Experimental

Three types of porous media were prepared for SEM-BSE observation. Resin impregnated flat and polished casts of non-consolidated and consolidated sandstone, and one fragment of aloxite ceramic, provided the raw digital images that were processed and analyzed to get information on pore body and pore throat size distribution and also information on pore connectivity and pore shape. All these attributes are explained in detail on each example.

Consolidated sample images (aloxite, consolidated sandstone) show a less disturbed pore geometry that can be visualized in 3-D using original 2-D images as input. This practice gives a clear picture of how tortuosity would be and how pore throats can be related to restrictions of flow path. Non-consolidated samples unfortunately are affected by confining pressure conditions that change from bottom hole to surface. Handling of this kind of sample (freezing, trimming, and cutting) alters original spatial grain arrangements.

Results and Discussion

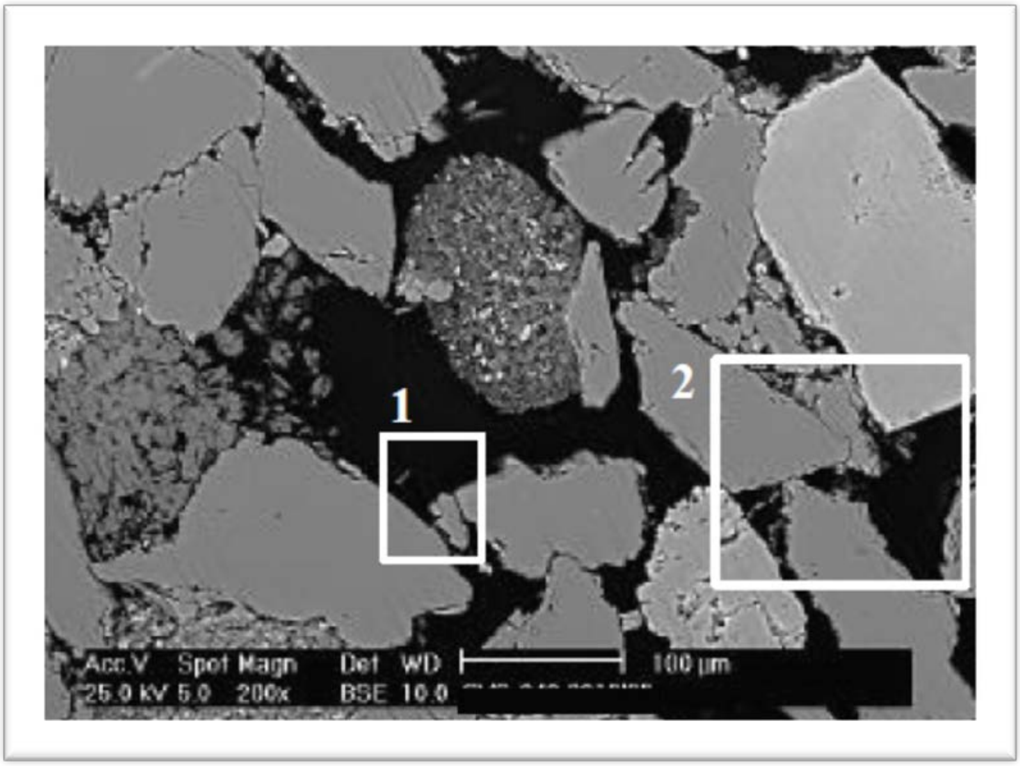


Figure 5: 3.D Conversion from 2-D rock image, defining pore throat, pore body and pore connectivity

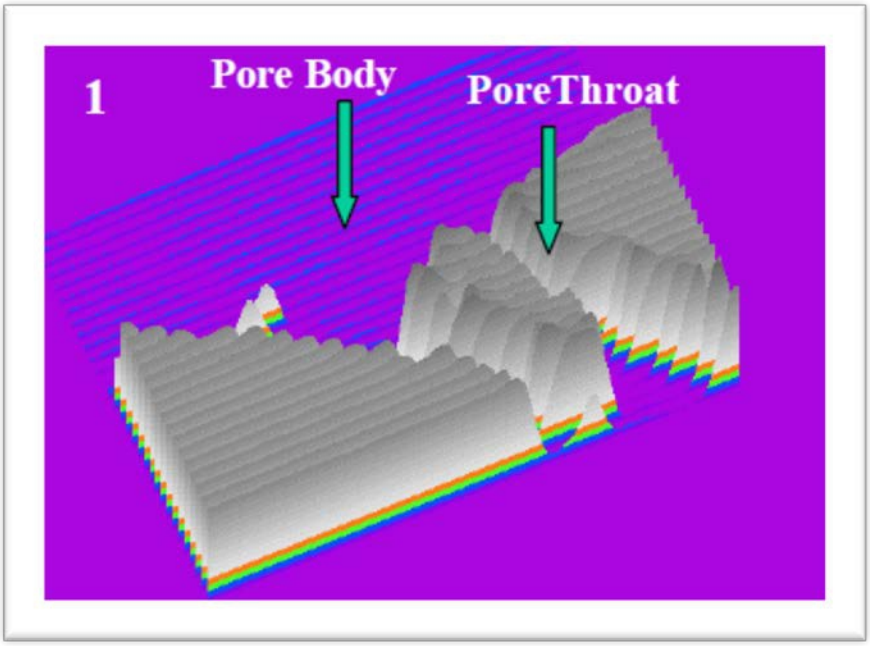


Figure 6: Defining pore throat, pore body and pore connectivity

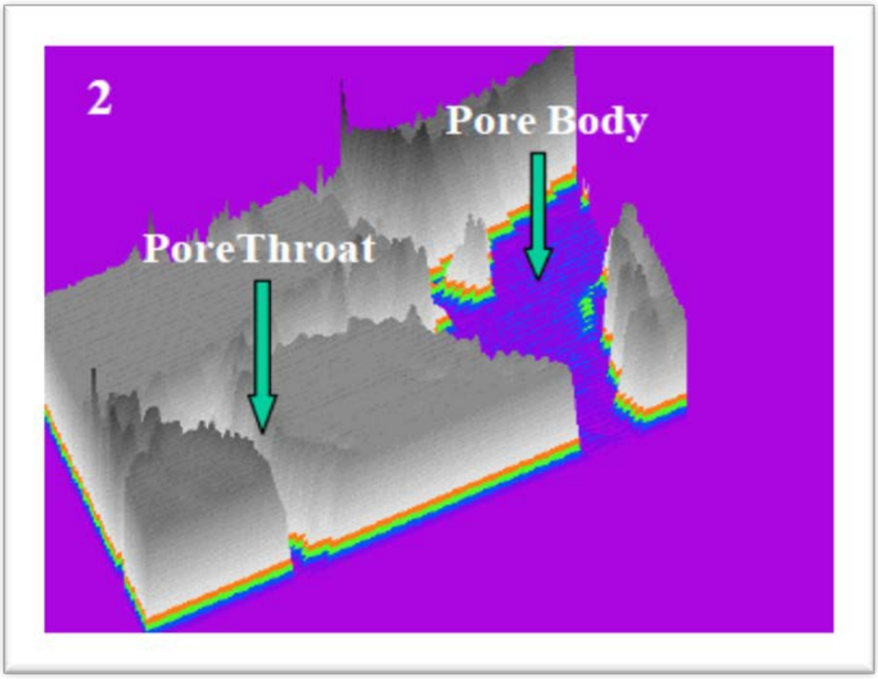


Figure 7: Defining pore throat, pore body and pore connectivity

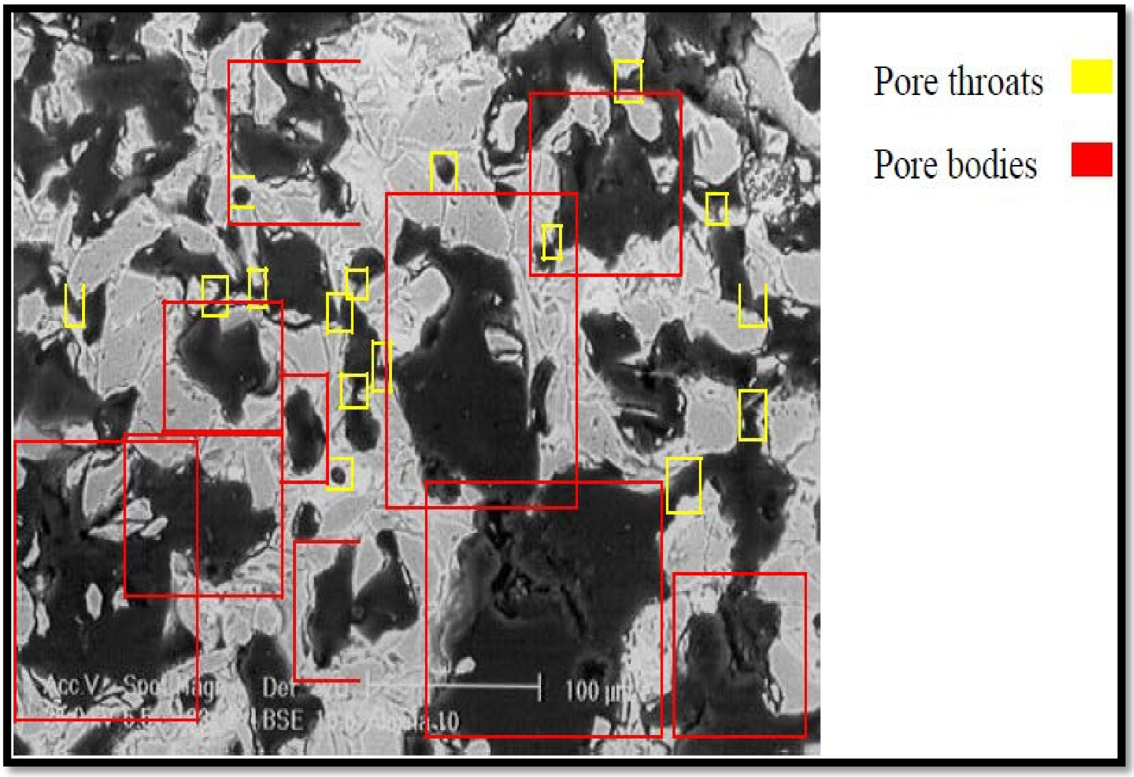


Figure 8: Synthetic Porous Media (aloxite ceramic – 10 ☐)

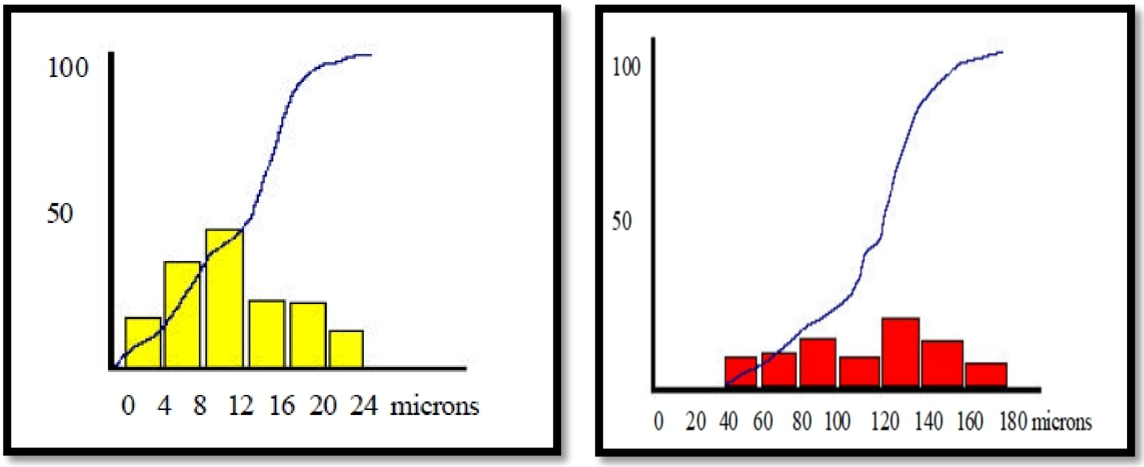
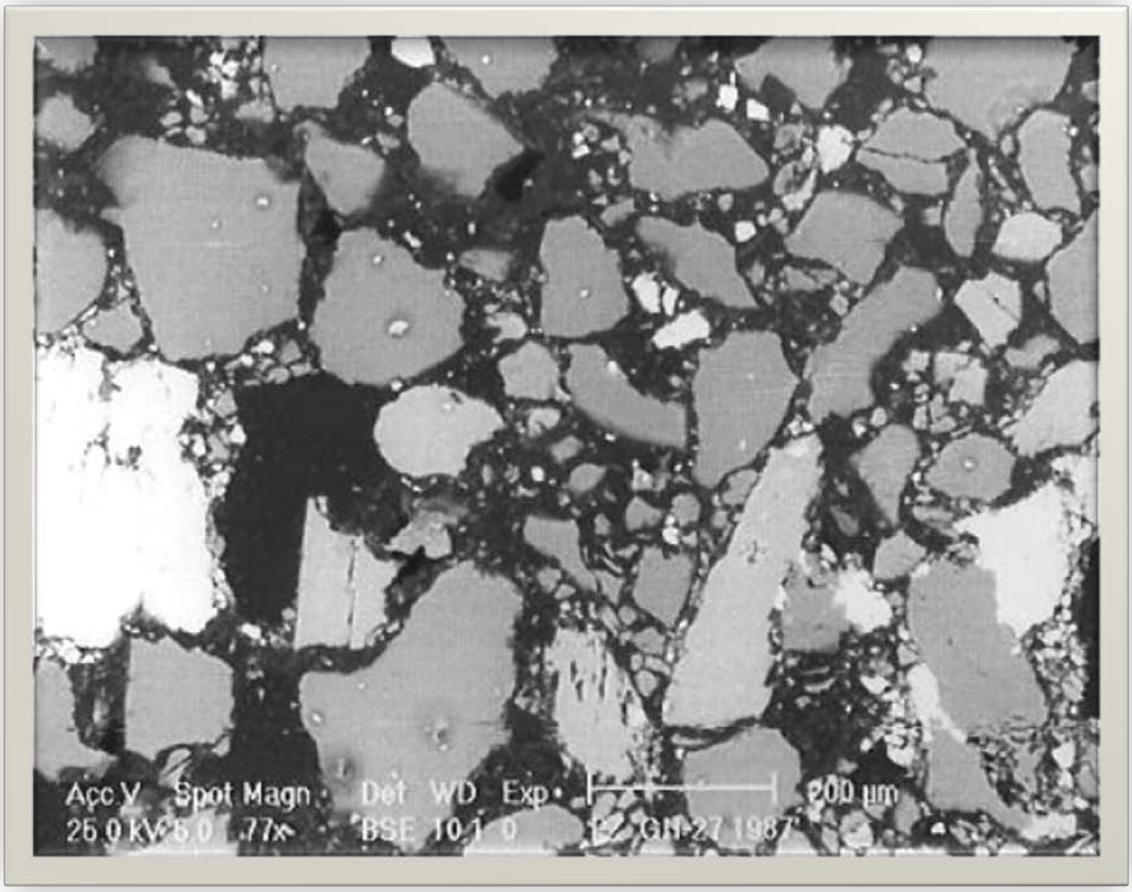


Figure 9: Non-consolidated sandstone (bitumen)

Picture bar scale is 100 microns. Black tone is resin filled pore space. Size distribution is given for both pore bodies and throats. This synthetic media shows high connectivity between pores with irregular shapes. Pore throat size distribution is narrow and gives a mean value of 11 microns.

Figure 10: Non-consolidated sandstone (bitumen)



The manufacturer reports 10 microns as the mean value. Pore body size distribution is broad with a mean value of 110 microns. With these numbers this porous media can be subjected to filtration tests selecting the optimum particle size distribution of bridging agent.

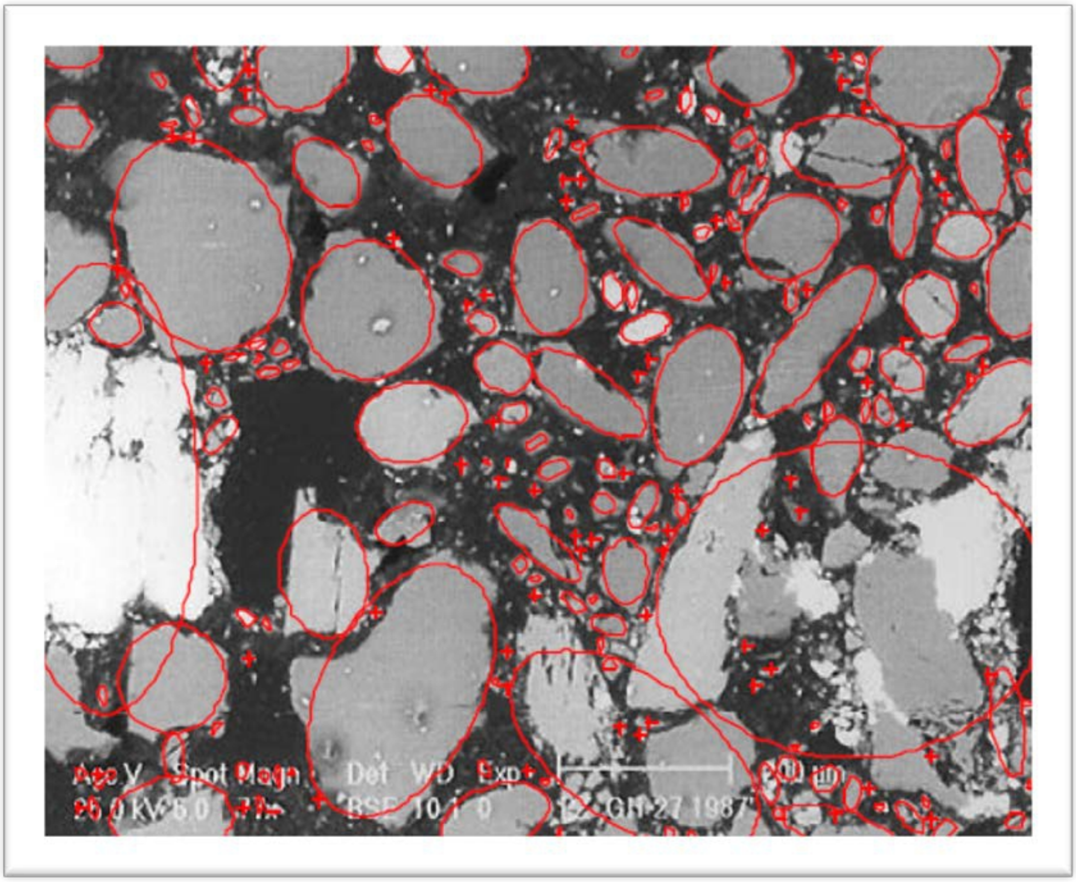


Figure 11: Non-consolidated sandstone (bitumen)

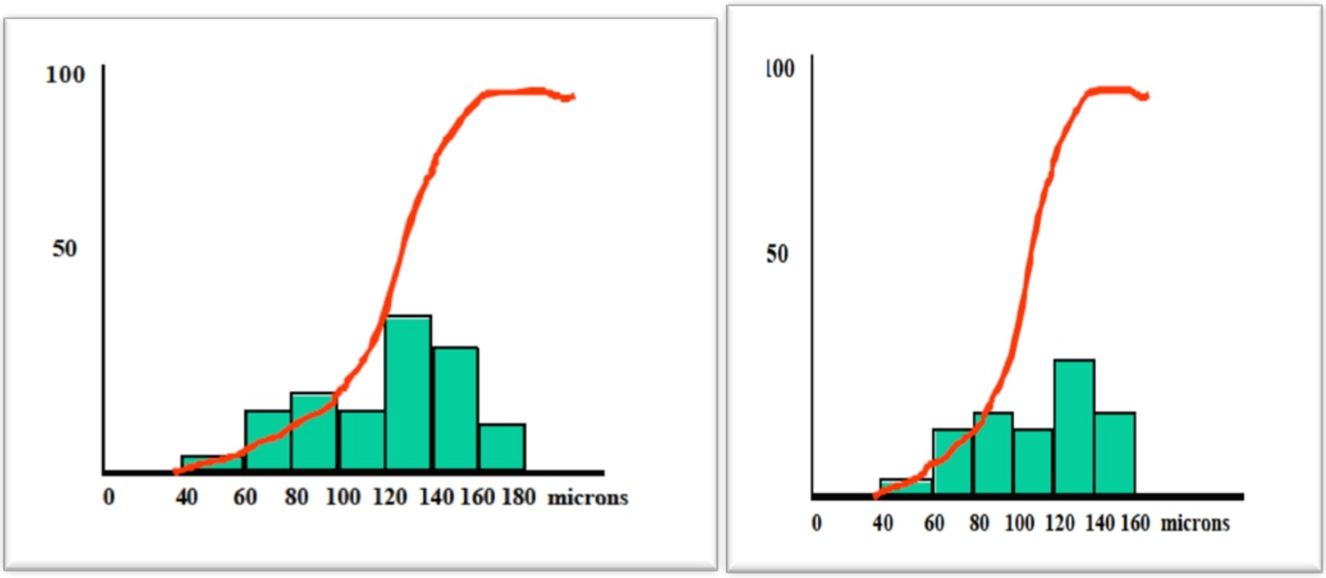


Figure 12: Non-consolidated sandstone (bitumen)

Clastic grains are computer measured to resemble an ellipse, with equivalent average diameters. Two big ellipses include several grains and are not considered for actual calculations. The histogram presented represents a visual granulometry with a mean (D) of

130 microns. Grain shapes are quite irregular in some cases where prismatic habit dominates (potassium feldspar) and also the effect of cementing material is observed (siderite). If the expression d = 0.155 (D) is used, an equivalent pore throat for a rhombohedral arrangement is about 20 microns, and for a cubic arrangement would give an equivalent pore throat of d =0.414 (D), or 54 microns.

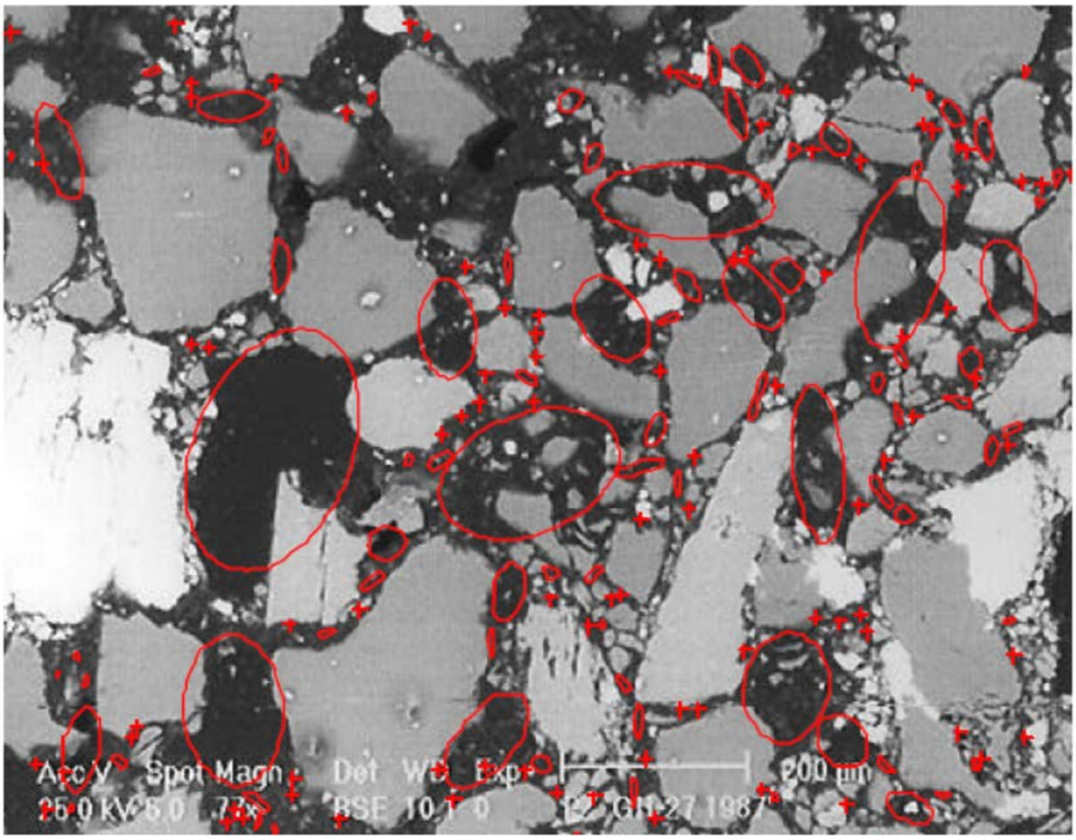


Figure 13: Non-consolidated sandstone (bitumen)

As an exercise, the computer program considers the open pore space for equivalent ellipses. Values range from 15 to 200 microns pore bodies, with a mean value of 38 microns. Bitumen holds the grains in this sample. In non-consolidated sandstones for gas or condensates, this type of structure will tend to collapse and loose its original packing arrangement. Therefore a higher degree of error is introduced when working with nonconsolidated rocks as compared to consolidated rock samples.

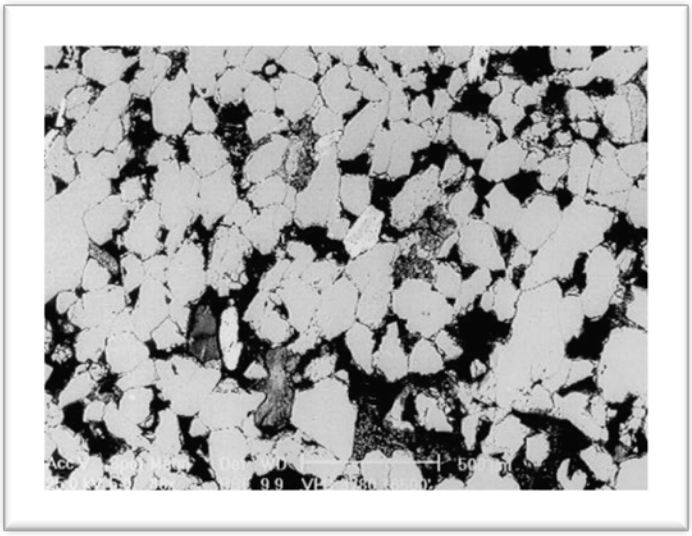


Figure 14: Consolidated Sandstone

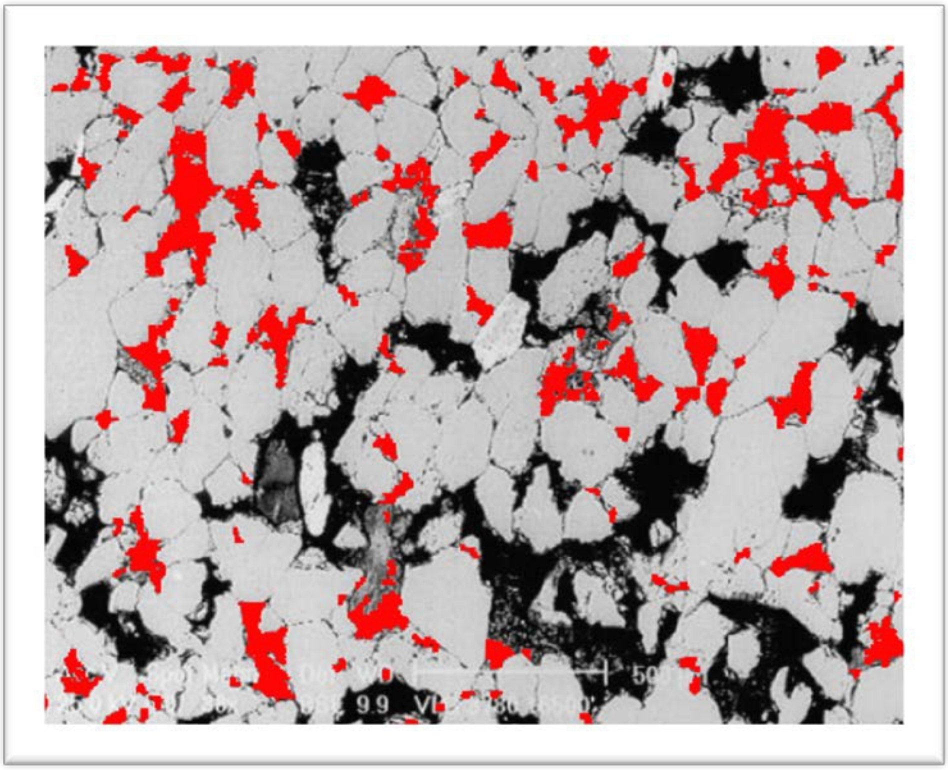


Figure 15: Consolidated Sandstone

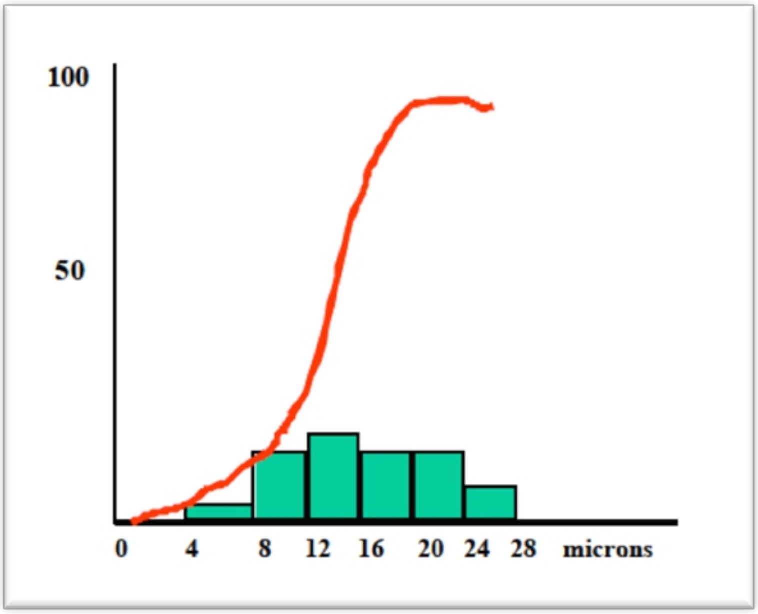


Figure 16: Consolidated Sandstone

Consolidated rock samples have the advantage of providing direct pore geometry measurement. On the example above, the range of pore throat sizes is between 6 and 30 microns, with a mean value of 16 microns.

Conclusion

In consolidated porous media (aloxite/consolidated formation) pore throats or flow path restrictions can be measured using the minimum diameter size distribution from the computer program. Pore body measurement presented a broader distribution, which might not provide a valid statistics.

In non-consolidated porous media, grain size distribution as well as its shape provides a more representative statistics than the direct measurement of pore bodies and throats due to a highly irregular spatial arrangement that depends on the original confining pressure, so original pore geometry might be lost during handling and sampling.

Permeability should not be a parameter to compare rock formations in terms of how bridging agents can create a seal. Different pore geometries can have the same permeability but not the same filtration properties. This means, a test failure when assuming that permeability can give a representative average pore throat size.

If rock pore geometry information can be provided before any drill-In or completion fluid is designed, the probability of success would be higher. Sidewall core samples and even drill cuttings from consolidated formations could be useful to get this information.

Computer programs on image processing and analysis are a valuable tool that makes simple the interpretation of pore geometry attributes in formation material.

Acknowledgements

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References:

Russ, J.C. “Practical Stereology”, 1991. Plenum Press, New York

Graton, L.C. and Fraser, H. J. “Systematic packing of spheres with particular relation to porosity and permeability”. J. of Geol., 1935, Vol. 35. pp 785-909.

Morrow, N. R. “Small scale packing heterogeneities in porous sedimentary Rocks” Bull. Am. Assoc. Pet. Geol., 1971, Vol. 39. pp 514-522.