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GEOCHEMICAL, MINERALOGICAL, AND PETROGRAPHICAL STUDIES OF IRONSTONES AROUND MOUNT PATTI, SOUTHERN BIDA BASIN, NIGERIA: IMPLICATIONS FOR QUALITY ASSESSMENT, PROVENANCE AND ENVIRONMENT OF DEPOSITION

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ABSTRACT

The mineralogical composition, geochemistry, and depositional environment of the ironstone exposed on Mount Patti in the southern Bida Basin of Nigeria were assessed using integrated geochemical, mineralogical, and petrographic techniques. X-ray fluorescence spectrometry, X-ray diffraction, and transmitted light microscopy were used in geochemical, and petrographical investigations of fourteen representative ironstone samples. Average chemical analysis results showed that the concentrations of SiO_2 (5.93 wt%), TiO_2 (0.09 wt%), Al_2O_3 (10.76 wt%), and Fe_2O_3 (77.47 wt%) were as follows. The ironstone may be found in a shallow marine environment or non-marine environment if the concentrations of CaO, Na_2O, K_2O, MnO, and CuO are less than 0.40. This assertion is supported by the absence of sulfur oxide (SO_3) in the examined samples and the bivariate plot of SiO_2 versus Al_2O_3 and triangular plot of Fe-Mn-(Cu+Zn). Low levels of CaO and the absence of CO_3 indicate that the environment is oxidizing. The iron's grade was calculated and found to be approximately 54.180%, which has been classified as low grade. The study also revealed that the ironstone contains a high amount of gangue materials (Al_2O_3 and P_2O_5), its silica (SiO_2) content is within permissible limits, and it is devoid of harmful materials like sulfur. Based on petrographic studies, the floating contact displayed by the framework grains indicates that the iron cements were eodiagenetic in origin. Although it can be used more effectively as cast iron, sufficient beneficiation (to remove excess silica) can make it useful for iron and steel production.

Keywords: Hematite, Provenance, Agbaja ironstone, Mount Patti, Nigeria

INTRODUCTION

Ironstone is a sedimentary rock that has a significant amount of an iron (Fe) compound, which can be smelted for commercial use. It can be created chemically or directly as a ferruginous sediment. The iron minerals that make up ironstones might be oxides, like magnetite, hematite, and limonite; carbonates, like siderite; silicates, like chamosite; or a combination of these. Ironstone, often known as iron ore, is naturally occurring iron. According to Chard (1995), iron ores are rocks and minerals that can be economically used to extract metallic iron. Nigeria's ironstone reserves are attracting attention because to the importance placed on the expansion of the steel industry. There are two main categories of iron deposits in Nigeria. They are as follows: (i) BIF, or banded iron formation: The Pre-Cambrian metasedimentary schist belts that are exposed in the western portion of the nation are linked to the Formation, which is found in folded bands and lenses. The iron formation bands, which range in thickness from roughly 3 cm to 5 m, are typically encountered as isolated thin units or in groups intercalated within the nearby country rocks. The bands vary in their strike length, with some of them extending for many kilometers in an irregular manner. Tajimi, Itapke, Ajabanoko, Ochokochoko Toto, Farin Ruwa, Birnin Gwari, Maru, Jamare, Kaura Namoda, Kakun, Isanlu, Roni, and Ogbomosho regions are considered to be prominent sites (MSMD, 2010). (ii) The oolitic sedimentary iron deposits of the Cretaceous: Despite being classified as sedimentary, they have some lateritic characteristics and are primarily found in the north central, south eastern, and Agbaja regions of the nation, respectively (MSMD, 2010). Obaje (2009) claims that Koton Karfi is home to notable ironstone bodies that need close examination. Koton Karfi and Mount Patti are surrounded by tablelands and cap hills made of ironstone deposits.

Adeleye (1973) considered the Patti Formation and Lokoja Sandstone as the lateral equivalents of the Mamu Formation and Enugu Shales, respectively. Tattam (1943) proposed that the sediments outcropping at the south-eastern end of the Bida Basin are laterally continuous with beds in the Anambra Basin occurring at the stratigraphical level of the Enugu Shale. Adeleye (1973) concluded that a Maastrichtian transgression advancing from the northwest was affecting the Bida Basin by correlating the Batati/Agbaja ironstones with the Dukamaje Formation in the Sokoto Basin. Adeleye (1973) and Oresajo (1979) proposed a synsedimentary origin for the ironstones, citing evidence from the deposits' depositional features and connections to other Bida Basin strata suggesting the ooids developed in a high energy domain. The lack of fossils in the ironstone strata (Du Preez, 1956) and the presence of iron hydroxide and oxide in the ooids (Jones, 1955, 1958; Kogbe, 1978) led to the initial hypothesis of the lateritic model.

For the ironstone deposits, Ladipo et al. (1988, 1994); Mucke (1993); and Mucke et al. (1994) proposed a post-diagenetic iron enrichment. Because of the current specific industrial demands for the ore, this assessment consequently concentrates on the mineralization of ironstone in the studied region. The ore's mineralization pattern will become clear through a variety of analyses. Thorough geochemical and petrographic analyses of the ironstone samples are used to accomplish this. Using XRF and XRD analyses as well as petrographic studies on the Agbaja ironstone deposit, the current study aims to characterize the features of the Agbaja Formation's ironstone facies, as well as their mineralogical composition and paleoenvironmental conditions in the southern Bida Basin surrounding Mount Patti. In order to assess the mineralogical features, interpret the paleoenvironments and provenance, and ascertain the ironstone's economic potential in the study area, the goal is to conduct the mineralogical and geochemical characterization of the Agbaja Formation's ironstone facies exposed on and around Mount Patti in the southern Bida Basin. The Bida Basin contains the research area. It is located in the southern part of the Bida Basin and is bounded by the Lokoja Northwest, sheet 247, latitudes N7° 48' 0" and N7° 50' 0" and longitudes E6° 43' 0" and E6° 45' 0". The Ado Ibrahim-Patti road is the primary entry point into the research area (Fig. 1).

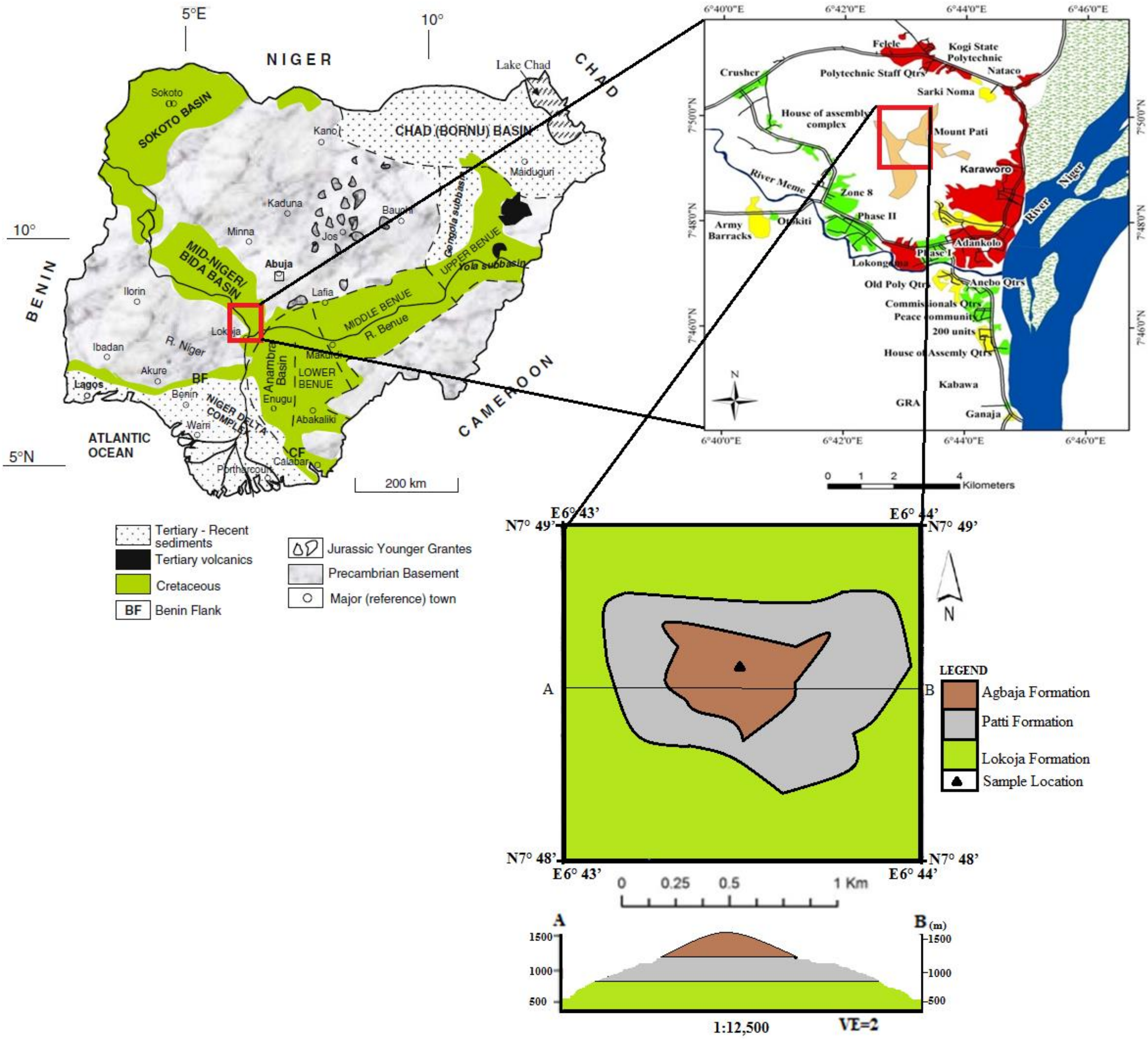


Figure 1: Nigerian map displaying the Bida Basin (after Obaje, 2009). Take note of where the Agbaja Ironstone's sampling portions are located.

Geology and Origin of Bida Basin

Origin of Bida Basin

Numerous studies aimed at revealing the basin's origin have resulted in the proposal of divergent ideas concerning the creation of the NW-SE inland Bida basin. According to King (1950) and Kennedy (1990), it was defined as a rift-bounded tensional structure created by drifting apart of the African and Brazilian Plates and faulting connected to the Benue Trough system.

The Bida Basin is a down-warped trough whose formation is closely linked to the Santonian oregenic processes of south-eastern Nigeria and the Benue basin. Adjacent to and somewhat perpendicular to the main axis of the Benue Trough and Niger Delta Basin, the basin is an embayment with a NW-SE trend. It is typically recognized as the Anambra Basin's northwest extension; both served as important depocentres for southern Nigeria's third major transgression cycle during the Upper Cretaceous period (Murat, 1972; Adamu et al., 2018a; Adamu, et al., 2018b; Adamu et al., 2020; Adamu et al., 2023; Alege et al., 2020; Yusuf et al., 2023).

According to Adeleye (1976) and Adamu et al. (2023), the basin may have begun as a straightforward sag structure after Santonian folding in the Benue Trough, which was an unsuccessful branch of the tripartite division. Whiteman (1982) postulated that the basin's genesis is a straightforward cratonic sag, supported by the field relationship and absence of a fault scarp. Despite this, he left open the possibility that the gravity and aeromagnetic measurements indicate a rift origin. An origin of the rift was proposed by Adeniyi (1985) and Okosun et al., (2007).

Kogbe et al., (1983) state that the Mid-Niger Basin is confined by a system of linear faults trending NW–SE based on interpretations of Landsat pictures, borehole logs, and geophysical data over the entire basin. Despite the fact that Ojo and Ajakaiye (1989) acknowledged that the genesis of the basin has been linked to isostatatic readjustment and mild downwarping of the basement as a result of earth material removal during the Jurassic period's emplacement of younger granite. According to Ojo and Akande (2012), the Benue Trough basin is a graben that has evolved at an angle to the main strike-slip fault movement. Although Likkason (1995) proposed that the Bida basin originated during the Campano-Maestrichtian, he linked the basin's genesis to a mantle plume that is thought to be located near the junction of the Niger and Benue rivers. According to Zaborski (1998), the Bida Basin may have formed earlier than is generally believed. This could have happened as a result of strikeslip movement along the Benue Trough translating into extensional stresses. The relative undisturbed nature of the sediments and the apparent lack of mid-Cretaceous marine beds favor a post-Santonian origin. Nonetheless, Udensi and Osazuwa (2004) estimated the thickness of the Bida basin using spectral determination of depth to buried magnetic rocks, and their findings indicate that the thickness is roughly 4.7 km. According to Tsepav and Mallam (2017), a recent study conducted in a portion of the basin utilizing spectral depth analysis reveals two prominent magnetic zones: one at a shallow depth of 0.968 km and the other at a deeper depth of 3.063 km.

Stratigraphy of Bida Basin

The stratigraphy and sedimentation of the Bida basin have been the subject of numerous studies, including those by Russ (1930), Adeleye (1973, 1974), Ladipo (1988), Abimbola (1997), Braide (1992), Obaje (2009), Obaje et al. (2011), and Adamu et al. (2023). The Northern and Southern sub-basins of the Middle Niger Embayment, also known as the Bida basin, are divided into two geologic successions known as the Nupe group (Adeleye & Dessauvagie, 1972). The sediments surrounding Lokoja were referred to as the Nupe sandstone by Russ (1930).

Three formations make up the southern Bida basin: the Agbaja Ironstone, the Maestrichtian Patti formation, which is composed of sandstone, claystone, and shales, and the Campanian Lokoja Sandstone, which is composed of pebbly and clayey sandstones (Jones, 1958). Four stratigraphic units in the northern Bida basin and their lateral equivalent in the southern sub-basin were recognized by Adeleye and Dessauvagie (1972) (Fig. 2). The Sakpe Ironstone Formation, which is composed of Pisolithic and Oolithic Ironstones, the Enagi Formation, which is composed of siltstone, claystone, and fine-grained sandstone, and the younger Batati Formation, which is composed of Goetithic and Oolithic Ironstone, make up the northern Bida basin. Obaje (2009) made modifications to the basin's stratigraphy recently. He was also aware of the northern and southern Bida basin sub-basins.

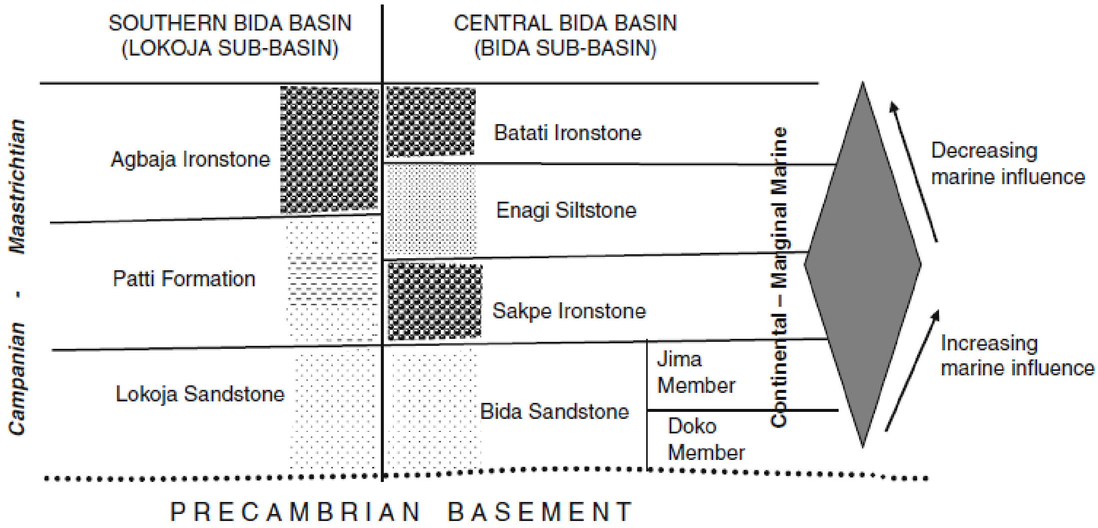


Figure 2: Stratigraphic successions in the Bida Basin (Obaje, 2009)

MATERIALS AND METHODS

Field Method

The research region, which includes Mount Patti and its surroundings, was the site of geological fieldwork and sample collection. Samples were collected from the exposures, and analyses in the lab were performed. Road cuts and other exposed outcrops were used in the sampling plan to gather stratigraphic samples across a large portion of the area. At each outcrop, data on the types of rocks, bed thicknesses, textural characteristics, sedimentary structures, structural features, and field measurements were documented. Physical characteristics of the samples, such as gain size, color, lithology, bedding trend, and shape, were reported for each location.

Sampling

In statistical analysis, sampling is the process of selecting a predefined number of observations from a larger population. A hammer and sampling bags were used to collect the samples from the summit of Mount Patti. Located in longitudes E007o 34C 30″ and E007o 35′ 00ź, and latitudes N07o 27′ 00″ and N07o 28′ 00M. A sample of clay and ironstone was taken at the summit of Mount Patti.

Sample Preparation and Analyses

Eleven samples of the specimens underwent crushing, grinding, pulverization, and sieving via a 60µm sieve using the standard techniques. To prevent contamination, every sample was stored in a polythene sample bag before being sent to the lab for examination. The geochemical (X-Ray fluorescence) and mineralogical (X-ray diffraction) analyses for the ironstone was carried out in the research laboratory of the Nigerian Geological Survey Agency (NGSA), Kaduna, while the sample preparation and petrographical (thin section) analysis were conducted in the Petrology Laboratory, Department of Earth Sciences, Prince Abubakar Audu University Anyigba.

Geochemical Analysis (X-Ray Fluorescence X.R.F)

Samples with complex expression are typically recommended for geochemical investigation. The chosen eleven (11) samples had to be first taken to the sample preparation lab for pulverization in order to perform the geochemical analysis. The rock sample is ground or milled by the pulverizing machine into fine grains with crystals no larger than 60 µm. This is necessary to ensure that the rock sample is homogenized and that every portion of it is participating in the geochemical study that it will undergo. Deionized water is used to quantify the ground sample and further grind it into pellets. After air drying, the pellet is placed inside the Energy Dispersion X-ray Fluorescence Spectrometer machine's vacuum chamber. Typically, the outcome is displayed as oxides.

X-ray Diffraction Analysis

In materials science, X-ray diffraction analysis (XRD) is a technique used to ascertain a material's crystalline structure. In order to measure the intensities and scattering angles of the X-rays that leave a material after subjecting it to incident X-ray radiation, XRD is used. The identification of materials by their diffraction pattern is one of the main applications of XRD analysis. In addition to identifying phases, XRD provides details on how internal tensions and flaws cause the real structure to differ from the ideal one.

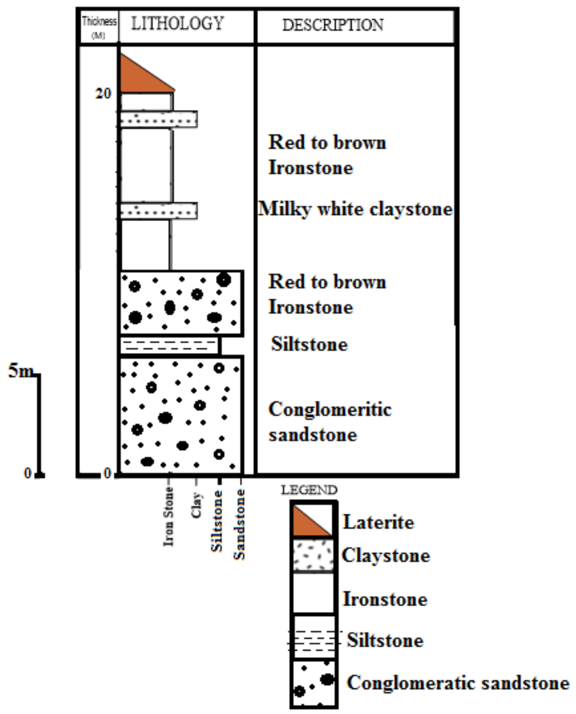
Petrographic (thin section) Analysis

To make thin sections, carefully selected and cut ironstone samples were obtained from Mount Patti. The pieces of these rocks that were sliced were placed over a Canada balsam glass slide and topped with frosted glass. The excess rock thickness was then cut off from the Frosting section of the thin section machine and manually frosted using carborundum on a level surface in order to achieve the required thickness of 0.003µm for a rock slide. The petrographic analysis was carried out in the Department of Earth Sciences' Petrology Laboratory at Prince Abubakar Audu University in Anyigba, Nigeria using the standard methods.

RESULTS AND DISCUSSION

Field Relationship

This section establishes the distinctive field connections, which provide a brief description of the lithofacies found in the study area. Clay and ironstone are the two main lithofacies in the research area (Fig. 3). The exposure occurred a few meters from Mount Patti's summit. It is 1120 meters above sea level and is located at latitude N07o 49'8" and longitude E0060 44'0". Claystone and ironstone are layered atop one another in the exposure. The claystone was found to be white to milky in color and measured to be around 0.5 meters thick. There are roughly 2.5 m and 2.0 m of claystone right on top of and beneath it, respectively. A 1.5 m thick reddish-brown lateritic overburden conformably covers the ironstone (Fig. 3 and 4) at the majority of the lithological sections at the locations, this sequence was seen.



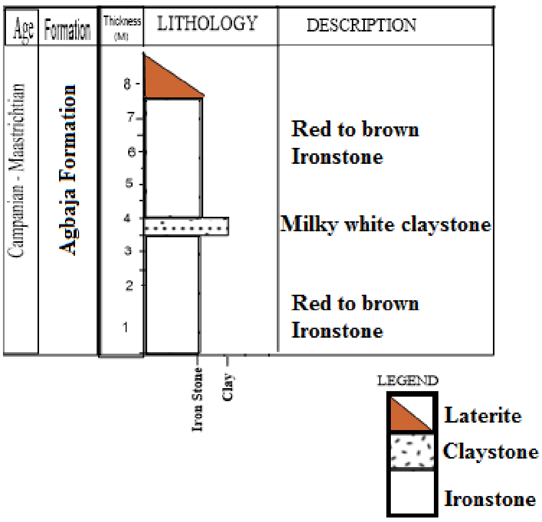


Figure 3: (a) Stacked Lithologic section of outcrops in the study, (b) Lithologic section of location 1 exposed at Latitude N07° 49’8’’ and Longitude E006⁰ 44’0’’

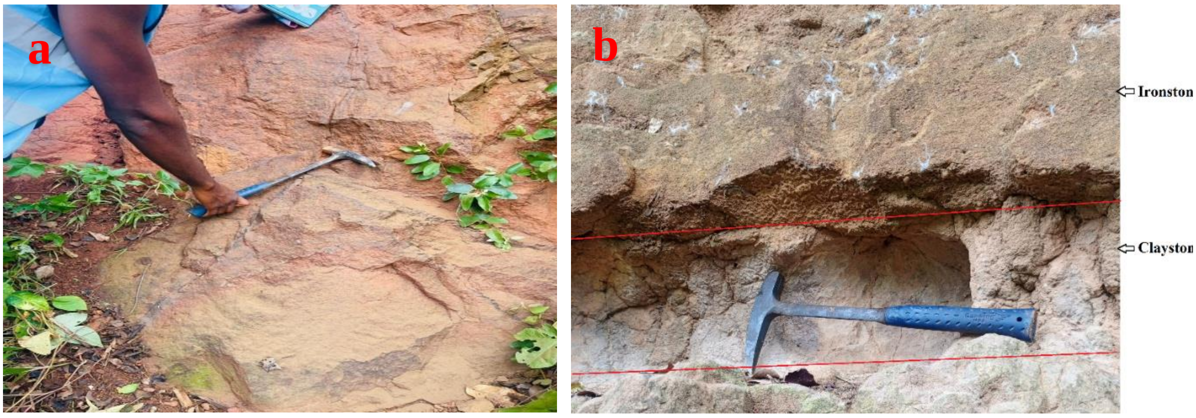


Figure 4: Exposure of (a) ironstone, and (b) ironstone-clay sequence on Mount Patti (N07° 49'8'' and E006° 44'0'')

Petrography

Two primary minerals were found in the petrographic thin-section analysis: quartz and iron (hematite), with additional minor or accessory minerals that may have been clay. Grains of oolite and pisolite were noted. The quartz grains that make up the framework are colorless, cleavage-free, and exhibit floating contact. After hematite, they are typically the most common minerals. The cementing materials, on the other hand, are non-pleochroic dark brown with a reddish brown tint and a little amount of yellowish materials that may represent hematite (Fig. 5a and b). The fabric examined in these samples is matrix supported, meaning it is made up of cementing materials and framework grains. It is well-sorted, sandy, and mostly composed of quartz, which serves as the primary framework grain. The cementing materials are made up of minerals that contain iron (Fig. 5). The crevices in between the frame work grains were filled with the cementing substance. This suggests that the irons are eodiagenetic, meaning they originate early before the sediments get compacted. Since quartz predominates, there are likely many impurities in the ironstone, which could lower the iron's grade and quality (Ayok et al., 2020).

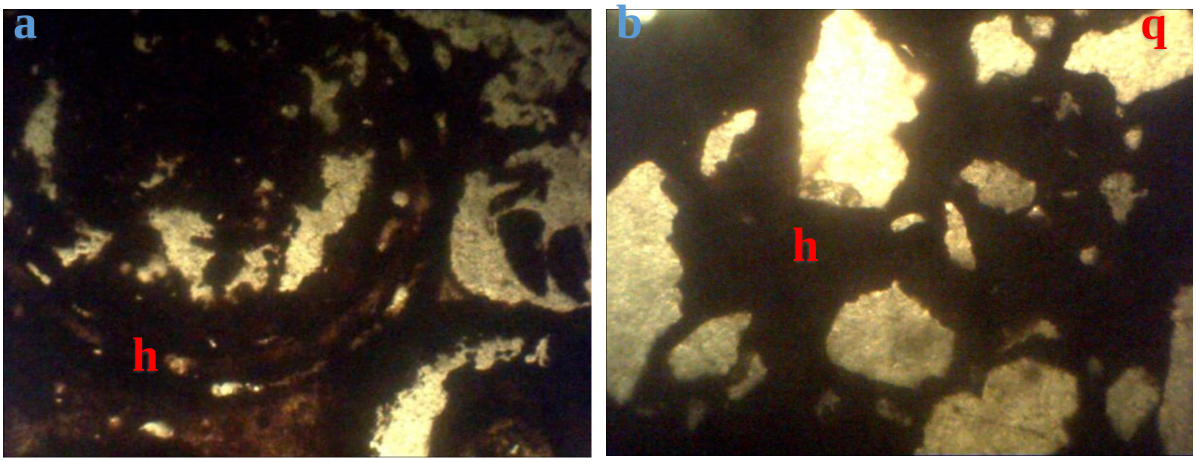


Figure 5: Photomicrographs of Ironstone under cross polarized light: (a) the ferruginized coarse grain, and (b) oolithic nature of the ironstone showing hematite (h) and quartz (q).

Mineralogy

The most common mineral found in the XRD study results is quartz, which is shown in Figure 6. Rutile, goethite, and hematite are some more minerals. Figure 7 displays the representative diffraction patterns, whereas Figure 6 is a pie chart that illustrates the mineral abundance. Due to overlap with the strongest peak, the identification is somewhat impeded by the absence of what is often recognized as the faith strong peak. Four minerals were discovered in the samples by X-ray diffraction analysis: orthoclase ($KAlSi_3O_8$), muscovite ($KAl_2(AlSi_3O_{10})(OH)_2$), quartz ($SiO_2$), and hematite ($Fe_2O_3$). Muscovite is the major mineral within the samples, accounting in average for up to 38.20%, hematite 32.50%, quartz 29.20%, and goethite 15% (Figure 6). The petrographic analysis of these samples verifies that quartz and muscovite outweigh iron minerals like hematite (Figure 5a and b). The XRD analysis's findings are corroborated by petrographic analyses of these samples. The interstitial spaces between the framework grains are filled with iron material, which ranges in hue from yellow to gray, and forms the framework grains, which are supported by a matrix (Ayok et al., 2020).

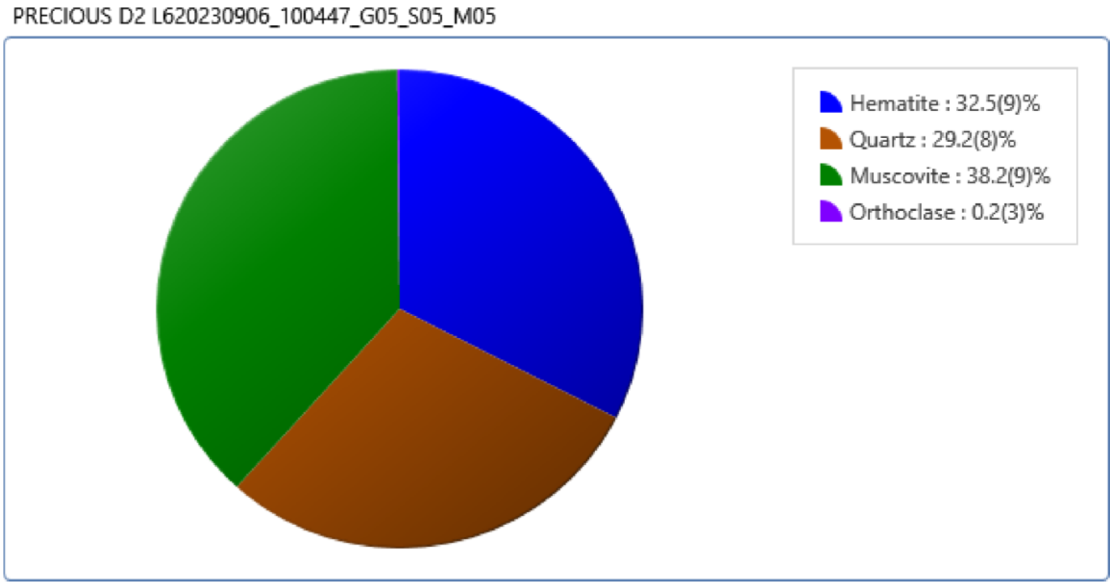


Figure 6: Pie chart showing result of mineralogical analysis of ironstone sample

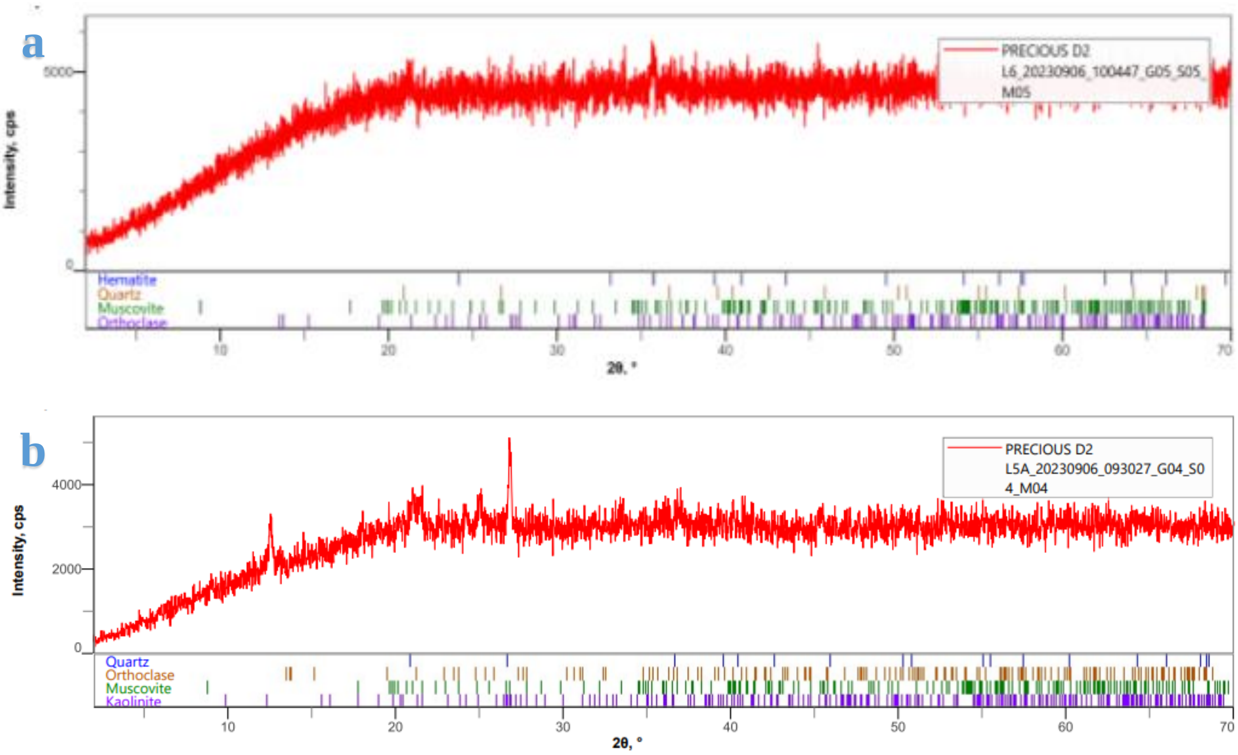


Figure 7: Powder diffraction pattern for the studied samples

Geochemistry

Tables 1 and 3 displays the average results of the X-ray fluorescence study of Ironstone exposed on Mount Patti location. Fe_2O_3 (77.466 wt%) and SiO_2 (5.936 wt%) concentrations. TiO_2 is 0.087wt% and Al_2O_3 is 10.756 wt%, respectively. The iron ore contains significant amounts of traces of impurities including MnO, CaO, K_2O, Ba, Cr, Zn, Zr, and Pb (Tables 1 and 3), but less than 0.001 of CuO, MgO, Rb, Hf, Nd, and Th. 1.500 wt% is the loss-on-ignition figure. Nevertheless, SO_3 is either undetectable in the samples or present at low levels. Agbaja Ironstone near Mount Patti has a higher iron (Fe_2O_3) and alumina (Al_2O_3) content within the same values when the average chemical composition of the examined samples of the Mount Patti ironstone is compared to other Nigerian ironstone. It does, however, include higher impurities when compared to other ironstones found elsewhere in Nigeria (Table 2) and has lower silica (SiO_2) and titanium (TiO_2) content, with the exception of olitic and pisolitic ironstone as described by Agunleti and Salau (2015). Table 1 displays the distribution pattern of the material under analysis as well as the modal content of oxides. Iron oxide concentration is seen to have the largest peak, followed by alumina concentration and silica concentration. The petrography confirms this as well.

Table 1: Average Major Elements Concentration in the analyzed Agbaja ironstone around Mount Patti

Element (Oxides %)	A	B	C	D	E	F	G	H	I	J	K	Average
SiO_2	5.06	4.47	6.96	7.11	5.89	7.19	3.99	5.94	5.85	6.89	5.95	5.94
Al_2O_3	11.99	9.98	10.58	11.52	10.98	8.97	11.14	10.45	10.85	10.98	10.88	10.76
SO_3	-	-	-	-	-	-	-	-	-	-	-	-
P_2O_5	4.09	3.23	3.08	2.29	3.3	2.22	3.5	2.91	3.11	3	2.58	3.03
Na_2O	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
K_2O	0.04	0.05	0.05	0.05	0.05	0.05	0.06	0.04	0.05	0.05	0.05	0.05
MgO	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
CaO	0.34	0.54	0.35	0.54	0.24	0.1	0.15	0.32	0.41	0.46	0.41	0.35
TiO_2	0.09	0.09	0.1	0.09	0.11	0.09	0.08	0.08	0.08	0.08	0.07	0.09
MnO	0.2	0.01	0.08	0.1	0.1	0.07	0.1	0.1	0.09	0.09	0.09	0.09
Fe_2O_3	74.85	79.69	77.53	74.99	75.61	78.63	78.79	79.09	77.78	77.21	77.96	77.47
Total	96.68	98.08	98.75	96.71	96.30	97.34	97.83	98.95	98.24	98.78	98.01	97.80

Table 2: Comparison of the average chemical composition of the analyzed ironstone around Mount Patti with other Nigeria ironstones

Elenent (Oxides %)	Present Study N=11)	Abimbola,1997 (AgbajaFormation)	Agunleti&Salau,2015 (Oolitic&pisolitic)	Imrana&Haruna,2017 (Kotonkarfe Oolitic)
SiO_2	5.94	11.05	3.41	16.98
Al_2O_3	10.76	10.82	8.98	12.49
SO_3	-	-	-	0.15
P_2O_5	3.03	3.09	2.23	0.98
Na_2O	0.02	0.2	-	-
K_2O	0.05	1.0	-	-
MgO	0.001	0.2	-	0.2
CaO	0.35	0.24	0.54	0.178
TiO_2	0.09	-	0.4	0.279
MnO	0.09	0.24	0.57	0.125
Fe_2O_3	77.47	64.06	83.42	67.81

Table 3: Trace Elements (ppm) Concentration in the analyzed Agbaja ironstone around Mount Patti

Elenent (Trace ppm)	A	B	C	D	E	F	G	H	I	J	K	Average
Ba	214	494	149	380	195	233	395	139	179	147	135	241.8
Cd	0.3	0.5	0.2	0.4	0.1	0.1	0.2	0.3	0.1	0.1	0.1	0.2
Co	37.1	22.3	18.7	20.1	24.1	13.1	21.4	12.4	22.8	19.7	26.7	21.7
Cu	9.5	6.2	5.7	8.3	12.7	13.3	9.7	6.2	5.5	6.8	7.4	8.3
Cr	392	288	237	284	184	165	189	135	281	403	310	260.7
Hf	1.3	1.5	0.9	1.2	1.1	1.5	1.2	1.3	1.3	1.1	0.8	1.2
Nb	5.5	4.7	3.5	3.6	4.1	5	4.1	3.7	4.5	3.8	5.4	4.4
Ni	23.3	16.7	22.2	16.5	19.7	14.6	10.3	13.4	11.7	18.7	10.9	16.2
Pb	150.2	101.6	89.5	157.6	76.2	57.9	90.5	83.1	101.4	74.6	100.1	98.4
Rb	0.2	0.2	0.1	0.1	0.2	0.1	0.1	0.2	0.2	0.2	0.1	0.2
Th	16.4	11.8	11.1	11.4	13.1	14.6	16	6.6	7.8	2.3	3.2	10.4
V	493	304	259	324	508	358	417	39	35	118	14	260.8
Zn	302	431	427	270	185	143	224	19	57	228	55	212.8
Zr	74.5	44.3	37.4	43.9	45.6	191.5	81.7	547.7	960.7	138.3	248.5	219.5
(Cu+Zn)	311.5	437.2	432.7	278.3	197.7	156.3	233.7	25.2	62.5	234.8	62.4	221.1

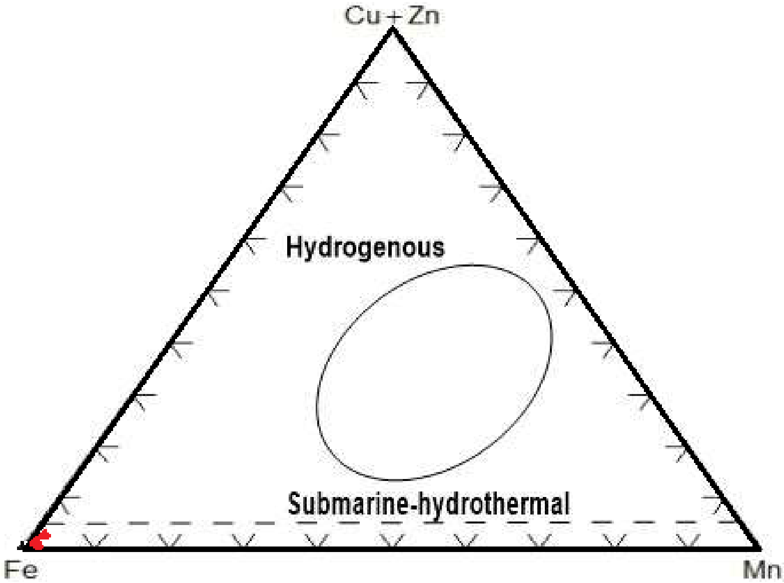


Figure 8: Fe-Mn-(Cu+Zn) diagram to differentiate submarine hydrothermal and hydrogenous deposit (Bonatti *et al*., 1972) and the analytical plot of the ironstone in the study area.

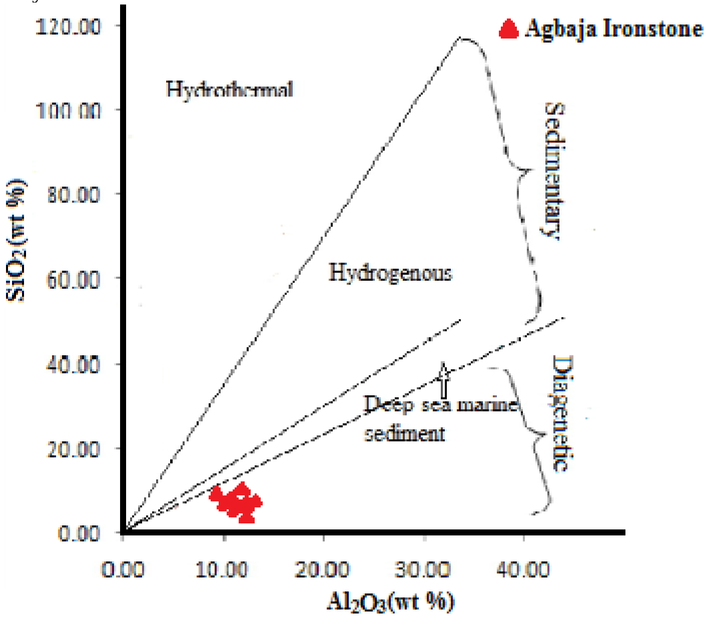


Figure 9: Bivariate Plot of SiO_2 versus Al_2O_3 for the Ironstones (After, Wonder et al., 1988; Crerar et al., 1982)

Grade Determination

Iron oxide (Fe_2O_3) was reduced to its elemental form, iron total (tFe), in order to calculate the grade. The grade was then obtained by multiplying the conversion factor by the average weight percentage of iron oxide.

Table 1 shows the geochemical analysis result for ironstone on Mount Patti, which is 77.466wt% Fe_2O_3. Below is an explanation of the conversion.

Atomic weight of Iron (Fe) = 55.845g

Atomic weight of Oxygen (O) = 15.999g

Therefore the molecular weight of Fe_2O_3 = 2(55.847) + 3(15.999) = 159.69 g/mol

For the Iron (Fe total) proportion = Fe2/Fe_2O_3= 2(55.847/159.69) = 111.694/159.69 = 0.6994

Therefore to get the grade, the average wt% of Fe_2O_3 (52.65wt %) is multiply by the conversion factor above. That is 77.466 x 0.6994 = 54.180% (Grade).

Quality of ironstone on Mount Patti

The geochemical results of the ironstone were compared with the composition of the extracted and analyzed ore of other ironstones in Nigeria in order to evaluate the quality of the ironstone at Mount Patti (Table 1). The most crucial factors to take into account while assessing the quality of the iron ore body are its iron concentration, contaminants, and harmful substances like phosphorus and sulfur (Marden, 1982). According to Dobbins and Burnet (1982), in order for natural iron ore to be considered suitable, it must have low levels of silica (<6%), alumina (3-4%), phosphorus (0.05-0.07%), and sulfur (0.1%). Dobbins and Burnet (1982) separated the raw iron ores into three basic classes based on the total iron content for the purpose of classifying and evaluating the quality and grade of ironstone. These classes were (i) high grade iron ores with a total iron content above 65%, (ii) medium grade ores with an iron content between 62 and 64%, and (iii) low grade ore with an iron content below 58%.

Nonetheless, an ore is considered high grade if it contains more than 54 weight percent iron, citing Natural Resources Canada (2012).

As a result, the ironstone on Mount Patti has a high iron content of 77.466Wt%. The grade above 54.180% indicates that the iron ore is of high quality according to Natural Resources Canada (2012) and low quality using the generalized percentages of elements of major interest by Dobbins and Burnet (1982). With 5.936% of silica (SiO_2), it falls within the broad range of less than 6% (Dobbins and Burnet, 1982). In this study, the percentage of alumina (Al_2O_3) is 10.756%, which is higher than the 3-4% generalized percentage by (Dobbins and Burnet, 1982). In this study, phosphorus (P_2O_5) is 3.028%, which is greater than the generalized proportion of ranges 0.05–0.07%. It was discovered that the ironstone had no sulfur. This indicates a lower level of contamination in the ironstone.

Provenance and Environment of Deposition

The environment in which the ironstone was deposited was inferred from the geochemical makeup of the examined samples using bivariate plot of SiO_2 versus Al_2O_3, triangular plot of Fe-Mn-(Cu+Zn). The chemical analysis results showed that the magnesium oxide (MgO) concentration is less than 0.001wt%. CaO, Na_2O, K_2O, MnO, and CuO concentrations are, in order, 0.351, 0.020, 0.049, 0.094, and 0.001 on average. The low magnesium concentration in each of the examined samples suggests that the ironstone was deposited in a shallow marine environment. Sulfur oxide (SO_3) absence in every sample examined lends credence to this assertion. The cause is that marine ironstone is typically heavy in sulfur and magnesium. The absence of CO_3 and the similarly low quantity of CaO both point to an oxidizing atmosphere.

A ternary plot of Fe-Mn-(Cu+Zn) is plotted for the ironstone in the study area. The Figure 8 shows that the ironstone is from submarine-hydrothermal source. Bonatti (1975) suggested that hydrothermal metal – rich deposits could be distinguished from hydrogenous deposits that are formed by diagenetic processes on the basis of the relative abundances of SiO_2 and Al_2O_3. On the SiO_2 vs Al_2O_3 discriminatory plot (Fig. 9), the Agbaja ironstones fall within the diagenetic domain signifying that the original chemical sediments necessary for the formation of the studied ironstones was purely diagenetic in origin.

CONCLUSION

According to the study's findings, the ironstone exposed on Mount Patti in the middle southern Bida Basin has a reasonably high concentration of iron oxide, or 77.466 weight percent, in the form of hematite. The iron grade, as determined by calculation, came out to be roughly 54.180%, which Dobbins and Burnet (1982) classified as low grade and Natural Resources Canada (2012) as high grade. Additionally, the analysis has demonstrated that the ironstone possesses a high concentration of gangue elements (Al_2O_3 and P_2O_5). Its silica (SiO_2) content is within allowed bounds and free of harmful elements like sulfur. Based on the low content of magnesium (MgO) in all of the studied samples, it was concluded that the environment in which the sediments were deposited was non-marine to shallow marine. Additionally, while sulfur is mostly abundant in marine sediments, the absence of sulfur confirmed this assertion. According to field outcrop research, the ironstone is interbedded with claystone and is oolitic. The framework grains' floating contact, as inferred from petrographic research, indicates that the iron cements were eodiagenetic in origin. In summary, low to medium grade ironstone can be found exposed atop Mount Patti in the Southern Bida Basin's central region. With proper beneficiation (to remove excess silica), it can be more valuable as cast iron.

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