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Estimation the relations between porosity and permeability using core data

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الملخص

المسامية والنفاذية هي خصائص مرتبطة بأي صخر أو رواسب صخرية. كلاهما مرتبط بعدد وحجم ووصلات الفتحات في الصخر. وبشكل أكثر تحديدًا ، تعد مسامية الصخور مقياسًا لقدرتها على الاحتفاظ بالسوائل. رياضيا ، هو الفراغ المفتوح في الصخر مقسومة على الحجم الكلي للصخور (الصلبة و الفراغ). النفاذية هي مقياس لسهولة تدفق السائل عبر مادة صلبة مسامية. قد تكون الصخور مسامية للغاية ، ولكن إذا لم تكن المسام متصلة ، فلن يكون لها نفاذية. وبالمثل ، قد يحتوي الصخر على عدد قليل من الشقوق المستمرة التي تسمح بسهولة تدفق السوائل ، ولكن عند حساب المسامية ، لا يبدو الصخر مساميًا جدًا.

غالبًا ما يتم اختبار الارتباطات بين المسامية ، Φ ، والنفاذية ، k، للصخور الرسوبية فيما يتعلق بالجيولوجيا البترولية وخصائص الخزان. يمكن توقع اتجاه عام لزيادة النفاذية مع المسامية. ومع ذلك ، فإن تأثيرات حجم الحبيبات ، والتعبئة ، والضغط ، وعمليات إذابة المحلول المتعلقة بتطوير المسامية الأولية والثانوية أو الحفاظ عليها أو فقدها ، يمكن أن تؤدي إلى مجموعة متنوعة من العلاقات بين النفاذية وأشكال مختلفة من المسامية.

ABSTRACT

Porosity and permeability are related properties of any rock or loose sediment. Both are related to the number, size, and connections of openings in the rock. More specifically, porosity of a rock is a measure of its ability to hold a fluid. Mathematically, it is the open space in a rock divided by the total rock volume (solid and space). Permeability is a measure of the ease of flow of a fluid through a porous solid. A rock may be extremely porous, but if the pores are not connected, it will have no permeability. Likewise, a rock may have a few continuous cracks which allow ease of fluid flow, but when porosity is calculated, the rock doesn't seem very porous.

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Correlations between porosity, Φ , and permeability, k, are often tested for sedimentary rocks in relation to petroleum geology and reservoir characterization. A general trend of increase in permeability with porosity can be expected. However, the effects of grain size, packing, compaction, and solution dissolution processes related to development, preservation or loss of primary and secondary porosity can lead to a wide variety of relationships between permeability and various forms of porosity

Keywords: porosity , Reservoir permeability

INTRODUCTION AND LITERATURE REVIEW

The main factor is the amount of space available between particles, sediments, and rocks in the soil layers and spaces between particles in rocks and rock layers. The amount of pore space in soil, sediments, and rock is called porosity, which can also be defined as the percentage of a material's total volume that is taken up by pores. This "empty" space has a fantastic ability to hold water that seeps down from the land surface. Material with good porosity can be called "porous". Mathematically, porosity can be expressed as the ratio of the volume of pore space to the total volume of the material as given by the following formula:

$$\% \text{ porosity} = \frac{\text{Volume of pore space}}{\text{Total volume of sediment}} \times 100$$

Porosity depends on the size, shape, and mixture of grains and particles that compose soil and rock. For instance, small particles such as clays are able to compact more closely together, reducing the amount of porosity. However, larger particles such as sand and gravel will have more spaces available between them. Round particles compacted together will have more spaces than elongated grains that stack more tightly. Particles of uniform size (well sorted) will also have more pore space available than grains of varying sizes (poorly sorted) because small particles can fill in the spaces between the larger grains. Porosity can change between various layers of soil and types of solid rock. [1]

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In addition to porosity (the amount of pore space), permeability is another important factor needed for groundwater movement to occur. Permeability is the measure of how easily water flows through soil or rocks, so it depends on the size of the pore space and how well connected they are to one another. It is often defined as pore interconnected and the unit of measurement is usually distance (cm, m, or ft.) per time (second, minute, day). Permeability can also be referred to as hydraulic conductivity. Like porosity, permeability can also change between various soil layers and types of solid rocks.

Permeability depends on several factors – grains size of particles and the amount of cracks and fractures. If the sediments or rock particles are composed of very small grains, such as in clays and silts, the space through which water can flow is limited. In addition, clay particles have a lot of surface area to which hygroscopic water attaches, creating a further resistance to fluid movement. If sediments are comprised of coarser grains like sand and gravel, pore space is more available. These coarser grains also have less surface area, so less water can attach to them, allowing better fluid movement. With grains of many sizes, the permeability will be at medium rates. Fine sediments fill in spaces between larger particles, reducing poor space and increasing surface areas to which water can adhere.

For rocks composed of poorly sorted material or fine grains, water movement can be slow unless there are fractures and cracks in the rock. Along roadside rock cuts, it is common to observe groundwater seeping from cracks or forming icicles. Some rocks such as limestone and dolomite can form more than just cracks; water can actually dissolve them causing openings within the rocks to widen, possibly wide enough to become caves.

Sediments that have high porosity and permeability tend to form rocks with the same characteristics; for instance, sands form sandstones and clays form shales. [2]

Generally, the greater the porosity, the greater the permeability. Both of these factors are important to consider when determining how much groundwater is stored in our underground layers. If you needed to drill a well to find groundwater to drink, you would hope to find a good groundwater aquifer. It would probably be rock and sediment with high

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porosity so that it can hold large amounts of water, and high permeability, so the water can be pumped and sucked through the layers easily.

Usually the larger the consolidated (well sorted) grain size, the better the porosity and permeability (aquarium gravel). If the materials are poorly sorted (lots of different sizes) then it reduces porosity and permeability because smaller grains fall between larger grains, reducing space and flow paths (gravel and sand; sand and clay mixture). Surprisingly, clay can have high porosity too because clay has a greater surface area than sand, therefore, more water can remain in the soil. However, clay has bad permeability. The connectedness between clay particles is low and clay tends to retain water (because of the greater surface area again), slowing gravitational flow downward.

Porosity has been classified by Lucia (1995) as antiparticle and vuggy. Antiparticle porosity includes intergraui and intercrystal porosities and correlates reasonably well with permeability. Porosity identified as vuggy, which may include separate vugs and fractures, does not correlate with permeability . Porosity of porous media is defined as,

$$\Phi = Vp / Vb$$

where Vp is the pore volume and Vb the bulk volume. Conceptually, if Vp = total pore volume, the porosity is the total porosity. If Vp = effective pore volume, the porosity is the effective porosity. Obviously, the effective porosity will correlate better with permeability than the total porosity. However, the difference between the total and effective porosities is generally very small for sedimentary rocks and will be neglected. [3]

For a core sample of bulk volume Vb porosity is proportional to the pore volume. Although all the pore bodies and their throats contribute to porosity, pore bodies of their size) is more Important role than the pore throats. [4]

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Permeability is defined by Darcy 's law

$$K = \frac{q\mu L}{A\Delta P}$$

where q is the flow rate, μ the fluid viscosity, L the length, A the cross sectional area of the sample, and ΔP the pressure drop. [5]

Intuitively, it is clear that permeability will depend on porosity; the higher the porosity the higher the permeability. [6] However, permeability also depends upon the connectivity of the pore spaces, in order that a pathway for fluid flow is possible. The connectivity of the pores depends upon many factors including the size and shape of grains, the grain size distribution, and other factors such as the operation of capillary forces that depend upon the wetting properties of the rock. [7]

The permeability of the sandstone is extremely well controlled by the porosity, whereas the carbonate has a more diffuse cloud indicating that porosity has an influence, but there are other major factors controlling the permeability. In the case of carbonates (and some volcanic rocks such as pumice), there can exist high porosities that do not give rise to high permeabilities because the connectivity of the vugs that make up the pore spaces are poorly connected. [8,9]

Poroperm trends for different lithologies can be plotted together, and form a map of poroperm relationships[10], as shown in Fig.1

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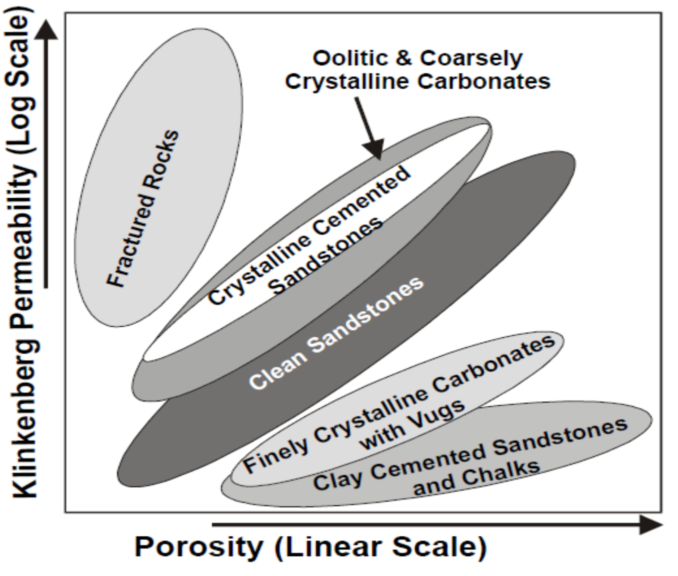

Fig. 1 : Poroperm relationships.

The permeability of rocks varies enormously, from 1 nanodarcy, nD (1□10-9 D) to 1 microdarcy, □D (1□10-6 D) for granites. [11] Shales and clays that form cap-rocks or compartmentalize a reservoir, to several darcies for extremely good reservoir rocks. In general a cut-off of 1 mD is applied to reservoir rocks, below which the rock is not considered as a reservoir rock unless unusual circumstances apply (e.g., it is a fractured reservoir). For reservoir rocks permeabilities can be classified as in Table 1 below. [12]

Table .1: Reservoir permeability classification

Permeability , (md)	Classification
< 10	Fair
10 – 100	High
100 -1000	Very High
> 1000	Exceptional

Many correlations between permeability and porosity have been reported, like Purcell (1949) , Thomeer (1983) ,Swanson (1981), Kamath (1992).

Database and Objectives of This Study

The Aswad field is located in the concession area NC74B, in the extreme southwest of the Sirte Basin. A total of 100 data sets that included measurements of k and Φ were used in the present study. The main objective of the present study was to test correlations between k, Φ

In this study, the relationship between permeability and porosity has been found, but not clear for all permeability readings. The samples were divided into four groups, based on the classification of permeability, and compared to the relationship in the case of being as one group.

Table 2 : experimental reading for porosity & Fair permeability

Sample	Total porosity (%)	Permeability (md)
A1	12	1.4
A2	12.5	1.6
A3	12.1	2.0
A4	15	2.6
A5	13	1.9
A6	14	2.0
A7	14.1	2.0
A8	13	2.5
A9	12.7	4.3
A10	20	6.1
A11	11	0.8
A12	35	7.3
A13	12.6	1.5
A14	30	6.8
A15	32	5.7
A16	50	9.5
A17	41	7.2
A18	44	7.6
A19	36	7.5
A20	14	2.1
A21	19	1.8
A22	24	7.0
A23	38	8.1
A24	39	8.5
A25	10	1.2

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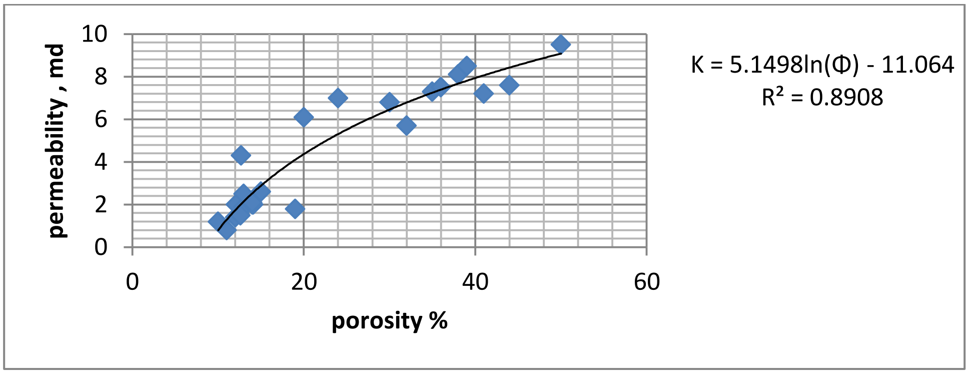

Fig .2 : Correlation between permeability and porosity for data set with K< 10 md

Table 3 : experimental reading for porosity & High permeability

Sample	Total porosity (%)	Permeability (md)
B1	25	23
B2	10	40
B3	29	50
B4	33	22
B5	18	15
B6	12	34
B7	10	25
B8	27	85
B9	38	35
B10	19	78
B11	11	55
B12	37	47
B13	31	67
B14	28	35
B15	24	24
B16	41	15
B17	50	59
B18	9	75
B19	12	53
B20	17	75
B21	24	53
B22	18	68
B23	20	57
B24	22	24
B25	34	12

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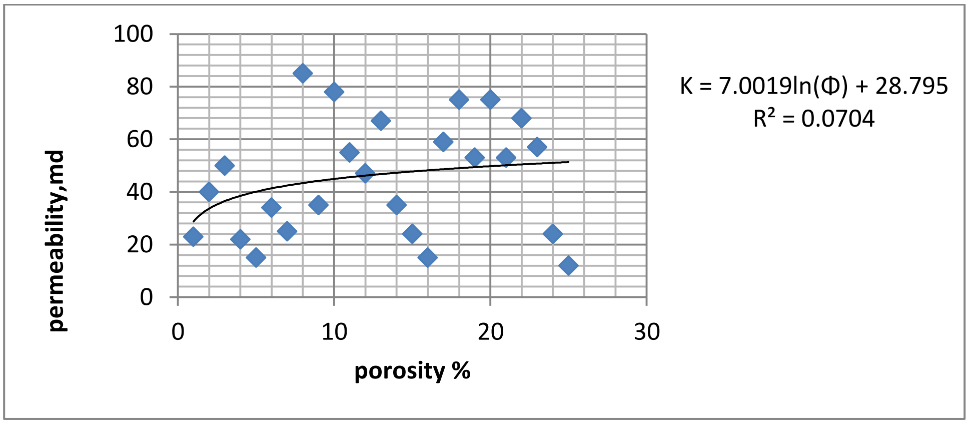

Fig. 3 : Correlation between permeability and porosity for data set with 10<K<100 md

Table 4 : experimental reading for porosity &Very High permeability

Sample	Total porosity (%)	Permeability (md)
C1	29	243
C2	21	587
C3	14	456
C4	18	951
C5	37	753
C6	31	741
C7	25	852
C8	28	369
C9	17	953
C10	10	751
C11	15	684
C12	18	153
C13	39	846
C14	32	624
C15	50	574
C16	42	254
C17	17	652
C18	13	352
C19	15	658
C20	34	785
C21	38	442
C22	36	689
C23	10	623
C24	25	475
C25	28	252

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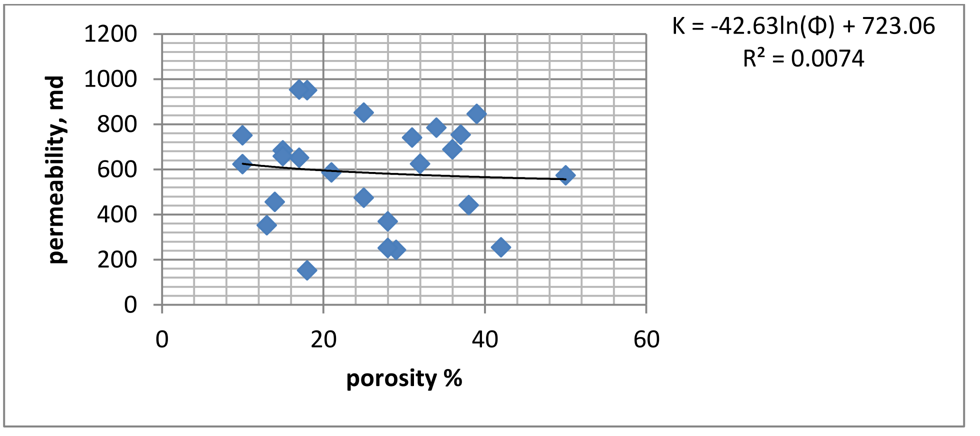

Fig .4 : Correlation between permeability and porosity for data set with 100<K<1000 md

Table 5: experimental reading for porosity &Exceptional permeability

Sample	Total porosity (%)	Permeability (md)
D1	50	3521
D2	25	2564
D3	27	9587
D4	33	7532
D5	34	1478
D6	26	1532
D7	18	9562
D8	37	3578
D9	42	9865
D10	49	7845
D11	37	3254
D12	31	7596
B13	24	4561
D14	26	1547
D15	17	9514
D16	18	1532
D17	10	6587
D18	28	7856
D19	35	4523
D20	29	3254
D21	24	6594
D22	11	4875
D23	22	2525
D24	28	6985
D25	39	7548

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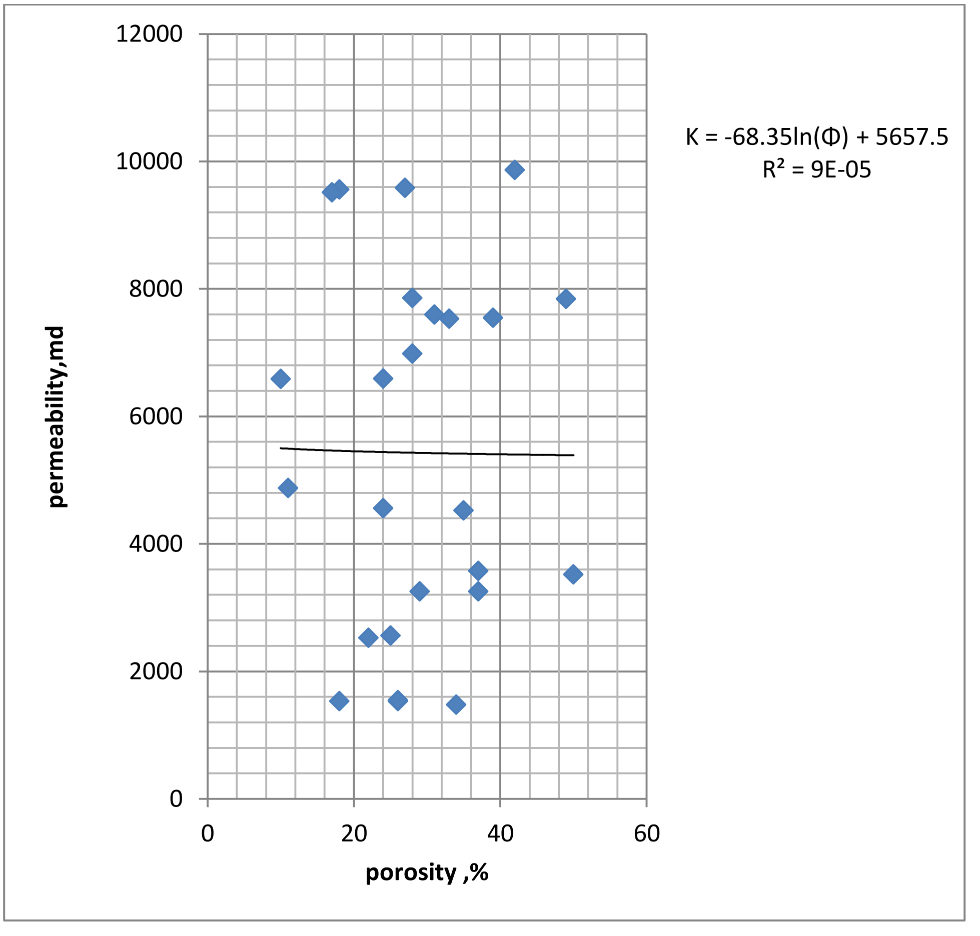

Fig .5 : Correlation between permeability and porosity for data set with K >1000 md

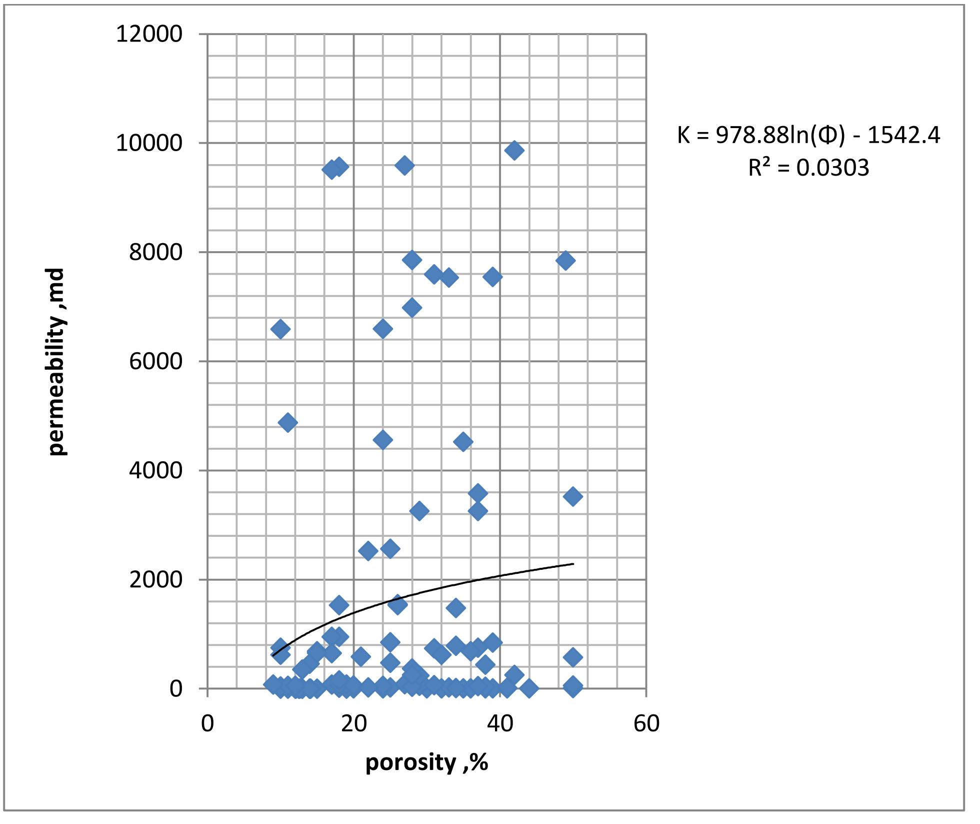

Fig .6 : Correlation between permeability and porosity for all permeability data

RESULTS AND DISCUSSION

Examination of a very large set of permeability, porosity data showed weak correlations exist Especially for some permeability readings.

- The correlation between permeability and porosity when K< 10 md is shown in Fig. 2 (correlation coefficient $R^2 = 0.8908$). $K = 5.1498\ln(\Phi) - 11.064$
- The correlation between permeability and porosity when 10<K<100 md is shown in Fig. 3 (correlation coefficient $R^2 = 0.0704$). $K = 7.0019\ln(\Phi) + 28.795$

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- The correlation between permeability and porosity when 100<K<1000 md is shown in Fig. 4 (correlation coefficient R^2= 0.0074). K = -42.63ln(Φ) + 723.06
- The correlation between permeability and porosity when K >1000 md is shown in Fig.5 (correlation coefficient R^2 = 9E-05). K= -68.35ln(Φ) + 5657.5
- The correlation between permeability and porosity for all permeability data is shown in Fig .6 (correlation coefficient R^2 = 0.0303). K = 978.88ln(Φ) - 1542.4

CONCLUSIONS

We can make some generalizations if all other factors are held constant:

- The higher the porosity, the higher the permeability.
- The smaller the grains, the smaller the pores and pore throats, the lower the permeability.
- The smaller the grain size, the larger the exposed surface area to the flowing fluid, which leads to larger friction between the fluid and the rock, and hence lower permeability.

Also permeability:

*· Depends upon porosity.

·* Depends upon the connectivity of the flow paths in the rock.

·* Depends, therefore, in a complex way upon the pore geometry of the rock.

*· Is a directional quantity that can be affected by heterogeneous or directional properties of the pore geometry.

* I expect that by taking more samples, the relationship between permeability and porosity will be clearer.

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