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Rock formations and their petrophysical properties for Zubair oilfield in Basrah

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Abstract:

This article focuses on two aims the first one is to define and modeling rock types of Zubair formation in Basrah and the second one is to modeling the petrophysical properties of Zubair formation. Accurate methods have been used to achieve these aims. The rock formations of the Zubair oil field was analyzed and important results were obtained from that analysis, then 4 rock samples from the reservoirs in the Zubair formation have taken at different depths at different temperature, pressure, and rock type. We used Mercury Injection and Gamma-ray Logging to determine and calculate the porosity of these rock samples, also we used deep autoencoders in borehole image logs to determine and calculate permeability. At "Mercury Injection" Method, the results of this study have suggested that the estimated accessible porosity has been considerably decreased in the case of implementing new corrections on the MICP (i.e. Mercury Injection Capillary Pressure) test data. From the “Gamma Ray “method we found that the level of the gamma-ray has been assumed to be associated with the size of the grain. We found that the best depth to calculate the properties of sandstone is (650 – 1100 m) underground. We found that the best depth to calculate the properties of shale is (1300 – 1650 m) underground.

Keywords: Rock formations, petrophysical properties, Zubair oilfield, modeling, autoencoders, Gamma Ray.

1. Introduction

Zubair Field is an oil field that is located west of Basrah in southern Iraq as shown in Figure 1. It has been found in 1949 by Basra Petroleum Company, which is an Iraq Petroleum Company associate and is one of the world's largest fields. It possesses 4.5 billion barrels (about 6.1x108 t) of known reserves and currently produces over 490,000 barrels each day, yet production is predicted to peak at 1.125 million barrels per day in the coming years as part of the field's growth plan [1] [2].

Rock Formations Of Zubair Oilfield A formation of rocks is an out-cropping of the surface rock which is isolated, spectacular, or scenic. Weathering and erosion sculpt existing rock, resulting in the formations of the rocks. In petrologic and stratigraphic investigations, phrase rock formations might as well indicate specific sedimentary strata or other units of rocks. Zubair Formation, which is of Upper Cretaceous age and is located in the southern part of Iraq in Basrah, is one of the most significant formations in oil fields. Those references will be used to discuss the rock formations of the Mishrif oil field. According to (Geoffrey Mibei 2014), rocks could be categorized into three major types depending on their formation process[3]. Zainab AL-Tool et al. (2019)[3] studied the petrophysical properties of the upper sandstone member of Zubair Formation at Zubair oil Field by using an interpretation of several different borehole logs for the open wells (Zb-40, Zb-84, Zb-114, Zb-212, Zb-233). These Properties include shale volume (Vsh), effective porosity (Øe), water saturation (SW), permeability (K), and Pore throat type classification R35. The petrophysical properties (Vsh),(Øe), and (SW) were drawn for each reservoir unit to determine the direction of the improvement of reservoir characteristics within the selected wells. Mofaq AL-Shahwan et al. (2018) [4] divided Upper Shale Member from Zubair formation in Luhais field into six units of reservoir and non-reservoir, including the main reservoir unit 1C, and studied in terms of thickness and lithology. The reservoir unit 1C was associated with environmental sediment, which was the environment of the tidal channels, explaining the sedimentation mechanism that helped to form the oil traps and improve the petrophysical characteristics. Also, Aiad Al-Zaidy, Kamal Mohammed (2017)[5] divided the Zubair formation into three lithofacies:- The upper unit is composed mostly of shale layers, the middle unit consists of thick layers of sandstone rocks, and the lower one consists mainly of Shale with fewer sandstone layers. These units are characterized by three types of petrophysical features according to total porosity/effective porosity. The reservoir geology which represent by property modeling, preparation data, construction of three-dimension clumps and scale-up for the studied oil fields. The Rachi oil field is appeared a better hydrocarbon saturation compared to the Luhais oil field.

The objective of this research is to evaluate the petrophysical characteristics of the reservoir, the most important of which are the reservoir's porosity and permeability, and these characteristics can provide important and useful information for water flooding operations to enhance and increase oil production.

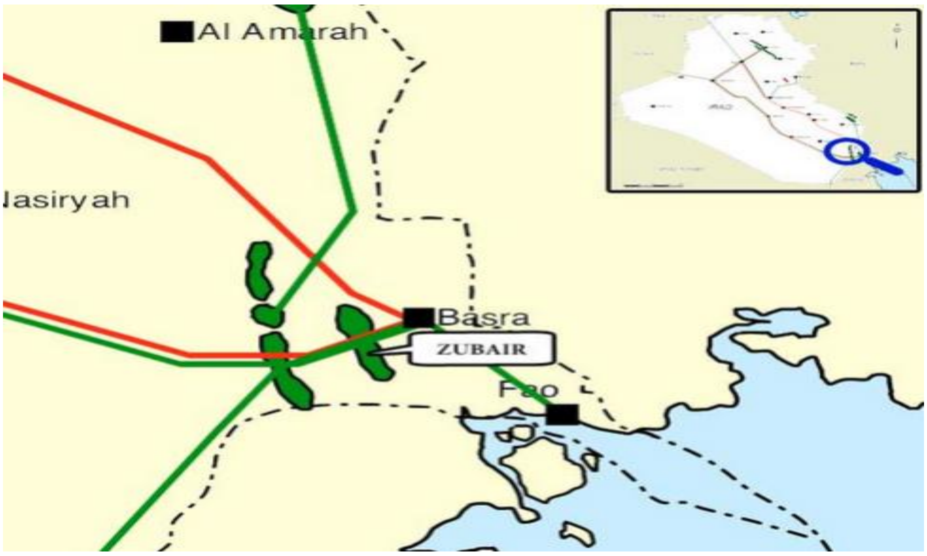

Figure 1 Zubair Field location

Porosity: Porosity can be defined as the percentage of the void space or the pore volume, or volume within a rock which might be containing the fluids, and is one of the most significant petrophysical qualities. Porosity could be a deposition relic (mainly the porosity, like the space between the grains which haven't been compacted together) or it might form as a result of rock alteration (secondary porosity, like the case where the feldspar grains or fossils have been dissolved preferentially from the sand-stones)[5].

Calculations of Porosity: The porous medium (sediment or rock) porosity indicates void space fraction in material, in which that void might include, for instance, water or air. Porosity was utilized in hydrogeology, geology, building science, and soil science. It is defined by the ratio[6]:

$$\emptyset = (Vv) \div (Vb) \quad (1)$$

In which $\emptyset$ represent the porosity (dimensionless), Vv represent the void-space volume (like fluids) in (m^3) and Vb represent bulk or total material volume, which includes void and solid components, in (m^3).

Methods of Measuring Porosity: Many approaches could be used for measuring porosity[7]:

- Direct approaches (specifying bulk volume regarding porous sample and subsequently skeletal material's volume with no pores (total volume − material volume = pore volume).

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- With the use of industrial CT scanning, 3-D rendering of the internal as well as the external geometry, which includes the voids, is created. After that utilizing the computer software for conducting defect analyses.
- Optical approaches (specifying material's area vs the area of pores that can be visible under a microscope). Concerning porous media with random structures, the "volumetric" and "areal" porosity values are the same.
- Imbibition techniques involve immersing porous samples within a fluid which preferentially wets pores while under the vacuum.
- Water evaporation technique (volume of the pore = (saturated sample weight − dried sample weight)/water density).
- The technique of the saturation of water (pore volume = total water volume − the volume of water remaining following soaking).
- Mercury intrusion porosimetry (many non-mercury intrusion methods were created because of the toxicological issues, and the fact that mercury tends to form amalgams with various alloys and metals).
- The technique of gas expansion, in a known volume container, known bulk volume sample is enclosed. It's connected to an evacuated container (in other words near vacuum pressure) with a known volume.

Permeability: For assessing the porous rocks' permeability, geologists frequently employ the method of pore pressure oscillations. This is potentially the optimal technique to utilize for other materials, however, depending on the material under investigation, a few changes may be required [8]. A computational approach to quantify the fabric conducts permeability based upon Lattice Boltzmann approach was created and proven acceptable to predict effective pre-form permeability based upon a number of the layers of the fabric in the preform, shear angle, and force of compaction. Under some conditions, this or similar software can be significant in the prediction of permeability. In US, SRI International and Southern Research Institute are 2 separate contractors who can perform this measurement.

There are three kinds of permeability. The absolute permeability indicates the permeability of the porous medium in the case where only one fluid is present (single-phase flow). Effective permeability (k_o, k_g, k_w) represents the permeability of rock to a flowing fluid when at least two fluids are present. The effective to absolute permeability ratio has been referred to as relative permeability [9].

Calculations of Permeability: Darcy's law, relating discharge (i.e. flow rate) and fluid physical characteristics (viscosity) to the gradient of pressure that is applied to the porous media, includes permeability as a proportionality constant part [6]:

$$V = (K * \Delta P) \div (\mu * \Delta X) \tag{2}$$

Therefore:

$$K = (V * \mu * \Delta X) \div \Delta P \tag{3}$$

V represent fluid velocity through a porous medium. (m/s), K represent the permeability. (darcys).

μ represents dynamic viscosity regarding fluid (Pa.s), ΔP represents a difference of the applied pressure (Pa), ΔX represents the thickness of the porous medium bed (m).

Methods of Measuring Permeability: Soil permeability, which is referred to as hydraulic conductivity as well, has been specified by various techniques, which include the constant and falling head lab experimentations on intact specimens or reconstituted ones. In-situ borehole permeability testing and field pumping tests can also be utilized to determine permeability in the field. The empirical derivation of the coefficient of permeability from the results of simple laboratory experiments like the distribution of grain size is a less appealing approach. Cone/piezocone penetration tests have been used to determine soil permeability[10]. The permeability coefficient has been evaluated with the use of a field falling head at various depth levels in the presented work.

Resistivity : The log of resistivity is obtained by measuring the resistance of coal and related rocks to electrical current flow, as well as generating currents into the reservoir rock[11]. As a result, depending upon the diameter of the borehole, the salinity of the fluid, and the drilling fluid, different combinations of the electric and induction logs of resistivity are utilized. therefore, the fluids are utilized for the quantification of the resistance of rocks that surround the borehole in the logs of resistivity. A "profile of resistivity," or variation in coal reservoir from the borehole, has been utilized for the expression of resistivity. The high deflections of the resistivity on profiles of resistivity are a result of high coal bed moisture content (for example, sub-bituminous coal and lignites). The mineral exploration (e.g., for the copper and iron ore bodies), geological explorations (deep geological disposal and geothermal wells), and water-well drilling all utilize the logging of resistivity. It is a necessary tool for the evaluation of the formations in oil and gas well drilling. As it has been stated earlier, the majority of the rock materials are electric insulators, however, their surrounding liquids are electric conductors. The hydrocarbon fluids, in contrast to the aqueous solutions that contain the conducting ions, are fundamentally indeterminately resistive since they are lacking the carriers of the electrical charge.

Petrophysics: Archie and Thomeer[12] invented the word "petrophysics" in a quiet café in The Hague. Petrophysics is the research of the chemical and physical qualities of rocks and the fluids that they contain, according to their definition. The mission of the Society of Petrophysicists and Well Log Analysts (SPWLA) is to raise the awareness that petro-physics, well logging, and formation evaluation are the optimal practices in the gas and oil industry. Petrophysics focuses on properties related to fluid distribution, pore system, and flow properties. Hydrocarbon sources, hydrocarbon reservoirs, aquifers, and seals are all identified and evaluated using these features and their relations.

Motivation: The motivation for this idea is to learn about the rock types in Zubair oil field and model them, as well as physical properties such as porosity, permeability, and resistivity, which will help us determine whether the location is economically viable for drilling and extracting petroleum, as well as what types of devices we must use for extracting petroleum there. Defining and modeling rock types of Zubair formation in Basrah and Modeling the petrophysical properties of Zubair formation in Basrah will be studied and analyzed based on the findings of our research.

Petrophysical Properties of Zubair Oilfield: The features of a reservoir necessitate accurate knowledge of some basic reservoir characteristics. Porosity, resistivity, lithology, shale volume, water saturation, hydrocarbon saturation, and permeability are all characteristics that log measurements can infer or define. Using the next references, we shall discuss a few of such qualities for Zubair oil field.

Porosity: Porosity petrophysical characteristics range from 19 to 28%, according to (Janet Pitman, Thamer Al-Amiri, et al., 2010)[13] Zubair Formation, which has a gross thickness of 150m–250m and a net thickness of 90m–170m, is the principal reservoir in most south oil fields. While (Aiad and Kamal 2017)[4] published an article on granule porosity and how it reduces as granules impact with each other, the granulator wall, and the impeller in a high-shear granulator. Also, he mentioned in this book (Module in Earth Systems and Environmental Sciences for Nimmo, 2013)[14] that welding or cementation of the particles not only produces pores that differ in the shape from the ones of the particulate media, yet as well decreases the level of the porosity by taking up space which might be pore space otherwise. Lastly, while porosity might improve thermal resistivity and thus be advantageous in a few refractories, it is a disadvantage in dense advanced ceramics of the type (Alumina Ceramics for Andrew Ruys 2019)[15].

Resistivity Logging: According to (Aiad and Kamal 2017) [5], the upper unit of Zubair Formation at Luhais oil field has been divided into 2 horizons. The upper part is represented by high resistivity-high gamma ray, whereas the lower part is represented by low resistivity-low gamma ray. The existence of shale, which comprises K-feldspar, clay minerals, and organic material that emits the natural gamma radiation, is indicated by a reading of high gamma-ray response, according to Mohanad Al-Jaberi, Methaq kh et al. Because clean sandstones emit less radiation, their gamma-ray count analysis is lower[16]. The reservoir parameters and reservoir architecture are examined thoroughly using well log data from seven wells chosen from a large number of wells in this work. One pay zone has been detected in Zubair Formation, but it may split into two zones locally. Romeo M. Flores (2014) indicates that different combinations of electric and induction resistivity logs have been used based on the diameter of the borehole, the salinity of the fluid, and the drilling fluid[17]. It is the reason for of utilization the fluids for the quantification of resistance of rocks that surround boreholes in logs of resistivity. Lastly, in 2015, (Elements of Petroleum Geology (3rd Edition) for Richard C. Selley and Stephen A. Sonnenberg was published.) After reviewing the different logs of resistivity and their qualitative interpretations, it's time to move on to a quantitative estimate of a reservoir's hydro-carbon concentration[18].

Permeability: In 2014, Salih M. Awadh conducted research on permeability declination caused by kaolinite owing to pH changes in Zubair reservoir (i.e. Lower Cretaceous) throughout secondary production using the water injections' approach[19]. In 2016, (Amna H. Handhal) researched calculating reservoir permeability from measured porosity utilizing several methods such as adaptive neurofuzzy inference system, linear regression, and M-5 decision trees[20]. Furthermore, (Ritesh Bhakta, Moustafa Dernaika et al., 2018) demonstrated in their research that the majority of the reservoirs of carbonate are identified through the multiple-porosity systems which are imparting the petro-physical heterogeneity to an interval of the gross reservoir; such heterogeneity results in complicating the reservoir description and requires the establishment of a detailed and accurate understanding regarding geological heterogeneities as well as their effect upon petro-physics and reservoir engineering[9]. Lastly, G. W. Scherer, H. J. Castelijns, et al. (2007) wrote in their paper that "the impact of the in situ formed gel of silica upon permeability regarding porous material has been examined experimentally," and that "the solutions of gelling of tetra-methyl-ortho-silicate and methanol in the water have been imbibed in dry sand-stone plates and cured for several days."[8].

Analyzing Of Rock Formations of Zubair Oilfield: With regard to quality, quantity, and thermal maturity, the primary parameters of potential source rock inside Zubair Formation have been satisfactory. A total of 38 samples (23 cuttings, 15 cores) are examined for pyrolysis characteristics, and 9 rock samples (3 cuttings, 6 core) are studied using gas mass spectrometry (MS). A total of 6 oil samples were examined for carbon isotopes, composition, biomarkers, and correlation. MS is used for quantitative analysis. Infrared analysis was also performed on 14 rock samples. All of this information comes mostly from Zubair and West Qurna fields of oil in Zubair Sub-zone.

Determining The Petrophysical Properties of Zubair Oilfield: We will talk about the methods that we used to get results, and also will talk about the properties, photos, and graphs that are related to our used methods and their devices. We had chosen 4 rock samples three of them are sandstone and one is shale with different depths, shape densities, and weights as shown in Table 1.

Table 1 Rock samples properties.

No.	Rock Type	Depth (m)	Density, (g/cm^3)	Weight, (g)
1	Sandstone	836.50	2.61	147.54
2	Sandstone	838.10	2.63	133.89
3	Sandstone	840.90	2.58	141.67
4	Shale	1435.60	2.67	139.13

Mercury Injection: For different rock types, MICP (i.e. mercury injection capillary pressure) is a commonly utilized method for the measurement of the pore throat size distributions, porosity, and pressure of injection versus saturation of mercury as shown in Figures 2 and 3. Based on the latest investigations, the accessible porosity regarding sandstone samples evaluated from MICP test has been corrected to account for conformance and grain compressibility with the use of MICP for sandstone samples. To reliably estimate the accessible sand-stone sample porosity with the use of MICP data, we suggest a general technique that consists of 3 distinctive corrections: (1) grain compressibility, (2) conformance, and (3) inaccessible pore compressibility. With the use of MICP data, we first create a mathematical model to predict pore as well as grain compressibility, and after that use the above-mentioned corrections to compute accessible porosity. The shale matrix is divided into three elements in the mathematical formulation: (1) grains, (2) inaccessible pores, and (3) accessible pores.

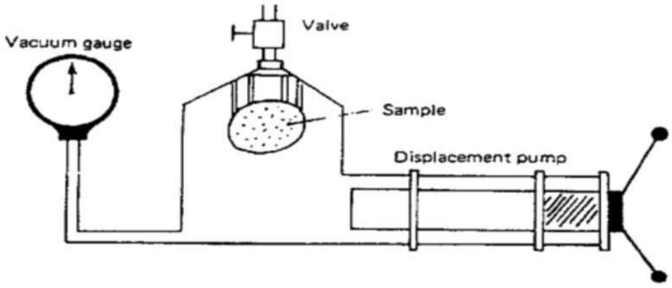

Figure 2 Mercury injection pump[21]

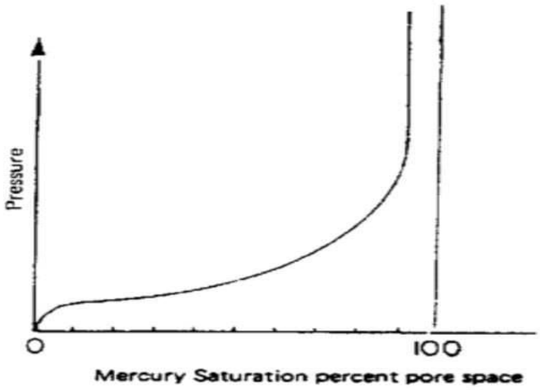

Figure 3 Porosity through mercury injection[21]

Porosimiter: We utilized the equipment "Porosimeter" for measuring porosity with the use of "Mercury Injection". A device utilized to evaluate pore sizes, porosity, and pore volume is critical for the porous materials' characterization. The most extensively utilized approach for assessing the pore size distribution regarding accessible macro- and mesopores in solids is mercury porosimetry. The method is based on the pressure-dependent intrusion of mercury into a porous material as a non-wetting liquid. The equivalent pore size is estimated from the applied pressure with the use of Washburn equation as shown in Figure 4.

Figure 4 Porosimeter

Gamma Ray Logging: For many years, rock radioactivity was utilized to assist determine lithologies. The elements thorium, uranium, radium, potassium, and radon, as well as the minerals which contain them, are known as NORM. Although there is no direct link between distinct types of rock and observed gamma-ray intensities, there is a high association between radioactive isotope mineralogy and content. For reading gamma rays that have been emitted via such elements and interpreting lithology from data that had been obtained, logging techniques were created. Passive gamma-ray devices are the most basic tools in terms of concept. There is no source for handling and simply one detector in most cases. Simple gross gamma-ray counters for the shale and bed-boundary delineations to the spectral devices for the clay typing and geo-chemical logging are amongst those as shown in Figure 5.

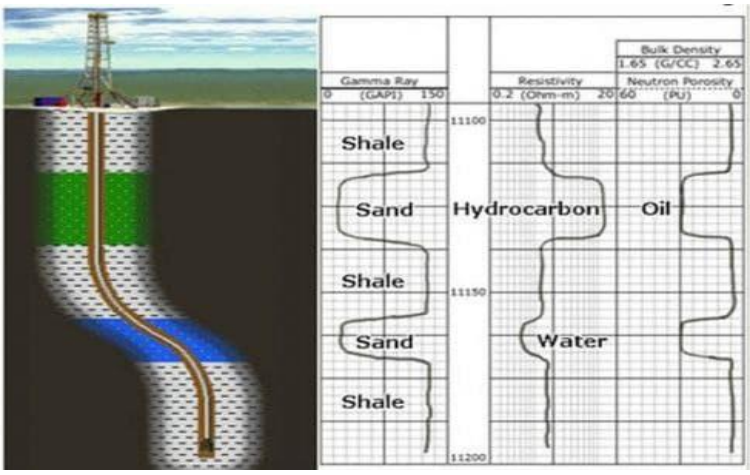

Figure 5 Gamma Ray Logging[22]

Natural Occurring Radioactive Materials (NORM): a material that is found in the environment which contains the natural origin of radioactive elements is known as the NORM. In addition, NORM is mostly made up of thorium and uranium (which are elements that decay to create radon and radium gas), and potassium. Those elements decay naturally and they represent a significant component of a person's yearly background radiation dosage. NORM is frequently identified in rocks or sand in its natural state. It's also found in the residue of gas and oil productions (such mineral scale in the sludge, pipes, and contaminated equipment), coal ash (made when coal is burned for energy), and filter media (utilized filters from the equipment of the treatment of the municipal drinking water).

Estimations of the Permeability and Effective Porosity Logs with the Use of the Deep Auto-encoders in the Logs of the Borehole Images: Rock permeability and porosity represent two of the most significant physical properties for determining throughout the exploitation of hydrocarbon reservoir, as such physical characteristics aid the petro-physicists in determining the

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most potential presence and/or distribution of the reservoirs of oil/gas, along with if or not a field is exploitable as shown in Figure 6.

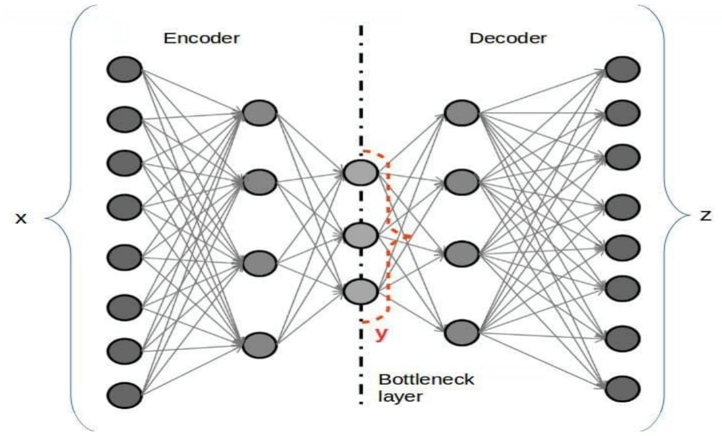

Figure 6 Deep autoencoder & deep autodecoder[23]

Support Vector Machine Regressor (SVM): An SVM produces a hyper-plane or group of the hyper-planes in infinite-or high-dimensional space that could be utilized for regression, classification, or other problems, such as the detection of the outliers. The hyper-plane that has a maximum distance to the nearest training-data point of any of the classes (i.e, functional margin) accomplishes decent separation, because the higher the margin, the lower the generalization error of the classifier as shown in Figure 7.

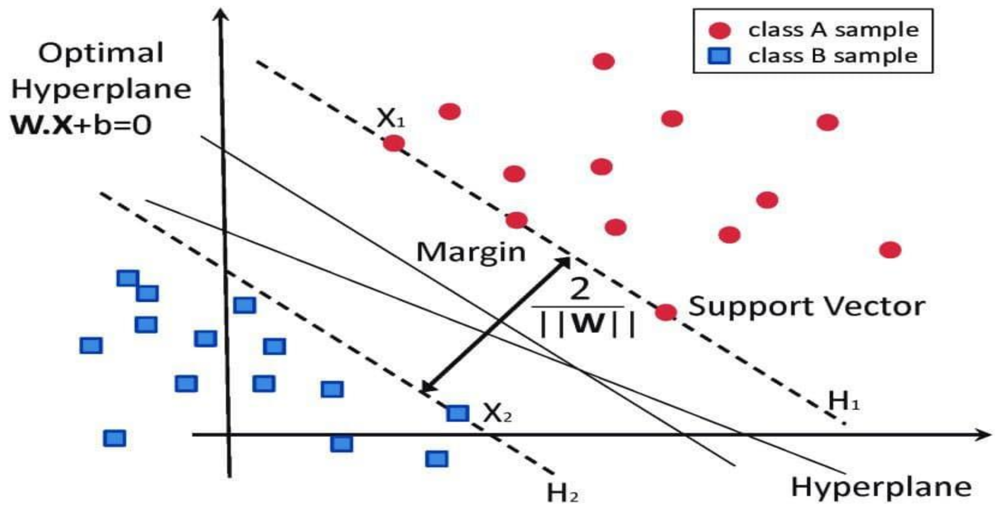

Figure 7 Classification of data by support vector machine[24]

Even if the initial issue is represented by finite-dimensional space, the sets for the discrimination are usually not separable linearly in that space. As a result, it has been suggested that original finite-dimensional space be transferred to considerably higher-dimension space, purportedly making the separation there easier.

2. Results and Discussion: We will talk about the results of analyzing rock formations of Zubair oil field and the results that we have gotten from the methods we used to find permeability and porosity of the reservoir by applying these methods on 4 rock samples. The results are shown in Figures 7 and 8.

Results of Analyzing of Rock formations Of Zubair oil field: Because of the shallow depths of Zubair Formation, along with the terrestrial supply of organic matter, the maturity of Zubair Subzone was specified as early-peak oil generation (Ro max 0.81%), whereas Euphrates Sub-zone was indicated as an immature-early generation of the oil (Ro max 0.69%). The optical examination demonstrated that the formation is a mature zone reliant on the color index. Shale intervals in Zubair Formation are in general acceptable to very good as source rocks in terms of total organic carbon (TOC) values, except for the lower sections, particularly the Lower Shale Member in Zubair Sub-zone, which has a decent level of total carbon content. Whereas type 3 gas-prone kerogen is the most common, type 2/3 oil-gas prone kerogen and type 2 oil-prone kerogen have also been found in lower and upper sandstone components.

Results of the methods of finding porosity

Results of mercury injection: the effects of newly suggested corrections on petrophysical characteristics including pore size distribution and permeability are assessed. In the case when additional corrections are applied to the MICP test data, the estimated accessible porosity reduces dramatically, according to our findings. The findings imply that including correction will shift the distribution of the pore sizes towards the small pores and that permeability estimates could be reduced by two orders of magnitude. This research's findings may aid in determining the sample's accessible porosity fraction.

Results of gamma-ray: Gamma-ray logs are most commonly used to determine shale "volume" in rocks. It's vital to keep in mind that the tool measures radioactivity, and shale content correlation is purely experiential. Clay minerals are thought to be present in shale. As a result, the gamma-ray level has been thought to be proportional to the size of the grain. Shales can contain up to 30% quartz as well as other minerals. Clays in shales could not be radioactive, but nearby sands could have radioactive isotopes. Porosity and radioactivity have been usually proportional to the size of the grain. The core plugs have been tested for the median size of the grain and level of radioactivity, with the dots representing silts and clay-rich rocks and the crosses representing fine-grained sands.

Results of the utilization of deep auto-encoders in borehole image logs: We will be able to attain a correlation coefficient of R^2 =96.3% for effective porosity logs and R^2 = 96.06% for logs of permeability utilizing this approach as shown in Table 2

Table 2 Rocks samples data

No.	Rock Type	Depth (m)	Density (g/cm^3)	Weight (g)	Permeability (md)	Porosity (%)
1	Sandstone	836.50	2.61	147.54	1098.558	27.17
2	Sandstone	838.10	2.63	133.89	832.468	27.15
3	Sandstone	840.90	2.58	141.67	1155.052	26.05
4	Shale	1435.60	2.67	139.13	321.215	6.09

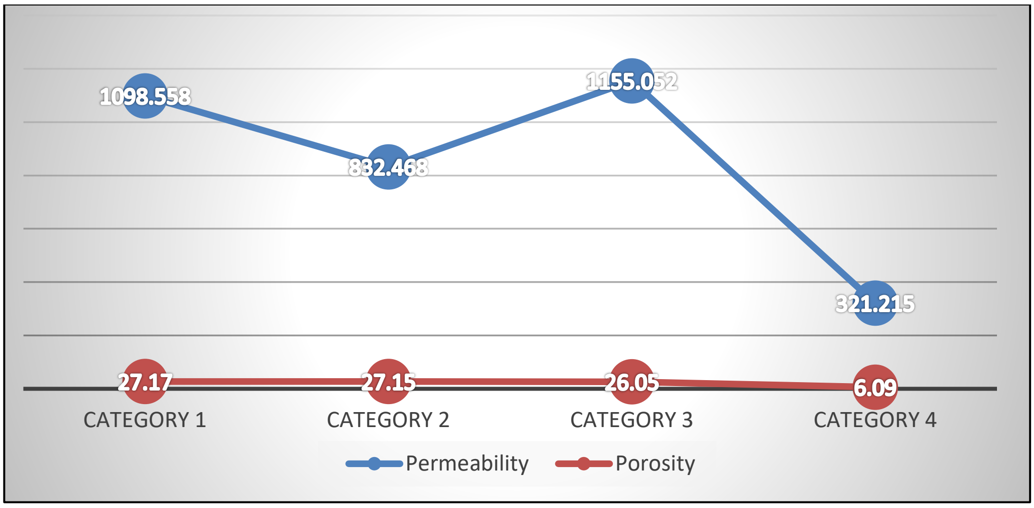

Figure 8 Comparison chart between permeability and porosity

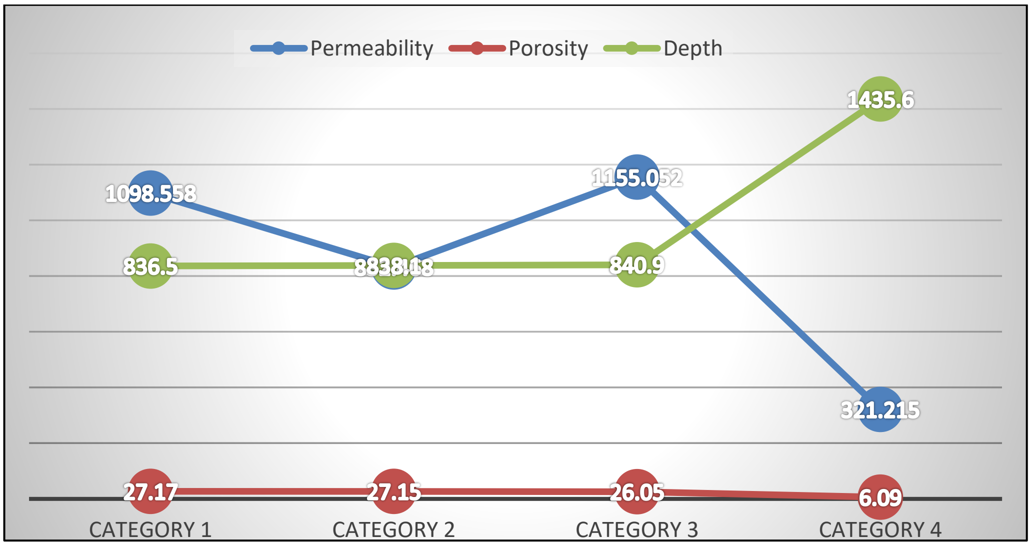

Figure 9 Comparison chart between porosity, permeability, and depth

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3. Conclusions: When additional corrections are applied to MICP test data using the "Mercury Injection" technique, the results of this work show that estimated accessible porosity reduces dramatically. Also, the results show that including correction will shift the distribution of the pore sizes towards the small pores, potentially reducing permeability estimates by two orders of magnitude. We discovered that the gamma-ray level is associated with grain size using the "Gamma Ray" approach. Shales can contain up to 30% quartz as well as other minerals. The clay in shale formations could not be radioactive, but nearby sands could have radioactive isotopes. We found that the best depth to calculate the properties of sandstone is (650 – 1100 m) underground we found that the best depth to calculate the properties of shale is (1300 – 1650 m) underground.

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التكوينات الصخرية وخصائصها البتروفيزيائية في حقل الزبير النفطي في البصرة

خلاصة: *تركز هذه المقالة على هدفين ، الأول هو تحديد ونمذجة أنواع الصخور في تكوين الزبير في البصرة ، والثاني هو نمذجة الخصائص البتروفيزيائية لتكوين الزبير. تم استخدام طرق دقيقة لتحقيق هذه الأهداف. تم تحليل التكوينات الصخرية لحقل الزبير النفطي وتم الحصول على نتائج مهمة من هذا التحليل ، ومن ثم تم أخذ 4 عينات صخرية من الخزانات في تكوين الزبير على أعماق مختلفة بدرجات حرارة وضغط ونوع صخري مختلف. استخدمنا حقن الزئبق وتسجيل أشعة جاما لتحديد وحساب مسامية عينات الصخور هذه ، كما استخدمنا أجهزة تشفير آلية عميقة في سجلات صور البئر لتحديد النفاذية وحسابها. في طريقة "حقن الزئبق" ، اقترحت نتائج هذه الدراسة أن المسامية المقدرة التي يمكن الوصول إليها قد انخفضت بشكل كبير في حالة تنفيذ تصحيحات جديدة على بيانات اختبار MICP (أي الضغط الشعري لحقن الزئبق). من طريقة "أشعة جاما" وجدنا أنه من المفترض أن يكون مستوى أشعة جاما مرتبطًا بحجم الحبة. وجدنا أن أفضل عمق لحساب خصائص الحجر الرملي هو (650-1100 م) تحت الأرض. وجدنا أن أفضل عمق لحساب خصائص الصخر الزيتي هو (1300 - 1650 م) تحت الأرض.*