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A review of gold mineralisation in the Ashanti belt of Ghana and its relation to the crustal evolution of the terrane

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The Ashanti belt of Ghana is the key district of gold mineralisation in the Palaeoproterozoic terrane of West Africa. The area considered is covered by lithologies of the volcanic/sedimentary Birimian Supergroup (2.2-2 1 Ga) and the overlying Tarkwaian Group (<2132 Ma). Birimian and Tarkwaian rocks were jointly folded and metamorphosed under greenschist facies conditions during a single progressive deformation, the Eburnean tectono-thermal event or orogeny at about 2.1 Ga. Regional foliation and subparallel shear zones hosting mesothermal gold mineralisation developed during deformation coeval with metamorphism.

Four major types of gold mineralisation are present in the Ashanti belt:

(i) Mesothermal, generally steeply dipping quartz veins in shear zones mainly in Birimian sedimentary rocks.
(ii) Sulfide ores, spatially closely associated with the quartz veins, mainly in sediments or pervasively carbonatised rocks of Birimian age.
(iii) Disseminated and stockwork-type hydrothermal mineralisation in granitoids.
(iv) Palaeoplacers of the Tarkwaian Group.

Hydrothermal gold mineralisation is an integral constituent of the Palaeoproterozoic crustal evolution in Ghana. A metamorphic fluid model is preferred which involves fluid generation by devolatilisation reactions of Birimian strata at depth, during prograde metamorphisms in the course of the Eburnean orogeny. The mineralising fluids were focused into tectonically distinct zones, .predominantly the contact zones between Birimian volcanics and sediments. Palaeoplacer gold in the Tarkwaian originates from distal and older Ashanti-type gold mineralisation situated towards the east of the Tarkwa depository.

Introduction

Gold mineralisation constitutes an important economic factor in the Palaeoproterozoic terrane of West Africa. The largest and most prominent mines, with a cumulative past production in excess of 1500 t of gold, are located in Ghana, more specifically in the Ashanti belt (Fig. 1). Geologists of the German Federal Institute for Geosciences and Natural Resources (BGR) and the Ghanaian Geological Survey Department have mapped and explored large parts of Ghana in the course of a number of projects of bilateral technical cooperation in recent years. Lately, work concentrated on gold mineralisation in the Ashanti belt of Ghana as part of the project "Metallogenesis of Gold in Africa". This paper reviews and summarises the results of continuous geological work (Leube and Hirdes, 1986; Eisenlohr, 1989, 1992; Hirdes and Leube, 1989; Leube *et al.*, 1990; Eisenlohr and Hirdes, 1992; Hirdes *et al.*, 1992; Taylor *et al.*, 1992: Blenkinsop *et al.*, 1994; Davis *et al.*, 1994; Hirdes and Nunoo, 1994; Höhndorf *et al.*, 1994; Oberthür *et al.*, 1994) and specifically intends to place gold mineralisation into the framework of crustal evolution deciphered so far. Open questions and critical points will be discussed.

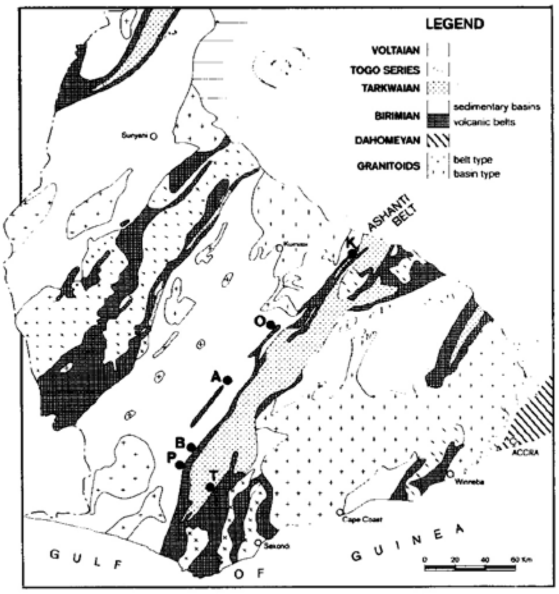

Figure 1: Geology of the southern part of Ghana and location of gold mines in the Ashanti belt. K = Konongo, O = Ashanti mine at Obuasi, A = Ayanfuri and Bokitsi, B = Bogosu, P = Prestea, and T = Tarkwa.

General geology

The relative timing of volcanism, sedimentation, emplacement of various granitoid suites, tectonism and hydrothermal events in the vast Palaeo proterozoic terrane of West Africa is controversial (e.g. Abouchami *et al.*, 1990; Leube *et al.*, 1990; Boher, 1991; Milesi *et al.*, 1991, 1992; Eisenlohr and Hirdes, 1992; Davis *et al.*, 1994). The following descriptions are based on concepts developed for the Ghanaian sector of the terrane by the BGR and counterpart scientists (Leube and Hirdes, 1986, Leube *et al.*, 1990) which were supplemented by structural studies (Eisenlohr and Hirdes, 1992; Blenkinsop *et al.* 1994) and geochronological work (Hinles *et al.*, 1992; Taylor *et al.*, 1992; Davis *et al.*, 1994; Höhndorf *et al.*, 1994).

Large areas of Ghana are covered by Palaeoproterozoic lithologies which are subdivided into the volcanic/sedimentary Birimian Supergroup (2.2-2.1 Ga) and the clastic sedimentary Tarkwaian Group. The classical subdivision of the Birimian into Lower Birimian (mainly volcaniclastics, wackes, argillites and chemical sediments) and Upper Birimian (basalts with some interflow sediments) as proposed by Junner (1932, 1935, 1940), has been reinterpreted by Leube and Hirdes (1986) and Leube *et al.* (1990). The latter authors regard the Lower and Upper Birimian as coeval sequences with the sedimentary/volcaniclastic assemblage ("sedimentary basins") representing a distal facies of "volcanic belts". The Ashanti belt represents one of these NE-SW-trending volcanic belts which is adjoined by the Kumasi basin to the west and the Cape Coast basin to the east (Leube and Hirdes, 1986). The Tarkwaian clastic sediments were deposited between 2132 and 2116 Ma (age of youngest detrital zircon in the Tarkwaian sediments, and age of oldest basin-type granitoid, respectively, Davis *et al.*, 1994), at the onset of deformation. Birimian and Tarkwaian rocks were jointly folded and metamorphosed under greenschist facies conditions during a single progressive deformation (Eisenlohr, 1989; Eisenlohr and Hirdes, 1992), the Ebumean tectonothermal event, at about 2.1 Ga. NW-SE directed crustal shortening produced major thrusts and shears which acted as channelways for mineralising hydrothermal fluids (Eisenlohr, 1989; Blenkinsop *et al.*, 1994). Epigenetic gold mineralisation in the Ashanti belt is largely synkinematic and synmetamorphic, i.e. coeval with the Ebumean event (Oberthür *et al.*, 1994).

Two major types of granitoids are distinguished in Ghana, (i) the metaluminous Dixcove or belt-type granitoids which occur within and are regarded comagmatic with the basalts of the volcanic belts (Leube *et al.*, 1990; Taylor *et al.*, 1992), and (ii) the peraluminous, late- to post-kinematic Cape Coast- or basin-type granitoids in the sedimentary basins which postdate the Tarkwaian (Fig. 1). Their intrusion took place at different, well constrained, time intervals between ca. 2180-2170 Ma and 2116-2088 Ma, respectively (Hirdes *et al.* 1992).

Gold mineralisation

In the Ashanti belt of Ghana, the following types of primary gold mineralisation are present:

(i) Generally steeply dipping quartz veins in shear zones mainly in Birimian sedimentary rocks (e.g. Konongo, Ashanti and Prestea mines)

(ii) Sulfide ores, spatially often closely associated with the quartz veins, with auriferous arsenopyrite as a major host of gold (e.g. Konongo, Ashanti, Bogosu and Prestea mines)

(iii) Disseminated and stockwork mineralisation in basin-type granitoids (e.g. Ayanfuri mine)

(iv) Quartz-pebble conglomerates of the Tarkwaian Group which locally carry gold, magnetite and hematite as originally detrital components (e.g. Tarkwa, Iduaprim, and Teberebie mines).

In an exemplary manner, Figs. 2 and 3 show the shape and setting of the orebodies (quartz vein and sulfide ores) at Ashanti mine. Note that no distinction is made between quartz vein and sulfide ores due to the scale of the figures.

(i) The *quartz veins* contain free-milling gold of variable fineness (730-950 at Ashanti mine). Single, massive or laminated veins, commonly between 0.2 and 5 m wide, locally reaching thicknesses of up to 25 m, and multiple quartz veins with intercalated, sheared and sulfidised wall rocks are present. Gold occurs as irregular individual grains and intergrown with a number of Cu-Pb-Zn-Sb-sulfides (galena, bournonite, boulangerite, tetrahedrite, chalcopyrite, sphalerite). Rare aurostibite, Bi-tellurides and auriferous lollingite are also present in the quartz vein ores at Ashanti Mine, whereas

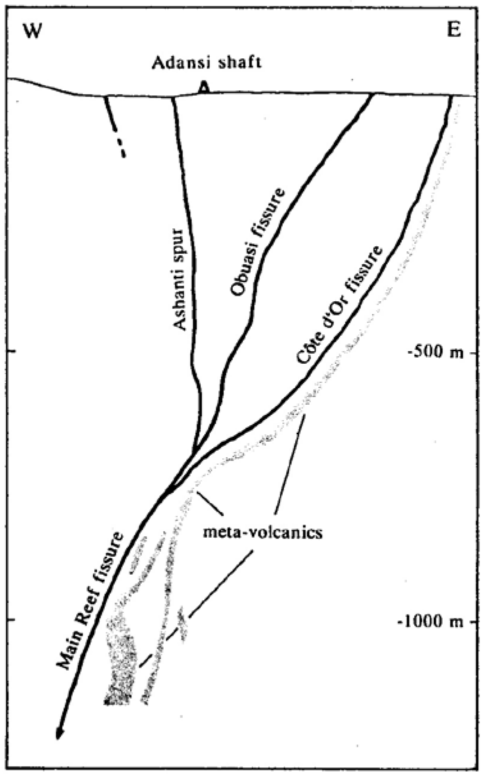

Figure 2: Projection of orebodies (E-W) at the Ashanti mine. After Amanor and Gyapong (1988).

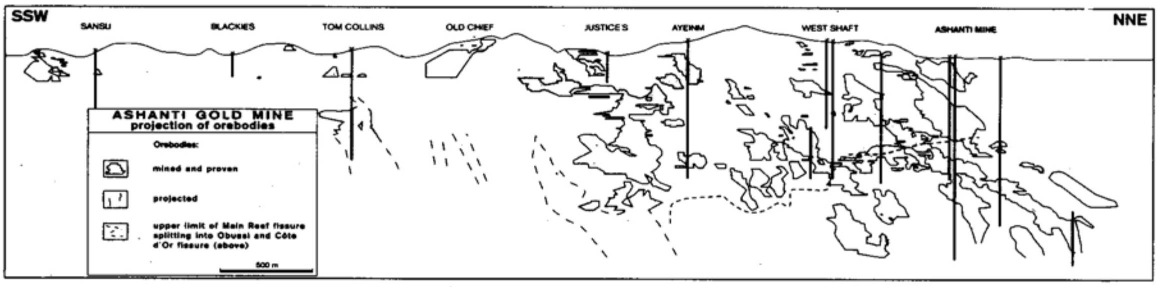

Figure 3: Projection of orebodies (NNE-SSW) at the Ashanti mine. After Amanor and Gyapong (1988).

occasional pyrite and arsenopyrite are usually bound to fragments of wall rocks incorporated in the veins.

Fluid inclusions in quartz possess unusual characteristics. They are dominantly CO_2-rich gas mixtures, the other components being N_2 and minor CH_4. Maximum densities range up to 1.12 g/cm^3 with most values ranging from 0.89-0.95 g/cm^3. Aqueous inclusions are subordinate.

Stable isotope studies revealed $\delta^{18}O$ ranging from 12.8-15.6 per mil SMOW (quartz) and δD in the range -37 to -53 per mil for aqueous fluids extracted from quartz (Ashanti and Prestea Mine), indicating deep-seated fluids of magmatic/metamorphic origin (Oberthür *et al.*, 1994). Furthermore, the fluid inclusion characteristics are interpreted as pointing to formation of the quartz veins at 400 ± 50°C at fluid pressures between 2 and 5 kbar. High densities of gaseous inclusions (e.g. 1.0 g/cm^3) are incompatible with the lithostatic pressure due to overburden. Estimation of the principal stresses (Blenkinsop *et al.*,1994) indicate a maximum compressive stress of ca. 10 kbar. The high densities of gaseous inclusions are suggested to result from secondary re-equilibration to the tectonic stress. Pb/Pb model ages obtained from galena, bournonite and gold (Ashanti Mine) cluster between 2120 and 2080 Ma, thus indicating that mineralisation was coeval with the Eburnean event at ca. 2.1 Ga (Höhndorf *et al.*, 1994).

(ii) The *sulfide ores* form ore bodies up to 50 m wide and are dominated by arsenopyrite, followed by pyrite, pyrrhotite, marcasite, subordinate chalcopyrite and sphalerite .and rare microscopic gold. The sulfides occur as disseminations or more massive concentrations in the host rocks, mainly Birimian metasediments which are locally pervasively carbonatised.

The orientation of arsenopyrite needles parallel to foliation points to synkinematic (and syn- to late-metamorphic) crystallisation of the sulfides. Internal disequilibrium and oscillatory zoning with respect to As/S ratios is typical for arsenopyrite crystals. Arsenopyrite compositions, therefore, cannot be used as geothermometers for the Ashanti belt sulfide mineralisations. Secondary ion mass spectrometry (SIMS) proved that at the Konongo, Ashanti and Bogosu Mines most of the gold is hosted in arsenopyrite (mean contents = 280, 190 and 237 ppm Au respectively). The iron-sulfides show insignificant gold contents (means <1ppm) with the exception of one sample from Bogosu where As-rich zones in pyrite contained up to 92 ppm Au. Gold concentration mapping revealed low Au-contents in the centers of arsenopyrite crystals and elevated contents along distinct growth zones towards the crystals' rims, indicating repeated deposition and dissolution of gold during crystal growth. An outermost crystal layer is usually gold-poor. Furthermore, gold contents appear independent of specific As/S ratios of the host arsenoypyrite.

Arsenopyrite and cogenetic pyrite are isotopically light with respect to sulfur isotope compositions (range: -4.6 to -10.2 per mil CDT for Ashanti, Bogosu and Prestea), the exception being Konongo with data ranging from -0.5 to -3.1 per mil CDT. It is proposed that the depleted $\delta^{34}S$ values of the sulfides largely reflect a fractionated source; i.e. syngenetic/diagenetic sulfides in Birimian sediments, where pyrites display a wide range of $\delta^{34}S$ from +7.26 to -20.9 per mil CDT indicative of (biological) sulfate reduction (Oberthür *et al.*, 1994). Notably,

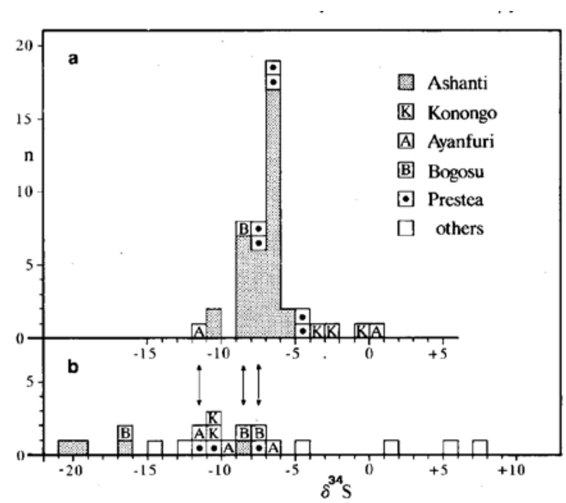

Figure 4: Sulfur isotope compositions ($\delta^{34}S$ in per mil CDT) of arsenopyrite concentrates from gold mineralisation (a, top) and pyrite (b, bottom) from unmineralised Birimian schists and gold mineralisations. Arrows indicate coexisting arsenoyprite and pyrite.

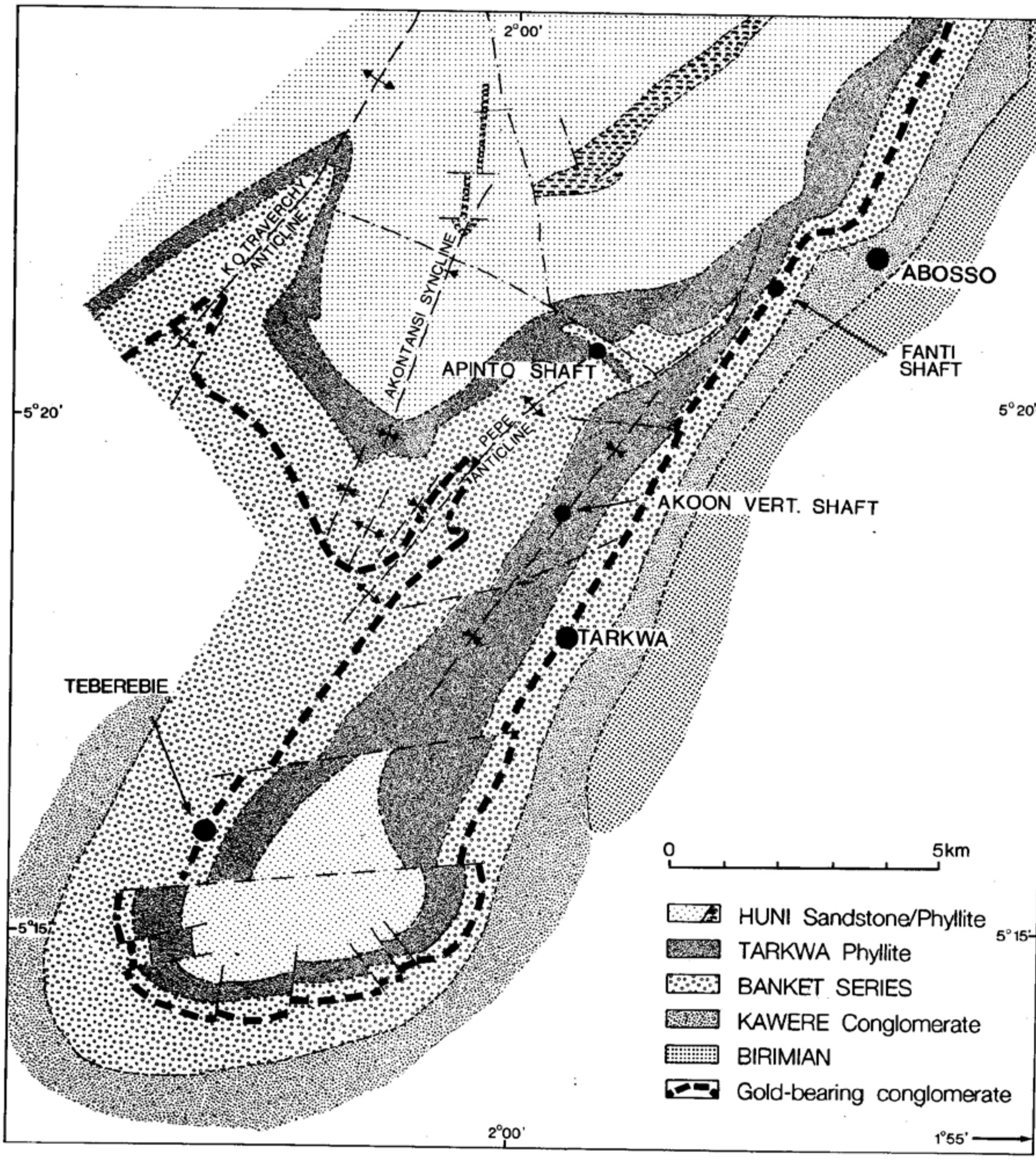

Figure 5: Geology of the Tarkwa area. After Hirdes and Nunoo (1994).

the mean $\delta^{34}S$ of pyrite from Birimian sediments (ca. -7 per mil CDT) and of arsenopyrite from gold mineralisation closely match each other (Fig. 4).

Pb isotope analyses of arsenopyrite concentrates (Ashanti Mine) gave an excellent secondary isochron corresponding to an age of 2224 ± 20 Ma (all errors are quoted at the 1 sigma level). The geological meaning of this age, however, is still uncertain (it may reflect ages of inclusions of detrital components in the arsenopyrites, or synsedimental mineralisation, or early epigenetic mineralisation), as do K/Ar ages of fine-grained muscovite from sulfide ores which range from 1867 ± 21 to 1893 ± 22 Ma.

The major orebodies, both quartz vein and sulfide ores, lie along major shear zones. According to Blenkinsop *et al.* (1994) and a number of earlier workers, both types of mineralisation are structurally controlled by fissure development and folding, synkinematic and syn- to late metamorphic' related to prolonged multistage episodes of tectonic-activity and hydrothermal fluid flow. On the other hand, Hirdes and Leube (1989) propose that some of the sulfide mineralisation formed syndepositionally due to synmetamorphic fluid discharge onto the seafloor. Sulfide mineralisation texturally appears to predate the quartz veins. However, this relationship could also express overlapping events (vein formation

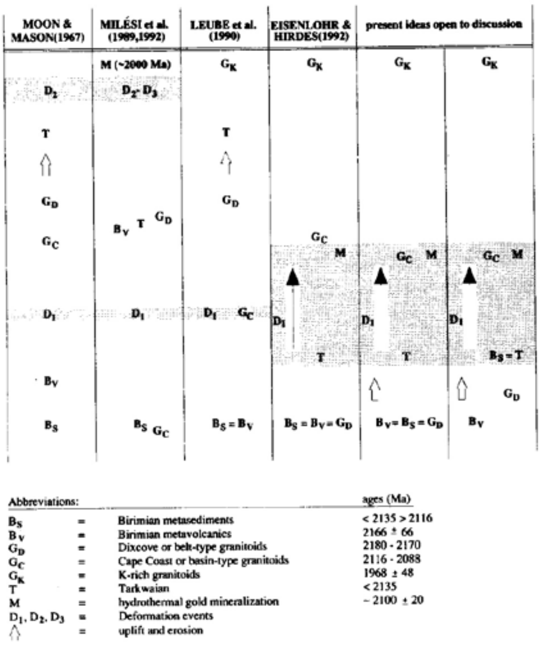

Figure 6: Summary of different interpretations on the sequence of Palaeoproterozoic geological events in SW Ghana. Note that Milesi *et al*.'s model intends to embrace the whole Palaeoproterozoic of West Africa. Age data from Taylor *et al*. (1992), Hirdes *et al*. (1992), Davis *et al*. (1994) and Höhndorf *et al*. (1994).

and wall rock alteration/mineralisation) due to repetitive fluctuations in fluid flow, or different crustal levels of mineral deposition.

(iii) Disseminated and stockwork *mineralisation in basin-type granitoids* constitutes an ore-type recognised only recently. At Ayanfuri, a number of granitoid stocks intrusive into Birimian sediments are exposed. The granitoids are pervasively altered by hydrothermal fluids and interspersed with stockwork-like quartz veining and disseminated sulfides.

Gold is not contained in the quartz veins, instead microscopic free gold is associated mainly with disseminated arsenoyprite, pyrite and accessory galena and chalcopyrite.

Arsenopyrite displays a "magmatic" $\delta^{34}S$ composition (+ 0.7 per mil CDT). Fluid inclusions in the quartz veins show that the fluids evolved from low-saline mixed H_2O CO_2 to CO_2-rich fluids. The latter are found in the quartz stockwork in the mineralised granite and clearly predominate in the nearby Bokitsi shear zone hosted gold deposit. One of the granitoids at Ayanfuri was dated at 2105 ± 3 Ma (U/Pb on monazite, probably the age of magmatic emplacement), and U/Pb on hydrothermal rutile yielded an age of 2087 ± 4 Ma. The latter date corresponds well to a K/Ar age obtained for hydrothermal alteration related muscovite (2070 ± 20 Ma).

(iv) Auriferous quartz pebble *conglomerates of the Tarkwaian Group* constitute another important type of gold mineralisation. Economic gold concentrations are contained in the Banket Series in the Tarkwa area (Fig. 5), which is characterised by well packed quartz pebble conglomerates which were deposited from rivers flowing from SE to NW. Particulate, originally detrital gold is associated with black sand minerals like hematite and magnetite as well as zircon; detrital sulfides are absent (Hirdes and Nunoo, 1994).

The originally detrital nature of the gold is documented by the sedimentary ore control (payshoots follow palaeochannels) and its occurrence independent of and unrelated to local sulfidisation. Detrital zircons in the Tarkwaian conglomerates at Tarkwa yielded U/Pb ages ranging from 2245 ± 5 to 2132 ± 3 Ma, the latter date providing a maximum age of sedimentation. 80% of the precise single zircon ages cluster in the 2185 to 2155 Ma age range (Davis *et al.*, 1994).

Fluid inclusions in quartz pebbles (Klemd *et al.*, 1993) display similar unusual characteristics (CO_2-dominant, presence of N_2, high densities) as the inclusions in the quartz veins (Ashanti and Prestea Mine). However, palaeotransport directions (from SE to NW) of the Tarkwaian conglomerates at Tarkwa, and the fact that epigenetic quartz vein mineralisation of the Ashanti belt is younger than the Tarkwaian depository calls for sources of the quartz pebbles, and by inference of the gold, from similar but older "Ashanti-type" mineralisation located towards the east of Tarkwa.

It is speculated that the apparent temporal/spatial problem can be solved by assuming a diachronous movement of tectonothermal activity from SE to NW in these parts of the Birimian terrane of Ghana (Davis *et al.*, 1994; Hirdes and Nunoo, 1994). This would allow "early" formation of Ashanti-type gold mineralisation towards the east of Tarkwa (e.g. in the realm of the Kibi-Winneba belt), their uplift, erosion and sedimentary transport into the Tarkwa depository followed by the latter's deformation jointly with the Birimian strata, and subsequent epigenetic mineralisation along the western flank of the Ashanti belt.

Concluding remarks

Fig. 6 portrays earlier and recent suggestions on the temporal sequence of geological events specifically in southern Ghana. It is evident that ideas put forward by BGR and counterpart scientists have developed considerably over the past years, mainly due to the recent acquisition of a number of precise age dates (Hirdes *et al.*, 1992; Davis *et al.*, 1994; Höhndorf *et al.*, 1994) and the deciphering of the structural evolution of the terrane (Eisenlohr, 1989; Eisenlohr and Hirdes, 1992; Blenkinsop *et al.*, 1994).

The age dates given in the captions of Fig. 6 bracket crustal evolution of southern Ghana into a relatively tight range from about 2180 to 2080 Ma. Epigenetic gold mineralisation in the Ashanti belt is confined to the 2120-2080 Ma time span. Our views are in contrast to the model of Milesi *et al.* (1989, 1992) developed for a much larger terrane of West Africa, in some major points and open to discussion. One question still inherent in our chronological sequence is the position of the Birimian sediments; one sample investigated (Davis *et al.*, 1994) revealed detrital zircons with ages as young as 2135 ± 3 Ma, similar to the detrital zircons from the Tarkwaian clastic sediments. This fact gives the possibility of interpreting Birimian fine clastic and Tarkwaian coarse clastic sediments as time-equivalent rock successions.

As a general note, we must support statements of Vidal and Alric (1994) based on investigations of the Palaeoproterozoic of Haute-Comoe in the Ivory Coast: "None of the global interpretations of the West African craton can be fully applied to Birimian units or basins when the scale of investigation becomes more detailed. We believe that the situation is more complex, and the interpretations must take into account: the existence of several basic volcanic assemblages, the evidence for several major periods of clastic sedimentation, the fact that stratigraphic correlations become quite hypothetical across long distances, and that studies of the Birimian need to be reconsidered in the framework of each individual unit, which should a prior be regarded as unique and interpreted independently."

Indeed, taking into account the vast area (at least 1600 x 1000 km) covered by Palaeoproterozoic rocks in the West African craton, any far reaching extrapolation of local situations appears at least questionable for 'this geologically relatively under explored terrane. Therefore, we must stress that the local situation in the Ashanti belt of Ghana must be seen as a contribution to the much larger puzzle of crustal evolution of the West African craton.

Gold mineralisation forms an integral part of the Palaeoproterozoic crustal evolution of southern Ghana. Structural and petrographic investigations (Blenkinsop *et al.*, 1994; Höhndorf *et al.*, 1994; Oberthür *et al.*, 1994) revealed that hydrothermal gold mineralisation in the Ashanti belt is largely metamorphogenic, contemporaneous with the Eburnean tectonothermal event at ca. 2.1 Ga. Fluid flow was focused in shear zones that were active late in the deformation history. Stable isotope compositions reflect large, homogeneous fluid sources of deep seated, magmatic/metamorphic origin, whereby unequivocal metamorphic signatures predominate (Oberthür *et al.*, 1994).

H_2O and CO_2 possibly originate from the dewatering and decarbonatisation of Birimian strata undergoing prograde metamorphism at greater depth. The possible role of the late- to post-kinematic basin-type granitoids and their temporal and genetic relationship to gold mineralisation is as yet unclear and needs further investigation. At least a close temporal link is indicated by recent age dating (Davis *et al.*, 1994; Höhndorf *et al.*, 1994) which brackets intrusions of basin-type granitoids west of the Ashanti belt close to 2105 Ma, and metamorphic/hydrothermal overprint in the range 2120 to 2080 Ma.

The genesis of CO_2-rich, partly high density fluid inclusions in quartz veins and Tarkwaian pebbles is still enigmatic and needs further studies. Oberthür *et al.* (1994) favour a (possibly) synchronous two-stage model for quartz vein and sulfide mineralisation which embraces sulfidisation of country rocks with a distinct mineralogical and geochemical signature (As, S, Au) and emplacement of gold quartz veins characterised by Ag-rich gold and Pb, Cu, Sb, Zn-sulfides. The proposed model intends to explain the apparent bimodal distribution of gold (in quartz veins and in sulfide ores) and largely follows suggestions put forward by Bonnemaison and Marcoux (1990) for mainly French gold deposits. Epigenetic gold mineralisations of the Ashanti belt are largely contemporaneous and owe their origin to the same fundamental process, hydrothermal fluid flow and its focusing into shear zones during the final stages of the Eburnean tectono-thermal event. The palaeoplacers at Tarkwa most probably obtained their sediment load including detrital gold from earlier formed Ashanti-type gold mineralisation situated towards the east of the depository, possibly in the area of the Kibi-Winneba belt (Hirdes and Nunoo, 1994).

Current models on the Palaeoproterozoic crustal evolution of southern Ghana and the timing of events including gold mineralisation are by far incomplete and are continually being developed further.

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