

A Review of Gemstone Occurrences, Provenance, and Origins in Nigeria

Juliana Omotayo¹, Oluwatoyin Ajilore¹, Temitayo Adeyemi^{2*}

¹Department of Geology, University of Ibadan, Ibadan, Oyo, Nigeria; ²Department of Petroleum Engineering, Louisiana State University, Baton Rouge, USA

ABSTRACT

Nigeria is the most important producer of gemstones in Western Africa, with commercial deposits of precious and semi-precious stones like Paraiba tourmaline, sapphire, emerald, aquamarine, spessartite, amethyst, zircon, and a few rare species like ruby, phenakite, kunzite, tanzanite, tsavorite, and lepidolite. When cut, faceted, and polished for use in jewellery or other personal adornments, gemstones belong to a particular class of commercial minerals. Nigeria is endowed with significant gemstone resources. Gemstones are minerals that are part of a nation's natural endowment and can be explored, exploited, and the profits can be used for the good of the community. They are also minerals having distinctive physical characteristics such as strong colour, increased specific gravity, high Mohs scale of hardness, perfect cleavage, etc. Nigeria has economic reserves of precious and semi-precious stones in Western Africa. Because of their special qualities, such as their beauty, shine and glitter, gems are charming objects that are coveted by both royalty and the wealthy. In pegmatite veins that are oriented N-S, NE-SW, and occasionally vertical or steeply dipping, in the southwest of Nigeria, gemstone occurrences can be discovered. These veins penetrate older lithology of the schistose, mafic-ultramafic, and migmatite gneiss complex rocks. Tourmaline such as garnet, topaz, and the coloured gemstone tourmaline etc., can be found in pegmatites as single crystals buried in anhedral to euhedral structured crystals, particularly in the weathered kaolinized zones. Many of commercial gemstone deposits in Nigeria are in small pockets of weathered bedrock (pegmatite, granites, and basalts) with associated eluvial and alluvial deposits. Due to their value and part of their rarity, gemstones have a variety of uses, both for consumers and for industries that employ them as raw materials to create products and byproducts made from jewels. The existing, careless method of exploitation generates a lot of trash and does not preserve the environment, artisanal mining and government regulation are urgently required for proper exploitation and management of Gemstones in Nigeria.

Keywords: Gemstones; Jewellery; Lithology

INTRODUCTION

Gemstones have no single, precise definition. Unlike diamonds, colored gemstones are not a single commodity. Instead, they are a category that includes dozens of different types of precious gemstones, with different sources and different values. A gemstone that has been cut and polished are referred to as a Gem. Diamond, corundum (ruby and sapphire), beryl (emerald and aquamarine), topaz, and opal are generally classed as precious stones. All other gemstones are usually classed as semiprecious [1].

According to UN Standard International Trade Classification system [2], used for compiling international statistics on all merchandise entering international trade. Here gemstones are defined as: All precious and semi-precious stones (whether or not

they have been worked or graded) excluding: All categories of diamonds; all precious stones composed of non-mineral, organic materials (i.e., pearls, ivory, corals, and lignite); and all precious stones made of synthetic or reconstructed materials.

Adesugba, et al. [3], defined Gemstones as natural organic matter, minerals or stones, which are available mostly in igneous rocks and alluvial gravels, but sedimentary and metamorphic rocks may also contain gem minerals. Gem minerals found in sedimentary rocks include: Beryl; Opal; Malachite etc. while Gemstones associated with metamorphic rocks include: Jade; Beryl; Sapphire and Zircon. Gemstones in cut and polished forms are used to make jewelry or other adornments. Mining of gemstones in Nigeria is an old practice. Nigeria is known for the availability of different gemstones including Corundum, Beryl, Quartz and its varieties, Tourmaline, Garnet, Aquamarine, Topaz, and Spinel.

Correspondence to: Temitayo Adeyemi, Department of Petroleum Engineering, Louisiana State University, Baton Rouge, USA, Tel: +12254188920; E-mail: tadeye2@lsu.edu

Received: 05-May-2023; Manuscript No. JGG-23-23918; **Editor assigned:** 08-May-2023; PreQC. No. JGG-23-23918 (PQ); **Reviewed:** 22-May-2023; QC. No. JGG-23-23918; **Revised:** 30-May-2023; Manuscript No. JGG-23-23918 (R); **Published:** 06-Jun-2023, DOI: 10.35248/2381-8719.23.12.1111.

Citation: Omotayo J, Ajilore O, Adeyemi T (2023) A Review of Gemstone Occurrences, Provenance, and Origins in Nigeria. J Geol Geophys. 12:1111.

Copyright: © 2023 Omotayo J, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Gemstones occur in most major geological environments, and each environment tends to have a unique suite of gem materials. Gemstones are characterized to be precious or semi-precious stones as a result of its characteristics of beauty, rarity, and durability. Gemstones that fall into the category of precious stones are diamond, corundum, beryl, topaz, and opal, while the likes of garnet, tourmaline, amethyst and all other stones are classified as semi-precious. Other key features of gemstones are hardness and specific gravity. The hardness of stone is known as its resistance to scratching, while specific gravity shows the ratio of how large a gem of any volume is to an equal amount of water. The geological environment in which a gemstone is found or mined is known as the gemstone occurrences; most gemstones are available at the site where their formation took place. However, rain, wind or rivers transport some gemstones from their place of formation; these are known to be Alluvial gem deposits.

According to Samuel, et al. [4], the locality of a gem deposit is the country or area where the gem exists; some parts of the earth seem to have been more blessed than others by geological conditions favorable to the formation of gemstone deposits. Some countries and villages are fortunate in this regard as they are known for their abundance of gem deposits. Each type of gemstone differs from one another, and the gems have different mineral and chemical composition. Gemstones are the formation of crystals, amorphous minerals, or organic rocks. Gemstones are used for jewelry, adornment, and healing. Gems are an oddity of nature; over the years, humans have ascribed importance to gemstones and the jewelry made from them. Charms made from gemstones were thought to prevent evil from entering the body. Gemstones are a product of the earth. Some, like diamond and zircon, were formed deep in the earth and brought to the surface by explosions of molten rock. Many, like topaz, tourmaline and aquamarine, crystallize slowly from hot fluids and gases as they cooled and solidified, far below the surface of the earth.

Adesugba, et al. [3], additionally discussed that, gemstones and crystals have pure energy. Some people believe that when the vibrations of gemstones and crystals come into contact with our vibration, they will have effects in much the same way as we experience sound waves. Gemstones are a special class of industrial minerals that are cut or faceted and polished for use as jewelry and other personal adornments. Gemstones, on the other hand, are minerals that constitute part of a country's natural endowment to be explored, exploited and revenues used for community benefit. Nigeria is endowed with substantial gemstone resources and the only country in Western Africa with commercial deposits of precious and semi-precious stones including paraiba tourmaline, sapphire, emerald, aquamarine, spessartite and rhodolite garnets, beryl, topaz, amethyst, zircon, and a couple of rare species such as ruby, phenakite, kunzite, tanzanite, tsavorite and lepidolite. Most of the gemstones are mined mostly "informally" from weathered rocks [5].

LITERATURE REVIEW

General properties of gemstones

Gemstone is a precious or semiprecious stone which can cut and polished to use in ornaments. Precious gemstones are beautiful, durable and rare as to semi-precious ones. So, semi-precious are abundant and low in quality than precious gemstones. Other than the aforementioned qualities that make a gem precious are size, shape and brilliancy. Gemstones are used in jewelry or other

adornments after cutting and polishing [6].

A natural gemstone is a mineral, stone, or organic matter that can be cut and polished or otherwise treated for use as jewelry or other ornament. A precious gemstone has beauty, durability, and rarity, whereas a semiprecious gemstone has only one or two of these qualities.

Gemstones are precious or semi-precious stones. It is a piece of mineral crystal and is of various kinds, colors, and grades. Examples of gemstones are turquoise, emerald, diamond, labradorite, kyanite, sapphire, ruby, aquamarine, topaz, garnet, amethyst, ammolite, benitoite, zircon, and many more. There are certain rocks like lapis lazuli that are not minerals like amber but are all considered to be gemstones and can still be used for jewelry. Gemstones are generally hard and before use especially for jewelry that is cut and polished, but no matter what it is used for, gemstones are always admired and valued because of their rare characteristics.

Gemstones (or gems) are a special group of non-metallic minerals (and rocks) that are valued for various reasons and used in the production of jewelry and other personal adornments. They are cut, faceted, and polished, and sold at relatively high prices by jewelers. Gemstones are mostly minerals that occur naturally in rocks as well-formed crystals, sometimes spectacular objects of beauty; valuable in their rarity, and sufficiently durable to give lasting pleasure to their owners. Although most gemstones are minerals, there are a few that are rocks (e.g., lapis lazuli) or organic materials (e.g., amber and pearl); they are valuable as jewelry, and therefore, considered as gemstones [5].

Olade, [5], also discussed in his study that there are over two hundred minerals recognized as gemstones but only about 10% are found in commercial quantities and traded worldwide. For a mineral to qualify as a gemstone, it must possess certain qualities, including beauty and colorful appearance, luster and clarity (no inclusions), durability and hardness, and extreme rarity. These attributes have made gemstones so valuable that they are sought after by both royalty and the wealthy. Although the general populace may also value gemstones, they may only afford the cheaper varieties or the synthetic look-alikes. Prices of normal gemstones range from a few dollars to over \$15,000 per carat (1 carat=200 mg). Blue diamond, the most expensive gemstone in the world, is worth about \$4 million per carat.

Mineralogical, gemstones are mostly silicates characterized by their unique physical properties including intense color, enhanced specific gravity, and high Mohs' scale of hardness, excellent cleavage, and sparkling luster. Gemstones are classified using several criteria including chemical characteristics (organic and inorganic), mineralogical groups (e.g., beryl, corundum, garnets, tourmalines), and commercial value (e.g., precious, semiprecious). The commercial classification devised in the 1800s is based on quality and value and is still the most widely used classification by jewelers and marketers. The two groups identified are: Precious and semi-precious stones.

Precious stones are highly valuable and attractive, comprising four minerals: Diamond, emerald, ruby, and sapphire. Diamond made of recrystallized carbon is the most precious and alluring of all gemstones; often sparkling and colorless or faintly colored. Emerald is a green variety of the mineral beryl ($\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$). Ruby is a pink to blood-red variety of the mineral corundum (Al_2O_3), white sapphire is a royal blue variety (polymorph) of the same mineral corundum. The different colors are attributed

to different trace element content. The semi-precious stones comprise all other gemstones; mostly colored gems that are considered less valuable or less appealing. Examples include tourmaline, topaz, zircon, garnets, amethyst, aquamarine, and peridot (olivine) [5].

History of gemstones

Gemstones have been since over 25,000 years ago. In ancient times, they were called healing stones, crystals, healing crystals mood stones, and a host of other names. However, different places have their own origin of gemstones. The Egyptians are known to import obsidian gemstones which they used in making weapons as well as jewelry around 4000 BC. In China around 3600 BC, gemstones were used to make tools as well as jewelry. Chinese were known with Nephrite Jade. Indians, Greece, Romans, Europeans, Africans, and a lot of other places in the world used gemstones for numerous purposes especially in healing and ornaments up till the 21st century. Kanis, et al. [7], posited that around 1980 the first information about new gemstone discoveries in Central Nigeria reached the outside world and by the middle of the eighties, Nigeria had become an important producer of aquamarine, topaz, tourmaline, and sapphire. Most of these gemstones have been taken out of the country illegally and very little is known to date about production figures, or about the location and paragenesis of these gem deposits. Aquamarine and topaz occur in areas generally related to the edges of Younger Granite bodies. Tourmalines are associated with pegmatite of the Older granite bodies. Sapphires and zircons have been extracted from eluvial deposits on weathered alkali basalts. The gem-quality zircons range from red to colorless and chemical analyses are reported of stones covering this range. The gemstone path starts with the discovery of the gemstone.

According to Hausel, [8], gemstones represent some of the more valuable commodities on earth and knowing the geological conditions and environment where certain gemstones are found can lead to discoveries. The gemstone from the point of exploration to the final consumer goes through the gemstone pipeline through activities that are dispersed both geographically and organizationally [9]. A gemstone moves from hand to hand among miners, gem dealers, stakeholders and covers a long distance through this process. For the gemstone to arrive at the final customer fit for jewelry, major steps which are included in the path are involved in the processing such as panning, cleaving, bruising, polishing, and final inspection as gemstones in its natural state has a highly irregular geometry and includes many contaminations [10].

Origin of gemstones

Nigeria is richly endowed with significant gemstones occurrences of high economic potential. These gemstones were formed at different stages in the geological evolution of Nigeria. However, because many of these gemstones are worked by small scale miners, production figures are extremely difficult to come by and the potential of this resource to the economic development of the country is thus sadly neglected.

Girei, et al. [11], attempted to synthesis all the available data on Nigeria gemstones including their geological settings, lithological control, style of occurrences and their distribution in their research. This is imperative to providing a framework for more detail research in the future that will subsequently enable better

exploration and mining of gemstones in the country. Three important episodes of magmatism associated with the formation of gemstones in Nigeria have been highlighted by researchers in their study. These are:

- The Pan-African cycles of magmatism related to amalgamation of western Gondwana ended with the production of numerous mineralized pegmatite fields in many African countries including Nigeria and in Brazil. Important gemstones associated with the Pan-African pegmatite in Nigeria include tourmaline, gem beryl, garnet and kunzite.
- Mesozoic gemstone occurrences associated with late stage albitization that accompanied the emplacement of biotite granite of the epizonal anorogenic younger granite complexes include emerald, topaz and occasionally ruby.
- The emplacement of Tertiary to Recent alkaline basalt was also contemporaneous with the formation of significant gem quality sapphire. The sapphire occurs in seven broad fields located proximal to Jos, Biu and Mambilla Plateaus. Weathering of these gemstone-bearing Pan-African-Mesozoic and Tertiary-Recent rocks and subsequent alluvial processes also lead to formation of secondary economic gemstone deposits. Most of the gemstones therefore are mined as alluvial, colluvial and eluvial deposits.

Gemstones are rarely discovered *in situ* and the prospecting methods for primary deposits are based on geology, geochemistry, and mineralogy [12-15]. The mother rocks of corundum may include charnockite, gneiss with quartz, feldspar, garnet, sillimanite, graphite, and marble and calcitic gneiss [14].

The P-T conditions of formation of gem corundum in the amphibolite facies was approached by de Maesschalk, et al. [16], studying fluid inclusions trapped by corundum from gem gravels.

Dahanayake [13], studied gem-bearing gravels and suggested that gem corundum and spinel derived from both garnet-bearing gneiss and skarn deposits. Munasinghe, et al. [17], suggested that corundum formed at the contact between basic charnockitic intrusions and aluminous metasedimentary rocks. Rupasinghe, et al. [18], and Dissanayake, et al. [19], used Be and F geochemistry to locate the bedrock sources. Origin determination is of increasing importance in the gem trade. It is possible because there is a close relationship between the geological environment of formation and the physical and chemical properties of gemstones, such as trace element and isotopic compositions that can be measured in the laboratory using combinations of increasingly sophisticated instrumentation. Origin conclusions for ruby, sapphire, and emerald make up the bulk of demand for these services, with growing demand for alexandrite, tourmaline, and spinel.

Olade [5], Discussed that primary gemstones are minerals formed mostly by geological processes that occur at great depths under conditions of relatively elevated temperatures and pressures. Surficial processes only form a few gemstones but assist in recirculating already formed primary minerals through erosion and sedimentation. Gemstones can be found in several geological environments and are typically associated with certain rock types and suites of minerals. The following geological environments and host rock associations are the most common for gemstones (Table 1).

- Plutonic-Hypabyssal (alkaline granites, syenites, pegmatite, lamprophyre, kimberlite)

- Volcanic (Alkaline basalts)
- Metamorphic (Regional and Contact Metasomatic)
- Sedimentary (Placer)
- Weathering and Supergene

In the context of the geological associations outlined above, the geology of Nigeria is characterized by the prevalence of Precambrian metamorphic and igneous rocks intruded by Jurassic alkaline ring dykes and overlain by Cretaceous to Quaternary sedimentary and volcanic rocks. Rock types within the Precambrian basement include Archean migmatites and gneisses, Proterozoic schists and metavolcanics that are intruded by Pan-African granitoids (Older granites) and pegmatite. Currently, the gemstones mined in commercial quantities in Nigeria include tourmaline, sapphire, ruby, emerald, aquamarine, beryl, amethyst, fluorite, topaz, garnets, and zircon [20]. One precious stone which is missing from the list is diamond. No occurrence of diamond has been confirmed in Nigeria, although there are numerous claims of diamond specimens from Nigeria by unscrupulous gem dealers: They are believed to be misidentifications or fake. Several rare gems of mineralogical or scientific curiosity have been reported from Nigeria by gemologists including kunzite, phenakite, gahnite, and tanzanite [21]. Gemstone mining is widespread in Nigeria, and mostly carried out informally by artisanal and small-scale miners digging pits using crude hand tools including diggers, shovels, sledge hammers etc. There are a few instances where small-scale miners have used some mechanization in placer mining [22].

Occurrence of gemstones

Mode of occurrence: Gemstones are not very common because the unique conditions that promote their formation are unusual, and the lithology they are associated with are usually of limited extent. Consequently, gemstones generally occur in small quantities and do not form the large ore deposits' that we know for metallic minerals. So, the term gem deposits' will be used in this context to describe the natural concentrations of gemstones where single mineral crystals can be so valuable to be worth millions of dollars. Value rather than size is a defining characteristic of gem deposits. The high value of gemstones often justifies the mining of small deposits. In their mode of occurrence,

primary gem deposits tend to be disseminated or scattered sparsely throughout a large body of rock (e.g., diamond in kimberlites), or crystallize as clusters of small aggregates or in small hydrothermal veins and cavity fillings in host rocks where their crystallization may range from syngenetic to epigenetic. Chemical weathering, erosion and alluvial transportation of primary minerals produce alluvial deposits that may not be too far from source areas. As a result of their relatively high specific gravity and hardness, gemstones are able to resist chemical degradation, and physical abrasion to preserve intrinsic features and survive attrition during long-distance transportation. When stream gravels contain concentrations of gem minerals, they also tend to be small in size, appearing as small pockets or small gravel lenses in a stream bed. Gemstones in decomposed rock may occur several meters below the surface requiring the removal of overburden by pitting or trenching. Paleo placer deposits of gemstones can form from the compaction and cementation of alluvial deposits, [5]. Nigeria, West Africa is not an exception when it comes to gemstones, the country is richly blessed with one of the world's most sought-after semi-precious and precious stones. Paraiba tourmalines are the most common type of gemstone found in Nigeria particularly in Oyo state, other states with these deposits include Benue, Kaduna, Ondo, Kano, Nasarawa, Ogun, Bauchi, and the Plateau States (Figure 1).

Popular gemstones in Nigeria

Nigeria has a large deposit of minerals and precious stones. These gemstones are deposited in many states of the country. Some states have larger deposits of some of these gemstones while other states have very little quantity. The most popular of all the gemstones is the Paraiba tourmaline, this gemstone is deposited at Ogun, Kano, Oyo, Nasarawa, Ondo, and Kaduna states.

The types of gemstones popularly found in Nigeria

Tourmaline: Tourmaline leads in the list of most popular types of gemstones in Nigeria. This is because it is found in abundance, comes in many colors and it is readily available for buyers. The colors of tourmaline include blue, white, green, pink, watermelon, red and lots [23].

Each color may be given a different name e.g., pink and red (Rubellite), blue (Indicolite), green (Verdalite), blue-green

Table 1: Source rocks, origin, and gemstone forming processes [5].

Gemstone	Source rocks	Origin	Processes
Sapphire	Granite pegmatite	Synorogenic Magmatism	Late-stage fractional crystallization
	Alkali basalt	Continental rift volcanism	Xenocrysts in basaltic lavas
Aquamarine	Granitic pegmatite	Synorogenic magmatism	Late stage fractional crystallization
	Granite/vein	Anorogenic magmatism	Metasomatic and hydrothermal
Emerald	Granitic pegmatite	Synorogenic magmatism	Late stage fractional crystallization
	Granite/vein	Anorogenic magmatism	Metasomatic and hydrothermal
Spessartite rhodolite garnet	Granitic pegmatite	Synorogenic magmatism	Late stage fractional crystallization
	Metasediments	Regional metamorphism	Metamorphism of Mn-rich sediments
Topaz	Granitic pegmatite	Synorogenic magmatism	Late stage fractional crystallization
	Granite/vein	Anorogenic magmatism	Metasomatic and hydrothermal
Amethyst	Granite/vein	Anorogenic magmatism	Metasomatic and hydrothermal
	Granitic pegmatite	Synorogenic magmatism	Late stage fractional crystallization
Zircon	Alkali basalt	Continental rift volcanism	Xenocrysts in basaltic lavas
	Granite	Anorogenic magmatism	Metasomatic and hydrothermal

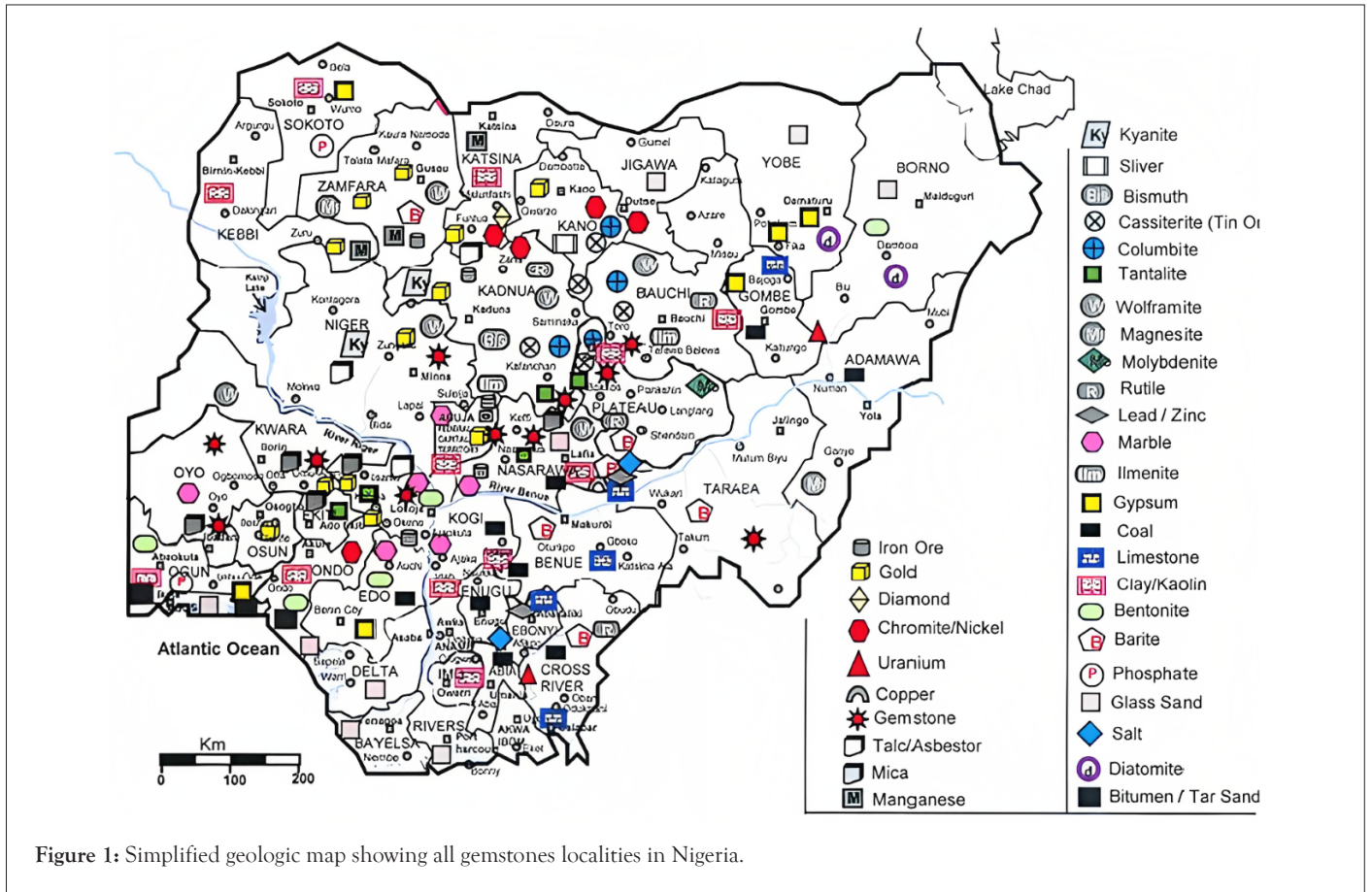


Figure 1: Simplified geologic map showing all gemstones localities in Nigeria.

(Paraiba), and black (schorl). Tourmaline is the most popular and valuable gemstone in Nigeria mainly because of its bright and beautiful colors, in addition to its multicolored varieties, Tourmaline is mined from the weathered rock and alluvials associated with the Older granite pegmatite in several localities across the country, including Oyo State (Idoko, Ofiki, Komu, and Itasa), Kwara State (Oro, Lemo Ndeji), Nasarawa State (Keffi, Saura, etc.), Kaduna State (Kagarko, Gidan Waya, etc.), Kogi State (Egbe, Ajaokuta, Lokoja), Osun State (Ife, Ilesha), Ekiti State (Ijero, Aramoko) and Taraba State. However, the best deposits are found mainly in Kaduna and Oyo States. Among the varieties of tourmaline, the most valuable and highly sought after is the Paraiba Tourmaline—a copper-bearing tourmaline that has an electric blue-green color that is both unusual and stunningly beautiful. Nigeria is known worldwide in the gem trade for its Paraiba tourmaline which is found only in two other countries in the world; (Brazil and Mozambique). Paraiba tourmaline was first reported from Brazil in 1988 and was valued for its glow that was not seen in other gemstones due to the presence of copper. Although gem quality tourmaline from Central Nigeria has been known since the 1960s, it was at the end of the 1990s and early 2000s that significant discoveries of gem-quality tourmaline were made. Paraiba tourmaline was first reported in Nigeria in 2000 from western Nigeria in the area around Edeko near Ilorin in Kwara State [24].

It exhibits a wide range of colors, from light blue, purplish (violet) blue, neon blue, and bluish green to emerald green; these colors are mainly due to variations in the copper and manganese contents. A relatively large deposit was discovered around 2000 in farmland in Oyo State, about 25 miles west of Ibadan. The deposit was mined for several years and reserves have dwindled. Mining for

tourmaline by artisanal miners has continued at several locations in Osun, Kaduna, Ekiti and Kogi States. Bi-colored tourmaline in pink, green, and blue has been reported in a recent discovery near Ile-Ife (Osun State). Other bi or tri-colored tourmalines in wine red blended with green and yellow have been reported from Keffi, Nasarawa State. Rubellite in raspberry pink to burgundy-red colors is being mined in Oyo State about 135 km NNW of Ibadan while indicolite (light blue to bluish-green tourmaline) is found near Oro in Kwara State. All these tourmalines occur in alluvial pockets originating from erosion of weathered pegmatite [5]. When it comes to Kaduna State, tourmaline can be found in places like Gidan Waya, Kagarko, and lots more. Other states with tourmaline deposits include Osun State, Kogi state, Bauchi state, and Taraba states among others [23].

Sapphire: Sapphire ranks second in the list of most popular gemstones in Nigeria after tourmaline. Sapphire is a blue gemstone that is most valuable and costly. In Nigeria, it comes in colors like pale green, rich blue, colorless, indigo blue, and lots more. The quality of Nigeria sapphire is of a high grade and a gram of the unpolished sapphire in the international market is worth about \$10,000 US dollars. This gemstone can be in Nigeria in the following places: Bogoro in Bauchi State; Mambila Plateau in Taraba State; Gunda in Yobe State; Antah, Nisama, Gidan waya in Kaduna State, and Bokkos in Plateau State [23].

Aquamarine: Aquamarine is another widely known gemstone in Nigeria. It is sold in large quantities in the country. It comes in varieties ranging from the mineral beryl green-blue to blue colors [5]. Aquamarine can be found in places in Nigeria like Isanlu and Okene in Kogi State; Akwanga; Igbo Ora, and Ijebu Igbo in Ogun State; Nasarawa; Ibadan in Oyo State; Jenta; Agwada and Igwo in Nasarawa State [23]. Top-grade quality occurrences found

in pegmatite have been mined at several localities in central and southwestern Nigeria including Nasarawa State (Akwanga, Nassarawa, and Jenta, etc.), Oyo State (Ibadan, Igbo-Ora), Kogi State (Isanlu, Okene), and many parts of Jos Plateau in Plateau State. These occurrences are mostly associated with the Older granite pegmatites. However, some Sn-Nb mineralized biotite granites within the Younger Granite complexes such as at Ropp and Dorowa (Plateau State) and Rafin Gabas in the Afu Complex (Nasarawa State) have produced beautiful euhedral crystals of aquamarine as accessory minerals and crystals within miarolitic cavities of quartz veins and greisens [7]. Aquamarine has also been reported from a Precambrian pegmatite dyke in the Jos Plateau. Recently in May 2019, a new find of deep blue aquamarines from Nasarawa State was reported from near-surface workings in a weathered pegmatite body [21]. The pegmatite around Okene and Ajaokuta in Kogi State have also yielded aquamarine gems that are bright medium blue with a green tint [5].

Emerald: Emerald is of the family of beryl minerals, and it has a bright green color. Emerald deposits are found in Nigerian states like Nasarawa Egon in Nasarawa State as well as at Gwantu in Kaduna State. The produced quantities of emerald from the two deposits are quite small, and reserves are limited. Minor occurrences have been reported from Adavi near Okene (Kogi State). The relatively lighter green color of Nigerian emeralds makes them clear and usually inclusion-free. Some blue-green emeralds have also been reported from Gwantu in Kaduna State [25], and the bluish tinge has been attributed to some Fe impurities while the greenish color is attributed to traces of chromium and vanadium. Well-formed crystals of colorless beryl (goshenite) and green beryl, emerald and phenakite (another Be silicate) have been extracted from albitized Younger Granite complexes) in the Jos Plateau and Afu Hills (Nasarawa State) where they occur as disseminated accessory minerals, and rarely in quartz vein material. The quantity of emerald discovered in Nigeria has been very limited compared to other gemstones, although some of the specimens have been of value in scientific research by mineralogists and gemologists [5].

Garnet: Garnet is another gemstone found in Nigeria in large amounts. Garnet comes in many colors ranging from orange to brown. Garnets are a group of silicate minerals that were used as gems since the ages because of their attractive colors. They occur in a variety of colors reflecting their complex chemical composition, but the most common are red, orange, green, and grey varieties. In Nigeria, different varieties of garnet are mined such varieties include; spessartite garnet found in Komu in Oyo state. This variety comes in colors like orange, orange-brown, to deep red. Another variety of garnets popular in Nigeria is the Rhodolite garnet found in the axis of Jos-Bauchi. Another is green tsavorite garnet, but this variety is usually confused to be tourmaline. It is popular in middle belt axis of the country, which include Bauchi, Oyo and Plateau states [23].

Zircon: Another gemstone common in Nigeria is Zircon. It comes in colors like yellow, white, brown, pink, red, or even in a colorless form. Oftentimes, this gemstone can be confused with diamond because they share almost the same features. Zircon deposits in Nigeria include kunzite zircon found in the mines of Komu, Oyo state. Other places include Jos, Plateau state, Nisama, and Antah in Kaduna state. Zircon is used as a gemstone because of its characteristic crystalline form and similarity to diamond. Zircon appears in various colors from colorless (which resembles diamond), to white, brown, red, blue, green or pink, and can be

used as a semi-precious stone. In Nigeria, zircon in commercial quantities is associated with three geological environments: Granitic, volcanic, and pegmatitic. Zircon in well-formed crystals is common in the tin mining areas of Jos Plateau (Jos, Bukuru, Kigom, Ropp) and Nasarawa State (Rafin Gabas)), where it is associated with the Jurassic Younger Granites as an accessory mineral sometimes enriched in the albitized biotite granites. The Younger Granite zircons are crystalline and euhedral, and colorless to white. Zircon is also found in the decomposed alkali basalts near Jemaa where it accompanies sapphire as xenocrysts embedded in the basalt flows. The zircon crystals, usually brownish to reddish, show dull, slightly corroded surfaces and rounded edges not attributable to alluvial transportation but to magmatic corrosion. Zircon is also found within the granitic pegmatite and available in commercial quantities in Antan and Nisama in Kaduna State. Beautiful crystals of kunzite zircon have been extracted from mines in Komu, Oyo State (Kunzite Zircon is a mix of kunzite (Li Al (SiO₃), a pink to lavender violet variety of the mineral spodumene that and zircon). The cool lavender color of kunzite zircons makes them attractive for use in personal adornments. Nigeria's zircons respond to heat treatment producing very attractive colors and can be used in place of diamond because of its hardness and color [5].

Topaz: Another attractive gemstone in Nigeria is topaz. It comes in colors ranging from white to blue, pinkish to red, orange to red and oftentimes, it is used as a diamond substitute. Topaz can be sourced in Oyo State; Akwanga and Jenta in Nasarawa State; Bauchi; and Jos in Plateau State. Qualities of Topaz is deposited in Jos, Plateau state, Bauchi state, Nasarawa state (precisely in Jenta and Akwanga) and Oyo state [23].

Amethyst: Amethyst in Nigeria is of very high quality and usually has a purple color. It is sourced in places like Nasawara, Bauchi, Oyo, Kano, Kaduna, and lots more. In nature amethyst crystals are mainly formed in the inner surface of an amethyst geode (small cavity filled with crystals, found on the surface of the Earth). Amethyst can also be found on the vugs holes in rock by dissolving or eroding on the surface of rock, and form deep cavities Amethyst is mainly used as a gemstone due to brilliance in color and translucent in transparency

Diamond: Diamond is a rare, naturally occurring mineral composed of carbon. It is a unique material because it is economically important and pre-eminent both as gem and hard tool. Most industrial diamonds are gray or brown. Diamond of deep colors are extremely rare in nature and are therefore extremely expensive. The use of treatment processes to color diamonds had become common but testing these diamonds for induced as against natural color is extremely difficult. Each carbon atom in a diamond is surrounded by four other carbon atoms and connected to them by strong covalent bonds-the strongest type of chemical bond. This simple, uniform, tightly-bonded arrangement yields one of the most durable and versatile substances known. Diamond is the hardest known natural substance. It is also chemically resistant and has the highest thermal conductivity of any natural material. These properties make it suitable for use as a cutting tool and for other uses where durability is required. Diamond also has special optical properties such as a high index of refraction, high dispersion, and adamantine luster. These properties help make diamond the world's most popular gemstone and enable it to be used in specialty lenses where durability and performance are required. Diamonds are found in three types of deposits: Alluvial gravels,

glacial tills, and kimberlite pipes. The kimberlite pipes (such as those at Kimberley, South Africa) form from intrusions of magma into the earth's crust and deliver diamonds and other rocks and minerals from the mantle. Diamonds found in alluvial and glacial gravels must have been released by fluvial or glacial erosion of the kimberlite matrix and then redeposited in rivers or in glacial till.

Gemstone mining

Olade [5], reported in his study that, Gemstones in Nigeria are found usually in small pockets in weathered rock, and associated eluvial and alluvial deposits. Extraction of the gemstones is undertaken mostly by artisanal and small-scale miners who carry out the excavations using their hands or crude hand tools such as picks, diggers, and shovels. He also stated in his study that most of the gemstone mining is done informally by individuals, families, or very infrequently by organized partnerships or cooperatives. Due to widespread and severe lateritic weathering that results in thick regolith of decomposed rock suitable for eluvial mining, hard rock mining is uncommon. By digging and pitting, alluvial deposits on river terraces and banks are also exploited. The excavation of loose worn rock fragments and alluvial sands and gravel takes place in pits, where multiple miners may be working simultaneously. By using a ladder and rope, they can sometimes descend 5 to 20 meters into the pits. When they

reach the bedrock containing the gems at that depth, they might need to blast and tunnel to reach the gems. Mechanical tools may be used in some bigger open-pit excavations to excavate and remove mineral deposits. Women are crucial to the extraction of gemstones. The excavated heaps and pits are subsequently abandoned, endangering the nearby farmers' ability to farm. Olade [5], added that best gemstones are found in Kaduna, Oyo, Nasarawa, Plateau, and Taraba States. Because most of the gemstone mining is informal, and the artisanal operators are mostly illiterate farmers, all they desire is to sell the gems for cash to intermediaries and unscrupulous gem dealers who ultimately smuggle the precious stones out of the country with no value added through gem processing. No records of production are kept, or any revenues paid to the Federal Government coffer. Because to a lack of organizational structure, regulatory oversight, and monitoring, Nigeria loses a lot of money from the diamond industry. Nigerian tourmalines, sapphires, and emeralds are prized worldwide, and some of the finest stones have sold for millions of dollars each. In Nigeria, mining and selling gemstones is a lucrative business. To the benefit of all Nigerians, the Federal Government and other stakeholders must organize and regulate the gemstone industry. Adesugba, et al. [3], have published a qualitative review of the gemstone industry's pipeline and value chain and found out several leakages and loopholes in the management of the gemstone industry. The report made several



Figure 2: Mining of Aquamarine in the younger granite, Rafin Gaba [5].



Figure 3: Artisanal tourmaline mining [5].

recommendations for implementation so that the gemstone industry can contribute its rightful share to the country Gross Domestic Product (GDP) (Figures 2 and 3).

DISCUSSION

Provenance and origin

Olade [5], noted in his study that the bulk of primary gemstone deposits are created by igneous, hydrothermal, or metamorphic processes that start at high pressures and temperatures deep beneath the earth's upper mantle or crust. Some of gemstones' alluring qualities, such their crystal structure, habit, and brightness, are a result of the unique physical and chemical environments in which they are created. He continued by citing an example, saying that only specific varieties of sapphire and diamond are known to crystallize at extremely high temperatures and pressures inside the mantle. Even though pegmatite gemstones may have formed at relatively lower temperatures and pressure, their chemical environment volatile-rich residual fluids with enriched trace elements might have provided conditions that were suitable for the formation of coarse and vivid gemstones. He continued by saying that, if precisely recognized, a gemstone's origins or provenance can serve as a helpful indicator of how it was made.

As summarize in Table 2 by Olade [5], there are three main source rocks of Nigerian gemstones:

- Pan African granitic pegmatite,
- Jurassic alkaline granites,
- Cenozoic alkali basalts

These three groups of rocks have certain characteristics in common.

- They seem to originate from magmas that are relatively rich in some alkali elements such as Na, K and Li.
- They show evidence of late magmatic sodic metasomatism [26-28].
- The emplacement of the magmas is related to some tectonic events including the Pan-African orogeny (600-450 my)

- The Jurassic tectonic uplift, and the Cenozoic doming, rifting and alkaline volcanism

The mantle and/or lower sialic crust are somehow involved in these regional tectonic episodes. Several Nigerian gemstones, such as the Paraiba tourmaline, emerald, aquamarine, amethyst, ruby, garnets, and topaz, are found in the granitic pegmatite connected to the older granites. Large crystals of excellent quality gemstones can form due to the granitic pegmatite's very coarse texture, which results from slow cooling in a vapor bubble. The Lithium, Cesium Tantalum (LCT) family of pegmatite, which are abundant in Li, Rb, Cs, and REE, are also important sources of cassiterite and tantalite in Nigeria [29]. The pegmatites have yielded crystals of the Li minerals lepidolite, spodumene, and kunzite [30].

From the pegmatites, crystals of the Li minerals lepidolite, spodumene, and kunzite have been recovered. In their 2009 study of compositional differences in pegmatites from the gemstone and tin-producing region of Keffi, Nasarawa State, Okunlola and Ocan discovered that these pegmatites are richer in Li, Rb, Be, REE, Sn-Ta and other alkali elements with sodium metasomatism. This is in line with the frequent occurrence of a number of beryllium minerals, such as emerald and aquamarine. One of the typical characteristics of the mineralized pegmatites in Nigeria is sodic (Na) metasomatism, which occurs during the middle to late phases of crystallization and is marked by extensive albitization [31]. Some coarse-grained and stunning gems of minerals, including amethyst, rose quartz, geode, beryl, spodumene, lepidolite, and kunzite, have been created as a result of vug-filling in druse cavities that took place during the waning phase of pegmatite crystallization.

The Nigerian Paraiba (copper-bearing) tourmaline is thought to have formed by direct crystallization during the early to medium phases of pegmatite crystallization from a vapor-rich residual granitic melt containing significant boron and lithium with elevated concentrations of copper and other elements. Pegmatite, which are composed of residual solutions linked to granitic intrusive, are thought to have given rise to some of the greatest jewels in the world.

Table 2: Location of major gemstone and source in Nigeria [5].

Gemstone	Location	Host rock types
Tourmaline	Nasarawa State (Keffi, Saura, Angwan, Mayo, Angwan Tudu, Garaku, Gidan Kadiri, etc.); Oyo State (Idoko, Komu, Itasa, Budo, Agree, etc.); Osun State (Ife, Ilesha, etc.); Kaduna State (Kagarko, Gida Wayo, etc.); Kwara State (Lemo, Ndeji, Ora, Oro, etc.); Kogi; Bauchi and Taraba States.	Pegmatite
Sapphire	Taraba State (Karima lamido, Gambu, Guroji, Mambilla plateau); Kaduna State (Antan, Nisama, Jemaa, etc.); Bauchi State (Bogoro); Plateau State (Bokkos); Yobe State (Gunda, Gilde); Adamawa State (Ganye); Gombe State.	Alkali basalt
Aquamarine (Blue beryl)	Nasarawa State (Akwangu, Nasarawa, Jenta, Igwo, etc.) Kogi State; Oyo State (Ijebu, Ibadan, Igbo oran); Ogun State (Ijebu Igbo); Plateau State (Jos, plateau).	Pegmatite granite/vein
Emerald (Green beryl)	Kaduna State (Gwantu); Nasarawa State (Keffi, Nasarawa Eggon); Kogi State (Adavi); Plateau State (Jos, Plateau).	Pegmatite
Ruby (Red corundum)	Jos-Bauchi; Oyo State (Komu), Osun State (Ife-Ijesha).	Pegmatite
Amethyst (Quartz)	Bauchi State; Kaduna State; Kano State; Oyo state; Nasarawa State.	Pegmatite Granite/vein
Topaz	Nasarawa State (Jenta, Akwangu); Plateau State (Jos); Bauchi State, Oyo State.	Granite/vein pegmatite
Zircon	Taraba States (Karim, Genbu, Guroji Mambilla plateau); Plateau State (Jos- Bukuru Kigom, Ropp), Nasarawa State (Rafin Gabbas); Oyo State.	Alkali basalt Granite vein Pegmatite

According to Katsurada, et al. [32], there may have been a spatial connection between Madagascar and Nigerian Paraiba tourmalines prior to continental drift and the fragmentation of Gondwanaland. Although they are known to be geographically and chronologically connected with the older granites, which were deposited during the waning stage of the Pan-African thermo-tectonic event, the origin of the Nigerian granitic pegmatites remains a matter of debate. Although they are known to be geographically and chronologically connected with the older granites, which were deposited during the waning stage of the Pan-African thermo-tectonic event, the origin of the Nigerian granitic pegmatite remains a matter of debate. Numerous researchers have examined the sources of the Older granite and Pegmatite Magmas, Rb/Sr isotopic study [33].

Compared to the parent granites, the pegmatite is more fractionated and enriched in lithophile elements. While the pegmatite with an initial Sr ratio of 0.7678 are thought to have come from extreme fractionation of Older granite magmas, which were created by partial melting of crustal materials, the Older granite magmas with initial Sr isotopic ratios of 0.7155 to 0.7233 are thought to have mixed with ancient crustal material [34,35].

The Jos Plateau's Jurassic Younger granites are made up of complexes of high-level intrusive rocks that originated as ring dykes occasionally in conjunction with violent alkaline volcanism. They are the southernmost portion of a 500-mile-long, N-S trending alkaline igneous complex that was erupted during the Cretaceous breakup of Gondwanaland. This uplift was caused by hotspot, mantle plume activity [36,37]. The hydrothermal greisenized veins of quartz-cassiterite and wolframite, as well as the peraluminous albitized biotite granites of the Younger granite complexes, are well known for being the origins of primary and related secondary deposits of cassiterite and columbite [27,38]. On the other hand, zircon and pyrochlore crystals can be found in peralkaline granites. A typical metasomatic effect in the mineralized biotite granites is albitization. The Younger granites and related minerals are thought to have both crustal and mantle origins. It has been hypothesized that some of the Younger granites may be the result of partial melting of the Older granites given their similar mineralogy and distribution in the same approximate area of Central Nigeria [36,39]. The only commercial sapphire deposits in Nigeria are found in the Cenozoic alkaline basalts of the Jos Plateau and Mambilla Plateau in central and northeastern Nigeria. The Benue Trough, Jos Plateau, and the Bamenda Hills in Cameroon are the only long-established tectonic uplift zones where these volcanic rocks with alkaline affinities may be found [40].

These rocks were categorized into three groups:

- The Older Basalts,
- The Lateralized Older Basalts
- The Newer Basalts

These volcanic rocks are both Older Basalts and Newer Basalts on the Jos Plateau. The Mambilla Plateau is primarily composed of Newer Basalts. Zircon and sapphire xenocrysts can only be found in the Newer Basalts. The host rocks, which contain the sapphire gems, have extremely fine-grained crystals [41-44]. They are thought to be xenocrysts that formed in the mantle's depths and were brought to the surface as inclusions by slow-moving basaltic lava flows. The Biu-Mambilla Plateau's eruption of Miocene-Quaternary alkali basalts and trachytes, which extends eastward

into the eruption of more recent lava flows in the Bamenda Hills and volcanic islands along the Cameroon Volcanic Line, represent the effects of hotspot tectonics on the domed lithospheric crust and emerging continental rifting [45-50]. This is in line with the idea that these volcanic rocks and the gemstones that go with them were likely created in the mantle or in the lower crust above a mantle plume [51-57].

CONCLUSION

Nigeria is a leading gemstone producer in Africa and in recent years has become a prominent destination for gem dealers and gemologists. Most of the commercial deposits are derived from small pockets of weathered bedrock (pegmatite, granites, and Basalts) and associated eluvial and alluvial deposits. Currently, there is a lack of organized effort for the systematic prospecting and exploration for gemstone deposits using well known geological conceptual models for target selection, the artisanal and small-scale miners who randomly select the locations for extraction of gemstones should be organized and assisted by the appropriate government agencies so as to minimize environmental degradation and ensure that revenues are collected into government coffers.

Southwest Nigeria has a number of gemstone occurrences that have been noted. Pegmatite, which occurs as near horizontal or vertical dykes and intrudes earlier Precambrian lithologies, is the primary host rock. Gemstone crystals of anhedral to euhedral shapes, such as tourmaline, garnet, and beryl, can be found embedded in hard rock, weathered elluvials, or kaolinized pegmatite. Given the significant profit margin that may be realized, investment potential in diamonds is highly favorable. However, the current strategy for exploration and exploitation needs to be thoroughly examined in order to realize the greatest benefits.

In recent years, Nigeria has emerged as a popular travel destination for gem dealers and gemologists. Nigeria is one of Africa's top producers of gemstones. Small pockets of bedrock (pegmatite, granites, and basalts) that have weathered as well as related eluvial and alluvial deposits are where the majority of commercial deposits are found. A systematic approach to prospecting and exploring for gemstone deposits utilizing established geological conceptual models for target selection is lacking at the moment. In order to limit environmental damage and guarantee that government coffers are replete with funds, the proper government agencies should coordinate and support the artisanal and small-scale miners who arbitrarily choose the places for gemstone extraction.

Reforms and rules should be put into place to promote local investment and offer jobs to young people in the local communities where the gemstones are mined. To prevent severe leaks that have an impact on manufacturing, processing, and marketing, the gemstone supply chain's upstream and downstream segments should be closely watched.

REFERENCES

1. van der Wal S, Haan ED. Rough cut: Sustainability issues in the coloured gemstone industry. SSRN. 2010.
2. UNO. UN Standard International Trade Classification. 2010.
3. Adesugba A, Hoon S. Understanding the gemstone path and value chain in Nigeria. J Sci Res Stud. 2018;5(7):175-185.

4. Samuel Ayodele O, Ominyin Ajigo I. Geological mapping and gemstones prospecting in deformed precambrian rocks, east of okemesi fold belt, Southwestern Nigeria. *Jordan J Earth Environ Sci.* 2020;11(4).
5. Olade MA. Gemstones of Nigeria: An overview of their geological occurrence, provenance and origin. *Achiev J Sci Res.* 2021;3(1):1-22.
6. Ahmed J, Kakar MI, Khan MA, Ghaffar A, Naeem A. The classification and distribution of gemstones from Northern Balochistan, Pakistan. *Lasbela U J Sci Technol.* 2017;6:290-298.
7. Kanis J, Harding RR. Gemstone prospects in central Nigeria. *J Gemmol.* 1990;22:195-202.
8. Hausel WD. Gemstone discoveries in Wyoming. *Newsletter of the rocky mountain association of geologists.* 2006;55(3).
9. van Ostaeyen J, Kerremans Y, van Goethem G, Dufloy JR. A PSS model for diamond gemstone processing: Economic feasibility analysis. *Procedia CIRP.* 2013;7:395-400.
10. Gaywala MR, Surat N. Gemstone processing. United States patent application publication. Retrieved from Gagan Chondhary and Cliaman Golecha Paraiba tourmaline and similar looking gemstones material. *Gems Jew.* 2014;17(1):16-18.
11. Girei MB, Bamali US. Perspective for Nigerian gemstones occurrences: A review. *Nigerian Institute of Mining and Geosciences, Jos Nigeria.* 2012.
12. Katz MB. On the origin of the Ratnapura-type gem deposits of Ceylon. *Econ Geol.* 1972;67(1):113-115.
13. Dahanayake K. Modes of occurrence and provenance of gemstones of Sri Lanka. *Miner Depos.* 1980;15:81-86.
14. Dissanayake CB, Chandrajith RO, Tobschall HJ. The geology, mineralogy and rare element geochemistry of the gem deposits of Sri Lanka. *Bull Geol Soc Finland.* 2000;72(1):5-20.
15. Walton L. Exploration criteria for colored gemstone deposits in Yukon. 2004.
16. de Maesschalck AA, Oen IS. Fluid and mineral inclusions in corundum from gem gravels in Sri Lanka. *Mineral Mag.* 1989;53(373):539-545.
17. Munasinghe T, Dissanayake CB. The origin of gemstones of Sri Lanka. *Econ Geol.* 1981;76(5):1216-1225.
18. Rupasinghe MS, Banerjee A, Pense J, Dissanayake CB. The geochemistry of beryllium and fluorine in the gem fields of Sri Lanka. *Miner Depos.* 1984;19:86-93.
19. Dissanayake CB, Weerasooriya SV. The hydrogeochemical atlas of Sri Lanka. *Natural Resources, Energy and Science Authority of Sri Lanka.* 1986:103.
20. Igonor EE. Gemstone business in Nigeria. 2017.
21. Palke AC, Hapeman J. New find of deep blue aquamarine from Nasarawa State in Nigeria. *Gem News Int.* 2019;437-439.
22. NS Energy March. 2020.
23. Daniel M. List of gemstones in Nigeria. 2020.
24. Henricus J. New Nigeria tourmaline finds exciting trade interest. *Jew New Asia.* 2001;207:77-87.
25. Kanis J, Hanni HA. Blue-green Emerald from Nigeria (A consideration of terminology). *Aust Gem.* 1992;28:16-17.
26. Olade MA. Early Cretaceous basalt volcanism and initial continental rifting in Benue Trough, Nigeria. *Nature.* 1978;273(5662):458-459.
27. Olade MA. Geochemical characteristics of tin-bearing and tin-barren granites, Northern Nigeria. *Econ Geol.* 1980;75(1):71-82.
28. Olade MA, Emeforieta W. Geochemical characteristics of alkali pegmatites in relation to tin mineralization, S.W. Nigeria. *J Afr Earth Sci.* 1988;8:53-64.
29. Okunlola OA, Ocan OO. Rare metal (Ta-Sn-Li-Be) distribution in Precambrian pegmatites of Keffi area, Central Nigeria. *Nat Sci.* 2009;7(7):90-99.
30. Okunlola OA, Jimba S. Compositional trends in relation to Ta-Nb mineralization in Precambrian pegmatites of Aramoko, Ara and Ijero area, southwestern Nigeria. *J Min Geol.* 2006;42(2):113-126.
31. Okunlola OA, Oyedokun MO. Compositional trends and rare metal (Ta-Nb) mineralization potential of pegmatite and associated lithologies of Igbeti area, Southwestern Nigeria. *RMZ Mat Geoenviron.* 2009;56(1):38-53.
32. Katsurada Y, Sun Z, Breeding CM, Dutrow BL. Geographic origin determination of Paraiba tourmaline. *Gems Gemol.* 2019;55:648-659.
33. Matheis G, Caen-Vachette M. Rb-Sr isotopic study of rare-metal bearing and barren pegmatites in the Pan-African reactivation zone of Nigeria. *J Afr Earth Sci.* 1983;1(1):35-40.
34. Küster D. Rare-metal pegmatites of Wamba, Central Nigeria-their formation in relationship to late Pan-African granites. *Miner Depos.* 1990;25:25-33.
35. Akintola OF, Adekeye JI. Mineralization controls and petrogenesis of the rare metal pegmatites of Nasarawa area, Central Nigeria. *Earth Sci Res J.* 2008;12(1):44-61.
36. Bowden P. Origin of the younger granites of northern Nigeria. *Contrib Mineral Petro.* 1970;25(2):153-162.
37. Bowden P, van Breemen O, Hutchinson J, Turner DC. Palaeozoic and Mesozoic age trends for some ring complexes in Niger and Nigeria. *Nature.* 1976;259(5541):297-299.
38. Olade MA, Ekwere SJ. Aspects of tin-zinc mineralization at Ririwai lode, younger granite province. *Niger J Min Geol.* 1981;15:106-122.
39. Bowden P. Magmatic evolution and mineralization in the Nigerian younger granite province. In *Metallization associated with acid magmatism.* 1982;6:51-61.
40. Wright JB. *Geology and mineral resources of West Africa.* Springer. 1985.
41. Abaa SI. Hydrothermal fluids responsible for the formation of precious minerals in the Nigerian younger granite province. *Miner Depos.* 1991;26:34-39.

42. Abduriyim A, Kitawaki H, Furuya M, Schwarz D. "Paraiba"-type copper-bearing tourmaline from Brazil, Nigeria, and Mozambique: Chemical fingerprinting by LA-ICP-MS. *Gem Gemol.* 2006;42(1):4.
43. Ahmed YM, Oruonye ED. Socioeconomic impact of artisanal and small scale mining on the Mambilla Plateau of Taraba State, Nigeria. *World J Soc Sci Res.* 2016;3(1):1-12.
44. Bowden P, Kinnard JA. Geology and mineralization of the Nigerian anarogenic ring complexes. *Geol Jah.* 1984;56:3-65.
45. Bonewitz R. *Rocks and minerals.* Second Edition. 2012.
46. Fadipe AA. Chemical analysis of Beryl occurrence in Idao SW Nigeria. In *Book of Abstracts 29 Conf. Nigerian Min Geosci Soc.* 1991.
47. Harman AK, Ninomiya S, Adachi S. Optical constants of sapphire (α -Al₂O₃) single crystals. *J Appl Phys.* 1994;76(12):8032-8036.
48. Jacobson R, Webb H. *Pegmatite of Central Nigeria.* Geol Survey Nigeria. 1946:25.
49. Kayode A. Opening remarks on the occasion of first annual general meeting of the gemstones miners and marketers association of Nigeria. *Gemstones Miners and Marketers Association of Nigeria Database.* 2018.
50. Nesse WD. *Garnet in Introduction to Mineralogy.* Second Edition, Oxford University Press. 2012:341-344.
51. Okunlola OA. *Geology. Heavy mineral and geochemical surveys for Sn-Ta mineralisation in Jemma Kaduna State.* Abstracts 26 Nigeria Mineral and Geoscience Social Conference Kaduna. 1990.
52. Olade MA. *Mineral Deposits and Exploration Potential of Nigeria.* Prescott Publishers. 2020:404.
53. Olatunji AS, Jimoh OR. Geochemical study of tourmalines from some parts of Southwestern Nigeria. *Int Res J Geol Min.* 2016;6(1):9-27.
54. Olatunji J, Smulikowky. *Geology of the Wamba district.* Bull Dept Geol. 1986;2(2)120.
55. Haldar SK. *Introduction to Mineralogy and Petrology.* Second Edition. 2020.
56. Coulon C, Vidal P, Dupuy C, Baudin P, Popoff M, Maluski H, et al. The Mesozoic to early Cenozoic magmatism of the Benue Trough (Nigeria); geochemical evidence for the involvement of the St Helena plume. *J Petro.* 1996;37(6):1341-1358.
57. Okunlola OA. *Investment potential of gemstone occurrences in Southwestern Nigeria. Prospects for investment in mineral resources of southwestern Nigeria.* 2003:41-45.

