Investigation Pore Geometry Wettability Preference in Oolitic Oil Reservoir: Pore Scale Imaging and Modelling Study

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Abstract. This study evaluates the wettability preference of Oolitic fresh core plug from a native Kuwaiti reservoir. This Oolitic calcite formation hosts hundreds of spherical grains (ooids) with thousands of pore-shapes. Thousands of tortuous pore/ grain-wall boundaries and their subsequent shapes are captured, of which boundaries geometry, size, and distribution are processed in an Oolite matrix images format. Level of information is reported at different magnifications X40 (mm), X400 (μm), and X4000 (nm), where statistical wettability contact angle distinct morphological feature is closely examined. The objective of this study is to investigate the size and shape driven static contact angle measured by 2D technology digitally captured images of available fresh cores utilizing SEM-BSE segmentations, of which high-quality images are generated. In abstract, the method utilizes counting complete contact angles manifested at pore area and pore/ grain -wall boundary system, which is scale-characterized at: pore-body, pore-throat, and nano-pores available in these Oolitic core plugs. However, in specific, pore-wall boundary contact angle wettability performance and recovery efficiency contributions is also captured, measured, processed and modeled. To model natural pore-wall boundary system static contact angle wettability is to understand the new physics that will advance reservoir characterization and production improvement.

Introduction

Oolite is a type of a chemical carbonate sedimentary rock, mainly limestone (Calcite) and to lesser degree dolomite, in a form of ooids that are cemented together. Ooids are spherical grains that forms when a particle of sand or other nucleus is coated with layers of calcite or other minerals. Ooids often form in shallow marine water.

Kuwaiti Oolite is considered as an Oolitic calcite in thick limestone oil reservoir, which exhibits significant amounts of hydrocarbons. These hydrocarbons are difficult/ slow in oil production [1]. There are many factors to delay EOR productions; however, according to this study, incomplete concept of quantitative wettability is considered the significant factor that controls reservoir fluids location, reservoir fluid flow, and reservoir fluid distribution inside this Oolitic calcite pore system. Wettability or its alteration process will affect core and hydrocarbon production studies, including porosity, permeability, Mean Hydraulic Radius (MHR or Pore Throat), Pore Size Distribution (PSD), capillary pressure (P_c), relative permeability (K_{rw} and K_{ro}), waterflood behavior, electrical properties, and any designed recipe of chemical, thermal, or mechanical tertiary recovery [2]. Therefore, this Oolite reservoir study highlights new measured and Unit-Circle-Trigonometry quantified contact angles (Fig. 6). Using the unit circle, wettability contact angles are measured in accurate, precise and repeatable big-data format to all captured pore/ grain wall including those which are greater than 180° and less than 360° (Fig.6). Digital contact angles are, then, morphologically distributed along thousands pore-wall boundaries (Fig-2-7) and (Tables 3-5) as big data format. This big data is, then, suitable to characterize and model wettability attributes of this fresh Oolitic core representations.

Previous methods have investigated the wettability measurement. Some methods are quantitative, such as contact angles, imbibition and forced displacement (Amott), and USBM wettability method. Others are qualitative methods, such as imbibition rates, microscope examination, flotation, glass slide method, centrifugal relative permeability curves, permeability/ saturation relationships, capillary pressure curves, displacement capillary pressure, reservoir logs, nuclear magnetic resonance (NMR), and dye adsorption [3].

Anderson (1986) described contact-angle measurement have been used the tilting plate method, sessile drops or bubbles, vertical rod method, tensiometric method, cylinder, method, and capillary rise method to measure the wettability in petroleum industry [4]. Okasha, et. al., (2007) was measuring the wettability by using contact angle method and the results showed the material recovered from the Unayzah reservoir rock with characteristics of the water-wet for both oil-brine/rock system and oil-brine/quartz system [5]. AlOtaibi, Azmy and Nasr-El-Din (2010) studied the Amott and wetting contact angle wettability. The outcome of the study gave a better result for recovery of oil [6]. Yuan and Lee (2016), investigated droplets on solid surfaces allow wetting methods

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to be examined down to the nanometer scale, providing new insight into contact angle phenomena and wetting behavior [7]. Alhakeem, et. al. (2017 and 2017*), measured the Wettability using contact angle, the results was successfully captured using morphological analyses of the thin section (TS) imaging. Better geological and petrophysical background is involved with obtaining big data from 2D images where accurate decisions made to describe Wettability features [8] and [9].

The prepared Oolitic Kuwaiti reservoir rock sample is in the form of a rock fragment and it is imaged and then characterized for pore area, and pore/ grain wall-wettability contact angle. The contact angles are in 2D format utilizing SEM-BSE imaging techniques. The generated images are quantified using pre-defined K-Means logics. K-Means clustering is a method of vector quantization that aims to distribute several thousand contact angle observations into K = 10 clusters in which each observation belongs to the wettability contact angle cluster with the nearest mean. K-Means Clustering algorithm is a useful tool for statistical wettability contact angle preference measurement. The contact angles data generated are used to estimate the wettability classification. Each image captured at X40, 400X, and 4000X magnifications will be investigated for matrix pore-body, pore/ grain boundary and nano- pore system to ensure all possible wettability size classifications as well as distribution from captured representations of the matrix features [10].

The study aims to investigate Kuwaiti Oolitic reservoir's wettability preference by using imaging methods for capturing rock physics. The approach used for this study is counting then clustering contact angles in the measured pore/ grain wall using high resolution 2D imaging technology formats [11]. The processed big data is modeled using K-Means Clustering algorithm to essential unsupervised machine compassionate algorithm. K-Means clustering algorithm computes the centroids of 10 defined boundary contact angle clusters, cluster 1 is the smallest in area and cluster 10 is the largest in area available from the captured image. K-Means clustering algorithm iterates all 10 clusters until optimal centroid is found. In comparison, conventional administered big data to machine knowledge algorithms, K-Means endeavors to evaluate data without first being trained with labeled data. Once the algorithm has been run, and the groups are defined, any new data can be easily assigned to the most relevant group. Useful applications of K-Means are wettability preference profiling and contact angle boundary segmentations.

Problem Statement

The authors feel that this study will narrow the gap in contact angle wettability characterization from static conditions standpoint and, hence, the reservoir crude oil recovery history profile. Capturing and measuring detail static physical pore-wall contact angles through big data contact angles characterization is a key understanding of subsurface crude oil recovery programs from planning to forecasting production. Also the forecasted duration for each recovery stage when total rock Wettability distribution is manifested. In this study, valuable information from the literature is integrated and utilized in developing unique static characterization pre-logic to understand the nature degree wetness of the Oolitic calcite pore-wall size wettability distribution and its attributes on recovery efficiency [12].

Results & Discussions

In this study, two dimensional images 2D are used to characterize the morphology of Oolitic calcite grains and pores, using two-step technique process, image capturing and image mathematical processing. In the first step, the image is captured using backscattered electron detector (BSE), digital electron microscopy imaging, and the second step, the statistical pore/ grain-wall geometry features are counted, pore area are measured, and pore/ grain-wall shape contact angles are also measured. These big data obtained from the captured image is the 2D digital approach for processing technology. All of sample grain/ pore features captured in the image are reported in millimeter, micrometer, and nanometer length units. In the second step, the pore area and pore contact angles of such features are scanned using image analysis software that has the ability to accurately measure several morphological parameters of pore and grain spaces (Tables 4-6).

A robust technique of visual estimate is used, which has the advantage of speeding the image analysis process. The visual analysis software tool counts different pores and grains and also measures their shapes boundaries and sizes that are crucial for contact angle wettability calculations. Several pore morphological models have been considered for optimum accuracy comparisons, including: pore/ grain-wall relationships (Area/ Perimeter), pore contact angle (θ), and pore count. Wettability preference is estimated based on refracted angle of the pore/grain-wall boundaries measured from two-dimensional images [12].

Wettability Attributes in Oolitic Reservoir

The wettability in this Oolitic reservoir study has six tasks experimental designs and attributes. The designed factors are: general mineral description, sample preparation, surrounding environment, macroscopic/ microscopic measurement scale, surface roughness, Surface Contamination and Organic Matter (Fig 1). This study will start with general mineral description task. According to Oolite physical, chemical, Crystallography, Optic, Crystal Habitat, and other Optic System properties and description suggests the contribution of Calcite in regards to wettability preference is principle and tends towards weakly-oil-wet (WOW) or contact angle θ° is between 90°-120°.

The second and third tasks are sample preparation and surrounding environment. Only one rock sample is selected for this study from an end plug rock core fragment. The rock is fresh Oolitic sample without removing its fluids. The sample is gently/ slowly cut to fit the Scattered Electron Microscope (SEM) chamber. No coating is required to maintain the pollution of sample at zero level. From previous studies, Al-Bazzaz et. al (2018) and (Almudhhi et.al 2019 & 2021), purity of the sample must be honored (As much as possible) to examine the mineral in its natural arrangement. High voltage 30 KeV is used to produce high quality images. The sample is subject to 24-hours vacuum treatment and images are then captured at slow scan.

The fourth task is Macroscopic/ Microscopic Measurement Scale. Reservoir Rock sample imaging and testing for Oolitic Calcite reservoir is highly successful. Oolite sample is represented with one sample throughout the vertical thickness and three SEM magnifications are studied at X40 (mm), X400 (µm), and X4000 (nm) (Fig. 2). The images are captured using backscattered electron detector (BSE) digital electron microscopy. As a result, this (SEM-BSE) imaging tool is excellent to characterize the morphology of the areas of grains and pores (Fig. 3). Also, the boundary angles captured (Fig. 4) is scanned using image analysis software to measure several morphological parameters twice for each selected image – once for pore area morphology and once for boundary angle morphology. Big angle data is produced, counted, and statistically numerated.

The fifth task is the Mineral Surface Roughness. This digital imaging method has successfully captured the roughness inside the Oolite pore space. Rough surfaces can complicate contact angle wettability measurements. Averaged electron bombardments have successfully reflected hundreds of Oolitic calcite grain-wall surfaces that surrounds the pore. An example of captured 2D boundary of one Oolitic pore at a 4000X (Nanometer) is included in Figure 5. The green-color tortuous surfaces correspond to the boundary pore/ grain-wall, which are measured independently, and then, an overall mean average contact angle captured and measured is reported. Then an overall technical average is calculated and modeled for all pores captured in the 2-D image.

The final task is surface contamination by the Organic Matter (OM). This task, unfortunately, is not completed up to date of this manuscript. As a result, the analysis of OM on Oolite pore/ grain-wall will not be included in this research.

Wettability Classification

Oolite show all wettability contact angles from electron measured refractions (Almudhhi et.al 2021) spanning from 0°-360°. These pore/ grain-wall refracted angles are successfully located and distributed in the images. A new classification is based on the big data generated (Fig. 6-7) and (Table 1). Eighteen classes show the degree of wetness preference that each pore area or pore/ grain boundary can possess.

One interesting find is zero angles (Fig. 7) are now possible to be measured in the imaging laboratory. They are the majority pores available in any matrix in general, as well as in this Oolite sample in particular. Also, the zero angle size of pores is considered nano-pores, and understanding this pore wettability will help unlock future unconventional tight oil. The nano region in Oolitic matrices is considered as an absolute water wet region (AHWW). AHWW region will be reported in 0° degrees or 360° degrees, and shows as "water-film" shape of the water rather than a droplet-like shape. Also their natural orientation is horizontally measured just like Unit-Circle-Trigonometry.

Another interesting find is measuring the true vertical mixed wettability (TVMW), which are the 90° and the 270° respectfully. These angles are mirrored of each other [10-12]. They are the same but available upside of each other as nature rock orientation dictates. They will also represent the true mixed wettability preference in this Oolitic calcite.

While 180° is the absolute horizontal oil wet (AHOW). AHOW, it is the strongest oil wet preference region available in this Oolite. AHOW is described as "paint-like" or "stain-like" shape on the calcite grain-wall. Removing this "paint-like" or "stain-like" oil molecules will suggest 100% recovery of oil. These pores and subsequent boundaries should be the ultimate goal for any EOR/ IOR program. AHOW requires extreme thermal, chemical, or mechanical EOR/ IOR recipe techniques to dispatch this paint-like droplets of oil from the calcite-grain-mineral-wall and make it mobile in the production stream. All reservoirs have this phenomenon, but at different percent-quantities and distributions. Due to existing and reporting of these contact angles, the authors will recommend more research work towards these difficult oil regions.

This Oolitic Calcite rock sample has captured all 18 wettability classified regions of contact angles from reported images at mm 40X, µm 400X, and nm 4000X (Fig. 2-5) (Table 1). This method is classified by reflected angles between 0° - 360° [9-12]. Eighteen (18) classes are identified with distinct colors. Next smallest nano-pore angles with tan orange color 0°-36° is the strong water wet region SWW. But angles with blood red color144° - 180° are identified with strong oil wet SOW.

Wettability Using Clustering Algorithm

From the Oolite rock sample, three levels of magnifications are determined 40X, 400X, and 4000X. The 40X magnification (Fig. 2-4) & (Table 3) is an extensively significant capture of the rock sample illustrated in the millimeter scale. This scale is useful to study the largest pores, pore bodies. In the 40X image, 3,283 pores are manifested for processing and the yielded wetting contact angle is 52.4°. This overall average medium-water-wet (MWW) preference is suitable for a long successful secondary water injection program. The 400X is the micrometer scale of pore-spaces Fig. 2-4) & (Table 4). This magnification scale, 400X image, represents pore throat region of the matrix. Image captures has yielded 2,223 pores for processing the wetting contact angle preference, and the wetting preference is 55.99°. This result suggests the overall wettability contact angle is medium-water-wet (MWW). Also good region for secondary water injection program. The final pore system is the 4000X (Fig. 2-4) & (Table 5), this region shows the nanometer-scale. The 4000X image captures and produces 1,340 pores for processing. the overall average wetting contact angle is 33.2° (Al-Bazzaz et al. Pore Counting Method, 2007) [1].

In the K-Mean clustering model, the maximum number of pores are 3,283 pore at 40X measurement. All counted pores, and the SEM-BSE process tested the pore-wall contact angles. Hence, the region angles are determined, and the group regions (clusters) wettability preference overall average is technically computed. The technical average assists us in understanding the contact angle in each tenth clusters shown in the (Figures 8-11) & (Table 2). Furthermore, the more pores in any cluster, the better the wettability contact angle estimation. From the result, we observed that clusters 1, 2, 7, 9 and 10 have more pores than the other clusters. Therefore, in this study, we are neglecting the other cluster of 3, 4, 5, 6, and 8 for limited data. Only the model will focus on the following clusters: 1, 2, 4, 7, and 10.

The model has the following results: cluster 1 captures 3,886 boundary surfaces of 0° (AHWW) contact angles spanned over 99.5% confidence of pores/ grain-wall boundaries. Cluster 2 captures 123 surfaces of 120° - 150° within cluster dominance spanned over 95.1% confidence. Cluster 2 will be considered as Medium-Oil-Wet system (MOW) within the cluster preference. This region requires thermal and chemical EOR/ IOR treatments. Cluster 4 is modeled at and 90° spanned over 87.7% confidence. Cluster 4 is the True-Vertical Mixed Wettability (TVMW), Light thermal, Low Salinity (LoSal), or surfactant treatment (or mix-and-match recipe) will enhance the recovery in this region. Cluster 8 is modeled at Medium-Water-Wet (MWW) at 30° - 60° spanned over 84.5% confidence. This cluster will estimate secondary water injection treatments. The final cluster, cluster 10 is 150° - 180° spanned over 62.8% confidence. This region is considered as Strong-Oil-Wet (SOW), which means aggressive thermal, chemical, and mechanical treat might work for this portion of Oolite rock.

The Kuwaiti overall pore/ grain-wall wettability preference is 84.3% towards generally water wet spread between (AHSW & SWW) and (MWW). However, the remaining overall pore/ grain-wall boundaries tends towards 15.7% general oil wet spread between mixed wet (TVMW & MOW) and Strong-Oil-Wet (SOW). This Oolitic reservoir will be an excellent candidate for water displacement developments.

Conclusions

From measured data and computed logics, the majority portions of natural pore voids/ grain walls and discrete nanopores in size, and mineral grain-walls are Absolute-Strongly-Water-Wet (ASWW); however, some pore/ grain walls show mixed and strongly oil wetting. The main factors in the understanding the Oolite wettability are matrix pore-size distribution and pore-numbers, and morphology where pore/ grain-wall boundary is directly measured, hence, suggests the wettability likely affinity preference. This study shows natural pores connectivity contact angles measurements are important in crude oil recovery as well as water productions performance through the life time crude recovery stages of Kuwaiti Oolite reservoir. Reported measured contact angle can assist in planning for oil potential recovery such as water injection. Also, big data measured contact angle also show some new interesting feature characterizations.

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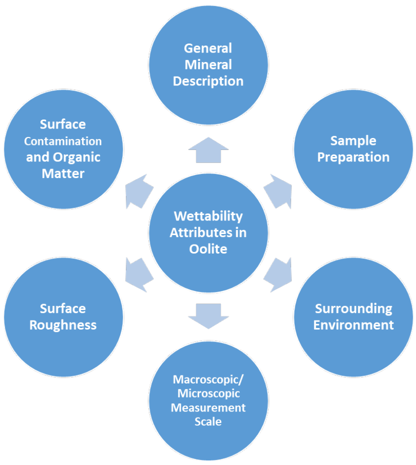


Figure 1 Hydrophilic (Water Wet) and Hydrophobic (Oil Wet) Wettability Attributes in Oolitic Reservoir Minerals

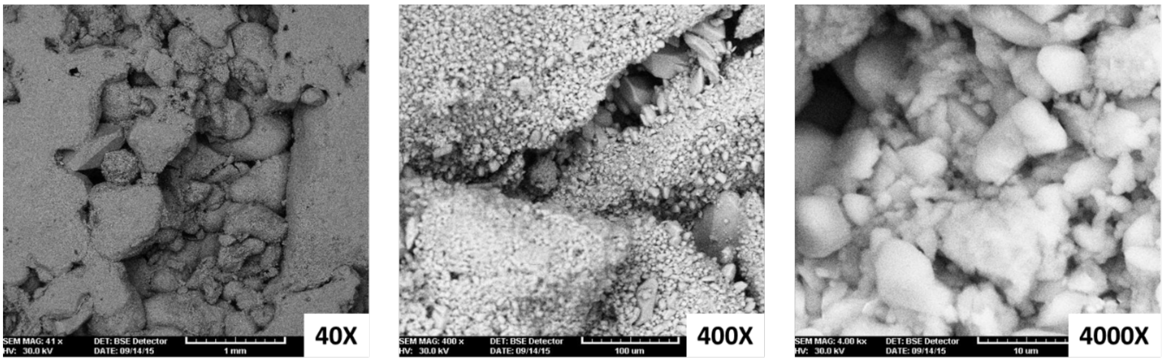


Figure 2 Oolite Rock SEM-BSE image capturing at different magnifications, X40 (mm), X400 (μm), X4000 (nm)

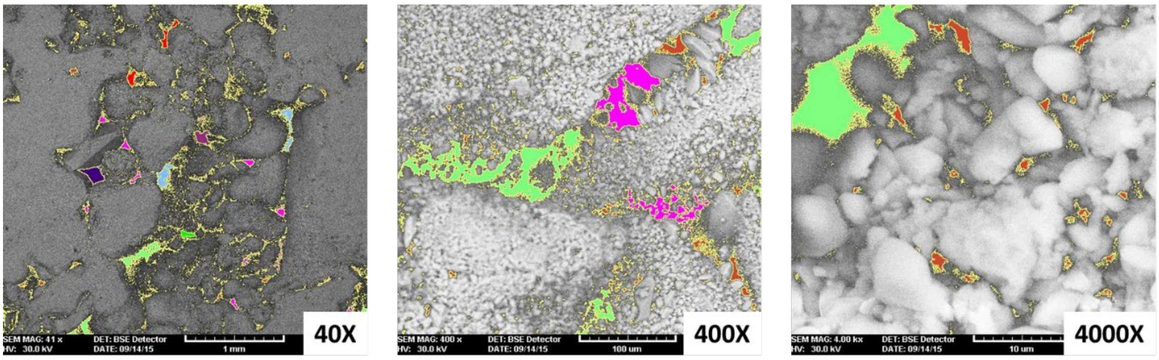


Figure 3 Captured 10 Pore Area Clusters in all Magnifications X40, X400, and X4000 in the Oolite Core Sample.

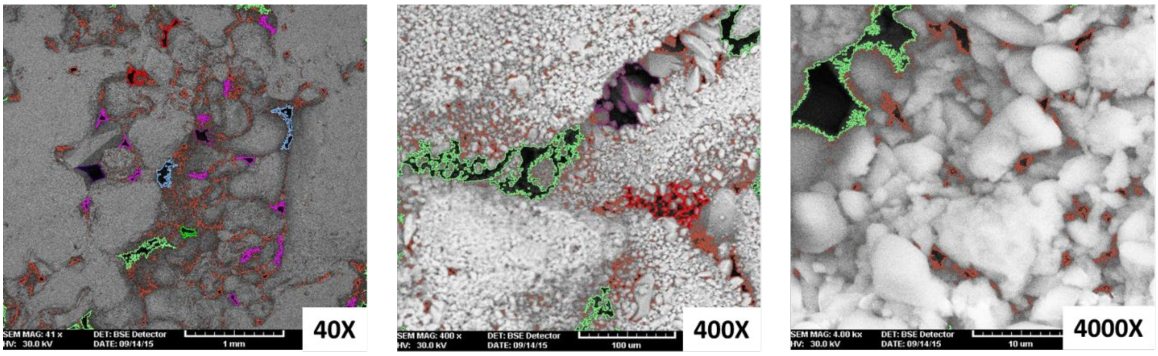


Figure 4 Measured Thousands of Pore/ Grain Wall Surface Boundaries in the Three Scales, X40, X400, X4000 in 2D Image Technology of the Oolitic Calcite.

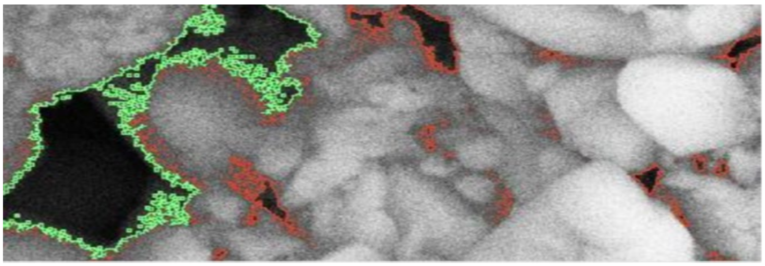


Figure 5 Example of Captured 2D Boundary of one Oolitic pore at a 4000X (Nanometer). The Boundaries between the Grain and the Pore Are Measured and Then Mean Average Contact Angle for Each Pore is Reported. Hundreds of Tiny Surfaces Are Captured Inside One Pore System as Seen in This Nano-scale Image. All These Surfaces Are Accurately Quantified Per Al-Bazzaz et.al (2018-2019) Contact Angle Wettability Statistical Classifications.

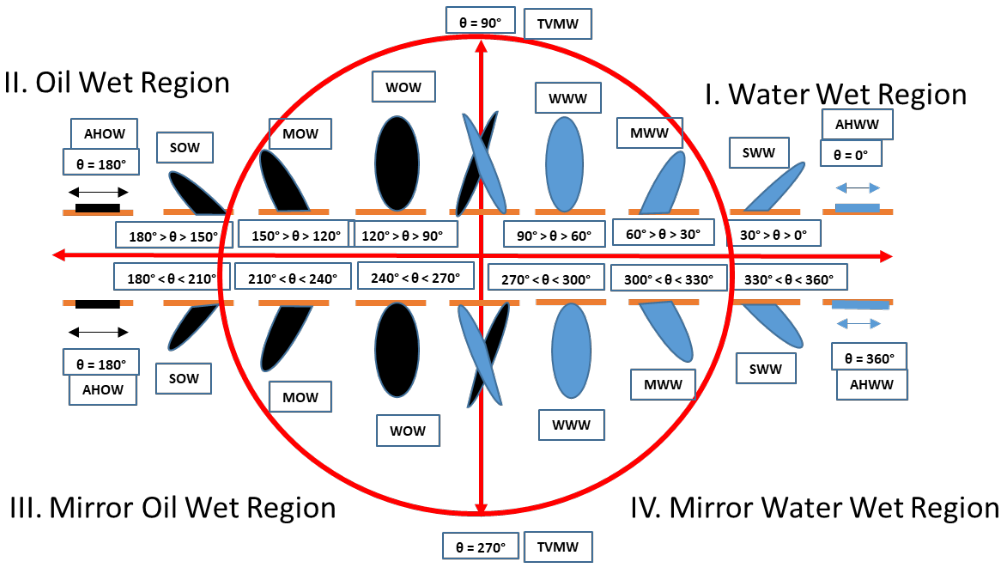


Figure 6 Al-Bazzaz Wettability contact angle(ϴ°) Classification Chart. All Angles Follow the Central Angle Theorem in a Unit-Circle-Trigonometry (Red Circle). Blue Droplets Angles Define Water Wet Angles and Black Droplets Angles Define Oil Wet Angles. The Orange Surface Resembles the Grain Wall/ pore Boundary.

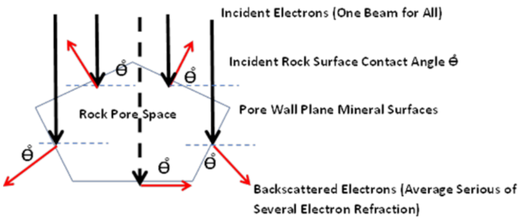
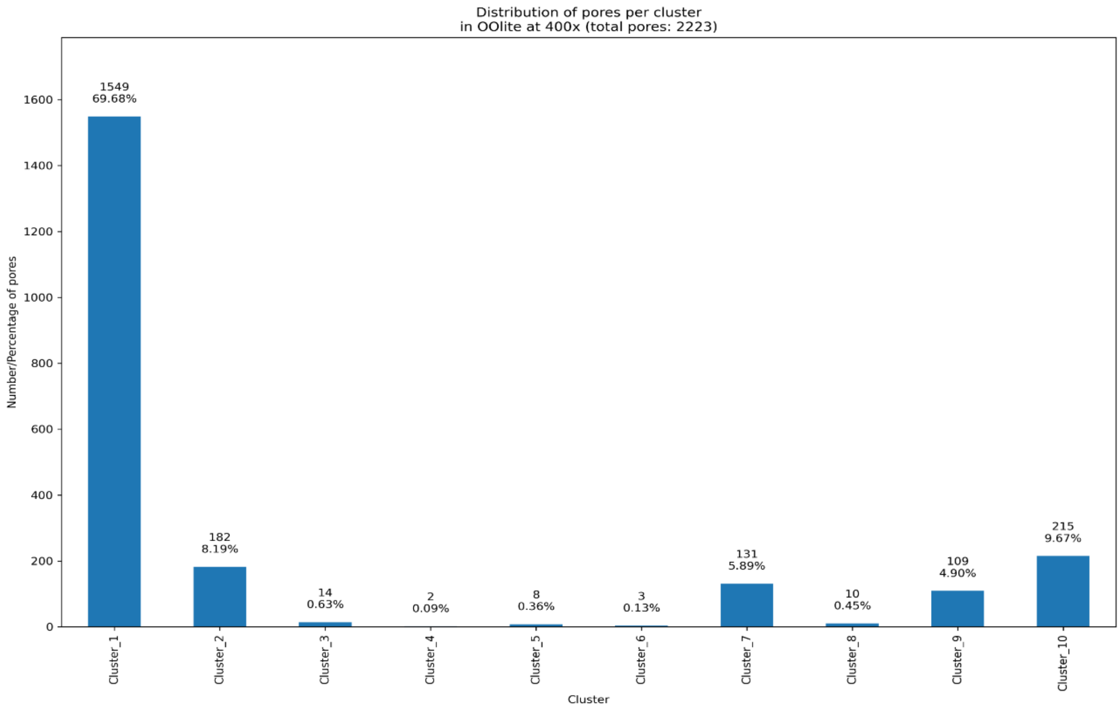


Figure 7 The Incepted Wetting Contact Angle Measurement through Backscattered Electron Refracted Angles from All Minerals Pore-Walls Surrounding the Pore-Space.



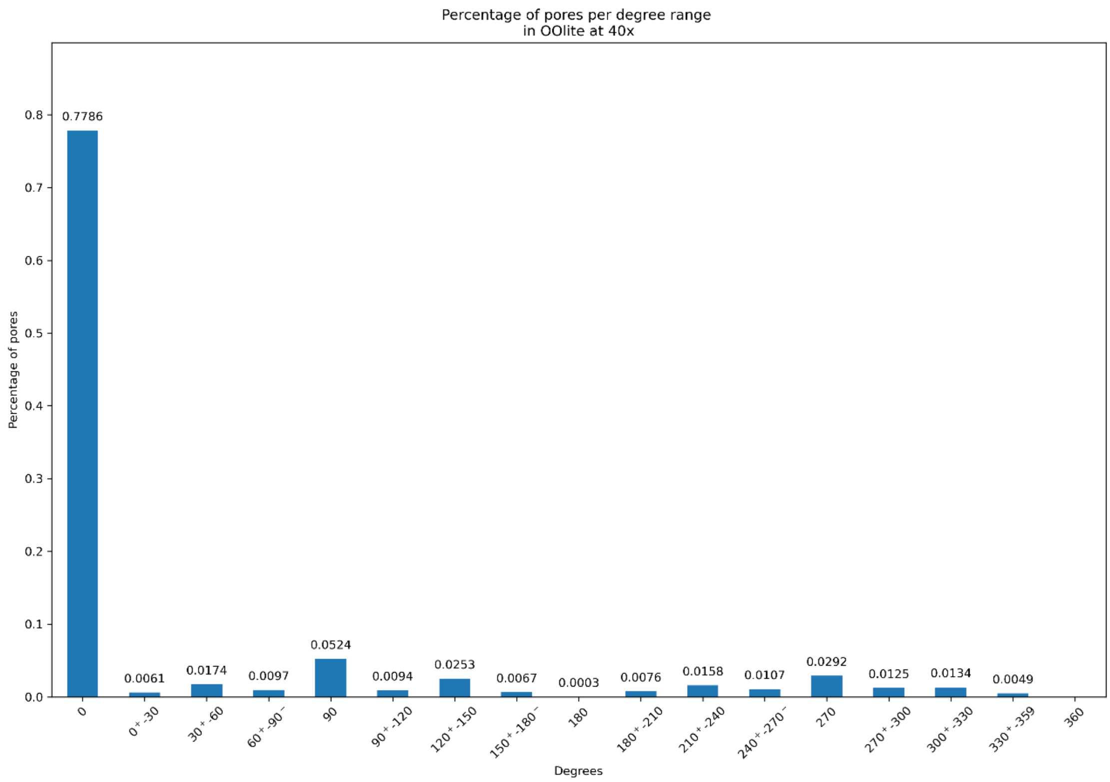


Figure 8 K-Mean Clustering Algorithm Using Python Distributions Using Counting Numbers of Pores Per 10-Clusters, and Per 18-Class 0° - 360° Contact Angle Classifications in the Oolitic Reservoir Sample at 40X (mm).

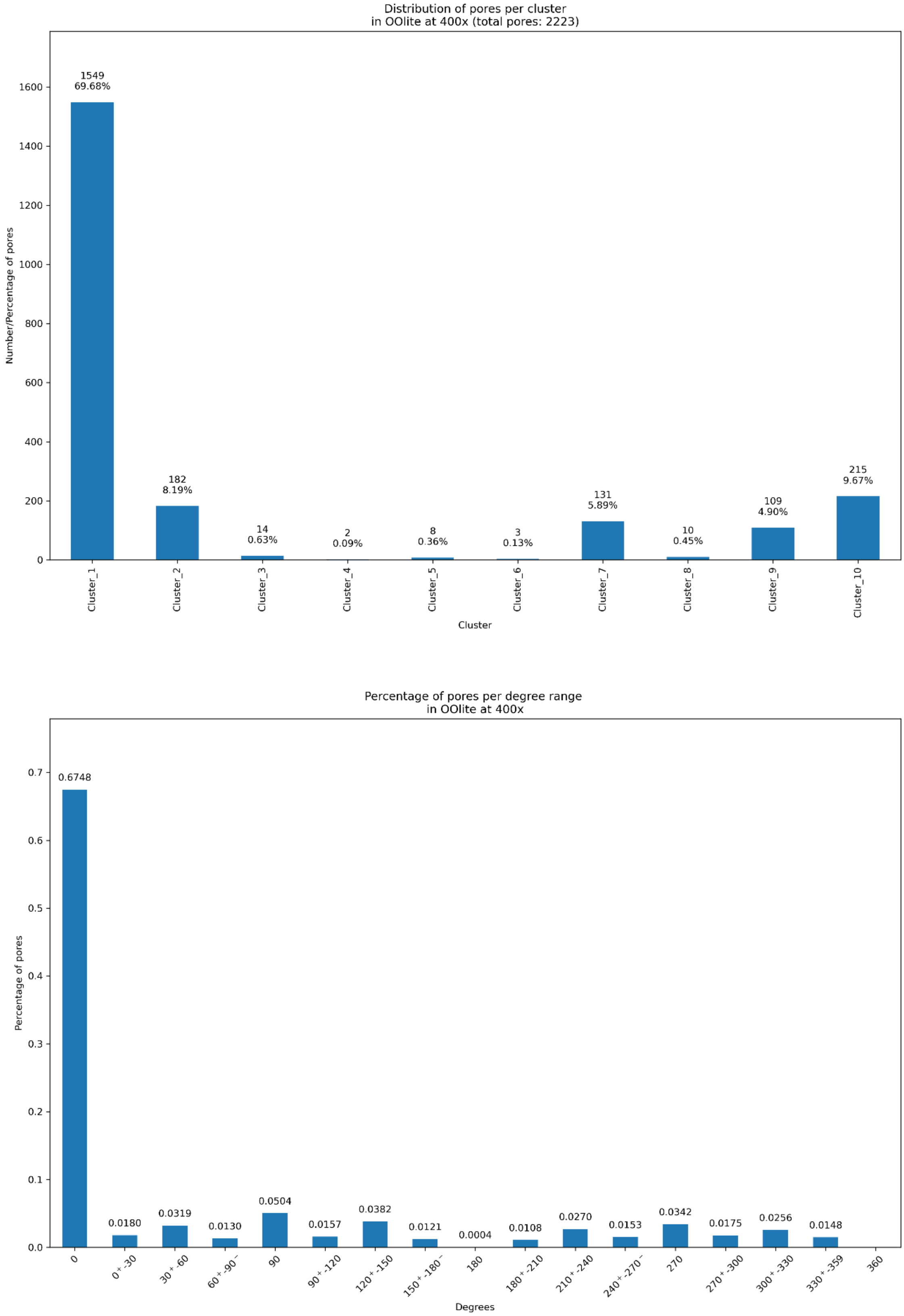
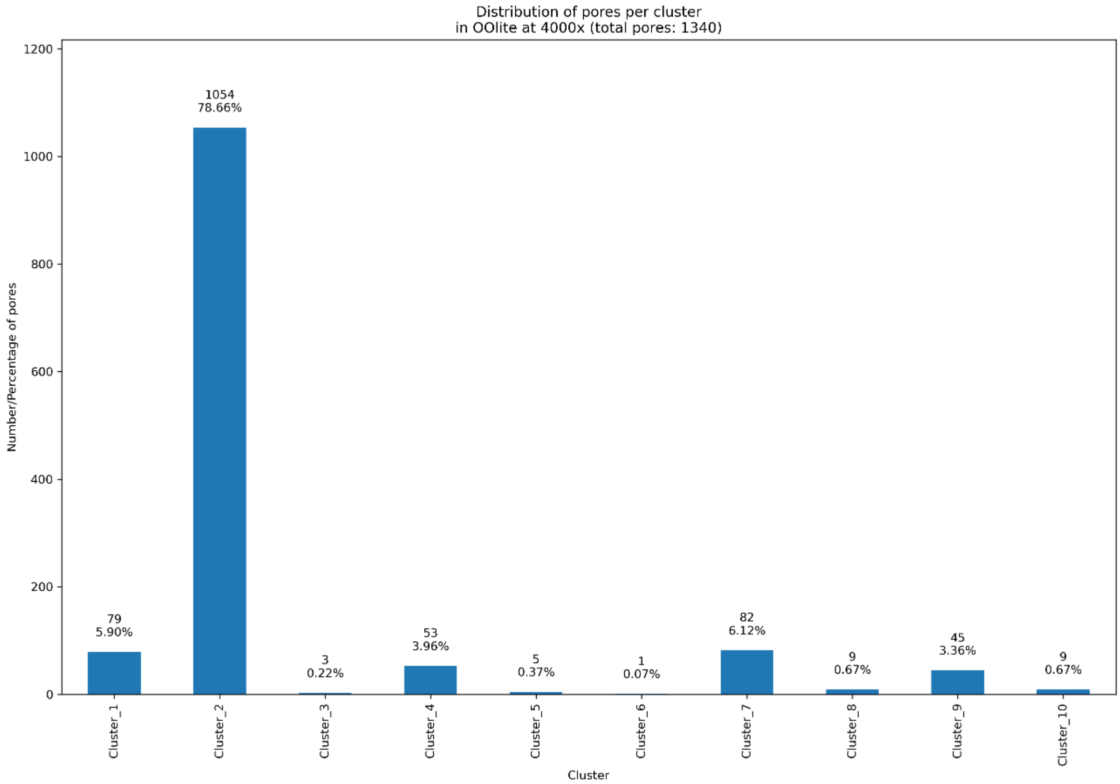


Figure 9 K-Mean Clustering Algorithm Using Python Distributions Using Counting Numbers of Pores Per 10-Clusters, and Per 18-Class 0° - 360° Contact Angle Classifications in the Oolitic Reservoir Sample at 400X (μm).



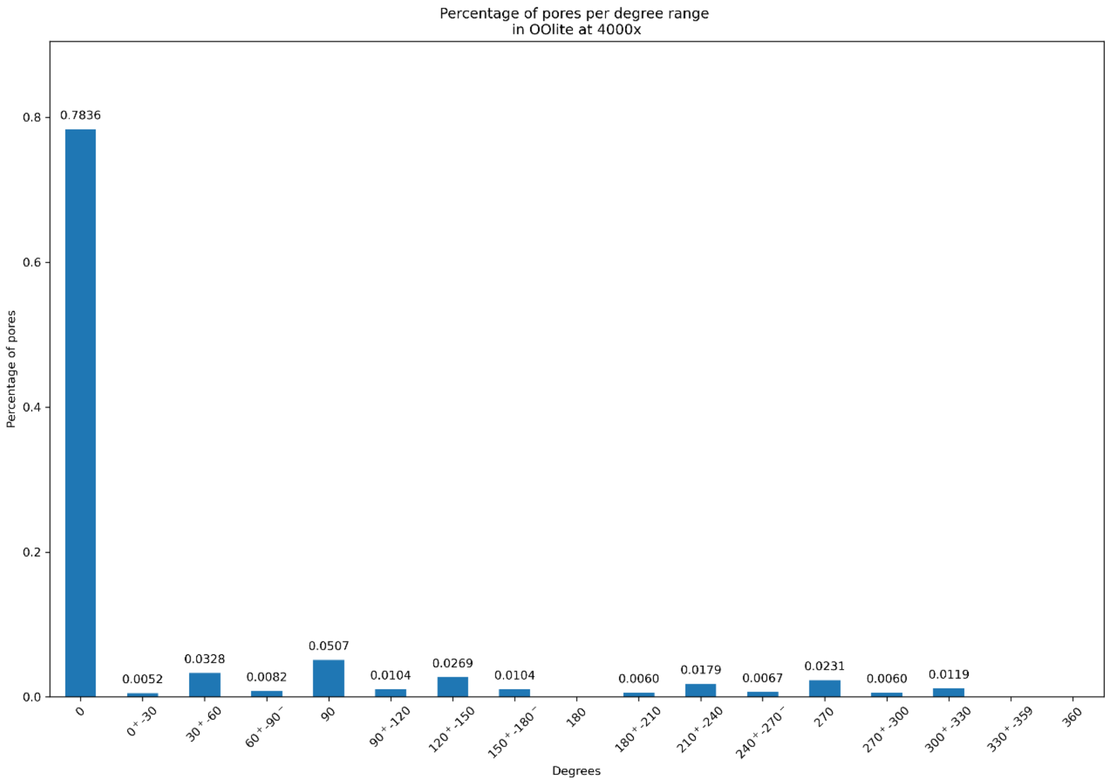


Figure 10 K-Mean Clustering Algorithm Using Python Distributions Using Counting Numbers of Pores Per 10-Clusters, and Per 18-Class 0° - 360° Contact Angle Classifications in the Oolitic Reservoir Sample at 4000X (nm).

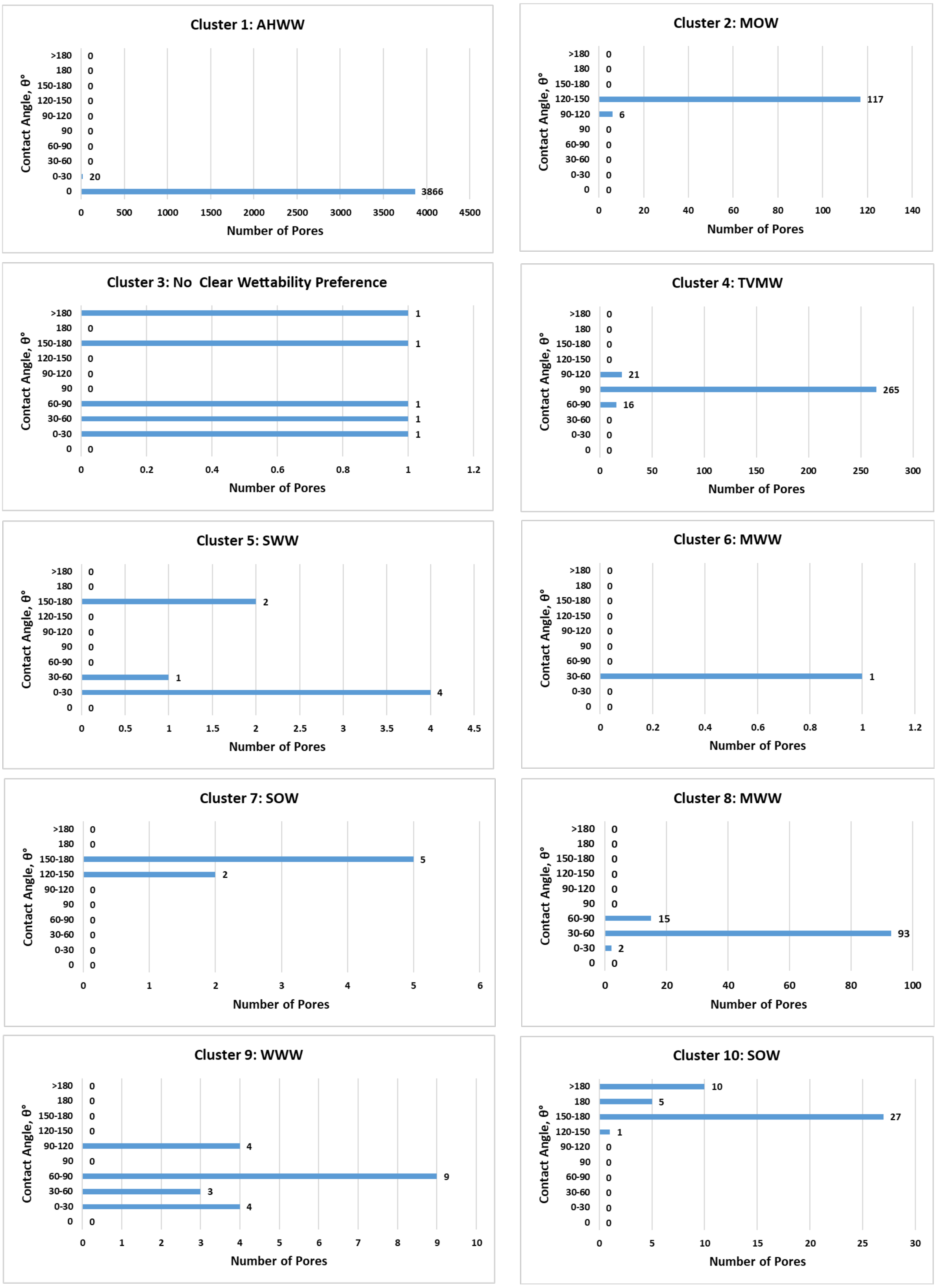


Figure 11 K-Mean Contact Angle and Wettability Preference at Each Cluster

Table 1 The Complete 2D Digital Angle Measurements Classification Inside the Oolite Reservoir Sample

Pore/ Grain Boundary Cluster Class #	Cluster Mean Wettability Contact Angle (θ°)	Unit Circle Wettability Quadrant Region	Wetting Preference According to Al-Bazzaz et. al. (2018-2019)	Symbol	Description
1	θ° = 0°	I. Water Wet Region	Absolute Horizontal Water Wet	AHWW	Only Water Film on the Grain Wall
2	0° < θ° < 30°	I. Water Wet Region	Strongly Water Wet	SWW	Grain Wall Forces Attract Water Droplets and Resist Oil Droplets
3	30° < θ° < 60°	I. Water Wet Region	Medium Water Wet	MWW	Grain Wall Forces Attract More Water Droplets than Resist Oil Droplets
4	60° < θ° < 90°	I. Water Wet Region	Weak Water Wet	WWW	Grain Wall Forces Attract Water Droplets Slightly More than Resisting Oil Droplets
5	θ° = 90°	I. (Water Wet) & II. (Oil Wet)	True Vertical Mixed Wet	TVMW	Grain Wall Forces will Not Distinguish Between Water Droplets and Oil Droplets
6	90° < θ° < 120°	II. Oil Wet Region	Weak Oil Wet	WOW	Grain Wall Forces Attract Oil Droplets Slightly More than Resisting Water Droplets
7	120° < θ° < 150°	II. Oil Wet Region	Medium Oil Wet	MOW	Grain Wall Forces Attract More Oil Droplets than Resisting Water Droplets
8	150° < θ° < 180°	II. Oil Wet Region	Strong Oil Wet	SOW	Grain Wall Forces Attract Oil Droplets and Resist Water Droplets
9	θ° = 180°	II. Oil Wet Region	Absolute Horizontal Oil Wet	AHOW	Only Oil Film on the Grain Wall
10	θ° = 180°	III. Mirror Oil Wet Region	Absolute Horizontal Oil Wet	AHOW	Only Oil Film on the Grain Wall
11	180° < θ° < 210°	III. Mirror Oil Wet Region	Strong Oil Wet	SOW	Grain Wall Forces Attract Oil Droplets and Resist Water Droplets
12	210° < θ° < 240°	III. Mirror Oil Wet Region	Medium Oil Wet	MOW	Grain Wall Forces Attract More Oil Droplets than Resisting Water Droplets
13	240° < θ° < 270°	III. Mirror Oil Wet Region	Weak Oil Wet	WOW	Grain Wall Forces Attract Oil Droplets Slightly More than Resisting Water Droplets
14	θ° = 270°	III. (Mirror Oil Wet) & IV. (Mirror Water Wet)	True Vertical Mixed Wet	TVMW	Grain Wall Forces will Not Distinguish Between Water Droplets and Oil Droplets
15	270° < θ° < 300°	IV. Mirror Water Wet Region	Weak Water Wet	WWW	Grain Wall Forces Attract Water Droplets Slightly More than Resisting Oil Droplets
16	300° < θ° < 330°	IV. Mirror Water Wet Region	Medium Water Wet	MWW	Grain Wall Forces Attract More Water Droplets than Resist Oil Droplets
17	330° < θ° < 360°	IV. Mirror Water Wet Region	Strong Water Wet	SWW	Grain Wall Forces Attract Water Droplets and Resist Oil Droplets
18	θ° = 360°	IV. Mirror Water Wet Region	Absolute Horizontal Water Wet	AHWW	Only Water Film on the Grain Wall

Table 2 Wettability Preference Based on Number of Static Contact Angle Distribution Measured in the Oolitic Reservoir Sample on K-Mean Clustering Algorithm

Contact Angle, θ°	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8	Cluster 9	Cluster 10
0	3866	0	0	0	0	0	0	0	0	0
0-30	20	0	1	0	4	0	0	2	4	0
30-60	0	0	1	0	1	1	0	93	3	0
60-90	0	0	1	16	0	0	0	15	9	0
90	0	0	0	265	0	0	0	0	0	0
90-120	0	6	0	21	0	0	0	0	4	0
120-150	0	117	0	0	0	0	2	0	0	1
150-180	0	0	1	0	2	0	5	0	0	27
180	0	0	0	0	0	0	0	0	0	5
>180	0	0	1	0	0	0	0	0	0	10
Σ Contact Angles	3886	123	5	302	7	1	7	110	20	43
Wettability Preference within Cluster Dominance %	99.5	95.1	20.0	87.7	57.1	100.0	84.5	84.5	45.0	62.8
Wettability Preference	AHWW	MOW	No Clear preference	TVMW	SWW	MOW	SOW	MWW	WWW	SOW

Table 3 Captured and Measured Morphological Pore Area Contact Angles for Oolitic Sample at 40X (mm).

Total Pore Objects #	Area (µm2)	Perimeter (µm)	Length (µm)	Width (µm)	Roundness	Elongation	Lgn.Prin.Long (µm)	Lgn.Prin.Short (µm)	Equiv. diameter (µm)	Angle [°]
15,257										
Mean	89.041	16.178	11.145	7.673	1.079	1.169	4.211	1.578	8.953	52.459
Deviation	245.104	41.452	11.407	6.553	0.467	4.846	6.771	3.505	5.763	95.505
Minimum	27.013	0	5.197	5.197	1	0	0	0	5.865	0
Maximum	16936.924	1542.98	289.48	246.632	16.133	42.968	158.206	100.158	146.849	360

Table 4 Captured and Measured Morphological Pore Area Contact Angles for Oolitic Sample at 400X (µm).

Total Pore Objects #	Area (µm2)	Perimeter (µm)	Length (µm)	Width (µm)	Roundness	Elongation	Lgn.Prin.Long (µm)	Lgn.Prin.Short (µm)	Equiv. diameter (µm)	Angle [°]
2,229										
Mean	7.775	4.293	1.979	1.316	1.115	1.348	1.055	0.781	0.324	55.992
Deviation	128.105	34.782	5.899	3.023	0.919	0.526	4.328	3.04	1.338	98.731
Minimum	0.549	0	0.741	0.741	1	1	0	0	0	0
Maximum	5136.392	1212.896	198.513	85.325	22.893	7	41.447	103.499	36.083	359.225

Table 5 Captured and Measured Morphological Pore Area Contact Angles for Oolitic Sample at 4000X (nm).

Total Pore Objects #	Area (µm2)	Perimeter (µm)	Length (µm)	Width (µm)	Roundness	Elongation	Lgn.Prin.Long (µm)	Lgn.Prin.Short (µm)	Equiv. diameter (µm)	Angle [°]
1,346										
Mean	0.085	0.305	0.165	0.116	1.074	0.733	0.057	0.022	0.132	33.212
Deviation	1.961	3.049	0.587	0.287	0.507	3.907	0.308	0.123	0.3	75.674
Minimum	0.005	0	0.074	0.074	1	0	0	0	0.084	0
Maximum	71.605	105.865	19.061	9.032	12.455	41.447	10.097	3.741	9.548	342.848