Journal of African Earth Sciences 120 (2016) 186–197

Contents lists available at ScienceDirect

Journal of African Earth Sciences

journal homepage: www.elsevier.com/locate/jafrearsci

The economic potential of El-Gedida glauconite deposits, El-Bahariya Oasis, Western Desert, Egypt

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A R T I C L E I N F O

Article history:
Received 25 December 2015
Received in revised form
19 April 2016
Accepted 7 May 2016
Available online 9 May 2016

Keywords:
El-Gedida iron mine
Glauconite deposits
Physical properties
Chemical properties
Potassium fertilizer

A B S T R A C T

The mining work at El-Gedida iron mine, El-Bahariya Oasis, in the Western Desert of Egypt extracts commercial iron ore deposits without attention paid to the large glauconite deposits overlying these iron ore deposits. For this reason, the present paper aims at evaluating and attracting the attention to these glauconite deposits as alternative potassium fertilizers. The study was achieved by investigating mineralogical, physical and chemical properties of the green deposits. Mineralogical and physical properties involved the determination of glauconite pellets content in different grain size fractions relative to impurities and the analysis of the percentage of clay matrix and grain size distribution. Different pre-treatment strategies and methods including comminution, sieving, magnetic separation, and X-ray diffraction were used for investigating those mineralogical and physical properties. On the other hand, chemical analyses included potassium content, heavy metal concentrations, and pH and salinity measurements. The major elements and trace elements were measured using ICP-OES and the pH was measured using a pH conductometer. Moreover, this study investigated the nature of grain boundaries and the effect of sieving on glauconite beneficiation. Results of this study suggest that El-Gedida glauconite deposits are mineralogically, physically and chemically suitable for exploitation and can be beneficiated for use as an alternative potassium fertilizer.

1. Introduction

Glauconite is defined as a green, iron-potassium-rich micaceous mineral, with 2:1 dioctahedral illite-like structure. It is characterized by inter-stratification of nonexpandable (10 Å) and expandable Fe-smectite layers. Glauconite-smectite (sensu lato) contains more than 50% expanding layers, but glauconite (sensu strict) contains less than 10% expanding layers (McRae, 1972; Odin, 1988).

Glauconite deposits have been used as natural potassium fertilizers, especially in forage crops, for over 100 years (Dooley, 2006). The commercial value of glauconite is attributed to its potassium content. Beside, nitrogen and phosphorous, potassium is an important macronutrient essential for osmotic regulation and plant growth (Ryoung et al., 2006). The global demand for potassium-bearing fertilizers continuously increases and is expected to grow annually at 3% from 2012 to 2017, reaching 37.4 Mt K_2O in 2017 (Heffer and Prudhomme, 2013).

Glauconite deposits have been studied in many countries for use as an alternative to potassium salt fertilizers. Franzosi et al. (2014) magnetically treated and evaluated green sands from the Salamanca formation, Patagonia, Argentina, as a substitution potassium fertilizer, with potassium contents around 4.05% K_2O. The authors found that the fertilization effect of green sands was similar to that of KCl, and they also referred to the low cost of treatment and production of these deposits compared to KCl mining.

According to Levchenko et al. (2008), glauconite in Russia has been reported from glauconite-bearing deposits: the Koporskoe and Karinskoe deposits with reserves of about 100 million tons. The most important use of glauconite is as a chemical fertilizer and soil conditioner for agricultural and land reclamation purposes. The application of glauconite as fertilizer owes to its high content of potassium (5–9.5%), phosphorous and micro-nutrients (such as Mn, Cu, Co, Ni, etc.).

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http://dx.doi.org/10.1016/j.jafrearsci.2016.05.007
1464-343X/

In New Jersey, Delaware, and Maryland Districts (in the USA) the most significant glauconitic green sands lie at the Mid-Atlantic Coastal plains, in the Upper Cretaceous and Early Palaeocene formations. The glauconitic sediments are used for fertilization and soil enhancement (Heckman and Tedrow, 2004).

Karimi et al. (2011) tested glauconitic sandstone from Maraveh, northeast Iran as a potassium fertilizer for olive plants. The authors carried out lixiviation tests of the ground deposit (−250 μm) in water and various types of 1 M acids (phosphoric and hydrochloric acids) and measured the potassium contents in the extractant solutions. They found that the potassium content extracted in water was 23 mg K^+ kg^{-1} of sandstone powder while that released in acid solutions was 2200 mg K^+ kg^{-1} of sandstone powder. The authors also suggested the possibility of applying green sands, with 2.24 wt % K_2O as source of soil soluble potassium for a long time.

In Egypt, glauconite deposits have been reported from El-Gedida iron mine, El-Bahariya Oasis, in the Western Desert. These deposits belong to the Bartonian age and occur as a green sands cover overlying the Lutetian iron ore, of about 25 m thickness at the eastern and western wadis of the mining area. The glauconite sediments have been studied by many authors (El-Sharkawi and Khalil, 1977; Mesaed and Surour, 1999; Hassan et al., 2011; Baioumy and Boulis, 2012) in terms of their petrology, mineralogy and geochemistry. The deposits are mined as overburden and are removed to reach the commercial iron ore deposit. The main objective of this paper is to add value to El-Gedida glauconites by performing mineralogical, physical and chemical assessments of the deposits for use as an alternative to potassium salt fertilizers.

2. Geological setting

El-Gedida glauconite deposits are located at the eastern and western wadis of El-Gedida mining area as a condensed section that reaches a thickness of up to 25 m above the commercial Middle Eocene ironstone deposit (Hassan and Baioumy, 2007). According to El Aref et al. (1999) and Mesaed and Surour (1999) the glauconite deposits belong to the Upper Eocene Hamra Formation divided into two units. The lower unit consists of highly fossiliferous glauconitic mudstone and sandstone with marl intercalations while the upper unit is composed of well-bedded green sand, glauconitic mudstone and sandstone with intercalations of lateritic iron bands. The glauconite deposits are equivalent to the upper unit of the Upper Eocene Hamra Formation. The studied glauconites are unconformably covered by fluvial deposits of the Qatrani Formation (Oligocene) and overly the carbonates of the Naqb Formation (Middle Eocene). Depending on stratigraphy, mineralogy and geochemistry, El-Habaak et al. (2016) proved that the Upper Eocene glauconites were deposited in a shallow marine environment under regressive conditions at 100 m depth.

3. Materials and methods

The rock samples investigated in this study were collected from sandy glauconite deposits at the eastern and western wadis of El-Gedida mine, El-Bahariya Oasis, in the Western Desert (Figs. 1 and 2). For the petrographic characterization of the samples, thin sections were prepared and examined using the conventional optical microscope attached to a Leica camera. The acquired images were processed using the Image Analyzer Software for investigating the nature of optical appearance of the glauconite grains. To achieve this, the image processing techniques of linear stretching and edge detection were applied. The bulk mineralogy of these deposits was determined using X-ray diffractometer (X'Pert PRO-PAN).

The contents of glauconite pellets were determined through three steps. The first step involved a size reduction of the two representative samples (100 kg per each sample) up to -1 mm by using a jaw crusher and a rod mill in a closed circuit. Secondly, each 100 kg representative sample was subjected to coning and quartering processes. Afterwards, a representative sample (50 g) of the ground ore was beneficiated using a Frantz isodynamic magnetic separator adjusted to a current intensity of 0.7 Am, 20° forward slope, 15° side slope, and feed rate of 10 g/minute. The magnetic and tailing fractions were mineralogically examined using XRD. The principal aim of separation was to investigate the amounts of glauconite pellets compared to that of impurities. The percentage of clay matrix and the grain size of glauconite were determined by a dry sieving of the ground ore, resulting in five size fractions (−1+500, −500 + 250, −250 + 125, −125 + 75 and −75 μm).

The glauconite deposits were chemically studied to determine the contents of macronutrients and heavy metals using ICP-OES at Acme laboratory, Canada. The influence of sieving on the beneficiation of glauconite, a representative sample of each size fraction was mineralogically and chemically analysed using XRD and ICP-OES, respectively.

Measuring the pH of glauconite was performed using multiparameter pH meter (WTW Multi 340i), at the ratio of 1:5 glauconite/water mixture, according to Kalra (1995). For each glauconite sample, a 10 g portion was weighed and dried at 60 °C for 1 h. The dried sample was put into a 100 ml beaker and 50 ml of distilled water was added. The mixture was stirred for 1 h and allowed to stand for 30 min. After the calibration of pH meter using two buffer solutions of pH 7 and 4.01, the pH was measured at 25 °C. For measuring salinity of the glauconite deposits, another glass electrode was used. The procedure for calibration was performed by immersing the conductometer electrode into a standard solution of 0.01 mol/l KCl.

4. Results and discussion

4.1. Microscopic characterization

The studied glauconite deposit is composed mainly of green pellets with minor amounts of quartz, calcite, halloysite and iron oxyhydroxides set in a matrix that consists of a greenish (glauconitic) mud (Fig. 3a). Glauconite occurs as green, brownish green and yellowish green pellets ranging in diameter from 100 to 500 μm, thus these pellets are moderate to well sorted. Originally, the glauconite pellets developed in specific micro-environments such as faecal pellets and/or in bioclasts by increasing the contents of Fe and K during maturation from smectitic glauconite to glauconitic mica, but the alteration and extensive weathering of the pellets result in oxidation of the divalent Fe and depletion of K forming brown pellets that contain nanometric inclusions of Fe-oxyhydroxides (Pestitschek et al., 2012). The oval, sub-oval, rounded to subrounded glauconite grains detected contain random microcrystalline internal structures that occasionally are fractured (Fig. 3b). The cracks are interpreted as a result of expansion related to the differential mineral growth in the pellets (Odin and Matter, 1981). As illustrated in Fig. 3c some fractured pellets are filled with a greenish glauconitic mud generated by the destabilization of the glauconite pellets (Meunier, 2004). The pellets have experienced three stages of development: (1) initial pellet formation, (2) pellet fracturing and (3) infilling of pellet cracks with a glauconitic mud.

Quartz occurs as angular to sub angular detrital grains that are 100−250 μm in diameter, associated with glauconite pellets. White halloysite vienlets cutting through the clayey matrix were detected (Fig. 3d). Botryoidal masses composed of sparry calcite occur as independent aggregates or as vienlets replacing the glauconitic