Shear-related gold mineralization in Northwest Ghana: The Julie deposit

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Abstract

The Julie deposit is currently the largest gold prospect in NW Ghana. It is hosted in sheared granitoids of TTG composition of the Paleoproterozoic Julie greenstone belt. The main mineralization consists of a corridor of gold-bearing quartz veins forming a network of a few tens of meters in thickness, trending E-W and dipping 30-60° N, contained within the main shear zone that affects these rocks. The core of this vein corridor is altered by sericite, quartz, ankerite, calcite, tourmaline and pyrite, and is surrounded by an outer halo consisting of albite, sericite, calcite, chlorite, pyrite and rutile. A second set of veins, conjugate to the first set, occurs in the area. These veins have alteration halos with a similar mineralogy as the main corridor, however, their extent, as well as the size of the mineralization, is less important. In the main corridor, gold forms micron-sized grains that occur in pyrite as inclusions, on its edges, and in fractures crosscutting it. Silver, tellurium, bismuth, copper and lead commonly accompany the gold. Pyrite occurs disseminated in the

veins and in the surrounding rocks. Up to several ppm Au occur in the structure of pyrite from the main mineralization.

1 Introduction and exploration history

In the Birimian terranes of southern Ghana, commercial gold exploration and exploitation have been active since the early 1900s, notably with the development of world-class deposits in the Ashanti and Sefwi belts, which have received extensive attention in the literature (e.g. Junner, 1932; Milési et al., 1989; Klemd et al., 1996; Allibone et al., 2002; Feybesse et al., 2006; Perrouty et al., 2012, 2015; White et al., 2015; Fougereuse et al., in press). Conversely, very little is known of the Birimian mineralization of NW Ghana (Fig. 1), where alluvial and bedrock indications of gold have only been reported since the early 1960s. Nevertheless, it is now recognized that this part of the country hosts an important gold-producing area, known as the Wa-East gold district. Numerous gold camps occur in this district, the most important of which is the Julie deposit. Other examples include Collette, Kjersti, Julie West (Fig. 2), plus Kandia, Baayiri and Danyawu, which lie just outside the area covered by the map in Figure 2.

The first discoveries of mineralization in this part of Ghana are attributed to the Gold Coast Geological Survey (Griffis et al., 2002). Survey geologists mapped the area and outlined prospects in the Wa-Lawra greenstone belt during the early 1960s, in the adjacent Koudougou-Tumu granitoid domain and in the Julie greenstone belt. A Russian geological team carried out additional prospecting and geological mapping, also in the 1960s. However, it was not until the 1990s that systematic exploration activities started. Kenor Corporation held the first prospecting

licence for the Julie deposit, from September 1996 to May 1999, which was then taken over by Crew Gold Corporation who detained it until February 2010. These companies focussed their work mainly on target generational prospecting, which included interpreting Landsat satellite and airborne geophysical data, geological mapping, and geochemical sampling (mainly soil, grab and auger sampling methods). Surface targets generated by these first-pass geological and geochemical surveying methods were tested further to top of bedrock by rotary air-blast (RAB) and air-core (AC) drilling. From December 2004 to May 2005 a total of about 4,815 m of reverse circulation (RC) core were drilled, to assess bedrock mineralization. Crew Gold Corporation identified 312,000 oz (8.8 t) of gold (grading at 2.9 g/t) and estimated mineralization to extend to depths of over 30 m along a 3.5 km strike length (Azumah Resources Limited, 2012). Further exploration was carried out by Azumah Resources Limited in 2006 and beyond, who discovered 834,000 oz (23.6 t) of measured and indicated gold (at 1.53 g/t), with a proven reserve of 202,000 oz (5.7 t) (at 2.84 g/t) in the Julie deposit (Table 1). Azumah acquired the prospecting licence in February 2012. Currently, they have drilled some 43,700 m, to establish trend and continuity of the mineralization first detected by Kenor. In 2013, 2.21 Mt of indicated resources were estimated, making Julie the largest gold resource in NW Ghana.

2 Regional geological overview

Northwest Ghana lies on the eastern edge of the Paleoproterozoic Birimian terrane of the West African Craton (WAC). The Wa-East gold district occurs within the Julie greenstone belt, an E-W trending structure bounded to the east by the Bole-Nangodi greenstone belt, to the south by the Bole-Bulenga domain, to the west by

the Wa-Lawra greenstone belt and to the north by the Koudougou-Tumu granitoid domain (Fig. 1). The Koudougou-Tumu granitoid domain is composed of tonalite-trondhjemite-granodiorite (TTG) intrusions formed between 2155 to 2135 Ma (U-Pb zircon ages; Agyei Duodu et al., 2009). Potassic porphyritic granites, dated at 2128 and 2086 Ma (U-Pb zircon ages; Taylor et al., 1992, Agyei Doudu et al., 2009), intrude these rocks. The Wa-Lawra belt is composed of shales, volcano-sediments, basalts and granitoids. Geochronological U-Pb dating on detrital zircons in the volcano-sediments gives ages older than 2139 Ma (Agyei Duodu et al., 2009). The Wa-Lawra and Koudougou-Tumu domain are juxtaposed along the crustal scale sinistral Jirapa fault. The Bole-Bulenga domain is composed of high-grade gneisses, intruded by TTG plutons commonly exhibiting migmatitic textures. The Julie belt is composed of basalts, granitoids, gabbros and volcano-sediments. To date, no geochronological data exist for the rocks from the Julie belt.

Baratoux et al. (2011), de Kock et al. (2011) and Block et al. (2015) highlighted the evidence for multiple deformation phases in the Birimian terranes of NW Ghana. An early, short-lived event (termed Eoeburnean) was identified by de Kock et al. (2011), and interpreted to be driven by pluton emplacement and basin folding, between 2160 and 2150 Ma. Block et al. (2015) proposed that the first Eburnean event (D_1) in NW Ghana occurred around 2137 ± 8 Ma (*in-situ* U-Pb dating on monazite). This event is characterized by intrusions of voluminous granitoid plutons, locally associated with volcanism and sedimentation, allochthonous thrusting, folding and development of penetrative metamorphic fabrics resulting in crustal thickening driven by N-S shortening. Peak metamorphic conditions of D_1 reach upper amphibolite facies (Block et al., 2015). The second Eburnean phase, D_2 , is interpreted to have occurred between 2130 to 2110 Ma (U-Pb dating on rhyolites).

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99 This event is characterized by regional scale WNW- trending sinistral and NE-
100 trending dextral transcurrent faulting and shearing, which affected most of the rocks
101 within the Wa-Lawra belt, west of the Julie area. Gold mineralization has been
102 reported along these structures (e.g., Allibone et al., 2002; Béziat et al., 2008;
103 Amponsah et al., in press). Block et al. (2015) report late, post-Eburnean brittle NE-
104 and NW-trending faults that crosscut all existing Eburnean structures in the region.
105 These faults are subvertical and of limited extent.

106 Metamorphic conditions in this region range from greenschist to granulite
107 facies. The highest grades (granulite facies) are observed in the Bole-Bulenga
108 domain, whereas amphibolite facies dominate in the Koudougou-Tumu domain.
109 Rocks in the Julie belt are metamorphosed to greenschist facies, at temperatures
110 between 230°C to 350°C and pressures between 1 to 3 kbar, determined by
111 equilibrium mineral assemblages (chlorite-muscovite-epidote-calcite) by Block et al.
112 (2015).

114 **3 Local geology**

115 **3.1 Main rock types**

116 The principal lithology in the area of the Julie deposit consists of
117 metamorphosed granitoids that are deformed to various degrees, and which are in
118 contact with basalt and volcanic sediments, a few km to the north (Fig. 2; see also
119 Fig. 3). The granitoids are metaluminous and their normative composition overlaps
120 the compositional fields of tonalite, granodiorite and trondhjemite (TTG) (Amponsah
121 et al., in press). Their trace geochemistry corresponds to typical magmatic rocks in
122 active margins, with a Rb vs Y+Nb signature corresponding to the volcanic arc

granites field of Pearce et al. (1984; Amponsah et al., in press). Texturally, the TTG are medium to coarse grained, and are primarily composed of quartz, hornblende, plagioclase and biotite plus accessory magnetite, zircons and titanite. A greenschist metamorphic assemblage consisting of epidote, calcite, chlorite and rutile overprinted these minerals.

To the north of the Julie shear zone, the basaltic flows alternate with sediments consisting of metamorphosed volcanic sediments with minor intercalated greywacke and shale. The basalts are strongly magnetic and are made up of plagioclase, green amphibole, calcite, chlorite with minor titanite and magnetite. The sediments are fine to medium grained, black to grey in colour, and consist of quartz, muscovites, chlorite, biotite and locally graphite.

3.2 Structural features and quartz veins

Three deformational phases were mapped in the deposit area (D_{J1} , D_{J2} and D_{J3} ; Amponsah et al., in press). In the TTG, the D_{J1} deformation is defined by an E-W-trending penetrative foliation (S_1) that dips between 35° and 70° to the north, representing a brittle-ductile shear zone. This shear reflects a regional scale thrust, and has a general top-to-the-south movement, although E-W to WNW-ESE mylonitic dextral shears can be observed to locally crosscut the ductile fabric and are interpreted as late D_{J1} . Quartz veins are abundant within this shear zone and are commonly boudinaged parallel to it (Fig. 4a). In addition to quartz, the veins contain lower proportions of calcite, ankerite, tourmaline and pyrite. These veins host the main mineralization at Julie. A few isolated, undeformed quartz veins ranging in strike from N-S to NE-SW were observed in exploration trenches and pits. They are

interpreted to represent a conjugate set to the E-W (S_1 -parallel) veins (see section 6). They never extend for more than 100 m along strike, have a vuggy aspect and, in addition to quartz, contain chlorite, carbonates, muscovite and pyrite (Fig. 4b). These veins also host some mineralization, although to a lesser extent than the E-W veins.

D_{J2} is characterized by an E-W compression, which produced F_2 isoclinal folds with a fold axis verging northwards, and axial planes striking N-S with subvertical dips. This event is not observed in the intrusives at Julie but affected the basalts and volcano-sedimentary units north of the deposit, mostly in the form of crenulation of the D_{J1} fabric. Quartz veins formed within the S_2 foliation plane, but were only observed in the basalt. They are deformed, contain traces of calcite and tourmaline, and are not mineralized.

The latest stage of deformation recognized at Julie, D_{J3} , is characterized by brittle faults that crosscut the D_{J1} and D_{J2} structures, strike NE-SW and dip 30 to 40° to the northwest.

4 Ore body characteristics

Mineralization in the Julie deposit is mostly related to the E-W trending D_{J1} -related S_1 shear zone. The main ore body consists of a network of numerous quartz veins, which form a corridor striking E-W and dipping 30 to 60° to the north (Fig. 3). The ore body extends over 3.5 km along strike and has a thickness varying from 20 to 30 m. It is enclosed by an alteration envelope that gradually changes away from the mineralized zone into the barren rock; an inner zone affects the vein corridor, within a width of about 50 m (Fig. 3), and has particularly-low magnetic susceptibility

relative to the barren rock. This alteration consists of sericite + quartz + ankerite + calcite + tourmaline + pyrite. In this zone, the average gold grade is about 3.0 g/t. A second alteration envelope surrounds this inner zone and consists of albite + sericite + calcite + chlorite + pyrite + rutile (Fig. 3). Here, pyrite partially replaces primary magnetite and albite replaces most feldspars, and gold grades range between 0.1 g/t to 0.4 g/t. Further away from this zone, a metamorphic assemblage of chlorite, epidote and calcite affects the barren rocks.

Gold mineralization also occurs in the N-S trending quartz veins. An alteration envelope, similar to that affecting the main ore, characterizes these veins, although in this case it is much more limited in space. In these veins, gold grades range around 0.2 g/t, although in a few places values up to 3.5 g/t have been measured.

5 Microscopic features of the ore

Mineralization in the D_{J1}-related vein corridor occurs mostly in the form of micron-sized gold grains that form inclusions in pyrite crystals that are commonly deformed, as well as larger grains occurring within fractures in pyrite or along its crystal edges (Fig. 4c, d). In many instances, gold is accompanied by silver, bismuth, tellurium, copper and lead. Gold-bearing pyrite occurs in the quartz veins as well as disseminated in the wall rock, within the alteration selvages described above, and no particular difference was observed between the two. In the N-S trending veins, gold occurs in quartz as rare free grains, although mostly in fractures within pyrite from the veins and the alteration halos, and it is commonly accompanied by minor silver. However, in these veins gold was not found as inclusions in pyrite.

Amponsah et al. (in press) detected the presence of up to 15 ppm Au in pyrites from the main mineralized zone by LA-ICP-MS analyses; the data did not allow to distinguish whether gold is in the structure of this sulphide or forms nanoparticles (cf. Deditus et al., 2011). Only ppb amounts of Au were detected by this technique in a few pyrites from the N-S veins. In addition to gold, other metals detected by LA-ICP-MS in pyrite from the main mineralization include Ag, Te, Pb, Se, Ni and Co.

6 Genetic considerations

The main ore body in the Julie deposit occurs in the form of a network of quartz veins along the E-W trending S_1 shear zone. The hydrothermal alteration that affected the rocks containing the vein network, defines the mineralized corridor. It consists mainly of sericitization, carbonatization and sulphidation. Amponsah et al. (in press) show that these secondary minerals are foliated parallel to the local S_1 foliation plane, which is consistent with a syn-deformation emplacement of the mineralized system, which, in turn, is coherent with the fact that the veins are boudinaged along S_1 . The N-S trending veins are interpreted by these authors as being a conjugate set to the S_1 -parallel veins, i.e., they formed pene-contemporaneously, and represent the σ_3 direction for D_{J1} . They base their argument on the their orientations, as well as the fact that both vein sets display the same type of alteration halos and contain fluid inclusions with the same physicochemical characteristics. Nevertheless, the fact that in the N-S veins gold only occurs in fractures, suggests that these veins were under a brittle deformational regime, and recorded only the late stages of mineralization. The D_{J1} event, responsible for the formation of the S_1 shear zone and the mineralization at Julie, has the same

kinematic indicators as the regional D₁ of Block et al. (2015) and likely represents a local expression of this regional scale deformation episode.

A study of the fluid inclusions found in the veins indicates the presence of immiscible aqueous and carbonic fluids circulating at about 250°C and 1 kbar (Amponsah et al., in press). Their composition suggests a metamorphic origin of the mineralizing fluids, rather than orthomagmatic. This is consistent with the alteration mineralogy, which is typical of orogenic gold deposits hosted in metamorphosed volcanic rocks (e.g., Saunders et al., 2014). The PT conditions are interpreted to record hydrostatic regime during drops in pressure subsequent to the creation of open space during deformation (e.g., Sibson et al., 1998). As suggested by Amponash et al. (in press), these pressure drops most likely triggered gold precipitation (e.g., Kouzmanov and Pokrovski, 2012), along with other metals and quartz.

7 Summary and conclusions

The Julie deposit, hosted in the Wa-Lawra greenstone belt in NW Ghana, will be potentially the next operating mine in the country and the largest resource in the region. It is hosted in sheared Paleoproterozoic granitoids of TTG composition and the main ore consists of a mineralized corridor, trending E-W and dipping N, formed by a network of quartz veins emplaced along the main shear zone, which is an expression of the regional D₁ deformation episode. Minor gold mineralization was also found in a set of quartz veins that are conjugate to the main veins though formed slightly later, mostly under a brittle regime. Within the main vein corridor, gold occurs almost exclusively within pyrite, as inclusions, in fractures and along its edges. In both vein sets, this sulphide occurs in the veins as well as in the host rock

where it is contained within an alteration selvage, which defines the extent of the mineralized body. Invisible gold occurs in pyrite from both vein sets, although only ppb amounts were detected in pyrite from the conjugate veins.

Acknowledgement

This work was financed by the AMIRA WAXI Phase II sponsors (project number P934), including AusAid and the ARC Linkage Project LP110100667, and by Azumah Resources Limited. The latter are also thanked for field assistance, access to their core and data, and for granting permission to publish this paper. We also acknowledge the contribution of Geological Surveys/Department of Mines in West Africa as sponsors in-kind of WAXI. Constructive reviews by German Vélasquez and Steven Micklethwaite were appreciated and contributed to improve the quality of the manuscript.

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Table captions

Table 1. General information on the Julie deposit.

Figures captions

Figure 1. Regional litho-structural map of Precambrian terranes in NW Ghana (modified after Block et al., 2015), showing the geological context of the Julie belt. The red insert localises the study area.

Figure 2. Simplified map of the Julie Belt, showing several mineralized occurrences in the Wa-East district (modified after Amponsah et al. in press). The Julie deposit, in the lower right of the map, consists of several potentially exploitable workings. The N-S cross-section shown in Figure 3 is also located.

Figure 3. Cross-section of the Julie deposit along 579100 m E (see Figure 2 for location), constructed based on drill core information (single drill holes are labelled on the section). The section shows the main mineralized corridor, which is defined by wall-rock alteration. High-grade mineralization is confined to the inner alteration zone. The external alteration selvage contains low-grade mineralization.

Figure 4. Macroscopic and microscopic images of samples from the Julie deposit. (a) Drill core of sheared granitoid from the main mineralization zone, showing several quartz veins and pyrite grains (Py) stretched along the main foliation. (b) Hand sample of vuggy quartz from the N-S veins. The sample shows a pyrite agglomerate in quartz. (c) Photomicrograph under reflected light of a pyrite grain deformed parallel to the foliation (vertically with respect to the image) from the main mineralized zone. (d) SEM image showing details of a pyrite grain, also from the main mineralized zone, where gold occurs as micron-sized inclusions and in a fracture. Inclusions of ankerite (Ank), sericite (Ser), rutile (Rt) and biotite (Bt) are also visible.

Figure 1

Figure 2

Figure 3

Figure 4

Table 1

Deposit name	Julie
Commodity of exploitation	Au
Location	NW Ghana
Longitude-Latitude [dec degrees]	10.205°N–2.189°W
Geographic location	NW Ghana, Upper West Region. The deposit is situated 60.8 km west of the regional capital (Wa)
Geological location	Leo-Man shield of the West African Craton; in the Julie greenstone belt, between the Wa-Lawra and Bole-Nangodi belts
Deposit status	Prospect under development (mine development stage)
Deposit type	Granitoid hosted; shear-zone related, quartz veins
Current owner	Azumah Resource Limited
Average grade	2.0 g/t
Tonnage	2.21 Mt of measured and indicated resource; 202,000 oz proven reserves (September, 2014)
Past production	No production to date