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The paleoproterozoic Ghanaian province: Geodynamic model and ore controls, including regional stress modeling

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Abstract

A multicriterion approach has made it possible to propose a paleoproterozoic evolution of the Ghanaian province and a gold-emplacement model in terms of structural control, geodynamic context, multi-scale orebody control and crustal-scale stress partitioning. The evolution, which began at the margin of the Archean São Luis Craton (SLC), started around 2.35–2.30 Ga with plutonic activity and the deposition of BIF-bearing volcano-sediments in basins resulting from the craton's break up. Magmatic accretion reached its peak phase around 2.25–2.17 Ga with the emplacement of huge quantities of juvenile basic volcanic–plutonic rock – accompanied by greywackes deposited no later than 2.22 Ga – that initiated the creation of crustal segments (Sefwi, Ashanti, Kibi belts, ...). This was followed at around 2.16–2.15 Ga by extensive monzonitic plutonism whose emplacement led to the formation of the first segments of continental crust.

A transition period between the magmatic accretion and the Eburnean orogeny is marked by the Sunyani, Kumasi-Afema and Comoé basins that developed between 2.15 and 2.10 Ga. They are considered to be foreland basins in that their flysch-like sedimentary fill was partly contemporaneous with the onset of the Eburnean orogeny at 2.13 Ga.

The Eburnean orogeny, with the D1 and D2–3 periods of deformation, lasted from 2.13 to 1.98 Ga. The D1 thrust tectonism, from 2.13 to 2.105 Ga, caused crustal thickening through unit stacking; it was related to horizontal crustal shortening attributed to lithospheric convergence in a plate-tectonic setting. The Tarkwaian Basin was partly contemporaneous with this D1 episode and is thus considered as a foreland basin whose infill continued during D2 tectonism. The D2–3 events, from 2.095 to 1.98 Ga, was a period of strike-slip movement. Peak D2 activity was accompanied by sinistral to reverse-sinistral shearing that controlled the geometry of the Tarkwaian Basin and the emplacement of plutonic-volcanic bodies. D2 structures also channelled and trapped gold-bearing hydrothermal fluids, and thus had a multi-scale control over the distribution of the mineralization; i.e. (a) at regional-scale, first-order D2 faults (e.g. the Konongo-Ashanti-Prestea Fault) acted as channels exercising a control on deposit distribution, (b) at semi-regional scale (10 km), the deposits are sited in or adjacent to second-order structures (e.g. intense folding) associated with the regional faults and (c) at deposit scale (1 km), the mineralization is trapped in tension gashes, faults and shears, stockworks, etc., developed in the hinge zones of the folds.

Syn-D2 stress partitioning at the scale of the Ghanaian province reflects the displacement and geometry of a rigid block (southeastern Ghana) coinciding with a high stress zone. Tectonic forces in front of this block induced movement along sinistral and reverse-sinistral faults centred on the western border of the Ashanti Belt and formed a synclinorium centred on the Tarkwaian Basin. Ahead of this front, a zone of moderate deformation reflects a huge low-stress zone corresponding roughly to the Kumasi-Afema Basin.

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A multicriterion and multi-scale analysis was made of the spatial and stress controls in order to determine the relationship between the gold-bearing hydrothermal event and the geodynamic evolution. This made it possible to identify significant points in terms of ore-deposit geology, and led to the nine following conclusions and interpretations concerning the Ghanaian province.

1. A pre-Birimian proto-Ghanaian province existed at the margin of the Archean São Luis Craton where gold deposits were emplaced as a result of crustal growth (through magmatic accretion) and the subsequent Eburnean orogeny when the province marked a collision zone between an Archean continental block (SLC) and segments of newly formed paleoproterozoic crust. Such a setting combining a continental margin, juvenile magmatism, convergence and continent-juvenile crust collision, appears particularly favourable for the presence of gold.
2. Within the paleogeographic setting at the end of the Eburnean D1 event at the craton margin, the proto-Ghanaian gold province was located in the foreland of the main tectonic zone.
3. The Ashanti Belt, which hosts Ghana's main gold resources, marks the boundary between a continental domain (Archean craton) and an oceanic domain (Birimian crust).
4. The Konongo-Ashanti-Prestea, Bibiani and Yamfo-Kenyase faults, which are well know regional metallotects, are polyphase tectonic contacts that were initiated as D1 thrusts and reworked as D2 transcurrent faults. The deposits are thus located in a paleotectonic setting whose paleogeographic and geotectonic speciation lasted throughout the Eburnean orogeny.
5. As is commonly the case with orogenic gold (Groves, D.I., Goldfarb, R.J., Knox-Robinson, C.M., Ojala, J., Gardoll, S., Yun, G.Y., Holyland, P., 2000). Late-kinematic timing of orogenic gold deposits and significance for computer-based exploration techniques with emphasis on the Yilgarn Block, Western Australia. Ore Geol. Rev. 17, 1–38], mineralization itself was emplaced at the end of the Eburnean orogenic process.
6. Circulation of gold-bearing fluids was favoured by late-orogenic events that increased crustal permeability. The first was the change in tectonic style from D1 thrusting to D2 sinistral shearing. The second was a pre-D2 period of uplift and erosion that brought the host rocks to a shallow position, thus enabling their brittle behaviour when put under syn-D2 stress. The third was a period of reduced tectonic activity (stress quiescence) between D1 and D2.
7. The position of the gold deposits in relation to the syn-D2 stress partitioning at the scale of the Ghanaian province indicates that: (a) most of the prospects are located in huge low- and medium-low-stress domains and (b) the major orebody controls, such as the Konongo-Ashanti-Prestea Fault, correspond to a contrast in stress and rock competence. A proposed model for the large-scale control over fluid distribution envisages that the Kumasi-Afema low-stress domain collected crustal fluids transiting through this storage medium and fed them laterally to the shear zones with their stress and competence contrasts.
8. Magmatic activity from slightly before to slightly after the hydrothermal event appears to have played an important role as a thermal driving force.
9. One of the specific features of the Ghanaian gold province seems to be the percolation of CO_2-rich fluids (see references in Section 6.2) through the crust during the Eburnean orogeny.

Keywords: West Africa; Ghana; Archean; Paleoproterozoic; Structural analysis; Geochronology; Ore-deposit geology; Structural controls; Magmatic and tectonic accretion; Multi-scale orebody controls; Geodynamic model; Crustal-scale stress partitioning

1. Introduction

The Ghanaian gold province (in reality a subprovince of the West African paleoproterozoic) is the only metallogenic province in West Africa that can be considered as world-class. It contains the Tarkwa-type paleoplacers (modified or not), and numerous primary (epigenetic) deposits. The primary mineralization is well documented in terms of mineralogy, geochemistry, structural controls and thermo-barometry (Klemd et al., 1993, 1996; Hammond and Shimazaki, 1994; Mumin and Fleet, 1995; Klemd and Hirdes, 1997; Klemd, 1998; Oberthür et al., 1998; Bird and Sylvain, 1999; Ledru et al., 1988; Billa and Feybesse, 1996a,b, 1997; Feybesse and Billa, 1996; Feybesse, 1999; Allibone et al., 2002a,b, 2004; Robb, in Yao et al., 2001; Ireland et al., 2001; Yao et al., 2001; Wille and Klemd, 2004), but the studies have, for the most part, been limited to the deposits and their immediate host rocks—few studies have considered the mineralizing process at province scale. However, many of the deposits lie preferentially along major faults implying a regional-scale structural control. In order to place the mineralizing event within the paleoproterozoic evolution of the Ghanaian province, and so determine exploration guidelines, we adopted a multicriterion and multi-scale approach based on a double premise: (1) that an economic concentration is the end result of a complex process in which several parameters play a role and (2) that a metallogenic approach must go beyond orebody scale and integrate the miner-