ARTICLE IN PRESS
CLAY-03189; No of Pages 11
Applied Clay Science xxx (2014) xxx–xxx
Contents lists available at ScienceDirect
Applied Clay Science
journal homepage: www.elsevier.com/locate/clay

Research paper

Composition, origin and industrial suitability of the Aswan ball clays, Egypt

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ARTICLE INFO

Article history:
Received 29 June 2013
Received in revised form 7 August 2014
Accepted 25 September 2014
Available online xxxx

Keywords:
Aswan ball clays
Egypt
Mineralogy
Geochemistry
Source
Industrial applications

ABSTRACT

Although Aswan ball clays occur in relatively large reserves, information on their geochemistry and source is still lacking. This paper presents detailed petrographic, mineralogical, and geochemical investigations on these clays to examine their source as well as their possible use as raw materials for ceramic and refractory industries.
Aswan ball clays occur as gray, yellowish gray, reddish to brownish gray, massive to faint laminated, and moderately hard clays. Grain-size distributions indicate the dominance of clay fractions (45–57 wt.%). Low-ordered kaolinite is the main constituent (39–60 wt.%) along with quartz (24–46 wt.%) and low crystalline illite (10–19 wt.%). Fine-grained anatase is reported as a minor constituent (~2 wt.%). Aswan clays are typically ball clays ($SiO_2/Al_2O_3 = 2.3–4.1$) with relatively high Fe_2O_3 and TiO_2 contents. The trace elements occur in two assemblages. Elements associated with the Fe-bearing phases include Cu, Ni, Co, Zn, V, and Pb as indicated from the positive correlations with the Fe_2O_3 contents. Elements occur as silicate minerals but not in clay minerals such as Nb, Zr, Y, Hf, Ta, and U as revealed from the positive correlations of these elements with the SiO_2 and the negative correlations with the Al_2O_3 contents. The sum of rare earth elements (REEs) ranges from 291 to 335 ppm with negative correlations with the Al_2O_3 and positive correlations with the SiO_2 suggesting the occurrence of REE as silicates but not in clay minerals. Chondrite-normalized REE patterns exhibit light rare earth element enrichment relative to heavy rare earth elements ($(La/Yb)_N = 9.2–11.7$) and slightly negative Eu anomalies ($Eu/Eu^* = 0.74–0.83$) without Ce anomalies ($Ce/Ce^* = 0.96–1.03$).
Major, trace, and rare earth elements geochemistry of the clay fractions indicates a mixture of more than rock types as a source of the Aswan ball clays. The high Zr and Y contents and La/Yb ratios suggest a contribution of granitic rock, while the relatively high contents of TiO_2 and Ti are suggestive for a contribution of mafic source rock. Plot of the study clays in the Rb-K_2O and Hf–La/Th binary plots supports mixed felsic and mafic source rocks of the study clays. In addition, high Nb contents indicate a contribution of alkaline source rock. Plot of the study clays in the phyllite and schist field in the Co–Th binary diagram also indicates contribution of metamorphic source rock to the source of the clays.
The abundance of clay size fractions (<2 μm), low-order kaolinite and illite, absence of I/S minerals, low fluxing agents such as alkali oxides (Na_2O and K_2O) and alkaline earth oxides (CaO and MgO), low S and Cl contents, and low contents of toxic elements (As, Cd, Hg, and Pb) reveal the suitability of the Aswan ball clays as a good quality and environment-friendly raw material for ceramic and refractory industries.

1. Introduction

The term "ball clay" originated from an early English mining practice of rolling the highly plastic clay into balls weighing 30–50 lb. Ball clay is used primarily in the ceramic industry for making such items as pottery, dinnerware, stoneware, and sanitary ware (e.g. Andreola et al., 2009). Ball clay is composed of poorly crystalline kaolinite with small amounts of illite, and (or) smectite. Quartz sand or silt and iron oxide minerals are virtually absent from the best-grade ball clays, but carbonaceous material may be abundant. The color of ball clay is nearly white, but some colors range from pink to brown through shades of gray to black. After firing, it is usually almost white. Ball clays require between 40 and 65 percent water of plasticity to become workable. Its plasticity, toughness, high green strength, and adhesion are the outstanding characteristics of ball clay. When fired, ball clay becomes dense and vitreous and its temperature of deformation (melting) is between 1670 °C and 1765 °C (Hosterman, 1984; Wilson, 1998).

Ball clays in Egypt occur in relatively large reserves (10 million metric tons for sure) mainly northeast of Aswan City (Fig. 1A). They are produced by several companies for domestic ceramic

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http://dx.doi.org/10.1016/j.clay.2014.09.041
0169-1317/

Please cite this article as: Baioumy, H.M., Ismael, I.S., Composition, origin and industrial suitability of the Aswan ball clays, Egypt, Appl. Clay Sci. (2014), http://dx.doi.org/10.1016/j.clay.2014.09.041

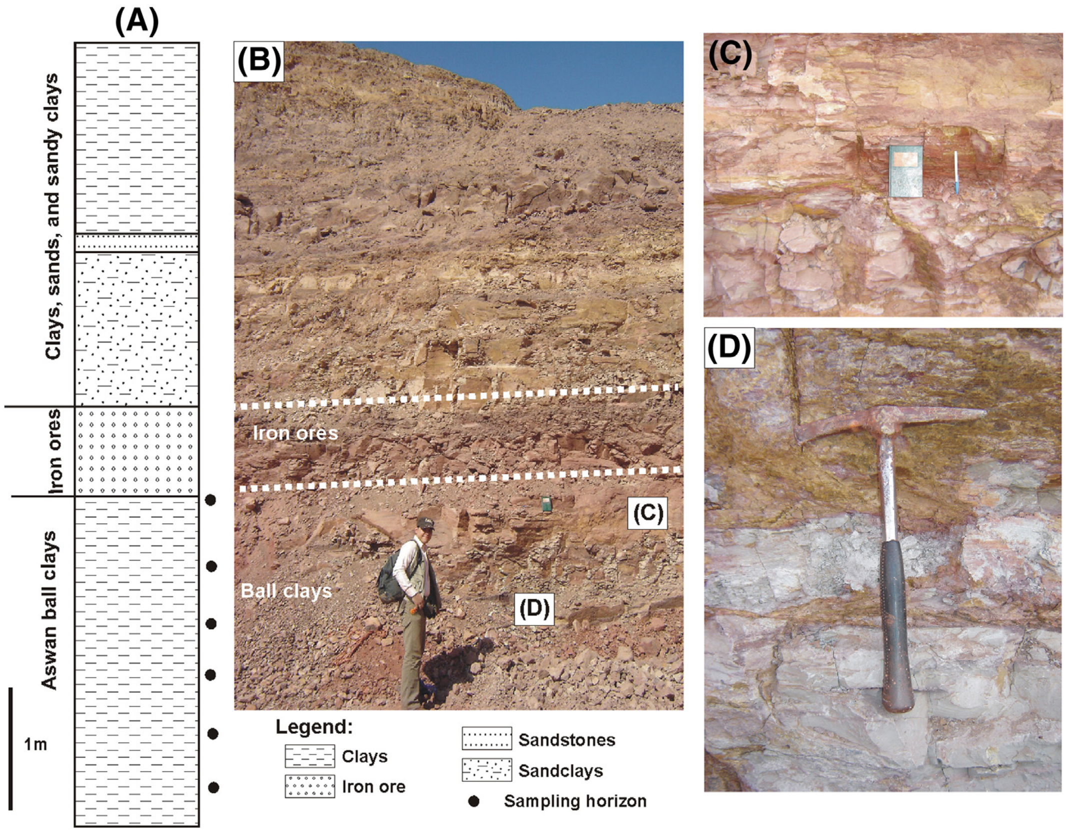

Fig. 1. Stratigraphic column shows the stratigraphic position of the Aswan ball clays (A) with field photo of the studied section (B). (C and D) field photos show the lithological characteristics of the Aswan ball clays. (C) Yellowish to brownish gray faint laminated clays. (D) Gray massive clays with fractures filled with Fe-rich brownish clays. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

and tile industries mainly from Wadi Abu Sobeira and Wadi Abu Agag areas (Fig. 1B). The production rate is approximately 5000 metric tons per month. Due to the industrial importance of the Aswan ball clays, they were subjected to some technical studies to examine their physical properties as the main raw materials for ceramic and tile industries or as a mixture with other raw materials (e.g. Amin et al., 2011; Nour and Awad, 2008). However, to the best knowledge of the authors, the studies on the geochemistry of these clays particularly trace and rare earth elements and their source and origin are lacking in the previous investigations. This paper shows the mineralogy of both bulk and clay fractions as well as the major, trace and rare earth element geochemistry of the clay fractions of the Aswan ball clays. The results of these analyses address the possible source rock(s) of these clays. The industrial suitability as well as the environmental impact of these ball clays is also examined based on these results.

2. Geological setting of the studied area

The studied area comprised Precambrian metamorphic and igneous rocks as well as the Upper Cretaceous sandstones and clays of the Nubian Sandstones Series (e.g. Attia, 1955; Germann et al., 1987; Khedr, 1984; Mesaed, 1995).

The metamorphic rocks are mainly schists with subordinate gneisses. Mica- and hornblende-schist occurs either as huge masses covering extensive areas or as small masses in the granite. Mica schist is grayish, brownish or buff in color and composed of mica (biotite, sericite, and muscovite), quartz, and feldspars. The hornblende schist is greenish or grayish and composed of hornblende, quartz, and feldspars. Hornblende schist is distributed through the southern main wadis. The area of Wadi Abu Agage is formed mainly of metamorphic rock including quartz–biotite–schist, muscovite schist and hornblende schist. The schist is grayish or greenish and intruded by thin (15 cm) milky-white quartz veins. Gneisses occur as dark gray and fine-grained, and are composed of plagioclase feldspar and quartz with minor biotite, hornblende, and muscovite.

The igneous rocks in the study area are comprised of diorites, granodiorites and granites. The diorites are dark-green massive and composed of amphibole and feldspar. They represent the oldest intrusive rocks in the area and intruded into the gneisses and schists. Granodiorites only exposed in the east of the River Nile between Aswan and El-Shellal district as well as on the islands scattered in the river. The most extensive variety, which forms the main mass and represents the normal type of granodiorite, is gray with up to 3 cm white and pinkish porphyroblasts. They are composed of quartz, feldspars, biotite, and hornblende (Attia, 1955). The red coarse-grained granite of Aswan is the most abundant rock in the area between the River Nile and the Paleolithic Nile Channel. It forms most of the hills between Aswan and El-Shallal and underlies the Nubian Sandstone in many parts. This granite generally forms low hills composed of huge rounded masses owing to its spheroidal weathering. The coarse-grained Aswan granite is essentially composed of feldspars, quartz, biotite, and hornblende. Pegmatite occurs in the form of dyke-like bodies and irregular masses attain a length of about 1 km and a width of 2–3 m cutting the metamorphic and igneous rocks. They are pink, very coarse-grained and composed of feldspar and quartz with occasional flakes of mica.

The sedimentary sequence in the study area is represented by the late Cretaceous sedimentary rocks that were subdivided by Klitzsch (1986) into three units: the basal Abu Agag Formation, the Timsha Formation and the uppermost Um Barmil Formation. The Timsha Formation, which is of Coniacian to Santonian age, has a thickness between 10 and 35 m and consists of three coarsening-upward sequences, which contain at least four horizons of ooidal ironstone.