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Petrology and geochemistry of the banded iron-formations from Ntem complex greenstones belt, Elom area, Southern Cameroon: Implications for the origin and depositional environment

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ABSTRACT

Banded iron-formations (BIFs) form an important part of the Archaean to Proterozoic greenstone belts in the Southern Cameroon. In this study, major, trace and REE chemistry of the banded iron-formation are utilized to explore the source of metals and to constraint the origin and depositional environment of these BIFs. The studied BIF belongs to the oxide facies iron formations composed mainly of iron oxide (mainly magnetite) mesobands alternating with quartz mesobands. The mineralogy of the BIF sample consists of magnetite and quartz with lesser amount of secondary martite, goethite and trace of gibbsite and smectite. The major element chemistry of these iron-formations is remarkably simple with the main constituents being SiO_2 and Fe_2O_3 which constitute 95.6–99.5% of the bulk rock. Low Al_2O_3, TiO_2, and HFSE concentrations show that they are relatively detritus-free chemical sediments. The Pearson's correlation matrix of major element reveals that there is a strong positive correlation ($r = 0.99$) of Al with Ti and no to weak negative correlation of Ti with Mn, Ca and weak positive correlation of Si with Ca, suggesting the null to very minor contribution of detrital material to chemical sediment. The trace elements with minor enrichments are transition metals such as Zn, Cr, Sr, V and Pb. This is an indicator of direct volcanogenic hydrothermal input in chemical precipitates. The studied BIF have a low ΣREE content, ranging between 0.41 and 3.22 ppm with an average of 0.87 ppm, similar to that of pure chemical sediments. The shale-normalized patterns show depletion in light REE, slightly enrichment in heavy REE and exhibit weak positive europium anomalies. These geochemical characteristics indicate that the source of Fe and Si was the result of deep ocean hydrothermal activity admixed with sea water. The absence of a large positive Eu anomaly in the studied BIF indicates an important role of low-temperature hydrothermal solutions. The chondrite-normalized REE patterns are characterized by LREE-enriched (Mean $La_{CN}/Yb_{CN} = 8.01$) and HREE depletion (Mean $Tb_{CN}/Yb_{CN} = 1.61$) patterns and show positive Ce anomalies. With the exception of one sample (LBR133), all of the BIF samples analyzed during this study have positive Ce anomalies on both chondrite- and PASS-normalized plots. This may indicate that the BIFs within the Elom area were formed within a redox stratified ocean. The positive Ce anomalies in the studied samples likely suggest that the basin in which Fe formations were deposited was reducing with respect to Ce, probably in the suboxic or anoxic seawaters.

1. Introduction

Banded iron-formations (BIF) are marine chemical precipitates that form an integral parts of the preserved Archaean to early Proterozoic sedimentary succession in different part of the world (Klein, 2005; Bhattacharya et al., 2007; Mloszewska et al., 2012). They are typically thinly banded or laminated and contain 15% or more iron of sedimentary origin, commonly but not necessarily containing layers of chert or quartz (James, 1954). According to Klein (2005), typical BIF consists of alternating Si- and Fe-rich layers within an evaluated total Fe and Si content of 20–40 wt.% and 43–56 wt.% respectively. More recently, Planavsky et al. (2010) have proposed the composition-based definition of Fe-formations as 'siliceous and Fe-rich sedimentary chemical precipitates with

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low levels of detrital siliciclastic or volcaniclastic material (<1% Al_2O_3) and greater than 10% total Fe, regardless of whether Fe is associated with a carbonate or oxide phase'. This definition of Fe formation encompasses both granular and banded Fe formations as well as ferruginous cherts (e.g. distal hydrothermal jaspers). Banded iron-formations occur in the geologic record from 3.8 Ga (Isua, West Greenland) to about 1.83.8 Ga with a maximal abundance at about 2.53.8 Ga, and a reoccurrence in Neoproterozoic time (from about 0.8 and 0.63.8 Ga; e.g. Rapitan iron-formation, Yukon, Canada; eg. Spier et al., 2007; Frei et al., 2008; Bekker et al., 2010; Basta et al., 2011). Although many aspects of their origin remains unresolved, it is widely accepted that secular changes in the style of their deposition are linked to the environmental and geochemical evolution of the earth (Bekker et al., 2010). Classically, two types of Precambrian iron formations have been recognized with respect to their depositional setting: (i) Algoma-type iron formations are in close proximity to ancient volcanic centers suggesting a sub-aqueous hydrothermal origin similar to modern day sea-floor spreading centers (Gross, 1983); (ii) the Lake Superior-type BIFs are developed in passive-margin sedimentary rock successions and generally lack direct relationships with extrusive volcanic materials and are therefore interpreted as chemical precipitates of iron-rich waters in a shallow sea (James, 1954).

In Cameroon, the Archaean greenstone belt crops in the southern part of the country within the Ntem complex which corresponds to the northern edge of the Congo craton. This craton, as other cratonic areas around the world, hosts many mineral deposits, some of which include iron ore with banded iron formation protore. The major iron ore deposits of the Congo craton include Avima, Boka Boka and Nabeba in Congo, Mitzic, Belinga and Minkebe in 3.8 Gabon and, Mbalam and Nkout deposits in Cameroon (Suh et al., 2008). The Elom greenstone belt forms part of the iron belt of the Archaean Ntem unit. This belt is characterized by the occurrence of banded-iron formations. The origin and genetic models of these formations are not precisely constrained, although the genetic model of a mineral deposit is fundamental for a more efficient mineral exploration plan. Few detailed studies on the Ntem Complex BIF have been carried out in the particularly on the high-grade iron ore Mballam deposit (Suh et al., 2008; Nforba et al., 2010; Chombong and Suh, 2013; Ilouga et al., 2013). This study presents petrographical and geochemical data on the Elom BIF from the Ntem greenstones belt in southern Cameroon. These data are used to characterize the iron-formations samples that are considered to represent the precursor of iron ore in order to place some constraints on the source of chemical components of these rocks and clarify their origin and depositional environments.

2. Geological setting

The Elom area is located within the Archean Ntem complex greenstones belt at the northwestern margin of the Congo craton (Maurizot et al., 1986; Nédélec et al., 1990; Goodwin, 1991), which is bordered in the north by the Yaounde Group (e.g. Nzenti et al., 1988; Barbey et al., 1990; Mvondo et al., 2003; Toteu et al., 2006), of the Pan-African orogenic belt in Central Africa (Fig. 1A). The Ntem complex is predominantly made up of Archaean rocks that were partially reworked during the Paleoproterozoic–Transamazonian cycle (Toteu et al., 1994; Tchameni et al., 2001). The greenstone formations are Mesoarchaean in age and include metagrewacke, banded-iron formations, sillimanite-bearing gneiss, and amphibolite, now preserved as xenolith in younger intrusive complexes (Shang et al., 2007; Shang et al., 2010). The intrusive complexes consist of charnockite and a variety other of rocks which define a TTG (tonalite–trondjemite–granodiorite) suite (Nédélec et al., 1990; Pouclet et al., 2007). Abundant gneissic and migmatitic structures in the TTG are indicative of late- to post-tectonic partial melting events between 2700 and 2500 Ma, which affected both the TTG and greenstone terranes (Kornprobst et al., 1976; Nédélec et al., 1990; Shang et al., 2001; Shang et al., 2010). The main structures in the Ntem complex are E–W-trending S_1 foliation and numerous granitic plutons that are usually emplaced along a SW–NE-tending S_2 foliation. The S_1 foliation dips steeply to the north and its locally deformed into mesoscopic isoclinal D_2 folds (Suh et al., 2009). The S_2 foliation is a regional, steeply dipping planar fabric with variably oriented stretching lineation and large scale open folds that are associated with N–S-trending sinistral and dextral strike-slip faults and S_3 mylonitic foliation. It has been suggested that the Ntem complex later underwent regional metamorphism associated to the Eburnean–Transamazonian orogeny (Toteu et al., 1994; Shang et al., 2004).

In the study area (Fig. 1B), banded iron-formations, high-K granites intruding TTG and cross-cutting dolerite dykes were identified (Maurizot et al., 1986; Shang et al., 2010). The doleritic magmatism has been dated as Late Archaean and interpreted as the heat source for remelting TTG and charnockites and generating high-K granites, thus suggesting the coeval nature of doleritic magmatism and high-K granite genesis in the Ntem complex (Shang et al., 2007, 2010). Banded-iron formations are the main lithology at Elom area. They form prominent ridges with NW–SE orientation and consist of rhythmically alternating fine bands of Fe-oxide and metachert metamorphosed into greenschist to amphibolite facies. The main prospect (Elom hill) is 11 km long and 0.5–2 km wide, but smaller size prospects also exist in the area. The BIF bands are folded and generally trend NW–SE to E–W with steeply dip (70–90°) towards the NE or SW and N, respectively.

3. Sampling and analytical methods

Samples were collected from several discontinuous outcrops of the Elom iron ore prospect, a mineral exploration property of Divine Mining Ltd. (Fig. 1B). Proper care was taken to collect the best possible fresh sample. Eight representative samples of banded-iron formations were investigated in terms of their mineral chemistry and whole rock geochemistry. Polished thin sections were prepared from representative samples at Geotech Lab (Vancouver, Canada) using conventional techniques. Mineral identification was attained by means of X-ray diffraction (XRD) and petrographic studies under both transmitted and reflected light. Chemical analysis was done using the pulp Whole-rock analyses were done by Inductively Coupled Plasma-Atomic Emission (ICP–AES) for major elements and by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) for trace elements and REE at ALS Minerals Global Group, Vancouver (Canada). The samples were pulverized to obtain a homogeneous sample out of which 50–60 g was obtained for the analyses. 0.2 g of rock powder was fused with 1.5 g $LiBO_2$ and then dissolved in 100 mm^3 5% HNO_3. Analytical uncertainties vary from 0.1% to 0.04% for major elements; 0.1 to 0.5% for trace elements; and 0.01 to 0.5 ppm for rare earth elements. Loss on ignition (LOI) was determined by weight difference after ignition at 1000 °C. Various standards were used and data quality assurance was verified by running these standards between samples as unknowns. Analysis precision for rare earth elements is estimated at 5% for concentrations >10 ppm and 10% when lower.

4. Results

4.1. Petrography and ore mineralogy

The studied banded iron-formations crop as ridges (Fig. 2a) within their host rocks because they are resistant to weather-