



# Mineralogy, geochemistry and the origin of high-phosphorus oolitic iron ores of Aswan, Egypt



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## ABSTRACT

The Coniacian-Santonian high-phosphorus oolitic iron ore at Aswan area is one of the major iron ore deposits in Egypt. However, there are no reports on its geochemistry, which includes trace and rare earth elements evaluation. Texture, mineralogy and origin of phosphorus that represents the main impurity in these ore deposits have not been discussed in previous studies. In this investigation, iron ores from three localities were subjected to petrographic, mineralogical and geochemical analyses. The Aswan oolitic iron ores consist of uniform size ooids with snowball-like texture and tangentially arranged laminae of hematite and chamosite. The ores also possess detrital quartz, apatite and fine-grained ferruginous chamosite groundmass. In addition to Fe<sub>2</sub>O<sub>3</sub>, the studied iron ores show relatively high contents of SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> due to the abundance of quartz and chamosite. P<sub>2</sub>O<sub>5</sub> ranges from 0.3 to 3.4 wt.% showing strong positive correlation with CaO and suggesting the occurrence of P mainly as apatite. X-ray diffraction analysis confirmed the occurrence of this apatite as hydroxyapatite. Under the optical microscope and scanning electron microscope, hydroxyapatite occurred as massive and structureless grains of undefined outlines and variable size (5–150 μm) inside the ooids and/or in the ferruginous groundmass. Among trace elements, V, Ba, Sr, Co, Zr, Y, Ni, Zn, and Cu occurred in relatively high concentrations (62–240 ppm) in comparison to other trace elements. Most of these trace elements exhibit positive correlations with SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, and TiO<sub>2</sub> suggesting their occurrence in the detrital fraction which includes the clay minerals. ΣREE ranges between 129.5 and 617 ppm with strong positive correlations with P<sub>2</sub>O<sub>5</sub> indicating the occurrence of REE in the apatite. Chondrite-normalized REE patterns showed LREE enrichment over HREE ((La/Yb)<sub>N</sub> = 2.3–5.4) and negative Eu anomalies (Eu/Eu\* = 0.75–0.89). The oolitic texture of the studied ores forms as direct precipitation of iron-rich minerals from sea water in open space near the sediment-water interface by accretion of FeO, SiO<sub>2</sub>, and Al<sub>2</sub>O<sub>3</sub> around suspended solid particles such as quartz and parts of broken ooliths. The fairly uniform size of the ooids reflects sorting due to the current action. The geochemistry of major and trace elements in the ores reflects their hydrogenous origin. The oolitic iron ores of the Timsha Formation represent a transgressive phase of the Tethys into southern Egypt during the Coniacian-Santonian between the non-marine Turonian Abu Agag and Santonian-Campanian Um Barmil formations. The abundance of detrital quartz, positive correlations between trace elements and TiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub>, and the abundance mudstone intervals within the iron ores supports the detrital source of Fe. This prediction is due to the weathering of adjacent land masses from Cambrian to late Cretaceous. The texture of the apatite and the REE patterns, which occurs entirely in the apatite, exhibits a pattern similar to those in the granite, thus suggesting a detrital origin of the hydroxyapatite that was probably derived from the Precambrian igneous rocks. Determining the mode of occurrence and grain size of hydroxyapatite assists in the maximum utilization of both physical and biological separation of apatite from the Aswan iron ores, and hence encourages the use of these ores as raw materials in the iron making industry.

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## 1. Introduction

Oolitic iron ores of high phosphorus are widely distributed with some large-scale deposits worldwide such as the Wadi Fatima mine in

Saudi Arabia (Manieh, 1984), Lorraine mine in France (Champetier et al., 1987), Bell Island mine in Canada (Ozdemir and Deutsch, 1984), Dilband mine in Pakistan (Abro et al., 2011), and Xuanhua and Ningxiang regions in China (Li et al., 2011; Zhang et al., 2014). The main problem associated with exploiting these deposits is the dissemination of fine silicate minerals and the high level of phosphorus content due to the poor liberation of iron minerals from the gangues (Song et al.,

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2013). Although these iron ores have economic and geological significances, their geochemical characteristics were not discussed widely in the previous investigations (Petruk, 1977; Stuesson, 1995, 2003). A considerable amount of literature focused on the physical and chemical processes to remove phosphorus from the ores using chemical, thermal and biological methods (Delvasto et al., 2009; Wen-tang et al., 2011; Omran et al., 2015), without due deliberations on the sources and origins of the P-bearing minerals.

The high-phosphorus oolitic iron ores in Aswan area is one of the major iron ore deposits in Egypt. Other significant iron ore sites include the sedimentary iron ores at the Bahariya Oasis and banded deposits (BIF) in the Eastern Desert. Iron ores from the Bahariya Oasis are currently utilized by the Egyptian Steel Company (ESC) to produce steel for domestic consumption. Due to the predictable depletion of these ores, there were attempts to exploit other ores for the iron making industry from the oolitic iron ores of the Aswan. However, these attempts were unsuccessful due to the high phosphorus contents in the Aswan ore deposits. This proliferation is due to the poor liberation of iron minerals from impurities which include the P-bearing minerals. Part of this problem is probably due to the paucity of data on the mineralogy and mode of occurrence of phosphorus in these iron ores. Also, the geochemical characteristics which include trace and rare earth elements of these iron ores were not discussed in previous literature. Thus, this study highlights the texture and origin of P-bearing minerals in the ore deposits. The work also examined the distribution and mineralogy of the trace and rare earth elements and appraised the possible source(s) of iron and the depositional conditions of these valuable iron ores based on their geochemistry.

The exploitation of iron ore at the Aswan site could influence an economic impact in the worldwide distribution of oolitic iron ores. The geochemical investigations of the iron ores appreciate the origin of these deposits and the nature of phosphorus which represents one of the most significant impurities. This evaluation provides the platform for a maximum utilization of both the physical and the biological separation of P-bearing minerals from these ores.

## 2. General geology

The oolitic iron ores are widely distributed in Africa, which includes southern Egypt, northern Sudan, and Nigeria (Mucke, 2000) (Fig. 1). In Egypt, oolitic iron ores occur in the Wadi Abu Agag and Wadi Subeira areas, east of Aswan (Fig. 2A) and Um Hibal area southeast Aswan (Fig. 2B) (Doering, 1990). East Aswan area is located about 12 km to the northeast of Aswan, between latitudes of 24°05'00" and 24°15'00" N and longitudes of 32°55'00" and 33°15'00" E. Um Hibal area is located about 60 km to the southeast of Aswan, between latitudes of 23°36'00" and 23°52'00" N and longitudes of 33°07'00" and 33°30'00" E (Fig. 2B) (Ghazaly et al., 2015). Both areas are occupied by highly lateritized Precambrian metamorphic and igneous rocks of the Arabo-Nubian Shield (ANS), unconformably overlain by Upper Cretaceous clastic successions. The ANS is composed mainly of granites, granodiorites, quartz diorites, gneiss, gabbros, amphibolites and metasediments (e.g. Liégeois and Stern, 2010; Kuster and Liegeois, 2001; Ali et al., 2009). The Upper Cretaceous sediments of the studied areas are divided into three units that overlay the Precambrian basement rocks; the basal Abu Agag Formation (Turonian), the Timsha Formation (Coniacian-Santonian), the uppermost Um Barmil Formation (Santonian-Cambrian) (Fig. 3) (e.g. Klitzsch, 1986; Bhattacharyya, 1989; El Aref et al., 1996; El Sharkawi et al., 1996; Mucke, 2000). The iron-bearing formation (Timsha Formation) has a thickness of 10–35 m and consists of four coarsening-upward sequences. Furthermore, sequences contain at least four horizons of ooidal ironstone (Fig. 3). The total reserves are about nine million tonnes (Hussein and Sharkawi, 1990; Mucke, 2000).

From the deep to shallow layers, the sedimentary sequence of the Timsha Formation at Wadi Abu Agag and Wadi Subeira areas (Fig. 4A) is comprised of yellowish grey and reddish grey laminated mudstone with non-oolitic ironstone intercalations of what is called Aswan clays (Fig. 4B). This mudstone interval is overlain by two large oolitic iron ores beds with a thickness ranging from 2 m (lower bed) to about 4 m (upper bed) and separated by yellowish to reddish grey 30 cm-thick shale layer (Fig. 4C and D). Iron ore occurs as hard and massive beds

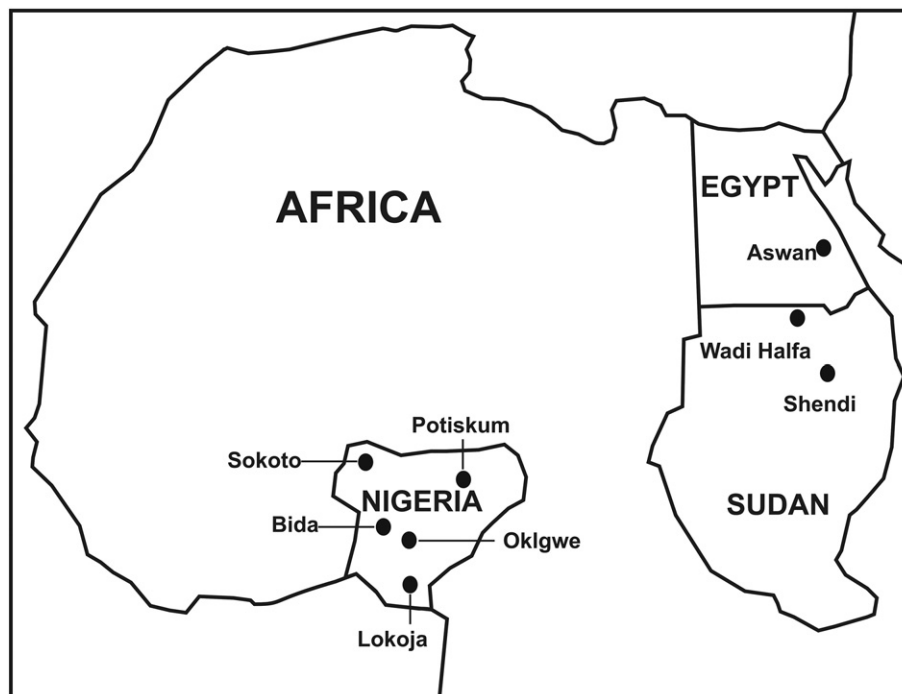


Fig. 1. Geographical setting of the late Cretaceous ooidal ironstone deposits of Egypt, Sudan and Nigeria. (Adapted from Mucke (2000)).

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