

Mapping and 3D modelling of structural controls in the Chirano gold deposits, Ghana: keys to better resource delineation and near-mine exploration targeting

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Abstract

Gold deposits in the Chirano district in SW Ghana are hosted in a variety of structural settings along the Chirano shear zone (CSZ), in Paleoproterozoic rocks of the Sefwi-Bibiani belt. Most gold mineralisation occurs in strongly sheared and hydrothermally altered Birimian mafic igneous rocks and tonalite intrusions within the CSZ. A recent program of open-pit structural mapping, core logging, and 3D modelling helped to define deposit-scale structural controls on gold mineralisation. These include strain domains, shear zone flexures, shear zone intersections, and vein arrays associated with host-rock competency contrasts. Interestingly, the plunge of higher-grade shoots in some deposits appears to be associated with the intersection of the CSZ and broadly folded Tarkwaian sedimentary rocks, which are not significant gold hosts in the Chirano district. This paper presents the results of 3D modelling that were used to define structural controls on mineralisation in several open-pits and one underground mine along a nine-kilometre length of the CSZ. Leapfrog™ software was particularly useful because it highlighted the orientations of structural features that focused hydrothermal fluid flow during alteration and mineralisation. The improved understanding of structural controls provided two main benefits: near-mine exploration drill targets and better definition of structural domains for resource estimation.

Introduction

The Chirano district is relatively mature in terms of exploration with considerable mapping, geochemical, geophysical and drilling datasets. Exploration efforts in the early phases of the project were largely empirical, with the known deposits discovered by soil geochemistry, follow-up trenching and drilling (Stuart, 2007). This led to the discovery of fourteen deposits over a strike length of nine kilometres and Proven and Probable Reserves estimated at July 2004 of 17.8 Mt grading 1.9 g/t for a total of 1,090,000 ounces of gold (Stuart, 2007). Mining operations at Chirano began in 2005 and have generated considerable new exposures within eight open-pits and one underground mine (Figure 1).

The discovery of the Akwaaba Deeps orebody, which is currently being exploited by an underground mine, resulted in a re-assessment of the potential for steeply plunging mineralisation that may not have been discovered by previous exploration methods. Exploration for such targets is more conceptual and requires a better understanding of the 3D geometry of structures and rock units to reduce the exploration risk. This paper presents the results of a recent investigation of the structural controls on gold mineralisation and 3D geological modelling in the Chirano district, which has allowed better definition of structural domains for resource estimation and near-mine exploration drill targets.

Regional Geology

Paleoproterozoic supracrustal rocks in southwest Ghana are subdivided into Birimian and Tarkwaian units. The Birimian comprises successions of sedimentary and volcanoclastic rocks (Lower Birimian), which separate five northeast-trending volcanic belts (Upper Birimian). Available field evidence suggests that the volcanic and sedimentary rocks are lateral equivalents (Leube *et al.*, 1990). The Tarkwaian system is dominated by coarse clastic sedimentary rocks of fluvio-deltaic origin. Age dating suggests that the Birimian and Tarkwaian sedimentation broadly overlap in the period 2140 to 2100 Ma. However, clasts of Birimian rocks within the Tarkwaian suggest that locally the Tarkwaian is younger (Pigois *et al.*, 2003).

Birimian and Tarkwaian rocks were deformed and metamorphosed under greenschist facies conditions during the Eburnean tectonothermal event at ca. 2.1 Ga (Oberthur *et al.*, 1998). NW-SE shortening during this event resulted in progressive folding and thrusting and a late phase of localised strike-slip shearing (Eisenlohr and Hirdes, 1992; Allibone *et al.*, 2002). The region has been intruded by two major suites of granitoids: the Dixcove- or belt-type granitoids, which occur within the volcanic belts; and the Cape Coast- or basin-type granitoids that intrude the sedimentary basins.

Ghana is a major producer of gold in Africa. Gold is primarily mined from two styles of deposits: structurally controlled epigenetic vein/lode systems or paleoplacer mineralisation within quartz pebble Tarkwaian conglomerates. The epigenetic deposits, such as those in the Chirano district, are mostly located within or adjacent to fault zones at the margins of the volcanic belts, which were re-activated late during the Eburnean tectonothermal event (Allibone *et al.*, 2002).

Chirano Gold District

The Chirano gold district is located at the boundary of the Sefwi-Bibiani volcanic belt and the sedimentary Kumasi basin (Figure 1). The Birimian belt and basin rocks are separated by a narrow (<2 km wide) sliver of Tarkwaian sedimentary rocks. To the east the Bibiani shear zone separates Birimian and Tarkwaian sedimentary rocks. To the west the CSZ separates Tarkwaian sedimentary rocks from Birimian mafic igneous rocks.

The Birimian igneous rocks are mostly basalts, dolerites and gabbros with minor tuffaceous sedimentary rocks and felsic lavas and dykes. The Birimian sedimentary rocks comprise mafic phyllites and fine grained argillaceous sandstones. The Tarkwaian comprises polymictic conglomerate, fine to coarse-grained quartz and arkosic sandstones, arenites and thin mudstone beds. Sedimentary structures such as cross-bedding, graded bedding, channel structures and fluting indicate a fluvial origin. Tarkwaian conglomerates contain clasts of granitoid and mafic igneous rocks (presumably Birimian). Granitoid batholiths occur to the east and west of Chirano within the Birimian volcanic and sedimentary rocks. The CSZ has also been intruded by smaller tonalite bodies and dykes. Previously, it was considered that these intrusions were the main host to gold mineralisation (Allibone *et al.*, 2004). However, recent open pit exposures show that gold mineralisation is hosted mostly within strongly hydrothermally altered mafic igneous rocks. Volcano-sedimentary rocks and the tonalites are metamorphosed to greenschist facies assemblages (Allibone *et al.*, 2004).

The Chirano gold deposits are located along the CSZ and also along a parallel structure that occurs approximately 200 m to the west within mafic igneous rocks. Historically, this has been referred to as the Chirano lode horizon but this name does not accurately reflect the fault zone that hosts the gold mineralisation in the open-pits. In this paper, this structural corridor is referred to as the Akoti-Tano fault zone (Figure 1).

A better understanding of the geological evolution of the Chirano district is developing as mining provides better exposures. It appears to be similar to the general history proposed for the Birimian of southwest Ghana (e.g., Eisenlohr and Hirdes, 1992; Oberthur *et al.*, 1998). The Bibiani and Chirano shear zones developed during early folding and thrusting related to NW-SE shortening. This progressive deformation resulted in gentle folding of the Tarkwaian rocks into open, gently S- to SW-plunging folds and the development of faults that have structurally juxtaposed Tarkwaian sedimentary rocks and Birimian mafic igneous rocks. Steeply (>60°) plunging drag folds adjacent to the CSZ re-orientated bedding in the folded Tarkwaian rocks suggesting a long history for this structure and supporting a late phase of strike-slip or oblique-slip motion. During continued shortening, existing fault zones were re-activated and new faults zones developed along linkages between pre-existing structures. During this phase of deformation these structural weaknesses acted as loci for granitoid intrusions and associated quartz-albite alteration and later for gold-bearing hydrothermal fluids (cf. Allibone *et al.*, 2004).

Structural Setting of Deposits

All deposits are located within or along strain domains flanking the CSZ and the Akoti-Tano fault zone (Figure 1). Gold mineralisation is associated with hydrothermal breccias, small splay faults, veins and foliation (Figure 2). In addition, broader zones of hydrothermal alteration and mineralisation occur in thicker zones of tonalite that intruded into dilational sites along the CSZ early in the deformation history, such as in the Tano deposit. The general steep plunge of ore shoots suggests that the structural permeability at the time of mineralisation was developed due to strike-slip movement along these sub-vertical fault systems (Figure 3A). This steep plunge is parallel to the σ_2 direction, along which tubular zones of structural permeability developed, such as fault-fracture intersections, conjugate fault intersections and dilational jogs. Oblique movement along these faults would yield non-vertical but steeply plunging ore shoots as seen in some deposits at Chirano.

A useful model for understanding deformation along faults is proposed by Chester and Logan (1986) and can be applied to the Chirano deposits (Figure 3B). In this model, the fault zone is divided into a fault core and a damage zone. The fault core is the volume of rock within which the majority of displacement has

occurred. The damage zone flanks the fault core and is the volume of rock that displays strain features related to the fault zone. The damage zone contains structural elements such as small faults, fractures, veins and foliation. An important aspect of this model for epigenetic gold mineralisation is that the fault core and damage zone commonly have different hydraulic properties relative to surrounding rocks. In some instances, the fault zone may be favourable for the focussed flux of large volumes of fluids, which are important for the formation of epigenetic gold deposits. The nature of the fault core and damage zone will depend on local factors such as rock type and pre-existing weaknesses, which may in turn impact upon the localisation of gold and therefore exploration targeting. This framework is useful for describing the structural features associated with mineralisation at Chirano, which are commonly distributed over a larger volume of rock than just the zone being mined. Although the CSZ is the main control on gold mineralisation, individual deposits along it differ in local factors such as host rock, small-scale structural features and orientations of high-grade ore shoots. These local factors are described in the next section, along with ore controlling features that were highlighted during Leapfrog™ modelling.

Leapfrog™ Modelling

The continuity of gold mineralisation in the Chirano district is controlled by structural features that focused hydrothermal fluid flow. Therefore, Leapfrog™ models of gold values from the drill hole database are important tools for interpreting structural controls on mineralisation. 3D models of gold mineralisation in the Chirano deposits are based on local structural controls determined from pit exposures and drill core. Wireframe models of structures and rock units are based on pit mapping and structural measurements taken from drill core. The wireframe models were generated using points from surveyed contacts or structures within the pits or the desurveyed points from drill hole data. This approach allows the rapid updating of the models as new mapping or drilling data become available.

Deposit Models

Obra

The Obra deposit is a tabular zone of mineralisation up to 20 m wide hosted between a northeast-striking, subvertical portion of the CSZ and several similarly orientated faults in the hanging-wall, which appear to be a continuation of the Akoti-Tano fault zone (Figure 4). Mineralisation occurs in strongly hydrothermally altered, brecciated and veined tonalite and dolerite. Leapfrog™ models show a moderate northerly plunge of mineralisation in this part of the CSZ. Bedding within folded Tarkwaian sedimentary rocks is steepened and drag folded adjacent to the CSZ. Important controls on mineralisation at Obra appear to be the closely spaced CSZ and hanging wall faults, which were intruded by tonalite early during deformation. The competent tonalite was subsequently fractured during continued deformation along this zone, when gold mineralisation occurred.

Tano

The Tano deposit is hosted within a brecciated tonalite in the hangingwall of a steeply (>80°) west dipping portion of the Akoti-Tano fault zone. The Akoti-Tano fault zone varies in strike from 350° to 020° from south to north along the deposit (Figure 1). The broadest zone of mineralisation occurs to the northwest of the fault zone flexure within a stockwork of quartz±carbonate veins in a domain of unfoliated, hydrothermally altered tonalite (Figure 5). Leapfrog™ models show a moderate northerly plunging zone of mineralisation along the CSZ in the south end of the pit, and the large sub-vertical zone of mineralisation in the brecciated and stockworked tonalite in the centre of the pit. This sub-vertical zone is associated with a thick bulge in the tonalite, where it intruded along a bend in the Akoti-Tano fault zone (Figure 5).

Akoti North and Extended

The Akoti North and Extended deposits are sub-vertical tabular zones of mineralisation hosted within two differently striking portions of the Akoti-Tano fault zone (Figure 6). The fault zone strikes about 035° in the south and about 000° in the north of the deposit and is hosted within dolerite. At both ends of the deposit, the main fault surface within the Akoti-Tano fault zone is sub-vertical and extremely planar (Figure 2A). A minor volume of the fault zone is intruded by tonalite that locally forms an intrusive breccia with dolerite. Mineralisation is hosted within hydrothermally altered basalt and tonalite, which are commonly foliated. High-grade zones contain hydrothermally brecciated rocks and cataclasite. The region between the differently striking portions of the fault zone contains strongly foliated and hydrothermally altered dolerite, but grade control sampling in the pit indicates this region is poorly mineralised. However, this region is poorly drill tested at depth (Figure 6).

Akwaaba

The Akwaaba deposit is a tabular zone of mineralisation hosted within a 050°-striking, steeply (>75°) northwest-dipping portion of the CSZ (Figure 7). Mineralisation is hosted within hydrothermally altered, variably foliated and brecciated basalt. The overall plunge of the orebody is sub-vertical. However, a sub-horizontal high-grade ore shoot, which is the focus of the Akwaaba underground mine, occurs at a subtle (5°)

dip change in the CSZ (Figure 7). Interestingly, Tarkwaian conglomerate occurs within the footwall to the CSZ below this high-grade orshoot. The current interpretation is that the conglomerate acted as a competent unit that caused a subtle (~5°) flattening in the CSZ, which then experienced preferential dilation during subhorizontal shortening. The dilation site was a focus for increased hydrothermal fluid flow and formation of higher grade gold shoots due to processes such as phase immiscibility.

Discussion

A key aim of the study was the definition of near mine exploration targets. At Chirano, late-stage deformation along the CSZ and the Akoti-Tano fault zone focussed gold-bearing hydrothermal fluids. However, early in their development, these structures cut through a mixed package of rocks of varying competencies, which created loci for tonalitic intrusions and albite-quartz hydrothermal alteration prior to the main phase of gold mineralisation. This pre-existing architecture influenced the formation of higher grade ore zones through a variety of local structural and chemical controls.

The main structural controls on high-grade ore shoots are local variations in the orientations of faults and shear zones. These variations are associated with the following features:

- intersections of shear zones or shear zone segments (Akoti)
- reactivation of shear zones (Obra between the CSZ and the Akoti-Tano fault zone)
- intersections of shear zones within rock units of varying competence (Tano)
- terminations of shear zone segments (Akoti)
- bends or jogs along the shear zone (Tano), and
- reactivation of the CSZ adjacent to conglomerates within folded Tarkwaian (Akwaaba).

An important outcome of recent pit-mapping has been the recognition of more mafic igneous rocks compared to tonalite within the ore zones. This has important implications for chemical controls on mineralisation related to rock type. Iron sulphidation is an important gold depositional mechanism in many gold deposits and is particularly relevant to mineralisation in iron-rich rocks, such as basalt and dolerite. Intersections of the CSZ and other late structures, such as the Akoti-Tano fault zone, with mafic igneous rocks are therefore exploration targets. This is an important change from earlier interpretations that suggested the deposits were mostly hosted within tonalite.

Conclusions

At Chirano, structural analysis requires the recognition of small-scale features and their distribution as products of broader deformation zones that control gold distribution. In addition, the integration of detailed structural studies at the core- to pit-scales with 3D geological modelling has improved the understanding of controls on higher grade gold mineralisation. 3D models also highlight areas where understanding is limited due to lack of data or uncertainties in interpretation. This has helped to focus near-mine exploration strategies.

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