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Research Article

Reservoir Characterization of Uzek Well Using Magnetic Susceptibility Signature Technique

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Abstract The magnetic susceptibility signature technique have been shown to be successful in the characterization and prediction of key petrophysical properties in suits of classic reservoirs in some North Sea oil and gas fields and suites of carbonate reservoirs in the Middle East oil and gas field; however, none of such work has been done in the oil and gas reservoirs in the Niger Delta using the magnetic susceptibility signature technique. This work presents the characterization of Uzek oil and gas reservoir in the Niger Delta Basin using magnetic susceptibility signature techniques. Volume magnetic susceptibility measurements (SI unit) were taken from core plug of this reservoirs using MS2E Bartington Instrument and processed using Bartsoft software to obtain the magnetically derived illite content (%) and afterward correlated with the core permeability obtained from routine core analysis (RCAL) technique to determine the coefficient of determination for each reservoir and compute the magnetically predicted permeability (mD) from the regression equations. The volume magnetic susceptibility of UZEK oil and gas reservoirs ranges from 1.01574 SI units to 1180.554 SI units. The magnetic derived illite content (MDI) ranges from 3.85% to 300.03%. The magnetically predicted permeability (MPP) ranges from 12.83 (mD) to 3927.57 (mD). It was observed that both the volume magnetic susceptibility (SI unit) and the magnetically derived illite content(%) increases with burial depth while on the average, a 2% increase in the later results to a 54% decrease in permeability (mD).

Keywords Volume Magnetic Susceptibility (VMS), Magnetically derived illite content (MDI), Magnetically Predicted Permeability (MPP), Reservoir

Introduction

The magnetic susceptibility is a dimensionless quantity that expresses the ease at which a material is magnetized in the presence of an external field. It can be expressed as a volume magnetic susceptibility κ measured in SI unit or as a mass susceptibility χ measured in m^3kg^{-1}. Magnetic susceptibility signatures are characteristic response of the rock type and contents of its mineralogy [1-3].

Generally, rocks are heterogeneous assemblage of minerals mainly quartz in clastic reservoir or calcite in carbonate reservoir, which are diamagnetic in character that are often interspersed by lesser amount of permeability controlling clay minerals. These permeability controlling minerals are paramagnetic (illite, smectite, etc.); ferrimagnetic (magnetite); or antiferromagnetic mineral (pyrrhotite) and parasitic or spin scanted antiferromagnetic (haematite) [4].

The conventional routine core analysis (RCAL), special core analysis (SCAL), well logs, well test and repeated formation test (RFT) techniques of key petrophysical properties measurements are very expensive, time consuming, destructive and unsafe whose results are ambiguous when there is clay build up. Especially in times like this where every efforts is geared towards maximizing oil and gas business gains, the use of a more economical, rapid, safe and less expensive technique of which the magnetic susceptibility signature technique is known cannot be overemphasized.

This research paper employed the raw magnetic susceptibility signatures which were digitized and processed by Bartsoft software whose principle hinged on Potter's two minerals mixture model with geostatistical parameters, and analysed by comparing permeability logs derived from RCAL with those from reservoirs mineralogy in order to characterize and infer the reservoir qualities of UZEK oil and gas well in the Niger Delta oil and gas basin.

Materials and Method

The Volume Magnetic Susceptibility (VMS) measurements were taken using MS2E Bartington instrument/sensor (Plate 1a) connected to a MS2 meter through a TNC-TNC coaxial cable that is hooked up with a laptop (Plate 1b) that allow automatic transfer of all measurements into a spread sheet format by Bartsoft software and in the order of 10^{-6}SI units on Core plugs of UZEK oil and gas well in the Niger Delta oil and gas basin. The MS2E Bartington instrument is a high-resolution and very sensitive volume magnetic susceptibility-measuring instrument with an area response of 3.8mm by 10.5mm and a depth response of 50% at 1mm or 10% at 3.5mm (www.bartington.com/retrieved 3 July 2016).

Plate 1a: MS2E Bartington Sensor

Plate 1b: MS2E Bartington Sensor in use

The followings are measures taken in order to ensure accurate results:

i. The meter was allowed to warm up for about five minutes before measurement in order to activate the sensitivity of the sensor
ii. The sensor were calibrated by holding it in air for about 10seconds to record the surrounding magnetic susceptibility
iii. For full induction, the sensor was placed on the core slab for a minimum time of 10 seconds
iv. The instrument was checked for drift and possibly drifts correction effected between successive measurements, by rising up the sensor to the atmosphere where the magnetic susceptibility is equal to zero; and the reading will be calibrated to zero.

The measured unprocessed volume magnetic susceptibility represents the total volume magnetic susceptibility κ_T at each measurement depth. These values represent the combined response or characteristic signal from all the diamagnetic minerals and paramagnetic minerals at each measurement depth.

The Volume Magnetic Susceptibility data will be process using Potter's Two Mineral Mixture equations [4] in equation (1) modified by Asime [5] in equation (2):

$$F_I = \frac{(\kappa_T - \kappa_Q)}{(\kappa_I - \kappa_Q)} \times 100\% \qquad 1$$

$$F_I = 0.2343(\kappa_T + 14.3) \qquad 2$$

Where F_I = volume magnetically derived illite content (%), κ_I = Volume magnetic susceptibility of illite , κ_Q = volume magnetic susceptibility of quartz, and κ_T = total volume magnetic susceptibility of the reservoir rock at measured depth which is the value the instrument record. The values for the volume magnetic susceptibility of illite κ_I and that of quartz κ_Q will be extracted from [3, 6] in (Table 1) for the computation of magnetically derived illite content (%) and magnetically derived quartz.

The core Permeability data from routine core analysis (RCAL) were correlated with the magnetically derived illite content (%) to determine the strength of the two variables and compute the magnetically predicted permeability using the regression coefficients and the equation. The result from the correlation of core permeability with magnetically derived illite content was compared with that of core permeability with porosity using their respective coefficients of determinations. The spectra from the depth profile of core permeability and magnetically predicted permeability were analysed.

Table 1: Common minerals in oil and gas reservoirs, their densities and Magnetic susceptibilities [3,6]

Mineral Types	Minerals	Mass Magnetic Susceptibilities (MMS)*$10^{-8}m^3Kg^{-1}$	Densities*10^3 (Kgm^{-3})	Volume Magnetic Susceptibility (VMS)* 10^{-5} SI Unit
Diamagnetic Matrix Mineral	Quartz	-0.50 → -0.60	2.6	-1.3 → -1.56
	Feldspar	-0.49 → -0.67	2.65	-1.299 → -1.776
Paramagnetic Permeability ControllingClay Minerals	Illite	15	2.75	41.25
Scanted Antiferromagnetic Mineral	Haematite	10 → 760	5.26	52.6-3997.6

Results

Table 2: Data values for reservoir of Uzek oil and gas well with reservoirs I, P, Q and R

Depth (m)	Core permeability data (mD)	Volume magnetic susceptibility VMS*10^-6 SI Units	Magnetically derived illite (%)	Core analysis porosity (%)	Magnetically predicted permeability.
RESERVIOUR I					
3161.9	1649.7	8.67312	5.77	22	190.915863
3169.9	4068.78	1.1434	3.88	26	300.3574036
3172.1	597.64	38.9456	13.37	20	73.16515263
3176.15	3355.6599	4.7987	4.80	22	235.7049319
3178.7	944.55	21.6951	9.04	20	114.372157
3178.9	1926.37	5.8485	5.06	24	221.7446091
3179.15	4733.52	1.0154	3.85	24	303.2233022
3180.9	2505.79	6.552	5.24	22	213.2290977
3197.9	1332.2	10.8419	6.31	22	172.2422886
3198.9	180.98	217.8398	58.29	22	13.63558306
3199.9	1106.42	10.7625	6.29	33	172.8650454
3201.9	2271.6299	4.2423	4.66	26	243.7919393
RESERVIOUR P					
3816.5	2976.6201	3.7076	4.52	21	2919.631649
3820.8	2941.52	3.2475	4.41	16	2994.247063
3821.61	295.97	174.379	47.38	17	42.34412994
RESEVIOUR Q					
3850.55	96.39	483.9917	125.12	17	42.34412991
3850.8	64.32	542.2434	139.75	16	36.41264396
3854.8	78.02	498.9216	128.87	16	40.67168597
3855.35	679.32	168.655	45.94	21	166.248775
3855.8	2.22	1180.5537	300.03	14	12.83286985
3856.8	19.97	942.6045	240.28	21	17.37691854
3856.81	3.82	1037.382	264.08	19	15.27517302

3861.42	906.14	9.4365	5.96	19	2700.316248
3862.2	1299.4399	4.3215	4.68	20	3760.870568
3867.2	152.59	370.281	96.57	19	60.30454149
3869.2	129.98	326.5257	85.58	15	71.11345225
3869.6	224.95	169.8209	46.23	19	164.8134625
3871.2	121.45	273.864	72.36	14	89.42319379
3872.2	45.42	391.371	101.86	15	56.06617665
3875.2	326.53	118.2945	33.29	15	257.994875
3878.2	2.92	1147.3801	291.70	13	13.33568288
3880.85	125.82	390.1892	101.57	14	56.28989521
3881.2	338.64	116.8631	32.94	14	261.8457124
			RESERVIOUR R		
4005.9	3073.05	5.3858	4.94	16	2870.657116
4009.9	5.91	1050.236	267.30	18	18.51228869
4010.9	39.22	760.8594	194.64	18	27.64397895
4014.9	4.41	1050.2778	267.32	17	18.51136993
4018.9	2623.95	3.6707	4.51	15	3221.221933
4019.9	1271.89	4.6266	4.75	16	3016.97026
4023.9	356.09	350.5116	91.60	16	71.66977486
4029.9	1762.0699	6.5327	5.23	20	2672.368922
4030.9	768.28	104.2693	29.77	19	296.6810919
4032.9	268.1	227.4923	60.71	15	120.5367625
4033.9	322.26	32.0462	11.64	20	972.6328603
4037.9	8.63	1014.9163	258.44	19	19.31889969
4038.9	429.86	215.6907	57.75	20	128.4070925
4042.9	41.54	814.3636	208.08	16	25.40742642
4043.9	5399.3301	1.0619	3.86	20	3927.57425
4044.9	4311.29	2.1325	4.13	19	3606.960597

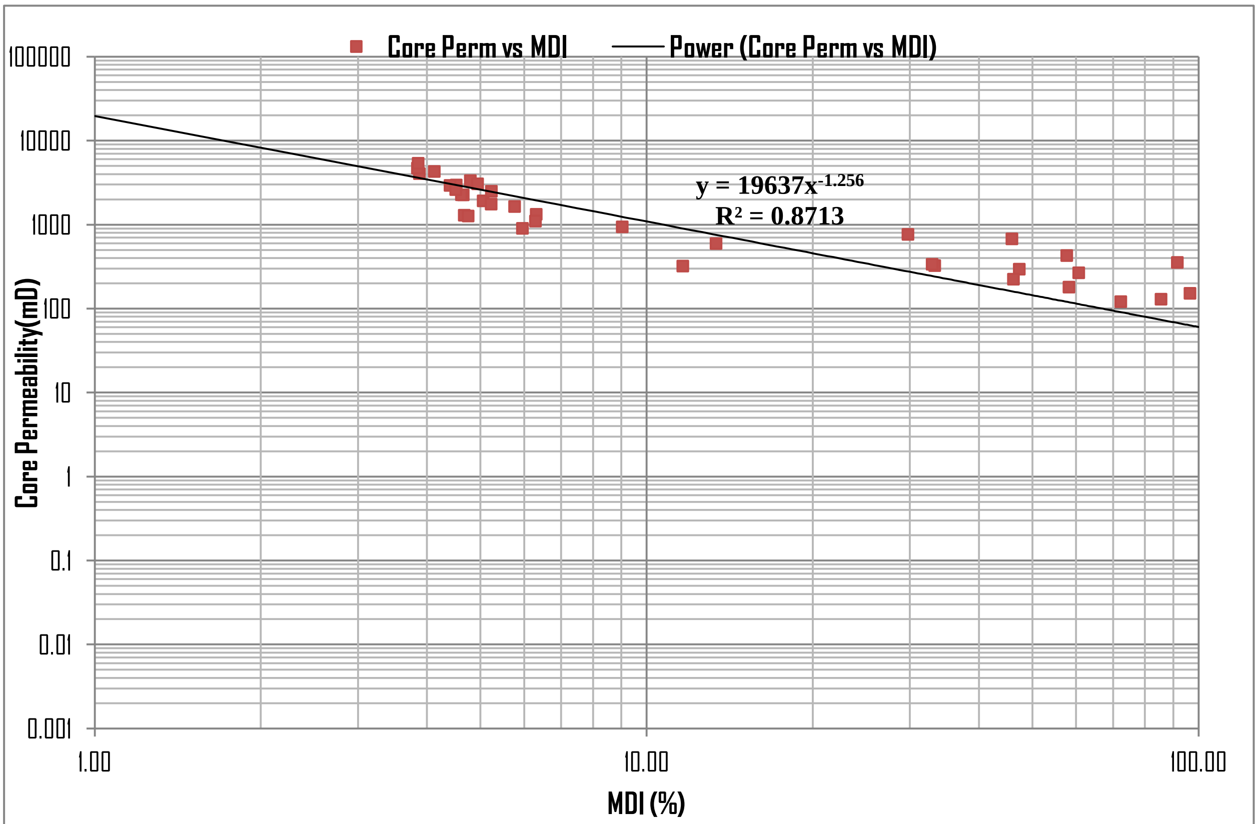

Figure 1: Scatter plot of core permeability against magnetically derived illite content of UZEK oil and gas well

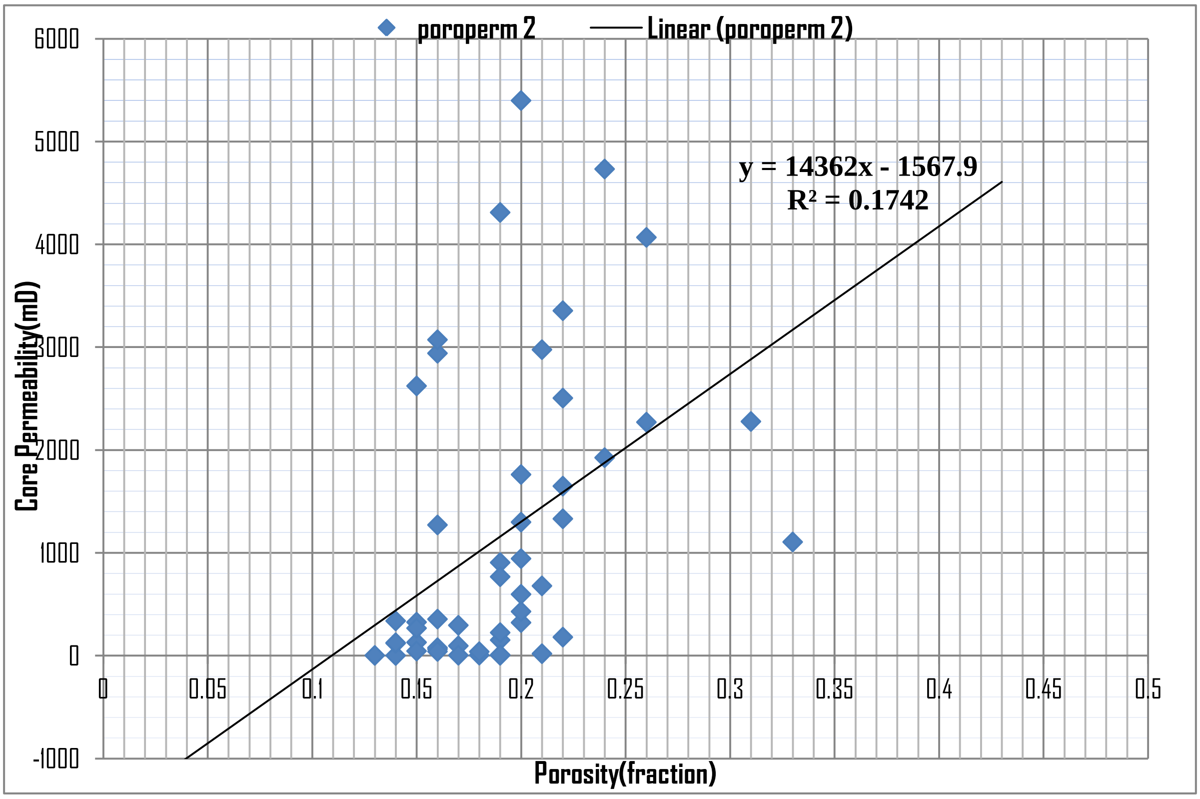

Figure 2: Scatter plot of Permeability (mD) against porosity (fraction) that is the (Poroperm) of Uzek oil and gas well

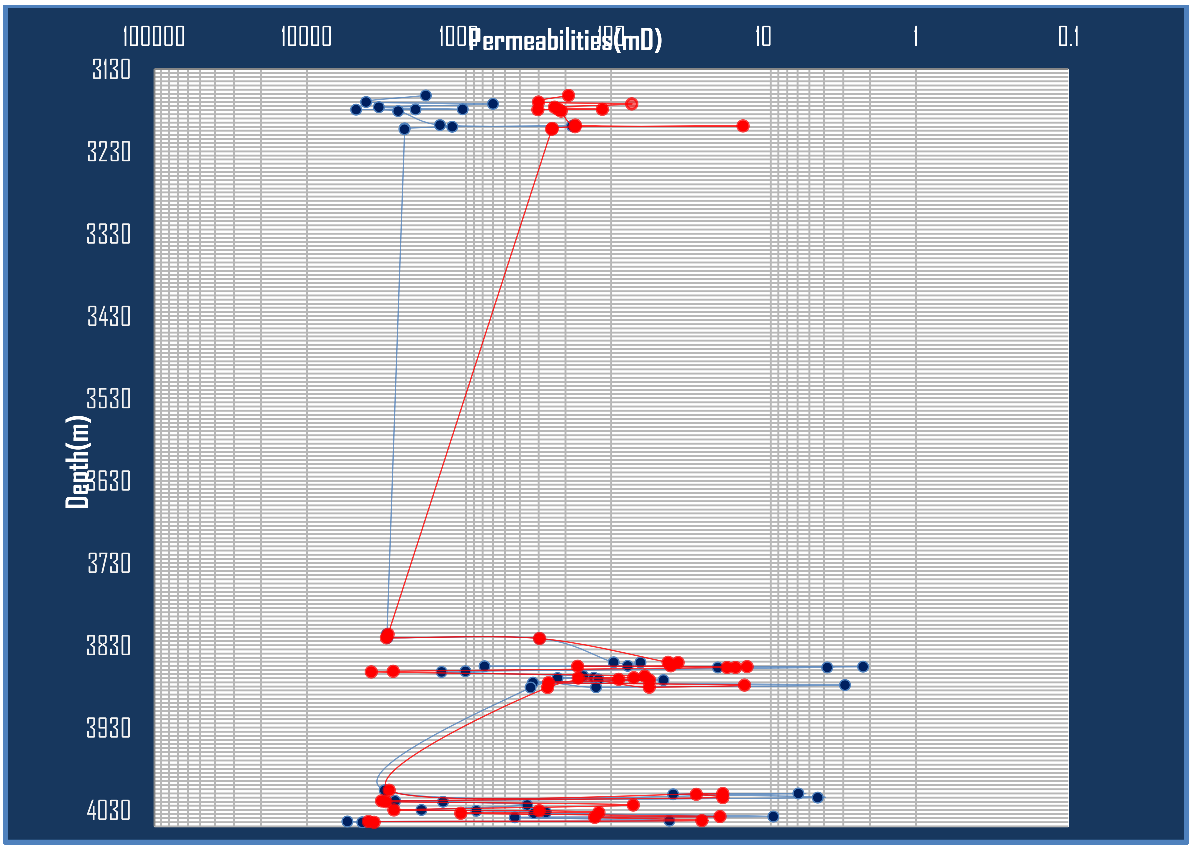

Figure 3: Plot of depth against core permeability magnetically predicted Permeability (MPP) of UZEK oil field

Discussion

Permeability and porosity are two important attributes of reservoir quality. These attributes are conventionally used to characterize oil and gas reserviour, in order to determine the amount of oil and gas a rock can contain and the producibility rate an oil and gas well. The approach of using Poroperm, which is permeability(mD) and porosity(fraction) relationship to determine the quality of a reserviour has deter several effort due to errors and high uncertainties level especially in the carbonate reservoirs where zero relationship exist. Hence, the advent of using permeability (mD) and magnetically derived illite content (%) which has yield positive results where Poroperm had no relationship. Illite as a type of clay mineral has great affinity to permeability and most sandstones and carbonates contain appreciable fine-grained clay material including kaolinite, chlorite, smectite, mixed layer illite-smectite and illite. These clay minerals commonly occur as both detrital matrix and authigenic cement in reservoir sandstones.

The volume magnetic susceptibility of Uzek oil and gas well ranges from 1.0154 x 10^{-6} S.I units to 1180.554 x 10^{-6} S.I units. The trend of volume magnetic susceptibility increases with burial depth. After processing data with Bartsoft using Potter's two mineral mixtures function, a magnetically derived illite contents that ranges from 3.85% to 300.03% varying increasingly with depth. This is evident in Table 1. This observed increase in illite with increasing burial depth and temperature was an obvious indication of deep burial diagenesis in this formation. The magnetically predicted permeability (MPP) ranges from 12.83mD to 3927.57mD with an exponentially decreasing trend with burial depth. The decreasing MPP trend might be caused by an increase in illite content with increasing burial depth. In addition, as the illite content increases, the large voids between kaolinite crystals are filled with illite particles. In addition gradual change of swelling smectite clay mineral to non-swelling illite clay results through intermediate mixed-layer illite/smectite clay with increasing depth of burial, in course of this, the pore sizes decrease substantially which in turns decreases the reservoir permeability.

There exist a strong correlations or relationship between oil and gas reservoir permeability and illite content even where there was a very poor correlation or zero correlation between permeability and porosity. This observation is evident on Figure 1, where a power coefficient of determination (R^2) of 0.8713 and linear coefficient of determination (R^2) of 0.1742 were recorded for the scatter plots of permeability (mD) against magnetically derived illite content (%) and permeability (mD) against porosity (fraction) respectively. These values of coefficient of determinations depict that a very strong correlation exist between illite content and permeability as compared to that of porosity and permeability which is very weak.

Figure 3 is a permeability logs for magnetically predicted permeability (MPP) and core permeability of Uzek oil and gas reserviour wells measured in milliDarcy (mD).The red colour spectrum represents core permeability log while the blue colour spectrum represents the magnetically predicted permeability log. It can be observed that the two permeability spectra of Figure 3 are almost in point -point phase. This in-phase characteristic of the spectra validates the magnetic susceptibility reserviour imaging technique as an alternative to the routine core analysis (RCAL) technique. It can also be observed that magnetically predicted permeabilities are mostly higher than those of core permeabilities at corresponding depths. On the other hand these depth permeabilities variations of the two spectra departed from the normal at depths between 2816.5m and 4037.9m where the two values overlapped or the core permeability became higher than the magnetically predicted permeability. These anomalies might be caused by metastability of smectite-illite transformation or presence of ferromagnetic or antiferrimagnetic minerals such as heamatite at depth between 2816.5m and 4037.9m. Generally the permeability of Uzek reservoirs permeabilities ranges from very poor (12.83mD) to excellent (3927.57mD). The depths such as 3198.9m, 3855.8m, 3878.2m etc. where the permeabilities measurements are very poor (2.12mD to 8.63mD) could result from noise generated into the readings by influences from heamatite or other antiferrimagnetic minerals. The Uzek's oil and gas reserviour becomes more heterogeneous as depth increases which is evident from both spectra overlapping and intersecting each other as the change in permeability values between successive depths increasingly feasible.

Conclusion

Magnetic susceptibility signature technique was carried out to characterize reservoir of UZEK oil and gas well. From the study it can be concluded that:

- The volume magnetic susceptibility of UZEK oil and gas well ranges from 1.01574 S.I units to 1180.54 SI units.
- The magnetically derived illite content (%) of UZEK well ranges from 3.85% to 300.03%.
- The magnetically predicted permeability of UZEK well ranges from 12.83 (mD) to 3927.57 (mD).
- The power coefficient of determination (R^2) of 0.8713 and a linear coefficient of determination (R^2) of 0.1742 were recorded for UZEK oil and gas well.
- 5. Volume magnetic susceptibility magnetically derived illite content and reserviour heterogeneity increases with burial depth while permeability decreases with burial depth.
- There is a very strong correlation between magnetically derived illite content and permeability
- In Uzek oil and gas reservoir where Poroperm relationship is weak, the core permeability and magnetically derived illite contents still correlate very strongly.
- On average a 2% increase in illite content results a 54% decrease in permeability

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