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Geology and mineral resources of Ebonyi State, southeastern Nigeria

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ABSTRACT

Ebonyi State is underlain at depth by the Precambrian Basement Complex and by Cretaceous sedimentary units which include the Abakaliki Formation, Nkalagu Limestone, Amasiri Sandstone and Afikpo Sandstone and spans through Southern Benue Trough and Anambra Basin. Shales, sandstones, siltstones and limestones which range from shallow to deep marine depositional environments have intermediate to basic intrusive dolerites, extrusives and pyroclastics rocks emplaced in them. The sediments are dominated by physical structures such as faults, folds, fractures, joints, cross beds, mud cracks and an unconformity; chemical structures such as concretions and solution cavity; and biogenic structures such as burrows and bioturbation. The presence of benthic foraminifera such as *Bolivina anambra* and *Haplopragmoides sp.* suggest an upper bethyal deep to shallow marine environment for the sediments. Natural resources and mineral deposits such as lead, zinc, granite, limestone, dolerite, pyroclastics, salt-lake/brine, sand, laterites, clay, kaolin, iron ores, chalcopyrite, illmenite, fluorite, marble stone, quartz and copper ore which spread across the area, contribute largely to the gross domestic products of the state. Data gathered shows that 26% of the mineral deposits are partially exploited, 30 % are locally exploited, 4 % are highly exploited, while 39 % are dormant. Unfortunately, the reserve estimate of these mineral deposits are yet to be documented.

keywords: Anambra Basin, Ebonyi State, Mineral deposits, Southern Benue Trough, Structure; Uncomformity

1.0: INTRODUCTION

Ebonyi State lies mostly in the Ebonyi (Aboine) River Basin and the Cross River Plains and between longitudes $7^0$28'0"E and $8^0$25'0"E and latitudes $5^0$40'0"N and $6^0$50'0"N in the South-Eastern Nigeria (Fig. 1a). The state occupies about 5,670 km^2 landmass and has the population of 2,880,700 (NPC, 2016). The drainage system of Ebonyi State is dendritic drainage patterns. The rivers showed a parallel drainage pattern at their upper course and a dendritic pattern in their lower course (Fig.1b). The drainage is controlled by the Cross River and its tributaries. Over the year, the mean temperature range of the state is between 27^0 to 30^0C (Ogbuene, 2010) and its relative density is 508.0/km^2. The temperature is highest from February to April and it is about 31^0C (Ogbodo, 2013). Moderate relief, which range between 125 and 245 m above sea level, characterized the state. The highest elevation in the state is around Afikpo with elevation of 170m above sea level. Texturally clay loamy soil, fairly to poorly drain with gravely subsoil, characterized the upland location which is adjacent the lowland areas in the state (Ekpe *et. al.*, 2005). The vegetation is dominated by semi-savannah grassland with forests and swamps.

The area is made up of three lithostratigraphic units which is spread across Southern Benue Trough and Anambra Basins: the Albian Asu River Group which comprises the Abakaliki Formations and the Turonian Eze Aku which comprises the Nkalagu Limestone and the Amasiri Sandstone belong to the Southern Benue Trough; while the Campanian Nkporo Group which comprises the Afikpo Sandstone belong to Anambra Basin.

Ebonyi State as one of the states in Nigeria is rich in mineral resources. In recent times, there has been an intensified regional exploration activities in order to discover more minerals deposits especially larger ore bodies of lead-zinc and its associated minerals and the extent of mineralization in the state. Many authors (Nwachukwu, 1974; Olade and Morton, 1985; and Oha, Onuoha and Dada, 2017) had reported different origins for the mineral deposits. Nwachukwu (1974) had suggested a magmatic origin for the deposits, however, Olade and Morton (1985) and Oha, Onuoha and Dada (2017) reported that the origin of the lead-zinc which is the dominating economic minerals in the state, is yet to be established. Oha, Onuoha and Dada (2017) also reported that the lead-zinc-barium are epigenetic and their associated minerals, are hosted in carbonaceous shales and siltstones of Albian – Turonian age, and the veins trends in NW-SE trends.

Report has shown that the mineral resources has not been fully harnessed. If these resources were fully harnessed, they would have added more to the gross domestic product of the state and possibly categorize the state as one of the self-sufficient and self-sustainable economy.

Thus, this review focused on understanding the geology underlying the state and identifying all natural resources and mineral deposits in the state and where they are located and possibly make a recommendation on how they can be harnessed.

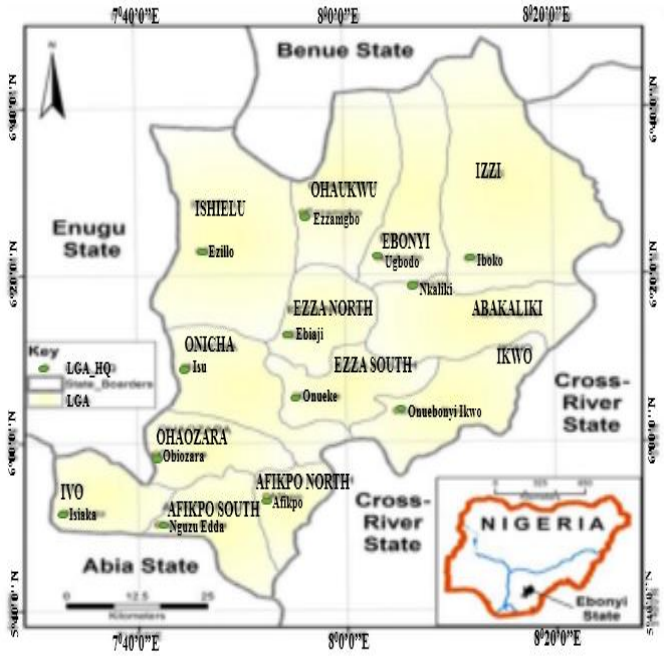


Fig 1a. Map of Ebonyi State, Nigeria showing the Local Government Areas (Source: Geospatial Analysis Mapping and Environmental Research Solutions 2018)

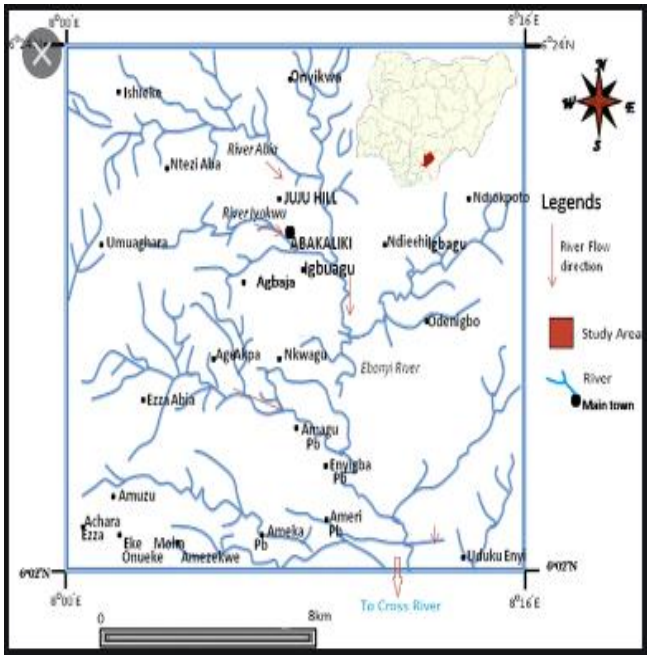
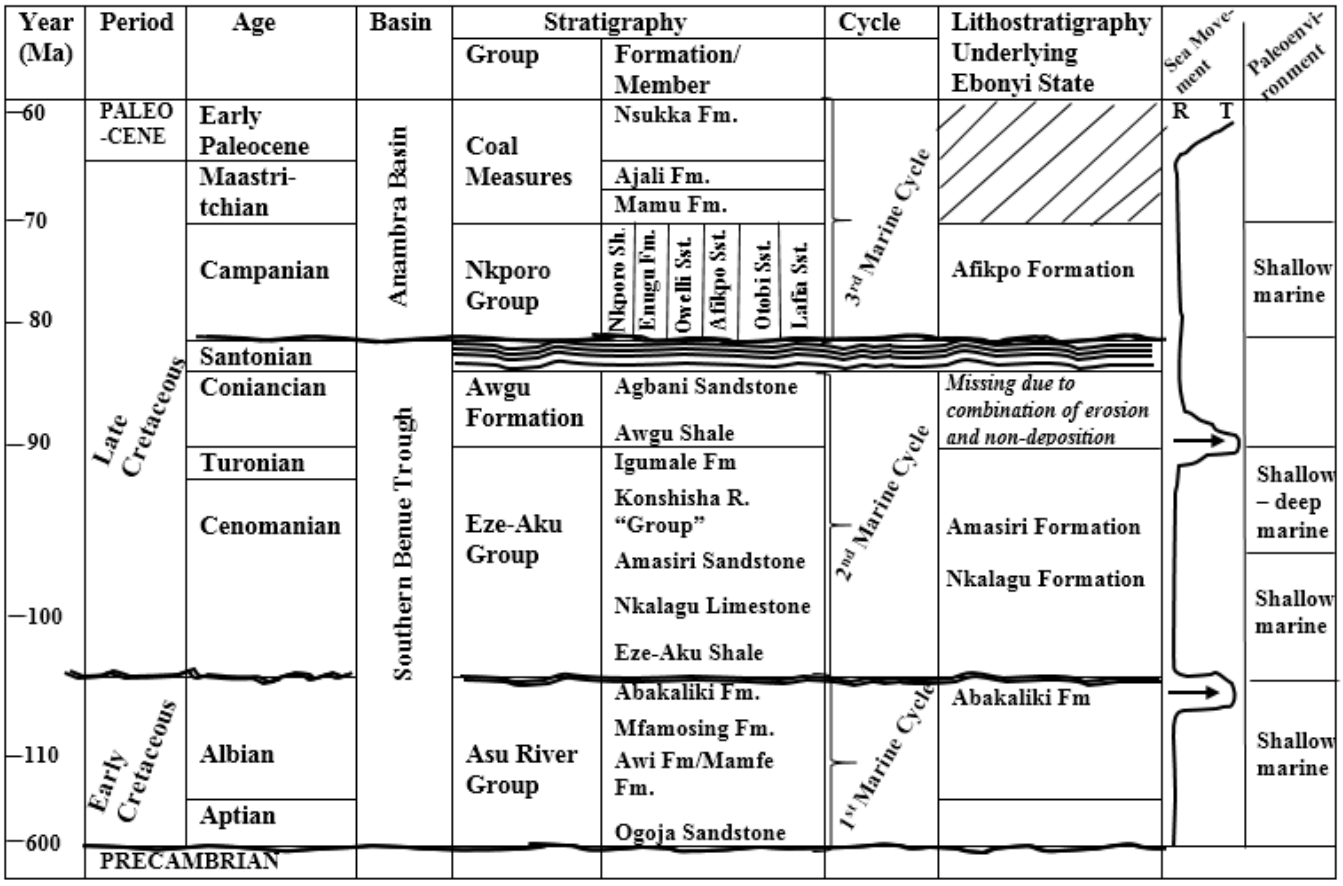


Fig 1b. Map of drainage pattern of Abakaliki in Ebonyi State

Geology (Stratigraphy and Structural) Settings

Several authors have widely discussed and reviewed the origin and tectonic evolution of the Benue Trough and the Anambra basin (Murat, 1972; Kogbe, 1976; Petters, 1977; Benkhelil, 1987; Ojoh, 1992; Reijers and Nwajide, 1998, Nwajide 2013). In Southern Benue Trough, three major unconformity-bounded depositional successions make up the sedimentary fill. These include Aptian - Albian Asu-River Group which overlies the Precambrian Basement Complex. This group has the Ogoja Sandstone, Awi Formation with its lateral equivalent of Mamfe Formation, Mfamosing Formation (Petters et al., 1982) and Abakaliki Formation as component formations; the Cenomanian - Turonian Eze Aku Group comprising the Eze Aku Shales, Nkalagu Limestone, Amasiri Sandstone, Konshisha R. "Group" and Igumale Formation; and lastly the Early Turonian - Coniancian Awgu Formation which has the Awgu Shale and Agbani Sandstone (Nwajide 2013). This is presented in Table 1.

Table 1. Litostratigraphy of Southern Benue Trough and Anambra Basin Succession showing the lithostratigraphy of Ebonyi State (modified after Murat, 1972; Whiteman, 1982; Nwajide, 2013 and Onwe et al., 2019).



The Asu River Group is underlain by the Abakiliki Anticlinorium (Reyment, 1965). The Asu River Group sediments are predominantly shales, and localized occurrences of sandstone, siltstone and limestone intercalations (Ofoegbu and Amajor, 1987). It was generally believed to have started depositing in the mid-Albian period and continued within the Southern Benue Trough, southeastern Nigeria. Emplaced in these Asu River Group sediments are intermediates to basic intrusive diorites and dolerites, extrusives and pyroclastics (Murat, 1972; Nwachukwu, 1972; Ofoegbu and Amajor, 1987; Tijani et al., 1996). The group has average thickness of about 2000 m and rests unconformably on the Precambrian Basement (Benkhelil et al., 1989). The type locality of the sediments of Asu River Group is at Abakaliki, and Ishiagu areas (Whiteman, 1982). The group is rich in ammonites such as *Oxytropidoceras hausa* and *Oxytropidoceras manuaniceras sp.* which are used for dating period of deposition of the sediments (Murat, 1972).

The sediments of the Eze-Aku Group were deposited during the extensive marine transgression at the beginning of the Turonian when the sea invaded the Benue Trough from the Gulf of Guinea (Reyment, 1965; Kogbe, 1989). It unconformably overlies the Asu River Group. The Eze-Aku Group consists of flaggy, fissile, dark-grey to black, fossiliferous, carbonaceous shales interbedded with mudstones, and parallel laminated sandstones and surbodinate limestones which are rich in pelagic faunas, pelecypods and gastropods, foraminiferas, ostracods, and fish teeth (Reyment 1965, Adeleye 1975, Petters, 1980). This group has its type locality at the Akaeze, Amasiri, Ezillo, Akpoha, Isimkpuma, Abaomege and Nkalagu (Simpson 1953, Reyment 1965, Whiteman, 1982).

According to Nwajide (2013), the tectonic event of the Santonian led to uplift, folding, fracture and widespread erosion in the sediment fill of the Benue Trough and another transgression occurred in the Campanian-Maastrichtian resulting in deposition of marine sediments. Prior to the marine incursion in the early Campanian, the Abakaliki Sub-basin in the southern sector of the Trough was folded into series of anticlines (Whiteman, 1982). This tectonic phase was resulted from the differential movement between parts of the African plate as a consequence of differences in the rate of spreading and direction between the section of the Mid Atlantic Ridge opposite the bulge of Africa and also south of the Gulf of Guinea. (Burke et al., 1971).

Nwajide (2013) had opined that the post-deformational sedimentation in the Anambra basin and the Afikpo Syncline commenced with deposition of the Campanian- Maastrichtian marine and parallic shales of the Nkporo Formation and Enugu Formation and their aranaceous facies of the Afikpo and Owelli Sandstones respectively. The Enugu and Nkporo Formations represent the brackish marsh and fossiliferous pro-delta facies of the late Campanian - Early Maastrichtian depositional Nkporo cycle (Reijers and Nwajide, 1998). Reyment (1965) reported that the deposition of sediments of the Enugu/Nkporo Formations reflects a funnel- shaped shallow marine setting that graded into channeled low energy marshes. These were overlain successively by the Mamu, the Ajali and the Nsukka Formations (Short and Stauble, 1967). The Coal bearing Mamu Formation and the Ajali Sandstone accumulated during this epoch of overall regression of the Nkporo cycle (Murat 1972). These units are presented in figure 2.

2.0: MATERIALS AND METHODS

The method adopted in this study include the logging and description of outcrop sections of Abakaliki Formation, Nkalagu Limestone, Amasiri Sandstone and Afikpo Sandstones exposed in Abakaliki and environs, Nkalagu, Amasiri and environs and Afikpo and environs. The structures on the lithofacies were briefly explained and the evidence was provided by photographs. The data of the mineral deposits obtained from Ebonyi State Ministry of Mineral Development and SN Consult Limited, Abakaliki, Ebonyi State was used to generate a map of mineral deposits in the state.

Facies Assosciations of Lithologies in Ebonyi State

The lithology underlying Ebonyi State are predominantly shales, sandstones, siltstones and limestones. The sediments range from deep to shallow marine. Emplaced in these sediments are intermediates to basic intrusive diorites and dolerites, extrusives and pyroclastics. The lithostratigraphic unit of the area is shown in Table 2.

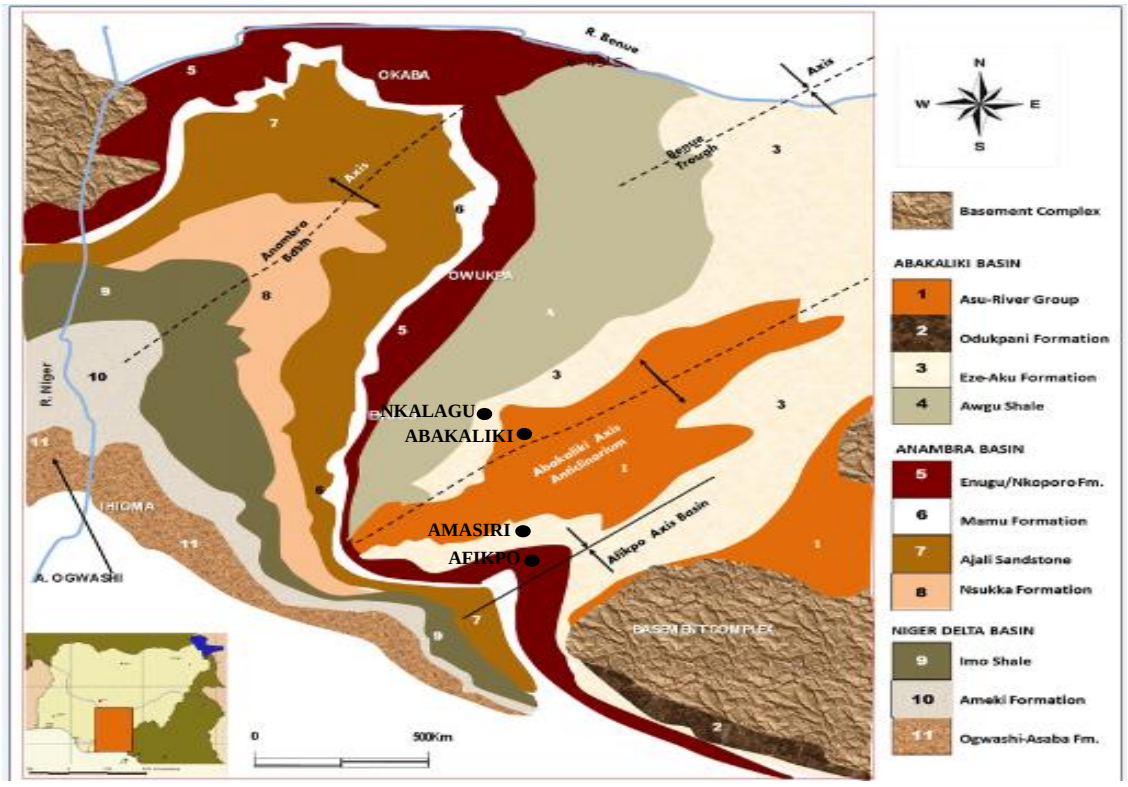


Figure 2. Map of Southern Nigeria sedimentary basins showing surface geologic formations in Abakaliki Basin, Anambra Basin and up dip Niger Delta (after Akande et al. 2007; Dim et al. 2017).

Abakaliki Formation

Abakaliki lithofacies is the oldest lithofacies underlying Ebonyi State. The Albian aged lithostratigraphic unit is among the sediments of Asu River Group in southern Benue Trough. The Albian sediments which includes Abakaliki Formation, were all deposited in a shallow marine environment (Rayment, 1965). The formation belongs to transgressive phase of the first cycle deposits of Murat (1972). The lithofacies comprises shale, sandstone, siltstone, limestone and minor pyroclastics. The shales are carbonaceous, dark grey, black and brown shales. In some areas, the shales are laminated and fissile while in other areas, they are well bedded, hard and baked. The hardness and baking of the shale is resulted from the magmatic activities which have baked the shale. The limestone is greenish brown in colour, highly consolidated, with notably quartz, feldspar and mica minerals. The shale is exposed at Agbaja, Onuebonyi. Ishieke (Fig.2).

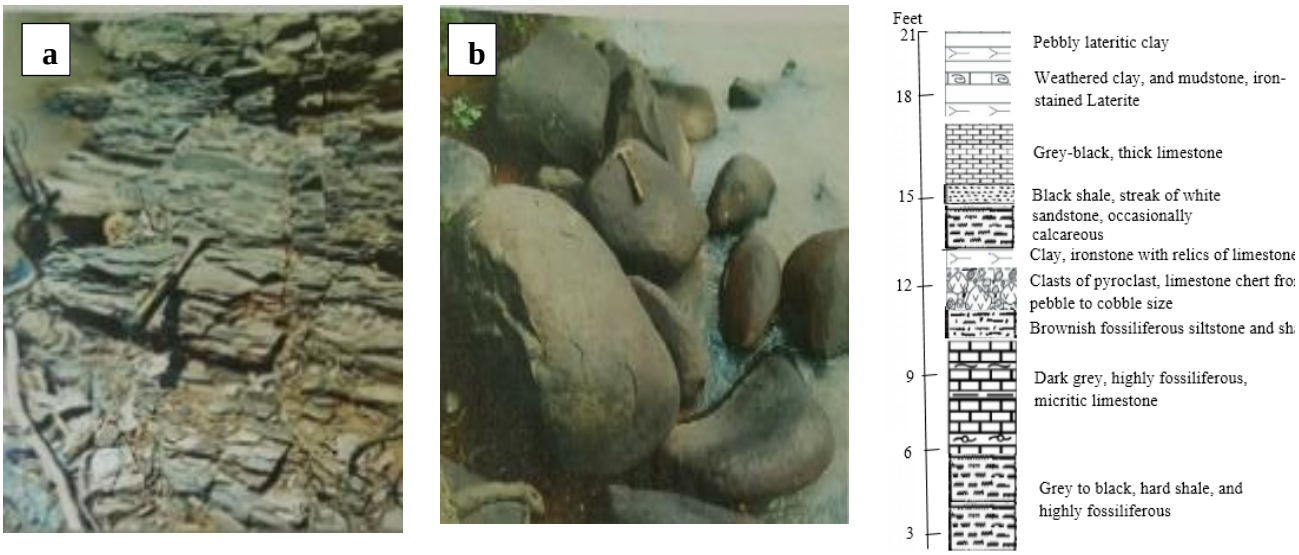


Fig. 2 (a) Laminated shales at Egwudinagu River, Ishieke, (b) Boulder limestone at Ogbogbo River, Ekebeligwe, Ishieke (c) Lithologic section of Abakaliki Formation. Type section at Ngbo

Pyroclastics

Based on field relationships, the pyroclastics exposed in Abakaliki area are grouped into two pyroclastic masses: the Onu-Ebonyi and Strabag quarry pyroclastic deposit. The Onu-Ebonyi pyroclastics outcrops an enlongate feature and aligned on a NE-SW direction.

The rock has been exposed as a large and massive outcrop due to quarrying activity. According to Igwe (2013), it is composed of agglomerates and tuffs (Fig. 6a). The agglomerate is grey to dark in colour and porphritic in texture, comprising of angular to sub-angular fragments in a very fine grained groundmass. The tuffs are fine grained (aphanitic)

with the colour ranging from grey to almost white. They show normal and graded bedding, as well as prominent cross-bedding or cross-laminations.

The Pyroclastic deposit in Strabag Quarry is a dome-shaped body that is large and massive. Quarrying activities expose the rock for study (Fig. 6b). The lower levels consist of pyroclastic flows and vesicular rocks interbedded with shales. The main pyroclastic body comprises mainly of tuff with a lot of quartz veins/segregations and nodules characterized by lieseagang rings but dominantly light grey on weathered surfaces where they appear brownish to reddish. They show normal and graded bedding and are generally fine grained with occasional phenocrysts of olivine. The texture is ophitic with thin plagioclase lathes interwoven with pyroxene crystals. Mudstone and shale xenoliths characterize the rocks. Pyroclastics also crop out as elongate and domical body along the core of the anticline at Ezzagu, former Ministry of Work, Government House and Methodist Cathedral Abakaliki.

Fig. 6. (a)Outcrop of Abakaliki Pyroclastic rocks exposed by quarrying at Onu-ebonyi (Igwe

Fig. 6. (b) Pyroclastic rocks being mined at Ezzeagu

Nkalagu Limestone

The Sedimentary limestone of Cretaceous and Tertiary ages is associated with shale, siltstone, and fine grained sandstone in Southern Benue Trough. According to Ikane *et. al.*, (2012), the Nkalagu Formation was deposited in a shallow marine environment and later displaced into relatively deeper water probably that of the off shelf zone, by some sedimentary flow mechanics. In all occurrences the deposition of limestone is related to the transgressive and regressive cycles in the Trough (Ikane *et. al.*, 2012). The Nkalagu limestone lithofacies overly the Abakaliki lithofacies. The Turonian-aged sediment is the oldest of the Eze-Aku Group in Southern Benue Trough. It is gray coloured, highly

consolidated, shelly, and massive with a lot of solution cavities and lenses of quartz. In some areas, it is interbedded with a dark gray, laminated and fissile shale. Fossil imprints such as bivalve imprints and pelecypods are present in the lithofacies. The type locality is at NIGERCEM, Nkalagu (Fig.3).

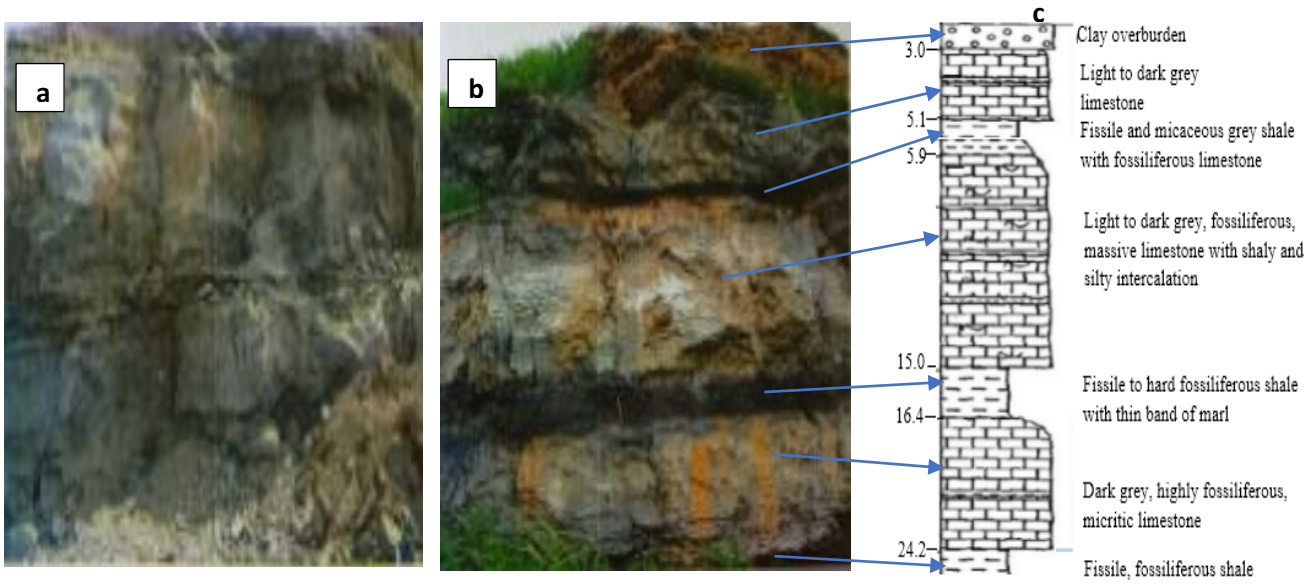


Fig 3. (a) Limestone unit at NIGERCEM Nkalagu, (b) Limestone interbedded with shale at NIGERCEM, Nkalagu (c) Lithologic Section at NIGERCEM Quarry Nkalagu

Amasiri Sandstone

The Turonian-aged Amasiri Sandstone overlies the Nkalagu Limestone in Eze-Aku Group, Southern Benue Trough. Igwe and Okoro (2014) had concluded that Amasiri Sandstone indicated depositional environments which evolve from shallow marine shoreface environment through moderate to low energy deep water marine environment into very low energy deep water environment. Simpson (1954) and Reyment (1965) identified the Turonian Amasiri Sandstone as a shallow marine sequence. The lithofacies in the Amasiri Sandstone, according to Ajaegwu *et. al.*, (2015), can be classified into matrix-supported conglomeritic bioturbated siliceous sandstone (Ta); parallel laminated bioturbated calcareous sandstone (Tb); ripple laminated sandstone (Tc); cryptobioturbated mudstone facies (Td). This classification represents Bouma Sequence as recognized by Bouma (1962).

Matrix-supported conglomeritic bioturbated siliceous sandstone (Ta):

The facies is light grey, fine-grained, well-sorted sandstone with limestone rip-up clasts of pebble to boulder size (Ajaegwu *et. al.*, 2015). The round-shaped limestone clasts have been dissolved to form holes. *Skolithos Ichnofacies (e.g. Ophiomorpha isp., Skolithos isp., Cylindrichnus isp.* and *Arenicolites isp)* are the bioturbation on the facies. The large size

Arenicolites isp. exhibited by suspension-feeding passive carnivorous biogenic structure and limestone cobbles/boulders within the siliceous sandstone showed a zone of coastal upwelling deposition for the sediment. The type localities of the facies are an outcrop exposure behind Government Technical College, Akpoha; abandoned quarry located between Government Technical College, Akpoha and Amoha Development Centre and the premises of St. Gabriel Catholic Church, Amasiri.

Parallel laminated bioturbated calcareous sandstone (Tb):

This calcareous sandstone is parallel laminated, fine to medium-grained with *Skolithos Ichnofacies (*mainly *Ophiomorpha isp.)* bioturbation.

Ripple laminated sandstone (Tc):

The sandstone is medium grained and well sorted with ripple lamination. The facies also shows a graded lamination as a result of the upward decrease of the beds.

Bioturbated mudstone facies (Td):

The sandstone is light grey, very-fine grained, parallel laminated and cryptic bioturbated. It is dominated by mud. This facies is interpreted to be deposited in a mid - fan environment (Ajaegwu et. al., 2015).

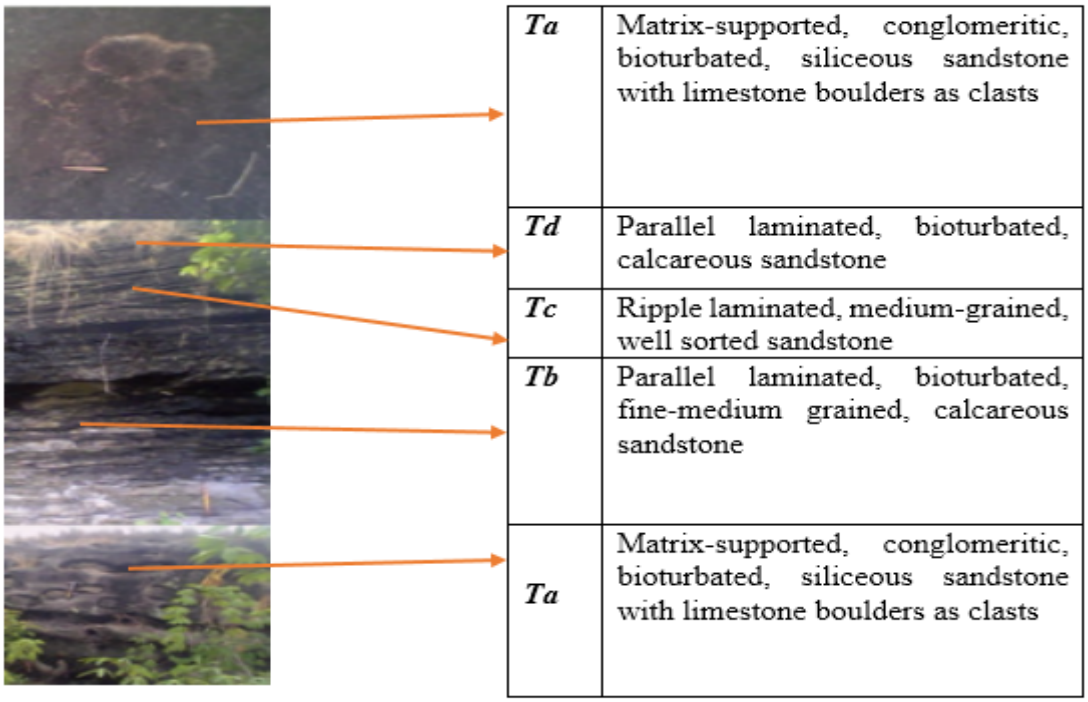


Fig. 4. Typical Bouma sequence interpreted behind Government Technical College, Akpoha (modified from Ajaegwu *et. al.*, 2015)

Afikpo Sandstone

The Afikpo Sandstone is the youngest of all the lithofacies underlain Ebonyi State. The Afikpo Sandstone as a part of Nkporo cycle deposit is a shallow marine facies deposited during the major transgression. The Campanian age outcrop ranges from friable to consolidated sandstone. Quartz, feldspar, fragment-like mica are the dominating minerals in the rock. The grain size is medium to coarse grained with some pebbles, while in some areas, it ranges from fine to medium grained. The white coloured sandstone, which is among Nkporo Group in Anambra Basin, forms an angular unconformity with Eze-Aku Formation of Southern Benue Trough and Nkporo Group of Anambra Basin. This is seen at Akpoha. The sandstone is exposed at McGregor Hill Afikpo, Amaorie Village Ozizza, Ozizza beach, Akpoha, Ebonyi Hotel Afikpo and Government College Afikpo (Fig. 5).

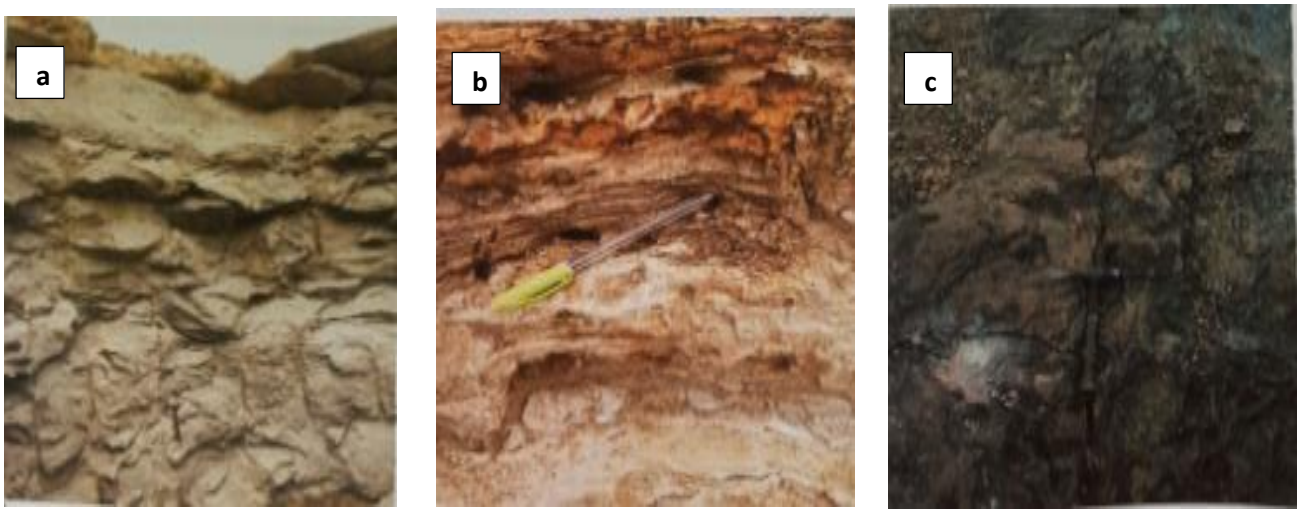


Fig 5. (a) Calcareous sandstone at local quarry along Abakaliki-Afikpo road. (b) Planar crossbed sandstone along Afikpo-Ozizza Road, (c) sandstone outcrop at Ebonyi Hotel, Afikpo

Igneous rock

Gabbro, anorthosite, trocolite, and dolerite are intrusive igneous rocks. Gabbro is a coarse-grained, dark-coloured igneous rock composed of plagioclase and augite minerals; anorthosite is a phaneritic coarse-grained igneous rock composed of plagioclase feldspar with minimal mafic minerals such as pyroxene, ilmenite, magnetite, and olivine; and trocolite is a coarse-grained igneous rock which consists of olivine and calcic plagioclase with minor pyroxene. Dolerite is a medium-grained igneous rock comprising plagioclase, pyroxene, and olivine minerals. Gabbro and troctolite (Fig 6c) and anorthosite outcrops are mined at Ezza Imagu (6d) while dolerite and gabbro outcrops are mined at Mimico Quarry at Afikpo (Figs. 6e).

Fig 6c. Gabbro, troctolite and mining sites at Ezza Imagu (Egesi, 2019).

Fig 6d. Anorthosite mining sites at Ezza Imagu (Egesi, 2019).

Fig. 6e. Dolerite and gabbro mining site at Mimico Quarry at Afikpo (Ayodele and Ukaegbu, 2017)

Structural Characteristics of Lithologies in Ebonyi State

Volcanic eruption that took place in Ebonyi State, especially at Abakaliki area has characterized the area as a volcano-sedimentary region. The erupted materials classified the shape of the volcanoes. The build-up steep cones in the area can be said to be as a result of a thick lava eruption.

Cinder and composite cones can be identified at the Hilltop area (Fig 7a-b), while shield volcanoes were seen at Ezza Imagu Area. One of the water reservoir tank in the state was built on the composite cones. A fractured and brecciated sandstone nodules and concretions boulders were observed at the sides of the composite cone. At the base of the cinder cone is a deposit of quartzo-feldspathic sandstones with concretions and nodules (Fig. 7c). The minerals in the sandstone can be seen to occur in irregular masses of small sub-hedral crystals which may be due to restricted growth of the minerals.

Faults, such as normal fault (Fig.7d) and strike-slip (sinistral) (Fig. 7e) characterized many sandstones exposed at Akpoha and Oguzu Edda respectively. Also, folding can be observed on the sandstone exposed at Amanze Primary School, Afikpo (Fig.7d).

Fig. 7(a) Cinder cone volcano from the top of composite cone volcanic feature Hilltop, Abakaliki (Egesi, 2019)

Fig. 7 (b) Composite Cone Volcano about 500m from the Cinder Cones feature in Abakaliki (Egesi, 2019)

Fig 7 (g) Field Photograph of Nodules and Concretions in the Feldspathic Sandstones in the Abakaliki (Egesi, 2019)

Fig 7. (d) Sinistral fault observed at Oguzu Hill, Edda

Fig 7. (c) A view of the fault plane. The hill in the distance is offset from the hill in the foreground at Akpoha (Okonkwo, 2014)

Fig 7 (h) Anticlinal fold behind Amanze Primary School, Akpoha

Physical Structure

Fracture/Joints are observed on the outcrops located on a shale unit along the banks of the Asu River at Ohaozara (Fig. 8a), along Iyuoge River, Amata, (Fig. 8b) and at Achiokenyi Bridge in Ugwongwo Village, Idembia (Figure 8c). A mudcrack is observed near Ebonyi River at Ohange Village Idembia (Fig. 8d). A distinctive cross stratified beds are shown at the base of Amasiri Sandstone exposed behind Catholic Church, Akpoha (Fig. 8e) and in Afikpo Sandstone body at Afikpo Junction (Fig 8f). Planar and trough cross bed can be observed on the aranaceous sandstone of the Amasiri Sandstone (Figs. 8g and 8h). A reactivation surface on the ferrugeneous sandstone at Nguzu Hill, Edda (Fig. 8i). This resulted from the surbpordinate currents capable of eroding the ice face of the dune formed by the preceding dominant current in the area.

Chemical Structure

Chemical sedimentary structures observed on the outcrop in the study area are a concretions and solution cavity (dissolved concretions) which are seen on the sand unit at Ibii Junction, along Abakaliki, Afikpo Road, Akpoha (Figs. 8j and 8k). They are formed as a result of precipitation of mineral materials from solution. A septarian concretion is present on the shale unit showing at Amaiyi, Edda (Fig.8l).

Biogenic Structure

Burrows, a biogenic sedimentary structure, can be seen on the sandstone units at Onuebonyi Onugbo Oshifu Ebonyi River at Obago Village Ukwuato Idembia (Fig.8m) and Amaigbo, Edda (Fig. 8n). Bioturbation can been seen on the sandstone outcrop at Ebonyi Hotel, Afikpo (Fig. 8o and 8p).

Fig. 8a. Fractured and Dipping Shale Units along the banks of the Asu River at Ohaozara (Okonkwo, 2014)

Fig. 8b. Sandstone unit showing a joint along Iyuoge River, Amata.

Fig. 8c. Sandstone body showing an extension fracture (fissure) at Achiokenyi Bridge in Ugwongwo Village, Idembia

Fig. 8d. Mudcrack is observed near Ebonyi River at Ohange Village Idembia

Fig 8e. Sandstone unit showing a planar cross bed behind Catholic Church, Akpoha (Igwe and Okoro 2012)

Fig 8f. Sandstone with crossbed and skolithos burrow in Afikpo Sandstone body at Afikpo Junction (Avodele and Ukaegbu, 2017)

Fig. 8g. Planar cross bedded sandstone Amasiri Sandstone (Ajaegwu et. al., 2015)

Fig. 8h. Trough cross bedded sandstone of Amasiri Sandstone (Ajaegwu et. al., 2015)

Fig 8i. Reactivation surface on the ferrugeneous sandstone at Nguzu Hill, Edda

Fig 8j. Sandstone unit showing a rip-up clast at Ibii Junction, along Abakaliki-Afikpo Road Akpoha

Fig 8k. Sandstone unit showing a solution cavity (dissolved concretion) at Ibii Junction, along Abakaliki, Afikpo Road, Akpoha

Fig 8(l) Shale unit showing a septarian concretion at Amaiyi, Edda

Fig. 8m. Burrows on the sandstone outcrop at Onuebonyi Onugbo Oshifu Ebonyi River at Obago Village Ukwuato Idembia

Fig. 8n. Burrows on the sandstone outcrop at Amaigbo, Edda

Fig. 8o. Bioturbation on the sandstone outcrop at Ebonyi Hotel, Afikpo

Fig. 8p. Paranois ichno facies on the sandstone unit at Ama-orie Village, Ozziza, Afikpo

Unconformity

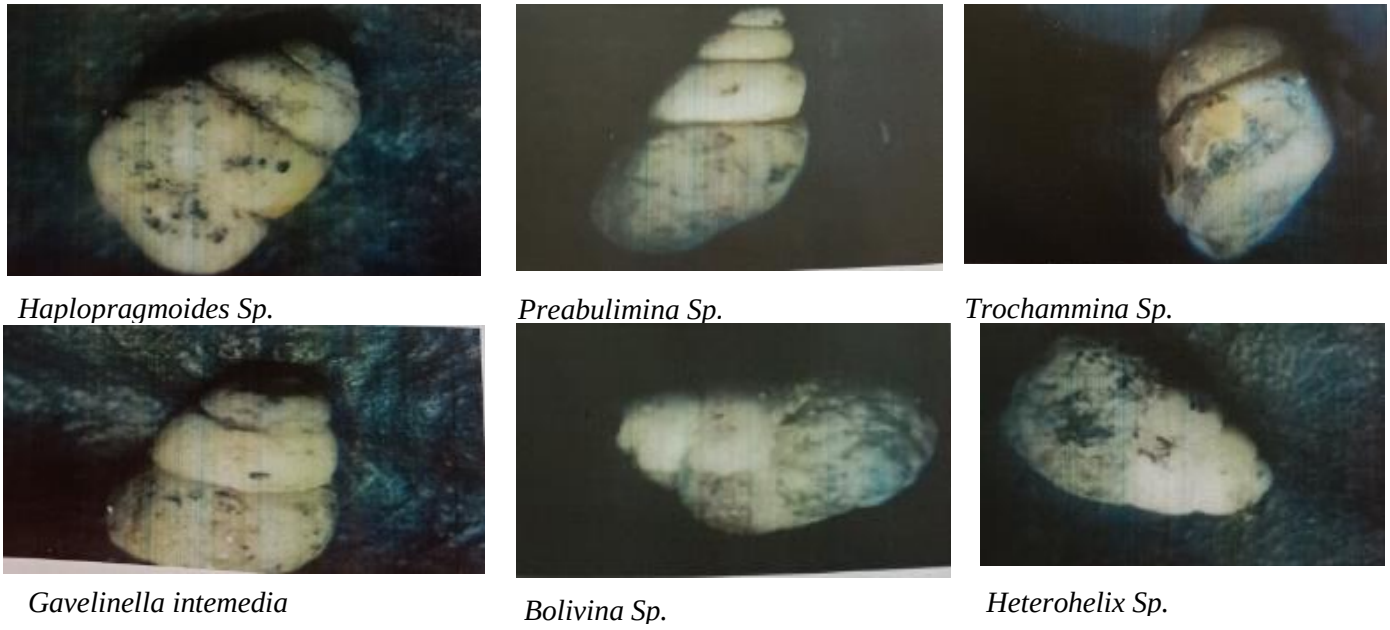
Angular unconformity separating Southern Benue Trough (Amasiri Sandstone) and Anambra Basin (Afikpo Sandstone) at Akpoha (Fig 9).

Fig. 9. Angular unconformity separating southern Benue Trough and Anambra Basin at Akpoha (Ajaegwu et al., 2015)

Paleoecology

Bathymetry

Benthic foraminifera were identified in the sediments of Ukeje and its environs. The fossils were used to interprete the environment of deposition for the sediments. For instance the presence of *Bolivina anambra* suggest an upper bethyal, deep marine environment with oxygen deficiency or a high organic influx. The presence of *Haplopragmoides Sp.,* however, suggests an outer shelf, upper bethyal, shallow marine environment (Fig. 10).



Haplopragmoides Sp. *Preabulimina Sp.* *Trochammina Sp.*

Gavelinella intemedia *Bolivina Sp.* *Heterohelix Sp.*

Fig. 10. Photomicrograph of some foraminiferal present in the shale deposits of Ukeje and its environs

3.0: RESULTS AND DISCUSSION

3.1: Mineral Resources in Ebonyi State

The data of mineral resources of Ebonyi State obtained from Ebonyi State Ministry of Solid Mineral Development Communities, Geological Survey of Nigeria Agency, Ebonyi Area office, and SN Consult Limited, Abakaliki shows that 26% of the resources are partially exploited, 30 % are locally exploited, 4 % are highly exploited, while 39 % are dormant (Table 3). The reserve estimate of the mineral deposits are yet to be documented. SN Consult Limited, a mineral resources consultant to Ebonyi State Government and other private companies in the state and environs, carried out a detailed geological and geophysical surveys and produced a detailed mineral deposit and their locations in the state.

The mineral resources can be classified into metallic and non-metallic resources. The metallic resources include lead, zinc, sulphur, iron, silver, fluorite, pyrites, chalcopyrites, marcasites, illmenite; while the non-metallic resources include sand, gypsum, halite, kaolin, pyroclastics, limestone and clay.

The tectonic activity that affected Asu River sediments resulted in the deformation of the rocks along NE-SW trending axes which produces multiple folds that were transected by steeply dipping NW-SE trending tensional faults and fracture systems. The minerals are

basically localized within a series of steeply dipping fractures and sheeted zones within these sediments.

The origin of the mineral resources can be said to range from hydrothermal ore deposits to sedimentary ore deposits.

a) The hydrothermal ore deposits which are concentration by hot aqueous (water-rich) fluids flowing through fractures and pore spaces in rocks include are massive sulphide deposits such as sphalerite (zinc sulfide) and chalcopyrite (Copper, Iron sulfide); vein deposits such as rich deposits of zinc, lead, and silver; and statabound ore deposited such as sulfide minerals like sphalerite (zinc sulphide) and chalcopyrite (copper-iron sulphide).

b) The sedimentary ore deposits which are substances concentrated by chemical precipitation from lake or sea water. These include evaporite deposits such as halite (salt water) and gypsum.

The spread, the lithologies and the locations of deposition of the natural resources and mineral deposits in the state are shown in Figure 11.The mineral resources are discussed below.

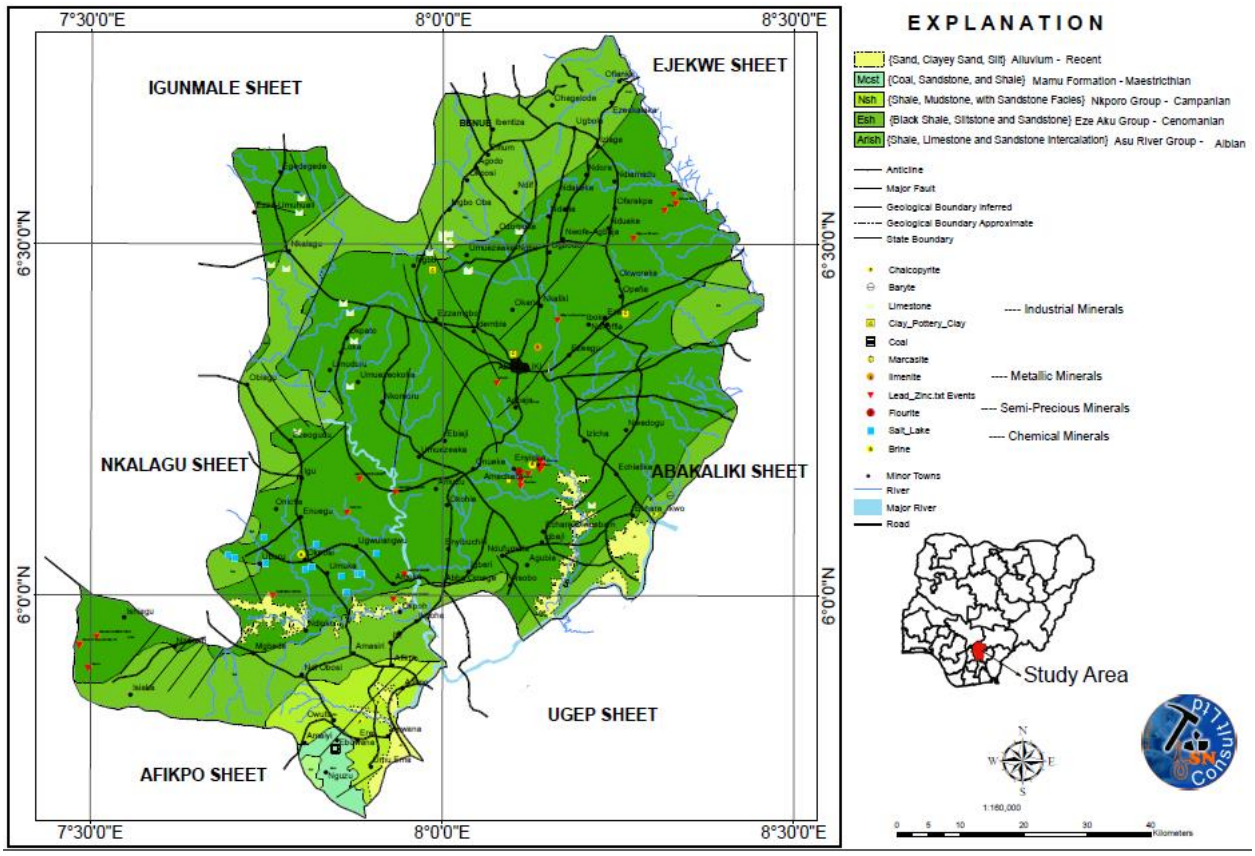


Fig.11. Geologic Map showing the Lithologies and Mineral Deposits of Ebonyi State (Source: SN Consult Ltd, 2020)

Lead-Zinc-Barytes Mineralization

The occurrence of lead-zinc-barytes mineralization as epigenetic fracture-controlled vein are restricted to Albian–Turonian sediments of Lower Benue Trough. The work of Oha and Onuoha (2013) and Fatoye *et. al.,* (2014), showed that lead-zinc-barytes deposit in the Abakaliki field is made up of four lodes which include Ishiagu, Enyigba, Ameki and Ameri. The mineralization are restricted to NW-SE and N-S fractures and the NE-SW fractures are barren (Oha and Onuoha, 2013). The host lithologies range from shale to siltstone, sandstone and occasionally igneous bodies while the ore assemblage also varied remarkably in the areas, with lead-zinc-barytes ratios range from approximately 3:1:0 at Ishiagu, to 2:1:0 at Enyigba (Oha and Onuoha, 2013).

Lead – Zinc: Deposits of sphalerite (zinc ore) and galena (lead ore) is associated with barytes mineralization of Cretaceous sediments of the Southern Benue Trough. The lead–zinc of Abakaliki is of hydrothermal origin deposited at low temperature (about 140^{o}C) which comprise Ishiagu, Enyigba, Ameri and Ameki lodes in Ebonyi State.

The Enyigba lode is the largest mineralized body in the Southern Benue Trough. The about 2km long and 30km wide lode occur in an open vein fillings at steeply dipping N-S near vertical fault that cuts regional fold of Abakaliki anticlinorium. The Ameri lode which is a southward extension of Enyigba lode, trends almost N-S and flanks the southeastern limb of the Abakaliki anticlinorium. At the southeast of Enyigba and Ameri lodes is the Ameki lode which is bounded by siltstone in the north and the south. Lead-zinc mineralization is associated with calcareous shales and shaly limestones in Abakaliki area. The uses of lead and zinc are listed in Table 3.

Barytes: Barytes is associated with the vein of lead–zinc lodes of Pre-Cambrian Basement and Cretaceous Sedimentary rocks of the Southern Benue Trough. It economic importance is listed in Table 3. The importance of barytes in oil industries. Barytes is used as a weighting agent for drilling fluids in oil and gas exploration to suppress high formation pressures and prevent blowouts. As a well is drilled, the bit passes through various formations, each with different characteristics. The deeper the hole, the more barytes is needed as a percentage of the total mud mix. An additional benefit of barytes is that it is non-magnetic and thus does

not interfere with magnetic measurements taken in the borehole, either during logging-while-drilling or in separate drill hole logging.

At present, Nigeria imports a considerable quantity of this mineral for use in its oil-operations.

Limestone: In Nkalagu area of Ebonyi State, reserve estimate of over 174 million tonnes of limestone exist. This occur within the Turonian – Eze-Aku Formation. The six major limestone beds at Nkalagu area vary in thickness from 3 – 10 metres each. The Nigerian Cement Company (NIGERCEM) was the sole worker of this deposit for cement manufacture. The uses of limestone are listed in Table 3.

Clay: Clay deposits in Southern Benue Trough is less sufficient in quantity or less suitable in quality for modern industrial purposes. As an earliest mineral substances utilized by man, clay was very useful in the ancient civilizations for making brick buildings, in monuments and in pottery, and as inscriptions upon clay tablets. The modern uses of clay in listed in Table 3.

Gypsum: Gypsum is found as scattered crystals in the Cretaceous clays of Southern Benue Trough. The uses of gypsum are listed in Table 3.

Salt-Lake/Brine: Most dilute brine springs in the Southern Benue Trough are produced from the folded Cretaceous rocks. Such springs are mainly found in Abakaliki. Several unsuccessful attempts were made in the past to determine the quality and quantity of the brine, until in 1966 when the samples of water obtained at depth of 76.2 m mine shaft by Geological Survey of Nigeria and the Nigerian Lead-Zinc Mining Company during dewatering at Ameri were analyzed. The result showed that the water contained relatively high salinity of about 7.98 percent of the total dissolved solids in the brine to be common salt (NaCl). However, no buried rock salt has been found in the Trough in particular, or in Nigeria generally. The importance of salt for domestic and industries are listed in Table 3.

Pyrites and Marcasite: Pyrites, also known as fool's gold, is an important ore of sulphur and sulphuric acid. At present, sulphur is known to be a by-product of oil and gas processing and gold production. Marcasite, also known as white pyrite, is a pseudomorph of pyrite because it has the same chemical composition but different crystallization as pyrite.

Chalcopyrites: Chalcopyrites is also known as fool's gold, is a brass-yellow mineral which is an ore of copper and occurs in most mineral deposits in the world include mineral deposits in

Southern Benue Trough. Just like pyrites and marcasites, chalcopyrites are hydrothermal in origin occurring in veins. They serve as copper source for many secondary mineral deposits. The use of sulphur are listed in Table 3.

Illmenite: Illmenite, a weakly magnetic, heavy, iron-black or steel-gray solid, metallic oxide mineral composed of iron and titanium oxide. The use of the titanium ore is listed in Table 3.

Fluorite: Fluorite is a mineral form of calcium fluoride (CaF_2). The halide minerals, also known as flouspar, are used, based on their grades, in chemical, ceramic and metallurgical processes. Acid grade flouspar contains over 97% CaF_2, ceramic grade flouspar contains between 85 and 97% CaF_2 and metallurgical grade flouspar contains between 60 and 85 % CaF_2. The uses of the minerals are listed in Table 3.

Sulphur: Sulphides of iron, pyrites and marcasites could be possibly concentrated with the lead-zinc ores of Abakaliki. The iron ores can be mined for their sulphur content. The use of sulphur are listed in Table 3.

Silver: In Abakaliki lead-zinc field, small amounts of silver are present in the lead-zinc ores of galena and sphalerite, although, the recovery can be as a by-product if the ore is mined in large quantity.

Pyroclastics/Dolerites/Laterites/Ironstones: Pyroclastics is the product of volcanic activity and it is common in the study area, especially in Abakaliki. Dolerites formed as a sill along Afikpo-Akpoha road. Ironstones are common in Owutu-Edda. Laterites are found everywhere in Ebonyi State. The use of pyroclastics, dolerites, laterites and ironstones are listed in Table 3.

Kaolin: Kaolin is abundant in Nguzu-Edda. Kaolin is used in commercially as a paper filter, merit absorbent, and in the manufacturing of pottery. Medicinally, it is used in the production of calamine lotion and kaolin syrups. Locally, it is used for earthen wares.

Table 3. Mineral Resources/Deposits of Ebonyi State, Uses and Locations

S/N	***Minerals***	***Locations***	***Exploitation/ Dormancy***	***Uses***
1.	*Lead-ore (Galena)*	*Ndijoko (Izzi LGA), Ndi-eze Echi (Izzi LGA), Otua (Izzi LGA), Abarunu (Izzi LGA), Nkaliki (Abakaliki LGA), Alibarihu Enyigba (Abakaliki LGA), Nkpuma Akpatapa (Abakaliki LGA), Amaka Ohankwu (Ezza South LGA), Amofia Ukawu (Ezza South LGA), Amofia Ohima Ukawu (Ezza South LGA), Amachara (Ezza South LGA), Amaka (Ezza South LGA), Ohankwu (Ezza South LGA), Ameri (Ezza South LGA), Oshiri (Onicha LGA), Onicha (Onicha LGA), Ogbuenu Uburu (Ohaozara LGA), Ishiagu (Ivo LGA).*	*Partially exploited*	*Pencils, solders, bearings, batteries, alloys, ammunition, bronze, fusible alloys, radiation shield, burial vault liners, ceramic glazes, cosmetics, leaded glass and crystal, paints or other protective coatings, pewter, water lines and pipes, cable coverings, pigments, sheet lead and pipes.*
2.	*Zinc-ore (sphalerite)*	*Ndijoko (Izzi LGA), Ndi-eze Echi (Izzi LGA), Otua (Izzi LGA), Abarunu (Izzi LGA), Nkaliki (Abakaliki LGA), Alibarihu Enyigba (Abakaliki LGA), Nkpuma Akpatapa (Abakaliki LGA), Amaka Ohankwu (Ezza South LGA), Amofia Ukawu (Ezza South LGA), Amofia Ohima Ukawu*	*Partially exploited*	*Manufacture of brass and alloys, lithographic plates, galvanizing steel plates, rubber vulcanizing, cosmetics, plastics, ointment, sun screen creams, soaps, paints, fertilizers, batteries, pigment production, and medicines and chemicals.*

		(Ezza South LGA), Amachara (Ezza South LGA), Amaka (Ezza South LGA), Ohankwu (Ezza South LGA), Ameri (Ezza South LGA), Oshiri (Onicha LGA), Onicha (Onicha LGA), Ogbuenu Uburu (Ohaozara LGA), Ishiagu (Ivo LGA).		
3.	*Granite*	*Ishiagu (Ivo LGA), Otam (Izzi LGA)*	*Partially exploited*	*Chippings for road and building constructions*
4.	*Limestone*	*Ngbo (Ohaukwu LGA), Odomoke (Ebonyi LGA), Umuezeaka-Ngbo, Ezza-Umuhuli (Ishielu LGA), Nkalagu (Ishielu LGA), Loka (Ishielu LGA), Umuezeokoha (Ezza North LGA), Ezeogudu (Onicha LGA), Echara Omuebam (Ikwo LGA)*	*Partially exploited*	*Cement manufacturing, animal feeds, construction, glass, water treatment, tanning, chalk, filler in asphalt, rubber, paint, plastic, and fertilizers, flux in smelting copper and lead ores and in making iron and steel, production of asbestos, glass and ceramics.*
5.	*Dolerite*	*Abakaliki (Abakaliki LGA)*	*Locally exploited*	*Road and building constructions*
6.	*Pyroclastics*	*Abakaliki (Abakaliki LGA)*	*Locally exploited*	*Road and building constructions*
7.	*Brine (salt), Salt-Lake*	*Enyigba (Abakaliki LGA), Okposi (Ohaozara LGA), Uburu (Ohaozara LGA), Okposi (Ohaozara LGA), Umuka (Ohaozara LGA), Ugwulangwu (Onicha LGA)*	*Dormant*	*Refining yields native salt, caustic soda, sodium hypochlorite, chlorine, industrial chemicals like soda, sodium bicarbonate, caustic soda, chlorine, and certain acids; the smelting and refining of ores and metals, the making of soap*

				and dyes, the tanning of leather, the preservation of foods, the making of explosives, and the bleaching of cotton and paper.
8.	*Sand*	*Afikpo (Afikpo North LGA), Uburu (Ohaozara LGA), Ikwo (Ikwo LGA), Ezza (Ezza South LGA), Ishielu (Ishielu LGA)*	*Highly exploited*	*Mortar and concrete production for building and road constructions.*
9.	*Laterites*	*All parts of Ebonyi State*	*Locally exploited*	*Building and Road construction.*
10.	*Clay*	*All parts of Ebonyi State, especially in Abakaliki (Abakaliki LGA), Eze-Iboko (Abakaliki LGA), Ngbo (Ohaukwu LGA)* *Amachara (Izzi LGA)*	*Locally exploited*	*Pottery, earthenware, cooking ware, vases, plumbing fixtures, tiles, porcelain wares and ornaments, building bricks, vitrified and enameled bricks, tiles for floors, roofs, walls and drains, sewer pipes, ingredient of cement, conduits, sockets, insulators and switches, making refractory ware, such as fire bricks, furnace linings, chemical stone ware, crucibles, retorts and saggars.*
11.	*Kaolin*	*Ozizza Beach (Afikpo North LGA), Ndibe Beach (Afikpo North LGA), Nguzu-Edda (Afikpo South LGA), Ishiagu (Ivo LGA).*	*Locally exploited*	*Ceramics, pharmaceuticals, paints, detergents, rubber, agriculture, steel, etc.*
12.	*Iron ore (siderite)*	*Enyigba (Izzi LGA)*	*Locally exploited*	*Raw material for steel and rods and machine parts.*
13.	*Chalcopyrite*	*Enyigba (Abakaliki LGA),*	*Dormant*	*Ore copper, ornaments, gold*

	(Fool's gold)	*Ishiagu (Ivo LGA), Echara-Ikwo (Ikwo LGA), Afikpo (Afikpo LGA), Uwana (Afikpo LGA)*		*plating*
14.	*Illmenite*	*Abakaliki (Abakaliki LGA)*	*Dormant*	*Used in paints, printing inks, fabrics, plastics, paper, sunscreen, food and cosmetics.*
15.	*Fluorite*	*Amachara (Izzi LGA)*	*Dormant*	*Acid grade flouspar is used in manufacture hydrofluoric acid (HF) which is useful in the manufacture of fluorocarbon chemicals, foam blowing agents, refrigerants, different kinds of fluoride chemicals. Ceramic grade flouspar is used in used in the manufacture of specialty glass, ceramics, and enamelware. Metallurgical grade flouspar can be used as flux that removes impurities such as sulphur and phosphorous from molten metal and improves the fluidity of slag.*
16.	*Marble stone*	*Ishiagu (Ivo LGA), Ezza (Ezza North LGA)*	*Locally exploited*	*Building and art work.*
17.	*Gypsum*	*Agaga-Amangwu Edda (Afikpo South LGA)*	*Dormant*	*Cement production, plastics, chalk, pharmaceuticals, making plaster and plaster-board.*
18.	*Barytes*	*Nwezenyi-Igbeagu Izzi (Izzi LGA), Ishiagu ((Ivo LGA)*	*Dormant*	*Drilling oil in oil companies, filler in paint, paper, white pigment for textiles and plastics, sound reduction in engine compartments,*

				coat of automobile finishes for smoothness and corrosion resistance, friction products for automobiles and trucks, radiation-shielding cement, glass ceramics and medical applications (for example, a barium meal before a contrast CAT scan), and barium hydroxide for sugar refining.
19.	*Fullers earth*	*Unwana (Afikpo North LGA)*	*Dormant*	*Foundry, glass, abrasives, oil wells and breweries, electronics, water filtrating.*
20.	*Coal/lignite*	*Ebuwana (Afikpo North LGA)*	*Dormant*	*Energy and power generation, batteries, pencils, make-up kits.*
21.	*Pyrites and Marcasite*	*Enyigba (Abakaliki LGA), Ameri (Ezza South LGA), Amachara (Izzi LGA)*	*Dormant*	*Pyrite is used as gemstone, production of sulphide oxide for paper industry, production of sulphuric acid for chemical and fertilizer industry; mined for the gold, copper or other elements associated with it, ornamental stone.* *Macasite is used as decorative materials such as jewelry and ornamental stone.*
22.	*Sulphur*	*Enyigba (Abakaliki LGA), Ameri (Ezza South LGA)*	*Dormant*	*Used in chemical and fertilizer, insecticide, paper, paint, explosive, dye, rubber, oil-refining, textile, sugar, and many other industries.*

23.	*Silver*	*Enyigba (Abakaliki LGA), Ameri (Ezza South LGA), Ishiagu (Ivo LGA)*	*Dormant*	*Jewelry, tableware, and as coinage; as coat smooth glass surfaces for mirrors if the metal is vaporized or precipitated from solution; circuitry of electrical and electronic components; Colloidal silver and some insoluble compounds, such as potassium are in use in medicine as antiseptics and bactericides; silver-protein compound, argyrols, is used locally as antiseptic for the eyes, ears, nose, and throat; Silver-halide salts such as chloride, bromide and iodide of silver are used in emulsions for photographic plates, film, and paper.*
24.	*Quartz*	*Abakaliki (Abakaliki LGA), Izzi (Izzi LGA)*	*Partially exploited*	*Glass making, diode, scientific equipment, etc.*
25.	*Copper ore*	*Enyigba (Abakaliki LGA), Ameka (Ezza South LGA), Ameri (Ezza South LGA), Onicha (Ohaozara LGA), Ivo (Ivo LGA), Nkpuma-Akwaokuku (Izzi LGA), Nkpuma-Akpatakpa (Izzi LGA)*	*Partially exploited*	*Alloy making, electric conductors, etc.*

(Modified from Ebonyi State Ministry of Solid Mineral Development Communities, 2019)

The companies operating in Ebonyi State as at January 2020 and the type of mineral deposits they mine are presented in Table 4.

Table 4: List of registered mining companies, types of minerals mined and locations of operation in Ebonyi State as at January 2020

S/N	***Company Names***	***Location***	***Minerals Mined***
		QUARRY	
1.	*F.E. Nweke & Sons*	*Onyika village (Ebonyi LGA)*	*Pyroclastics*
2.	*Crushed Rock Ind. Nig. Ltd*	*Ishiagu (Ivo LGA)*	*Granite*
3.	*Conrock Nig. Ltd*	*Amasiri (Afikpo South LGA)*	*Consolidated sandstone*
4.	*Setraco Nig. Ltd*	*Amasiri (Afikpo South LGA)*	*Consolidated sandstone, dolerite*
5.	*CCNC*	*Nkalagu (Ishielu LGA)*	*Limestone*
6.	*Ebonyi State Stone Crushers Association (Industrial clusters)*	*Umuoghara (Ezza North LGA)*	*Pyroclastics*
7.	*Sam-Jenny Ventures Nig. Ltd*	*Ezza-Inyimagu (Izzi LGA)*	*Pyroclastics*
8.	*Yiter Quarry Nig. Ltd*	*Ishiagu (Ivo LGA)*	*Granite*
9.	*China Zhonghao*	*Okworeka (Ebonyi LGA)*	*Dolerite*
10.	*Ebonyi State Sand Dealers Cooperative Union Ltd. Abakaliki*	*Ndibe Beach (Afikpo North LGA)*	*Sand*
11.	*Nnjo Mitchel Coy. Ltd*	*Ezza-inyimagu (Izzi LGA)*	*Pyroclastics*
12.	*Trade Afrik*	*Ezza-inyimagu (Izzi LGA)*	*Pyroclastics*
13.	*Boko Mining Co. Ltd*	*Otam Izzi (Izzi LGA)*	*Granite*

14.	*Precuhe*	*Ezza-inyimagu (Izzi LGA)*	*Pyroclastics*
15.	*China Oriental*	*Ishiagu (Ivo LGA)*	*Granite*
16.	*Smogu Integrated Nig. Ltd*	*Ezza-inyimagu (Izzi LGA)*	*Pyroclastics*
17.	*Master Rock*	*Ukwuagba Ngbo (Ohaukwu LGA)*	*Granite*
18.	*Pioneer Sinochino*	*Ishiagu (Ivo LGA)*	*Granite*
19.	*Brass Engineering*	*Amasiri (Afikpo North LGA)*	*Consolidated sandstone, dolerite*
20.	*CGC Company*	*Ezza-Inyimagu (Izzi LGA)*	*Pyroclastics*
LEAD/ZINC			
21.	*Gexpam Nig. Ltd*	*Ishiagu (Ivo LGA)*	*Lead/zinc*
22.	*First Patrist Ltd*	*Ikwo (Ikwo LGA)*	*Lead/zinc*
23.	*Palladium Mining*	*Ishiagu (Ivo LGA)*	*Lead/zinc*
24.	*Green Field Metals*	*Ishiagu (Ivo LGA)*	*Lead/zinc*
25.	*Jidech Mining Company*	*Mkpuma-Akpatakpa (Izzi LGA)*	*Lead/zinc*
26.	*HSHF Oversea Mining*	*Mkpuma Ekwoku (Izzi LGA)*	*Lead/zinc*

(Source: Ebonyi State Ministry of Solid Mineral Development Communities)

4.0: CONCLUSION

This study has shown that a lot of geologic activities including syn-and post-depositional structures characterized the lithologies Ebonyi State. The state is rich in mineral resources which contribute more than fifty percent of the gross domestic product of the state. The minerals deposits has necessitated active mining some parts of the state.

5.0: RECOMMENDATION

Ebonyi State is one of the last newly created states in Nigeria in 1996. It is therefore, still grappling with juvenile issues plaguing the new state. Given the enormous potential of the rich mineral deposits in the state, this paper recommends that more in-depth studies and more exploration should be carried out in the state. This should be done by sponsorship of private consultants, proper funding of the Departments of Geology, Mining or Mineral exploration in the state's higher institutions and through public-private partnerships to enable quantification of the mineral deposits and settling a scene for its harnessing.

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