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GEOLOGICAL, GEOCHEMICAL AND MINERALOGICAL INVESTIGATION OF SAKPE IRONSTONE AROUND JIMA, NORTHERN BIDA BASIN, NIGERIA

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Abstract
The geology, geochemistry and mineralogy of the Sakpe Ironstone were studied around Jima, Northern Bida Basin, Nigeria. The ironstone was logged in relation to the overlying and underlying formations and ten (10) well labelled representative samples of the ironstone formation were collected. These samples were taken to the laboratory for analysis using XRF and XRD techniques. Thin sections of five (5) of the sample were also prepared and studied under a petrologic microscope. The ironstone is reddish-brown in colour and this appearance is due to oxidation. The texture of the ironstone is oolitic and pisolitic with a graduation from the former to the latter. The diameters of the oolites range from 0.08 to 1.95mm while those of the pisolites range from 2.0 to 6.0mm. Sedimentary structures that were observed include parallel laminations and some local occurrence of wavy beddings. The result of the chemical analysis revealed that the ironstone contains an average of 58.9wt% Fe, 28.94wt% Si and 12.91 % Al. The average concentrations of P, K, Ca, Ti, Mn, Mg, and Na are 0.03wt%, 0.002wt%, 0.071wt%, 0.177wt%, 0.184wt%, 0.027wt% and 0.008wt%respectively. The results show that the ironstones are of high grade, having iron content > 54 % set by the Natural Resources Canada. Similarly, the low Mg (MgO wt %) content of between 0.01 and 0.051wt% and absence of sulphur in the samples suggests that the ironstones were not deposited in a fully marine environment; perhaps they were deposited in a non-marine to shallow marine environment. Mineralogical analysis showed that the ironstones contain goethite and hematite as the major phases with kaolinite and quartz as impurities. The petrologic analysis showed that the structure of the iron bearing minerals are in form of river lines and plates which are the characteristics of goethite and hematite. The result of the XRD and the petrologic analysis both confirmed that the studied Sakpe ironstone is predominantly goethite and hematite iron bearing minerals from which a high grade iron ore can be mined.
Keywords: Sakpe Ironstone, Bida Basin, Oolitic ironstone, Pisolitic ironstone, Economic Geology

INTRODUCTION

Iron and steel are essential for the growth of any nation, especially developing countries like Nigeria. Prior to the discovery of oil and gas in Nigeria, the mining of iron ore was one of the important activities that contributed to the economy. An estimated reserve of about 2.3 Billion tones has been estimated from parts of Kogi, Niger, Nasarawa, Bauchi, Oyo Kebbi, Kaduna, Borno, Benue and Anambra states (Bamalli et al., 2011; Ohimain, 2013). The iron ore deposits of Nigeria occur in both basement complex terrain (Banded Iron Formations) and sedimentary basins (Oolitic and Pisolitic Ironstones).

The Study Area

The Bida basin is an intracratonic inland basin in North-central Nigeria. It is one of the several Cretaceous and later rift basins in West Africa whose origin are related to the opening of the South Atlantic (Adeleye and Desauvagie, 1972). The basin trends from northwest to southeast and basically extends from Kontagora (Niger State) to the north and Lokoja to the south (Braide, 1992). The basin is bordered in the northeast and southwest by basement complex (Figure 1) and merges with the Anambra basin in the southeast and the Sokoto basin in the North-west (Ladipo, 1988). It is one of the ironstone bearing sedimentary basins. In the better studied southern part of the basin (e.g. Abimbola, 1997), only one ironstone level (the Agbaja Ironstone) has been described. However, Adeleye (1973) identified two levels of ironstone in the northern part of the basin, namely, the Sakpe Ironstone at the lower part and the Batati Ironstone at the upper part separated by the siltstone dominated Enagi Formation. The Sapke Ironstone which is the interval of study has been described to consist of goethitic, oolitic and pisolitic ironstone with subordinate kaolinitic oolites and pisolites deposited in high energy sub-tidal shoreline (Adeleye, 1973). His work focused on thin section petrography without considering the geochemistry and its economic implications. The aim of the present study is therefore to investigate the geology, geochemistry and mineralogical aspects of the Sakpe Ironstone exposed in a mesa around Jima locality, about 10 km south-west of Bida city.

METHODOLOGY

Fieldwork and Sampling

The geological fieldwork was carried out in the study area in order to study and describe the ironstone. The mapping technique that was used is the traverse technique, and this was done using topographic map as a guide. The exposure of the ironstone (Sakpe Ironstone) at Jima was located with a Global Positioning System (G.P.S). The ironstone deposit was studied in the field with the view to understand its colour, thickness, texture, grain size, structure, and vertical as well as lateral extents. The Sakpe Ironstone was logged in relation to the overlying and underlying formations. After outcrop study and observations were carefully made, ten (10) representative samples of each bed of the ironstone formation were collected using a geological hammer, well labelled and these samples were utilized for laboratory study.

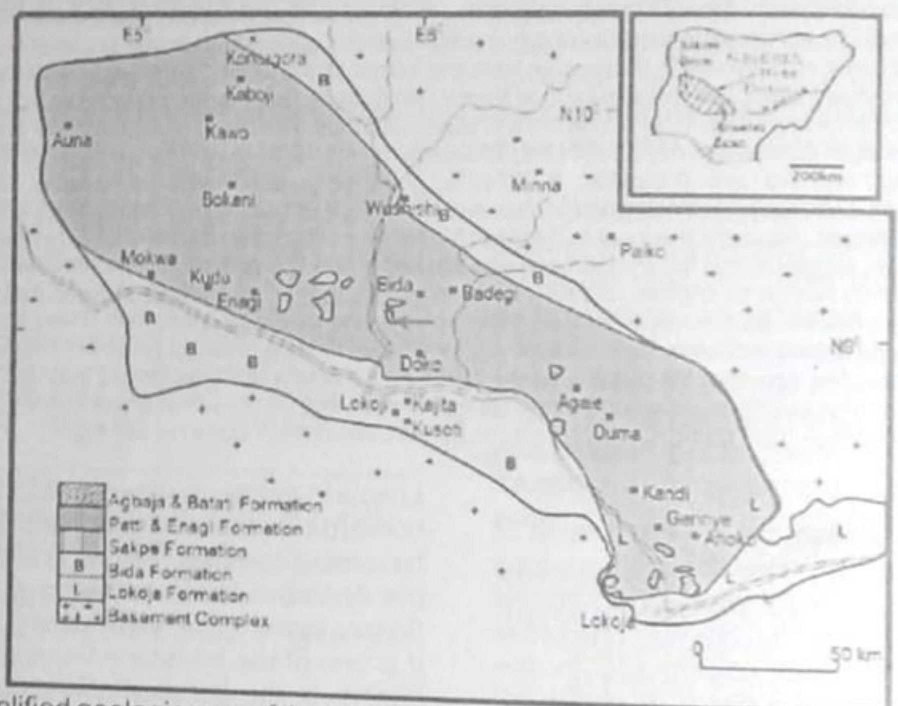


Figure 1: Simplified geologic map of the Bida basin showing the approximate location (red arrow) of the study area (Modified after Adeleye, 1970; Obaje et al., 2012)

Laboratory Analysis

Ten (10) representative samples collected during the fieldwork from the Sakpe Ironstone at Jima in northern Bida Basin were taken to the Nigerian Geological Survey Agency (NGSA) Kaduna for X-Ray Fluorescence (XRF) determination of the concentration of major oxides and trace elements. Five representative samples were also submitted for powder X-ray diffraction identification and quantification of mineralogical phases and reflected light thin section microscopy.

Whole Rock Chemical Analyses

The samples were pulverized a planetary micro mill pulverisette 7 to pass 150-micron mesh sieves. This was to ensure homogeneity of the samples. About 5 g of the pulverized sample was weighed into a beaker with the addition of 1 g of starch binder. The thoroughly mixed material was pressed under high pressure (6 tones) to produce pellets. Approximately 0.4 g of sample was fused with 7.6 g flux to produce glass beads. The samples were analysed for major and trace element concentration using an Energy Dispersive X-ray fluorescence (EDXRF) spectrometer (model "Minipal 4"). Loss on ignition (LOI) was determined gravimetrically by heating 1g of the powdered sample at 1000°C.

Mineralogical and Petrologic Analyses

The sample powders (< 150 microns) were smeared evenly on the sample holder made of aluminium material and analysed using a Schimadzu Model 6000 X-ray diffraction spectrometer. The analyses were carried out between 2 to 60 degrees 2θ as the sample scanning range and the scanning rate was set at 6 degree per minute. Thin sections of Sakpe ironstone samples were prepared for the petrologic analysis. The slides were studied under transmitted light microscope for identification of mineral phases present and determination of grain size of the various minerals.

RESULTS AND DISCUSSIONS

Field Observations

The Sakpe Ironstone exposure that was studied at Jima is reddish-brown in colour (Figure 2). The texture of the ironstone is oolitic and pisolitic with a graduation from the former to the latter (Figure 2B). The diameter of the oolites in the Sakpe Ironstone ranges from 0.08 – 1.95 mm and that of the pisolites ranges from 2.0 mm – 6.0 mm. The thickness of the ironstone varies laterally from about 8 – 10 m in the studied section. Sedimentary structures observed include parallel bedding (Figure 2A) leisegang structures (Figure 2C) and bioturbation.

Figure 2. Outcrop pictures: (A) Boundary between Bida Sandstone and Sakpe Ironstone. note parallel bedding in the Sakpe Ironstone; (B) Pisolotic texture of the ironstone; (C) Liesegang structure in the ironstone.

Mineralogy and Petrography

The results of X-ray diffraction analysis are presented in Table 1 and representative diffraction patterns are presented at Figure 2. Three minerals, namely goethite, kaolinite and quartz were identified in sample B2. Quartz is the dominant mineral within the sample, accounting for up to 91%, followed by kaolinite at 7% and goethite at 2%. The petrographic study of this sample confirms the predominance of quartz over other minerals (Figure 3) and the sediment has a sandy texture and a fabric that is matrix supported with a moderate degree of sorting.

Table 1: Mineral Abundance using XRD

	B2	B3	B7a	B7b	B9
Hematite	0	8	0	0	0
Goethite	2	19	38	100	14
Kaolinite	7		62	0	0
Quartz	91	73	0	0	86

The petrography result truly confirms the laboratory (XRD) analyses for this sample. Sample B3 contains 73% quartz in addition to goethite (19%) and hematite (8%). Comparing this to the petrographic result for the same sample, it showed that quartz is again the predominant and the minerals are held in clay matrix with reddish-brown cement. The shapes of the grains are platy, with river-line structures that are characteristic of goethite and hematite (Mohapatra, 2008).

Sample B7a consists of goethite and kaolinite as the two dominant minerals. The grains occur in concentric layers, with some non-concentric oolites also occurring (Figure 3C&D). The matrix consists of clay and sand particles and whitish in colour (kaolinite). The texture is oolitic and the fabric is both grain and matrix supported. The grains are well sorted and highly spherical and platy. This is characteristic of goethite and hematite (Mohapatra, 2008).

Sample B7b consists essentially of goethite (Figure 2) and petrographic study shows the grains occur as concentric layers with nuclei (Figure 3E&F). There are also dark and non-concentric pisolites. The grains are matrix supported and moderate to well-sorted. The shape of the grains is platy and highly spherical, which are characteristic of goethite (Mohapatra, 2008). Sample B9 has similar textural attributes, although quartz is the dominant mineral phase.

Geochemistry

The results of the major elements (oxides) of the analyzed ironstone samples are summarized in Tables 2 and 3 and compared with other Nigerian and global ironstones. The concentration of Fe_2O_3 ranges from 28.41 – 70.45 wt% with an average of 58.859 wt%, and SiO_2 ranges from 10.50 -62.41wt% with an average of 28.938wt%. The concentrations of P_2O_5, K_2O and CaO range from 0.006 - 0.04 wt%, 0.003-0.008 wt % and 0.02 - 0.12 wt % with average values of 0.02 wt%, 0.0025 wt% and 0.0705wt%, respectively. TiO_2 ranges from 0.812 – 0.952 wt% with an average of 0.1764wt%, Na_2O MgO and Al_2O_3 range from 0.01-0. %, 0.01-0.051wt%, 4.69-26.42wt% respectively, while Mn ranges from 0.0023 - 0.4105 wt% with an average of 0.184 wt%. The lost on ignition (represented by H_2O^{*}) ranges from 3.75 – 13.68 wt% with an average of 10.513 wt%. However, the concentrations of SO_3 falls below the detection limit of 0.001%, and thus they were not detected in all the samples.

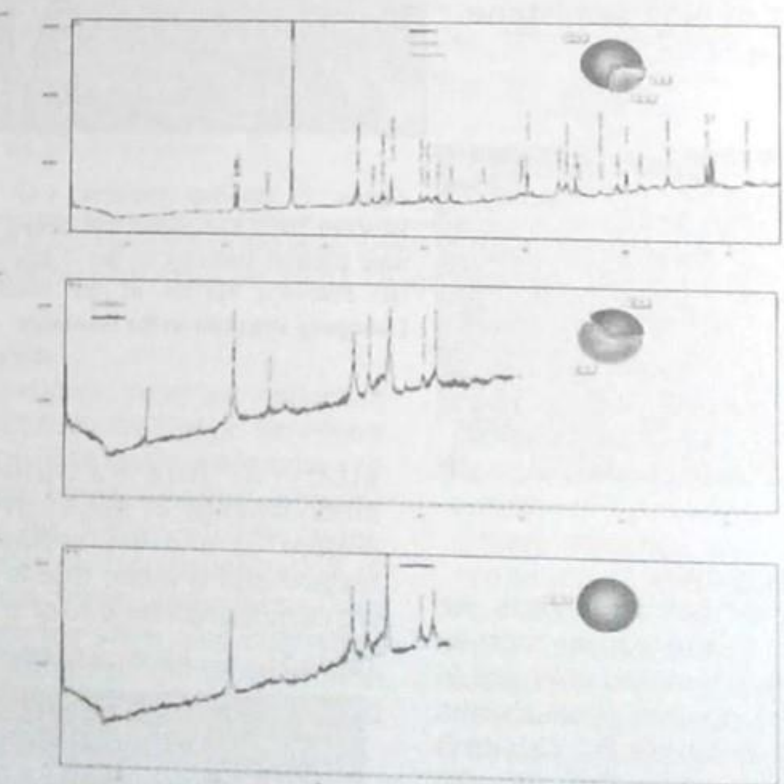
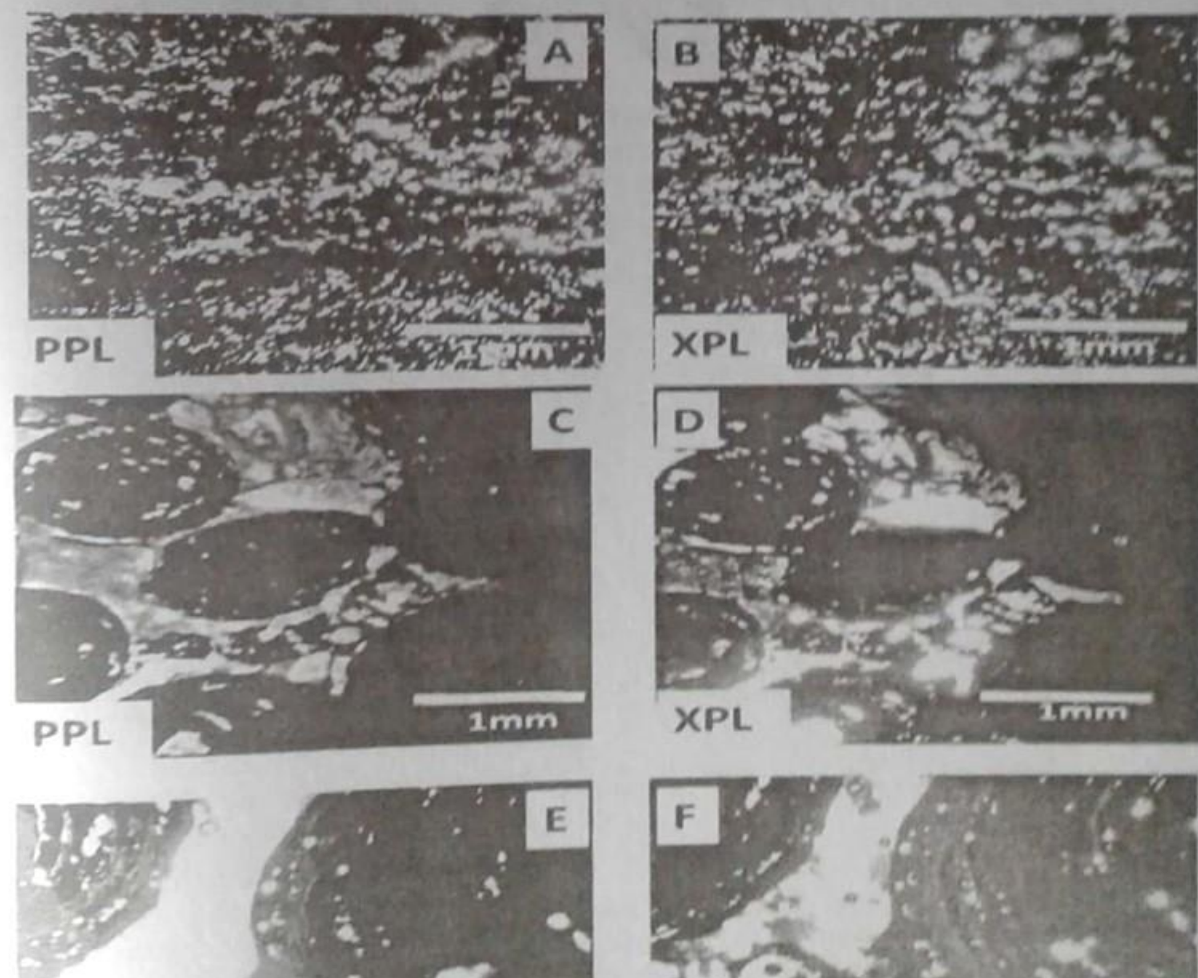


Figure 2 Powder diffraction pattern for samples B3, B7a and B7b.

Quality of Sakpe Ironstone

Iron content and their impurities are important features in the determination of the quality of iron ore body (Marden, 1982). Ohle (1972) has submitted that natural ores should be low in silica (< 8%), alumina (<1.5%), phosphorus (<0.18%), and sulphur (<0.15%) to be acceptable iron ore, and according to the Natural Resource Canada (2012), an ore that has > 54 weight% of iron is a high-grade ore. The Sakpe Ironstone is rich in iron ranging from 28.41 – 70.45 weight% with an average of 58.86 wt. % and can therefore be regarded as a high-grade ore. The silica from this study ranges from 10.50 – 62.41 wt. % with an average of 28.94 wt. %, alumina content for this study ranges from 4.69-26.42wt.% with an average of 12.91wt.%, which makes silica and alumina exceed the value of a natural ore stipulated by Ohle (1972). Phosphorus ranges from 0.06 - 0.04 wt. % with an average of 0.02 wt.% and this suggests that the ironstone is low in phosphorous. Similarly, sulphur was found to be absent in the ironstone. From the result of this study the silica exceeds Ohle's (1972) guideline and this high value of silica may reduce the iron ore grade and as such the iron ore will require beneficiation to remove the excess silica to further upgrade the iron ore.



ure 3: Photomicrographs of Sakpe ironstone under plane and cross polarised light: B is the siltstone to very fine sandstone facies; C&D is the oolitic ironstone facies; E&F e pisolitic ironstone facies.

Table 2: Comparison of the average chemical composition of the analysed Sakpe Ironstone at Jima with other Nigerian ironstones.

Elements (wt %)	This study	Abimbola, 1997 (Agbaja Formation)	Agunleti&Salau, 2015 (Oolitic & Pisolitic)
SiO_2	28.938	11.05	3.41
Al_2O_3	12.906	10.82	-
SO_3	-	-	-
P_2O_5	0.02	3.09	2.23
Na_2O	0.008	-	-
K_2O	0.0029	-	-
MgO	0.027	-	-
CaO	0.071	0.24	0.54
TiO_2	0.0176	-	-
MnO	0.1839	0.24	0.57
Fe_2O_3	58.859	64.06	83.42
H_2O^+	-	-	-

Table 3 Comparison of the average chemical composition of the analysed Sakpe Ironstone at Jima with the other ironstones around the world

Elements (Oxides %)	This study	Reboredo, Moncorvo (Orey, 1980)	Pedrada, Brazil (Rebelo, 1985)
SiO_2	28.938	36.7	36.9
Al_2O_3	12.906	7.3	6.0
SO_3	-	-	-
P_2O_5	0.02	2.4	1.7
Na_2O	0.01	0.2	0.2
K_2O	0.03	1.1	1.0
MgO	0.03	0.2	0.2
CaO	0.07	0.4	0.1
TiO_2	0.02	0.4	0.3
MnO	0.18	0.1	0.1
Fe_2O_3	58.86	48.2	51.9
H_2O^+	10.513	1.6	0.7

CONCLUSIONS

The result of this study has shown that the ironstone at Jima in the Northern Bida basin contains high percentage of iron oxide in the form of goethite which ranges from 28.41 - 70.45 wt. % with an average of 58.86 wt% and it could be described as a high-grade ore. This study has also shown that the studied ironstone is high in silica but low in alumina, phosphorous and absent of sulphur. As a result of the excess silica contained in the ironstone, its quality may be conceded. Hence, the iron ore requires beneficiation to upgrade its quality, and also needs a transformation of goethite to hematite. The study has also shown that the environment of deposition of the Sakpe Ironstone is non-marine or shallow marine on account of low Mg (MgO) concentrations in all the analysed samples and this claim is also supported by the absence of sulphur (SO_3) in the ironstone, since marine sediments are generally sulphur-rich.

From the XRD results, the dominant iron-bearing mineral is the goethite which is most abundant in sample B7b at 100% goethite. Followed by sample B7a at 38% goethite, sample B3 has 19% goethite and 8% hematite. Sample B2 has the least amount of goethite at 2% ad contains no hematite. The most dominant impurities are quartz and kaolinite.

From the petrographic analyses, it was found that the iron-bearing minerals are characterized by the platy, river-line structures that are characteristic of goethite and hematite. The results from both the petrographic analyses and XRD analyses show and confirm the presence of goethite and hematite as the dominant iron-bearing minerals.

It could be concluded from the result of this study that the Sakpe Ironstone at Jima in the northern Bida basin is a high-grade ore which requires the little beneficiation and transformation of goethite to hematite. Thus, it is potentially feasible for exploration and for the production of iron and steel. Further studies should be undertaken to estimate the reserve of the Sakpe Ironstone deposits.

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