

## A geochemical study of the Ashanti gold deposit at Obuasi, Ghana

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The Ashanti gold deposit at Obuasi occurs in the Early Proterozoic Birimian formation. The orebodies consist of gold-sulphides disseminated in metasediments and metavolcanics, and gold-bearing quartz veins. Gold occurs mainly as native gold normally with arsenopyrite, pyrrhotite and pyrite in the metasediments and metavolcanics. In the quartz veins, however, it is associated with tetrahedrite and sphalerite. Microprobe analysis of gold grains gave an Ag content of about 8 wt.%.

Textural relationships among the various mineral associations suggest that pyrrhotite, pyrite, arsenopyrite and possibly gold may have been formed earlier in the paragenetic sequence. The precipitation of some amounts of gold may have occurred during the later stages of the mineralisation sequence.

Average arsenopyrite composition determined from electron microprobe study is: Fe:  $33.6 \pm 0.5$  at.%, As:  $29.3 \pm 1.2$  at.%, S:  $37.1 \pm 1.1$  at.%. This suggests an average temperature of formation of less than 300°C for the sulphides and possibly the gold assuming equilibrium was attained between pyrite, pyrrhotite and arsenopyrite. The  $\delta^{34}\text{S}$  values for sulphide mineral separates are in the range between -4.1 and -10.8‰. The values were, however, constrained between -4.1 and -7.0‰. The narrow range and the depleted nature of the  $\delta^{34}\text{S}$  values may suggest a sedimentary source of sulphur which may have undergone high temperature homogenisation before deposition. Sulphides from quartz vein samples had the most depleted  $\delta^{34}\text{S}$  values. This may indicate a different mineralisation history of the sulphides in the quartz veins from those disseminated in metasediments and metavolcanics.

**Keywords:** Birimian, Ashanti, gold, arsenopyrite

### I. Introduction

The Ashanti gold deposit occurs at Obuasi in the rain forest region of Ghana about 230km NW of the capital Accra (Fig. 1). Exploitation of the deposit might have begun long before the official takeover by the Ashanti Goldfields Company in 1897. The deposit is the richest in the West African subregion. As of September 1986 the mine produced about 600t of gold with a reported average ore grade of about 22.5g/t (Kesse, 1985). Production for the year 1990 was 420,000 oz. (Oberthür et al., 1991).

The study was undertaken with the primary objective of determining some of the basic parameters for the derivation of a genetic model for the deposit. Although quite some literature may be found on this deposit, geochemical data which are required to provide the basis of a concrete genetic model for the deposit are still lacking. This study was mainly focused on the paragenesis and chemistries of the various ore minerals. The possible source of the mineralising fluid and the approximate temperature of mineralisation were also discussed.

### II. Geology and gold mineralisation

Gold occurrence in Ghana is concentrated on the Proterozoic rock formations found mainly in the southwestern part of the country. This rock formation, referred to as the Birimian, forms the eastern portion of the West African Precambrian Guinea Shield. The Birimian is subdivided, stratigraphically, into the Lower and Upper units. The Lower unit consists mainly of metasedimentary rocks and it occurs as basins between the NE-SW trending Upper unit which is predominantly made of metavolcanic rocks. Several gold belts occur at or close to the contact between these units (Fig. 1).

The most prominent of these is the Ashanti belt which bears five major gold producing mines including the Ashanti mine. The Ashanti gold belt extends a distance of about 195km to the SW of Obuasi and continues for 65km to the NE. The main rock types which occur in the vicinity of the mine are those of the Lower and Upper Birimian units but they are found partially overlaid by rocks of the Tarkwaian sedimentary series (Fig. 2). The Lower

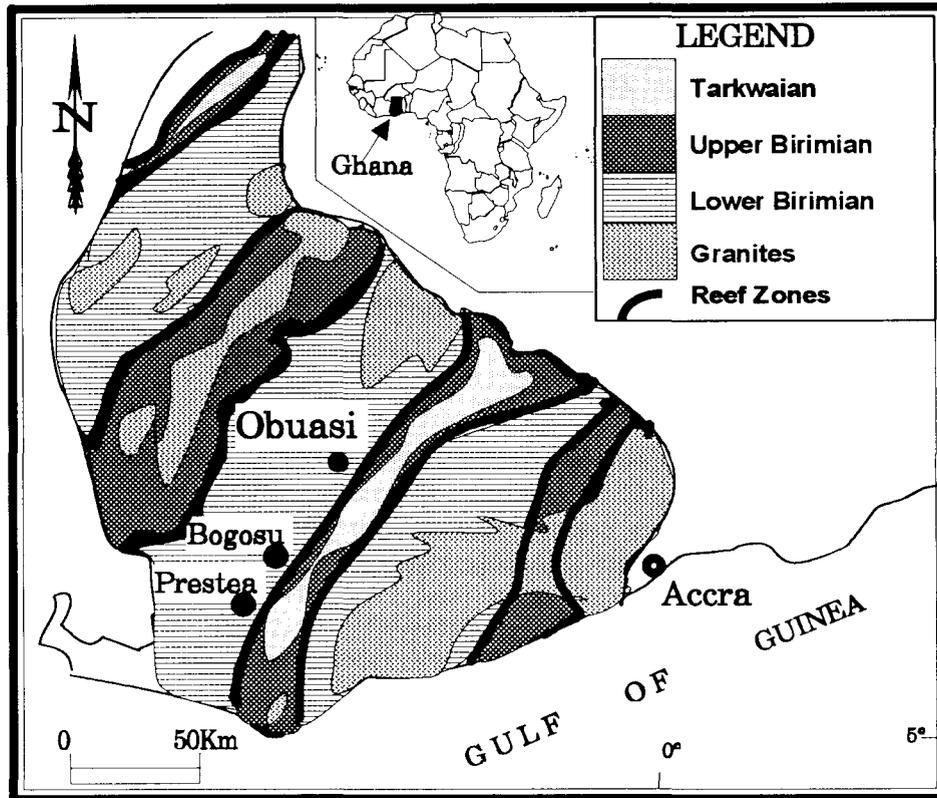


Fig. 1 General geological map of SW Ghana showing the principal gold belts (modified after Kesse, 1985).

Birimian at Obuasi is characterised by argillaceous and fine to intermediate arenaceous rocks dominated by phyllite (containing variable amounts of carbonaceous matter), greywacke, schist, sandstone and hornstone (Kesse, 1985).

The ore at Obuasi consists mainly of gold-sulphides disseminated in the metasediments and metavolcanics and gold in quartz veins. Oxidized ore also occurs within 30m from the surface in some places. Detailed geology and genesis of gold in the Birimian of Ghana and the Obuasi ore have been reported by several workers, e.g., Junner (1932), Kesse (1985), Adjimah (1988), Amanor and Gyapong (1988) and Cozens (1988).

### III. Samples and experiments

Samples, consisting of the major rock units of the deposit, were obtained from various orebodies at the mine (Fig 3). Twenty-six rocks of about 5kg weight each were obtained. They consisted of seven metasedimentary rocks (one phyllite, two greywackes and four schists), six metavolcanic rocks, four dykes and nine quartz veins.

Experiments undertaken in this research work include ore microscopy, electron microprobe analysis, X-ray powder diffraction, and sulphur iso-

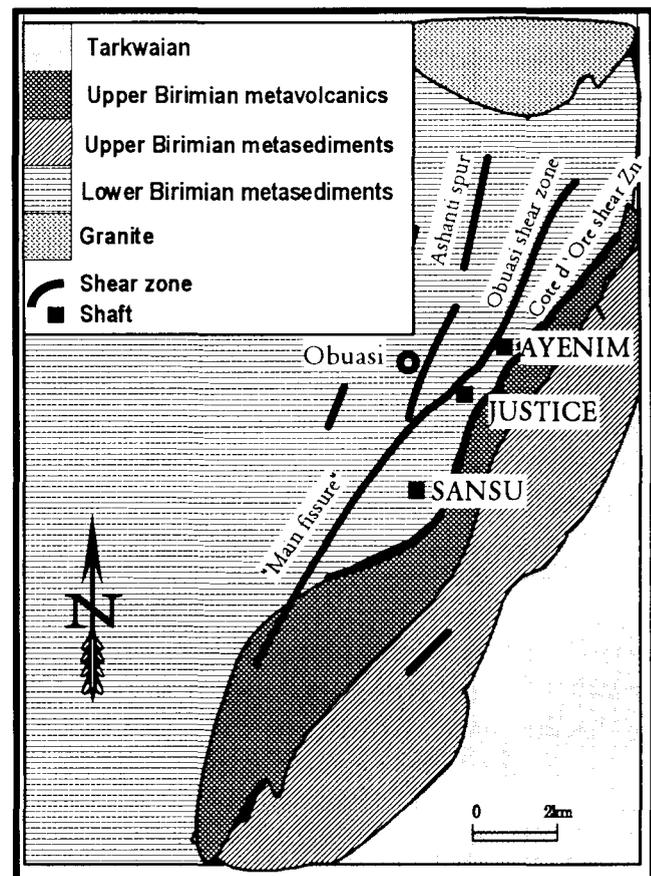


Fig. 2 Geology of the Ashanti gold mine concession (After Howell et al., 1990).

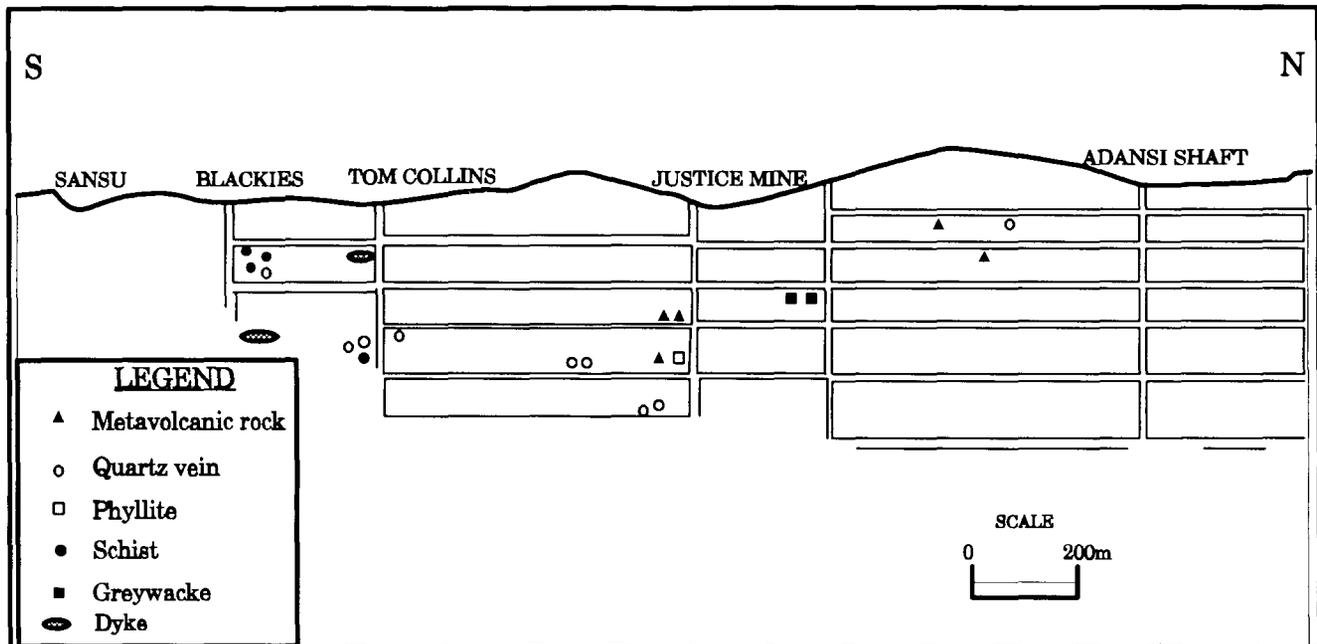


Fig. 3 North - south cross-section of the Ashanti mine showing sample positions.

topic study. For sulphur isotope determination twenty-three sulphide mineral concentrates were prepared from fourteen different rock samples. Isotope determination were done at the Laboratories of the Mitsubishi Material Company in Ohmiya.

The chemical compositions of arsenopyrite, gold, and related sulphides were determined on a JEOL electron probe microanalyser operating at an accelerating voltage of 25kV with a specimen current of  $2 \times 10^{-8}$ A measured on Cu metal. Relative X-ray intensities were corrected according to the ZAF program by Yui (1992).

#### IV. Ore microscopy and mineral chemistry

The major ore minerals occurring at the mine have been found to be arsenopyrite, pyrite and pyrrhotite. Marcasite and chalcopyrite are less abundant while tetrahedrite, gold, sphalerite, magnetite, bournonite and galena are present in trace amounts. Gangue minerals which are frequently associated with the ore are quartz, muscovite, carbonaceous material and rutile. Chlorite and albite are also present although their occurrences are less frequent. A summary of the occurrence of the minerals and their chemistries is described below.

##### 1. Arsenopyrite

This mineral occurs abundantly in almost all the samples, with the exception of the quartz veins in which it is rare. It occurs as idiomorphic crystals usually rhomboid- or lath-shaped commonly associ-

ated with pyrite and pyrrhotite (Fig. 4a). Their sizes vary widely having lengths ranging from  $300\mu$  to about 2.5mm. The larger crystals are frequently fractured. Crystals with broken edges, and those bent in the direction of schistosity are quite common. The crystals generally follow the direction of schistosity. The fractures in arsenopyrite are frequently seen hosting other minerals most commonly pyrrhotite and rutile. These minerals also occur in healing fractures or as inclusions completely embedded in the host arsenopyrite crystal. Arsenopyrite sometimes occurs as inclusions in pyrrhotite. Although some pyrrhotite grains may have been sealed up in arsenopyrite after the fractures healed, it may also show that

Table 1. Mineral chemistry of arsenopyrite (at.%)

Sample	As	Fe	S
A1-MV1	29.57	33.39	37.04
A3-MV2	29.11	34.08	36.82
A3-MV3	28.62	33.77	37.61
A7-MV4	28.84	33.63	37.45
A16-MV6	30.31	33.34	36.35
A10-MS1	29.06	33.60	37.34
A11-MS2	28.81	33.81	37.38
A12-MS3	30.24	33.31	36.33
A14-MS4	28.73	33.03	38.24
A5-Q3	31.49	33.07	35.44
A24-D1	29.32	34.07	36.61

Ax: sample number, MV: metavolcanic, MS: metasediment, Q: quartz, D: dyke

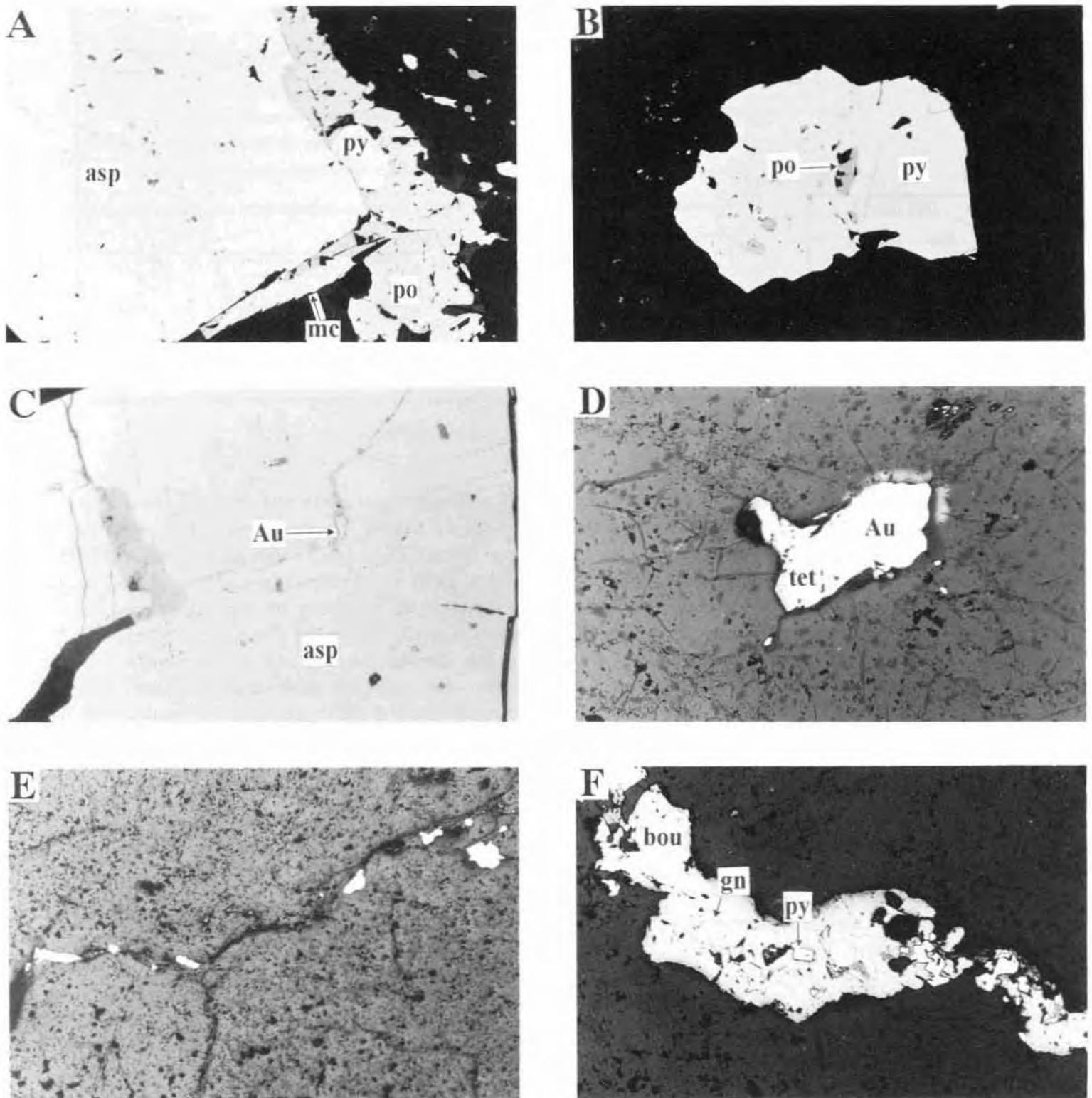


Fig. 4 Photomicrographs showing the mineral occurrences in the Obuasi ore. **A:** Arsenopyrite (asp) in association with pyrite (py), pyrrhotite (po) and marcasite (mc) (Field width is 0.15mm); **B:** Pyrite (py) with inclusions of pyrrhotite (po) (Field width is 0.6mm); **C:** Pyrrhotite (po) and gold (Au) in fractures of an arsenopyrite (asp) grain (Field width is 0.15mm); **D:** Gold (Au) in association with tetrahedrite (tet) (Field width is 0.15mm); **E:** Gold occurring in cracks of quartz veins (Field width is 1.2mm); **F:** Bournonite (bou) with inclusions of galena (gn) and other sulphides (Field width is 0.6mm).

pyrrhotite may have been the primary mineral from which some of the arsenopyrite crystals were formed. The observations as stated above may suggest a pre- or syn- deformational formation of the larger arsenopyrite crystals and most of the other minerals may have been formed after the crystallisation of the arsenopyrite.

Electron probe microanalyses of about 85 crystals indicated that the overall composition range of arsenopyrite is as follows: 32.1~34.5 at.%Fe, 26.5~33.4 at.%As, and 33.8~39.8 at.%S. Arsenic is constrained between 28.0 at.% and 30.1 at.%. This indicates an As depletion and an enrichment in S relative to the stoichiometric FeAsS. Table 1 shows the average arsenopyrite compositions in the various rock types. The occurrence of trace elements in arsenopyrite is rare.

## 2. Pyrite

This mineral occurs in sizes ranging from specks to more than 1mm. It usually occurs as anhedral crystals disseminated in most of the samples but its occurrence in the quartz veins is rare. Specks of pyrite, although quite difficult to identify, are usually seen in association with the dark carbonaceous material.

Most of the pyrite crystals have inclusions of other minerals (mostly pyrrhotite, magnetite, and/

or rutile) in them (Fig. 4b). Fractured crystals of pyrite are common and they usually bear other minerals in their fractures. Crystals with removed edges and those bearing pits which contain dark materials have also been observed. This mineral is most frequently associated with arsenopyrite and/or pyrrhotite and sometimes with chalcopyrite and marcasite. Idiomorphic pyrite occurring as inclusions in pyrrhotite has also been observed in some samples.

The chemical composition is shown in Table 2. Trace elements detected in pyrite grains are Ni, Co, and As. Up to 1.95 wt.% As was detected. The maximum contents of Ni and Co are 4.01 wt.% and 1.21 wt.%, respectively. The trace element chemistries of pyrite in the various rock types are quite similar and may indicate a concurrent deposition of this mineral in the metasediments and metavolcanics. Deformational features found in most pyrite grains coupled with its close association with other minerals, e.g., arsenopyrite, may suggest a pre- or syndefomational crystallisation of this mineral.

## 3. Pyrrhotite

This mineral is also quite abundant in samples of the metavolcanics and metasediments. The grains are usually anhedral and micrometer-sized but sizes of about 1mm are occasionally seen. Pyrrhotite is most commonly associated with either pyrite or arsenopyrite or both. Association with marcasite and chalcopyrite is also very common in some rocks. These minerals in some cases are seen to be a replacement of a primary pyrrhotite. Pyrrhotite also occurs with gold as inclusions and in cracks of arsenopyrite (Fig. 4c). This may give an indication of the timing of both minerals and the gold.

Pyrrhotite crystals with pits bearing dark carbonaceous material as well as those with inclusions of pyrite and arsenopyrite also occur. The occurrence of inclusions of pyrite and sometimes arsenopyrite may suggest that equilibrium might have been achieved among these major minerals during crystallisation. Crystals which have been bent in the direction of schistosity occur in the well schistose rocks. The observations above may suggest that pyrrhotite may also be one of the earliest formed minerals and may have been formed syngenetic to sedimentation or before a major deformational event.

Table 3 shows the composition of pyrrhotite determined by microprobe analysis. As in the case of pyrite and arsenopyrite no variations in composition exist among the various rock types studied. Trace element contents are relatively lower than

Table 2. Mineral chemistry of pyrite (wt.%)

Sample	Fe	Co	Ni	As	S	Total
A1-MV1-py1	48.40	0.16	0.01	0.23	52.84	101.64
A1-MV1-py2	48.17	0.05	0.02	0.54	52.57	101.35
A1-MV1-py3	47.45	0.04	0.69	0.42	52.68	101.28
A1-MV1-py4	48.27	0.06	0.02	0.22	53.03	101.60
A1-MV1-py5	48.22	0.06	0.02	0.16	52.69	101.16
A3-MV2-py1	48.60	0.05	0.37	1.11	52.16	102.29
A3-MV2-py2	48.74	0.04	0.14	0.23	53.15	102.30
A3-MV2-py3	48.37	0.06	0.10	1.38	52.36	102.27
A3-MV3-py1	48.16	0.07	0.13	0.20	52.48	101.04
A3-MV3-py2	45.77	0.02	4.01	0.00	52.67	102.48
A3-MV3-py3	48.90	0.05	0.02	0.00	52.17	101.14
A7-MV4	47.58	0.31	0.51	1.95	52.18	102.53
A16-MV6-py1	48.20	0.07	0.03	0.00	52.07	100.38
A16-MV6-py2	47.23	1.21	0.02	0.00	51.72	100.18
A14-MS4-py1	48.99	0.05	0.03	0.00	50.98	100.05
A14-MS4-py2	48.70	0.04	0.01	0.00	51.62	100.37
A14-MS4-py3	48.33	0.04	0.12	0.00	51.19	99.68
A14-MS4-py4	48.24	0.06	0.38	0.31	50.94	99.93
A6-MS-py1	48.51	0.06	0.01	1.08	53.00	102.66
A6-MS-py2	48.44	0.08	0.02	1.00	52.74	102.28
A6-MS-py3	47.92	0.08	0.12	0.97	52.43	101.52

Abbreviations are the same as in Table 1.

Table 3. Mineral chemistry of pyrrhotite (wt.%)

Sample	Fe	Co	Ni	As	S	Total
A1-MV1-1	60.81	0.00	0.00	0.10	38.96	99.86
A1-MV1-2	60.61	0.00	0.01	0.30	38.78	99.70
A3-MV2-1	61.01	0.05	0.29	0.15	39.52	101.02
A3-MV2-2	60.98	0.05	0.14	0.76	38.88	100.80
A3-MV3-3	61.53	0.04	0.08	0.60	39.12	101.36
A3-MV3-1	60.52	0.05	0.14	0.00	38.58	99.30
A3-MV3-2	60.77	0.06	0.33	0.00	38.26	99.41
A3-MV3-3	60.72	0.08	0.32	0.00	38.49	99.61
A7-MV4-1	60.91	0.07	0.07	0.05	38.91	100.01
A7-MV4-2	61.29	0.07	0.07	0.05	39.00	100.48
A7-MV4-3	61.11	0.07	0.07	0.05	38.55	99.85
A16-MV6-1	60.21	0.06	0.10	0.00	38.16	98.53
A16-MV6-2	60.61	0.07	0.11	0.31	38.99	100.09
A16-MV6-3	60.20	0.08	0.12	0.04	38.26	98.69
A16-MV6-4	60.59	0.07	0.10	0.00	38.45	99.21
A14-MS4-1	60.56	0.07	0.10	0.00	38.88	99.61
A14-MS4-2	61.22	0.09	0.08	0.00	38.90	100.28
A14-MS4-3	61.02	0.05	0.11	0.00	38.26	99.43
A14-MS4-4	61.39	0.07	0.10	0.00	38.67	100.23
A6-MS1	60.21	0.09	0.13	1.25	38.17	99.86

Abbreviations are the same as in Table 1.

in pyrite. Arsenic content of up to 1.25 wt.% has been determined while Ni and Co gave maximum values of 0.33 wt.% and 0.09 wt.%, respectively.

#### 4. Chalcopyrite

This mineral is usually micrometer-sized and commonly occurs with pyrrhotite and sometimes arsenopyrite and pyrite. It is sometimes sandwiched by pyrrhotite or may occur in fractures of pyrite and arsenopyrite. Chalcopyrite is also associated with sphalerite and tetrahedrite, mainly in the quartz veins. It occasionally occurs as lamellae and blebs in sphalerite.

#### 5. Marcasite

Marcasite occurs as idiomorphic crystals, forming wedge- or lath shaped crystals normally associated with pyrrhotite (Fig. 4a). It is quite frequently sandwiched by pyrrhotite although its occurrence with pyrite and arsenopyrite is also observed. Isolated crystals of marcasite are very rare. Its texture and occurrence with pyrrhotite may suggest that marcasite may be a replacement product of pyrrhotite.

#### 6. Gold

The studies so far have revealed the existence of two main forms of gold. They are the microscopic to sub-microscopic gold which occurs in

Table 4. Mineral chemistry of gold (wt.%)

Sample	Au	Ag	Total
A12-MS1-Au1	69.41	0.00	69.41*
A12-MS1-Au2	36.43	0.00	36.43*
A23-Q9-Au1	90.44	7.17	97.61
A23-Q9-Au2	93.10	7.57	100.67
A23-Q9-Au3	91.59	7.70	99.38
A23-Q9-Au4	91.83	8.43	100.26
A23-Q9-Au5	92.06	8.49	100.55
A23-Q9-Au6	92.07	7.99	100.06
A23-Q9-Au7	92.29	8.39	100.68
A23-Q9-Au8	92.54	8.10	100.64
A23-Q9-Au9	92.40	8.00	100.41

\*Small grain sizes affected X-ray count.

Abbreviations are the same as in Table 1.

metasediments and metavolcanics and that found in the quartz veins which is relatively larger with sizes of up to about 300 $\mu$ . The former, with sizes of up to about 30 $\mu$ , is usually associated with arsenopyrite, pyrrhotite, and pyrite while the latter occurs mainly in association with tetrahedrite, and occasionally sphalerite (Fig. 4d). Gold in the quartz veins generally occurs in fractures (Fig. 4e). The close association of gold with all the earlier formed minerals (especially pyrrhotite and arsenopyrite) in the metasediments and metavolcanics may suggest that some amounts of gold may have been deposited during the early stages of mineralisation. Those found in the quartz veins may however have been formed much later.

Electron microprobe analysis gave the composition of the two types of gold as shown in Table

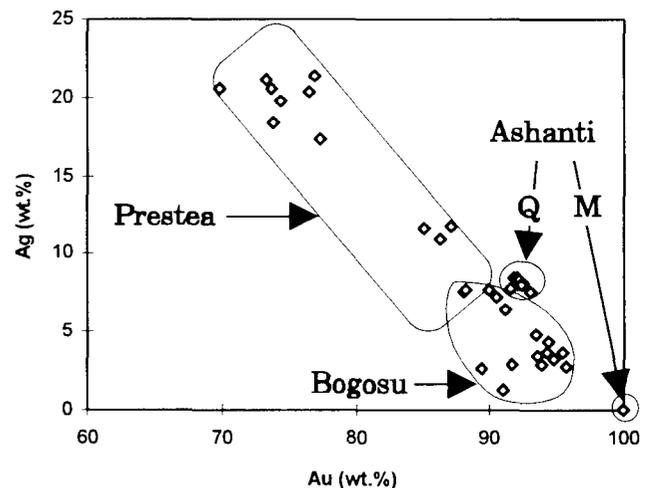


Fig. 5 Silver and Au contents of gold grains from the Ashanti and other gold mines from the same gold belt. Compositions from Prestea and Bogosu are from Mumin et al. (1994). M and Q indicate metasediments and metavolcanics, and quartz veins, respectively.

Table 5. Chemical composition (wt.%) and structural formula of tetrahedrite

	A9-Q5-t1	A9-Q5-t2	A23-Q9-t1	A23-Q9-t2	A23-Q9-t3
Cu	25.62	25.31	38.53	38.37	37.77
Ag	0.55	16.92	0.00	0.00	0.00
Fe	4.34	4.37	2.19	2.34	3.27
Zn	3.24	3.20	5.45	5.46	4.24
Pb	1.60	1.56	0.00	0.00	0.00
Sb	25.92	27.94	27.40	28.59	28.47
As	1.02	1.00	2.48	1.95	1.47
S	24.41	23.79	25.38	25.29	25.26
Total	86.69	104.08	101.43	102.01	100.47
Number of atoms based on 29 total atoms.					
Cu	7.64	6.90	9.89	9.84	9.80
Ag	0.10	2.72	0.00	0.00	0.00
Fe	1.47	1.36	0.64	0.68	0.97
Zn	0.94	0.85	1.36	1.36	1.07
Pb	0.15	0.13	0.00	0.00	0.00
Sb	4.03	3.97	3.67	3.83	3.85
As	0.26	0.23	0.54	0.43	0.32
S	14.42	12.85	12.91	12.86	12.99

4. The small grain size of samples A12-S1-Au1 and A12-S1-Au2 may have affected their X-ray counts. Relative Ag enrichment is obvious in the gold associated with tetrahedrite in the quartz veins. The compositional differences between the two types of gold may probably be due to differences in their genetic histories. A plot of the compositions of native gold from the Ashanti mine with those from other deposits which occur on the same gold belt in Ghana is shown in Fig. 5.

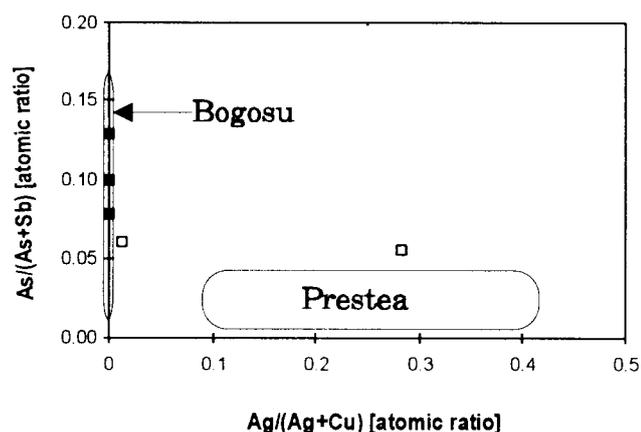


Fig. 6 Comparison of tetrahedrite chemistries of the Ashanti and other ores from the same gold belt. Filled squares represent tetrahedrite from the Ashanti ore which is in association with gold. Unfilled squares represent tetrahedrite from the Ashanti ore which is not in association with gold. Compositions from Prestea and Bogosu are from Mumin et al. (1994).

Table 6. Mineral chemistry of selected sphalerite grains (wt.%)

Sample	Zn	Fe	Cu	Cd	Mn	S	Total
A9-Q5-1	65.76	1.49	0.00	0.30	0.03	33.05	100.63
A9-Q5-2	64.39	2.19	0.51	0.22	0.02	32.53	99.85
A23-Q9	64.44	2.47	0.00	0.00	0.00	33.57	100.48

7. Tetrahedrite

This mineral is mainly found in the quartz veins and has been noted to exist in two forms. One kind occurs in the gold-rich quartz veins and is seen to be closely associated with the gold (Fig. 4d). The other occurs in association with sphalerite, chalcopyrite and bournonite also in the quartz veins. Both types are micrometer-sized with a maximum grain size of about 350µ.

Although no optical difference is noticeable between these two types of tetrahedrite, microprobe analysis has shown that tetrahedrite grains which occur with gold are generally depleted in Ag (Table 5). A plot of the composition of tetrahedrite from the Ashanti deposit alongside those from the same gold belt is shown in Fig 6.

8. Sphalerite

Sphalerite usually occurs as micrometer sized crystals sometimes seen in association with chalcopyrite, tetrahedrite and occasionally with gold. Isolated crystals also do occur. Results of microprobe analysis on sphalerite grains are shown in Table 6.

Table 7. Chemical composition (wt.%) and structural formula of bournonite

	A9-Q5-1	A9-Q5-2
Pb	42.45	42.30
Cu	12.86	12.98
Ag	0.15	0.17
Fe	0.04	0.00
Zn	0.00	0.01
Sb	26.21	26.15
S	18.98	19.67
Total	100.71	101.27
Number of atoms based on 6 total atoms.		
Pb	1.01	0.99
Cu	1.00	0.99
Ag	0.01	0.01
Fe	0.00	0.00
Zn	0.00	0.00
Sb	1.06	1.04
S	2.92	2.97

### 9. Bournonite and Galena

Galena is closely associated with bournonite (Fig. 4f), both occurring mainly in the quartz veins with the former sometimes included in the latter with other minerals such as pyrite. Galena occurs in sizes of not more than  $100\mu$  while bournonite of up to  $300\mu$  may be seen. These minerals occur together with chalcopyrite, sphalerite, and some tetrahedrite along veinlets in quartz veins indicating their later introduction after the formation of the quartz. The composition of bournonite is shown in Table 7.

### 10. Gangue

The most common gangue minerals identified in this study are quartz, rutile, and dark carbonaceous materials. They are observed very frequently in almost all the samples in close association with the ore minerals. Rutile occurs in the rock either as inclusions in the earlier formed sulphides or as skeletal grains disseminated in almost all the samples with the exception of the quartz veins. The occurrence of black carbonaceous material with the ore mineral is also noted in all the samples. Even in the less mineralised quartz veins, the carbonaceous ma-

terial is seen in the veinlets in which minerals such as pyrite, arsenopyrite, bournonite, and ilmenite are found. Dolomite occurs in many of the samples studied.

### V. Discussion

Ore microscopic observations as described above lead to the belief that a multi-stage mineralisation may have been responsible for the ore formation at Obuasi. Deformational events which occurred after the formation of the earlier stage minerals, most probably pyrite, arsenopyrite, and pyrrhotite, may have been responsible for the fractures clearly observed in some pyrite and the large arsenopyrite crystals. The paragenetic sequence for the ore minerals at Obuasi is summarised in Fig. 7.

The following models may explain the occurrence of microscopic and submicroscopic gold in the metasediments and metavolcanics. Firstly, inclusions of pyrrhotite and gold in the same arsenopyrite grain may suggest that minor amounts of gold may have been deposited with the earlier formed pyrrhotite. This is because inclusions of pyrrhotite in arsenopyrite could be relicts of the primary min-

Mineral	Pre-deformation	Syn-deformation	Post-deformation
Arsenopyrite	●—————		—————
Pyrite	●—————		—————
Pyrrhotite	●—————	—————	
Marcasite		—————	—————
Chalcopyrite		—————	—————
Sphalerite			—————
Tetrahedrite			—————
Bournonite			—————
Galena			—————
Gold		—————	—————

Fig. 7 Paragenetic sequence for ore minerals in the Obuasi ore.

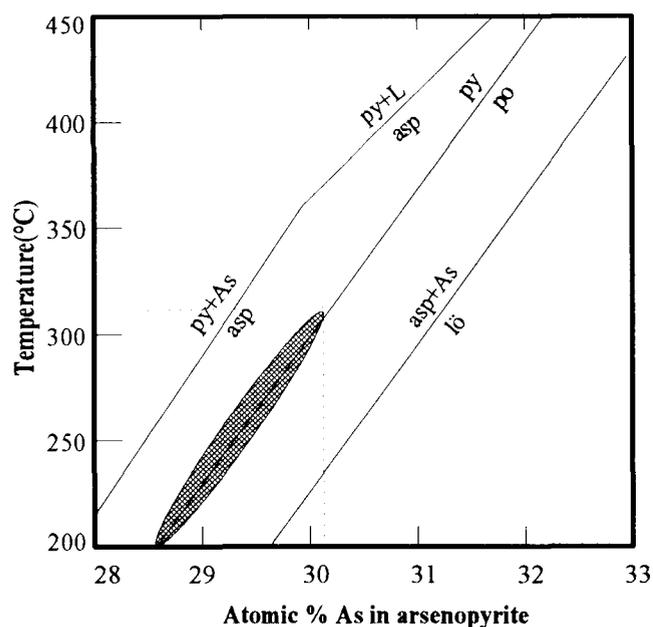


Fig. 8 A temperature plot of As content in arsenopyrite grains (Modified after Kreschmar and Scott, 1976). Abbreviations are: py: pyrite, po: pyrrhotite, asp: arsenopyrite, As: arsenic, lö: löllingite and L: liquid.

eral and, the gold, which was deposited with it, may have been left as specks and streaks after the host pyrrhotite was replaced by arsenopyrite. Also, gold could have been introduced after major deformational events had caused fractures in the earlier formed minerals. An alternative is that gold might have been deposited initially with arsenopyrite and/or arsenian pyrite and later "creeped" into fractures of the earlier formed minerals.

Gold occurrence in the quartz veins has been observed to differ from that in the metasediments and metavolcanics. In the former it occurs in close association with tetrahedrite in a manner suggesting that tetrahedrite and gold may have been formed from the same solution. This is supported by observation that tetrahedrite occurring in association with gold in the quartz veins was found to be depleted in Ag relative to those not associated with gold. On the other hand, gold grains which occur in association with tetrahedrite were enriched in Ag, relative to those found in the metasediments and metavolcanics. This may indicate that conditions prevailing at the time of gold mineralisation in the quartz veins were different from those in the metasediments and metavolcanics. This observation, therefore, suggests a different genetic history for the two forms of gold identified so far at the mine.

As shown in Table 1, the As content of arsenopyrite is constrained between 28.0 and 30.1

Table 8.  $\delta^{34}\text{S}$  of sulphides from the Obuasi deposit (values in ‰ CDT)

	Asp	Py	Po	Cp
A1-MV1	-4.1			
A3-MV2	-4.9			
A3-MV3	-6.6	-6.9		
A7-MV4	-5.2		-4.3	
A15-MV5	-4.1	-4.6		-6.1
A15-MV5-2		-4.4		
A16-MV6	-5.9		-5.6	
A2-Q1	-8.0	-10.8		
A11-MS2	-5.4	-4.7		
A12-MS3	-5.1	-4.7		
A14-MS4	-5.7			
A6-MS1	-4.1	-5.4		
A19-MS2	-5.9			
A20-MS3	-4.2			

Abbreviations are the same as in Table 1.

at.%. Assuming an equilibrium with pyrite and pyrrhotite, a comparison of this range to a modified calibration curve by Kretschmar and Scott (1976) (Fig. 8) gives an approximate temperature range of between 200 to 320 °C as the formation temperature of the sulphide assemblage. Other workers on the Obuasi deposit have reported similar results. Milesi et al. (1989) reported arsenopyrite composition of Fe:  $32.7 \pm 0.1$  at.%, As:  $31.2 \pm 0.2$  at.%, S:  $36.1 \pm 0.2$  at.%. The suspected temperature deduced from this composition is less than 350 °C. A temperature of formation between 281 and 363 °C has also been suggested from a mineralogical study (Amanor and Gyapong, 1988).

Sulphur isotopic study undertaken on the selected sulphide mineral concentrates yielded results as shown in Table 8. A general restriction of the values between -4 and -7 ‰ is observed. These results may be interpreted as an indication of a sedimentary sulphur source for the sulphides which occur at Obuasi. The narrow spread may, however, suggest that the sulphur may have undergone high temperature homogenisation prior to the mineralisation. Values from the quartz vein sample are seen to be more depleted. This may indicate a different history of the sulphides in the quartz veins.

Dark carbonaceous substances associated with sulphides may have played an important role in the precipitation of gold. Solutions ascending from deep sources were probably reduced by these carbonaceous substances in the metasediments. It is known that the solubility of Au is strongly related with  $f_{\text{O}_2}$ , and decreases toward the stability field of

pyrite and pyrrhotite equilibrium. This mechanism can explain the localization of Au deposit near the boundary between the metasediments and the metavolcanics.

## VI. Conclusions

This study has so far indicated that the gold deposit at Obuasi occurs mainly in the form of native gold containing up to about 8 wt.% Ag. Its textural relationship with the associated minerals coupled with their observed interconnected geochemistries may suggest that gold may have been deposited in at least two stages. This is supported by the fact that gold occurring with tetrahedrite (in the quartz veins) is enriched in Ag which happens to be depleted in the associated tetrahedrite grains. Other grains of tetrahedrite which are not associated with gold are relatively richer in Ag. So far, Ag has not been detected in gold grains found in the metasediments and metavolcanics.

The study has also revealed the abundant occurrence of pyrrhotite in the deposit contrary to some reports which indicated it as a rare mineral (Milesi et al., 1989). Their less abundance in certain parts of the deposit may, however, be a result of replacement of this mineral by other minerals such as arsenopyrite and marcasite. It is suspected that this mineral may have been deposited with some amounts of gold. Hydrothermal activities after its deposition may have caused its transformation into other sulphides like pyrite, arsenopyrite and marcasite.

Sulphur isotopic studies on sulphide mineral concentrates from the deposit showed a general depletion in  $^{34}\text{S}$ . The  $\delta^{34}\text{S}$  values were constrained between -4 and -7‰ suggesting a possible sedimentary source of sulphur which may have undergone high temperature homogenisation before deposition.

The arsenic content of arsenopyrite from the mine is constrained between 28.0 and 31.5 at.%. This range may indicate a temperature of formation of between 200 to 320°C assuming equilibrium was reached among arsenopyrite, pyrite and pyrrhotite (Kretschmar and Scott, 1976).

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