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Porosity measurements for some basalt rocks from the Gharyan Volcanic Province NW Libya

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Abstract: In this paper, Porosity and density measurements at atmospheric temperature and pressure were conducted on three basalt rock samples from Gharyan Volcanic Province (GVP) NW Libya. The properties examined for the basalts are: bulk and grain density and porosity. The properties found in the basalts are: the mean bulk density 2.823 grams/cm3 and the mean grain density 2.960 grams/cm3 and porosity range 1.311-7.809 %. To consider the possibility of using basalt rocks as a biological shielding against gamma-ray radiation, mass attenuation coefficients for basalt samples were calculated. Results indicate that the basalt rocks are more efficient against gamma-ray radiation than traditional lead materials. Some applications of basalt rocks in industries were suggested.

Keywords: Basalt, Grain Density, Porosity, Acid-Resistant Equipment, Mass Attenuation Coefficients, Radiation Shielding Material, Nuclear Power Plants, Storage of Radioactive Waste

1. Introduction

The rocks provide information about the earth layer formation, as well as the amounts of water, minerals and oil that may contain. Consequently, the studies of rocks have contributed to open new horizons for scientific and technological research [1]. The purpose of this work is to go into such an important topic and to acquire knowledge of the local scientific potential in this field.

Basalt is an extrusive volcanic (igneous) rock that is very dark in color, comprises more than 90% of all volcanic rocks. It is the most common type of rock in the Earth's crust and it makes up most of the ocean floor. It forms when lava reaches the Earth's surface at a volcano or mid ocean ridge. When lava gets to the surface, it cools rapidly, forming a solid rock, consists of voids in the volcanic rocks on the surface only; due to the exit gases to the surface through these rocks. Because of its relatively low silica content, basalt lava has a relatively low viscosity, and forms thin flows that can travel long distances [2-3].

Porosity is a term used to describe an important physical property of most materials. It is a measure of voids in rocks. It is the ratio between the intensities of the voids in the rock to the total mass of the rock [4]. However, there are other factors affecting the degree of porous rocks, such as the presence of cracks and breaks or the degree of interconnection between void spaces. If all of the spaces are discrete and isolated from each other, a material will not behave in the same way as a material with the same percentage of void space in the form of connected void spaces. When examining the rate of flow through materials, this property becomes especially important. If the spaces are connected, the flow is going to be higher, because liquids can move freely [5-6].

It was therefore thought to be of interest to measure the Porosity and density of these basalt rocks in order to acquire knowledge about this topic and to check the local scientific potential in this field. And to consider the possibility of using basalt rocks as a biological shielding against gamma-ray radiation, and other construction materials

An outline of this paper is as follows: Sec.2 describes briefly the basalt rock samples and other experimental aspects of the measurement. Sec.3 discusses the method of analysis. Sec.4 presents results and discussion. Sec.5 presents the mass attenuation coefficients of basalt rocks, followed in Sec.6 by some concluding remarks.

2. Description of Samples

Three basalt samples (A-14, A-18, B-12), shown in figure1, were selected from Gharyan Volcanic Province (GVP).

Figure1. *Three basalt samples taken from Gharyan area in Libya.*

Figure2. Show the locations of the selected samples. GVP is the smallest of the four Principal Tertiary volcanic areas in Libya, and consists of continuous lava sheets in the central part of Jabal Nafusah. The volcanic rocks in GVP are predominantly basaltic associated with ultramafic rocks plus phonolitic-trachytic intrusions. The major volcanic phases of GVP, shown in figure 2, are: plateau lava phase, including the old lava series (OLS) and its subordinate young lava series (YLS), phonolite and trachayte intrusions clustered at the foot of Jabal Nafusah escarpment, and late volcanic centers (LVC) [7].

These rocks caused by the accumulation of a group of minerals, crystallized from magma under the conditions of a joint pressure and temperature, which represents 95% of the components rocky crust. Basalt rocks have different uses: Basalt is used for a wide variety of purposes. It is most commonly crushed for use as an aggregate in construction projects. Crushed basalt is used for road base, concrete aggregate, asphalt pavement aggregate, railroad ballast, filter stone in drain fields and many other purposes. Basalt is also cut into dimension stone and sometimes polished for use as floor tiles, building veneer, monuments and other stone objects [8-9]. It is also used in the production of high quality textile fibers, acid-resistant equipment for heavy industrial use, Rockwool, basalt plastic pipers, basalt plastic reinforcement bars, basalt roofing fiber felt, basalt laminate used as a protective coating, heat-insulating basalt fiber materials, and fiberglass [10-11]. Most of the basalt rocks found in many locations in Libya were of basaltic volcanic rocks.

3. Method of Analysis

The purpose of the analysis: is to know the compositional elements in the basalt rock samples and to carry out bulk and grain density and porosity measurements for these samples. Elemental composition analyses were taken at The Nuclear Research Center in Tripoli's Atomic Energy Organization, using Total X-Ray Fluorescence (TXRF) system.

Porosity measurements were conducted at The Libyan Petroleum Institute, Tripoli, using Digital Modular Helium Expansion Volume Meter.

The samples preparation and digestions were carried out using acid digestion in the light of the standard methods using (Microwave Furnace). This was carried out once with the addition of some acids such as (HCL – HNO3 - HF), then re-digestion again with the addition of some acid group such as (HNO3 - HCL).

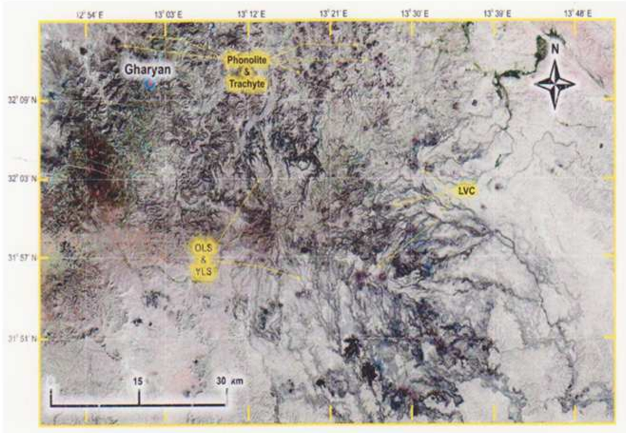

Figure2. *Shows the geographical locations of the samples, (Taken from [7]).*

4. Results and Discussion

Table1. Shows the results of the elemental composition analyses using (TXRF) system at The Nuclear Research Center at Tripoli's Atomic Energy Organization.

Table1. *Elemental composition analyses of the basalt samples*

Element	B-12 (ppm)	A-14 (ppm)	A-18 (ppm)
K	8726.98	7498.00	2660.00
Ca	32836.26	45257.59	31390.00
Mn	1331.07	1607.43	1560.00
Fe	120017.97	120016	128130.00
Ni	326.26	505.19	338.00
Zn	167.133	223.64	203.00
Sr	242.193	457.27	478.00
Ba	---	30071.88	24200.00
S	---	---	---
Mg	22854.20	28942.00	26946.00
Na	101796.00	203592.00	168662.00

Trace elements, by definition, are those which occur in very low concentrations in common rocks (usually < 0.1 % by weight). Their concentrations are so commonly expressed in parts per million, ppm, (1ppm = 10-4 weight%). Though trace elements, constitute only a small fraction of a system of interest, they provide unique geochemical information contained in the variation of concentration for each component. Trace element geochemistry has been of enormous use in understanding the evolution of the Earth.

It can be seen from the table1, that the major components of all three samples are: Fe (12% weight), Na (10-20% weight), Ca (3-4%weight), Mg (2-3% weight), K (0.2-0.8%

weight) and Ba (2-3% weight). Trace elements such as Sr, Zn, Ni, and Mn have concentrations (< 0.1 % weight).

4.1. Density Measurements and Porosity Calculations for Basalt Rock Samples

The importance of the porous rocks study rests in the search techniques for groundwater, and for oil and gas producers given the probability that the rock may be a hydrocarbon reservoir. Knowing the porosity of the reservoir rock will help in calculating the reserves of oil or gas.

In this analysis, Porosity measurements of basalt rocks were carried out using Digital Modular Helium Expansion Volume Meter at The Libyan Petroleum Institute, Tripoli.

Calculation of grain volume (Gr. Vol) in the samples is given by the following relationship [12]:

$$\text{Gr.vol} = 172.94383 + \left(\frac{-6168.15}{\text{Pexp}}\right) - \text{Filler Vol} \quad (1)$$

Where 6168.15 is the device Coefficient. P_{exp} is the experimental pressure. 172.94383 is an account of the intercept regression line. Calculation of Grain Density(Gr. D) of samples can be expressed as:

$$Gr.D = \frac{Weigh}{Gr.Vol} \quad (2)$$

Table2. Shows the Calibration data from the Digital Modular Helium Expansion Volume Meter. Table3. Shows values of grain density of the samples under study.

Table2. *Calibration units for the Porosity measuring system.*

P_{exp} (dyne/cm^2)	Filler.Vol (cm^3)
158.870	134.130
146.079	130.747
126.311	124.116
85.455	100.701
69.207	83.793
50.224	50.190
41.256	23.419

Table3. *Shows values of grain density of the samples under study.*

Sample	P_{exp} (dyne/cm^2)	Gr. Vol. (cm^3)	Weight (g)	Gr. Density (g/cm^3)
A – 18	75.56	17.529	51.11	2.916
A – 14	74.18	16.009	48.565	3.034
B – 12	81.80	30.388	89.088	2.932

Porosity is defined as the ratio of pore volume (P.V) to the bulk volume (B.V) and is given as [12]:

$$porosity\ \% = \frac{P.V}{B.V} \times 100 = \left(1 - \frac{Gr.V}{B.V}\right) \times 100 \quad (3)$$

Measurement of (B.V) was carried out using Archimedes Device. The pore volumes of the samples under study were calculated according to the relation2:

$$Pore\ Volume = Bulk\ Volume - Grain\ Volume \quad (4)$$

The Bulk density is calculated according to the following relationship [2].

$$Bulk\ \ Density = (1 - \phi_{fr}) \times Gr.D \quad (5)$$

Where ϕ_{fr} is a porosity fraction.

Porosity is defined as a measure of the capacity of reservoir rocks to contain or store fluids. The fluids stored in the pore spaces within the reservoir rocks could be gas, oil, and water. High porosity values indicate high capacities of the reservoir rocks to contain these fluids, while low porosity values indicate the contrary.

Results for bulk and grain density and porosity were in good agreement with data published elsewhere [13]. The grain density of the basalts ranges from 2.916 to 3.034 g/cm^3. This range is considerably higher than for the bulk density, indicating that much of the variation in bulk density arises from differences in mineralogy rather than variation in porosity. The bulk density of the basalts ranges from 2.70 grams/cm^3 for highly vesicular material to 2.88 grams/cm^3 for low porosity. Table4, Shows the values of porosity and bulk density for the basalt rock samples.

Table4*. The calculated values of porosity and bulk density for the basalt rock samples*

Sample	Bulk Vol. Cm^3	Gr. Vol. (cm^3)	Porosity %	Bulk Density g/cm^3
A – 18	17.762	17.529	1.311	2.88
A – 14	16.817	16.009	4.806	2.89
B – 12	32.962	30.388	7.809	2.70

Results of grain density and porosity shown in tables 3 and 4, may indicate a small correlation between porosity and grain density. Such a small correlation may suggest that the porosity of the low porosity rocks is underestimated and a significant fraction of the pore volume in the low porosity (low permeability) rocks is not interconnected. There also is the possibility that low porosity basalts trap significant amounts of gas on solidification so that some of the pores initially are gas rather than water filled.

5. Mass Attenuation Coefficient of Basalt Rocks

Since basalt rocks have complex structure (see table1) it was thought of interest to study these rocks further and conduct theoretical calculations of the mass attenuation coefficient of these basalt rocks. The purpose of this survey is to ascertain the possibility of using basalt rocks in the construction of protective biological barriers of radiation. These basalt rocks are inexpensive and locally sufficient.

The exponential attenuation that characterizes the passage of monochromatic electromagnetic radiation through a homogeneous material is given by the Beer - Lambert Law [14] as:

$$I = I_0 \exp(-\mu x) \quad (6)$$

Where μ is gamma-ray linear attenuation coefficient; I_0 is the intensity of first measurement without specimen; I is the intensity passing the specimen and x is the thickness of the specimen. The linear attenuation coefficient (μ) of the material is an intrinsic property of each material and would usually be associated with a specific element of a given atomic number.

A common approach to the modeling of gamma - ray fields is a semi - empirical one based on monoenergetic (unscattered) radiation. This calculation considers gamma ray attenuation in relation to the basalt rocks under study.

Basalts are characterized as a multi- compositional elements shown in table1. In the case of such mixtures, the total mass attenuation coefficients, μ/ρ, are given as follows [15]:

$$\mu / \rho = \sum_j w_j \mu_j / \rho_j \quad (7)$$

Where w_j is the proportion by weight of the jth constituent, μ_j is the linear attenuation coefficient of the j element and ρ_j is the density of jth element.

The photon energy used for these calculations was 1MeV. The results of the calculations for basalt rocks (A14, B12, A18) are in figure 2. Lead material was used for comparison . As can be shown in figure 2, that basalt rocks are more efficient (by a factor of about 20) for using as a biological shielding than lead. This important property of basalt rocks can have many useful construction applications as discussed above and can be used as an effective construction material in nuclear power plants.

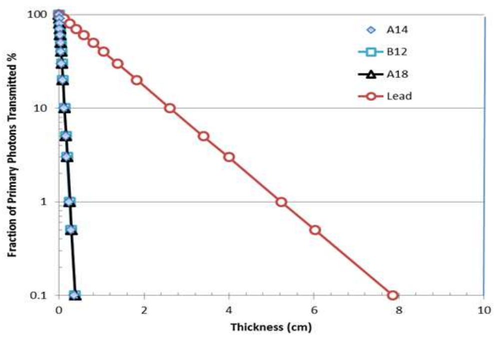

***Figure 2:** Transmitted photons (%) with energy 1MeV as a function of material thickness for basalt rocks (A14, B12, A18). Lead material was used for comparison.*

Recent study [16] has suggested that basalt rocks could be used for enhancing radioactive waste isolation during the storage and disposal phases and maintaining it during a significant portion of the post-closure phase. These rocks have been shown to have a long-term resistance to radiation, and have the ability to withstand any emergency or extreme situation. These properties can satisfy the main requirements of both the safe management and disposition of the generated long-lived, highly-radioactive, waste.

6. Conclusion

In this paper, elemental composition, bulk and grain density and porosity measurements for three basalt rock samples from Gharyan Volcanic Province (GVP) NW Libya were conducted. These analyses added to the value of study a great moral importance where such analyses were produced in Libya. Further work on this topic concerning the study of the electrical resistivity, thermal conductivity, and compressional and shear wave velocity of these basalt samples should help to provide additional relevant data. Besides these future studies, basalt rocks have shown to have important properties as an efficient radiation shielding and an effective construction material in nuclear power plants and storage of radioactive waste during disposal phases.

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