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ARTICLE

Petrographic Study of Sedimentary Iron Ore in Shendi-Atbara Basin, River Nile State, Sudan

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ABSTRACT

This paper presents the results of petrographic study of sedimentary iron ore from surface strata of the Shendi-Atbara Basin, River Nile State, Sudan. The aims of this study are to investigate the geological behavior and geological conditions affecting precipitation of sedimentary iron ore. The methodologies have been used to realize the objectives of this study include field work, office work and laboratory work including thin sections and polished sections analysis. According to field observation sedimentary iron ore can broadly be considered as occurring in three major classes: Ferribands iron, ferricrete iron and oolitic iron ores. The modes of occurrence of iron ore were described at the outcrops and vertical sedimentary profiles revealed that the iron occurred in the study area at different types in stratigraphic sequence such as cap, bedded and interbedded conformable with Shendi Formation. Petrographic study of iron ore in collected samples using polarized microscope and ore microscope includes study of the textures and structures of ores to obtain ore history. The main types of textures and structures in studied samples are oolitic, granular, lamellar and bands. According to these results the origin of iron ore is formed by chemical precipitation during chemical weathering of surrounding areas in continental lacustrine environment. The iron ore in study area is potential for future mining works and steel industry.

1. Introduction

The study area is located in the eastern part of the River Nile State of northern Sudan between Latitudes 17°20'0" and 16°40'0" N and longitudes 33°30'0" and 34°10'0"E (Figure 1). The distance from Khartoum to the study area is about 180 Km, and can be reached by a paved road, passing through Shendi, to Atbara, following the River Nile on the eastern bank. The study area is characterized by physiographic features varying from hilly terrains as in Al Musawarat, Umm Ali and Al Bagraweya areas. In between there are lots of areas crossed by valleys such as Wadi Al Sawad, Wadi Al Hawad and Wadi Al Awatib, all of which are seasonal streams. The area is characterized by generally low relief topography with scattered stratified flat topped hills.

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There is negative relief (valleys) caused by differential erosion. The area is dominated by arid climate conditions with a hot summer season extending from March to August with temperature reaching above 45°C during the day. The average temperature is about 35°C. The rainy season is extending from July to September with less than 200 mm per year rainfall. The winter season is from November to February and the temperature drops to less than 20°C. The area is poor in vegetation, which includes Acacia trees and short grasses along the seasonal valleys. There are date palm trees along the River Nile in addition to some other crops in the terraces of the River Nile. The area is dominated by parallel to dendritic seasonal streams flow in sedimentary rocks and seems to be structurally controlled. The main direction of these streams is to the W and NW, towards the river Nile [1]. Iron is estimated to make up 32.07% of the Earth's mass and its elemental abundance varies between about 5% of the Earth's crust and as much as 80% of the planet's core. It is therefore not surprising that there are a number of commonly occurring iron minerals and many iron ore deposits found at the surface of the earth. Suggested that just one of the iron-enrichment deposits types alone, derived from iron formations, represents the largest and most concentrated accumulation of any single metalliferous element in the Earth's crust. The term “iron ore” is used here as an economic term to refer to iron-bearing deposits and products that have been, are being, or could be expected to be exploited economically for their iron content. Any uneconomic iron accumulations are simply referred to as iron mineralization. The sedimentary iron ore is one of the largest deposit in the Sudan, and its reserve is estimated at 1351 million cubic meters at 30%Fe average grade. It is found in many occurrence modes; multiple layering in plateau and mesas, due to repeated sedimentary cycles, ore and sediments intercalated allochthons at meanderings, inselbergs, compacted boulders and massive biogenic ooze.

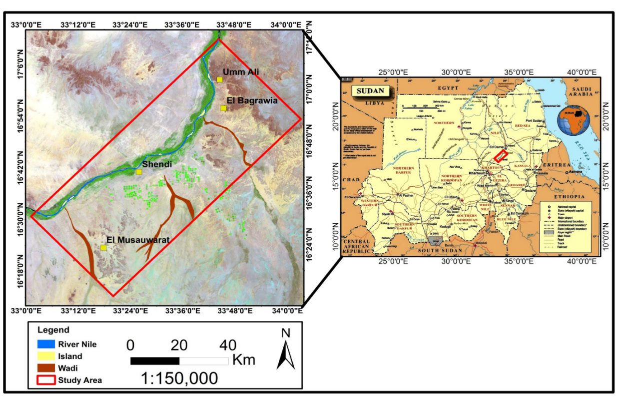

Figure 1. Location map of the study area

2. Geology of the Study Area

The main geological units are composed of Basement Complex (Pre-Cambrian), Upper Cretaceous Sedimentary Formation (Nubian sandstone), Hudi Chert (Oligocene) and Quaternary superficial deposit (Figure 2) in ascending chronological order [2].The stratigraphic sequence has been established as follows:

2.1 Basement Complex

Basement complex includes Igneous, Metamorphic & Metasedimentary rocks that overlain by Palaeozoic or Mesozoic sedimentary or igneous rock and they are mainly of Pre-Cambrian age [2, 3]. A good example is the Sabaloka Ring Complex that appeared to be of Cambrian age according to [4] the oldest rocks exposed in the central Sudan include an ancient group of crystalline gneiss and schist, metamorphic rocks and granites [5]. Representatives of this unit crop out in four places namely, in the sabaloka inlier north of the capital, west of the White Nile between Omdurman and Ed Dueim, east of the blue Nile in the parts of the Butana plains and south of the Gezira between Sennar and Kosti, elsewhere younger deposits cover them (Figure 2).

2.2 Shendi Formation (Upper Cretaceous Sandstone)

Kheiralla, M. K.[6] introduces the name quartzose sandstone to describe siliciclastic sedimentary rocks cropping out in Shendi area. These are well bedded, non-pebbly, clean, well sorted sandstone which contain ripple marks, rib and furrow structures. The sandstone contains mainly of quartz coated with iron oxide with interstices filled with ferruginous matter. A formal lithostratigraphic nomenclature of the units was given by [2] who proposed the name Shendi formation whose type locality is represented by outcrops north east of kabushiya village, River Nile state. The lithological evidence, from shallow borehole and the kandaka-1 well permits a downward extension of Shendi formation to include the mud-dominated lithofacies mainly identified. Consequently, the Shendi formation has been formally subdivided into two members: the umm Ali member and the Kabushiya member. The former, was mainly identified from boreholes with its type section located approximately 100m south of Umm Ali village. The type section previously selected to describe Shendi Formation [2] has been retained for the Kabushiya member. Lacustrine to fluvial-lacustrine condition could have prevailed during deposition of the Umm Ali member, while fluvial-dominated setting characterizes the Kabushiya member. Ter-

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restrial palynomorph of Campanian - maastrichian age were reported with the subsurface part of unit represented by Kabushiya member and the upper most part of the Umm Ali Member (Figure 2).

2.3 Hudi Chert (Tertiary Sediments)

The represents in hudi chert which composed of sub-rounded boulders, yellowish brown in color, which range in size from 5 to 20 cm. The rocks are very hard and fossiliferous with Gastropods fossils. The hudi chert was first identified by [7] from hudi railway station about 40 km NE of Atbara and later studied by [8, 9, 2]. The hudi chert rocks were regarded as lacustrine chalky deposits that have been silicified into chert [8]. The source of silica was probably from silica flow from the young volcanic activity of Jebel Umm-Marafieb of NW Berber. [7] Reported that the hudi chert is an upper Eocene/lower Oligocene Formation, which contains some types of fossils such as Gastropods and plant fossils. The sediments of Jebel Nakhara Formation represent part of the Nubian Sandstone Formation Hills from Shendi-Atbara region [6]. These rocks of Jebel Nakhara Formation are exposed west of the River Nile between the Cenozoic volcanic and the Nile. The Jebel Nakhara Formation mainly comprises sandstones with varying grain size, siltstones, mudstones and conglomerates. They overlie the basement discordantly and in turn covered uncomformably by Cenozoic volcanic. They are poorly sorted, coarse to medium-grained in texture and mainly consist of quartz and some clay minerals as the main components. Trough cross bedding, tabular cross bedding and graded bedding structures are common sedimentary structures. There is a general agreement that these sediments have been deposited mainly in Tertiary time [6] while [2] suggested a Cretaceous age to the same sediments (Figure 2).

2.4 Cenozoic Volcanic

First descriptions of these volcanic were given by [9, 10] described them in more detail and related them to Tertiary-Quaternary volcanic activity[11, 12] suggested a late Pliocene to Recent ages for the younger Bayuda volcanic rocks based on the slight degree of erosion. In Bayuda the lava flows cover both the Precambrian basement and the Tertiary Sandstone Formation. The outcrop is faulted in the eastern side of Jebel Nakhara, thus showing the unconformity relationship with the underlying sandstone. Their extrusion is connected with post-Nubian N-S and E-W striking faults [13]. They are assumed to be NW extensions of the great East African Rift System (Figure 2).

2.5 Superficial Deposits

The superficial deposits include wadies and galley deposits which course the Jebels. Recent fan deposits that emerged from the out crops and consist of poorly sorted sediments redeposit from pre-existing sedimentary boulders, fragments and leached coarse and fine sediments. North to Shendi area numerous mobile sediments consist of well sorted medium to fine sand, are covering the underlying Shendi formation and extend to the east and north east to the river Atbara boundary. The superficial deposits in Buttana include the clayey soil covering the flat plains, in addition to the valley fill and the deltaic deposits which are seasonally transported by the ephemeral streams during the rainy season. The valley deposits cover the drainage beds and are mainly composed of sands and pebbles. The superficial deposits in Bayuda include gravels, sands, clays, sandy clays and silt. The alluvial deposits are very thick around the River banks consisting mainly of dark clays and clayey silt with fined-grained sands used for Cultivation. The Wadi alluvial consists of fined to medium-grained sands, which form the middle and lower courses of the Wadis, while the upper parts are covered with unconsolidated coarse sand and fine gravels. Superficial deposits in Sabaloka include Nile silts, alluvial fans, Aeolian sands and lag gravels, sandy residual soils [14] (Figure 2).

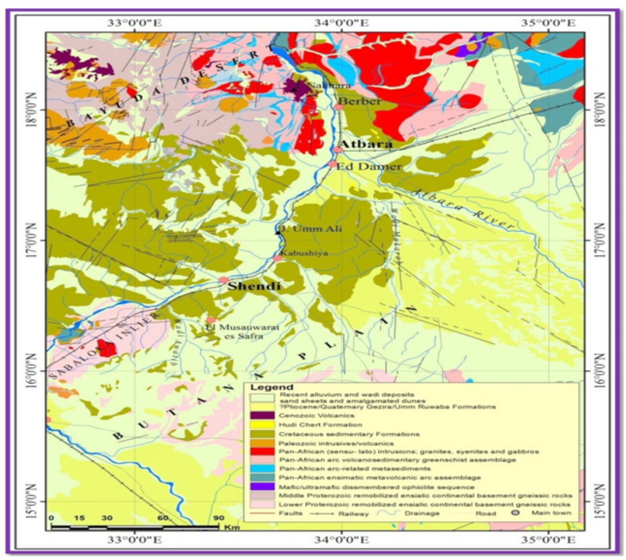

Figure 2. Geological map of the study area

3. Objectives of This Study

The main objectives of this study are:

•Investigate the geological behavior of the iron ore in the study area.

•Investigate the modes of occurrence of iron ore in the

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out crops.

•To study the Textures and structures of ore deposits to obtain ore's history.

•Determine the origin and gneiss of iron ore in the study area.

•Determine the potentiality of iron ore to industrial uses.

4. Methodology

Eleven representive samples were taken during field work from the surface strata of the Shendi -Atbara Basin have been analyzed in this study. Occurrence of iron ore was described at the outcrops and representative rock samples were collected from each of the 12 localities. Thin sections from various samples were prepared, partly at the laboratories of Al Neelain University and partly at Central Petroleum Laboratories (CPL) in Khartoum. They have been studied under the polarized microscope to determine the mineralogical composition, textural and microstructural characteristics. Similarly, polished sections from iron ore deposit were made and examined using ore microscope. The mineral paragenesis, textures and structures of the ores have been studied at the laboratories of Khartoum University.

5. Results and Discussion

The geological and structural setting of the iron ores bearing areas evaluation of the available information. In study area, several types of iron accumulations occur in a widespread distribution within and on top of the sediments of the Nubian formation in an area of approximately 50km in diameter between the cities of Shandi, Kabushia and Atbara. The iron stone beds attain a maximum thickness of approximately one meter (Figure 3). They occur within fluvial sediments on the Shandi formation. The Shandi-Kabushia region lies within the Atbara rift system, an asymmetric half-garben structure which is characterized by locally high subsidence rate as indicated by the maximum depth of the basin of approximately 3100m. The structural control of sedimentation is indicated by the lateral facies association. The outcropping sediments seem to be deposited in the sag-phase of the graben development. The fining upwards sequences begin with the erosional surfaces pass upwards into trough and tabular cross-bedded sandstone and finally into ripple cross-bedded or laminated fine grained sand. Deposits of oolitic ironstones occur mostly on top of bioturbated fine grained sediments. Within this meandering river environment also extensive flood plain sediments occur with this meandering river environment also extensive flood plain sediments occur which yield lens-shaped deposits of kaolin (Figure 3). The (Nubian strata) belong to the upper-most cretaceous to tertiary cycle of a sequence of three mega-cycle. Most of the strata studied consist of clastics deposited mainly in alluvial environment. Facies and thickness of the sediments strongly depend on the structural evolution which is late-Jurassic to early cretaceous time (Figure 3, 4, 5, 6).

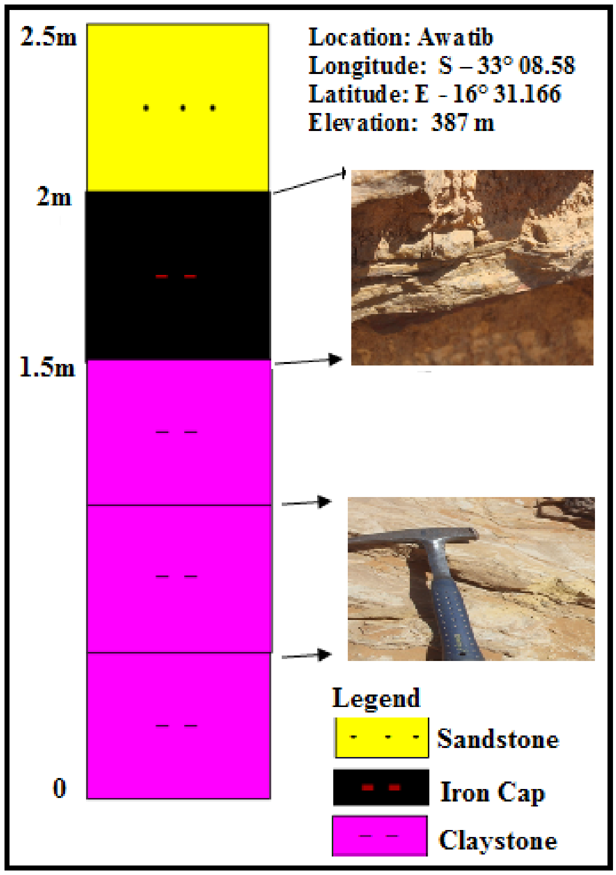

Figure 3. Vertical sedimentary profile showing iron ore capping clay stone in the sequence of Awatib area

5.1 The Iron Ores

Deposits of the ferruginous sediments are very abundant within and on top of the cretaceous and tertiary sediments of the Shendi-Atbara Basin. Three genetic groups can be distinguished in this study they are:

•Thin bands of ferruginous sediments (ferribands).

•Ferricrete capping on hills.

•Beds of fluviatile oolitic ironstones.

Two phases of ferricrete formation can tentatively be distinguished. Ferricrete sandstone on an early tertiary erosion surface is abundant around Shendi and Atbara. Oolitic ironstone within fluviatile sediments of the mid cretaceous Shendi formation has been discovered in locally widespread distribution. Stemming from the close sim-

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ilarities of continental and marine iron oolites, a common origin in made probable. As iron ooliths have been detected also being formal in-situ within ferricrete it appears to be possible to interpret marine and alluvial oolitic ironstone as being derived from ooliths formed in ferricrete, thus representing (a lateritic derived facies).

5.1.2. The Ferribands

Thin bands of less than 50cm in thickness occur within the sedimentary strata (Figure4). They are very common at the contact of different lithology especially when there is an abrupt change in grain sizes on both sides of permeability boundary (Plate 7 B). The fine grained as well as the coarse grained sediments are ferruginized by secondary impregnation of iron oxides and o hydroxides. Iron enrichment also occurs along bedding plane. Iron impregnated clay and siltstones are oftenly finally laminated (Plates 1, 2, 3). Mineralogical associations and textures characterized by banding resulting from the interlayering of oxides and silica , both on a coarse and a fine scale; the units may be lenses rather than layers, giving a "wavy“ appearance to the stratification (Plates 1, 2, 3).

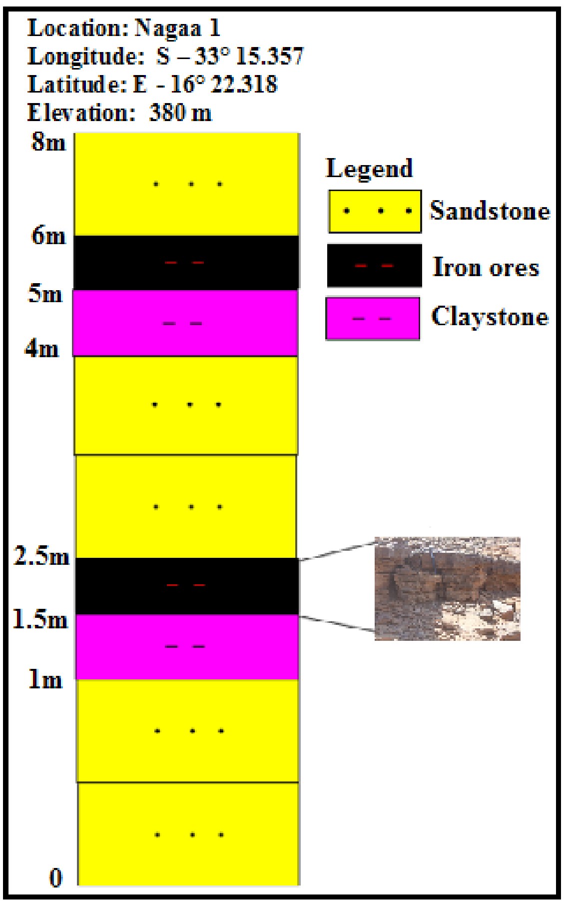

Figure 4. Vertical sedimentary profile showing two beds of iron ore in the sequence Alnagaa1 area

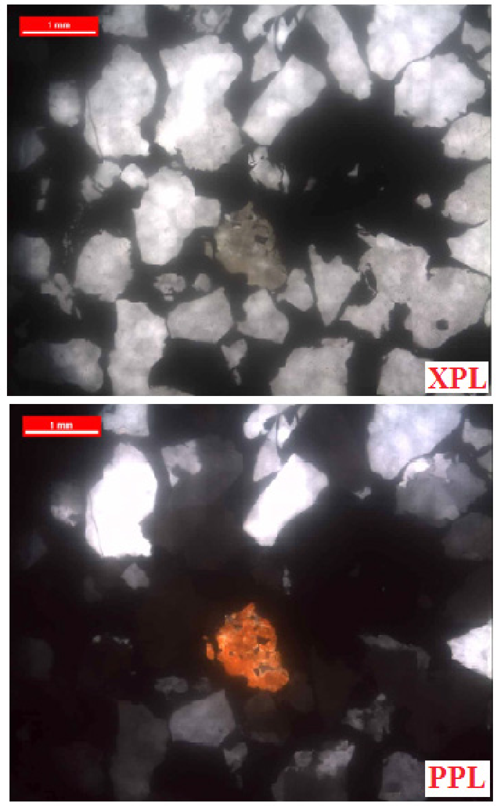

Plate 1. Photomicrograph showing the Iron oxide cement medium to coarse sub round quartz grain, Rock fragment - Alnagaa1 area

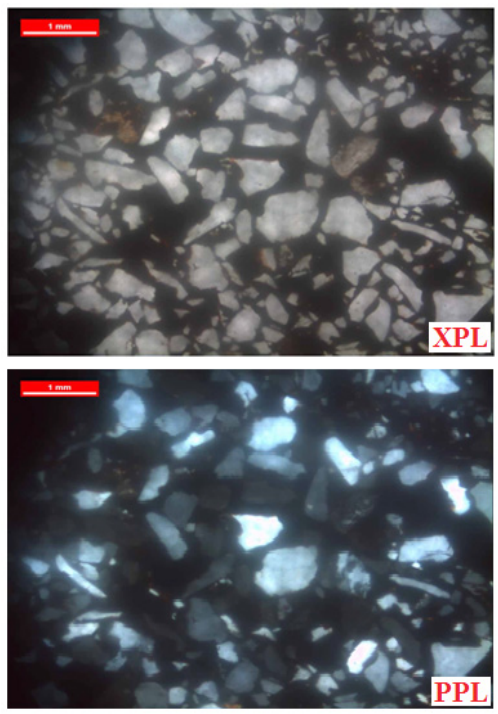

Plate 2. Photomicrograph showing light color (brownish), granular texture, angular to sub angular grains (mainly quartz); iron ore matrix fine grain - Alkarbican area

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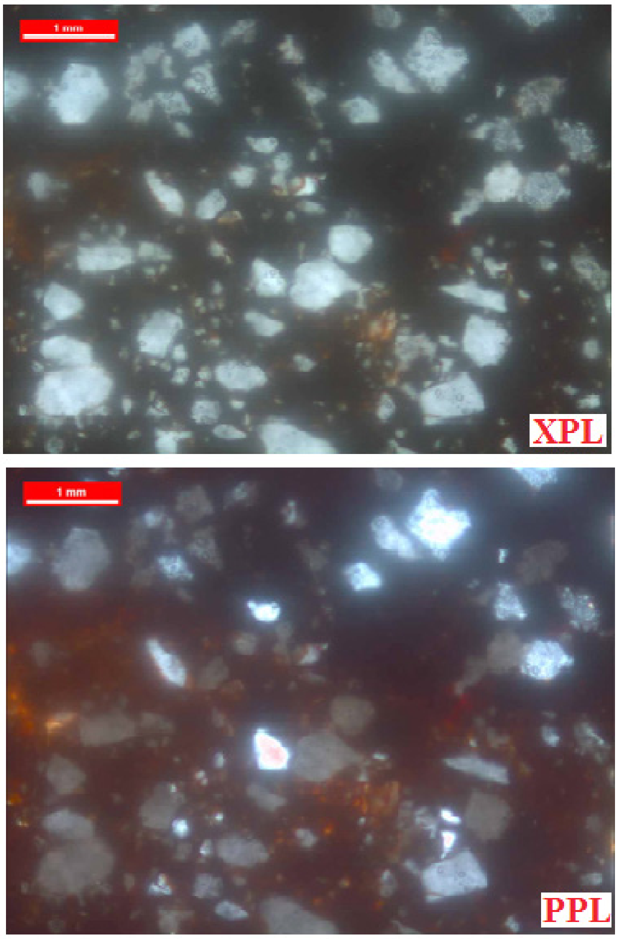

Plate 3. Photomicrograph showing the light color (brownish), granular texture, showing manganese (black) and iron (red) cements surrounding quartz - Musawarat 3 area.

5.1.2. Ferricretes

They may attain a thickness of several meters and occur mainly on flat top or mesas (Figure 5). They are massive to vesicular pisolitic, nodular or vermiform in characters (Plate 4, 5, 6). Rocks consisting of nearly pure iron oxides and oxihydroxides occur as well as kaolinitic or quartz rich ironstones forming granular textures (Plate 7 A, B, C, D). Ferricrete are considered to be the residual products of lateritic weathering processes and thus form the top horizon of a deep weathering profile. In Goz Alhaj area microscopically the slab composed mainly of iron oxides cemented by silicates minerals and carbonates (Plate 10 B). The iron oxides mainly hematite, goethite and limonite appear as oolitic to pisolitic and sometimes peletal grains that partially replaced by interlayered limonite and hematite some of oolith and peletal have formed around sand grains. Minor pyrite is also detected. The sample is sand facies iron ores (Plate 4, 5, 6).

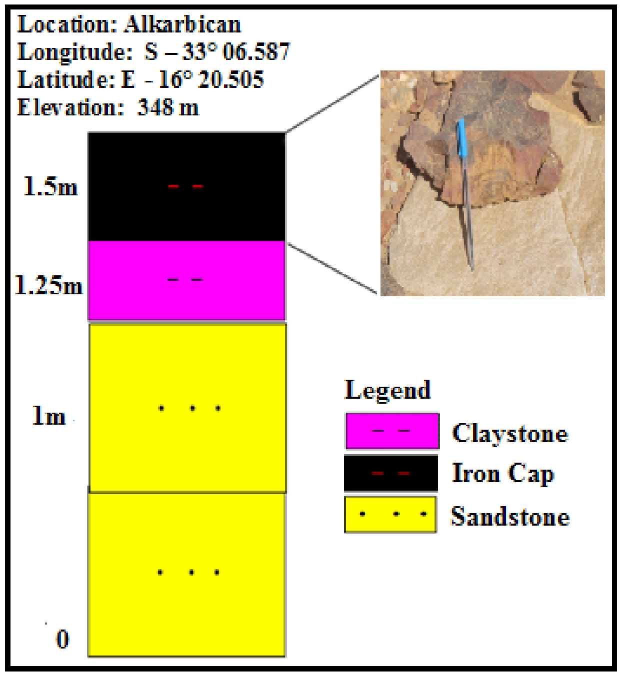

Figure 5. Vertical sedimentary profile showing iron cap in the sequence of Alkarbikan area.

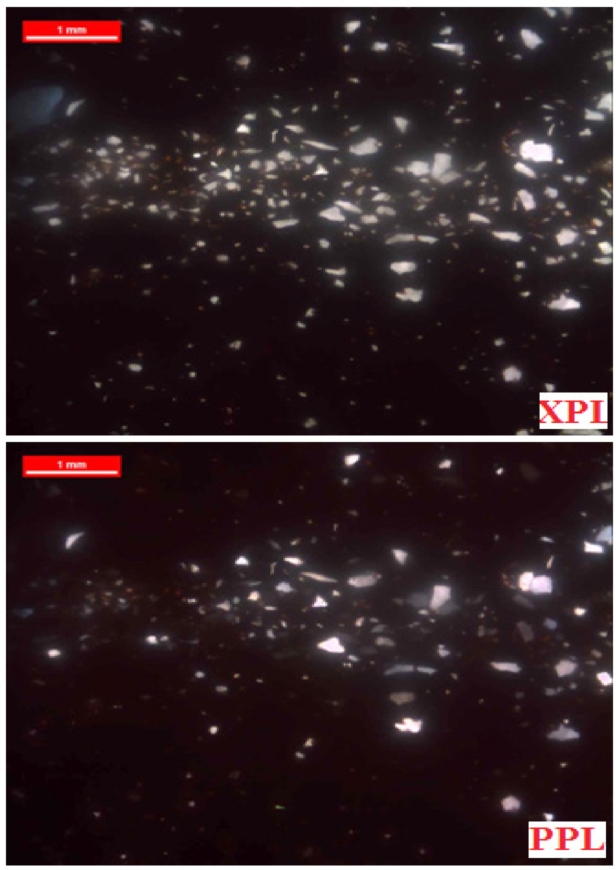

Plate 4. Photomicrograph showing interlayering of oxides and silica Typical banded iron formation assemblages and textures, Layered subhedral - Awatib area.

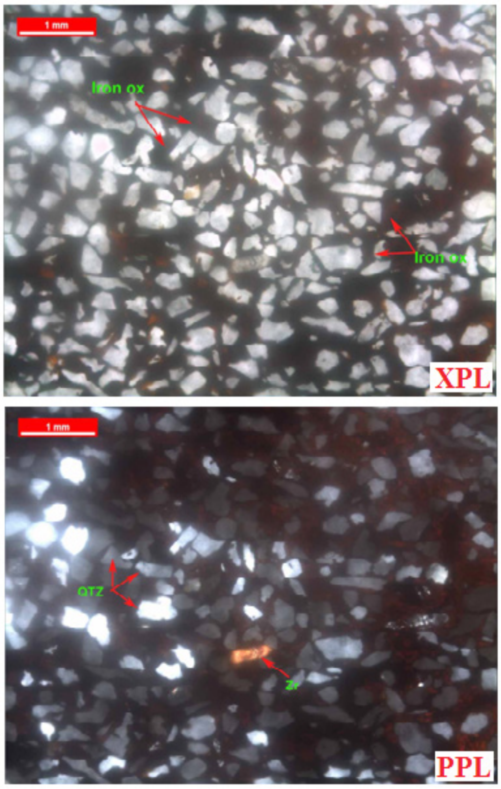

Plate 5. Photomicrograph showing light color (brownish), granular texture, angular to sub angular grains (mainly quartz); iron ore matrix fine grain - Awatib area.

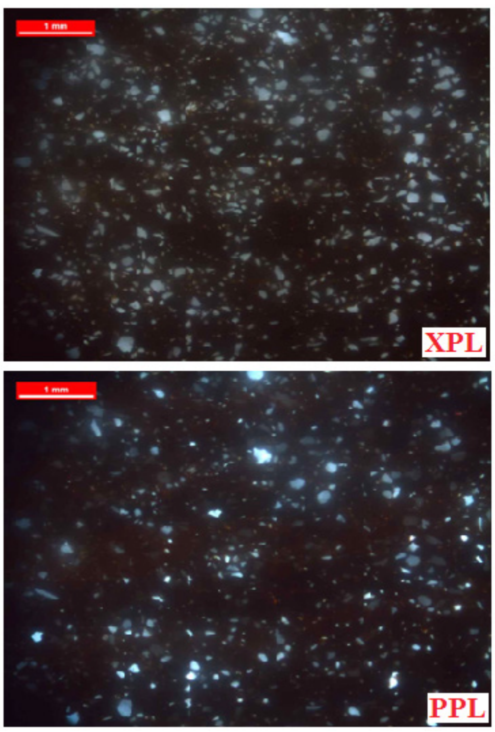

Plate 6. Photomicrograph showing light color (brownish), shows the typical rounded to subrounded quartz grains - Bigrawiah area.

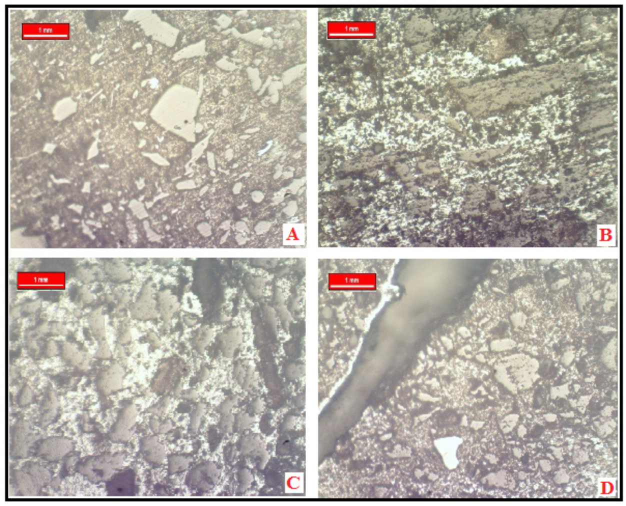

Plate 7. Showing: (A) Photomicrograph of the Magnetite is detected as euhedral crystals cubic to tabular - Alkarbican area. (B) Photomicrograph of the layering of iron oxides and silicates in banded iron formation - Awatib area. (C) Photomicrograph of the Iron oxide cementing the silicates minerals - Bigrawiah area. (D) Photomicrograph of the Iron oxide magnetite detected as a vein together with silicates - Bigrawiah area.

5.1.3 Oolitic Ironstone

Oolitic ironstones are found in many localities within the area extending between Shendi, kabushia and Eldamer, The ironstone beds attain a maximum thickness of approximately one meter (Fig 6). They occur within alluvial sediments on Shendi Formation. They occupy the top of bioturbated fine grained sediments. The iron oolities are mostly moderately to well sorting. The in- situ fragmentation of ooliths along desiccation cracks can be traced from complete ooliths to single fragments. Plastically deformed ooliths and spatolihs are missing in oolitic ironstones of fluvial environments. In some cases oolite outcrops occur on the Shendi Togni erosion surface. These oolites might be related to ferricrete formation of Tertiary age. In contrast to the intra sedimentary Cretaceous oolitic ironstones they abundantly consist of aggregates of ooliths which are surrounded by secondary cortex of goethite. Such pisolith like structure occurs within a reworking horizon above oolites. In Umm Ali area, oolitic ironstones were found at the upper most strata of the succession (Plate 8). This directly relates to the Phanerozoic ironstones because many such types of ironstone are oolitic and ooids can be composed of hematite (red), berthierine-chamosite (green), goethite (brown) and, rarely, magnetite (black) (Plate 9). Phanerozoic ironstones are mostly thin successions of limited areal extent, interdigitating with normal-marine sediments. They commonly weather to a rusty yellow or brown color at outcrop. Some ironstone feels heavy relative to other sedi-

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ments. The texture is similar to oolitic ironstones. Most of the biogenic structural forms are rounded, tabular or concretions as most forms of oolites. They all follow the same systematic sequence of burial depth and organic matter existence at the oxidation zone (Plate 10 A, B). In Um Ali area the ore composed mainly of oolitic and peletal iron oxides cemented by silicates and carbonates (Plate 8). The oolith contained chamosite, hematite, and lemoite together with goethite. Minor magnetite, pyrite are also detected. Iron minerals occur dominantly as concentric quartz grain coatings and intestinal filling (Plate 10 C, D).

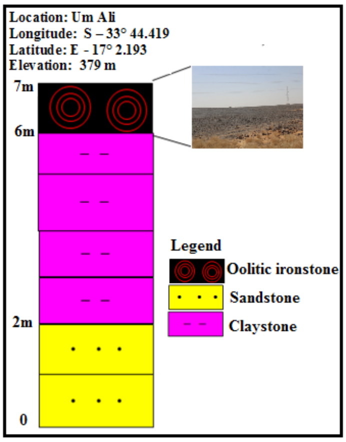

Figure 6. Vertical sedimentary profile showingoolitic ironstone in top sequence of Um Ali area.

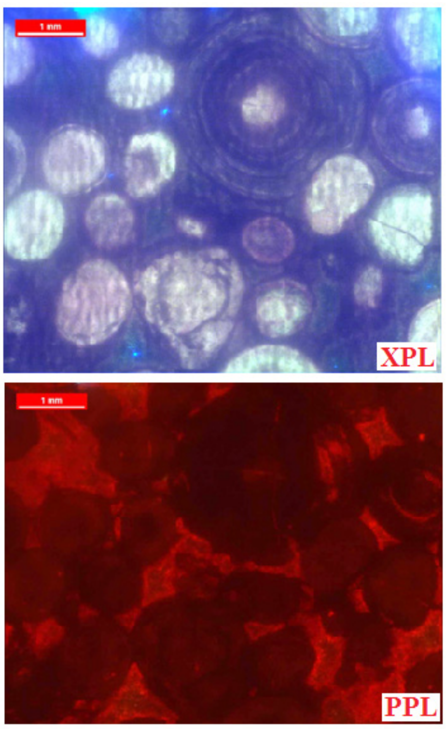

Plate 8. Photomicrograph showing the zonation of the iron (oolites), Textures observed in typical oolitic ironstones-Um Ali area.

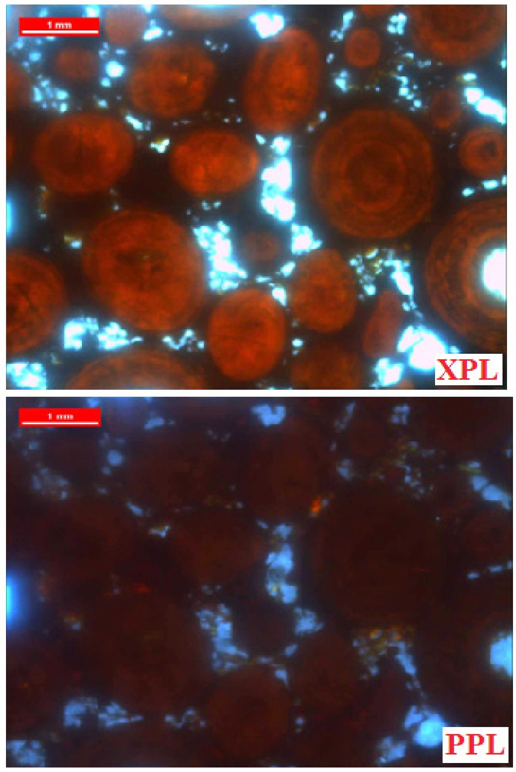

Plate 9. Photomicrograph showing the zonation of the iron, Textures observed in typical oolitic ironstones. Distorted ooliths comprised of fine-grained chamosite, Hematite and goethite - Goz Alhaj area.

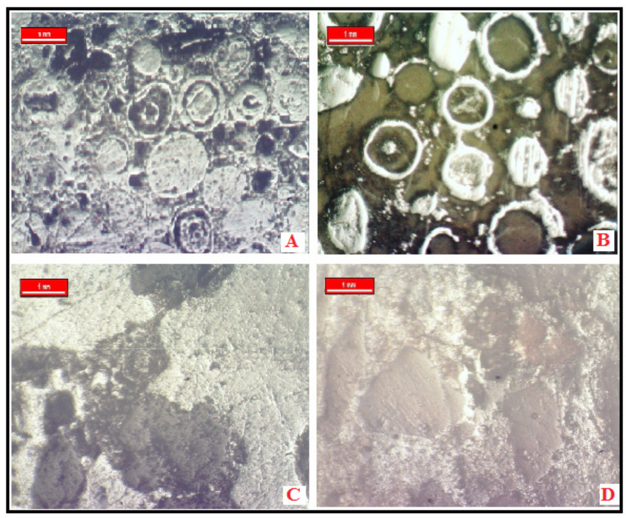

Plate 10. Showing: (A) Photomicrograph of the Oolitic and peletal iron oxides cemented by silicates and carbonates -Um Ali area. (B) Photomicrograph of the slab composed mainly of iron oxides cemented by silicates mineral and carbonates - Goz Alhaj area. (C) Photomicrograph of the very clear tabular euhedral iron oxide surrounding by manganese and silicates minerals - Nagaa 1 area. (D) Photomicrograph of the iron oxides is mainly magnetite and hematite together with goethite - Nagaa 2area.

6. Conclusions

The present work has been carried out according to a plan including office work, field work, laboratory work. Eleven representive samples were taken during field work from the surface strata of the Shendi -Atbara Basin has been analyzed. Occurrence of iron ore was described at the outcrops and representative rock samples were collected from the 12 localities covering an area under study. Samples have been studied under the polarized microscope to determine the mineralogical composition, textural and microstructural characteristics. Similarly, polished sections from iron ore deposit were made and examined using ore microscope. Sedimentary iron ore can broadly be considered as occurring in three major classes: Ferribands iron, ferricrete iron and oolitic iron ores. Vertical sedimentary profiles revealed that the iron ores in the study area are different types in stratigraphic sequence such as cap, bedded and interbeded. Petrographic study of iron ore in collected indicates that the main types of textures and structures in studied samples are oolitic, granular, lamellar and banded. According to field observation, Vertical sedimentary profiles and petrographic study the origin of iron ore was formed by chemical precipitation during chemical weathering of surrounding areas in continental lacustrine environment.

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