

GOLD POTENTIAL OF THE ASHANTI BELT OF GHANA

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Abstract

Traditionally, the principal gold belts of Ghana have been largely grouped with the greenstone/volcanic belts with which they are associated. The Ashanti belt is one of the main belts associated with gold mineralization in Ghana and it is over 200 km in length and is characterized by a large number of gold deposits, including both abandoned and active mines like AngloGold Ashanti, Golden Star Resources at Prestea and Bogoso and Goldfields at Tarkwa and Damang. The Ashanti belt is made up of two main rock systems that are associated with the main gold occurrences in the form of quartz vein and disseminated type gold deposits; gold bearing quartz pebble conglomerates; alluvial deposits and oxide deposits derived from the primary occurrences.

The Ashanti-type of gold occurrence usually features complicated quartz vein systems commonly associated with extensive disseminated sulphides. The vein systems almost invariably appear to be related to regional NNE to NE trending regional structures (tectonic corridors), which are typically concentrated along the margins of various Birimian 'greenstone' belts and adjacent metasedimentary basins. Although the N to NE trending 'structural corridors' may be of prime importance, there is increasing evidence to indicate that other structures may have played very important roles as well, and some may be responsible for the development of the really large vein deposits.

The recent exploration activities in the Ashanti belt have confirmed a great variety of settings in which gold can be concentrated in commercial quantities. Epigenetic vein systems and related disseminated sulphide gold deposits will continue to be a major focus for future exploration. Structural controls for these vein systems appear to be the most important feature from the explorationist's viewpoint but it is now believed that potential source rocks with anomalous background levels of gold may also be important. The geochemistry of depositional sites can be important in determining whether gold will be sufficiently concentrated to be of economic interest. The stockworks in the Damang area near Tarkwa have also opened up other opportunities to explore stockwork types of gold mineralization in other parts of the Ashanti belt. The much improved gold prices could eventually lead to renewed interest in the considerable underground exploration which will also likely take place in the central and northern portions of the Ashanti belt where Tarkwaian metasediments are widespread and some gold indications are known.

1, INTRODUCTION

The Ashanti belt is one of the main belts associated with gold mineralization in Ghana. Although many belts in Ghana and the region in general have become very important, it is pretty evident that the Ashanti belt dwarfs all others in its natural endowment in gold. Certainly the Ashanti belt as a whole, including the adjacent marginal basin areas, is a very major gold belt that would rank amongst the best in the world. The southern 200+ km section of this belt has produced over 50 million ounces (Griffs *et al.* 2002). Almost all the gold

producing mines including the famous AngloGold Ashanti (formerly Ashanti Goldfield), Goldfields at Tarkwa and Damang, Golden Star Resources at Prestea and Bogoso and former Konongo and Dunkwa goldfields are all located on the Ashanti belt.

The Birimian rocks of the Ashanti belt are overlain by the Paleoproterozoic clastic sedimentary rocks (i.e., Tarkwaian), and both formations were subjected to a single progressive deformation event, which involved compression along a southeast-northwest directed axis (Eisenlohr and Hirdes, 1992; Blenkinsop *et al.*, 1994). The geological structure of the Ashanti belt is that of a synform (Eisenlohr, 1989), whereby the Tarkwaian

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rocks occupy the center of the belt and the Birimian volcanic rocks flank the margins of the belt. The Tarkwaian sediments are considered as erosional products of the volcanic belts deposited in long intramontane basins (Klemd *et al.*, 1993; Hirdes and Nunoo, 1994).

The geochemistry of the volcanic rocks, particularly trace element signatures of the Ashanti belt point to a primitive island arc tectonic setting environment for the Birimian rocks (e.g., Sylvester and Attoh, 1992; Loh and Hirdes, 1996).

The Ashanti-type of gold occurrence usually features complicated quartz vein systems commonly associated with extensive disseminated sulphides. The vein systems almost invariably appear to be related to regional NNE to NE trending regional structures (tectonic corridors), which are typically concentrated along the margins of various Birimian 'greenstone' belts and adjacent metasedimentary basins.

The gold-bearing quartz-pebble conglomerates of the Tarkwaian also contribute to the gold production from the volcanic belt. Studies carried out on gold mineralization in the Ashanti belt have suggested that the gold-bearing fluids are coeval with (peak)-greenschist-facies metamorphism (e.g. Mumin and Fleet, 1995; Loh and Hirdes, 1996). It has also been indicated that higher grade mineral assemblages are mostly restricted to the contact aureoles of the belt-type granitoids (e.g., Junner, 1935; Leube *et al.*, 1990).

The timing of the extensive hydrothermal activity associated with gold mineralization is somewhat controversial but structural studies and limited age dating of accessory minerals in gold-bearing veins indicate that in many deposits, the most important phase of mineralization is related to late-stage structural features and may be close to 1900 Ma (Yao and Robb, 1998). However, there may have been earlier stages of mineralization and certainly the development of gold mineralization in the region is quite reasonably seen as closely tied in with the orogenic history of the Paleoproterozoic units.

2. GEOLOGICAL SETTING

Rocks of Early Proterozoic age occupy large parts of the West African craton and crop out extensively in Ghana where they are subdivided into the Birimian Supergroup and the volumetrically subordinate Tarkwaian Group. Both were deformed and metamorphosed to greenschist facies in the course of the Eburnean tectono-thermal event. The Birimian comprises an

assemblage of sedimentary/volcaniclastic rocks forming sedimentary basins composed mainly of dacitic volcanoclastics, wackes and argillites which separate a series of subparallel, roughly equally spaced, northeasterly trending volcanic belts of mainly tholeiitic basalts (basaltic lava flows, mafic dolerites, gabbros, etc) and minor calc-alkaline rocks (andesites, dacites, rhyolites, pyroclastites). Birimian sedimentary basins show a fairly consistent pattern of facies distribution from the margins against the volcanic belts towards the basin centres. A chemical facies is intermittently developed at the transition zone between the volcanic belts and the basins. This facies is the site of much of the gold mineralization in Ghana (Taylor *et al.*, 1992). Also developed locally at the basin margins is a wacke facies, consisting of sandstones rich in lithic fragments, deposited from turbidity currents. Beyond these marginal facies two rock-types dominate; volcanoclastics and argillites. There is a gradation from a high proportion of volcanoclastics near the basin margins to a very low volcanoclastic content at the centre of the basins. Both the basins and the belts are intruded by extensive granitoids of Proterozoic age. The Birimian rocks are associated with and overlain by the clastic Tarkwaian formation, which represent erosional products of the Birimian (Junner, 1940; Kesse, 1985; Leube *et al.*, 1990; Davis *et al.*, 1994), and are located exclusively within the volcanic belts. Tarkwaian sediments consist of conglomerates, quartzites, arkosic rocks and minor phyllites. These lithological units represent facies with notable vertical and lateral variability (Sestini, 1973; Leube and Hirdes, 1986). The clastic sediments of the Tarkwaian have been described by Sestini (1973) as alluvial fan deposits with braided stream channel patterns; these fans supposedly formed in elongated intramontane basins.

The Proterozoic granitoids can be grouped into four main types namely Winneba, Cape Coast, Dixcove and Bongo granitoids (Junner, 1940; Kesse, 1985); the latter three have been termed "basin", "belt" and "K-rich" granitoids by Leube *et al.* (1990). The Cape Coast- and Winneba-type granitoids are emplaced within the Birimian sedimentary basins, while the Dixcove- and Bongo-type granitoids intrude the volcanic belts.

The Birimian supracrustal rocks and, with a minor exception, the granitoids in Ghana, represent juvenile crustal additions with Sm/Nd model ages of 2.0 to 2.3 Ga (Taylor *et al.*, 1988). Recent field and isotope work suggests that the Birimian volcanic belts and sedimen-

tary basins formed contemporaneously as lateral facies equivalents (Taylor *et al.*, 1988; Leube *et al.*, 1990).

Traditionally, the Lower Proterozoic in Ghana was interpreted to have undergone two deformational events (Junner, 1940). However, new structural data show that the Birimian Supergroup and the Tarkwaian Group were deformed jointly in a single progressive deformation event (Eisenlohr and Hirdes, 1992). This event involved initially a regional penetrative low-strain phase and subsequently the formation of spatially restricted high-strain zones.

[STRUCTURAL FEATURES]

Most of the early workers recognized the favourable structural settings, particularly along the northwestern margin of the Ashanti belt where most of the major lode deposits are located. While the entire, over 200 km western margin may, in general, be prospective, there certainly are sections, which appear to be far more prospective than others. These sections appear to correlate with specific structures and, along the western margin, the three most important structures occur in the areas of Prestea-Bogosu, Obuasi, and Konongo; each can generally be traced along strike for 30–80 kilometres (Griffs *et al.*, 2002).

Although the N to NE trending 'structural corridors' may be of prime importance, there is increasing evidence to indicate that other structures may have played a very important role as well, and some may be responsible for the development of the really large vein deposits (Griffs *et al.*, 2002). The existence of cross-cutting structures was known to early workers in some of the mining districts but their full extent and the role they may have played in the localizing of vein deposits was not and is still not well understood. According to Cozens (1991), all the principal gold deposits, Birimian and Tarkwaian, are located above the intersection of two or more major trends of the structural fabric. While one may take issue on the orientation of some of Cozens' proposed structural corridors and their origin, there can be little argument that major crosscutting structural features are present throughout southern Ghana. This is clearly evident in satellite imagery, regional topographic patterns and, to some degree, in regional airborne geophysical data.

The major crosscutting features include for example, an ENE series of features that cut right across the Ashanti Belt; one of these may cause the abrupt jog in the western margin of the belt immediately north of

Obuasi. A similar feature appears to cut across the entire belt just north of Bogosu and there is a suggestion of several less well defined features of a similar nature along the southern sector of the Ashanti Belt, south of the Tarkwa district.

There are also several indications of major N–S ($\pm 15^\circ$) structural features, which are particularly prominent in the topographic patterns (Griffs, 1998) and to a lesser degree in the airborne geophysical data (magnetic, radiometric). Noteworthy features include a series of possibly coalescing structures in the central and eastern parts of the southern sector of the Ashanti Belt. At least one of these features cuts across the belt and appears to be traceable from the coastal area as far north as Obuasi.

There is also a very prominent N–S linear feature more or less along the western margin of the Ashanti Belt south of Prestea and extending to the Axim area on the coast. North of Prestea, this linear feature (Ankobra Lineament) appears to follow the course of the Ankobra and with a little imagination, it could be interpreted to veer off slightly to the west and pass through the Bibiani district. One may speculate on whether faults, other than those in the established 'structural corridors' on the margins of the belts and basins really do play a fundamental role. One cannot help but note that there seems to be a convergence of several faults in the Obuasi areas (Griffs *et al.*, 2002). These include:

- * the main NE trending structural feature;
- * the ENE feature along the NE margin of the belt, which appears to cut through the main belt in the direction of Obuasi, and
- * an approximate N–S structure extending from the coastal area right across the belt that seems to end just north of Obuasi.

There are very few detailed structural studies on most of the main lode deposits and it is therefore difficult to clearly relate any of the major megascopic cross-cutting structures to specific features that may have played an important role in localizing gold mineralization. The work by Blenkinsop *et al.* (1994) on the Obuasi deposits concluded that all of the gold mineralization is structurally controlled. Gold-bearing veins are within shear zones (NE structural corridors) and disseminated sulphides are closely related to the same shear systems. The veins and shear systems are interpreted to have formed in an extended stress environment with shortening in a sub-horizontal NW–SE direction and extension along a sub-vertical axis; high fluid pressures played a

very important role in the development of veins and shears. Early shears were buckled and folded by later movement and many of the main ore shoots plunge to the NE along the hinges of folds, which have a similar orientation to the regional folding pattern.

The supposed important role played by crosscutting structures often comes from observations of mesoscopic features at the deposit level. This may include crosscutting mineralized veins or lineaments at sharp angles to the prevailing symmetry of the mineralized body or structure. This could suggest a link with some crosscutting feature but correlation with an identified regional or even localized feature may be difficult and a detailed structural analysis could very well rationalize these apparent anomalous features within the existing structural regime (Griffs *et al.*, 2002). What is clearly required is more detailed structural analysis at all of the major lode deposits to better understand the existing structural controls and correlation with regional features.

The importance of some late-stage, largely brittle structures of regional extent may be well exemplified by the Damang quartz-stockwork system. Certainly the deposit appears to correlate very well with an N-S regional fault system (Damang fault) and the underlying Tarkwaian units include buried banket conglomerate that could have provided an excellent source of gold, which was remobilized into nearby structures by hydrothermal fluids. If this model is plausible, then it would seem that a structure of a similar vintage and character cutting across the 'structural corridor' at Obuasi would create a very favourable environment for late-stage gold mineralization remobilized from nearby sources. It was noted earlier that the intensely tectonized structural corridor in the Prestea-Bogoso area either narrows or is truncated to the north and that the long stretch (approximately 40km) between Dunkwa and the Bogoso concession has a far less prominent NE trending 'structural corridor' and substantially less gold mineralization. Despite perhaps the less prospective nature of this sector, there have nevertheless been several important discoveries of modest size in recent years and it generally appears that the new discoveries may be largely localized at intersections between NE trending structures and crosscutting features. The potential significance of crosscutting structures has been highlighted mainly as a result of the availability of satellite imagery, detailed digital topographic data, and airborne geophysical data. This new data clearly identifies an

abundance of structural features not fully recognized and appreciated in the past. Earnest advocates of the importance of intersecting structural lineaments have had a field day speculating on and explaining the presence of major gold districts based on the perceived importance of specific structural features. Some of these structures are quite real while others may be half imagined or at least their importance over estimated. While some of these models show a good correlation with some of the mining districts, they also identify an enormous number of potentially interesting structural intersections with, at least as yet, no major indications of associated gold mineralization.

The link between some major crosscutting regional structures and macroscopic features within major mining districts remains quite elusive and confirms the need for many more detailed structural studies. Intuitively, this possible link seems important from an exploration viewpoint and a successful resolution of the challenge to identify the critical structural controls could have very significant implications to future exploration in the region.

3. GOLD MINERALIZATION

Traditionally, the principal gold belts of Ghana have been largely grouped with the greenstone/volcanic belts with which they are associated. Thus, the main belts will include from the SE to the NW (Fig. 1)

1. Kibi-Winneba
2. Ashanti
3. Asankrangwa
4. Sefwi
5. Bui
6. Bole-Navrongo

The various gold belts have become very important, it is pretty evident that the Ashanti Belt dwarfs all others in its natural endowment in gold. The Ashanti Belt as a whole, including the adjacent marginal basin areas, is a very major gold belt that would rank amongst the best in the world.

Although Tarkwaian metasediments are widespread throughout the Ashanti Belt, the only producer outside the Tarkwa district was at Ntronang in the NE corner of the belt. In the 1930s, an underground operation was started up late in the decade and peak production of 300 tpd was achieved in 1939 (Peters 1993) but only about 17,000 ozs were recovered. Although very similar in geology to the Tarkwa district, recovered

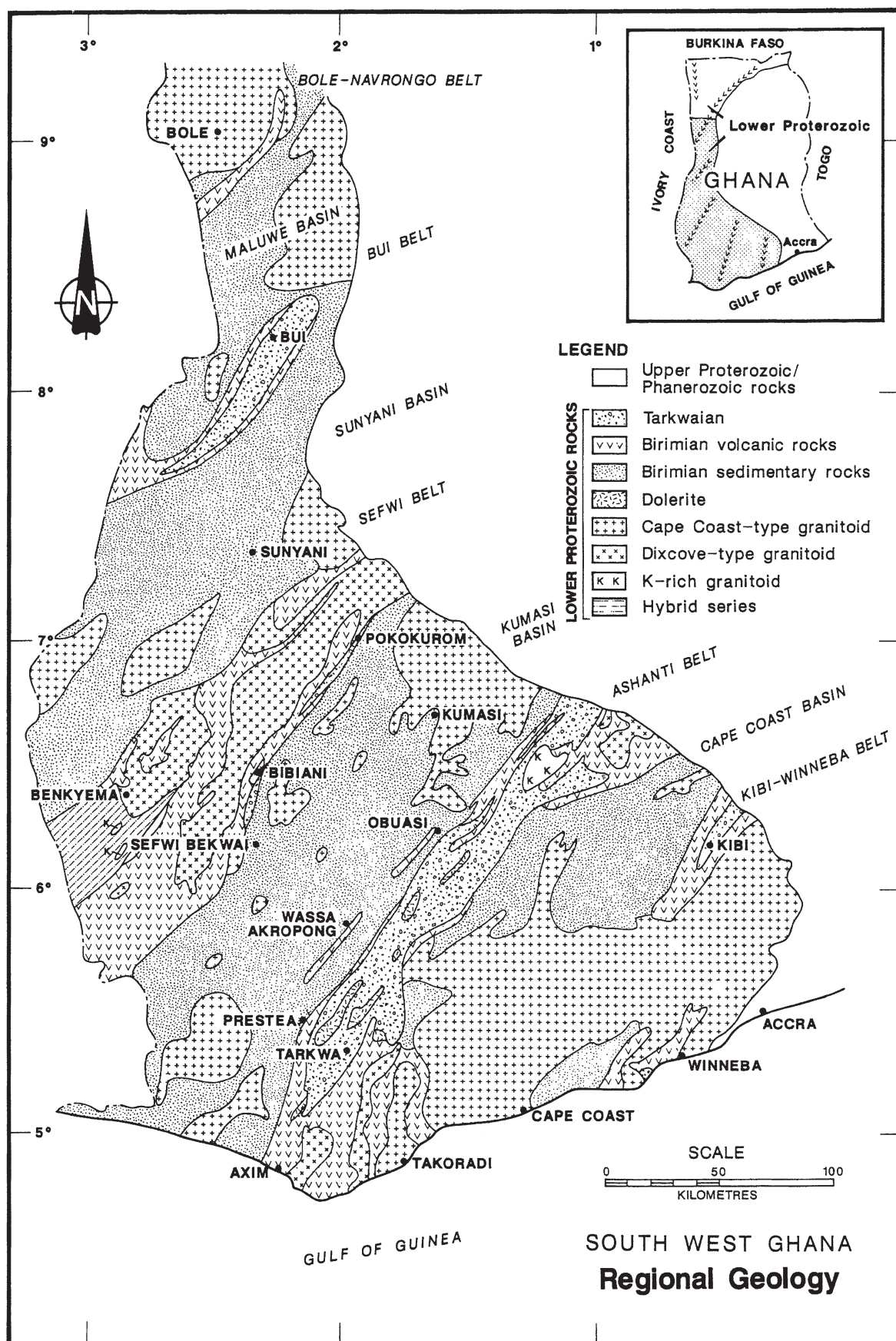


Fig. 1 Geologic map of southwest Ghana showing Birimian, Tarkwaian and distribution of granitoid types. (Eisenlohr, B. N. and Hirdes, W., 1992)

grades at Ntronang were only about 0.15ozs/ton and the operation was unprofitable and short-lived.

The main types of gold occurring in the Birimian and Tarkwaian rock systems of the Ashanti belt are; the quartz vein and disseminated type gold deposits; gold bearing quartz pebble conglomerates; alluvial deposits and oxide deposits derived from the primary occurrences.

3-1. BIRIMIAN GOLD MINERALIZATION

On a regional scale, the vast majority of the Birimian gold deposits occur aligned along the flanks of the volcanic belts. To a considerably lesser extent, gold deposits are present within volcanic belts where they sometimes show a spatial association with belt-type granitoid intrusions. Birimian gold deposits in Ghana are not evenly distributed in number or size. A high percentage of all gold occurrences and almost all of the major gold mines, abandoned or working, occur in the area of the Kumasi basin in southwest Ghana, i.e. are concentrated either along the northwest flank of the Ashanti belt or the southeast flank of the Sefwi belt.

To date no banded iron-formations (BIFs) have been detected in the Birimian of Ghana, whereas BIFs are generally widespread in Archean and Proterozoic greenstone terranes. In the Birimian of Ghana, manganese has completely taken over the role of iron, and laterally extensive Mn-rich sediments are characteristic. This Birimian-type Mn-Au association is not only restricted to the West African craton, but may extend to the originally connected Guyana, from where a comparable Mn-Au association has been reported in similar rocks of early Proterozoic age (Choubert, 1974). In addition to manganese and gold occurrences, the transitional zones along the flanks of the volcanic belts are characterized by the presence of other chemical sediments, namely sulphides, cherts, Fe-Ca-Mg carbonates, and rocks rich in carbon (Ntiamoah-Agyakwa, 1979; Leube and Hirdes, 1986). This chemical facies probably constitutes the most important favourable regional exploration guide for gold deposits in the Birimian of Ghana. The 'corridors' characterized by chemical sediments (and thus prospective for gold) may attain several hundred kilometres in length; their width is in the range of a few kilometres. The chemical sediments occur intermittently and are superimposed on and intercalated with metavolcanics, as well as metavolcaniclastics and minor phyllites. It seems that in the Birimian of Ghana, structure is of importance as a local ore control

(i.e. on the mine scale), whereas lithofacies (chemical sediments) controls gold regionally and to a lesser degree locally.

Two types of Birimian auriferous orebodies as distinguished by Leube et al. (1990) are: the disseminated-sulphide type (DST) and the quartz vein type (QVT). The QVT is always structurally controlled. The DST occurs as two subtypes: (1) lithofacies controlled, i.e., bound to chemical sediments; (2) structurally controlled, i.e., bound to the selvages of quartz veins. In general, QVT gold ores carry better grades than those of the DST. The quartz ore bodies are closely associated with deep-seated and laterally persistent graphitic shear zones. Smoky, blackish vein quartz, containing carbonaceous matter, generally reveals higher gold contents than white or clear quartz varieties. The sulphide type mineralization either forms envelopes, up to some metres wide, around the quartz veins, or form lenses in foliated and veined sedimentary or less commonly volcanic rocks (Oberthur *et al.*, 1991). Major differences between DST ores and QVT ores with respect to their ore mineralogy are: QVT ores contain visible 'free gold', whereas DST ores carry gold largely as submicroscopic inclusions in sulphide. In QVT ores, sulphides occur in orders of magnitude less than in DST ores: if sulphides are present in QVT ores, the base metal minerals, particularly galena, play a more important role than in DST ores. With regard to the lithofacies-controlled subtype of the DST ores, the good correlation of Au with K and As, similar to the QVT, could suggest that part of the Au precipitation mechanisms were not fundamentally different from those of vein deposits, i.e. destabilization of Au-S complexes through sericitization and resulting pH increase, probably after fluid discharge on the seafloor.

Vein and lode type deposits are commonly found (i) in the vicinity of the boundaries between the Birimian metasediments and metavolcanic rocks; (ii) where Birimian greenstones are intruded by Dixcove granite or porphyry; (iii) where Birimian greenstones are in close proximity to manganese deposits; and (iv) where the Birimian metasediment is intruded by Dixcove granites. In general, the basin-type granite and the more highly metamorphosed Birimian rocks do not contain gold deposits.

Areas of smoky and bluish-grey mineralised quartz, containing partings, streaks and fragments of the altered wall rocks are more favourable for gold mineralization than areas where white and glassy quartz are found.

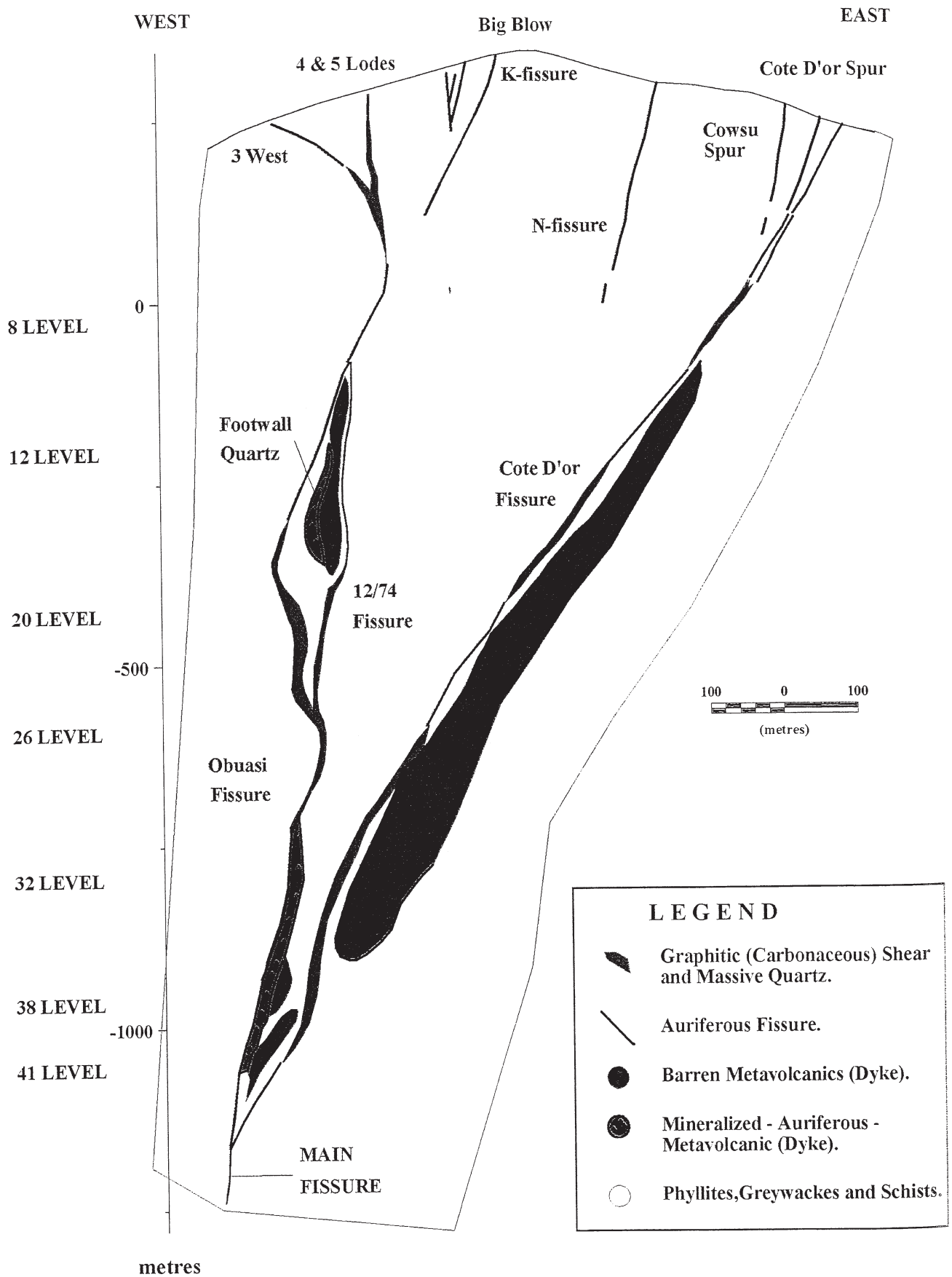


Fig. 2 Cross-section showing the major structures at the Obuasi, from Ashanti Gold Fields.
(Griffis, R. J., *et al*, Minerals Commission, 2002)

Arsenopyrite needles and galena are usually good indicators of gold but the gold is associated with pyrite or tourmaline with little or no arsenopyrite. Gold frequently occurs in fractures in sheared and shattered quartz reefs, commonly as elongated flat bodies of irregular shape and thickness that lie along and within shear zones. Hard, white quartz, free from sulphides and inclusions of wall rocks, is usually barren or contains very little gold.

In recent years, mineralized country rocks of the Birimian, consisting of tuffaceous phyllites within the greenstone series have been found to be an important source of sulphide ores. These tuffs, which can be up to 30 metres or more in width and range from a few thousand metres to many thousands of metres in strike length, carry disseminated and thin strings of pyrite and arsenopyrite with small amounts of free gold. At Prestea and Obuasi (Fig. 2, Photo 1), these sulphide ores form a major part of the ore which are treated. Gold values in sulphide concentrates range from 23 to 40 gm per tonne.

3-2. TARKWAIAN GOLD MINERALIZATION [Paleoplacer]

The banket conglomerates of the Tarkwa district have now produced about 10 million ozs of gold over the

past 100 years and although the last remaining underground mine closed in 1999 (Griff *et al.*, 2002), the district now has very substantial open-pit gold production and the regional resource potential is excellent (Fig. 3, Photo 2). The auriferous quartz-pebble conglomerates occur within the Tarkwaian System. The Banket Formation, overlying the Kawere, is economically the most important member of the Tarkwaian System as it contains the auriferous conglomerates. The gold is mostly concentrated in the basal 20 cm of the lowermost horizon and the highest contents are associated with well-sorted and well-packed hematite-rich conglomerates which occur in the thinner horizons and these, where enriched with hematite, contain the most gold.

The gold is very fine grained and free, averaging 40–60 microns in size. The intercalated quartzites also contain detrital hematite and gold. Pay streaks take the form of lenses of better-developed and better-sorted conglomerate up to 150 m wide and 1000 m in depth, orientated along the direction of the palaeoflow. Visible gold is rarely seen although it was apparently not uncommon in some of the very thin (less than 50cm), but high-grade conglomerates now mined out in selected areas on the eastern limb of the Tarkwa syncline. The relative abundance of ‘black sands’ is usually a good



Photo. 1 The Auriferous Quartz vein in the Ashanti mine, 500m depth shaft.

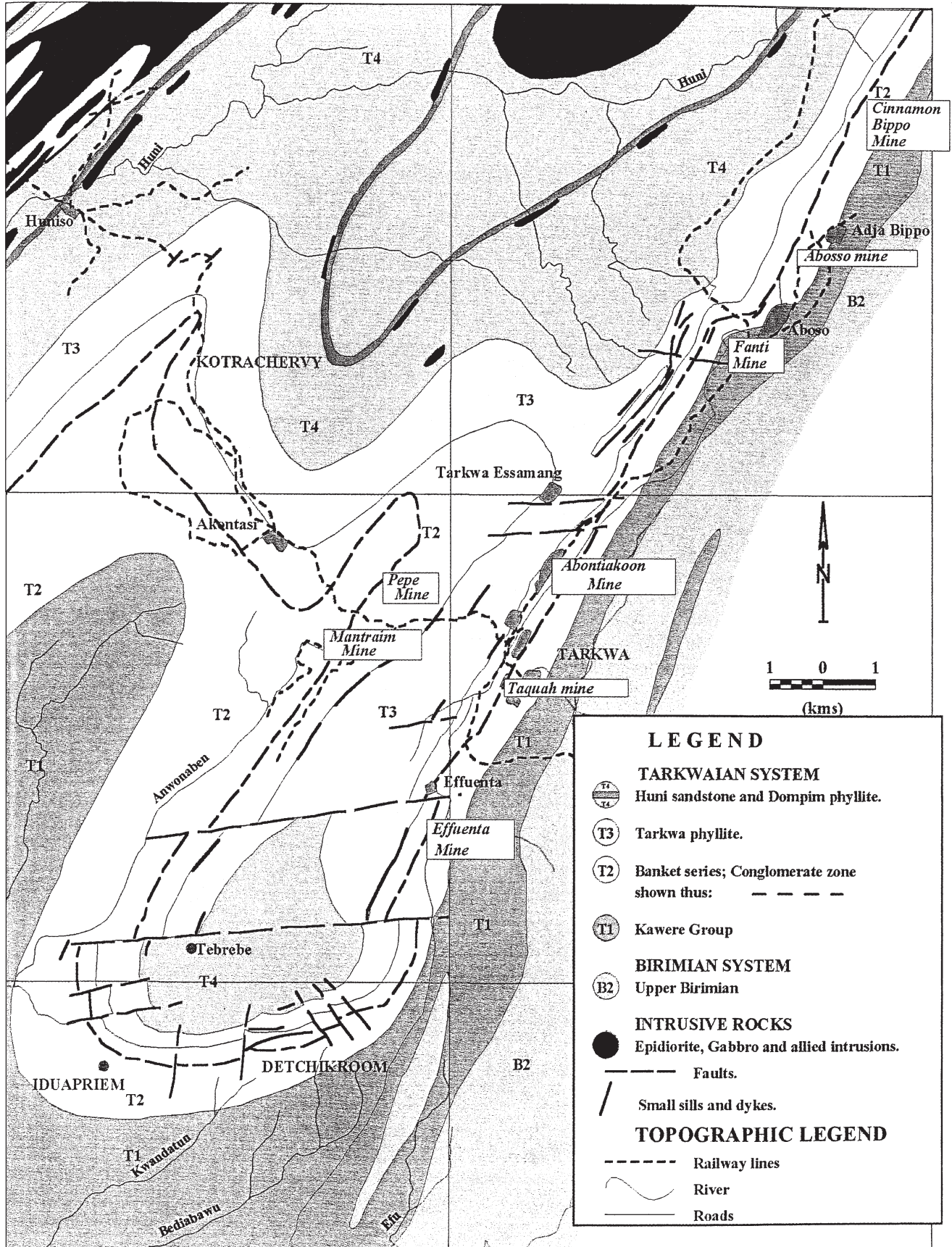


Fig. 3 Geological map of the Tarkwa district. (Griffis, R. J., *et al*, Minerals Commission, 2002)

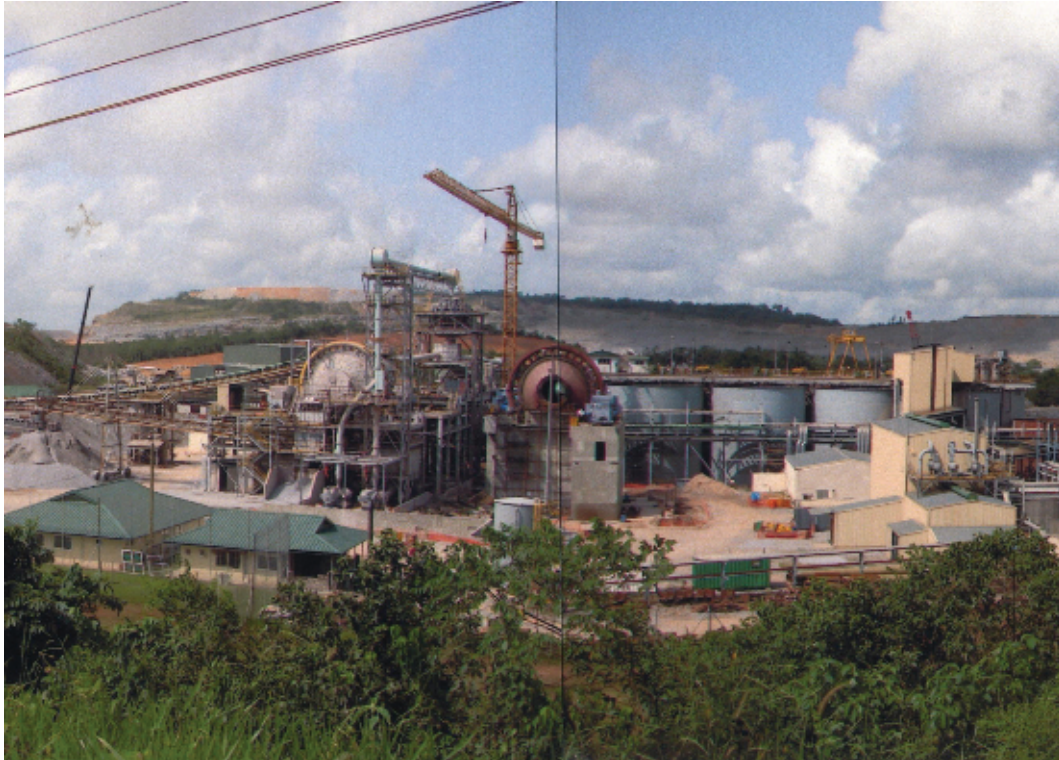


Photo. 2 The Open pit mining in the Tarkwa Mine.

indicator of favourable gold values. Various sedimentological studies (Sestini, 1976 and Stroger, 1991) clearly correlate gold distribution with sedimentary features similar to patterns seen in many modern day placers and the high-grade oreshoots are believed to result from extensive reworking of conglomerates.

The blanket conglomerates are similar to those of the great Witwatersrand and the blanket reefs of the Transvaal, South Africa. Gold values in these reefs are low ranging from 3 g to 14 g per tonne with an average of not more than 6 g per tonne.

[Vein System]

Since the discovery of the Damang quartz stockwork system deposit hosted in the Tarkwaian units, this type of occurrence has been the target of considerable exploration effort. It has also become very apparent in recent years that some of the old mining districts along the western margin of the Ashanti belt also contain mineralized quartz veins hosted in Tarkwaian units. These are closely associated with the major structures that have concentrated gold mineralization in nearby Birimian metasediments and volcanics. This certainly appears to be the case in the Prestea-Bogosu district where the Tarkwaian contact is highly tectonized and, in places, broad mineralized quartz stockwork and vein

systems have been developed. A similar situation is evident in the Konongo district where the Birimian and Tarkwaian units are intensely tectonized and there is some evidence of mineralized vein structures in the Tarkwaian metasediments. Work to date suggests the vein systems in general, are relatively low grade but they may be quite wide (20–50m) and, in the right circumstances, could be developed over considerable strike-length and thereby forming quite large potential resources of future possible interest. The epigenetic gold mineralization at Damang is a classic example of late-stage hydrothermal activity associated with a complex structural plumbing system created by movements along a regional fault system.

[Origin of gold in the conglomerates]

Evidence favours the source of the gold as being the Birimian schists which lie below the Tarkwaian System. The conglomerates are the products of a fluvial system in which low-sinuosity, high-energy, shallow-depth, braided streams were operative. Extensive studies have produced evidence that very strongly supports a placer origin for the gold found in the Tarkwaian conglomerates. The sites of heavy mineral concentrations point to a syngenetic origin for the mineralization. Much of the fine grained gold was deposited beyond the midfan area,

in a zone where the developments of mineralized, braided-stream-channel conglomerates were predominant.

It has also been recognized that the vein systems along the western margin of the Ashanti belt are associated with complex structures, which may have been reactivated over a considerable period of time. Although the most important phases of mineralization may post-date the Tarkwaian sediments, there may have been earlier phases of gold mineralization, which may pre-date or were synchronous with Tarkwaian sedimentation. The conclusion is that the productive Tarkwaian paleoplacers had source areas with gold-bearing vein systems of the Ashanti-type (Klemd *et al.*, 1996).

Many of the later stages of gold mineralization are associated with major fault systems that penetrated to deep crustal levels and these faults may have tapped magmatic fluids with unusual compositions similar to the high $\text{CO}_2 + \text{N}_2$.

3-3. ALLUVIAL GOLD

The vast majority of historical gold production from Ghana prior to the 20th century came from a myriad of small streams and rivers draining areas with underlying oxide and primary gold deposits. In addition, several of the major rivers (Pra, Tano, Ankobra, Ofin) have been mined with dredges starting in the early 1900s and more recently, large alluvial operations were started up on rivers in several districts.

The margins of the existing main river valley of Ankobra for example contain significant alluvial gold occurrences in gravels that are 6-10m thick underlying barren overburden that is usually at least, if not slightly more thick than the gravels. The main valley gravels are relatively low grade ($0.1-0.2 \text{ g/m}^3$) but contain higher grade sections and extensive terrace deposits along the margins of the valley also contain significant gold-bearing gravels.

Alluvial gold occurs in gravels of streams, river flats, old valleys and on terraces and in beach gravels and sand. They are derived mainly from the primary vein and lode-type deposits associated with the Birimian System. These primary deposits have been the subject of several cycles of erosion and deposition and, with wide areas drained by the same river systems; it is inevitable that alluvial gold traces should be widespread in Ghana. The alluvial gold is also accompanied by Platinum group metals, cassiterite, chromite, magnetite, diamonds, garnets, and other precious stones.

3-4. OXIDE AND LATERITE OCCURRENCES

Virtually all of the primary (and paleoplacer) gold deposits in Ghana have been intensely weathered to produce oxide caps. These oxide cappings (also called saprolite) have been a major target for exploration over the past 15 years because they are usually amenable to inexpensive surface mining and treatment schemes. Oxide deposits are gradational with underlying primary mineralization and the extent of oxidation is usually dependent on the climatic and geomorphological conditions. Oxide caps on the crest or flanks of hills may be 50-100m thick whereas oxidized zones in low-lying valleys may be less than 5m thick. The lateral extent of oxide zones, in most cases, is largely controlled by the geometry and nature of the underlying primary mineralization and by the extent of the in-situ weathering. It is not generally typical of most of the oxide zones in the tropical climatic conditions of southern Ghana to develop pronounced mushroom-shaped vertical profiles and most of the oxide zones are only marginally larger than the underlying primary zones of gold mineralization. It also generally appears that the overall grades within the oxide zones are similar to underlying primary mineralization and that supergene enrichment within the oxide zone does not appear to have been very extensive although there may be important exceptions to this general trend. Within the oxide zones, the gold appears to be relatively evenly distributed in a very fine-grained form, which is easily recovered by cyanidation either in conventional milling systems or by heap leaching.

The effects of oxidation and near-surface weathering have had a particularly beneficial effect on those deposits with extensive disseminated sulphides in the primary zone and where a high proportion of the gold was originally contained within the sulphide grains. The liberation of gold from the sulphides has rendered many of the oxide caps suitable for mining whereas the underlying primary zones may be too low grade to justify more expensive refractory recovery systems. Of course, the physical effects resulting from the weathering have also resulted in many benefits such as softer ores that require minimum blasting as well as substantially increasing the permeability of the host rocks, which may permit very low-cost heap-leach methods to recover the gold. These beneficial effects are not just confined to the mineralized vein systems and accompanying disseminated sulphides in Birimian units and belts intrusives. They have also had substantial benefits in the near-surface exposures of the Tarkwaian paleoplacers because the

hostrocks are softer and have a higher permeability, which permits very effective heap leaching of relatively low-grade mineralization.

The lack of a near-surface mushroom effect in most of the oxide resources of southern Ghana may result from the fact that most of these occurrences have truncated weathering profiles with the removal of overlying lateritic and shallow saprolitic zones of weathering. Where laterites are preserved, a lateral dispersion of gold is often quite pronounced and is generally manifest in much broader geochemical soil anomalies and some gold enrichment in the near surface environment. Where laterites overlie oxide and primary gold mineralization, it is not uncommon to see some depletion in the uppermost mottled saprolite zone so that shallow trenches within the mottled saprolite may yield gold values that are not representative of underlying mineralization. The southern part of the Ashanti Belt features many areas with thin but widespread laterites so that high-grade trench results in these areas have to be carefully assessed. It should also be noted that in some areas (i.e., part of the Yamfo-Kenyase district), there is iron-laterite crust (duricrust), which has quite low background levels of gold above buried mineralization. There appear to be few examples in Ghana where gold in laterites have been developed on a large scale but certainly it appears that a considerable amount of artisanal mining has involved washing of lateritic material for gold. Some of the early exploration efforts during the recent exploration boom were targeting possible bauxite targets similar to the Boddington-type of Western Australia.

It is also quite clear that lateritic cappings overlying oxide and primary gold deposits in some of the major mining districts were enriched in gold. This was evident in the early days (1937-41) of open-pit mining at Bogosu where several of the major pits had lateritic caps carrying considerable gold. In addition, recent exploration in the Kanyankaw area south of Tarkwa has confirmed substantial gold in the iron laterites that cap the hills of this area and which have been mined on an artisanal basis for generations.

One can also reasonably conclude that at one stage it is highly likely that there may have been numerous Boddington-type laterite gold occurrences in many areas of southern Ghana. The remnant deposits capping many of the highest ranges in southern Ghana indicate that bauxite and iron laterite deposits were probably very widespread throughout southern Ghana in early to

middle Tertiary times.

4. CONCLUSIONS

Ghana's endowment in gold remains very considerable and future exploration work in the country especially in the Ashanti Belt, including the adjacent marginal basin areas, will almost certainly result in new discoveries and new mines.

All the main types of gold mineralizations of Ghana are found in the Ashanti belt. These are the quartz-vein type, the disseminated sulphide type, placer type gold in the conglomerate in the Tarkwaian, the oxide ore and the alluvial deposits. Almost all the gold producing mines and the past mining activities have concentrated on the Ashanti belt because of its enormous gold potential. There are various structural corridors that favour gold mineralization. The stockworks in the Damang area near Tarkwa have also opened up other opportunities to explore stockwork types of gold mineralization in other parts of the Ashanti belt. Almost all the abandoned mines and collapsed mines could be explored and currently there are a lot of gold exploration activities going on in the entire Ashanti belt from near Axim in the coast to beyond Konongo and Nkawkaw, a distance of over 200 km length.

The recent exploration activities in the Ashanti belt have confirmed a great variety of settings in which gold can be concentrated in commercial quantities. Epigenetic vein systems and related disseminated sulphide gold deposits will continue to be a major focus for future exploration. Structural controls for these vein systems appear to be the most important feature from the explorationist's viewpoint but it is now believed that potential source rocks with anomalous background levels of gold may be an important issue. The geochemistry of depositional sites can be important in determining whether gold will be sufficiently concentrated to be of economic interest.

The Tarkwaian paleoplacer open-pit deposits will continue to be mined on a very large scale for many years. The much improved gold prices could eventually lead to renewed interest in the considerable underground exploration which will also likely take place in the central and northern portions of the Ashanti belt where Tarkwaian metasediments are widespread and some gold indications are known (Kim, *et al.*, 2010).

It is still believed that the most favourable environments for large mineralized vein systems are located

along the margins of belts and basins. These margins are where structural activity has been concentrated and where chemical and volcanoclastic facies of Birimian sediments provide a good source of gold. During major hydrothermal events, the anomalous gold in the source rocks is remobilized into nearby depositional sites. It is therefore likely that future exploration work will continue to scour these favourable settings. Although most of the western margin of the Ashanti belt has now been fairly well prospected at surface, the eastern margin has only received limited attention in recent years. Even the well-established districts in the Ashanti belt, such as Obuasi, Prestea-Bogoso, Akropong-Ayanfuri and Konongo, still have very considerable potential for the discovery of significant buried gold deposits. The discovery of these will, however, prove challenging and expensive.

The river systems of southern Ghana will continue to be important to the small-scale mining industry because of the employment and revenue it provides to many rural communities. With quite a rapidly growing population, future improvements in gold prices will likely result in extensive small-scale mining in many parts of the country. Some of the larger rivers (Tano, Ankobra, Ofin, Pra, and Birim) have considerable known alluvial gold resources (Photo 3), some of which were

dredged in the past. These deposits may be future exploration targets if gold prices continue to improve and if new methods of low-cost mining of these occurrences can be developed. Some of the main tributaries to the above major rivers will also attract attention and perhaps be modeled after the large Bonte alluvial operations in the Manso Nkwanta district. The potential for offshore concentrations of gold is intriguing and certainly very large amounts of alluvial gold must have been deposited into the offshore environment. Despite the obvious problems and costs involved with offshore mining, this warrants systematic testing.

REFERENCES

- Blenkinsop, T., Schmidt Mumm, A., Kumi, R. and Sangmor, S. (1994). Structural geology of the Ashanti gold mine. *Geologisches Jahrbuch*, **D100**, 131-153.
- Choubert, B. (1974). *Le Precambrien des Guyanas*, Bur. Rech. Geol. Min., Mem., **81**, 213pp.
- Cozens, B. (1991). Some of the Regional Geology of Ghana and its Relationship to Gold Mineralization; in G. O. Kesse (ed), *Proceedings of the Int. Conf. on the Geology of Ghana (1988)*, Geol. Soc. of Ghana, Accra, pp E1 to E16.
- Davis, D. W., Hirdes, W., Schaltegger, E., and Nunnoo, E.



Photo. 3 Alluvial gold resources, the small scale mining.

- A. (1994). U-Pb age constraints on deposition and provenance of Birimian and gold-bearing Tarkwaian sediments in Ghana, West Africa. *Prec. Res.*, v. **67**, pp 89-107.
- Eisenlohr, B. N. (1989). The Structural Geology of Birimian and Tarkwaian Rocks of Southwest Ghana. Rep. Arch. BGR, 106448, 66p, Hannover.
- Eisenlohr, B. N. and Hirdes, W. (1992). Structural development of the early Proterozoic Birimian and Tarkwaian rocks of southwest Ghana, West Africa. *J. Afr. Earth Sci.*, v. **14/3**, pp. 313-325.
- Griffis, R. J. (1998). Explanatory Notes - Geological Interpretation of Geophysical Data from Southwestern Ghana. Minerals Commission, Accra, 51p.
- Griffis, R. J., Barning, K., Agezo, F. L. and Akosah, F. K. (2002). Gold Deposits of Ghana. Minerals Commission, Accra, 430 pp.
- Hirdes, W., and Nunoo, B. (1994). The Proterozoic paleoplacers at Tarkwa Gold Mine, SW Ghana. *Geol. Jb. D100*, pp. 247-311.
- Junner, N. R. (1935). Gold in the Gold Coast. Gold Coast Geol. Surv. Mem. 4, 67p, Accra. (reprinted 1973).
- Junner, H.R. (1940). Geology of the Gold Coast and Western Togoland (with revised geological map). Gold Coast Geol. Surv. Bull., **11**: 40 pp.
- Kesse, G.O. (1985). The Mineral and Rock Resources of Ghana. Balkema, Rotterdam, 610 pp.
- Klemd, R., Hirdes, W., Olesch, M. and Oberthur, T. (1993). Fluid inclusions in quartz-pebble conglomerates of Ghana as guides to their provenance area. *Min. Deposita*, **28**; pp. 334-343.
- Klemd, R., Hunken, V., and Olesch, M. (1996). Fluid Composition and Source of Early Proterozoic Lode Gold Deposits of the Birimian Volcanic Belt, West Africa. *Intern. Geol. Rev.*, v. **38**, pp. 22-32.
- Kim, Y.U., Jerry S.K., Daniel B., and Sakamoto, I. (2010). Gold deposits in the Ashanti belt, Republic of Ghana, West Africa. *Resource Geology*, **60**(3), 199-205. (Japanese Language).
- Leube, A., and Hirdes, W. (1986). The Birimian Supergroup of Ghana - depositional environment, structural development and conceptual model of an Early Proterozoic suite. Rept No 99529, Arch. BGR: 260 p, Hannover (unpubl.).
- Leube, A., Hirdes, W., Mauer, R. and Kesse, G.O. (1990). The early Proterozoic Birimian Supergroup of Ghana and some aspects of its associated gold mineralization. *Precambrian Res.*, **46**: 139-165.
- Loh, G., and Hirdes, W. (1996). Explanatory Notes for the Geological Map of Southwest Ghana - 1:100,000 scale (Axim and Takoradi sheets). Ghana Geol. Surv. Bull. **49**, 63p, Accra.
- Mauer, R. (1990). Petrographische und geochemische Untersuchungen der prakambrischen (Birimian) Granitoide Ghanas. Dissertation, Technische Universität Berlin, 202 pp.
- Mumin, A. H., and Fleet, M. E. (1995). Evolution of gold mineralization in the Ashanti Gold Belt, Ghana: Evidence from carbonate compositions and paragenesis. *Min. and Petrology*, v. **55**, pp. 265-280.
- Ntiamoah-Agyakwa, Y. (1979) Relationship between gold and manganese mineralizations in the Birimian of Ghana, West Africa. *Geol. Mag.* v. **116**(5), pp. 345-352.
- Oberthur, T., Vetter, U., Schwartz, M. O. Weiser, Th., Amanor, J. and Gyapong, W. A. (1991). Gold mineralization and the Ashanti mine, Obuasi, Ghana: Preliminary mineralogical and geochemical data. In: E.A. Ladeira (ed.), *Brazil Gold '91*. pp. 533-537.
- Peters, J. W., (ed.), (1993). Statistics on Mining and Mineral Production in Ghana from 1880 to 1988. Ghana Geol. Surv. Arch. Rept. **6**, 112p, Accra.
- Sestini, G. (1973). Sedimentology of a paleoplacer: the gold bearing Tarkwaian of Ghana; in Amstutz, G. C. and A. J. Bernard (Eds): *Ores in Sediments*, pp. 275-305, Springer-Verlag, Heidelberg.
- Strogen, P. (1991). The Sedimentology, Stratigraphy and Structure of the Tarkwaian, Western Region, and its Relevance to Gold Exploration and Development; in Kesse, G.O., (ed.), *Proceedings of the International Conference on the Geology of Ghana*. Geol. Soc. Ghana, v. **3**, pp. R1-R39, Accra.
- Sylvester, P. J., and Attoh, K. (1992). Lithostratigraphy and composition of 2.1 Ga greenstone belts of the West African Craton and their bearing on crustal evolution and the Archean-Proterozoic boundary. *J. Geol.*, v. **100**, pp. 337-393.
- Taylor, P. N., Moorbath, S., Leube, A., and Hirdes, W. (1988). Geochronology and crustal evolution of early Proterozoic granite-greenstone terrains in Ghana, West Africa. Abstracts, Intern. Conf. and Workshop on the Geology of Ghana with special emphasis on Gold: pp. 43-45, Accra.
- Taylor, P.N., Moorbath, S., Leube, A. and Hirdes, W. (1992). Early Proterozoic crustal evolution in the Birimian of Ghana; constraints from geochronology and isotope geochemistry. *Precambrian Research*, **56**, pp. 97-111.
- Yao, Y., and Robb, L. J. (1998). The Birimian Granitoids of Ghana; A Review. *Econ. Geol. Unit, Univ. of the Witwatersrand, Info Circ.* **22**, 46p.

要 旨

アフリカ、ガーナ共和国、アシャンテ褶曲帯における金鉱床のポテンシャル

アシャンテ褶曲帯は、原生代のグリーン・ストーンベルトに属し、NE-SW 方向に、約 200km の規模で発達する。500 年前から開発された金山ベルトであり、現在もアングロ・アシャンテ鉱山、ゴールド・フィールド鉱山など、多くの鉱山が稼働している。鉱床の産状は、含金石英脈として形成する 1 次鉱床 (primarily gold) および礫岩などに形成する 2 次鉱床 (secondary gold) に区分される。前者の鉱床として知られているのがオブアシに鉱山があるアングロ・アシャンテ鉱山である。150 年の歴史を示し、産出額 1800t を越える。後者の鉱山として知られているのがタクアに鉱山があるゴールド・フィールド鉱山である。最近オープン・ピット工法により、毎年 30 トンの産出額を報告している。