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

Abubaker A. M. A. Abasher[1], Sadam H. M. A. Eltayib[1]*, El Sheikh M. Abdelrahman[2], Mohammed M. A. Amlas[1]

[1]*International University of Africa, Department of Economic Geology Faculty of Minerals and Petroleum, Khartoum, Sudan*
[2]*Al Neelain University Department of Mineral Resources, Faculty of Petroleum and Minerals, Khartoum, Sudan*

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Contact
*Sadam H. M. A. Eltayib
sadam_h3@yahoo.com

ABSTRACT

This paper emphasized on the geochemistry of sedimentary iron ore of Shendi -Atbara Basin, River Nile State, Sudan. The main geological units in the study area are composed of Basement Complex (Pre-Cambrian), Nubian Sandstone Formation (upper Cretaceous), Hudi Chert (Oligocene) and Quaternary superficial deposit in ascending chronological order. The aim of this study is to investigate the geochemical behavior and geochemical conditions affecting precipitation of sedimentary iron ore. The methodologies have been used to realize the objectives of this study included; fieldwork, geochemical data analyses. Geochemical investigation of studied samples includes chemical analysis such as major oxide analysis (Fe_2O_3, SiO_2, Al_2O_3, CaO, K_2O and Na_2O) and trace element analysis (Cr, Co, Cu, Zn, Mn and Ni) using Atomic Absorption Spectrometry (AAS). The results showed that the origin of iron ore is formed by chemical precipitation during chemical weathering of the rocks from surrounding areas. The study of iron ore showed that, the environmental conditions under which iron ore are formed were lacustrine environment and warm temperature. Concentration of Fe_2O_3 in the study area ranges between maximum 79.52% in Goz Alhaj area to minimum 27.22% in Alkarbican area and the average is 53.37% indicate that the quality of iron ore is good according to international standards. All these results have been to construct isoconcentration maps of the iron ore distribution in study area and potentiality for future mining works.

1. Introduction

The study area is located in the eastern part of the River Nile State of northern Sudan between Latitudes 17º20’0“and 16º40’0“N and longitudes 33º30`0“and 34º10’0“E (Fig. 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. There are negative relief (valleys) caused by differential erosion. It is noticeable that all water sources flow westward to the Nile, and take straight paths, which are probably controlled by faults. The area is dominated by arid climate conditions with a hot summer season extending from March to August with temperature reaching above 45 ºC during the day. The average temperature is about 35 ºC. The rainy season is extending from July to September with less than 200 mm per year rain fall. The winter season is from November to February and the temperature drops to less than 20 ºC. 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 (Abdel Mageed, 2006; Abubaker, 2020).

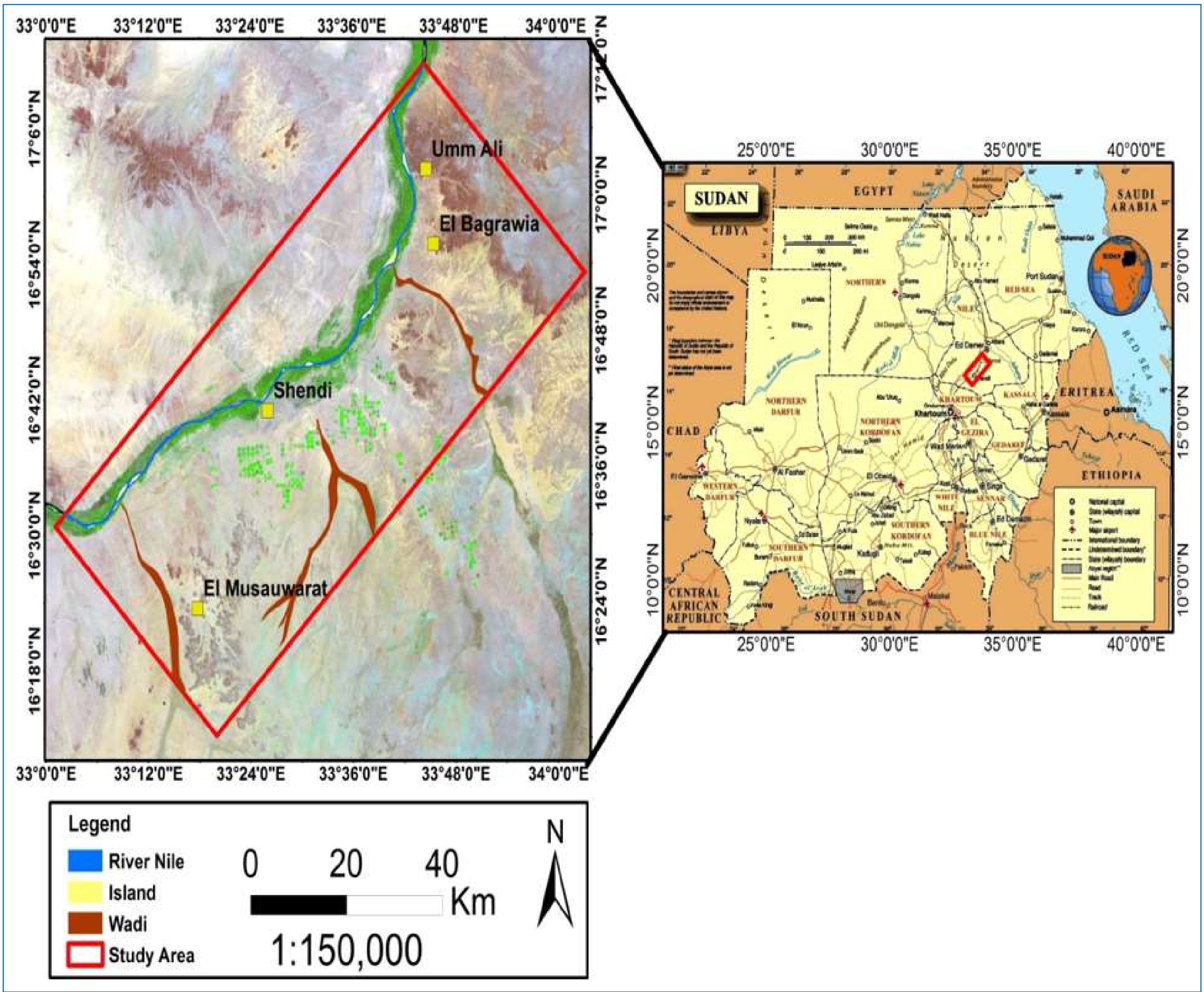

Fig. 1. Location map of the study area

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 (Fig. 2) in ascending chronological order (Whiteman, 1971; Vail, 1983; Vail, 1985; Vial, 1988). The basement complexes include igneous, metamorphic and metasedimentary rocks that overlain by Palaeozoic or Mesozoic sedimentary or igneous rock and they are mainly of Pre-Cambrian age (Whiteman, 1971). Kheiralla (1966) introduce the name quartoze sandstone to describe silisiclastic 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 Whiteman (1971) 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. Whiteman (1971) 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. Terrestrial 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 (Abdullatif, 1993).

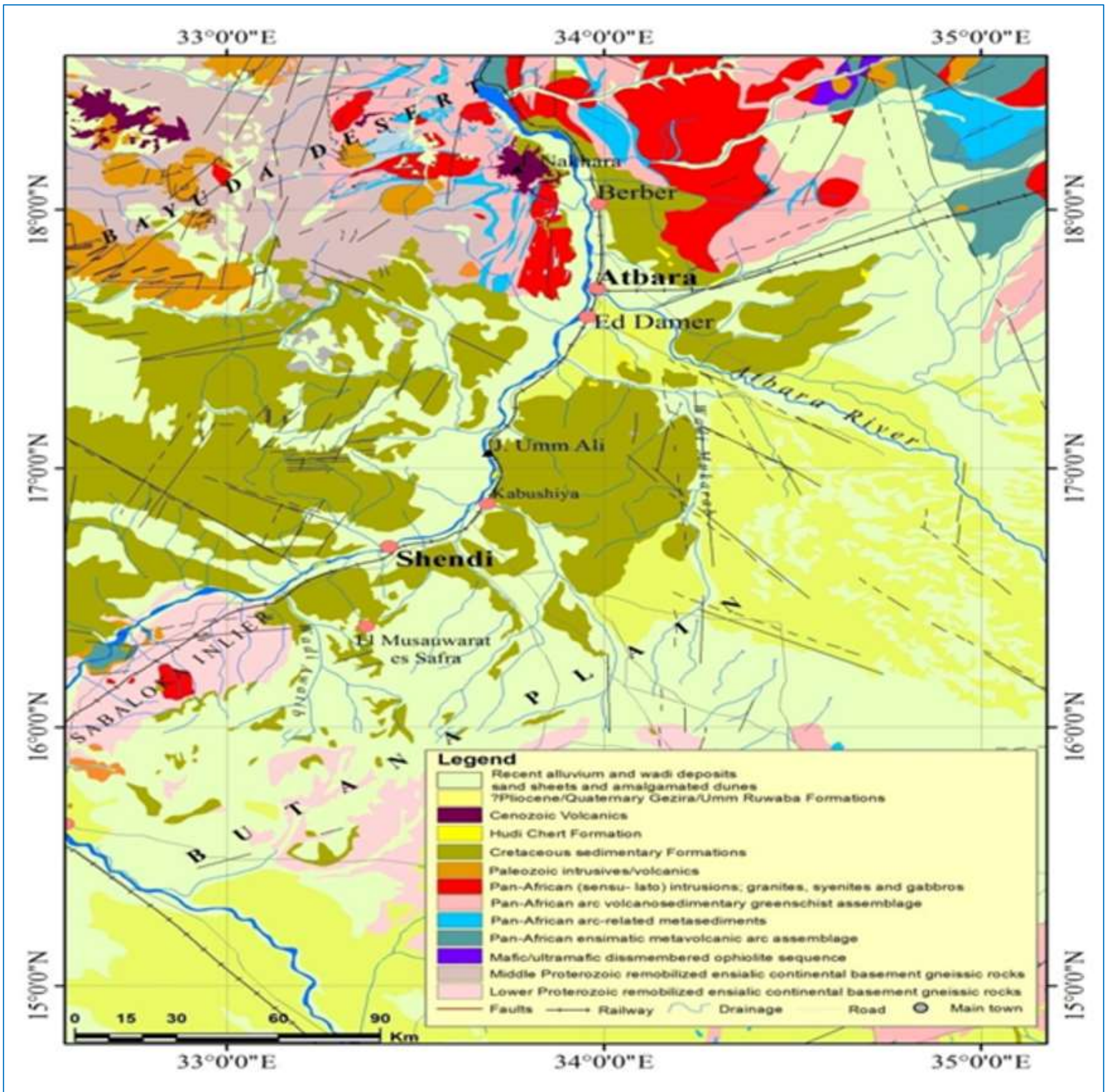

Fig. 2. Geological map of the study area and vicinity

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 (Abdullatif, 1995). The Hudi Chert was first identified by Cox (1932) from Hudi Railway Station about 40 km NE of Atbara and later studied by Andrew and Karkains (1945), Andrew (1948) and Whiteman (1971). The Hudi Chert rocks were regarded as lacustrine chalky posits that have been silicified into chert (Andrew and Karkains, 1945). The source of silica was probably from silica flow from the young volcanic activity of Jebel Umm-Marafieb of NW Berber. Cox (1932) 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 (Kheiralla, 1966; Ahmed, 1998). These rocks of Jebel Nakhara Formation are exposed west of the River Nile between Cenozoic volcanic and 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 (Hamed 2005). 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 times (Kheiralla, 1966) while Whiteman (1971) suggested a Cretaceous age to the same sediments. First descriptions of these volcanic were given by Andrew (1948) and Vail (1971) described them in more detail and related them to Tertiary-Quaternary volcanic activity. Almond et al. (1969) and Almond (1977) 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 (Vail, 1978). They are assumed to be NW extensions of the great East African Rift System. The superficial deposits include wadies and galley deposits which course the Jebels.

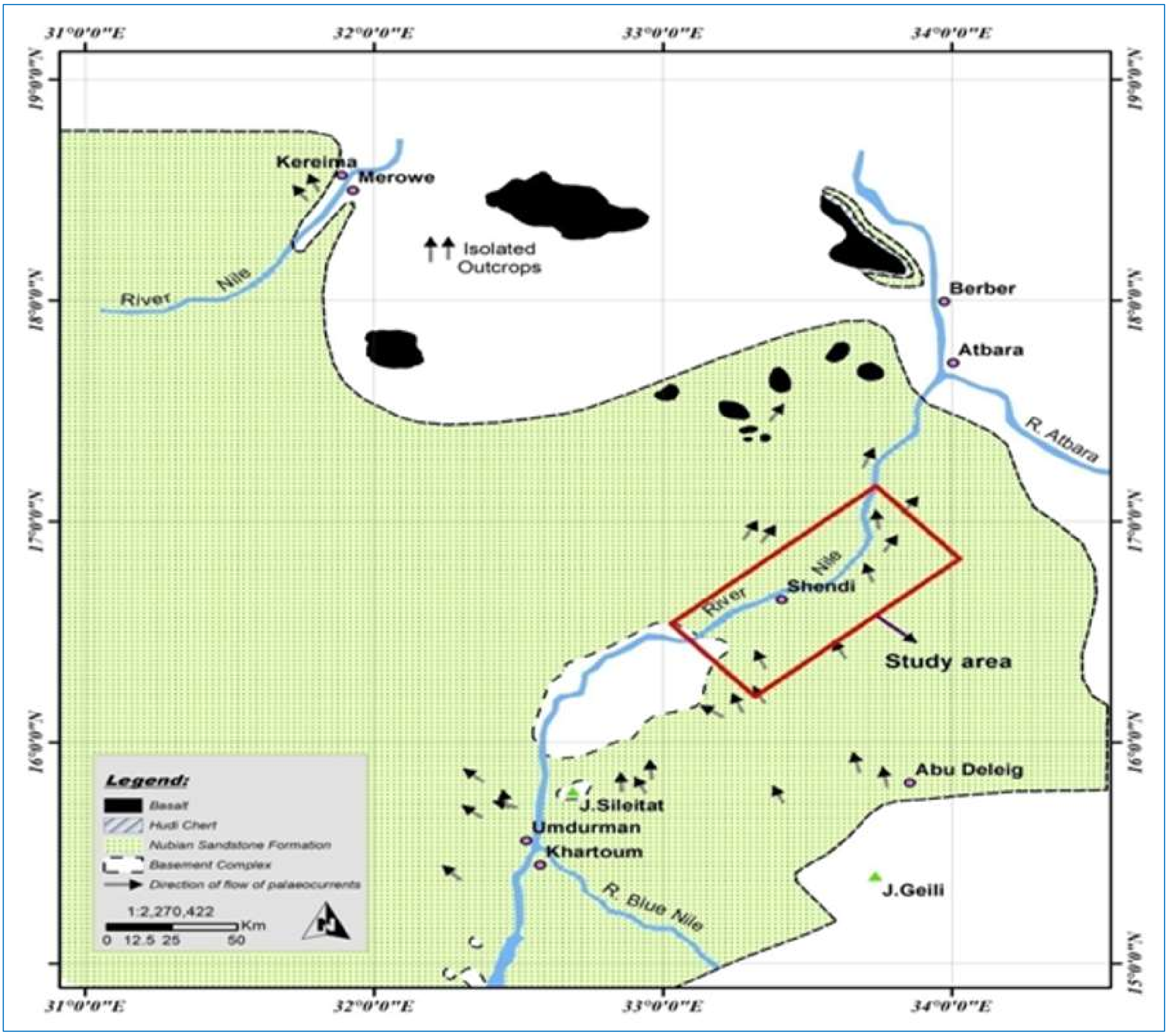

Fig. 3. Nubian Formation paleocurrent direction map, Khartoum, Shendi, Merowe region based on Kheirallah (1966), (modified after Abubaker, 2020)

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 (Abdirasak, 2019).

3. Objectives of Study

The main objectives of this study are the following:

- Investigate the geochemical behavior of iron ore in the source area.
- Investigate the geochemical conditions effecting of precipitation of iron ore in the study area.
- Determine the distribution of Fe_2O_3 in the study area.
- Construct isoconcentration map of the iron ore in the study area.

4. Methodology

The present work has been carried out according to a plan including office work, field work, and laboratory work. A total number of 12 rock (grab) samples weighting 13 kg each were collected from the area. The occurrence of iron ore was described at the outcrops and representative rock samples were collected from each of the 12 sites. Rock samples were prepared, partly at the laboratories of Al Neelain University and partly at Central Petroleum Laboratories (CPL) in Khartoum. The AAS was used to measure major and trace elements in the samples collected. The analytical data have been processed using special computer software and statistical methods have been used to determine the geochemical parameters for rocks in the study area.

5. Results and Discussion

5.1. Geochemical behavior of sedimentary iron ore

Geochemical process of selective concentration of elements is controlled by the dynamic tectonic evolution of earth in the geological time scale of millions of years. Iron crystallizes out from magmatic melt if the evolved basaltic melt is highly enriched with Fe (high chemical activity of Fe) and suitable pressure temperature (thermodynamic) condition to stabilize spinel magnetite and ilmenite. Iron is soluble in atmospheric Eh-pH conditions and is amenable to precipitate as hydroxide, oxyhydroxide, carbonate and sulphide in localized change in Eh-pH. The silicate minerals weather to release Fe which precipitates as goethite, chamosite, siderite, pyrite in sedimentary geochemical environment depending upon the low-temperature thermodynamics prevailing in the depositional site. The phase transition to magnetite and hematite is also possible during metamorphism and martitisation. So, concentration of iron in geological set up can occur in widely varied conditions from lacustrine to marine, even magmatic to metamorphic. While sedimentary iron deposit is associated with sedimentary rocks and to their metamorphic equivalent in case the terrain is metamorphosed, the magmatic iron deposit is associated with basalt and metabasalt.

It is also suggested that hydrothermal action can selectively leach out carbonate-silicate metasediments with supergene enrichment of Fe (Dymek and Klein, 1988). In study area, paleocurrent direction map shown Fe leached and migrated during chemical weathering of primary basic minerals in source area to depression of Shendi Atbara basin and precipitated conformably with Shendi Formation (Fig. 3).

5. 2. Geochemical signature of iron ore

Magmatic magnetitic iron ores are derived from Fe-rich evolved magma derived from the crystallization of basaltic melt. These ores are associated with gabbro-anorthositic suite and hence are associated with plagioclase, clinopyroxene, orthopyroxene, and olivine. Magnetite, Martite is the main minerals with ilmenite and rutile as exsolution (Levinson 1980). The ore body use to contain the portion of gabbroic and anorthositic lamellae and spinel group of minerals. Hence, they contain significant amount of MgO, higher concentration of Ni, Zn, Cr, Co (Tables 1 and 2).

Iron formation facies are of oxide type, silicate type, carbonate type and sulphide type depending upon the thermodynamics of the depositional environment. It is to note that the dominant mineralogy of iron bearing phase differs (Hematite, magnetite, siderite, pyrite) and also their Ethological attributes and host rock (chert, quartzite, jasper, dolomite, argillite/shale, tuft). The shale/tuff in these deposits is very often found altered to. gibbsitic-kaolinitic-litho unit.

Table 1. Showing the results of the chemical analysis (major oxides) of the samples using AAS

Sample Code	Location	Fe_2O_3%	SiO_2%	Al_2O_3%	CaO%	K_2O%	Na_2O%
1	Alkarbican	27.22	55.64	9.71	0.68	0.01	0.09
2	Awatib	52.00	34.4	11.37	1.24	0.13	0.11
3A	Bigrawiah 1	49.92	35.0	8.15	1.06	0.01	0.08
3B	Bigrawiah 2	48.09	40.38	8.05	0.83	0.02	0.07
4	Um Ali	77.24	8.38	6.04	0.54	0.00	0.07
5	Goz Alhaj	79.52	9.27	5.84	0.80	0.01	0.10
6	Musawarat 1	46.81	44.27	5.03	0.78	0.00	0.06
7	Nagaa 1	28.49	74.14	12.33	0.39	0.15	0.09
8	Nagaa 2	42.60	44.84	7.04	0.81	0.08	0.09
9	Musawarat 2	46.64	45.77	4.49	0.48	0.04	0.11
10	Nagaa 3	31.09	59.83	8.05	0.71	0.01	0.09
11	Musawarat 3	60.87	25.43	5.79	0.74	0.04	0.08

Table 2. Showing the results of the chemical analysis (trace elements) of samples using AAS

Sample Code	Location	Ni (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	Co (ppm)	Cr (ppm)
1	Alkarbican	29.3	266.5	164.4	51.2	14.8	41.4
2	Awatib	7.2	263.6	79.5	57.7	7.5	43.7
3A	Bigrawiah 1	34	806	97.7	57.8	26.9	59.3
3B	Bigrawiah 2	37.5	1891	192	112.7	58.1	85.2
4	Um Ali	25.1	1884	186	52.6	48.3	36.7
5	Goz Alhaj	60.4	9553.4	163.5	115.5	163.1	48.4
6	Musawarat 1	12.5	448	135.5	54	18.8	49.4
7	Nagaa 1	8.3	11659.7	120.3	136.4	548	66.3
8	Nagaa 2	16.7	563	179.6	98.7	31.6	67.8
9	Musawarat 2	31.1	273	188.3	114.2	31.5	74.2
10	Nagaa 3	9.8	216	81.6	110.3	87	87
11	Musawarat 3	76.2	8000	171.0	189.5	74	74

The iron ore associated with dolomitic itabirite use to have high LOI (as carbonate) and CaO, very low amount of silica and alumina where as those associated with BHJ/BHQ contain higher amount of silica and alumina. BHJ/BHQ use to contain silica as high as 45-65 wt%. The ore often contains higher amount of alumina due to the association of kaolinite, gibbsite interlocked within associated goethitic matrix. They contain very low amount of the trace elements as observable from Table 2. Limited geochemical data on the BIF hosted iron ore indicate very low amount, in few tens of ppm, of trace elements. But there is a variation in the silica alumina content because of their mineralogical association and the mineral chemistry.

5.3. Major oxides distribution

Distribution of major oxides most analysis is aimed at the determination of elemental concentrations in samples and usually of trace elements (Maynard, 1983). This ratio was plotted in isoconcentration map showed distribution of Fe_2O_3 in the study area (Fig. 4). Concentration of Fe_2O_3 in the study area ranges between maximum 79.52% in Goz Alhaj area to minimum 27.22% in Alkarbican area and the average is 53.37% (Fig. 5). Concentration of SiO_2 in the study area ranging between maximum 74.14% in Alnagaa1area to minimum 8.38% in Um Ali area and the average is 41.26% (Fig. 6). Concentration of Al_2O_3 in the study area ranging between maximum 12.33% in Alnagaa1area to minimum 4.49% in Elmusawarat2 area and the average is 7.6% (Fig. 7). Concentration of CaO in the study area ranging between maximum 1.24% in Alawatib area to minimum 0.39% in Alnagaa1 area and the average is 0.75% (Fig. 8). Concentration of k_2O in the study area ranging between maximum 0.15% in Alnagaa1 area to minimum 0 % in Elmusawarat1 and Um Ali area and the average is 0.041% (Fig. 9). Concentration of Na_2O in the study area ranging between maximum 0.11% in Elmusawarat2 and Alawatib area to minimum 0.06 % in Elmusawarat1 area and the average is 0.086 % (Fig. 10 and Table 1).

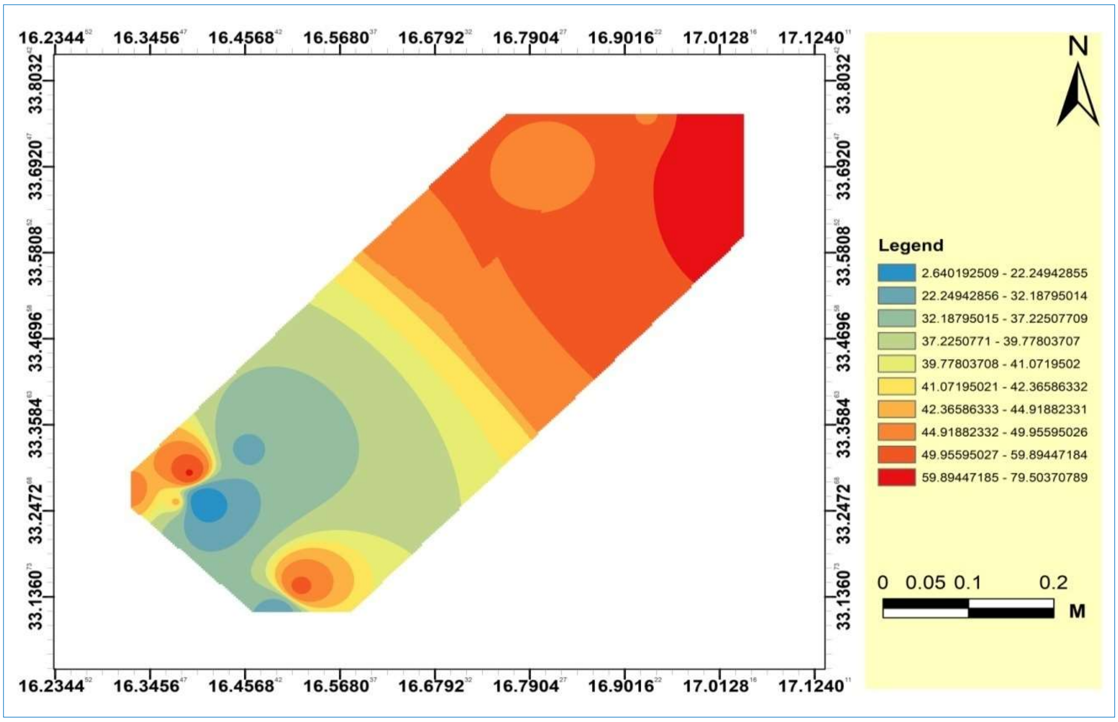

Fig. 4. Showing isoconcentration map of iron ore distribution in the study are

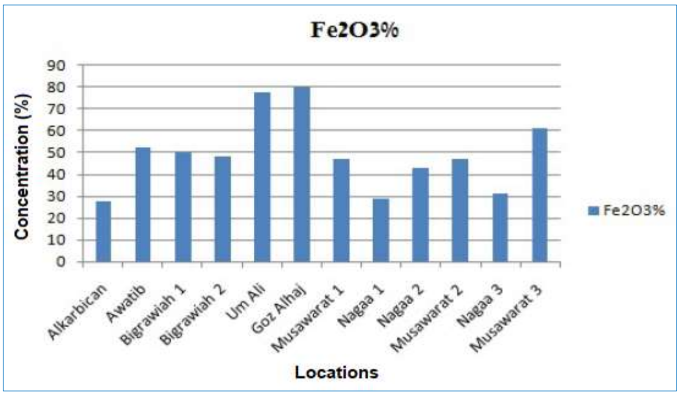

Fig. 5. Histogram showing Fe_2O_3% correlation for different locations

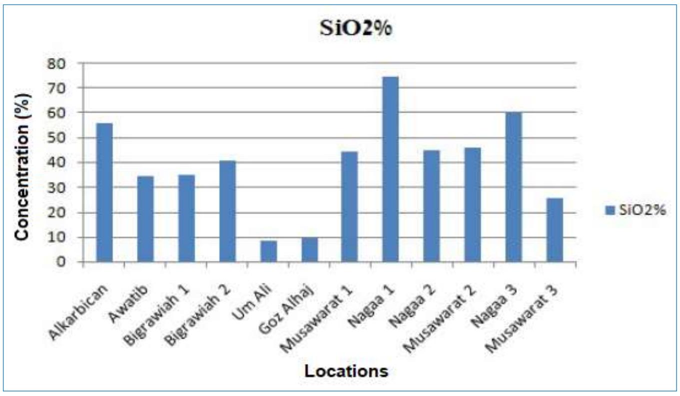

Fig. 6. Histogram showing SiO_2% correlation for different locations

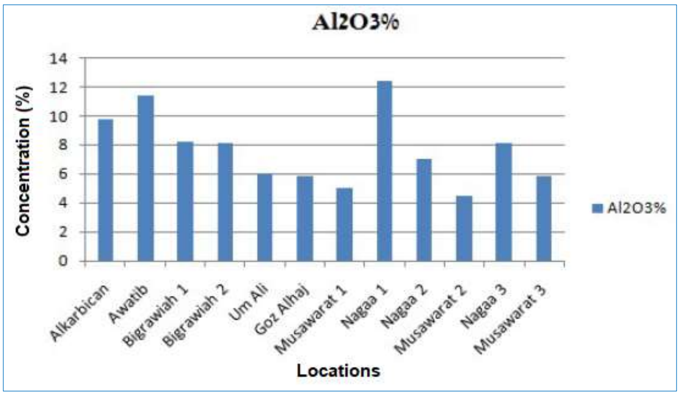

Fig. 7. Histogram showing Al_2O_3% correlation for different locations

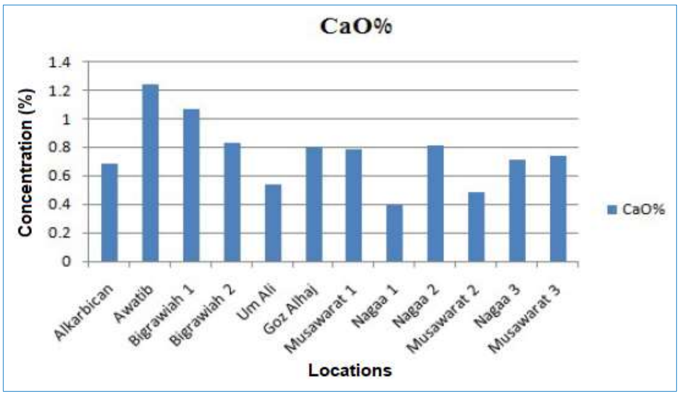

Fig. 8. Histogram showing CaO% correlation for different locations

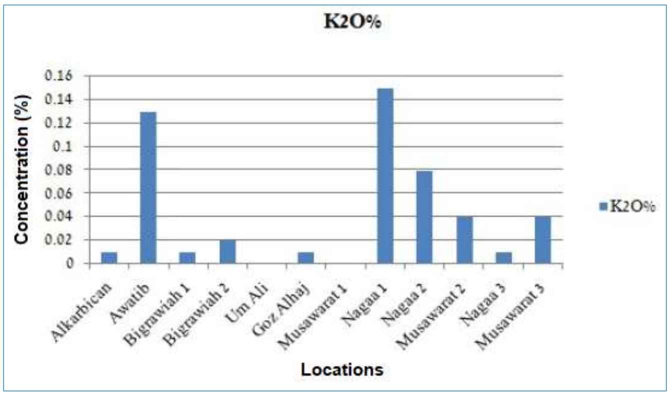

Fig. 9. Histogram showing K_2O% correlation for different locations

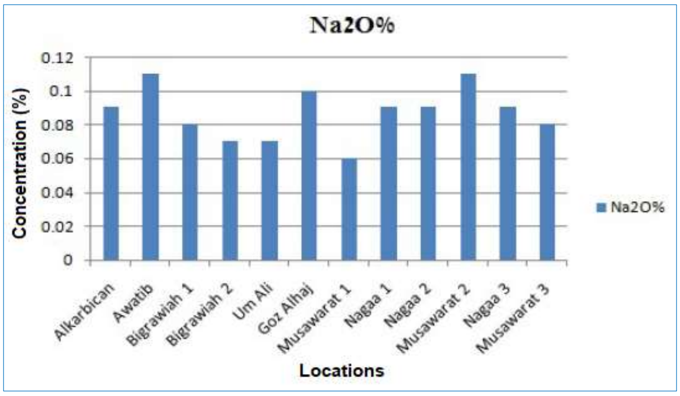

Fig. 10. Histogram showing Na_2O% correlation for different locations

5.4. Trace elements description

The concentration and distribution of trace elements within sedimentary cycles provide information about the composition of the source rock, weathering processes, depositional environment and digenetic processes (Alibert and McCulloch, 1993).

Hence, in this study, concentration of Cr in the study area ranging between maximum 87ppm in Elnagaa3 area to minimum 36.7ppm in Um Ali area and the average is 61.1ppm (Fig. 11). Concentration of Co in the study area ranging between maximum 548ppm in Elnagaa1 area to minimum 7.5ppm in Alawatib area and the average is 92.4 ppm (Fig. 12).

Concentration of Cu in the study area ranging between maximum 189.5ppm in Elmusawarat3 area to minimum 51.2ppm in Alkarbican area and the average is 95.89 ppm (Fig. 13). Concentration of Zn in the study area ranging between maximum 188.3ppm in Elmusawarat2 area to minimum 79.5ppm in Alawtib area and the average is 146.6 ppm (Fig. 14).

Concentration of the Mn in the study area ranging between maximum 11659.7ppm in Elnagaa1 area to minimum 216ppm in Alnagaa3 area and the average is 2985.35 ppm (Fig. 15). Concentration of the Ni in study area ranging between maximum 76.2ppm in Elmusawarat3 area to minimum 7.2ppm in Alawtib area and the average is 29.1ppm (Fig. 16).

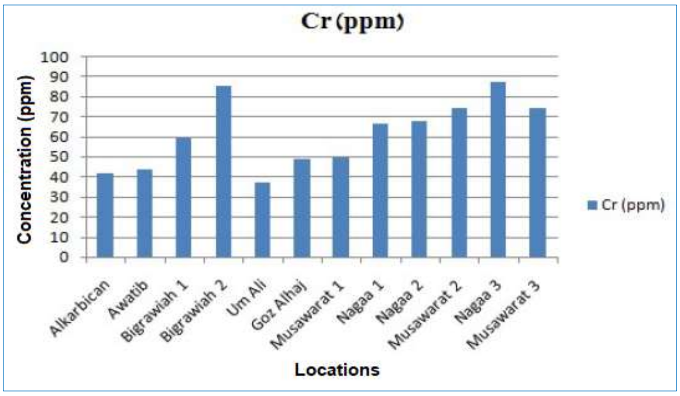

Fig. 11. Histogram showing Cr (ppm) correlation for different locations

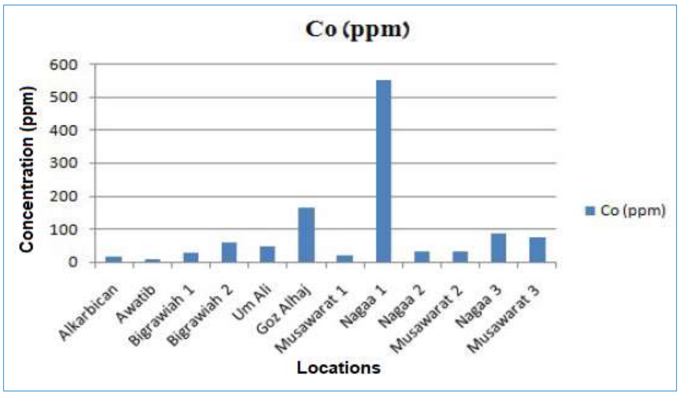

Fig. 12. Histogram showing Co (ppm) correlation for different locations

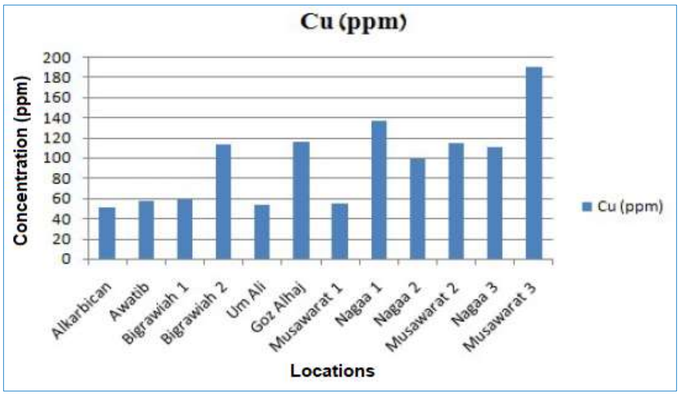

Fig. 13. Histogram showing Cu (ppm) correlation for different locations

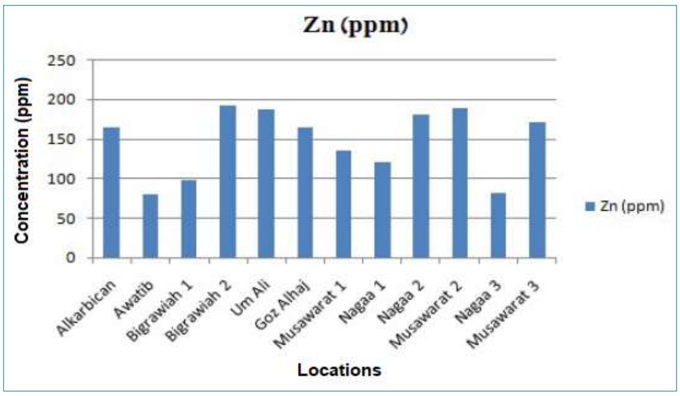

Fig. 14. Histogram showing Zn (ppm) correlation for different locations

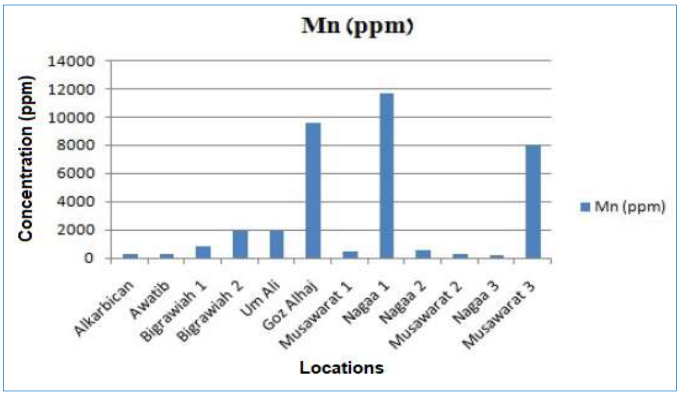

Fig. 15. Histogram showing Mn (ppm) correlation for different locations

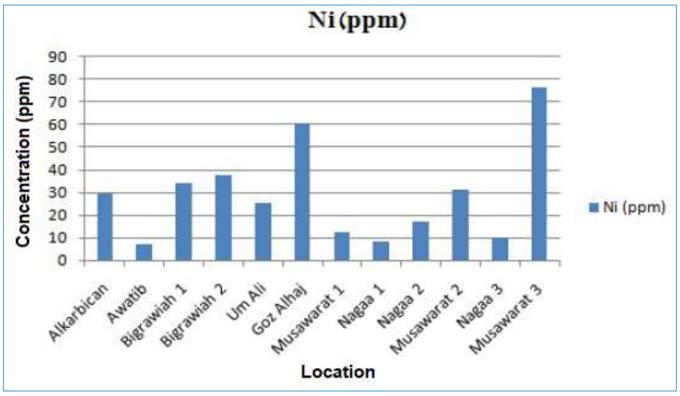

Fig. 16. Histogram showing Ni (ppm) correlation for different locations

6. Conclusion

Geochemistry is now used in virtually every exploration program, if only to determine the grade of the ores to be mined. However, exploration geochemistry has evolved from its early origins in assaying, to using the chemistry of the environment surrounding a deposit in order to locate it. 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 50 km in diameter between the cities of Shandi, Kabushia and Atbara.

Most sedimentary rocks contain significant quantities of iron, and there is a complete range up to those of ore grade. The results indicate that the quality of iron ore is good according to geochemical parameters and precipitated under non marine lacustrine environment, shallow depth and warm temperature. All results have been to construct isoconcentration maps of the Iron ore distribution in study area and potentiality for future mining works.

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