ISSN: 0067-2904

Determination of Porosity and Permeability of Darnah Formation at Al-Jabal Al-Akhdar-North Eastern Libya

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Abstract

The study area is located at AL Jabal AL-Akhdar region North Eastern part of Libya. The study includes (23) fresh samples that are taken from Darnah limestone Formation, these samples were distributed on and covered about (210) km^2. The porosities and permeabilities of these samples were determined. This study is important because this formation is considered as a good reservoir for hydrocarbon accumulation in other places in Libya.

The porosity was measured by three different methods namely by porosimeter (using core samples), thin sections and binocular microscope. The permeability are also measured by two methods, the first method was by Nitrogen method and the other is by Klinkenberg method. The instrument that used for measuring permeability is Permeameter, which is found in Arabian Gulf Oil Company Laboratories (AGOCO) in Benghazi.

Comparing the porosities by these three methods, it was clear that the porosity which was measured by porosimeter is better than the other two methods, because this instrument gives porosity by 3-Dimensions using core samples, but the other two methods give porosity in 2-Dimensions.

The results show that the range of porosities measured by porosimeter was between (2.3% - 29.8%), the range by thin sections was between (2% - 23%) and the range by binocular microscope was between (4% - 29%). On other hand the range of permeabilities by Nitrogen method was found between (0.1 – 1572) millidarcy, and by Klinkenberg method was between (0.05 – 1506) Millidarcy. This variety of the range depends on the locations of samples as well as on active and inactive porosities, so there is no significant difference between the porosities and permeabilities of the same sample

Keywords: porosity and permeability, Darnah Formation.

تعيين المسامية والنفاذية لتكوين درنة في الجبل الأخضر / شمال– شرق ليبيا

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الخلاصة

تقع هذه الدراسة في منطقة الجبل الأخضر شمال – شرقي ليبيا وتتضمن الدراسة أخذ (23) نموذجا نظيفا من تكوين درنة الجيري موزعة على مساحة حوالي (210) كم2 وذلك لقياس كل من المسامية والنفاذية لهذه النماذج حيث أن هذا التكوين المسامي يمكن ان يكون مكمنا جيدا لخزن الهايدروكاربونات في مناطق أخرى من ليبيا.

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تم قياس المسامية بثلاث طرائق مختلفة الأولى بجهاز متطور يستخدم غاز الهيليوم وهي جهاز (البروسيميتر) حيث ان غاز الهيليوم ذا الذرات الصغيرة يدخل إلى جميع الفراغات الموجودة في اللباب الصخري المحضر من اللباب الصخري والثانية بعمل شرائح ودراستها تحت المجهر والثالثة تم دراستها بمجهر ثنائي العينين (الباينوكلر) ، أما النفاذية فتم قياسها بطريقتين باستخدام جهاز قياس النفاذية المتطورة (البيرمياميتر) وان جميع الأجهزة متواجدة في شركة نفط الخليج العربي في بنغازي حيث يتم القياس أيضا من اللباب الصخري المحضر من النماذج . ففي الطريقة الأولى تم استخدام النايتروجين وفي الثانية بطريقة (كلينكنبيرغ).

أظهرت مقارنة نتائج المسامية بالطرائق الثلاثة ان المسامية المقاسة من اللباب الصخري أفضل من الطريقتين الآخريين وذلك لأن هذه الطريقة تعطي نتائج ثلاثية الأبعاد ، أما الطريقتين الآخريان فتعطي نتائج ذات بعدين، حيث كان مدى النتائج في الطريقة الأولى بين (2.3% – 29.8 %) أما المسامية في دراسة الشرائح فكان مداها بين (2% – 23%) وان الطريقة الثالثة أعطت مدى بين (4% – 29 %). اما قياس النفاذية فوجد ان قيم المدى باستخدام النايتروجين بين (0.1 – 1572) مللي دارسي ، وكان مدى طريقة (كلينكنبيرغ) بين (0.05 – 1506) مللي دارسي ، هذا الإختلاف بين النتائج سببه مواقع النماذج ونوع المسامية الفعالة وغير الفعالة، ولوحظ إنه لا يوجد فرق جوهري بين النتائج لنفس النموذج في الطرائق المختلفة.

Introduction

The essential properties of most rocks are their porosity and permeability. The pattern of rocks depends on grain size, shape, sorting and chemical composition as well as matrix of the rocks and cementing material between matrix and grains. There are other factors that porosity and permeability depend on such as fossils, fracturing, jointing and so on. [1, 2]. Darnah Formation is composed of carbonate rocks that consist of grains of solid matter with varying shapes and size. These grains are cemented partially and leaves empty spaces have the ablility to contain fluids and gases (hydrocarbons) which allow them to accumulate, so the Darnah Formation considered as porous and permeable rocks and this formation may be a good reservoir at other places in Libya.

Location of the study area

The study area is a small part of AL-Jabal AL-Akhdar region, which is located North- East of Libya Figure-1 and bounded by the desert of Egypt from the east, Sirte basin from the west, Mediterranean Sea from the north and the Sahara Plate form the south. The study area is bounded by longitudes ($20^o\ 25\ 05''$ and $20^o\ 45'\ 08''$) East, and latitudes ($32^o\ 14'\ 55''$ and $32^o\ 30\ 01''$) North. The total area is about $210\,Km^2$, which represents some of Darnah Formation that exposed at AL- Jabal AL-Akhdar region.

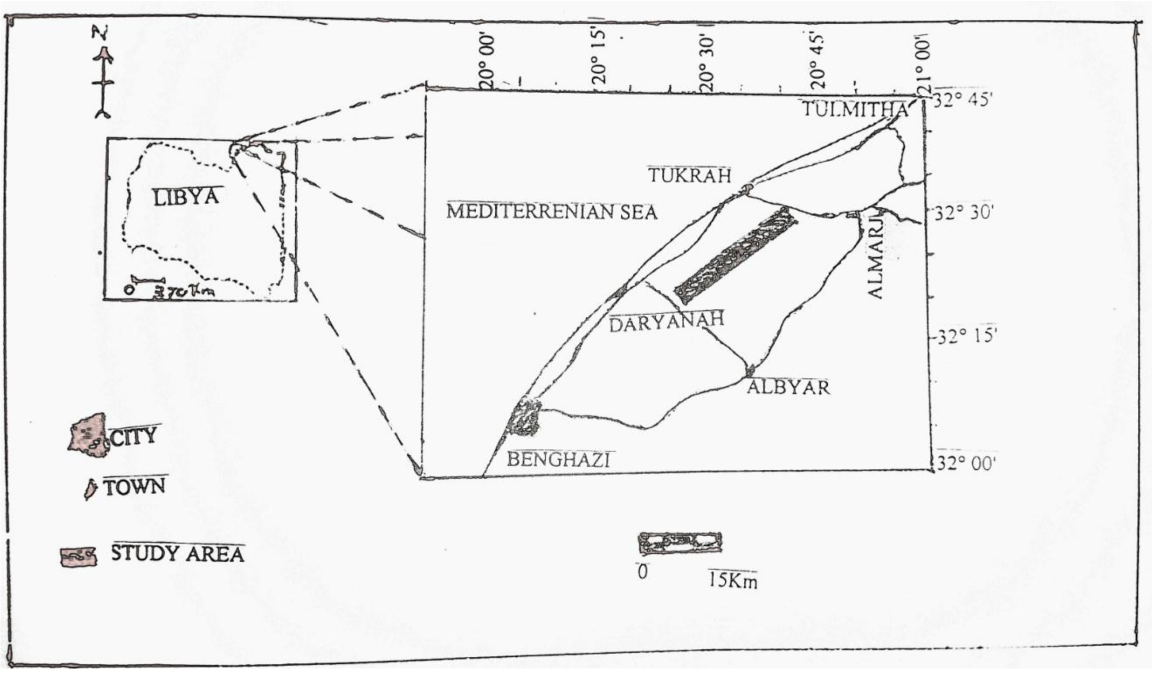

Figure 1- Shows the location map of the study area after [3] modified by researcher.

Objectives of the study

The objectives of this study is to determine the porosity of Darnah Formation by three methods by porosimeter using core samples that prepared from fresh samples, thin sections and corresponding plugs for binocular microscope study, as well as the permeability by using permeameter instruments, these instruments are exist at Arabian Gulf Oil Company (AGOCO)- Benghazi.

Field work and Methodology

The geological fieldwork of this research represent locating and studying of (9) traverses containing (23) stations for taking (23) fresh samples , which are chosen according to lithologic changes. These rock samples were collected and described by hand lens, and thin sections and cutting cores were prepared for detail studies by porosimeter, ordinary and binocular microscopes by researcher as well as determining the permeability by two different methods using Nitrogen and by Klinkenberg methods

Regional Geology

Regional geology of the study area includes the study and distribution of stratigraphic units, structural features, and surface forms [4, 5]. The study area represents a part of AL-Jabal AL-Akhdar anticlinorium, which is dominated by ENE-WSW trending uplift. The exposed rocks of AL-Jabal AL-Akhdar consist of sequences of carbonate rocks, which are ranging from Upper Cretaceous to Tertiary. These marine carbonate rocks were subdivided into several cycles of sedimentations [6]. The stratigraphic chart for surface and subsurface rocks of AL-Jabal AL-Akhdar have been prepared by [7].

Previous study of Darnah Formation

Al-Jabal Al-Akhdar region was an important subject of many geological surveys. Many geologists were worked with several companies and explored the region for water and hydrocarbon accumulations. The first study was done by [8] who had studied and named formations within Al-Jabal Al-Akhdar area including Darnah limestone.

The preparation of the geological map of Benghazi area with a scale (1:250000) and an explanatory booklet about the geology of Benghazi area are available in [3].

The stratigraphy in northern Cyrenaica was studied in detail in [9, 10].

The tectonic events and the geological development of Al-Jabal Al-Akhdar was studied by [6, 11].
A short notes and guidebook on the geology of Al-Jabal Al-Akhdar, North-East Libya have been presented in [7].

Tertiary system

There are many formations in this age, but Darnah Formation is the most important one for its relatively high porosity and permeability that can be cosidered a good trap for hydrocarbon in other places in Libya.

Darnah Formation (Lutetian - Priabonian)

The term was introduced by [8] as **"** Derna limestone**"**. The thickness of the formation in the type section is about (100 m.) gave by [12]. It consists of massive limestone, medium to coarse grained, Nummulitic, dolomitic and organodetrital limestone, with alternating of hard and soft bands of marly limestone, and shows an interfingering relationship with the microcrystalline limestone of Apollonia Formation, which is rich in Nummulites of Middle to Upper Eocene [13].

Definition and types of porosity

The porosity is defined as the ratio of the void-space to the bulk volume of a material, and according to this definition any one can measure the porosity according to the following equation [14]:

$$\text{Total porosity } (\text{Ø})\ \% = \frac{pore\ volume}{bulk\ volume} \times 100$$

This equation represents total and active means there are interconnections between pore spaces, it is commonly (5%-10%) less than the total porosity and inactive porosity that mean there are no interconnections between pore spaces. Generally there are two types of porosities, primary which forms with the time of deposition as intergranular and intragranular or (intraskeletal) and secondary that forms after the deposition due to diagenesis processes [15]. This type is divided in this study into intracrystalline, moldic, vuggy and fracture porosities. These types are very important because they increase the storage capacity of the reservoir due to the increase in interconnecting pores which increases the permeability [1]. The following Plates-3 to 8, show some types of above mentioned porosities in these thin sections which are taken from the location of the study area as shown in Figure-1.

Measurement of porosity

There are several methods for measuring of porosity [16, 17] the measurement is either in the field as indirect method [18] or in the laboratory as direct method that applied in this study by using the instruments in the laboratories of Arabian Gulf Oil Company (AGOCO laboratories) .

Direct method for porosity measurement:

In this study the Helium porosimeter is used for measuring the porosity and microscopic examination of thin sections as well as using binocular microscope as follows:

Helium porosity measurement by Helium porosimeter:

The Helium porosimeter, is an instrument which is used for determining the porosity of rock samples. The instrument has been designed to allow various sizes of core samples to be run, the most common diameters of the core being 1″ to 1.5″. The instrument operates on the principle of Boyle's law, which state that for an ideal gas, assuming constant temperature, the product of the pressure and volume, in a closed system, remains constant. In porosimeter, this means that if a known pressure of gas, in a known reference volume, is allowed to expand into the combined volume of the reference volume plus a second sealed volume, the product of the initial pressure and the reference volume, will equal to the product of the final pressure and combined volume [19]. Therefore, if the final pressure is measured, the combined volume can be easily calculated, similarly when the combined volume is known, the volume of any object placed in the second chamber can be easily calculated. Figure- 2 shows the theoretical principle of the Helium porosimeter and its equation for calculating the porosity of rock samples.

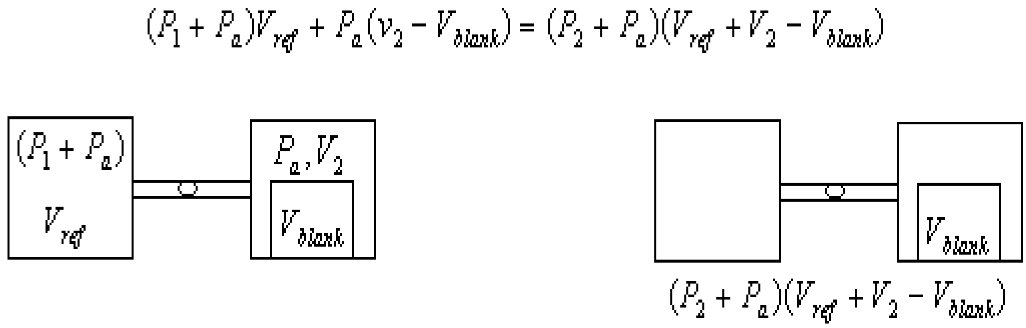

Figure 2- Represents the sketch of the instrument [19].

The following equations are derived for calculation of porosity for the core samples of Darnah Formation in the study area.

$$(P_1 + P_a)V_{ref} + P_a(V_2 - V_{blank}) = (P_2 + P_a)(V_{ref} + V_2 - V_{blank})$$

$$P_1V_{ref} + P_a(V_{ref} + V_2 - V_{blank}) = P_2(V_{ref} + V_2 - V_{blank}) + P_a(V_{ref} + V_2 - V_{blank})$$

$$P_1V_{ref} = P_2V_{ref} + P_2V_2 - P_2V_{blank}$$

$$P_2V_{blank} = P_2V_2 + P_2V_{ref} - P_1V_{ref}$$

$$V_{blank} = (V_{ref} + V_2) - (P_1V_{ref})\frac{1}{P_2}$$

$$Since\ P_1 = 100\ psi, we\ have: -$$

$$V_{blank} = (V_{ref} + V_2) - (100V_{ref})\frac{1}{P_2}$$

This is an inverse linear equation with **(-ve)** slope **(-100** V_{ref}**)** and intercept of **(**$V_{ref} + V_2$**)**. If the final pressure **(**P_2**)** is obtained, one can calculate the grain volume of the sample and porosity **(**V_{blank}**)** after entering into the above equations [19]. The gas used here in the porosimeter is Helium, as it is an inert gas, and has very small molecules, allowing it to penetrate the pore spaces in the sample more easily than other gases. This instrument is very simple to use, quick and accurate, as well as gives the results in 3- dimentions for any rock samples, after preparation the cores as a true horizontal core sample, Figure-3, and cleaning the cores by special solvent and instrument prepared for this purpose is shown in Figure-4, and Plate-1, they show the Soxhlet extractor instrument for cleaninig the samples. Finally the core samples must dry in an oven before using in porosimeter Plate-2 The above instruments and procedure used to determine the porosity of (23) samples which are distributed on Darnah Formation in the study area. The porosities ranged between (2.3%-29.8%) as seen in Table- 1).

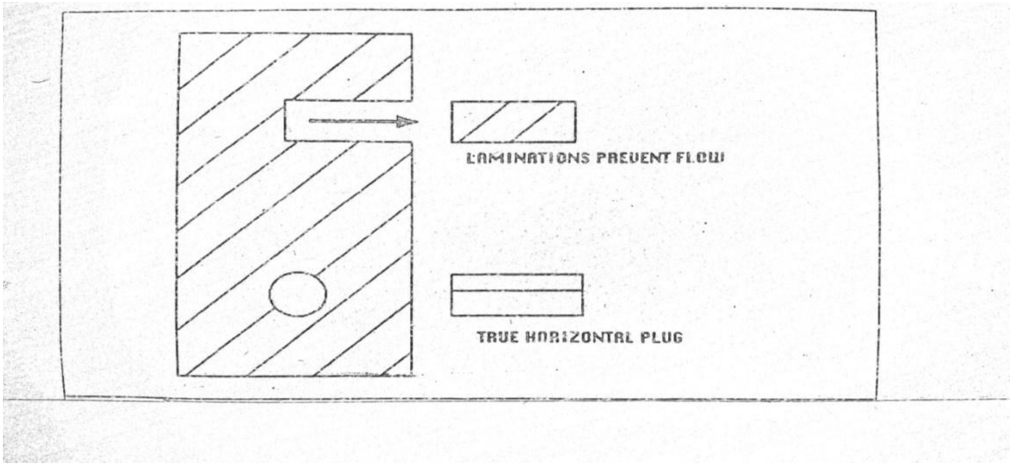

Figure 3- Shows cutting horizontal core plug for determination of porosity and permeability.

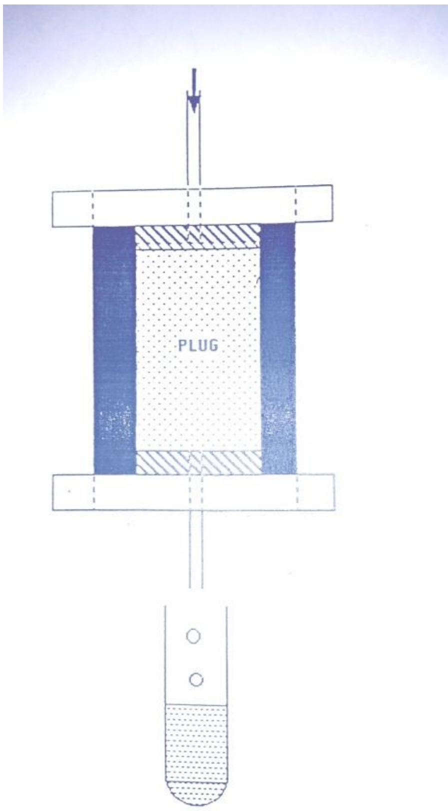

Figure 4- Shows sketch of dynamic displacement solvent cleaning.

Plate 1- Shows the Soxhlet extractor instrument used for cleaning core samples.

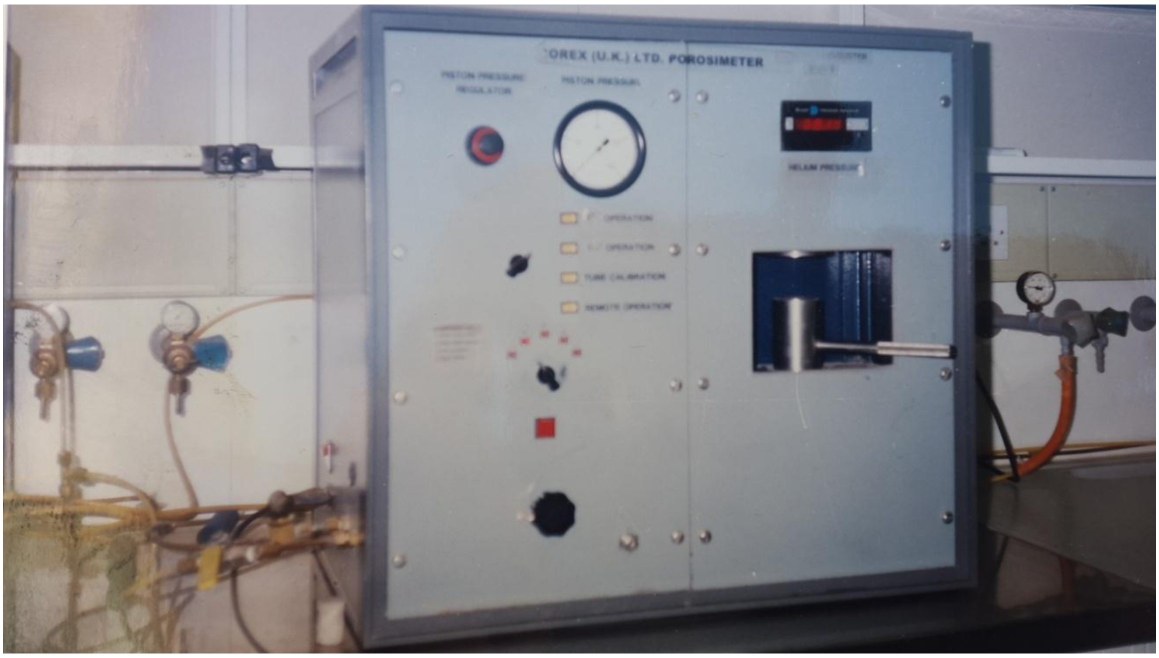

Plate 2- Shows the porosimeter instrument that is used for determination of porosity [19].

Table 1- Shows the Porosities which are determined by three different methods and Permeability by two methods for Darnah Formation.

STATION Numbers -------	Porosity by porosimeter (%)	Porosity by thin section (%)	Porosity by Binocular Microscope (%)	Nitrogen permeability (Millidarcy)	Klinkenberg Permeability (MilliDarcy)
St. No.1	26.4	23	29	0.1	0.05
St. No.2	9	15	25	0.9	0.8
St. No.3	9.3	10	12	1572	1506
St. No.4	10	15	15	2.6	2.4
St. No.5	18	15.5	20	23	21
St. No.6	27.2	25	29	453	431
St. No.7	7.9	12	12	18	16
St. No.8	11	16	16	20	18
St. No.9	17.6	12	19	18.7	15.2
St. No.10	18	13	16	105	97
St. No.11	13.2	14.3	15	910	890
St. No.12	2.3	2	2	0.07	0.04
St. No.13	22.7	16	18	14	13
St. No.14	15.3	13.2	18	19	16
St. No.15	2.7	4	4	2.95	2.14
St. No.16	14.1	16.5	17	990	960
St. No.17	16.2	12	15	199	195
St. No.18	5.9	12	13	0.05	0.03
St. No.19	20.9	11	19	140	132
St. No.20	29.8	14	21	99	93
St. No.21	24.9	16	22	204	198
St. No.22	22.4	15	20	77	74
St. No.23	17.4	16	14	37	35

Determination of porosity from thin sections and binocular microscope

The porosity of rock sample can be determined roughly from their thin sections under ordinary and binocular microscopes. The porosities that determined by these methods ranged between (2%-25%) and (4% - 29%) respectively. So they are classified from negligible to very good as it is clear in Table -1 and according to [1] the classification is shown in Table-2. The point counter was used for determining the porosities from thin sections and by binocular microscope.

Table 2- Shows the classification of porosity [1].

Range of porosities (%)	Classification
0 – 5	Negligible
5 – 10	Poor
10 -15	Fair
15 – 20	Good
20 – 25	very Good

As an example for description of some thin section samples under microscope, the following six samples were fully that are distributed all over study area were described as follows:

Thin section at station (3):

Wackstone, with foraminifera (including Nummulites) and Echinoderms; matrix of lime-mud and bioclastic debris; approximately (10%) Table-1. It is irregularly distributed mainly moldic porosity, with intercrystalline pore-type component. Moldic porosity is partly modified by cement precipitation formed as pore lining. A late-diagenetic stage brought about partial dissolution of this cement, together with parts of adjoining matrix, resulting in microvuggy pore type, thereby increasing porosity marginally. Plate-3 shows the thin section of this sample.

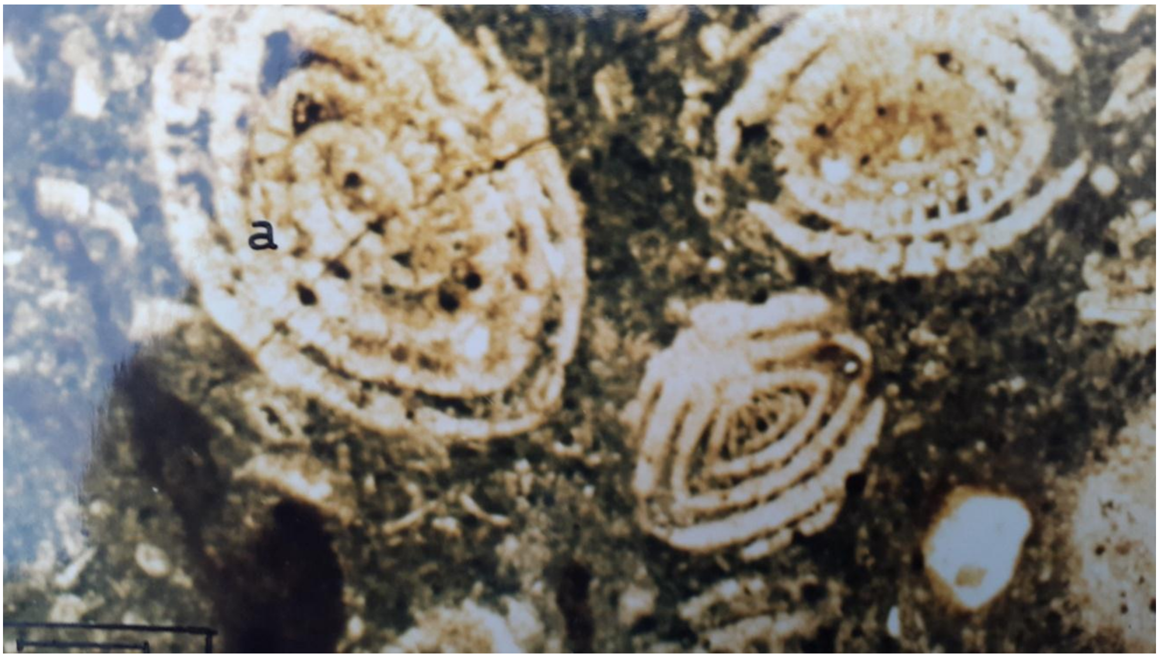

Plate 3- Shows solutional porosity (light blue) and intracrystalline type, bar scale=0.25mm.

Thin section at station (6):
Originally wackestone to packstone; porosity forms approximately (25%) of the bulk volume Table -1, porosity is irregularly distributed partly modified moldic type, with microvuggy affinity; a significant intercrystalline pore component is present, Plate-4 shows the thin section of this sample.

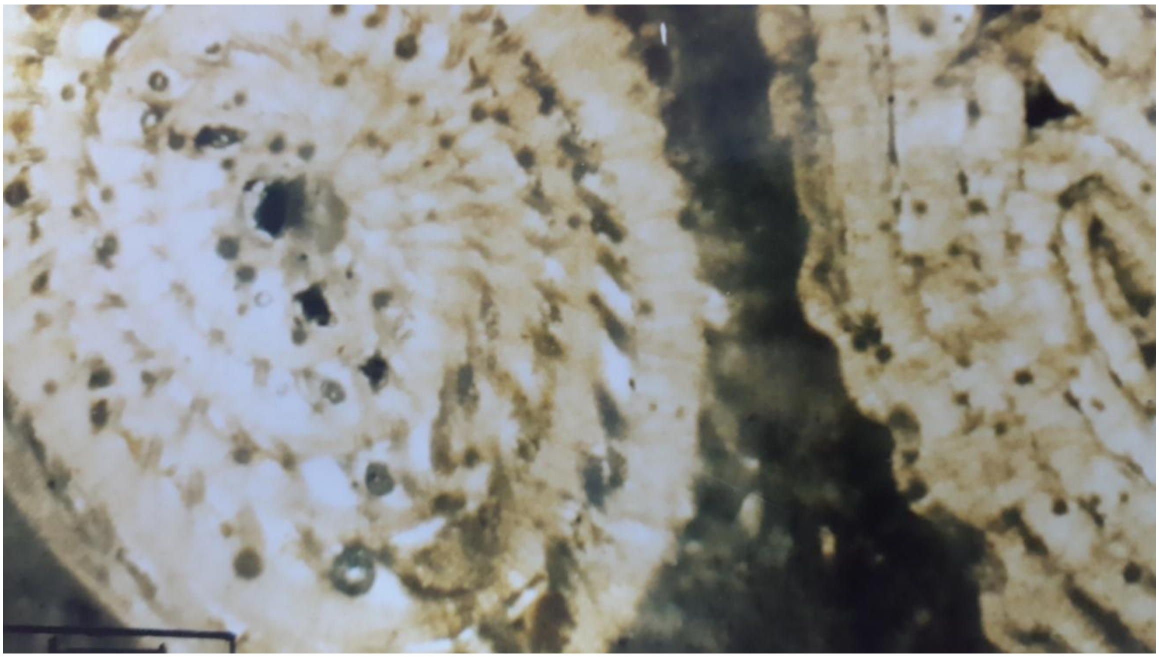

Plate 4- Shows microvuggy intracrystalline porosity (light blue), bar scale = 0.25mm.

Thin section at station (9):
Wackestone composed of Nummulites embedded in matrix of lime-mud and bioclastic debris; approximately (12%) Table-1, porosity of dominantly intraskeletal and intercrystalline pore types; the

latter is more evenly distributed; possibly some moldic porosity (after bioclast fragments) is present, Plate-5 shows the thin section of this sample.

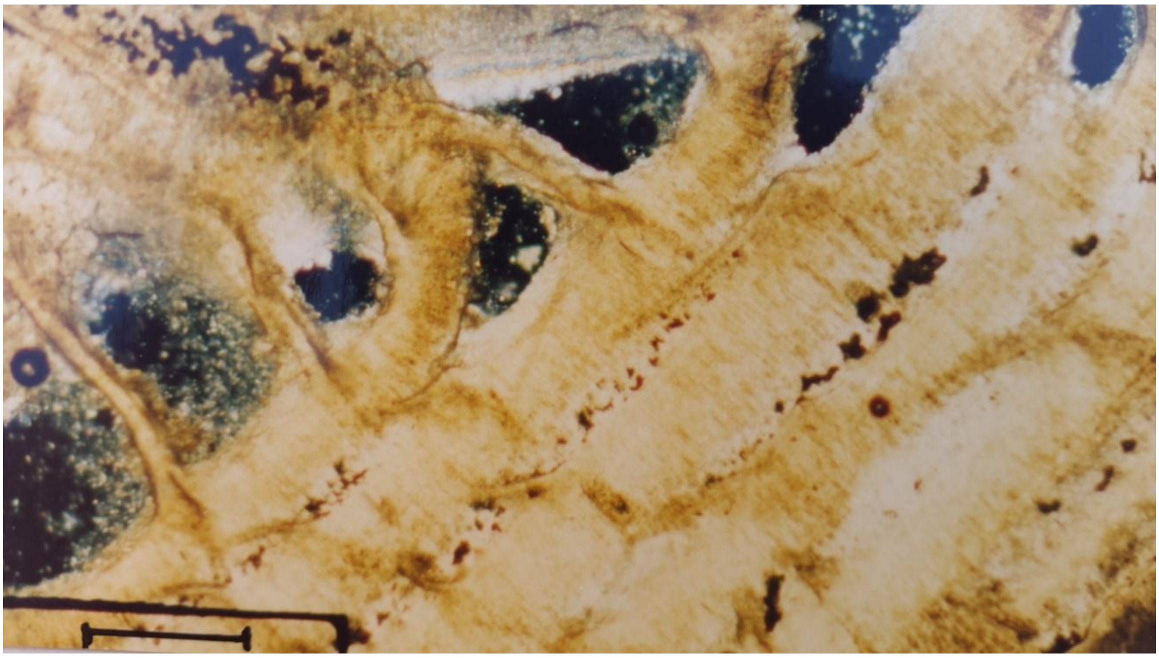

Plate 5- Shows intraskeletal porosity (black) in Nummulites, bar scale =0.25mm.

Thin section at station (12)

Nummulitic rudstone; Nummulithoclastic- debris and lime-mud matrix; very poor porosity about (2%) Table-1, due to the presence of matrix, compaction and cement precipitation within Nummulites, porosity is in the form of remnant intraskeletal type, modified by cement. Plate-6 shows the thin section of this sample

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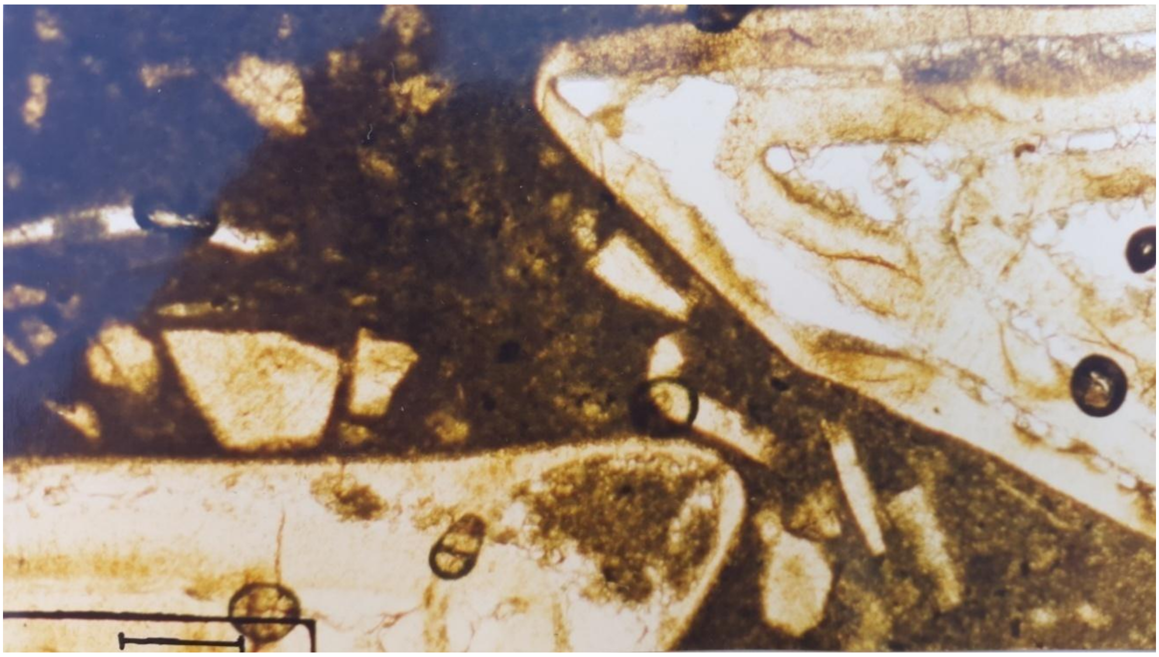

Plate 6- Shows intraskeletal porosity (light blue) modifid by cement and leaching, bar scale =0.25mm.

Thin section at station (15):

Wackestone, with Nummulites; poor porosity approximately (4%) of moldic type Table-1, modified by cement lining pore-space; overall weakly effective diagenesis**.** Plate-7 shows the thin section of this sample.

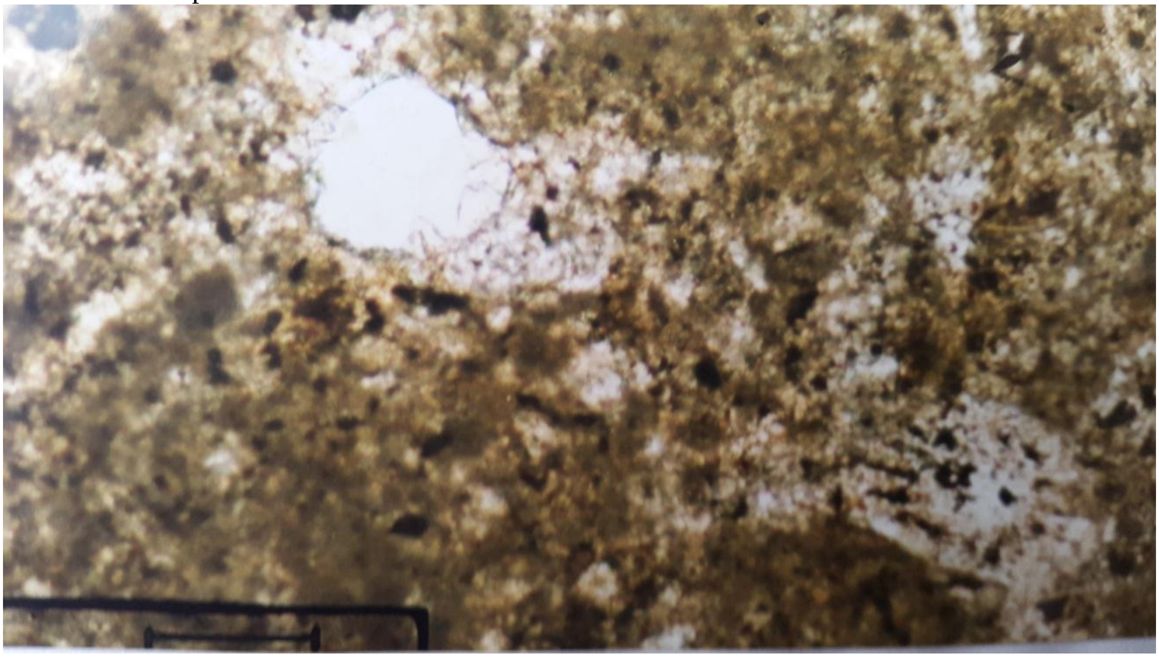

Plate 7**-** Shows modified moldic porosity (light blue) as intracrystalline type, bar scale =0.25mm.

Thin section at station (18):

Wackestone, with minor amounts of Nummulites; approximately (12%) of moldic and intercrystalline porosity, both modified by leaching, Table-1. Plate-8 shows the thin section of this sample.

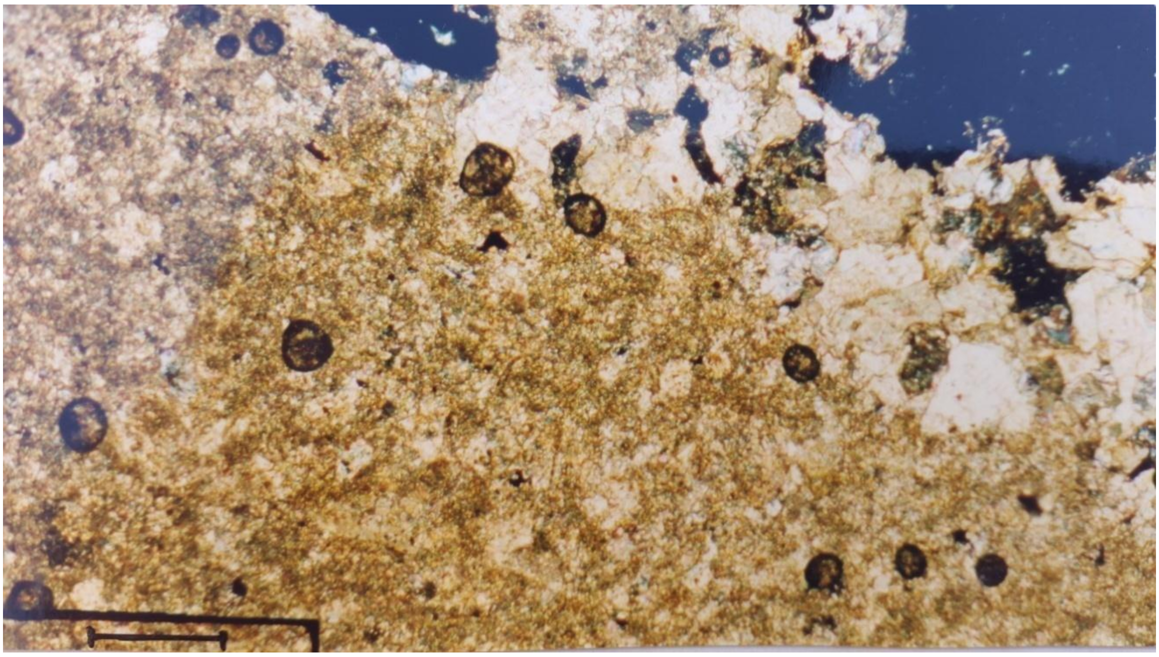

Plate 8**-** Shows modified solutional porosity (black) in Gastropod, bar scale =0.25mm.

Porosity values that are determined from the samples which described above are based on point counter assessment of the thin-section, with the benefit of systematic count. These values reflect two-dimensional pore distribution, whereas core analysis values by porosimeter represent three-dimensional pore geometry. By comparing the porosities measured by three methods at Darnah Formation Table-1, it is clear that the Helium porosimeter is better than the thin sections and binocular, because the first method represents three dimensional pore geometry and other two methods represent, two dimensional as mentioned above

Determination of permeability

Permeability is defined as a measure of ability of a porous sample to transmit fluids. There are three permeability classifications, Specific, Effective and Relative. The permeability can be derive indirectly like porosity measurement from down hole logs, such as NMR (Nuclear Magnetic Resonance), and also as a routine work in laboratory as a direct method, by using (gas permeameter) which is an instrument used to measure the permeability of a rock sample in the study area Basically, a gas pressure is applied to one face of a cylindrical (core) sample which is cut and prepared from Darnah Formation, and the flow rate of gas passing through the sample is measured from the opposite face of the sample as shown in Plate -9. By entering the dimensions of the sample, the applied pressure, the flow rate and the viscosity of the Helium gas, as well as the room temperature and atmospheric pressure, into Darcy's equation as given below, the permeability of the sample can be calculated. Darcy's Equation for liquid permeability can be written as following:

$$K = \frac{UQL}{ADP}$$

Where: K= Fluid permeability (in darcies), U= Viscosity of fluid (centipoises)

Q = Flow rate (in $cm^3/\sec$), L - is Length of plug sample (in cm)

A = Cross sectional area of plug (in cm^2)

DP = Differential pressure across plug (in atmosphere)

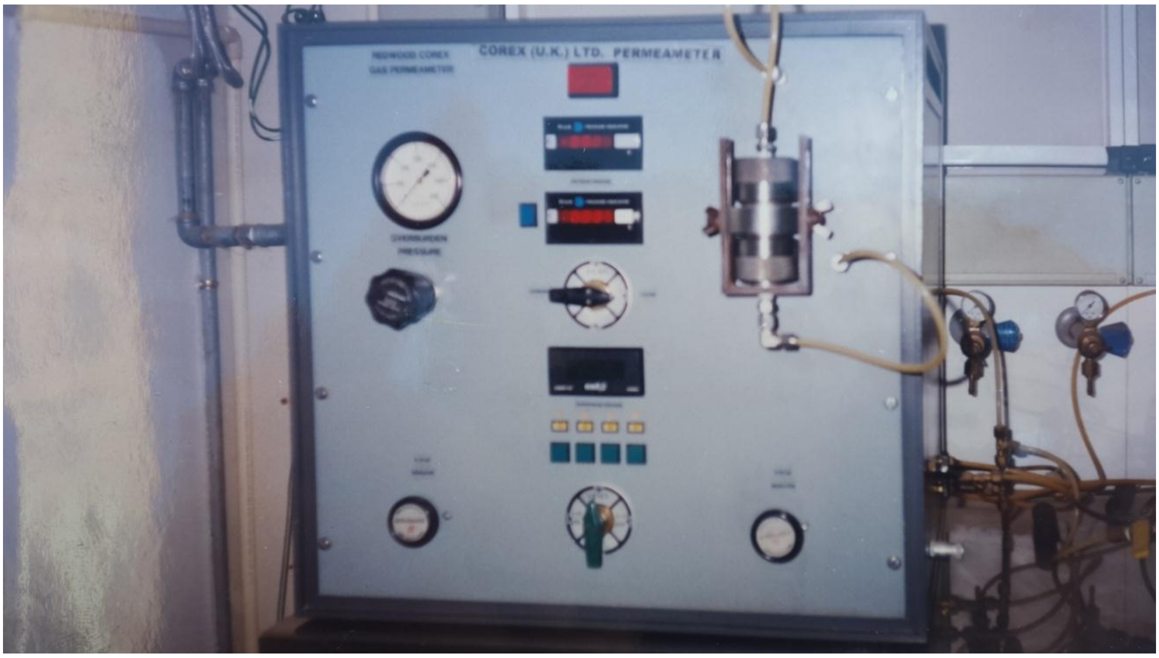

Plate 9- Shows the permeameter instrument that is used for determination of permeability [19].

There are several factors that affect on the permeability of the rocks like , viscosity, capillary forces, gravity forces, wettability and temperature. In the study area at Darnah Formation, the permeability was measured by two methods by using (Nitrogen method) and by (Klinkenberg method), which are shown in the Table-1. By comparing the porosities and permeabilities of the rock core samples, it is clear that the relationship between porosities and permeabilities of the stations is not good, that reflects the effective porosity at the third station core sample, the permeability here is very high, also it shows high permeability, and in the sixth station (core sample) the effective porosity is moderate, the permeability of this sample is lesser than the first one. Comparing these measurements with the classification of permeability by [1] so the porosity and permeability depends also on the location of the samples which are taken in the field, it is clear that the range of permeability are between (Fair-Very good) as shown in Tables -1 and 3.

Table 3- Shows the classification of permeability range [1].

Classification	Range (Millidarcy)
Very poor	Less than 1.0
Fair	1 - 10
Good	10 – 100
Very Good	100 - 1000

Conclusions

The following are concluded from this research for determination of porosities and permeabilities for Darnah Formation which exposed at Al Jabal AL- Akhdar NE of Libya.

1. There are large variety of porosities and permeabilities depending on the locations of the samples as well as presence of active and inactive porosities in these samples.
2. The porosity which determined by porosimeter is better than other two methods, because the first one gives 3-D and others two methods give 2-D, so the results of 3-D is better than 2-D.
3. Most of the thin sections are rich in Nummulites and Echinoderms and due to solution of these parts they left moldic, intraskeletal and intracrystalline porosities, some of them are active and others are inactive.
4. There are primary and secondary porosities in these thin sections, the latter is due to diagenesis.
5. The range of porosities measured by porosimeter for core samples ranges between (2.3% - 29.8%), the range of thin sections and binocular microscope is between (2% - 23%) and (4% - 29%) respectively.
6. The range of permeability measured by Nitrogen method is between (0.1 – 1572) millidarcy, while its range by Klinkenberg method is between (0.05 – 1506) millidarcy. These differences are due to active and inactive porosities mentioned above.

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