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Unlocking the Potentials of Helium in Nigeria

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Abstract: With the dwindling price of crude oil globally and its negative consequences on the economy and environment, there is an urgent need to diversify in the search for alternative sources of revenue for the country particularly in the Oil and Gas sector. The discovery of radiogenic helium in commercial quantity serves to augment the gross domestic product of any nation due to the various roles it plays in our everyday life; from entertainment to the medical field, where it is used for cooling superconducting magnets in medical Magnetic Resonance Imaging (MRI) scanners and Nuclear Magnetic Resonance (NMR) spectrometers to industrial applications as an agent for in maintaining controlled atmosphere and in detecting leakages. It is also useful in supersonic wind tunnels because of its stability, thermal and caloric perfect nature as well as its high speed of sound and high heat capacity ratio. Just recently, it was discovered that helium is being used to create hard drives in computers. Helium has no known substitution in cryogenic uses. It is obvious that there is a great need for the indigenous sourcing of this valued resource which is non-renewable. The discovery of large quantities of helium in Tanzania has heightened the search for this noble gas in Nigeria. This paper is therefore aimed at reviewing the generation, migration and reservoir accumulation of the gas from both biogenic and a biogenic sources.in order to support and likewise make vital contribution towards sourcing for helium in Nigeria.

Key words: Radiogenic Helium · Biogenic and Abiogenic Sources · Migration · Reservoir Accumulation

INTRODUCTION

The importance of helium in our world today is so encompassing that its full potentials is yet to be discovered. Helium is the second most abundant element in the universe after hydrogen; it is a stable noble gas. In liquid form, it is the only element that cannot be solidified by reducing its temperature as this can only be achieved by pressure increase.

Helium is formed both in the atmosphere and in the subsurface. According to a survey carried out by Oliver *et al.* [1], it was discovered that the concentration of helium in the atmosphere was only 5.2 parts per million by volume; which is low and constant despite the fact that helium is being produced continuously but most of it in the atmosphere escapes into space by several processes. Due to the small amounts of atmospheric helium which can be extracted, however the process for of extraction is expensive and so rarely used. Subsurface helium has two origins; helium-3 (^3He) is presumed to originate from the mantle as a primordial isotope and crustal helium, mostly available as helium-4 (^4He), is derived as a by-product from the radiogenic alpha decay of uranium, thorium and radium in crustal rocks. Large amounts of helium can be found associated with natural gas that escape through tectonic structures such as faults and fractures in the basement complex to overlying sedimentary rocks having an impermeable layer serving as a seal. According to Dembicki [2], nonhydrocarbon gases in addition to the hydrocarbon

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gases in petroleum accumulations include carbon dioxide, nitrogen, hydrogen sulphide, helium and hydrogen. The most effective impermeable layers for the trapping of helium are anhydrite and halite, although shale is applicable but not as efficient as the former.

Helium is commercially available in either liquid or gaseous form. The global reserves of helium are known to be approximately 48.8 billion cubic meters and are obtained from the United States of America (USA), Qatar, Algeria, Russia, Canada and China [3]. Annual global production of helium stands at about 175 million cubic meters, with USA topping the list of producers [4] Table 1. In 2016, helium was found in Tanzania in huge volumes worth an estimated 54 billion cubic feet (1.5×109 m^3) deposit [5, 6]. Presently, the world's bulk liquid helium market worth is above US$1.5 billion, with the unit price (US$ per thousand cubic feet) increasing by over 100% in the past decade [7].

MATERIALS AND METHODS

In an attempt to determine the availability of helium in Nigeria, a three-way approach was applied. Firstly, secondary data was collated to establish the geological setting of helium formation and establish the conditions necessary its migration and accumulation globally and attempt to identify such scenarios in Nigeria.

The second phase of the study applied the use of two sets of questionnaires. The first questionnaire was targeted at the sale of gases in the southern Nigeria. It was designed to investigate different types of gas sold, duration of sales of helium gas, their common uses, quantity consumed, imported or locally sourced and pricing. The second questionnaire was administered to a learned audience in western Nigeria, knowledgeable about helium, to establish the extent of awareness of the availability of helium in Nigeria as well as how this noble gas is being sourced. Seventy-five individuals were administered the questionnaire using the face-to-face method. This method required that pre-determined subjects be given questionnaires in the presence of the researcher. The use of self-administered questionnaire is based on a number of reasons; first, for a desired sample size, it is cheaper and quicker to use questionnaire rather than in-depth interview method. Also, the questionnaire offers anonymity and this allows the respondent to express themselves freely.

The final stage involved field survey to areas identified in the first phase of the study as having potentials for the occurrence of helium. The detection of helium was established by the use of a handheld Nuvair Pro He Alarm Analyzer, purchased for the rapid and accurate measurement of helium occurring in mixed gases.

Geological Setting for Helium Generation in Nigeria: In reviewing the geology of Nigeria to reveal the possible areas for the generation of helium, it can be seen that the components that are relevant to the sourcing, migration and storage of helium are found within the three major litho-petrological divisions of Nigeria, as described by Fatoye and Gideon[8], Obaje [9] as the Basement Complex, Volcanics and Sedimentary Basins (Figure 1).

Basement Complex: According to Black [9], the Nigerian Precambrian Nigerian basement complex is principally a part of the Pan-African mobile belt which lies between the West African and Congo Cratons and south of the Tuareg Shield. Occupying 50% of the surface of Nigeria, the basement complex comprises of three major lithological units; the oldest being the migmatite-gneiss-quartzite complex (Precambrian to Cambrian). metasedimentary schist series dominant in the western part of Nigeria. Lastly, is the older granite suite (Pan African Granitoids) that intruded into the migmatite-gneiss-quartzite complex and schist belt between 500 and 750 ma [10]

Volcanics (Younger Granite Suite): Volcanics comprise of the Jurassic Younger Granites and Tertiary volcanic rocks. Of particular interest in the formation of helium are the Younger Granite Suites as the pore water for gas interaction must be older than 100 million years [11]. There was an intrusion by the Mesozoic calc-alkaline ring complexes (Younger Granites) of the Jos Plateau which is unconformably overlain by Cretaceous and younger sediments. The Younger Granites were as a result of volcanic activities which can be associated with the discovery of helium in Tanzania. An estimated reserve of 54 billion cubic feet of helium was found below the Tanzanian Rift Valley in Rukwa Basin.

Sedimentary Basins: There are seven main sedimentary basins in Nigeria, ranging in age from middle Mesozoic to recent. The major secession series have been identified in the basins are the Lower Cretaceous (Albian) basal sediments of continental origin consisting of conglomerates, sandstones, siltstones and mudstones. This was followed by the Cenomanian to Turonian sediments comprising of marine lime stones and shales interbedded with sandstones. According to Brown [12], shales have high potentials for the generation of helium when compared with other rock types (Figure 2).

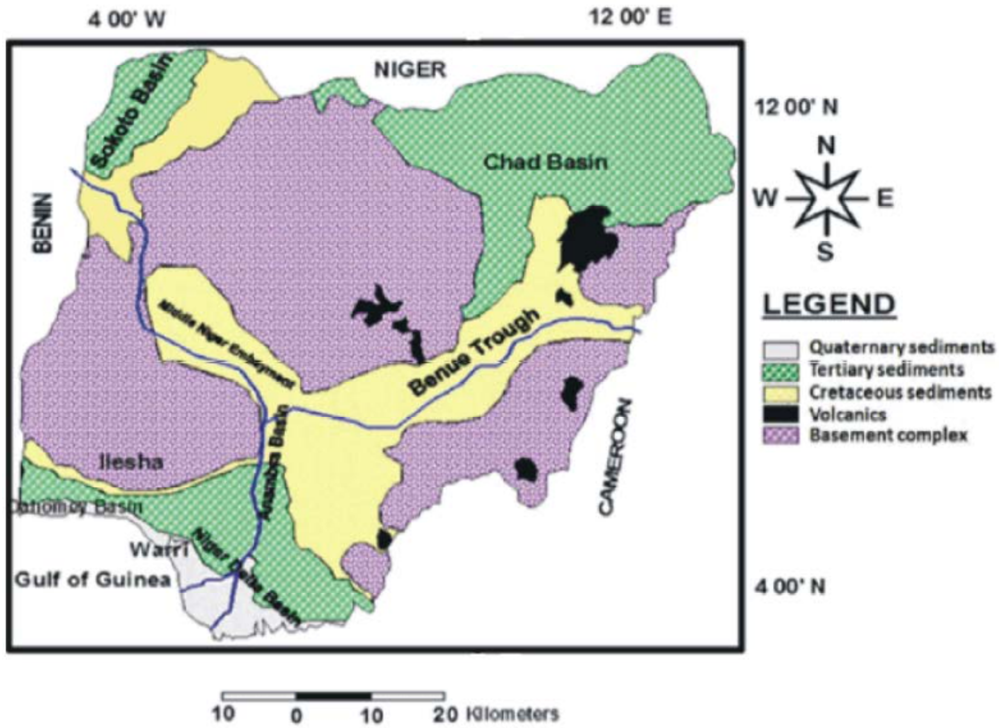

Fig. 1: Geological Map of Nigeria [8]

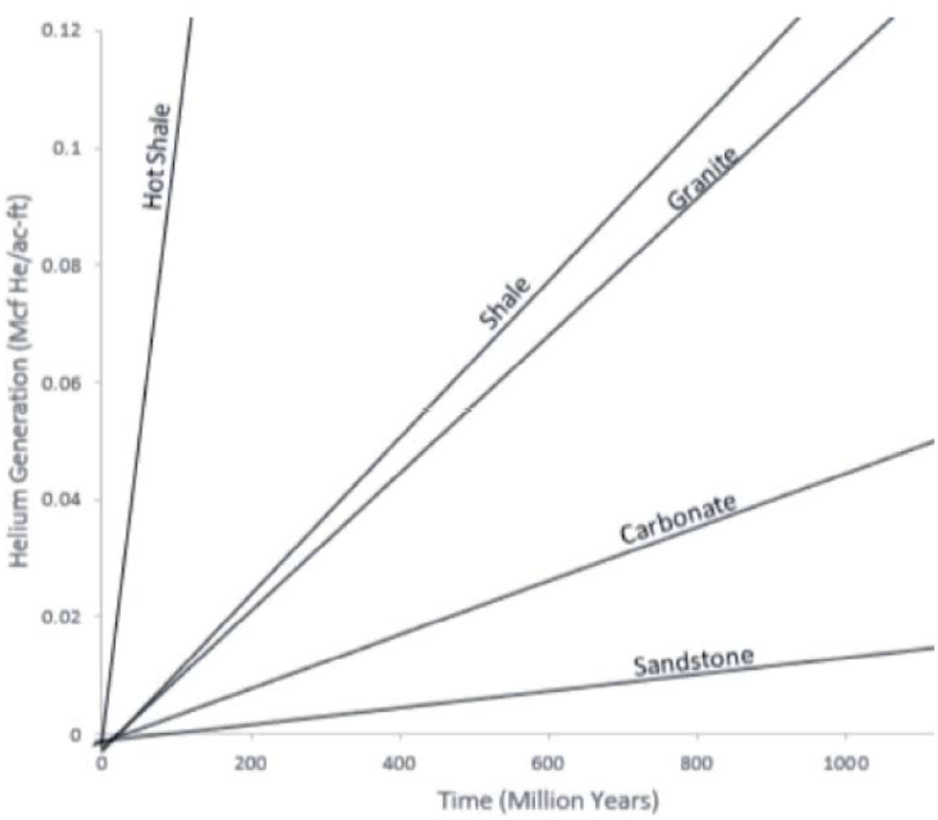

Fig. 2: Helium Generation in different rock types with age [12]

The Upper Cretaceous depositional cycle has a mixture of both marine and continental sediments made up of sandstones, siltstones, mudstones, claystone, evaporites with lignite beds. These sandstones serve as reservoir rocks for helium while the mudstones and evaporite provide excellent seals and cap rocks.

The Tertiary sediments overlying the oceanic crust in some sedimentary basins are of great importance as they serve as huge reservoirs for the accumulation of helium and also contain huge reoil and natural gas reserves.

Sources, Pathways and Reservoirs for Helium: Several authors have adjudged the generation of helium in the earth from a wide variety of sources ranging from granitoids [13] and sedimentary [14, 15]. Helium 4 also referred to as radiogenic helium is generated from the radioactive decay of Uranium and Thorium. Studies have shown that shales and granites [13, 18] possess a great source potential for the generation of helium, although huge rock volume and extensive geologic time are prerequisites.

Fractures and high temperature play vital roles in the migration of helium from the source rock to the reservoir. Fracture zones, serve as pathways for the migration of helium gases from their sources of generation. Identifying such zones is key in the exploration of helium. Two major facture systems have been identified in Nigeria [16], belonging to the West and Central African Rift System (WCARS). These northeast-southwest trending belts formed during the early Cretaceous to the early Tertiary, are in accordance with the Romanche and Chain fracture zones in the Atlantic and were formed earlier than the East African Rift System (EARS) where huge amount of helium reserve was discovered in. 2016.

Groundwater serves as a carrier for the transportation of helium and other gases from the source to reservoir rocks. Studies have shown that the presence of pore water aid the accumulation of helium in commercial quantity [12]. Hot spring vents also provide passages for helium by way of diffusion. India's helium is mainly sourced from thermal springs [17] and it is proposing to build the world first commercial helium exploration plant.

The presence of salt tectonic structural features also provides reservoirs for the storage of helium. After the formation of helium, it begins its upward movement through cracks and faults. Evaporites such as halite and anhydrite are known to stop the upward movement of helium. Shale could also stop the migration of helium but because of is pore spaces being plugged with organic matter known as "kerogen", it could serve the purpose of limiting the migration of helium once it is trapped.

RESULTS AND DISCUSSION

Results from the first set of questionnaire survey, involving twenty-five (25) gas vendors in Nigeria, showed that they were into the sales of a variety of gases such as helium (He) oxygen (O_2), carbon-dioxide (CO_2), nitrogen (N_2), argon (Ar), propane (C_3H_8), acetylene (C_4H_{10}), ammonia (NH_3), butane (C_2H_2) and liquefied petroleum gas (cooking gas). The longest company into sale of helium began business 16 years ago. Majority of the companies adjudged that their customers were mainly from the entertainment industry. All respondents indicated that helium was imported and are usually sold to vendors such as fast-food confectioneries,

From the second set of the questionnaire survey, the following results were obtained. On the sourcing of helium in Nigeria, out of the fifty (50) respondents who received the questionnaire, 42% of the respondents stated that helium was being imported into the country; while 42% stated that the helium was being sourced locally; two (2) respondents which is 4% stated that helium was being sourced locally and also imported from outside the country and finally 12% stated that they had no idea of how the helium was being sourced (Figure 3).

Out of the fifty (50) respondents who received the questionnaire, 72% stated that they were aware of helium being available in Nigeria; 18% stated that they are not aware of the availability of helium in Nigeria; while 10% stated that they had no ideas as to if helium is available or not in the country (Figure 4).

Probable Areas for the Discovery Helium in Nigeria: In order to predict the potential areas where helium can be located in Nigeria, various, data were sought for using areas where helium has been discovered around the world as a guide.

Benue Trough: Firstly, helium is derived from the radioactive decay of elements such as uranium and thorium which are found in granitic rocks. Such heavy elements can be found in the basement complex. Seismic studies have revealed the distribution of sedimentary and igneous rocks in Nigeria. The Benue Trough is the most possible area for the search of helium due to its stratigraphic and structural setting. The intrusive igneous rocks serve has probable "source rocks" for the generation of helium. This was later accompanied by rifting that occurred during the Cretaceous which aided the release of helium from the source rocks. Studies by [18] revealed the presence of thick overlying strata of sedimentary rocks of up to 6000 m in the Benue Trough

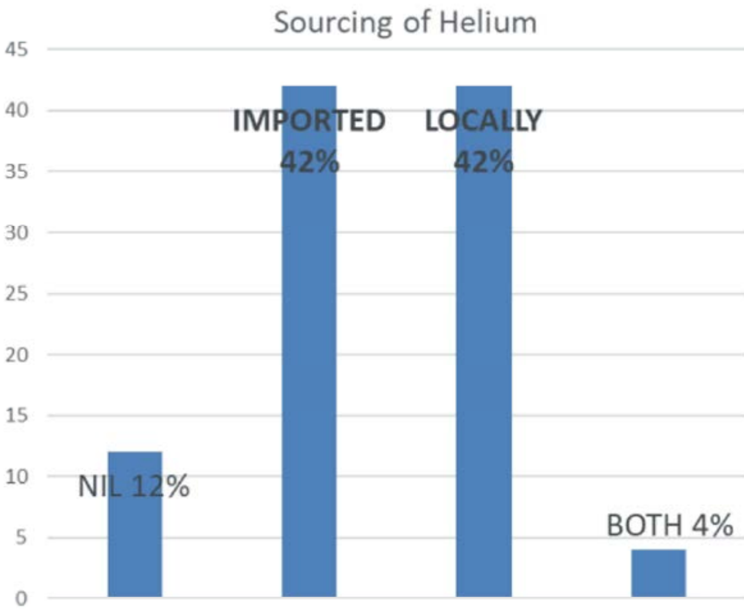

Fig. 3: Analysis of respondents of how helium is sourced

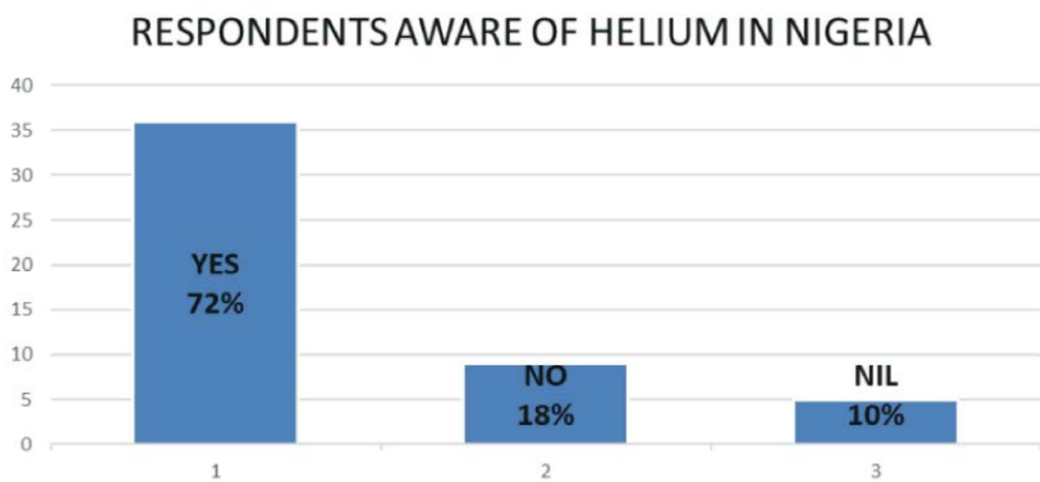

Fig. 4: Analysis of respondents on the awareness of availability of helium in Nigeria

provide excellent reservoir rocks for the generated and migration helium from the basement complex. The Benue Trough and the Rukwa basin experienced similar tectonic activities leading to the rifting which are overlain by sedimentary rocks (Figure 5a). The Rukwa Rift Basin where enormous amount of helium was discovered in 2016 is part of the third rift arm (failed arm) of the. East African triple junction. There were three depositional sequences that occurred in the basin. The earliest cycle is sedimentary record within the Rukwa Graben consisting of deposits of the Late Carboniferous to Early Jurassic Karoo Supergroup [19]. This was followed by the Red Sandstones and then the recent Lake beds made up of unconsolidated fluvial, alluvial and lacustrine deposits (Figure 5b). Similar to the Rukwa Rift Basin, is the Benue Trough which is also part of the West African failed arm (Figure 5c).

From studies using aeromagnetic, gravity and seismic data, basement highs can be identified. According to Brown [12], Helium shows high correlation with basement highs. The Benue Trough's basement morphology indicates the presence oof basement (Figure 6).

Finally, the occurrence of mudstones and limestone serve as seals and cap rocks for the trapping of helium (Figure 7). These rocks were deposited during the Cretaceous to Tertiary period. A good cap rock must possess low permeability, absence of faults and fractures high capillary entrance pressure.

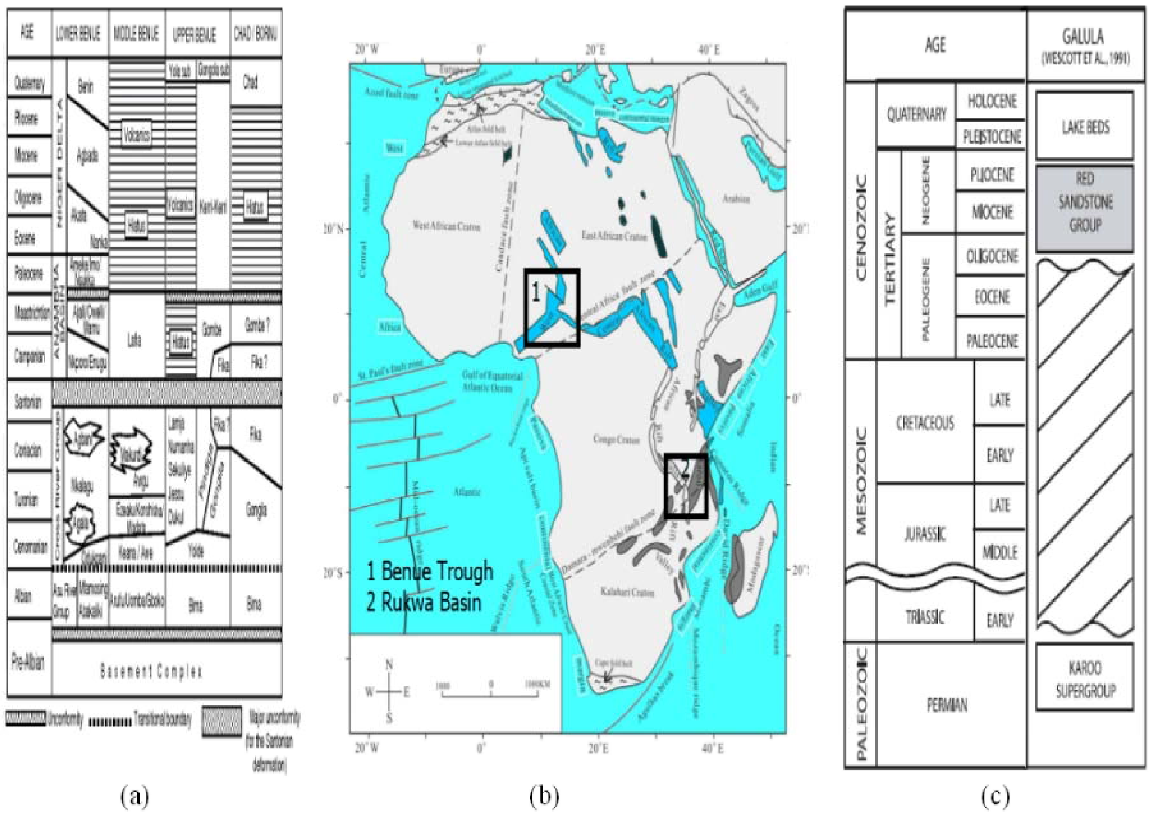

Fig. 5: (a) Tectonic structure of the African plate highlighting the Benue Trough and Rukwa basins [20] (b) Recent stratigraphic interpretations for the Rukwa and northern Malawi rift basins. Roberts *et al*. [21], (c) Stratigraphic sequence of the Benue Trough [22]

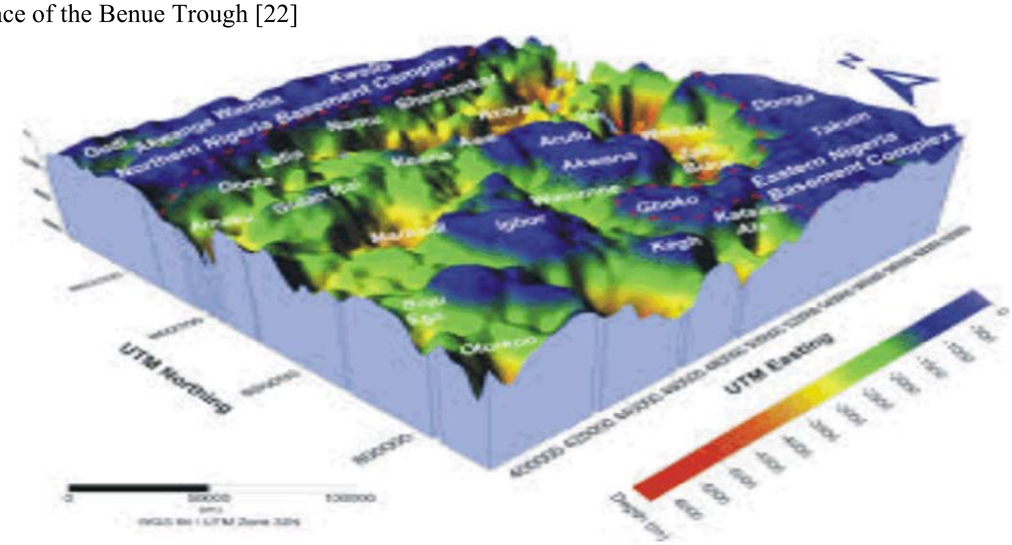

Fig. 6: Basement morphology of Benue Trough [18]

Geothermal Springs: Another source for helium is geothermal areas that are intrinsically connected to granitic basement rocks. Studies by Brown [12] and Bueno [23], indicate that igneous rocks have the high constituents of uranium and thorium, a major source of radiogenic helium in crustal rocks (Table 1).

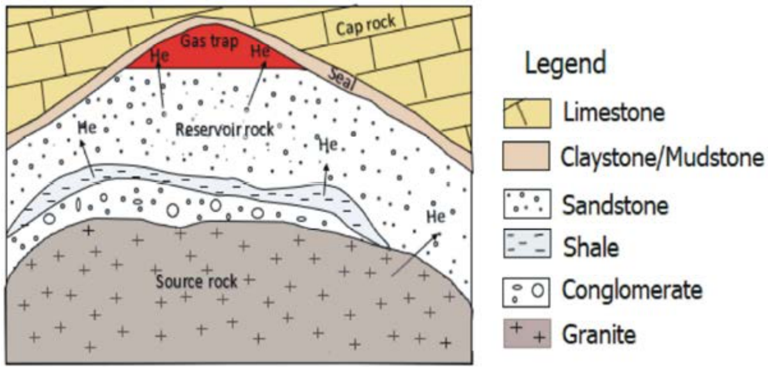

Fig 7. Model showing the trapping mechanism of helium

Table 1: Uranium and Thorium concentration in some common crustal rocks [23]

Rock Type	Uranium (ppm)		Thorium (ppm)	
Igneous	Average	Range	Average	Range
Alkaline Intrusives	8.2	(0.1 -19.7)	17.2	(0.6 - 35.0)
Silicic Extrusives	5			
Granitic	4.8	(2.2 - 7.6)	21.5	(8.0 -56.0)
Grabbroic	0.8	(0.2 - 3.4)	3.8	
Balsatic	0.4	(0.1 - 1.0)	1.6	(0.2 - 5.4)
Sedimentary				
Shales	4.2	(3.2 - 8.0)	11.7	(10.2 - 13.1)
Limestones	2.1	(0.3 - 9.0)	2.2	(0.1 - 7.5)
Sandstones	1.3	(0.5 - 3.2)	3.4	(1.0 - 9.0)
Metamorphic	2.9	(0.2 - 11)	8.6	(0.1 - 27)
Soils	1.13	(0.27 - 2.08)	6.94	(4.03 - 14.1)

Table 2: Composition of Thermal Spring Gases [17]

Gas	Bakreswar (Vol%)	Tantloi (Vol%)
Nitrogen	92.20	92.00
Helium	1.40	1.26
Argon	2.07	2.40
Oxygen	0.90	1.14
Methane	3.43	3.20

According to Chaudhuri *et al.* [11], a number of factors must exist for helium to be available in large volume. The first prerequisite is the presence of old pore water as pore water increases with the increase in the concentration of U and Th. Geothermal springs are regions where gases along with hot water escape from the earth's interior. Such gases also contain nitrogen, argon and oxygen (Table 2).

The presence of carrier gases such as methane and nitrogen aid in the transportation of He to reservoirs. The source of heat may be attributed to crustal magmatic events or to more recent volcanic activities. Typical examples of such locations are the warm springs located at Ikogosi, Ekiti State, Lamurde, Nasarawa, Adamawa State and Wikki in Bauchi State. Field survey to warm spring sites at Ikogosi indicated that the gases emanating from the spring recorded insignificant amounts of helium, thereby alluding to the fact helium may not be present in commercial quantities in the warm springs Figure 8.

Niger Delta Basin: The major source of helium globally is the extraction from natural gas through the process of fractional distillation. Nigeria has huge amounts of natural gas reservoirs in the southern part of the country. Most of the natural gas is harnessed for the both domestic use and export. Helium being very light is discarded during the processing of natural gas. The several natural gas fields in the region make up to 2.7% of the world's proven reserves, where helium can be harnessed. Nigeria ranks the highest in Africa with proven reserves of over 5 million cubic meters (Figure 9).

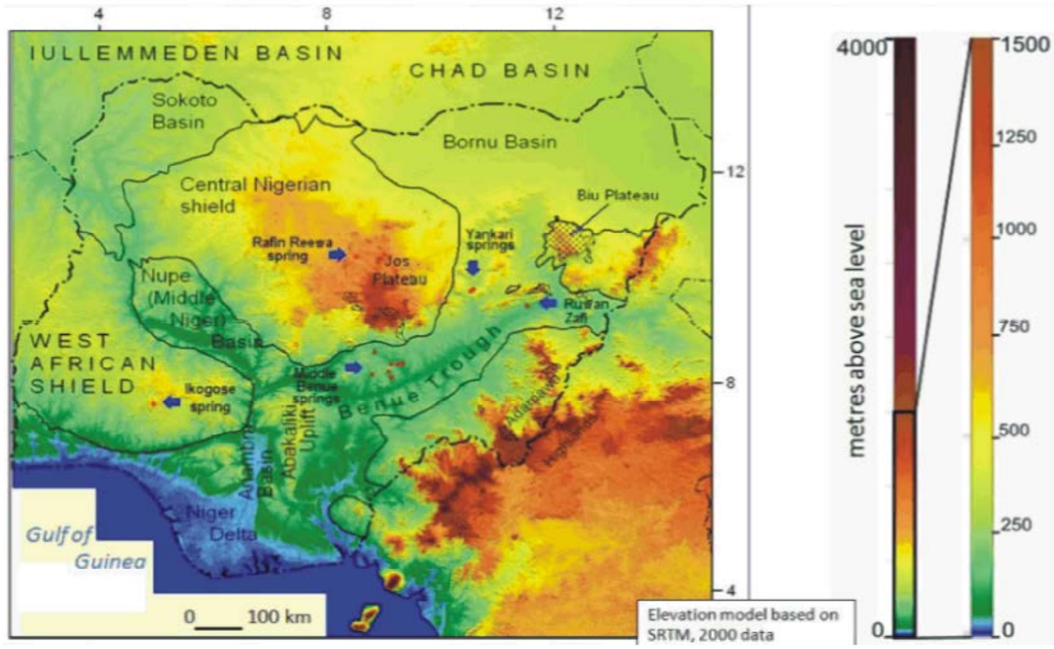

Fig. 8: Map of Nigerian thermal springs – geothermal surface manifestations on the background of topography (data source: SRTM 90m Digital Elevation Data)

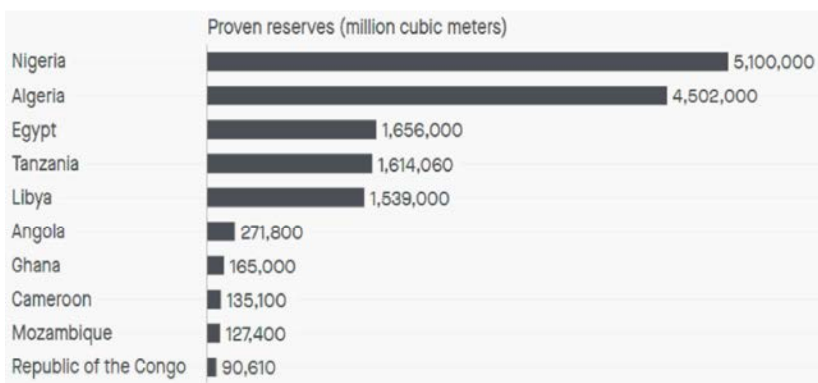

Fig. 9: Proven Natural Gas Reserves for African Countries

These fields can be likened to large quantities found around the American Great Plains. This discovery enabled the United States become the world's leading supplier of helium. Due to the similarity in trapping mechanisms between helium and natural gas, the largest concentration of helium in the subsurface can be extracted from natural gas rich in gases such as nitrogen, carbon-dioxide, methane and other heavy hydrocarbons. United States has huge amounts of helium associated with natural gas in the southern parts of the country.

Concluding Remarks: Helium is a nonrenewable noble gas of utmost importance to man. Helium can be found both in the atmosphere and the earth. Although helium is available in the atmosphere, being the second most abundant element, the methods of extracting it is quite exorbitant. Its probable availability in Nigeria has been highlighted in this study although further research should be done to ascertain the qualitative and quantitative extent of helium. Also, the government should be brought into awareness of its importance as their backing in this project is of paramount importance in order to improve the economy of the nation.

The government is therefore as a matter of urgency, put in steps to address the issue of the awareness of helium and make efforts to explore the various parts of the country with the intention of extracting the gas in commercial quantity.

Helium exploration field stations should be established at hot springs to ascertain the presence of economic quantity of helium. Also, in places where it is in commercial quantity, the deposits should be explored for use, which in turn would improve the economy of the country.

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