Journal of African Earth Sciences 101 (2015) 333–349

Contents lists available at ScienceDirect

Journal of African Earth Sciences

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

Diagenetic origin of ironstone crusts in the Lower Cenomanian Bahariya Formation, Bahariya Depression, Western Desert, Egypt

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ARTICLE INFO

Article history:
Received 8 May 2014
Received in revised form 6 October 2014
Accepted 7 October 2014
Available online 23 October 2014

Keywords:
Ironstone crusts
Late Cretaceous
Bahariya Formation
Egypt
Iron-rich carbonates
Selective replacement

ABSTRACT

In this paper, a new interpretation of the ironstone crusts of the Bahariya Formation as late diagenetic products is provided. The siliciclastic Lower Cenomanian Bahariya Formation outcropping in the northern part of the Bahariya Depression (Western Desert, Egypt) is subdivided into three informal units that are mainly composed of thinly laminated siltstone, cross-bedded and massive sandstone, fossiliferous sandstone/sandy limestone and variegated shale. Abundant ironstone crusts occur preferentially within its lower and upper units but are absent in the middle unit. The ironstone crusts show selective replacement of carbonate components, including calcretes, by iron oxyhydroxides. More permeable parts of the terrigenous beds such as burrow traces, subaerial exposure surfaces, concretionary features and soft-sediment deformation structures led to heterogeneous distribution of the iron oxyhydroxides.

A variety of diagenetic minerals, where goethite and hematite are the main end-products, were characterized by mineralogical analysis (XRD), petrography and SEM observation, and geochemical determinations (EMPA). Other diagenetic minerals include Fe-dolomite/ankerite, siderite, manganese minerals, barite, silica, illite/smectite mixed-layer, and bitumen. These minerals are interpreted to be formed in different diagenetic stages. Some minerals, especially those formed during eodiagenesis, show features indicative of biogenic activity. During burial, dolomite and ankerite replaced preferentially the depositional carbonates and infilled secondary porosity as well. Also during mesodiagenesis, the decomposition of organic matter resulted in the formation of bitumen and created reducing conditions favorable for the mobilization of iron-rich fluids in divalent stage. Telodiagenesis of the Cenomanian Bahariya deposits took place during the Turonian–Santonian uplift of the region. This resulted in partial or total dissolution of Fe-dolomite and ankerite which was concomitant to iron oxyhydroxide precipitation upon mixing with shallow oxygenated water.

Circulation of reducing iron-rich fluids through fractures and inter and intrastratal discontinuities is proposed as an alternative model to explain the controversial source of iron for the ironstone crusts of the Bahariya Formation. The origin of iron-rich fluids is probably related to the basement rocks. The provided model relates the fluid movements through fractures and discontinuities with the preferential replacement of carbonates. This combination of processes is consistent with the heterogeneous geometries and the wide distribution of the ironstones.

1. Introduction

The northern part of the Bahariya Depression in the Western Desert of Egypt shows a variety of ironstone occurrences including the presence of economic Cenozoic ironstone deposits in El Gedida, Ghorabi and El Harra areas (Akkad and Issawi, 1963; Basta and Amer, 1969; El Sharkawi et al., 1984; El Aref et al., 1999, 2006a,b; Dabous, 2002; Salama et al., 2012; Baioumy et al., 2013). These ironstones constitute a prominent landscape feature that has played a significant role in the geomorphological evolution of the region as they preclude extensive erosion of the outcropping sedimentary formations.

The continental to shallow marine deposits of the Lower Cenomanian Bahariya Formation contain abundant ironstone crusts whose origin has been matter of debate. The transformation of ilmenite to rutile was described as an important source of iron for the ironstone caps forming isolated hills in the Bahariya Depression (Mücke and Agthe, 1988). The ironstone crusts were interpreted as resulting from hematitization and/or oxidation of glauconite by lat-

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http://dx.doi.org/10.1016/j.jafrearsci.2014.10.005
1464-343X/

eritic weathering (El Aref et al., 1999; Mesaed, 2006; Catuneanu et al., 2006). In contrast, Tanner and Khalifa (2010) pointed to extensive weathering of Neoproterozoic basement rocks located south of Aswan, as a source for iron and subsequent transport of this element in solution or as colloid in the sediment load and by groundwater inflow. Early oxidative precipitation of iron in the subsurface, either in the vadose or the phreatic zone, accounted for the formation of the ferruginous sandstones and ferricretes in the Bahariya Formation (Tanner and Khalifa, 2010).

Terms for iron-cemented crusts include vaguely used names such as ferruginous bands, ferricretes, red beds, iron-rich paleosols and laterites (McFarlane, 1976; Tardy, 1992; Bourman, 1993; Ollier and Pain, 1996; Chan et al., 2000; Widdowson, 2007). In the Bahariya Depression, some of these terms, e.g., laterites, red beds, ferruginous bands, as well as glauconitic ironstone, were used by El Aref et al. (1999), Catuneanu et al. (2006) and Mesaed (2006), whilst Tanner and Khalifa (2010) termed the iron crusts observed in the region as ferricrete, especially those occurring in the sedimentary deposits of the Bahariya Formation. Moreover, Tanner and Khalifa (2010) pointed out that ferricrete is a poorly constrained term that identifies an iron-cemented crust formed by various processes in sedimentary strata, particularly pedogenesis.

In this paper, the simple descriptive term 'ironstone crust' is used to describe the iron strata-bound layers and concretionary iron beds, thus avoiding any genetic connotation. Moreover, new insight on the petrology and mineralogy of the ironstone crusts in the northern part of the Bahariya Depression is provided. Our results point to a more decisive role of diagenetic processes in the formation of the ironstone crusts than that proposed by previous works. The study is focused on the sandstone and variegated shales of the lower and upper units of the Bahariya Formation in this area.

2. Geologic setting

The Bahariya Depression is located nearby the central part of the Western Desert of Egypt (Fig. 1A). The depression is characterized by an elliptical shape representative of an anticline fold with a prevailing NE–SW major fault system (Allam, 1986). This structure is a part of the Syrian Arc System that lies on the same lineation of the Abu Rawach and Farafra areas, which are the main structures in the north and central Western Desert, respectively (Fig. 1A).

The Bahariya Depression is filled up by a thick stratigraphic succession spanning Cenomanian to Oligocene irregularly overlain by Quaternary deposits (El Aref et al., 1999). The stratigraphic framework is completed by the local occurrence of Middle Miocene interbedded basaltic and doleritic volcanic rocks (Meneisy and El Kalioubi, 1975; Meneisy, 1990). The oldest exposed rock unit in the Bahariya Depression is represented by the Lower Cenomanian Bahariya Formation that occupies the lowermost part of the depression and extends to the basal parts of the surrounding scarps (Said, 1962). This rock unit is underlain by subsurface succession that was studied at different drilled wells in the depression (Squires and Hermina, 1957) and spanning Early Cretaceous, Jurassic and Paleozoic above Basement rocks. The Bahariya Formation was subdivided into three informal units by Soliman and Khalifa (1993). The type section of the Bahariya Formation occurs at Gabal El-Dist (Said, 1962) (Fig. 1B). In this locality and surrounding areas, the Bahariya Formation is composed mainly of sandstones,

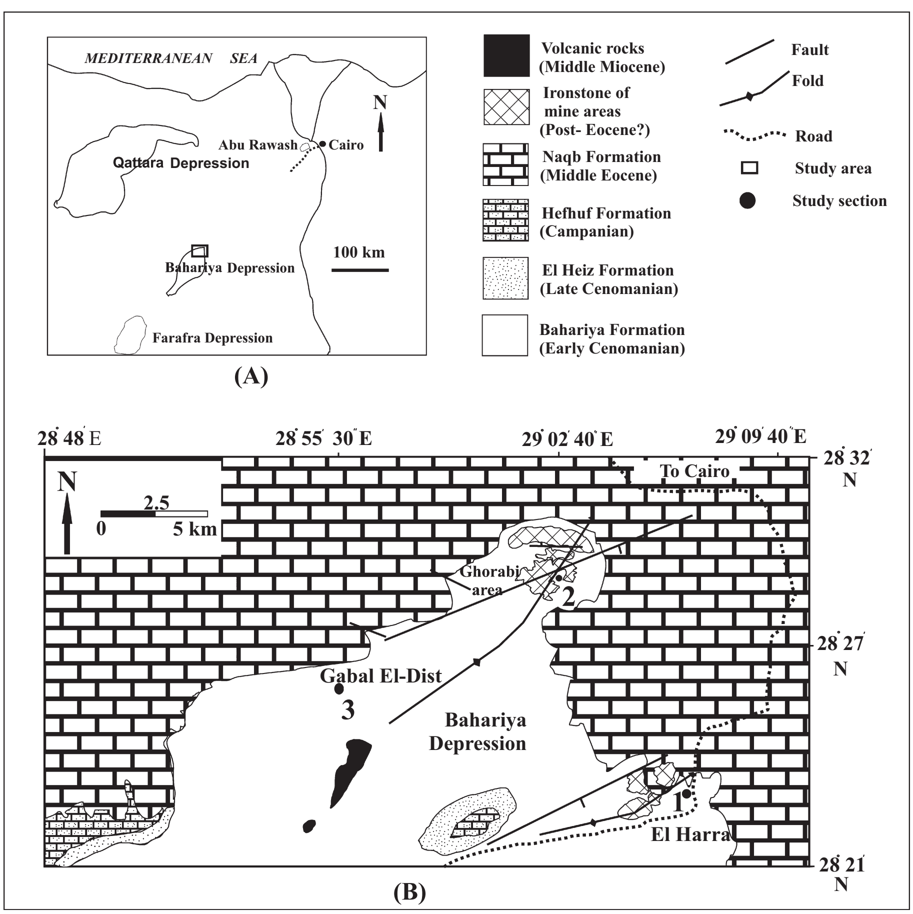

Fig. 1. A – Location of the Bahariya Depression. B – Geologic map of the northern part of the Bahariya Depression (square in A) modified after Catuneanu et al., 2006. (Study sections: 1 – El Harra area, 2 – Ghorabi mine area, 3 – Gabal El-Dist).