Guest Paper

Volume 3, Issue 1, pp 1-22, June 2021

ACHIEVERS JOURNAL OF SCIENTIFIC RESEARCH

Open Access Publications of Achievers University, Owo

Available Online at *www.achieverssciencejournal.org*

Gemstones of Nigeria: An Overview of Their Geological Occurrence, Provenance and Origin

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Submitted: May 20, 2021, Accepted: June 3, 2021 Published: June 28, 2021

ABSTRACT

Gemstones are a special class of industrial minerals that are cut or faceted and polished for use as jewelry and other personal adornments. Gemstones are adorable objects that are desired and sought after by both royalty and the wealthy for their unique properties including beauty and color, luster and sparkle, durability and hardness, and extreme rarity. 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 and associated eluvial and alluvial deposits by artisanal and small scale miners who are virtually illiterate individuals who sell their raw gems for quick cash with no value added. There are no records of production, and little or no revenue gets into the Federal Government coffers. This paper presents an overview of the geological occurrence, distribution, provenance and origin of Nigerian gemstones, and the potential application of the knowledge in gem prospecting and exploration. There is an urgent need for government reforms of artisanal mining and active regulation of the gemstone industry so that all the loopholes and leakages in the gem supply pipeline and value chain are fixed for the utmost benefit of the Nigerian economy,

KEYWORDS: Gemstones; Gem Distribution; Gem Minerals; Gemstone Origins; Geological Environment; Nigeria; Provenance

1. Introduction

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. 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 = 200mg). Blue diamond, the most expensive gemstone in the world, is worth about $4 million per carat. Mineralogically, gemstones are mostly silicates characterized by their unique physical properties including intense color, enhanced specific gravity, high Mohs' scale of hardness, excellent cleavage, and sparkling luster.

Gemstones are classified using several criteria including chemical characteristics (organic vs. 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 ($Be_3Al_2(SiO_3)_6$). 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).

2. Global Trade and African Production

The world trade in gemstones is very substantial: it is a multi-billion dollar business that attracts worldwide interest and investment. Most of the gemstones involved in global trade originate mainly from Africa and South America (Brazil, Columbia) with lesser contributions from SE Asia (Myanmar, India, Sri Lanka), from where raw gemstones are shipped to countries like Thailand, Hong Kong, Switzerland and the United Arab Emirates for processing, and ultimately to customers worldwide, particularly in Europe and the United States, - the world's leading consumers of gemstones. In 2018, the total value of the global production of rough diamonds alone amounted to $17.4 billion (U.S. dollars), while the colored-gem trade was estimated at over $6 billion.

Africa, the world's leading producer of gemstones is endowed with vast reserves of beautiful precious stones of which diamond is the best known. Six of the seven leading producers of gem-quality diamonds in the world are located in Africa, namely: Botswana, Angola, South Africa, the Democratic Republic of the Congo, Namibia, and Lesotho. They collectively produce over sixty million carats of diamond annually, and own some of the largest diamond mines in the world. Apart from diamonds, To date, Africa has produced over 75%, in value, of the world's diamonds with more than 1.9 billion carats worth an estimated $US 158 billion mined (Source: NS Energy, March 2020). Africa is also a major source of colored gemstones (e.g. ruby, emerald, sapphire, tanzanite tourmaline, aquamarine, garnets) that occur in more than half a dozen different countries in Southern and Eastern Africa, stretching from Namibia in the southwest, through South Africa, Zimbabwe, Zambia, Malawi and Tanzania, to Kenya and Mozambique in Eastern Africa, and the nearby island of Madagascar. Table 1 is a list of the major gemstone producing countries in Africa and

gemstone properties.

Outside of the Southern-Eastern Africa gemstone region, Nigeria in West Africa is the only other notable producer of gemstones in commercial quantities. Recently, Nigeria has become a destination for gemologists and gem traders seeking precious and rare gemstones. According to Kanis and Harding (1990), the first information about new gemstone discoveries in Central Nigeria reached the outside world for the first time around 1980 with the discovery of deep blue aquamarine which differed from other sources because the color was natural and not treated. Later, in 1983,, deposits of blue sapphire were discovered in parts of Nasarawa State, followed by deposits of orange spessartite garnet and pink to red tourmaline. By the end of the nineties, Nigeria had become an important producer of aquamarine, topaz, tourmaline, and sapphire. In 2002, Nigeria reported discoveries of a unique form of bluish tourmaline called “Paraiba* tourmaline" and became the only other source in the world apart from Brazil. Paraiba was later discovered in 2005 in Madagascar which is now the world’s leading producer.

Currently, the gemstones mined in commercial quantities in Nigeria include tourmaline, sapphire, ruby, emerald, aquamarine, beryl, amethyst, fluorite, topaz, garnets, and zircon (Igonor, 2017) (Fig. 1). 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 gemmologists including kunzite, phenakite, gahnite, and tanzanite (Palke. and Hapeman, 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. 2019). Gemstone mining is widespread in Nigeria, and mostly carried out informally by artisanal and small- 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.

The purpose of this paper is to present an overview of the geological occurrence, provenance and origin of Nigerian gemstones and the application of such knowledge to systematic exploration for gem treasures.

3. Geological Environments of Gemstones

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.

1. Plutonic-Hypabyssal (alkaline granites, syenites, pegmatites, lamprophyre , kimberlite)
2. Volcanic (Alkaline basalts)
3. Metamorphic (Regional and Contact Metasomatic)
4. Sedimentary (Placer)
5. 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 e intruded by Jurassic alkaline ring dykes and overlain by Cretaceous to Quaternary sedimentary and volcanic rocks (Fig. 2). 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 pegmatites.

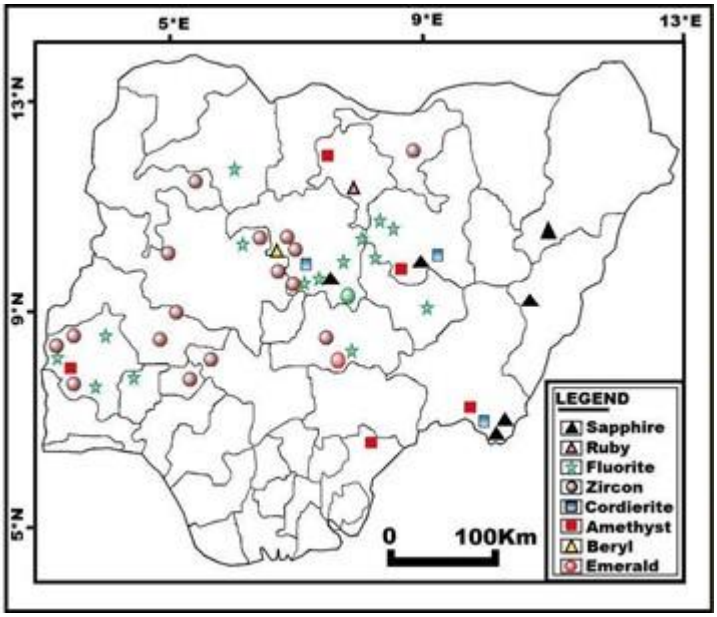

Figure 1: Location of gemstone deposit

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Table 1: Major Gemstone Producing Countries in Africa and Gemstone Properties

	Gemstone	Mineral Species	Color	Hardness (Mohs')	Producing Countries
1	Amethyst	Quartz(SiO2)	Purple	7	Madagascar, Namibia, SouthAfrica, Zambia, Nigeria
2	Aquamarine	Beryl (Be3Al2Si6O18)	Light-Blue	7.5-8 Brittle	Mozambique, Nigeria, Zambia,Madagascar, Malawi
3	Diamond	Carbon(C)	Colorless	10	Botswana, South Africa, CongoAngola, Namibia, Lesotho,
4	Emerald	Beryl (Be3Al2Si6O18)	Green	7.5-8	Zambia, Ethiopia, Nigeria,Madagascar
5	Ruby	Corundum(Al2O3)	Red	9	Mozambique, Kenya, Tanzania,Madagascar, Nigeria
6	Sapphire	Corundum(Al2O3)	Blue	9	Madagascar, Nigeria, Cameroon, Kenya, Ethiopia
7	Rhodolite	Garnet (Fe-Garnet)	Pink-Red	6-6.5	Tanzania, Kenya
8	Tsavorite	Garnet (Ca-Garnet)	Green	6-6.5	Tanzania
9	Mali	Garnet (Ca-Fe Garnet)	Yellow	6-6.5	Mali
10	Spessartine	Garnet (Mn-Garnet)	Orange, Mandarin	6-6.5	Nigeria
11	Tanzanite	Zoisite (Ca2Al3SiO12(OH)	Blue	6.5	Tanzania, Nigeria
12	Paraiba	Tourmaline	Blue-Green	7.5	Mozambique, Nigeria
13	Topaz	Topaz (Al2SiO4(F,OH)	Yellow-Brown	8	Nigeria, Namibia, Zimbabwe
14	Zircon	Zircon (ZrSiO4)	White/Red Brown	6-7.5	South Africa, Mozambique,Nigeria

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Gemstone deposits are found as primary and secondary deposits in five distinct geological environments, arranged in accordance with their relative importance as gem sources.

1) Early Paleozoic Older Granite Pegmatites
2) Jurassic Younger Granites
3) Cenozoic Alkaline Basalts
4) Quaternary Placer Deposits
5) Precambrian Metamorphic Rocks

5. Granitic Pegmatites

The Early Paleozoic (600-450 Ma) granitic pegmatites associated with the Older Granites are the leading source of gemstones in Nigeria. They are widely distributed within the basement complex but are mostly confined to a well-defined, 400-km long, ENE-WSW trending belt (Pegmatite Belt) that extends fromsouth of Ibadan area in SW Nigeria through Ijero, and Egbe to the Wamba-Jema'a area of north-central from where it swings to the northwest in the Gusau-Zuru area (Fig. 2) (Matheis, 1987; Okunlola, 2006). Primary and alluvial gemstones are common within the pegmatites and surrounding areas.

6. Alkaline Granites and Associated Veins

The Jurassic Younger Granites are a series of Jurassic alkaline igneous complexes that were emplaced mostly as ring dykes into the uplifted basement of the Jos Plateau and surrounding areas of central Nigeria. These rocks consist predominantly of biotite granites and peralkaline granites. The biotite granites are mineralized with cassiterite and columbite and gemstones within albitized zones where the economic minerals occur as disseminations, and greisen veins and quartz stringers in the roof zones of the intrusive rocks (Bowden and Kinnard, 1984). Rich alluvial and eluvial deposits that usually contain some gemstones formed from the unroofing of the granite cupolas. Gemstones found within the Younger Granites occur as primary disseminations or as crystals in miarolitic cavities of greisens and quartz veins. They include aquamarine, beryl, emerald, fluorite, rose quartz, topaz, and amethyst. Crystals of these minerals can be picked up in the dumps associated with tin mining in the Jos Plateau.

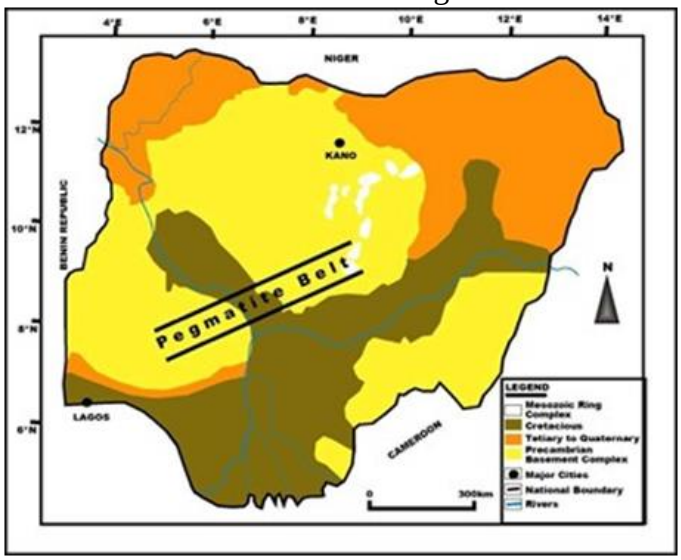

Figure 2: Simplified Geological Map of Nigeria

7. Alkali Basalts

Tertiary to Recent alkali basalts occur in the Jos Plateau, Biu-Mambilla Plateau, Gombe and other parts of the Upper Benue Trough. They are confined to long-established zones of tectonic uplift in the Jos Plateau, and adjacent Benue Trough, extending into the Cameroon volcanic belt in the Bamenda hills (Wright, 1985). Gemstones, particularly blue sapphires and zircon are found within weathered Newer Basalts in the Jemaa area of Kaduna State and the Mambilla Plateau of Taraba State. The sapphire and zircon are believed to be xenocrysts that were engulfed or embedded in the basalt flow and are characterized by euhedral prisms to dull, slightly corroded surfaces and rounded edges (Kanis and Hardman, 1990).

8. Metamorphic Rocks

Approximately 40% of Nigeria is underlain by Precambrian high-grade to low-grade metamorphic rocks, mostly gneisses, migmatites, and schists. Some gemstones found in metamorphic rocks include ruby, and garnets in association with kyanite and sillimanite (Al2SiO5). They are products of the regional metamorphism of impure sediments rich in silica and aluminum.

9. Gemstone Mineralization

9.1 Mode of Occurrence

Gemstones are not very common because the unique conditions that promote their formation

are unusual, and the lithologies 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 (Table 1), 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. Paleoplacer deposits of gemstones can form from the compaction and cementation of alluvial deposits..

10. Types of Gemstone Deposits

Based on the ore-forming processes, gem deposits can be classified into two major types: *primary* deposits and *secondary* deposits.

Primary deposits are formed by the concentration of gem minerals by primary crystallization as a result of magmatic, hydrothermal, and metamorphic processes. Such deposits are found in igneous rocks mostly as disseminations, such as in kimberlites (diamond), lamprophyre dykes (sapphire), alkaline granites and syenites (fluorite, beryl, topaz, emerald, zircon, apatite), pegmatites (garnets, tourmalines, emerald, aquamarine, sapphire, ruby), alkaline basalts (sapphire, zircon, spinel), and hydrothermal veins (beryl, fluorite, amethyst, topaz). Regional and contact metamorphic and metasomatic rocks contain a variety of gemstones including garnets, kyanite, sillimanite, corundum, zircon, sapphire, ruby, spinel, and scapolite.

Secondary deposits are formed by surface weathering and erosion of primary deposits, and concentration of the heavy minerals as eluvial, colluvial, and alluvial deposits. Primary gemstones of high specific gravity and resistance to erosion can accumulate as sedimentary placer deposits. Examples of gems in this category include diamond, corundum, and chrysoberyl, which are minerals with a hardness of 9 or 10 on the Mohs’ scale. Garnets, spinels, and beryl are sometimes found in both eluvial and alluvial deposits not too distant from the source. The majority of diamond and corundum gem (ruby and sapphire) deposits are found as eluvial and alluvial placers.

11. Gem Deposits of Nigeria

11.1 Distribution

The major gemstones found in Nigeria are tourmaline, sapphire, emerald, ruby, amethyst, zircon, topaz, beryl, garnets, fluorite, and other rare stones such as kunzite, phenakite, and tanzanite (Fig. 1). The secondary deposits are the main sources, and usually occur in small quantities that are usually close to the surface, and mined mainly from weathered rocks and/or alluvial sources. Because of their mode of occurrence, they are easily amenable to artisanal and small-scale mining. The states with gemstone deposits include Kaduna, Nasarawa, Plateau, Kano, Bauchi, Taraba, Zamfara, Benue, Kwara, Oyo, Ogun, Osun, Ekiti, Cross River, and Borno States (Fig. 2). However, the leading producers

are Kaduna, Nasarawa, Oyo, and Taraba States (Table 2). Five zones of gemstone mineralization have been identified (Fig. 3). Zone 1 coincides with the NE-SW trending belt characterized by pegmatite sources. This is the zone with most of the gemstone deposits stretching NE-SW from south of Ibadan in the south, through Ife-Ilesha and Lokoja-Egbe to the Keffi-Jemaa area of north-central Nigeria and extending eastwards to the Gombe/Taraba State nexus (Fig. 3). This distribution coincides broadly with the Pegmatite Belt in which the most richly mineralized zone is centered on Jemaa and Keffi-Nasarawa local government areas. Zone 2 is centered on Jemaa-Keffi-Udegi areas of Kaduna-Nasarawa States where the richest gemstone deposits are concentrated, most of which are derived from three combined sources; pegmatites, alkali basalt, and Younger Granites. Zone 3 is defined by the gemstones in the alkali basalts of the Mambilla Plateau in Taraba State. Zone 4 represents gemstone occurrences associated with the Younger Granite complexes in the Jos Plateau and adjoining Kano State. Zone 5 is an outlier in the northwest around Magami-Gusau where small quantities of gemstones are found within pegmatites and metasediments.

12. Gem Minerals

12.1 Tourmaline

Tourmaline is a boron aluminum silicate that occurs in a variety of colors (pink, purple, red, green, blue, blue-green, black, or multicolor). Each color may be given a different name e.g. pink and red (Rubellite), blue (Indicolite), green (Verdalite), blue-green (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 multi-colored varieties, Tourmaline is mined from the weathered rock and alluvials associated with the Older Granite pegmatites 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 (Fig.4a). 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 (Henricu, 2001). 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 reposted 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 pegmatites.

Table 2: Locations of Major Gemstone and Sources

	Gemstone	Locations	Host RockType
1	**Tourmaline**	Nasarawa State (Keffi, Saura, Angwan Mayo, Angwan Tudu, Garaku, Gidan Kadiri, Angwan Doka, Kokona, Jamma, Angwan Lele, Nike, etc.); Oyo State (Idoko, Komu, Itasa, Budo, Are etc.); Osun State (Ife, Ilesha), Kaduna State (Kagarko, Gidan Wayo etc,): Kwara State (Lemo, Ndeji, Ora,Oro etc.): Kogi, Bauchi, Taraba and Osun States	Pegmatite
2	**Sapphire** (Blue Corundum)	Taraba State (Karim Lamido, Gembu, Guroji, Mambilla Plateau): Kaduna State (Antan, Nisama, Gidan Waya, Jemaa); Bauchi State (Bogoro); Plateau State (Bokkos); Yobe State (Gunda, Gilde),Granite/Vein Adamawa State (Ganye); Gombe State	Alkali Basalt
3	**Aquamarine** (Blue Beryl)	Akwanga, Nasarawa, Jenta, Igwo, Rafin Gabas, Agwada (Nasarawa State); Okene, Isanlu (Kogi State); Ijebu Ibadan, Igbo-Ora (Oyo State), Ijebu-Igbo (Ogun State), Jos Plateau (Plateau	Pegmatite Granite/Vein
4	**Emerald** (Green Beryl)	Gwantu (Kaduna State); Keffi, Nasarawa Eggon (Nasarawa State): Adavi (Kogi State): Jos Plateau	Pegmatite
5	**Ruby** (Red Corundum)	Jos-Bauchi; Komu (Oyo State); Ife-Ilesha (Osun State)	Pegmatite
6	**Amethyst** (Quartz)	Bauchi State; Kaduna State; Kano State; Oyo State; Nasarawa State	Pegmatite Granite/Vein
7	**Topaz**	Jenta, Akwanga (Nasarawa State); Jos (Plateau State); Bauchi State,: Oyo State	Granite/Vein Pegmatite
8	**Zircon**	Taraba State (Karim Lamido, Gembu, Guroji, Mambilla Plateau): Plateau State (Jos-Bukuru, Kigom, Ropp) and Nasarawa State (Rafin Gabas):Oyo State (Komu).	Alkali Basalt Granite/Vein Pegmatite

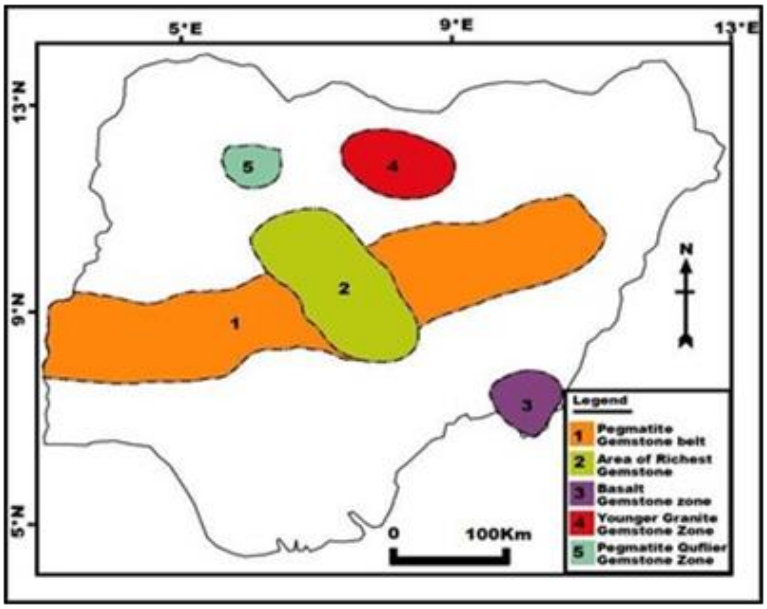

Figure 3: Distribution of gemstones in Nigeria

Figure 4: (a) Paraiba Tourmaline (b) Paraiba Tourmaline, Oyo State (c) Indicolite, Ile-Ife, Oyo State

(d) Purple Tourmaline (e) Rubellite, Oyo State (f) Ofiki Pink Tourmaline (g) Ife Green tourmaline

Geochemical studies of Paraiba tourmalines from Nigeria, Brazil, and Mozambique (Okrusch et al, 2016) show that most of them contained significant amounts of Cu, Mn, or a combination of both elements. The Nigerian samples contained 0.48–3.20 wt.% CuO and 1.70–6.06 wt.% MnO while the Cu and Mn contents of most Mozambique samples were lower than in samples from Nigeria and Brazil. There was no clear-cut correlation of the Cu and Mn contents with coloration. The blue color was in most cases due to Cu2+ (Okrusch et al, 2015). Pink and violet coloration (due to Mn3+) was shown by Mn-bearing tourmalines that contained no significant Fe. Green color in the Nigerian tourmaline was most probably due to a combination of Mn, Cu, and Fe. Some of the green samples from Brazil contained up to 0.6 wt.% V2O3 (Katsurada and Sun, 2019). Among the trace elements that show enhanced concentrations are Pb (up to 4,000 ppm) and Bi (up to 2,900 ppm). The price of Paraiba tourmaline varies considerably depending on the color, size, crystallinity, and source country. The most expensive variety of the beautiful and rare Paraiba Tourmaline can fetch $10,000 per carat and upwards depending on size and color saturation while smaller yellows may sell at $50 per carat.

12.2 Sapphire

Sapphire (royal blue corundum) is a precious stone that is usually of blue to deep blue, but with bluish-green and yellow varieties. It is probably the most valuable gemstone found in Nigeria today. Since 1984, Nigeria has emerged as a major producer of sapphires in Africa. Significant deposits are known from the Mambilla Plateau in Taraba State and Jemaa (Antan, Nisama, Gidan Waya) in Kaduna State where sapphire in both localities are retrieved from secondary deposits of weathered alkali basalts and related alluvial deposits (Fig. 5). Other known occurrences are in Gombe (Gombe State), Bauchi State (Bagoro), Plateau State (Bokkos), Yobe State (Gunda), and Adamawa State (Katsurada, 2017). These occurrences are all connected with Cenozoic alkali basaltic progeny where the gemstone occurred as xenocrysts in lavas derived from the mantle or deep in the crust.

Nigerian sapphires are described as primarily dark blues and bluish-greens (teal), mostly of

small size but of excellent clarity (Fig. 6a). Yellow, yellowish-green (bicolor) and green varieties have been reported from Gombe and Antan (Fig. 6c). In recent years, more high-quality, deep blue sapphires are being mined from Kaduna State and recognized for having an attractive size, high clarity, good color, and strong crystal habit (Pardieu et al, 2014). Overall, the quality of Nigerian sapphire is reflected in its color and crystallinity, ranging from rich indigo blue to well-shaped crystals of rich blue color to pale green variety. Most Nigerian sapphires have a distinct color zoning and show a flat prismatic habit. Although most sapphires range in colors from dark blue to fine blue, other varieties of green, yellow and bi-colors sapphires are also known (Kiefert and Schmetzer, 1987).

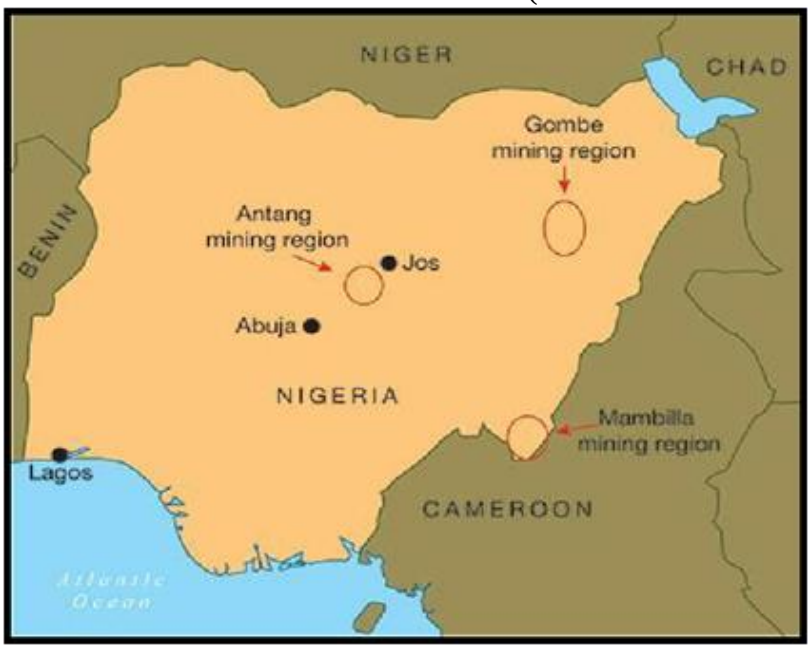

Figure 5: Location of major sapphire mining sites in Nigeria

Fig. 6: (a) and (b) Blue Sapphire, Mambilla Plateau (c) Yellow/Blue Sapphire, Antan

Small-scale mining of sapphire deposits is a viable economic activity among artisanal miners in the States of Borno, Kaduna, Taraba, Gombe and Bauchi. In the small town of Antan in Jemaa local government area in the southwestern corner of Kaduna State, the first commercial sapphire mining site was established in 1980, although some members of the local population have been engaged in gem extraction for several years in the area. According to Kanis and Harding (1990), the first sapphires were discovered in Antan by a tin mining company, but the company ceased operations after a few months. Most of the sapphires found were too dark to market at that time and the commercial

heat-treatment of sapphires was still unknown. Sapphires reported to be from this area excavated by artisans appeared in the gem market in 1974. Production seems to have increased considerably from 1984 onwards although no statistics of production are available as practically all sapphires have been smuggled. The Antan site isstill producing high-quality sapphires today in good quantity. The source rocks of the gems are decomposed Newer Basalts that occur over large areas in the northern part of the Jemaa local government area. Sapphires from the Mambilla Plateau in Taraba State have been known since the 1980s, and two areas containing deposits are mined at Gembu and Guroji, both in the Sardauna local government area of Taraba State. The deposits at Gembu near the Cameroun border have been mined for a long time and the stones produced were generally small and deep blue in color but of good form. However, the deposit near Guroj, a small village about 30km northwest of Gembu is a relatively recent discovery where the most recent sapphire mining sites were established in about 2013 (Pardieu et al, 2014). The deposit is located in decomposed alkali basalt extending for over 2 km along a stream valley within a rolling hilly terrain. The Mambilla sapphires from near Guruji are slightly different from Gembu gems in their predominantly light blue color, larger size, and the presence of several tabular and prismatic crystals. Most of the stones that are discovered here are of very high quality, very transparent, and with desirable cut sizes. They are beginning to be considered as some of the most beautiful sapphires by gemologists.

Fig. 7: Blue-green Aquamarine, Nasarawa (b) Aquamarine crystal, Jos (c) Aquamarine, Okene

12.3 Aquamarine

Aquamarine is a light blue (sea blue) to green-blue variety of beryl. It was the first gemstone of commercial importance from Nigeria to gain worldwide recognition in the gem market because of its natural and cool light blue color and clarity. Top-grade quality occurrences found in pegmatites have been mined at several localities in central and southwestern Nigeria including Nasarawa State (Akwanga, Nassarawa, and Jenta, etc.) (Fig. 7a), Oyo State (Ibadan, Igbo-Ora), Kogi State (Isanlu, Okene) (Fig. 7c), 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 (Fig. 7b) (Kanis and Harding, 1990). 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 (Palke and Haperman, 2019). The pegmatites around

Okene and Ajaokuta in Kogi State have also yielded aquamarine gems that are bright medium blue with a green tint (Fig. 7c).

12.4 Emerald

Emerald, a variety of beryl, is one of the most well-known and desired precious colored gemstones. It is colored bright green due to trace amounts of chromium and sometimes vanadium. Emerald is found in theweathered pegmatites at Nasarawa Eggon (Fig. 8a), and Keffi (Nasarawa State), and Gwantu in Kaduna State (Fig. 8c). The produced quantities of emerald from the two deposits are quite small, and reserves are limited (Schwartz, et. al, 1996). 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 (Hanni, 1992), and the bluish tinge has been attributed to some Fe impurities while the greenish color is attributedto 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.

Fig. 8: (a) and (b) Light green Emerald, Nasarawa Eggon (c) Green Emerald, Gwantu, Kaduna State

12.5 Garnets

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. The most common garnet gemstone is almandine which is red in color (rhodolite), spessartite (or spessartine) which is orange or mandarin in color, and grossularite which is mint green. There are blue and yellow varieties and blends of colors reflecting variations in chemical composition. Different varieties of garnets have been found in different parts of Nigeria. Rhodolite garnet is mined extensively around the Jos-Bauchi axis (Fig. 9a). A recent find of spessartite garnet in the Komu area of Oyo State has produced very good gems with colors varying from orange-brown to orange. The bright orange or reddish-orange spessartite is one of the most brilliant gems in the world. In terms of chemical composition, spessartite is a manganese aluminum silicate, and manganese content gives this gem its distinctive orange color

(Fig. 9b). Although the Nigerian spessartite occurrences are not as pure orange as the Namibian Mandarin orange garnets, they tend to be larger, are cut better, have more brilliancy, and are cleaner. The spessartite garnet occurrences are found in small alluvial deposits associated with granitic pegmatites. Unfortunately, the spessartine deposits were shallow and have been worked out and supplies have dwindled, while prices have risen. Rhodolite garnet is mined extensively in the eluvial and alluvial concentrations derived from Precambrian pegmatites in the Jos-Bauchi areas.

Fig. 9: Red Garnet (Rhodolite), Jos-Bauchi (b) Orange Garnet, Spessartite, Oyo State

12.6 Topaz

Topaz is a popular gemstone that occurs in a wide variety of attractive colors, but the most available colors in Nigeria are white and blue(Fig. 10). Nigeria is one of the major sources of white topaz to the International Gem Market. Several deposits are being mined from eluvial and alluvial sources associated with the granitic pegmatites and Younger Granites. Locations from which topaz is mined include Rafin Gabas, Jenta, and Akwanga in Nasarawa State; Jos and Jarawa in Plateau State, Koi in the Nok area, and in many parts of Bauchi, Kaduna, Kebbi, and Oyo States. In Rafin Gabas, near Keffi, white to pale blue topaz (Fig. 10c) occurs with aquamarine in quartz stringers and thin layers within the Afu biotite granite cupola. In the pegmatites, topaz is found within druse cavities around Akwanga (Kanis and Harding, 1990). Some of the white topaz are so clear and glistering that they can pass as a "fools" diamond (Fig. 10a).

Fig. 10: (a) White Topaz (b) Yellow Topaz (c) Blue Topaz

12.7 Amethyst

Amethyst (purple quartz) occurs in large quantities and mined in Nassarawa, Bauchi, Kaduna, Plateau and Oyo States where it is associated with the Younger Granite complexes, and the Older Granite pegmatites respectively. Nigerian amethyst is of very high quality and comes in a variety of colors, in hues of purple, and from pale to deeper colors (Fig. 11). Major localities are around Toro and Ningi (Bauchi State), Baade (Kaduna State), Jalingo (Taraba State) and Igbeti (Oyo State).

12.8 Zircon

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 pegmatites 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 ($LiAl(SiO_3)_)$), 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.

Fig. 11: (a) Blue Amethyst (b) Amethyst from Jalingo (c) Amethyst, Jos Plateau

Figure 12: (a) Zircon, Jemaa (b) Red Zircon, Mambilla (c) Kunzite Zircon

12.9 Other Gemstones

Other gemstones that have been reported in Nigeria include fluorite, rose quartz, turquoise, and other rare gems of scientific interest such as phenakite,goshenite (colorless beryl), kunzite, ruby, morganite (pink beryl), and tanzanite (Fig. 13). With the exception of tanzanite, these are all beryllium minerals.

However, no diamonds have been found or any reports confirmed although there are speculations that they do exist based on wrong identification or false claims of gem dealers. The geotectonic setting of Nigeria does not lie within the old cratons where most of the world's diamond-bearing kimberlites were emplaced.

Figure 13: (a) Goshenite (b) Phenakite (c) Morganite

13. Gemstone Mining

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. Gemstone mining is mostly informal, and operated by individuals, family members or rarely as organized partnerships or cooperatives. Rarely is there hard-rock mining because of the pervasive and intense lateritic weathering that produces thick regoliths of decomposed rock amenable to eluvial mining. Alluvial deposits in the banks of rivers and their terraces are also exploited by digging and pitting.

Loose weathered rock fragments and alluvial sands and gravel are excavated from pits in which several miners could be excavating in one pit. They sometimes descend 5 to 20 meters into the pits by ladder and rope, and when they hit the gem-bearing bedrock at depth they may be required to blast and tunnel before extracting the gems. Some larger open-pit excavations may use mechanical equipment to dig and remove ore materials. Women play important roles in the

mining of gemstones. The pits and excavated heaps are subsequently abandoned, creating environmental hazards for the local farmers.

The best gemstones are found in Kaduna, Oyo, Nasarawa, Plateau, and Taraba States (Figs.14-16). 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. Nigeria loses a lot of revenue from the gemstone industry due to a lack of regulatory control, organizationand monitoring. Tourmalines, sapphires, and emeralds from Nigeria are admired all over the world and some perfect stones have yielded millions of dollars per piece. Mining and selling of gemstones is a lucrative business in Nigeria and the Federal government and other stakeholders need to organize and regulate the gemstone industry to the benefit of all Nigerians.

Adesugba and Hoon (2018) 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 recommendations for implementation so that the gemstone industry can contribute its rightful share to the country's Gross Domestic Product (GDP).

Fig. 14: Mining of aquamarines in the Younger Granites, Rafin Gab

Figure 15: (A) Artisanal Tourmaline mining, Kaduna (b) Mining gemstones in placer deposits, Jos Plateau

Figure 16: Mining of Sapphire at Guruji, Mambilla Plateau

14. Discussion of Provenance and Origin

Most primary gemstone deposits are formed by igneous, hydrothermal or metamorphic processes that originate at elevated temperatures and pressure deep within the earth's crust or upper mantle. Some of the attractive features found in gemstones such as their crystal form, habit, and luster can be attributed to the unique physical and chemical environments in which they are formed. For example, diamond and some sapphire are only known to crystallize at great depths within the mantle under conditions of high temperature and pressure. While gemstones in pegmatites may have formed at relatively lower temperature and pressure, the chemical environment of volatile-rich residual fluids with enriched trace elements may have provided conditions conducive to the formation of coarse and colorful gemstones. The provenance or source of gemstones, if reliably identified, can serve as good indicators of their origin and processes of formation. As summarized in Table 3, there are three main source rocks of Nigerian gemstones: (1) Pan African granitic pegmatites, (2) Jurassic alkaline granites, and (3) Cenozoic alkali basalts. These three groups of rocks have

certain characteristics in common; (a) they seem to originate from magmas that are relatively rich in some alkali elements such as Na, K and Li, (b) show evidence of late magmatic sodic metasomatism (Olade, 1978; Olade, 1980; Olade and Emeforieta, 1988); and (c) the emplacement of the magmas are 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. These regional tectonic events have some connection with the mantle and/or lower sialiccrust.

The granitic pegmatites associated with the Older Granites are the sources of a variety of Nigerian gemstones including the Paraiba tourmaline, emerald, aquamarine, amethyst, ruby, garnets, and topaz. Also, as a result of the very coarse texture of the granitic pegmatite due to slow cooling in a vapor bubble, large crystals of excellent quality gemstones are able to form. The Nigerian pegmatites are also major sources of cassiterite and tantalite, and are enriched in Li, Rb, Cs, and REE (Okunola and Ocan, 2009) and belong to the Lithium, Cesium Tantalum (LCT) family of pegmatites (Okunlola, 2008). Crystals of Li minerals lepidolite, spodumene, and kunzite have been extracted from the pegmatites. Okunlola and Ocan (2009) studied the compositional variations in the pegmatites from the gemstone and tin producing area of Keffi, Nasarawa State, and found that they are enriched in Li, Rb, Be, REE, Sn-Ta and other alkali elements accompanied by sodium metasomatism This is consistent with the common occurrence of various beryllium minerals including emerald and aquamarine. Sodic (Na) metasomatism characterized by pervasive albitization is one of the common features of the Nigerian "mineralized" pegmatites during the medium to late phases of crystallization (Okunl0la and Oyedokun, 2009). Tourmalinization containing black tourmaline (schorl) is common in many of the pegmatite localities that I have visite d(Jacobson and Webb, 1946). Some vug-filling in druse cavities that occurred during the waning phase of pegmatite crystallization has produced some coarse-grained and beautiful gems of minerals such as amethyst, rose quartz, geode,beryl, spodumene, lepidolite, and kunzite.

The Nigerian Paraiba (copper bearing) tourmaline is believed to have formed by direct crystallization from a vapor-rich residual granitic melt containing significant boron and lithium with elevated concentrations of copper and other elements during the early to medium phases of pegmatite crystallization. Some of the world's best gemstones are associated with pegmatites formed from residual solutions connected with granitic intrusives. The similarities between the composition of Nigerian and Brazilian Paraiba tourmaline viz-a-vis the Madagascar variety (Katsurada and Sun, 2019) may indicate their geographic connection prior to continental drift and fragmentation of Godwanaland. The origin of the Nigerian granitic pegmatites is controversial although they are known to be spatially and temporally associated with the Older Granites emplaced during the waning phase of the Pan-African thermo-tectonic event. The sources of the Older Granite and pegmatite magmas have been studied by various workers including Matheis (1987), and Rb/Sr isotopic study (Matheis and Caen-Vachette, 1983). The pegmatites are enriched in lithophile elements and more fractionated than the parent granites. The Older Granite magma with initial Sr isotopic ratios of 0.7155 to 0.7233 are believed to have mixed with ancient crustal material while the pegmatites with initial Sr ratio of 0.7678 are believed to have originated from extreme fractionation of Older Granite magmas, derived from partial melting of crustal materials (Kuster, 1990; Akintola and Adekeye, 2008).

The Jurassic Younger Granites of the Jos Plateau comprise several complexes of high-level intrusive rocks that formed as ring dykes sometimes accompanied by explosive alkaline volcanism. They form the southern part of a 500 mile long, N-S trending alkaline igneous complexes emplaced in a region of tectonic uplift

related to hot-spot, mantle plume activity connected with the Cretaceous continental breakup of Godwanaland (Bowden, 1970; Bowden et al, 1976). The peraluminous albitized biotite granites of the Younger Granite complexes are well known as sources of primary and related secondary deposits of cassiterite and columbite (Olade,1980), and hydrothermal greisenized veins of quartz-cassiterite and wolframite (Olade and Ekwere, 1984). The peralkaline granites, on the other hand, contain pyrochlore and zircon crystals. Albitization is a common metasomatic effect in the mineralized biotite granites. The Younger Granites and associated mineralization are believed to be a combination of mantle and crustal origin. The occurrence in the same general area of Central Nigeria and presence of similar mineralization in both the Older and Younger Granites has led to the suggestion that some of the Younger Granites might be products of partial melting of the Older Granites (Bowden, 1970; 1982).

The Cenozoic alkaline basalts in the Jos Plateau and Mambilla Plateau of central and northeastern Nigeria are the sole sources of commercial sapphire deposits in Nigeria. These volcanic rocks have alkaline affinities and are confined to long-established zones of tectonic uplift in the Jos Plateau, Benue Trough, and extending into the Cameroon volcanic belt in the Bamenda hills (Wright, 1985). Turner (1971) subdivided these rocks into three groups: lateralized Older Basalts, Older Basalts, and the Newer Basalts. In the Jos Plateau, these volcanic rocks belong to both the Older Basalts, and Newer Basalts. In the Mambilla Plateau, the Newer Basalts are predominant. Only the Newer Basalts contain sapphire and zircon xenocrysts. The sapphire gems are very coarse megacrysts within very fine-grained host rocks. They are interpreted as xenocrysts that crystallized deep in the mantle and transported to the surface as inclusions by non-explosive basaltic lava flows. The outpouring of Miocene- Quaternary alkali basalts and trachytes in the Biu-Mambilla Plateau, extending eastwards into the outpouring of 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 incipient continental rifting (Olade, 1978). This is consistent with the view that these volcanic rocks and the associated gemstones were probably formed in the mantle or in the lower crust above a mantle plume (Coloum et al, 1996).

15. 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 (pegmatites, 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 (Olade, 2020). Reforms and regulations should be implemented to encourage local investment and create employment for youths within the local communities from where the gemstones are extracted. The upstream and downstream gemstone supply pipeline should be monitored to block serious leakages that affect production, processing and marketing.

Table 3: Source rocks, origin, and gemstone forming processes

	Gemstone	Source Rocks	Origin	Processes
1	Tourmaline	Granitic Pegmatite	Synorogenic Magmatism	Late Stage Fractional Crystallization
2	Sapphire	Alkali Basalt	Continental Rift Volcanism	Xenocrysts in Basaltic Lavas
3	Aquamarine	Granitic Pegmatite Granite/Vein	Synorogenic Magmatism Anorogenic Magmatism	Late Stage Fractional Crystallization Metasomatic and hydrothermal
4	Emerald	Granitic Pegmatite Granite/Vein	Synorogenic Magmatism Anorogenic Magmatism	Late Stage Fractional Crystallization Metasomatic and hydrothermal
5	Spessartite Rhodolite Garnets	Granitic Pegmatite Metasediments	Synorogenic Magmatism Regional metamorphism	Late Stage Fractional Crystallization Metamorphism of Mn-rich sediments
6	Topaz	Granitic Pegmatite Granite/Vein	Synorogenic Magmatism Anorogenic Magmatism	Late Stage Fractional Crystallization Metasomatic and hydrothermal
7	Amethyst	Granite /Vein Granitic Pegmatite	Anorogenic Magmatism Synorogenic Magmatism7	Metasomatic and hydrothermal Late Stage Fractional Crystallization
8	Zircon	Alkali Basalt Granite	Continental Rift Volcanism Anorogenic Magmatism	Xenocrysts in Basaltic Lavas Metasomatic and hydrothermal

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