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Paleoproterozoic plume-related basaltic rocks in the Mana gold district in western Burkina Faso, West Africa: Implications for exploration and the source of gold in orogenic deposits

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ABSTRACT

Birimian volcanic rocks of the Mana District are located in the an important gold-mineralized segment of the Paleoproterozoic Houndé greenstone belt, western Burkina Faso, which contains cumulative resources of ~11 Moz. Five orogenic gold deposits (~8 Moz) are hosted in or close to basaltic rocks. Theses rocks were studied to investigate their possible role as a gold source in younger orogenic gold deposits. They are Fe-rich tholeiitic basalts with flat REE patterns, with $(La/Yb)_N = 0.96–1.3$ and without negative Eu anomaly ($Eu/Eu^* = 0.92–1.26$). The basalts also have low initial Sr isotopic ratios (0.693612 −0.702190) and positive εNd values (+2.25 to +3.14). Using a Ce/Nb vs. Th/Nb diagram and various plume-related basalts worldwide for comparison, the Mana basalts are shown to be plume-related. In addition, using Zr/Nb vs. Nb/Th and Nb/Y vs. Zr/Y binary diagrams and reference fields, the Mana basaltic rocks appear to have formed directly above the plume head. Because plume-related basalts tend to be enriched in gold relative to MORB, we propose that the gold endowment of the Mana district is mostly related to the occurrence of plume-related basaltic rocks, which may have served as an important metal stock during subsequent remobilization for forming the orogenic gold deposits. We also propose that for gold exploration, two simple geochemical diagrams involving Zr, Y, Nb and Th could be used at an early stage to test the origin of the basaltic rocks and hence indirectly establish the fertility of a specific belt for hosting orogenic gold deposits.

1. Introduction

Orogenic gold deposits contribute over 75% of the world's total gold production (Phillips, 2013), but the primary sources of gold remain controversial (Tomkins, 2013a). Numerous workers have tried to address this problem (e.g., Pitcairn et al., 2006; Large et al., 2012; Tomkins, 2013a; Pitcairn et al., 2015) which also have fundamental implications for selecting potential gold exploration terrains. Recent works have highlighted three main sources of gold: 1) intrusion-related sources (e.g., Lang and Baker, 2001; Helt et al., 2014); 2) carbonaceous, pyrite-rich sedimentary rocks (Pitcairn et al., 2006; Large et al., 2007, 2009, 2012; Thomas et al., 2011; Gaboury, 2013); and 3) basaltic rocks (Bierlein and Pisarevsky, 2008; Bierlein and Craw, 2009; Willman et al., 2010; Pitcairn et al., 2015). Among basaltic rocks, plume-related rocks have the highest primary gold endowment and exhibit enrichment up to 13 times greater than that of mid-ocean ridge basalts (MORB) (Webber et al., 2013). Such plume-related rocks thus have greater potential to constitute important primary gold source (Bierlein and Pisarevsky, 2008; Webber et al., 2013) in the remobilization process during the metamorphogenic formation of orogenic gold deposits (Phillips and Powell, 2010).

Among the three main periods of orogenic gold mineralization recognized worldwide (Goldfarb et al., 2001; Tomkins, 2013b), including the Late Archean (2.7–2.5 Ga), Early Proterozoic (2.1–1.8 Ga), and Phanerozoic (<1 Ga), the Early Proterozoic is of special interest due to the recent high rate of gold deposit discoveries relating to this period (Nyame, 2013). This period roughly coincides

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with the formation of the Birimian greenstone belts that occur mostly in Western Africa, with a few additional examples in South America (Fig. 1). Most of the recent discoveries were in Burkina Faso, a country that is covered approximately 20% by greenstone belts (~70 000 km^2) (Béziat et al., 2008). In the last decade, seven mines were put into production, and numerous deposits are at advanced stage (Fig. 2a). Between 2007 and 2015, ~6.1 Moz were produced from total resources of ~30 Moz of gold (Avocet, 2015; Endeavour Mining, 2015; ITIE, 2014; 2016; IAMGOLD, 2015; Nordgold, 2015; Semafo Inc, 2015). Currently, Burkina Faso is the fourth highest gold-producing country in Africa, after South Africa, Ghana and Mali (Markwitz et al., 2016; Robertson and Peters, 2016). Among the various greenstone belts in Burkina Faso (Fig. 2a), the Houndé belt is currently known to be the richest in gold, with a cumulative production, reserves and resources of ~11 Moz (Roxgold, 2013; Endeavour Mining, 2015; Semafo Inc, 2015; Sarama Resources, 2016) (Fig. 2a). The Mana district is the richest segment within the Houndé belt and hosts five orogenic gold deposits containing a total of ~8 Moz (Semafo Inc, 2015), including the world class Wona-Kona gold deposit (>4 Moz: Augustin et al., 2016) (Fig. 2a).

The lithological succession of the Birimian terranes is made up of basaltic to andesitic rocks, interbedded with clastic sedimentary sequences including the late Tarkwaian group and intruded by several generations of granitoids (Leube et al., 1990; Milési et al., 1992; Sylvester and Attoh, 1992; Béziat et al., 2000; Roddaz et al., 2007; Lompo, 2009). In the West African Craton (WAC), the origin of the basaltic rocks, constituting the base of the Birimian greenstone belts, is still debated. Three geodynamic contexts for the formation of these rocks have been proposed including 1) a plume-related setting (Abouchami et al., 1990; Boher et al., 1992); 2) island arc setting (Dia, 1988; Sylvester and Attoh, 1992; Ama Salah et al., 1996; Baratoux et al., 2011; Béziat et al., 2000; Soumalia et al., 2004; Dampare et al., 2008; de Kock et al., 2012; Senyah et al., 2016); and 3) MORB (Lompo, 2010). The Mana district is thus a unique terrain in the western Burkina Faso to test the origin of these basaltic rocks and to address their potential role as the source of gold in orogenic deposits.

In this paper, we present new geochemical data for major and trace elements, and Sr and Nd isotopic data of the basaltic tholeiitic rocks in the Mana district. This dataset is compared with published data from the WAC and modern plume setting. The basaltic rocks of the Mana district are shown to be related to oceanic plume volcanism and interpreted to have been formed directly above the plume head. Even though other factors are likely involved in the formation of economic orogenic gold deposits (Goldfarb et al., 2001; Bierlein et al., 2006), we argue that gold endowment in Mana district is mostly related to the occurrence of plume-related basaltic rocks presumably enriched in primary gold. The rapid identification of the source of basaltic rocks based on trace elements and their position relative to the plume head can serve as a direct criterion for selecting more favorable belts during early exploration stages.

2. Craton scale geology

The Man-Leo Shield, in the WAC comprises a Paleoproterozoic domain (Baoulé-Mossi domain) to the east and an Archean domain (the Kénéma-Man domain) to the west. These two domains are separated by the Sassandra fault (Bessoles, 1977; Feybesse et al., 1989; Feybesse and Milési, 1994; Kouamelan et al., 1997; Egal et al., 2002) (Fig. 1). The Paleoproterozoic domain comprises the Birimian terrains (2.2–2.0 Ga) (Abouchami et al., 1990; Boher et al.,

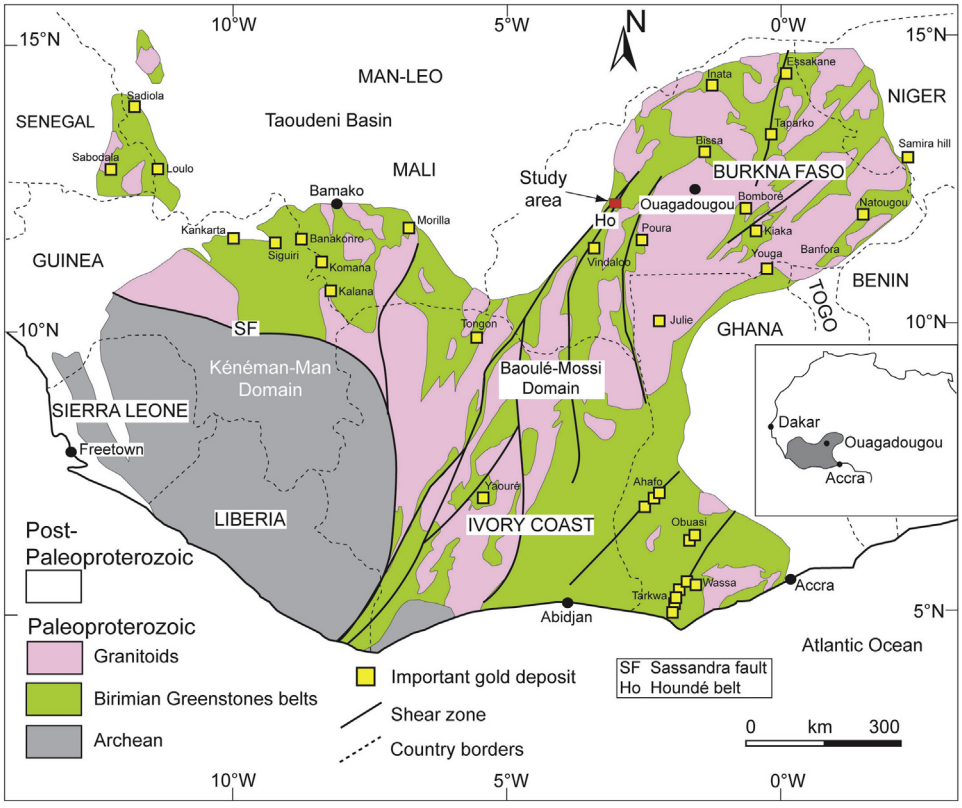

Fig. 1. Geological map of the Leo-Man Craton showing the location of the study area and the most important gold deposits across the WAC (Modified from Milési et al., 2004; Baratoux et al., 2011).