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GEOLOGICAL AND MINERAL RESOURCE EVALUATION OF THE UPPER BENUE TROUGH, NORTHEASTERN NIGERIA

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Abstract: The Upper Benue Trough, a sedimentary basin in northeastern Nigeria, holds significant geological and economic importance. Formed during the Cretaceous rift phase of the West and Central African Rift System (WCARS), the trough comprises of the Bima Sandstone Formation, Yolde Formation, and Pindiga Formation which has a total thickness of 6,000 meters of sedimentary rocks. Mineral deposits, including lead, zinc, barytes, gold, chromium, Uranium, and coal occur extensively throughout the region. Uranium, lead, zinc, and barytes deposits, particularly, exhibit potential for economic exploitation due to their diverse applications in energy storage, construction, manufacturing, and medical uses. This study provides an overview of the geology, tectonic evolution, and mineral resources of the Upper Benue Trough, highlighting its prospects for contributing to Nigeria's economic growth and development.

Keywords: Upper Benue Trough, Nigeria, geology, mineral resources, lead, zinc, barytes, Uranium economic prospects.

1.0 INTRODUCTION

Nigeria is located in West Africa, within the African Continental Plate. The country's geology is characterized by three major geological units; precambrian basement complex which covers approximately 60% of Nigeria, and comprising ancient rocks (over 540 million years old) of gneisses, schists, and granites, younger granite province which covers about 20% of Nigeria, comprising granitic rocks (around 500 million years old) formed during the Pan-African orogeny, and Sedimentary Basins which covers approximately 20% of Nigeria, comprising sedimentary rocks (from Cretaceous to Recent) deposited in various basins. The Benue Trough extends from the Niger Delta in the south to the Chad Basin in the northeast, and from the Anambra Basin in the southwest to the Cameroon border in the southeast and it is characterized by fault controlled subsidence, sedimentation and volcanic activity.

This vast trough accommodates up to 6,000 meters of sedimentary layers from the Cretaceous to Tertiary periods. The older layers, predating the mid-Santonian era, have undergone intense compressional folding, faulting, and uplift in various locations. A significant tectonic event during the Mid-Santonian period caused widespread compressional folding, resulting in over 100 anticlinal and synclinal structures (Benkhelil, 1989). Notable

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examples include the Abakaliki anticlinorium and Afikpo syncline in the lower reaches, Giza anticline and Obi syncline in the middle section, and Lamurde anticline and Dadiya syncline in the upper sector. Following the MidSantonian tectonic activity and magmatic events, the depositional axis shifted westward, causing subsidence in the Anambra Basin. The Benue Depression is conventionally divided into lower, middle, and upper sections, lacking distinct boundaries. Key localities (towns/settlements) within these sections have been well-documented (Petters, 1978). Depocenters in the lower section encompass Nkalagu and Abakaliki, while those in the Anambra Basin center around Enugu, Awka, and Okigwe.

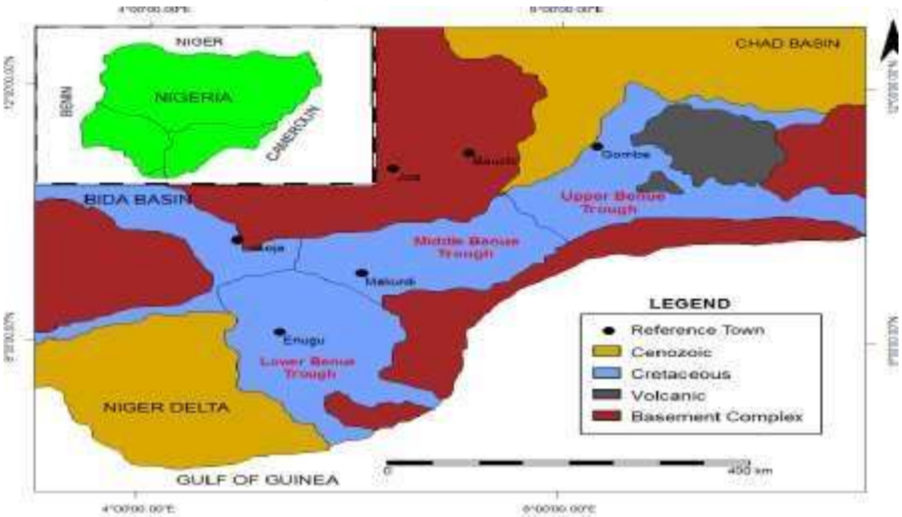

Fig. 1: Map of the Benue Trough showing it's major divisions (Obaje, 2009).

1.1 Geological Units of the Upper Benue Trough (Obaje, 2009).

The Upper Benue Trough is characterized by a complex geological setting, with sedimentary rocks overlaying Precambrian basement rocks (Obaje, 2009). The sedimentary sequence includes:

1. Bima Sandstone (Albian age): coarse to medium-grained sandstone
2. Yolde Formation (Cenomanian-Turonian age): shale, mudstone, and sandstone
3. Pindiga Formation (Turonian-Senonian age): limestone, shale, and sandstone
4. Lafia Formation (Paleocene-Eocene age): shale, mudstone, and sandstone

Table 1: Stratigraphy Successions of the Upper Benue Trough (Fatoye and Gideon, 2013)

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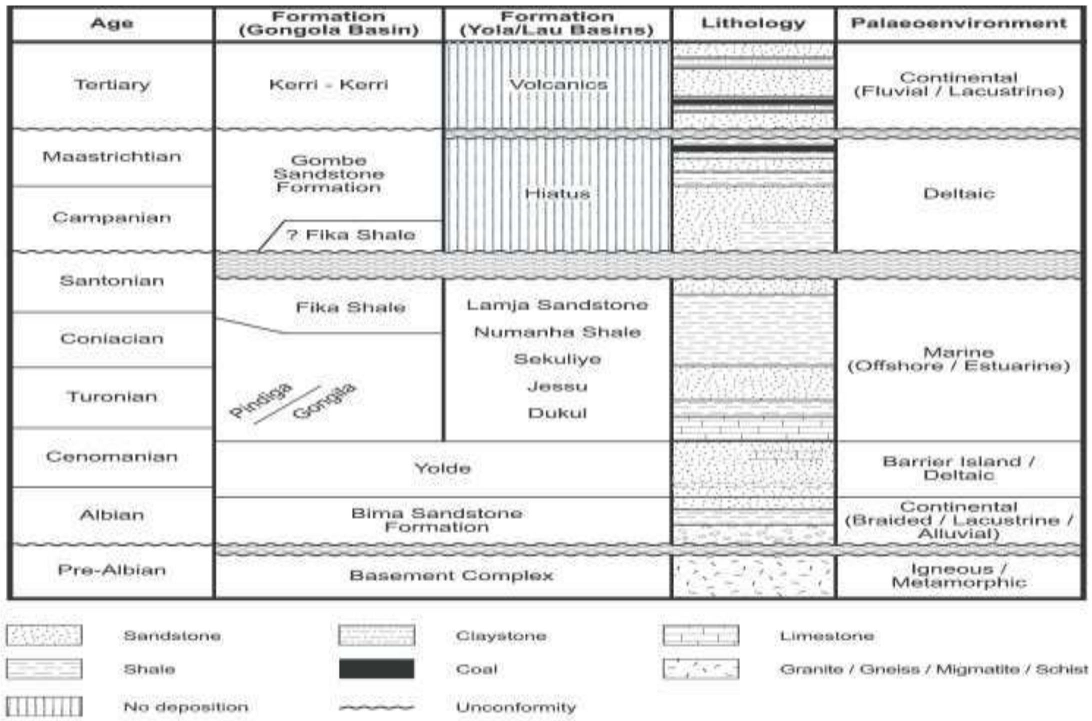

2.0 ORIGIN OF THE UPPER BENUE TROUGH

The Benue Trough's origin has been shrouded in uncertainty, with numerous theories and hypotheses emerging over the years. Initial observations suggest an abandoned rift structure. However, the lack of prominent rift faults along its margins and widespread folding of Cretaceous sediments pose a puzzle.

Researchers have linked the Benue Trough to the Atlantic Ocean's opening, proposing it as the third arm of a triple junction beneath the Niger Delta. Early models (Burke et al., 1970, 1971) drew parallels with similar structures like Afar, suggesting new oceanic crust formation beneath the Abakaliki Trough.

Key evidence supporting this hypothesis includes:

1. Silar gravity profiles between the Benue Trough and Central Red Sea depression.
2. Magnetic anomaly stripes beneath the Niger Delta, parallel to the Benue Trough's trend.

Later models (since 1980) shifted focus from plate tectonics to field geology and structural analysis (Benkhelil, 1982, 1986; Benkhelil and Robineau, 1983; Allix, 1983; Maurin et al., 1986).

Understanding the Benue Trough's origin requires a comprehensive grasp of its:

1. Tectonic framework.
2. Thermal history.
3. Geological and geophysical factors.

The Upper Benue Trough is a sedimentary sub-basin located in northeastern Nigeria, extending into neighboring Cameroon and Chad (Akande et al., 2012). It is a Cretaceous inland basin formed during the rift phase of the West and Central African Rift System (WCARS) (Genik, 1993). The Upper Benue Trough comprises the area extending from Bashar-Mutum Biyu line as far north as the "Dumbulwa-Bage high" Which separate it from the Bornu Basin, Zaborski et al. (1998). The Upper Benue Trough was significantly restructured by a Late Cretaceous deformation by causing widespread uplift and upward arching of the basin, especially along its long axis (Avbovbo et al., 1986). Thus compressional forces created an elongate, northeast-graben system reminiscent of the Santonian events of the southern Benue Trough. The deformation resulted in the formation of lowfrequency fold trending northeast-southwest and parallel to the long axis of the trough. The active rifting in the Upper Benue Trough is characterized by highly active crustal faults creating the rift, subsidence is very rapid, sediments accumulate quickly and are typically fan/fluvatile in nature and there in much lithofacies variation. Such sediment occurs in the basal part of the sedimentary succession in the Upper Benue Trough and are typified as the "Lower Bima Sandstone". The Upper Benue Trough is divided into two.

1. The East-West trending Yola basin (Yola arm): This arm is oriented east-west and is believed to have formed as a result of wrench tectonics, characterized by pull-apart basin features (Braide, 1992). The Yola Basin is filled with continental sediments, including the Bima Sandstone.
2. The North-South trending Gongola basin (Gongola arm): This arm is oriented north-south and is also part of the Upper Benue Trough's rift system. The Gongola Basin is characterized by active rifting, rapid subsidence, and sediment accumulation.

Both arms are significant components of the Upper Benue Trough, providing valuable insights into the region's geological history and tectonic evolution.

2.1 Tectonic Setting

The WCARS is a zone of extensional tectonics that formed during the break-up of the Supercontinent Gondwana (Unrug, 1993). The rift system is characterized by, Crustal thinning and subsidence, Faulting and volcanism, and Sedimentation and basin formation. These characteristics also determines how the various phases in it's origin manifested.

2.1.1 Rift Phase (Cretaceous)

The Upper Benue Trough formed during the rift phase, which lasted from the Early Cretaceous to the Late Cretaceous (Akande et al., 2012). This phase was characterized by:

1. Faulting and subsidence.
2. Sedimentation of Bima Sandstone and Yolde Formation.
3. Volcanic activity and intrusion of dykes.

2.1.2 Sag Phase (Cretaceous-Paleogene)

Following the rift phase, the Upper Benue Trough underwent thermal subsidence, resulting in the sag phase (Akande et al., 2012). This phase was characterized by:

1. Continued sedimentation of Pindiga Formation and other units.
2. Decreased faulting and volcanic activity.
3. Formation of structural traps for hydrocarbons.

2.1.3 Inversion Phase (Neogene-Quaternary)

The Upper Benue Trough experienced compressional tectonics during the Neogene-Quaternary, resulting in the inversion phase (Samaila et al., 2006). This phase was characterized by;

1. Folding and faulting
2. Uplift and erosion
3. Reactivation of older faults

There are several key players one must consider when discussing the origin of the upper benue trophy and they include;

1. **African plate**: The African plate's motion played a significant role in the trough's formation.
2. **South American plate**: The South American plate's motion influenced the opening of the South Atlantic Ocean.
3. **Central African shear zone**: The Central African shear zone affected the trough's geometry.

3.0 GEOLOGY OF THE UPPER BENUE TROUGH

The Benue Trough is regarded as an aulacogen basin within the central West Africa that stretches NNE–SSW for about 800 km in length and 150 km in width. The Gombe Formation which directly underlies the Kerri-Kerri Formation is made up of a mixture of sands, shales, clays and coals. Its type locality is Gombe. The area covered by the Formation is generally lowlying with some dissected ridges scattered sporadically across the area.

The Upper Benue Trough contains up to 6000 m of Cretaceous – Tertiary sedimentary rocks, of which those pre-dating the mid-Santonian have been folded, faulted and uplifted. The Upper Benue Trough can be subdivided into the east–west trending Yola Basin (or “Arm”) and the north–south trending Gongola Basin. Guiraud (1990) and Dike (2002) identified a third basin, the NE – SW trending Lau Basin or Main Arm. Reviews on the geology of the Benue Trough, and particularly the Upper Benue Trough, have been presented by Petters, 1982; Benkhelil, 1982; Dike, 1993, 2002; Obaje, 1994; Zaborski et al., 1997; and Zaborski, 2000, 2003.

The stratigraphic succession in the Upper Benue Trough is illustrated in Fig. 2. The oldest sediments consist of continental deposits of the Late Jurassic to Albian Bima Formation which rest unconformably on Precambrian basement rocks. The Bima Formation is conformably overlain by the Cenomanian continental to marine Yolde Formation, which consists of sandstones and shales at the base, and sandstones, shales and calcareous sandstones above. The formation is overlain by contemporaneous marine successions of the Pindiga and the Gongila/Fika Formations in the Gongola Basin, and their lateral equivalents (Dukul, Jessu, Sekuliye, Numanha and Lamja Formations) in the Yola Basin. Zaborski et al. (1997) proposed that the Pindiga Formation consists of five members in the Gongola Basin. The youngest Cretaceous sedimentary rocks in the Upper Benue Trough are restricted to the Gongola Basin, and are represented by the lacustrine to deltaic Gombe Formation which unconformably overlies the pre- mid–Santonian sequences in some places. The continental sandstones, siltstones and shales of the Paleogene Kerri – Kerri Formation mark the end of sedimentation in the Upper Benue Trough.

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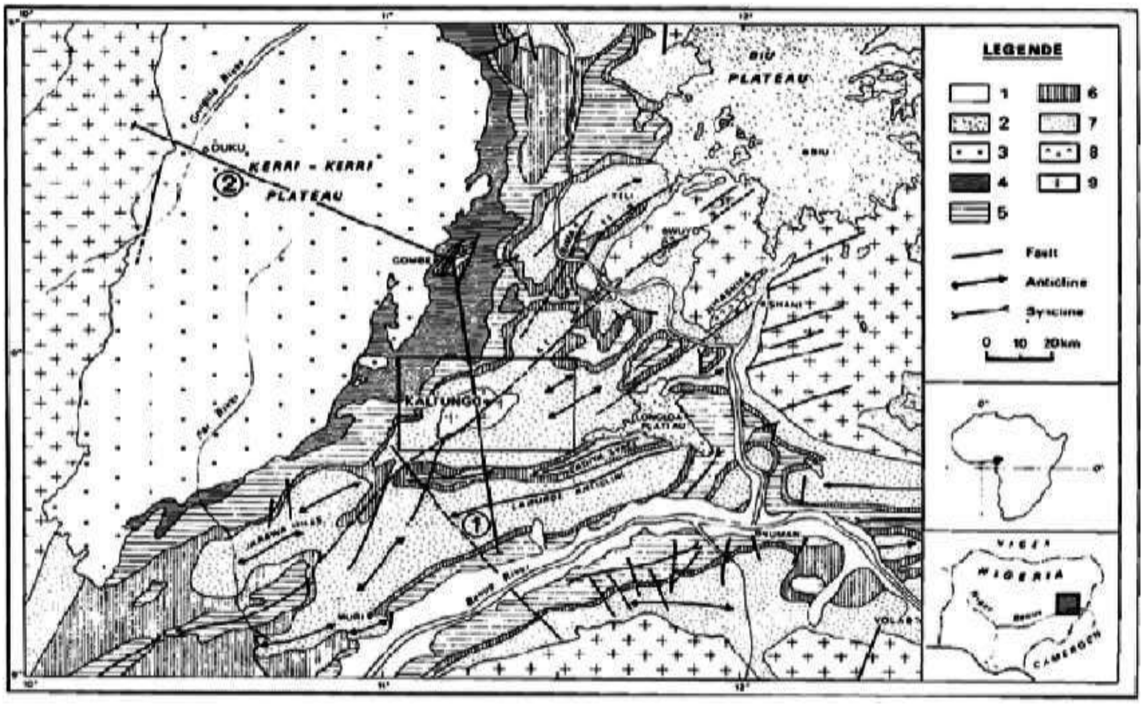

Fig 3. Simplified geological map of the Upper Benue Trough showing its stratigraphy and the structural elements. [1: Quaternary alluvium; 2: Tertiary volcanic; 3: Kerri-Kerri Formation; 4: Gombe Formation; 5: Pindiga Formation; 6: Yolde Formation; 7: Bima Sandstone; 8: Burashika Complex (Mesozoic volcanism); 9: Undifferentiated Basement Complex] (After Benkhelil, 1989)

3.1 Mineral resources of the Upper Benue Trough

These minerals play a crucial role in Nigeria's economy, providing raw materials for various industries, generating revenue, and creating employment opportunities. Most of these minerals occur in association with several other and has to be processed after securing the ores from the mining sites.

Table 2. Minerals in the Upper Benue Trough, their location and uses.

Minerals	**Locations**	**Uses/Economic importance**	**Reference**
Lead; (galena (PbS) and cerussite (PbCO3)).	Benue and Taraba state within the Yolde, Pindiga, and Gongila/Fika Formations.	1. They are mostly used in making batteries for which Nigeria's lead reserves is more than capable of	Obaje, 2000

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		supporting the growing demand for renewable energy. 2. It is also used in making ammunition, radiation shielding, and pigments.	
Uranium; (uraninite (UO_2) and carnotite ($K_2(UO_2)_2(VO_4)_2$)).	Gubrunde Horst area of the Northeast region in Adamawa State.	1. Uranium is a key component in nuclear power generation which is now explored by Nigeria to address the electricity challenges. 2. It is also used in production of radiation shielding, radioisotope for medical application and for research purposes.	
Gold (Au)	Adamawa State (mayo belwa,fufore areas) and Bauchi State (Toro, kirfi areas).	1. Gold is a valuable export commodity and a vital source of revenue for Nigeria. And it is used in making jewelry, coins, electronics, and	Dike, 2002

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		central banks' reserves..	
Coal; sub-bituminous to bituminous rank.	Found in Gombe and Lamja Formation	1. It provides energy security for it host nation. 2. It is used in various industrial process like cement production, steel manufacturing, textile production. 3. It contribute to the economy through generation of jobs and revenue.	Carter et al 1963, P.89
Chromium; chromite ($FeCr_2O_4$).	It can be found in Kaduna, Bauchi state (Gongola arm)	1. It is used for Stainless steel production, refractory bricks, and leather tanning. Chromium is essential for Nigeria's steel industry and export market.	Dike, 2002.
Zinc; sphalerite (ZnS) and smithsonite ($ZnCO_3$)-**Barites;** barium sulfate ($BaSO_4$).	They are found in Bima and Yolde Formation around Adamawa and Taraba states respectively.	1. Zinc is used for galvanization, brass production, batteries, agriculture as fertilizer, and in	

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		construction (roofing). 2. Barites is used as a weighting agent in drilling fluid to prevent blow out. It is also used in glass, ceramics, paints, and for radiation shielding.	

4.0 CASE HISTORY

4.1Uranium Ore Deposits in Northeastern Nigeria: Geology and Prospects (Bute, 2013).

The world total requirement for uranium until the end of this century has been estimated at several million tons (OPEC 1970). The energy crises occasioned by the oil windfall, expanding industrialization and the search for clean alternative source of energy is making the search for uranium as a viable source of clean alternative energy worthwhile. Sustainable uranium exploitation all over the world is a huge challenge to all stakeholders. This scenario has resulted in increase awareness for uranium. Uranium is expected to top the demand due to its peculiar nuclear properties.

Nigeria as a developing nation has a vast spread of Geological environment and conditions favorable for uranium mineralization. Though uranium deposits are known to occur in many parts of the world and in varied sections of the earth's crust, they are found in well-defined provinces, mainly Precambrian terrain in continental sediments derived from uraniferous older rocks and in association with acid igneous rocks (Funtua I.I., Okujeni, et. al.,1993). Uranium as a lithophile element is widely distributed in granites, arkosic sediments, black shale and sea water.

Uranium occurrence in NE. Nigeria

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Fig.4. Geologic map of Gubrunde and its environs showing areas of uranium mineralization (After Ige et al,1994: Ige and Funtua, 2000).

Geologically uranium ores occurs in fourteen (14) geological settings around the globe (IAEA, 2009). In view of this research will be restricted to the ores found in the area of study. Northeastern Nigerian uranium ore deposit occurrences are:

1. **Sanstone-hosted Mineralization**

Sandstone hosted mineralization is the main occurrence in the sedimentary/volcnosedimentary sequences, structurally controlled mineralization consisting of bright yellow secondary uranium, products in transitional brecciated Bima sandstone(B2, B3) within wall rock alteration zones. The mineralization is located at Zona and Dali (Fig.2). Zona mineralization is located at the northeastern flank of petasyncline along NNE-SSW trending tectonicwedge or fault zone and Dali deposit features spotty uranium mineralization in the volcanogenic Bima sandstone,(Dada and Suh 2006; and Ige et al 2000).

About 28.6% of world's uranium productions are sandstone deposit type (table 1). A typical example of such deposits around the globe is Mikoulougou deposit in Gabon with an extend of up to 100m long and 40m wide,contains up to 5100Tu at a grade of 0.15-0.5%U, (IAEA, 2009).

2. **Vein-type (Granite related U deposit)**

The vein-type mineralization occurs in the ganitoids, the major occurrences are the Gubrunde, Kanawa, Ghumchi, Mika and Monkin-Maza deposits.

Gubrunde uranium minerlization located at the SW fringe of the Gubrunde host, north of Gubrunde village, uranium ore occurs in pockets and dessiminated of meta-autunite sheared zone between rhyolite and granites(Fig.2). Kanawa mineralization is at the centre of the Gubrunde horst along shear zones trending N-S. (Ige et al 2000, Funtua, 1997). Ghumchi, Mika and Monkin-Manza deposits are of the central massif at zone of brittle –ductile deformation trending N-S and NW-SE (fig.2), hosting primary and secondary rich veinlets along mylonitic foliation showing in many cases wide spread kaolization and geothide formation.(suh and Dada, 1998; Dada and Suh 2006).

Table 3. Uranium production and number of active production centers by deposit type. (IAEA, 2009).

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Deposit Type	%of 2004 production	Number of production centers
Unconformity related	39.3	4
Sandstone	28.6	20
Metasomatic	10.2	3
Haematite breccia complex	9.0	1
Volcanic	8.0	2
Quartz-pebble conglomerates	1.8	1
Vein	1.6	6
Intrusive	<1	3
Surficial	0	-
Collapse breccia	0	-
Phosphorite	0	-
Others	0	-
Total	98.5	40

4.2 Economic And Environmental Prospects

The Upper Benue Trough in Nigeria has significant economic potential due to its rich mineral deposits, particularly uranium (Saleh 2013). The area's geology, with its Precambrian basement terrain and continental sediments, creates a favorable environment for uranium mineralization.

Uranium in the area is primarily hosted in faults and fractures, with primary uranium ores formed through magmatic processes. Secondary uranium deposits are found in Bima sandstones, formed through the remobilization of uranium by reducing groundwater. The sandstones were deposited on Precambrian basement rocks and were later fractured and faulted, creating pathways for mineralizing fluids (Suh and Silas 1997). The uranium mineralization process involved the mixing of uranium-containing magmatic melt with reducing groundwater, which then flowed through Jurassic-aged conduits to mineralize the sandstones. This process also resulted in the silicification of sandstones. Two types of uranium ore deposits are proposed for the area: primary deposits containing Uraninite ore, and secondary deposits containing Coffinite ore.

The presence of uranium deposits in the area has potential health implications due to radiation exposure, and expert assessment and action are recommended to mitigate these risks. The discovery of these mineral deposits in the Upper Benue Trough has significant economic implications for Nigeria. The exploitation of these resources could:

1. Generate revenue and create jobs
2. Support Nigeria's industrialization and economic growth
3. Enhance the country's energy security through the development of uranium deposits
4. Attract foreign investment and stimulate local economic development

However, it's essential to ensure that the exploitation of these resources is done in a responsible and sustainable manner, with due consideration for environmental and social impacts.

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5.0 CONCLUSION

The Upper Benue Trough in Nigeria is a complex geological region with significant economic potential. The trough's formation is attributed to the West and Central African Rift System (WCARS) and is characterized by sedimentary rocks overlaying Precambrian basement rocks. The region is rich in mineral resources, including lead, zinc, barytes, gold, chromium, and coal. Lead, zinc, and barytes deposits are found in fractures within Albian-Turonian sediments, with notable areas including Abakaliki, Azara, Enyigba, and Ameki. These minerals have various applications, including energy storage, construction, manufacturing, and medical uses.

The economic prospective of these minerals is substantial, with lead used in batteries, ammunition, and radiation shielding; zinc in galvanizing steel, rubber vulcanizing, and cosmetics; barytes as a weighting agent in oil and gas drilling and uranium are used for energy purposes through radioactive decay. Effective exploration and exploitation of these resources can contribute significantly to Nigeria's economic growth, support the growing demand for renewable energy, and provide valuable export commodities.

However, further research and investment are necessary to fully harness the potential of the Upper Benue Trough's mineral resources, ensuring sustainable development and environmental stewardship.

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