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The origin and hydrothermal mobilization of carbonaceous matter associated with Paleoproterozoic orogenic-type gold deposits of West Africa

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ABSTRACT

The chemical and physical properties of carbonaceous matter (CM) were studied in Paleoproterozoic metasediment-hosted, orogenic-type gold deposits in Burkina Faso (the Inata deposit), in Mali (the Syama deposit), and in Ghana (the Obuashi and Bogoso deposits). Two types of CM occur in all the studied deposits: metamorphosed and hydrothermal. Metamorphosed CM prevails in all the deposits. Hydrothermal CM occurs in small veinlets in hydrothermally altered rocks and in quartz veins or forms irregular accumulations parallel or sub-parallel to C-type cleavage within the shear zones. The origin of hydrothermal CM, which occurs in paragenesis with Au-bearing arsenopyrite or pyrite, seems to have been due to supersaturation of hydrothermal fluids with carbon at the deeper or middle crustal levels. The isotopic composition of carbon in bulk CM (−33.1 to −26.2‰, VPDB) indicates its biogenic origin. The isotopic composition of carbon in hydrothermal carbonates ranges from −14.5 to −4.4‰ (VPDB), which suggest mixing of carbon derived from a deep-seated source with carbon derived from an organic source. The interaction of hydrothermal fluids with metamorphosed CM could be one of the causes of the reduction of hydrothermal fluids and formation of the respective mineralization. The optical properties and Raman spectra of the metamorphosed CM particles in the individual studied mineral deposits differ considerably. The temperatures calculated on the basis of the Raman spectra of metamorphosed CM vary between 280 and 440 °C, depending on the thermometer used, and correspond to temperatures of metamorphism of upper sub-grenschist and greenschist facies. The temperatures calculated for hydrothermal CM at the individual deposits, are only slightly lower compared to the metamorphosed CM at the same deposits, which indicates approximately the same temperature of the metamorphic and hydrothermal processes.

1. Introduction

Many mesozonal orogenic gold deposits in metasediments (Groves et al., 2003; Hronsky et al., 2012) occur mainly as auriferous quartz veins or disseminations bound to fault- or shear zones, which contain a significant amount of carbonaceous matter (CM; i.e., a solid, black, heterogeneous substance containing mostly solvent-insoluble high-weight macromolecular structures of carbon, variable amount of organic sulfur, oxygen and some hydrocarbons).

At the Hoyle Pond deposit, Abitibi Greenstone Belt, Ontario, Canada, for example, the CM occurs in 5–20 m thick alteration zones (called gray zones) accompanying, and therefore, coeval with the auriferous quartz veins (Dinel et al., 2005). Gas chromatographic analyses (Downes et al., 1984), stable carbon isotope analyses (Hodges, 1982) and ultraviolet absorption investigations suggested that much of the CM is derived from carbonaceous rocks (black schists) and was deposited from reduced hydrothermal fluids.

In the Western Lachlan Orogen, Victoria, Southeastern Australia, Bierlein et al. (2001) describe several types of carbonaceous material associated with gold: (1) in fault-fill veins associated with

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micaceous laminae and stylolites; (2) as fine-grained dissemination in cataclased carbonaceous slate in faults; and (3) in high-grade gold-bearing quartz veins mainly in intersections with carbonaceous slates. Whereas Cox et al. (1995) quote examples where gold deposition in Australia may have been facilitated by the presence of carbonaceous matter, Bierlein et al. (2001) conclude that CM is not critical for ore genesis at a deposit scale.

The Otago Schist Belt, South Island, New Zealand, hosts a single world-class Macraes gold deposit. Craw et al. (1999) and Craw (2002) conclude that the CM of the mineralized zone is post-metamorphic and was deposited coeval with the mineralization. Similarly, Petrie et al. (2005) assume that the CM enrichment in "black shears" resulted during the late brittle deformation together with extensive fracturing and cataclastic deformation of pyrite and arsenopyrite and with remobilization of older gold mineralization. Craw (2002) and Petrie et al. (2005) hypothetize that the accumulation of CM may have occurred as a result of mixing of two fluids, water + methane, and water + carbon dioxide. During their study of the barren part of the Hyde-Macraes shear zones Henne and Craw (2012) identified several stages of the CM remobilization and metamorphic processes. The hydrothermal CM was also recorded in Late Archean gold deposits of the Hammersley Basin of Western Australia (Ventura et al., 2007).

The Paleoproterozoic gold deposits of the Ashanti Belt, Southern Ghana, occur mainly as auriferous veins in CM-rich shears located parallel or oblique to the regional schistosity of slightly metamorphosed sediments with numerous intercalations of black schists and tholeiitic volcanics. Allibone et al. (2002a,b) showed, using detailed maps and profiles, that CM-rich shear zones occur in direct contact with carbonaceous schists. Koch (1991) considered the CM in shear zones to be of sedimentary origin, deposited as a constituent of shales and later mechanically reconcentrated along shear planes. He did not detect any indications of hydrothermally or pneumatolytically formed carbon modifications. Leube et al. (1990), however, argued that significant amounts of CM in hosting auriferous quartz veins of the Ashanti belt gold deposits may have been remobilized in, and accumulated from reduced hydrothermal fluids together with gold.

Therefore, the origin and the mode of remobilization and deposition of CM into auriferous fault- and shear zones are still uncertain. Similarly, the role of the CM in the genesis of gold mineralization is also not clear. Some authors believe that carbonaceous matter plays a crucial role in the deposition of gold (Leube et al., 1990; Lotz, 1994; Upton and Craw, 2008; MacKenzie et al., 2010), whereas other authors conclude that carbonaceous matter is not critical for ore genesis at a deposit scale (Oberthür et al., 1994; Bierlein et al. (2001)).

The aim of this paper is to assess the possible origin and modes of carbonaceous matter remobilization and accumulation in auriferous orogenic-type deposits in Ghana (the Obuashi and Bogoso deposits), Burkina Faso (the Inata deposit) and Mali (the Syama deposit) using methods of optical microscopy, Raman spectroscopy, XRD measurements, elemental analyses of carbonaceous matter, microprobe and isotopic studies.

2. Regional geology

The Paleoproterozoic Birimian volcano-sedimentary belts with associated granitoids belonging to the Baoule-Moss domain of the West African Craton formed between 2250 and 1980 Ma (Feybesse et al., 2006). The dominant structural nucleus was formed during the Paleoproterozoic Eburnean orogeny. The greenstone belts (Fig. 1) consist of the Birimian sedimentary basins and volcanics, sometimes considered as separate units (Bessoles, 1977; Leube et al., 1990; Pouclet et al., 1996; Vidal et al., 1996).

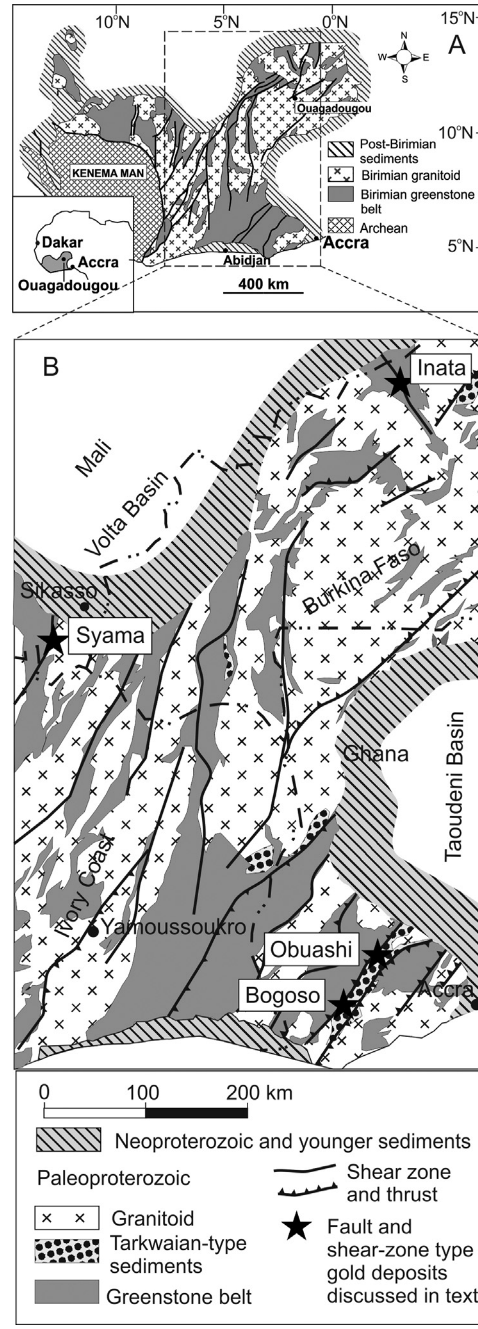

Fig. 1. A simplified geological map of the Leo-Man Craton (modified after Milési et al., 2004; A), with indication of the studied gold deposits (B).

The Tarkwaian sedimentary rocks are considered by most authors to be the youngest unit of the Paleoproterozoic greenstone sequence (Leube et al., 1990; Davis et al., 1994; Castaing et al., 2003; Feybesse et al., 2006).

Most of the volcanic and sedimentary suites were metamorphosed from prehnit-pumpellyite (Kříbek et al., 2008) to upper greenschist facies (cf. John et al., 1999; Feybesse et al., 2006). Regional amphibolite facies metamorphism was reported from Ghana (John et al., 1999; Klemd et al., 2002; Galipp et al., 2003).

Radiometric dating (Oberthür et al., 1998; Leube et al., 1990; Taylor et al., 1992; Davis et al., 1994) indicates that Birimian volcano-sedimentary belts and associated granitoids developed during two separate orogenic cycles during the Eburnean orogenesis.