Journal of Geography, Environment and Earth Science International

14(3): 1-14, 2018; Article no.JGEESI.40428
ISSN: 2454-7352

Pebble Size in Matrix of Palaeoplacer Conglomerate Correlated with Gold Grade

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Authors' contributions

This work was carried out in collaboration between both authors. Author GMT designed the study, guided author HDB to perform the statistical analysis and write an initial project report as a requirement for an undergraduate program. Author GMT did further literature review and drafted the manuscript. Both authors read and approved of the final paper.

Article Information

DOI: 10.9734/JGEESI/2018/40428
Editor(s):
(1) Masum A. Patwary, Geography and Environmental Science, Begum Rokeya University, Bangladesh.
(2) Ojeh Vincent Nduka, Department of Geography, Taraba State University, Jalingo, Nigeria.
Reviewers:
(1) Antipas T. S. Massawe, University of Dar Es Salaam, Tanzania.
(2) Eric S. Hall, USA.
Complete Peer review History: http://www.sciencedomain.org/review-history/24043

Original Research Article

Received 25th January 2018
Accepted 30th March 2018
Published 7th April 2018

ABSTRACT

This study aimed at finding a complementary field guide to recognize the relative gold 'grade' of the palaeoplacer banket conglomerate of the Tarkwaian Group in southwestern Ghana, West Africa. The study was conducted on a drill core from the Ajopa pit near Tarkwa, which, intercepted a palaeoplacer conglomerate from a depth of 5 m to 105 m. The conglomerate forms part of the Tarkwaian gold-bearing unit, deposited from 3132 Ma to 2095 Ma. The pebbles in the rock are mainly made up of oligomictic quartz of milky or vitreous whitish grey and coarse-grained. The size ranges from 8.50 mm to 30.50 mm, rounded, well to moderately sorted, and closely packed. Gold occurs in the matrix of the pebbles, composed of fine to medium-grained quartz, and associated with chlorite, and sericite, with heavy minerals mainly comprised of magnetite and hematite. The Tarkwaian Group sediments were sourced from the Birimian Supergroup which is a hydrothermal gold-bearing terrain of about 2.2 billion years (b.y.) old. The results of the study confirm that gold grade increases with increase in pebble sizes in the conglomerate. The study also found out that there is a relationship between bigger grain sizes in the matrix to gold grades. Also, the medium-

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grained fragments in the matrix which range in size from 0.60 mm to 4.35 mm show a positive correlation with gold grade (0.01 g/t to 3.67 g/t). These findings apply to higher and lower gold grades.

Keywords: Conglomerate; matrix; grain size; correlation; gold grade.

1. INTRODUCTION

The Ajopa pit is located at Tarkwa in the Tarkwaian Group (2.1 b.y.) which consists of palaeoplacer sedimentary rocks, unconformably overlying the Birimian Supergroup (2.2 b.y.) in Ghana. The basal rock of the Tarkwaian Group is polymictic, poorly sorted, Kawere conglomerate [1]. Above this unit is the Banket Series, made up of auriferous quartz conglomerate interbedded locally with cross-bedded sandstones. The pebbles in the Kawere conglomerate are predominantly made up of quartzite, greywacke, phyllite, and some hornfels, derived from underlying Birimian rocks [1]. Deposition of the pebbles was into alluvial fans with braided streams and rivers [2]. Sources of the pebbles in banket conglomerates in the area from current directions suggest from east and southeast of Tarkwa area [1]. An investigation was conducted on the matrix of non-deformed Palaeoprotorozoic Kolhan group in the Chamakpur Koenjhar basin in India to show that clay-rich matrix has various mineralogical compositions and polygenic provenance marked by two different palaeocurrent directions [3]. The deposit was, however, not related to any mineralization.

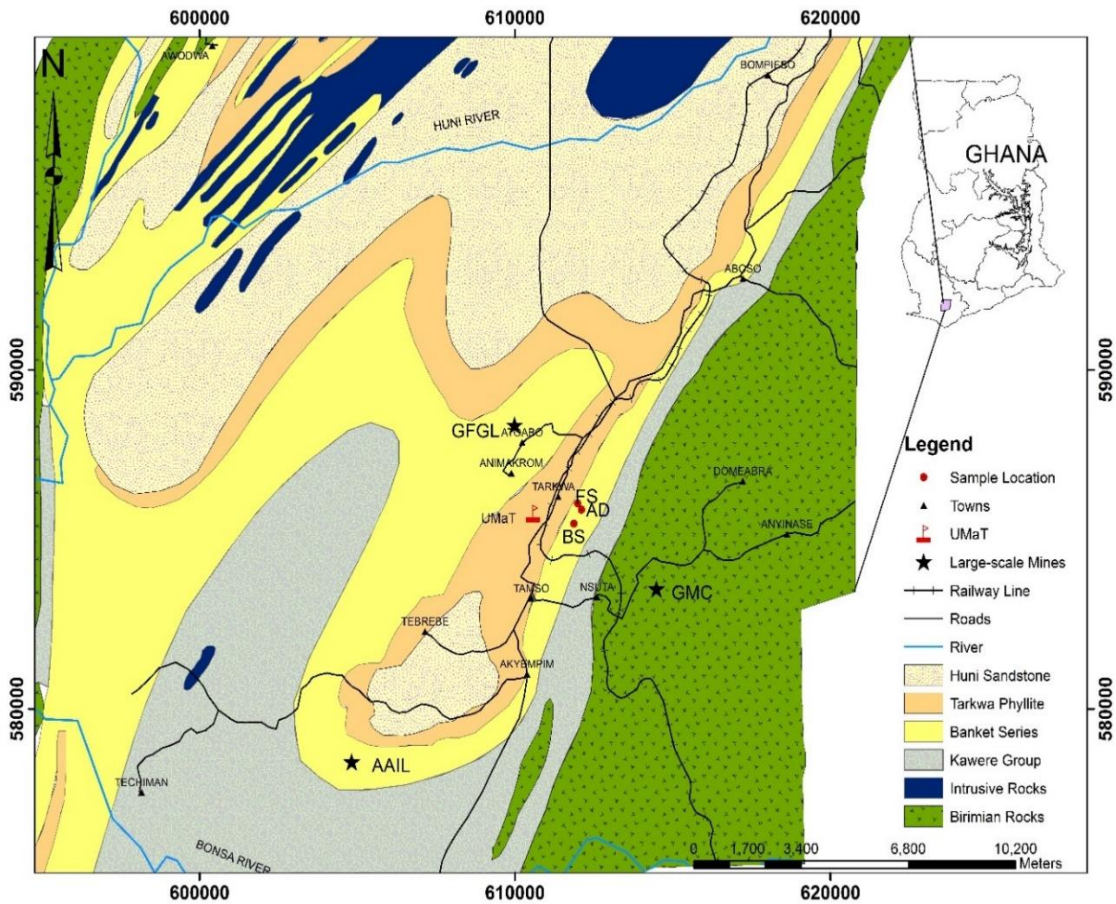

Fig. 1. Geological map of Tarkwa area showing the location of the study area at the Ajopa pit near Anglogold Ashanti Iduaprem Limited (AAIL) mine [5]

The palaeoplacer deposit at the Ajopa pit follows a sequence of mineralized reefs grouped into A, B, C and D in order of age, deposited about the same period. On the western flank of the pit, occurs the oldest reef, Reef A, has matured, well-sorted, rounded quartz pebbles. Reef B is characterized by bigger quartz pebbles, which decrease in size towards Reef C. The matrix of the conglomerate is made up of silt-containing fine-grained quartz with magnetite and hematite [1]. High gold grades correspond with bigger quartz pebbles which are more closely-parked and well-sorted [4]. The Tarkwaian conglomerate is barren of uranium because, at the period of deposition, an oxygenic atmosphere prevented the formation of uraninite placers, but the abundance of detrital hematite probably replaced detrital pyrite of the older uraniferous conglomerates of South Africa, Canada and Brazil [5]. Much of the hypotheses on gold mineralization in the Tarkwaian Group connect with the texture of pebbles [5,2,4]. Though the matrix in the conglomerate holds gold, no work has been done to relate matrix texture to gold grade. This paper highlights the relationship between matrix grain sizes in the conglomerate at the Ajopa pit in the Tarkwaian Group to gold grades.

The Ajopa pit at AngloGold Ashanti Iduapriem Limited (AAIL) mine is located within the Tarkwaian Group. The Tarkwaian forms part of the West African craton, which covered to a large extent, the Birimian volcanic rocks and metasedimentary rocks. The mine is located at Tarkwa, in the Western Region of Ghana, about 85 km north-west of Takoradi and 240 km west of Accra. Accessibility of the mine is by a 6 km unpaved road south of Bankyim near Tarkwa (Fig. 1).

The Birimian Supergroup, underlying the Tarkwaian Group consists of metamorphosed lava and pyroclastic rocks. It contains abundant greywacke, phyllites and intrusive rocks. As a result of deformation and greenschist facies of metamorphism, the rocks are greenish grey and contain notable gold, associated with a quartz vein and sulfide mineralization [1].

The Tarkwaian Group consists of a thick sequence of clastic metasedimentary rocks, which have suffered low-grade regional metamorphism, sheared and affected by hydrothermal alteration. Higher grades are common and often found at the contact with intrusive rocks [1]. The Tarkwaian Group subdivided into four main rocks in order of age is presented in Table A [5].

The basal Kawere conglomerate is polymictic, poorly sorted and matrix supported conglomerates, which contain no economic gold mineralization (generally <50 ppb). Gold mineralization occurs in the Banket Series, which is composed of stacked fluvial sedimentary rocks developed within a braided river system. It is essentially an accumulation of high energy, coarse clastics, represented by conglomerates, grits, and quartzites, which have suffered greenschist facies metamorphism. The deposit, which occurs in a sedimentary sequence, can be described as palaeoplacer, in which gold was deposited simultaneously with the sediments. This is similar to deposits found in the Witwatersrand of South Africa which is Achaean to Early Proterozoic (3100 – 2200 million years), and the Jacobina Series (Precambrian age) in Brazil. The Witwatersrand is of oligomictic and mature conglomerate beds in a thick sequence of less mature conglomerate and sandstone, deposited on Archean granite-greenstone. Locally, basal rocks are volcanic rocks and thick sedimentary sequences, such as Superior-type iron formation. Pebbles of quartz vein and chert are well-rounded, well-sorted and well-packed. Usually, the matrix is composed of quartz, mica, chlorite, pyrite and fuchsite. The mineralogy of the deposit is quartz, gold, pyrite, uraninite, brannerite, zircon, chromite, monazite, isoferroplatinum, and sperrylite. Middle Proterozoic (Tarkwaian) and Phanerozoic

Table A. Stratigraphic succession of the Tarkwaian group [5]

Series	Thickness (m)	Composite lithology
Huni Sandstone	1370	sandstone, grits, quartzite, phyllite (Dompim type)
Tarkwa Phyllite	120 – 400	phyllites, chlorite, sericite schist
Banket Series	120 – 160	quartzite, grits breccia, and banket conglomerates
Kawere Conglomerate	250 – 700	sandstone, quartzite, grits and conglomerates

occurrences have only traces of pyrite, but no uraninite. Jacobina palaeoplacer deposits are auriferous oligomictic, pyritic conglomerates and chaotic breccia layers of pale green quartzite, pelitic schist with conspicuous porphyroblasts of andalusite, garnet and well bedded micaceous quartzite [6]. In the Tarkwaian Group, all known gold mineralizations are found within the matrix that binds pebbles together in the conglomerates. Gold sizes range between 0.002 mm and 0.50 mm and are related to size and packing of the quartz pebbles [1]. Hence the bigger and more pebbles present, the higher the gold grade.

The upper stratigraphic limit of this zone marked by the hanging wall quartzite, siliceous and metamorphosed sandstones of buff colour, exhibits well-developed cross-bedding marked by hematite and black sand. The hanging wall quartzite also contains thin discontinuous grit inter-beds. Dikes and sills of doleritic affinity frequently intrude deformed zones [7,5].

Gold mineralization occurs within four reefs and is unrelated to metamorphic and hydrothermal alteration. The four reefs referred to as A, B, C, and D, which are equivalent to Sub-basal, Basal (or Main), Middle, and Breccia Reefs respectively. Mineralogical studies indicate that the grain size of native gold particles range between 2 and 5 microns, and trace sulfides (mainly pyrites), are not associated with gold [1]. Gold may occur as inclusions in late pyrites, which found in the proximity of veins, and so replacement overgrowths of hematite and magnetite preceded intrusion of dikes [4].

At the Tarkwa area, gold mineralization occurs within eight specific blocks namely, Block 1, Block 2, Block 3, Block 4, Block 5, Block 6 (Ajopa), Block 7 (Teberebie), and Block 8 (Awunaben). In Block 1, the deposit is composed of a single composite of C and D reefs. At the eastern end of Block 2, the single composite reef gives way to multiple zones (A, B, C, and D), which extends further west into Block 3, where there are up to four specific zones of the ore. The A, B, C, and D reefs also occur at Blocks 4, 5, 7 and 8. Although four zones are recognizable at Block 6 (Ajopa), only the B and C reefs are economic. They are narrow, steep and adjoin the Kotraverchy deposit at Goldfields Ghana Limited [8].

Gold deposits associated with quartz-pebble conglomerates are the world's largest source of gold, supplying more than fifty percent of the world's gold [9]. The Banket conglomerate mineralization of the Tarkwaian Group is believed to have originated from erosion and subsequent deposition of Birimian gold-bearing rocks [10]. These early mature gravels covered the area to the east of the main basin. Subsequent downward movement along the western boundary resulted in a new cycle of erosion, with re-working of the easternmost quartz gravels re-transported towards the west by large alluvial fans with a network of braided river channels [10].

The Banket Series, which overlies the Kawere, is composed of grey sericitic grit and quartzites with a middle zone of cross-bedded conglomerate and breccia. The matrix consists of quartz pebbles and black sand of mainly hematite with some ilmenite, magnetite, and rutile. Minor constituents are sericite, chlorite, epidote, tourmaline, zircon, garnet, and gold [1]. The Banket Series is succeeded by relatively thin Tarkwa Phyllite (approximately 150 m thick), followed by the very thick (up to about 1500 m) Huni Sandstone. The 'basal' or B conglomerate in the Banket Series usually contains the best gold values, but the overlying conglomerates also contain substantial gold. Interbedded quartzites frequently contain low gold values. On the eastern margin of the Tarkwa Syncline, where most of the underground mining is concentrated, the banket conglomerates are comparatively thin (often less than 1 m) and thicken towards the west [2]. 50% of gold size is within 1-10 µm, with maximum diameter up to 120 µm [4]. Gold also occurs as inclusions in late replacement pyrites [11]. The percentage of gold recovery ranges from 89.6% to 99.2%, with lime consumption ranging from 1.0 to 1.5 kg/t [12].

Rocks similar to the Birimian Supergroup of the West African craton also occur in the Amazonian and Sâo Franciscan cratons of Guyana and Brazil [13]. In southwestern Ghana, it outcrops as northeasterly trending metavolcanic rocks, earlier referred to as Upper Birimian, interbedded with metasedimentary rocks previously referred to as Lower Biriman [14,6]. On the other hand, [15,16] were of the view that the metasedimentary rocks were younger than the metavolcanic rocks. Later [17] supported the view of [18] and [19] that metasedimentary rocks and metavolcanic rocks are synchronous in age and form a lateral facies. The metasedimentary rocks are metamorphosed siltstones, greywackes, and tuffs, which contain chemical sediments of manganese and carbonaceous material, while the metavolcanic rocks are tholeiitic basalts. Volcaniclastic rocks are interbedded [17]. Sm-Nd ages show that Birimian volcaniclastic rocks could have been derived from the volcanic rocks [20]. Nd-Sm and U-Pb radiometric dating show that the volcanic rocks were deposited between 2240 and 2186 Ma whereas the metasedimentary rocks deposited between 2130 and 2116 Ma [21,22]. Four types of granitoids intrude the Birimian. Sedimentary basin granitoids (previously called Cape Coast type, G1) are composed of quartz diorites, tonalities, and rarely granites all with biotite as the representative ferromagnesian mineral, sedimentary basin granitoids of the Winneba type, which are commonly foliated, are mainly adamellites intruded by granites. Belt granitoids are unfoliated, quartz diorite, tonalite, characterized by hornblende with some biotite in felsic members [17]. U-Pb dating of 2172±2 Ma to 2179±2 Ma for belt granitoids and 2088±1 Ma to 2116±2 Ma for basin granitoids for younger belt granitoids [20]. The belt granitoid is 60 to 90 Ma older than the basin granitoids [23]. Bongo granitoids, which are K-rich containing pink porphyroblastic alkali feldspar, intrude Tarkwaian sedimentary rocks in the Bole-Navorongo belt [17]. Dikes of doleritic composition intrude the Birimian Supergroup and Tarkwaian Group [6,1].

According to [24,25,23,26], the Birimian Supergroup and Tarkwaian Group were deformed progressively during a single phase followed by a second deformation concentrated along basin-belt contacts. Eruption of volcanic rocks, emplacement of older granitoids and metamorphism occurred in Eburnean 1 event dated between 2240 and 2150 Ma, and Eburnean 2 orogeny involved the Birimian and Tarkwaian Group between 2130 and 2116 Ma [27]. The second major orogeny deformed and metamorphosed both the Birimian and Tarkwaian rocks to lower greenschist facies [28]. According to [29], amphibolite facies of metamorphism is in proximity to granitoid intrusives. The contacts may be unfoliated, fine-grained with disseminated sulfides that are gold-bearing. The regional pervasive NE-striking structural grain of Birimian and Tarkwaian rocks was possibly related to the Eburnean 2 orogeny [28]. Quartz veins commonly are associated with shear zone mineralization in the Birimian Supergroup [30,31,27]. According to [17], quartz veins (cherts) carry the highest gold grade particularly those that contain sulfides, followed by carbonaceous schists with granitoids being the lowest. The main gold mineralizations are the quartz-vein type and disseminated-sulfide type. Gold-bearing quartz veins at Obuasi are parallel to bedding, S1 and S2 and hence many are folded [26]. Usually fractured white, smoky, bluish or grey to black, quartz veins are richer in microscopic gold [32].

2. MATERIALS AND METHODS

Borehole core from the Ajopa pit was logged from 5 m to 105 m for textures of quartz pebbles in conglomerate such as grain size, grain shape, sorting, packing, and mineral composition. The determination of gold grades of the samples was by fire assay at the SGS Laboratory in Tarkwa, Ghana. The rocks, crushed with a jaw crusher, were also ball milled and panned to obtain the concentrate. To commence digestion process, 1000 mg of concentrate was measured into a beaker and subsequently filled with 5 ml of HNO_3 and 15 ml of HCl. A beaker containing the mixture was placed on a hot plate and allowed to boil for about 10 minutes, sampled, and allowed to cool after filtration. It was washed into a volumetric flask and filled with 100 ml of distilled water. The determination of gold in solution was by atomic absorption spectrometry at the SGS Laboratory, Tarkwa in Ghana, which meets ISO/IEC 17025 standard conformity [33].

3. RESULTS AND DISCUSSION

3.1 Results

Conglomerate at the Ajopa pit in the drill core was grey, coarse-grained with quartz pebbles ranging from 8.50 mm to 30.50 mm, well-sorted with the matrix containing quartz grains and ore minerals (Fig. 2). The matrix quartz grains which ranged from 0.60 mm to 4.35 mm, were sub-rounded and closely packed. In the thin section, the coarser pebbles were too big for the field of observation. The matrix quartz was, subrounded, weakly elongated, moderately sorted, and recrystallized into medium grains with triple junctions and are marked by sericite and chlorite, and fine granular quartz (Fig. 3).

Table 1 shows the average diameter of bigger pebbles (8.50 mm to 30.50 mm) and corresponding gold grades grouped into 0.01 to 0.70 g/t (as a low grade) and 0.70 to 3.67 g/t (as high grade). Table 2 shows larger grains in the matrix (0.60 mm to 4.35 mm). Graphs were plotted for the gold grade (g/t) versus average diameters of bigger pebbles (mm) or larger grains in the matrix (Figs. 4 and 5 respectively). Table 3 shows diameters of larger grains in the matrix, and corresponding high grades (g/t); scatter graph of high grade (g/t), and higher grades versus these larger grain diameters (mm) were also plotted (Figs. 6 and 7 respectively). Tables 4 and 5 show the diameters of larger grains in the matrix (mm), and corresponding low grades or high grades respectively (Figs. 8 and 9 respectively).

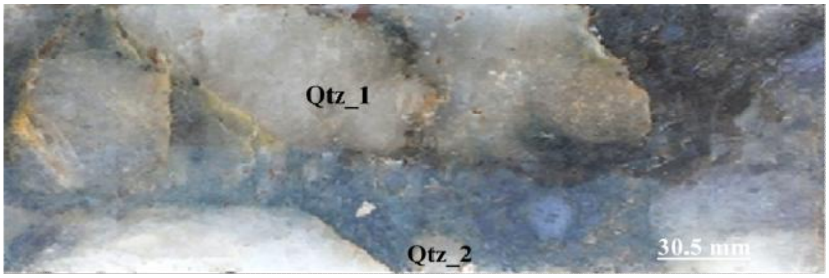

Fig. 2. Photograph of auriferous quartz pebble conglomerate showing bigger pebbles (Qtz_1) and larger grains (Qtz_2) in matrix

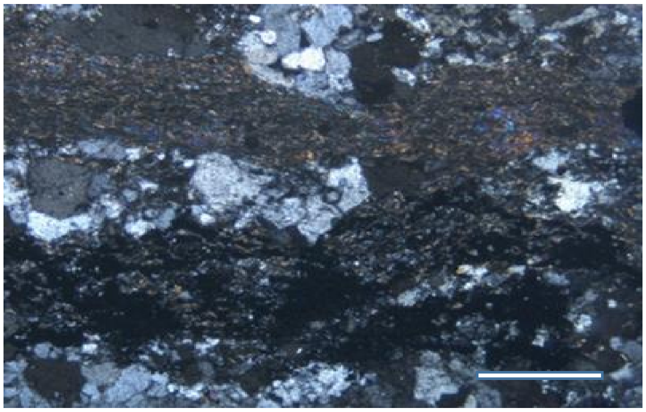

Fig. 3. Photomicrograph of banket conglomerate showing medium-grained quartz (Qz) (recrystallized) and marked by fine quartz, sericite and opaque minerals (Opq) (crossed nicols)

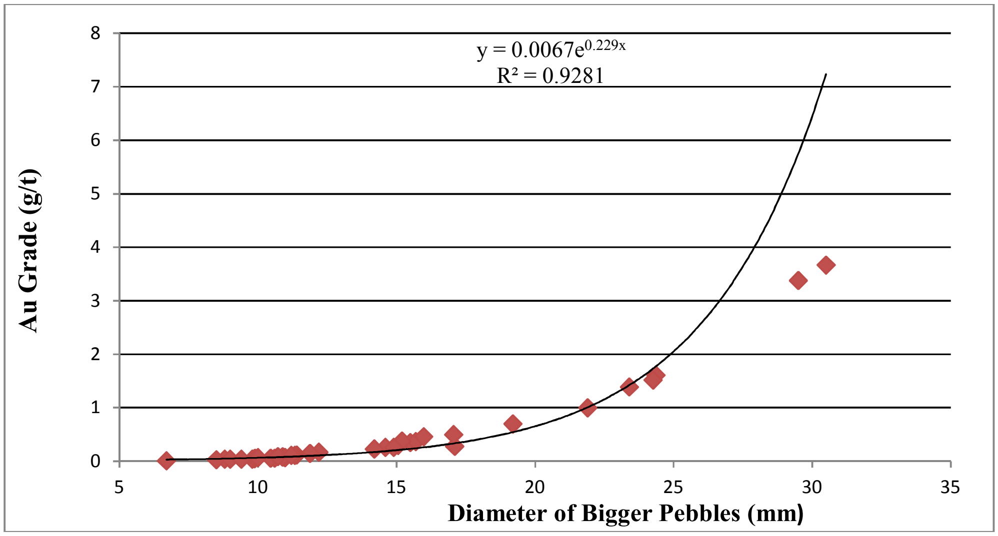

Fig. 4. Scatter plot of bigger pebble diameter against grade

Table 1. Diameter of bigger pebbles and corresponding grades for the borehole

Sample ID	Depth (m)	Average diameter of bigger pebbles (mm)	Grade (g/t)	Sample ID	Depth (m)	Average diameter of bigger pebbles (mm)	Grade (g/t)
21	31.17	10.60	0.06	53	77.00	09.80	0.04
22	32.00	08.80	0.04	54	78.00	10.72	0.09
23	33.00	09.88	0.05	55	79.00	15.98	0.46
24	34.00	10.98	0.07	56	80.00	21.90	1.00
25	35.00	15.06	0.30	57	81.00	29.50	3.38
26	36.00	15.50	0.35	58	82.00	30.50	3.67
27	37.00	14.60	0.26	59	83.00	23.40	1.39
28	38.00	19.20	0.70	60	84.00	17.10	0.28
29	39.00	24.36	1.61	61	85.00	24.26	1.52
30	40.15	12.20	0.17	62	86.00	17.06	0.50
31	41.00	10.90	0.08	63	87.29	11.33	0.11
32	42.00	11.88	0.15	64	97.26	09.00	0.04
33	43.00	14.20	0.23	76	98.00	11.20	0.11
35	44.00	15.70	0.37	77	99.00	09.90	0.06
36	44.91	16.70	0.01	78	100.0	15.50	0.38
49	73.27	10.88	0.08	79	101.0	14.90	0.26
50	74.00	10.46	0.06	80	102.0	09.40	0.04
51	75.00	11.40	0.12	81	103.0	10.00	0.07
52	76.00	08.50	0.03				

Table 2. Diameter of larger grains in the matrix and corresponding grades for the borehole

Sample ID	Depth (m)	Larger grains in matrix (mm)	Grade (g/t)	Sample ID	Depth (m)	Larger grains in matrix (mm)	Grade (g/t)
21	31.17	1.49	0.06	53	77.00	0.85	0.04
22	32.00	0.98	0.04	54	78.00	1.80	0.09
23	33.00	1.40	0.05	55	79.00	2.90	0.46
24	34.00	1.58	0.07	56	80.00	3.30	1.00
25	35.00	2.50	0.30	57	81.00	4.21	3.38
26	36.00	2.66	0.35	58	82.00	4.35	3.67
27	37.00	2.34	0.26	59	83.00	3.61	1.39
28	38.00	3.10	0.70	60	84.00	2.50	0.28
29	39.00	3.88	1.61	61	85.00	3.79	1.52
30	40.15	2.10	0.17	62	86.00	3.10	0.50
31	41.00	1.61	0.08	63	87.29	2.06	0.11
32	42.00	1.90	0.15	64	97.26	0.70	0.04
33	43.00	2.29	0.23	76	98.00	2.00	0.11
35	44.00	3.02	0.37	77	99.00	1.30	0.06
36	44.91	0.60	0.01	78	100.0	2.98	0.38
49	73.27	1.80	0.08	79	101.0	2.30	0.26
50	74.00	1.37	0.06	80	102.0	0.98	0.04
51	75.00	2.22	0.12	81	103.0	1.60	0.07
52	76.00	0.90	0.03				

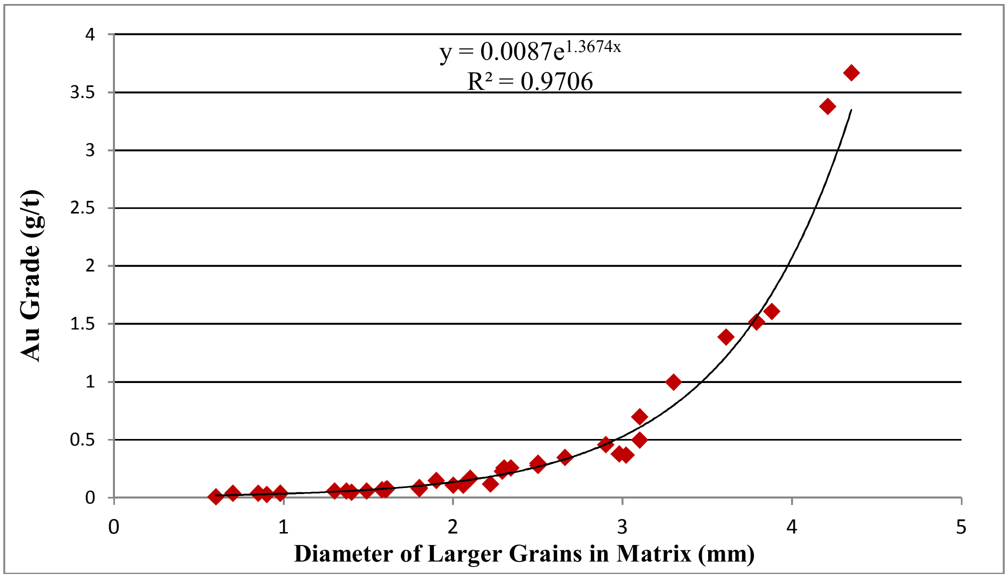

Fig. 5. Scatter plot of the larger grains in matrix against the grade

Table 3. Diameter of bigger pebbles (mm) and corresponding high grades in the borehole

Sample ID	Depth (m)	Average diameter of bigger pebbles (mm)	Grade (g/t)
28	38	19.20	0.70
29	39	24.36	1.61
56	80	21.90	1.00
57	81	29.50	3.38
58	82	30.50	3.67
59	83	23.40	1.39
61	85	24.26	1.52

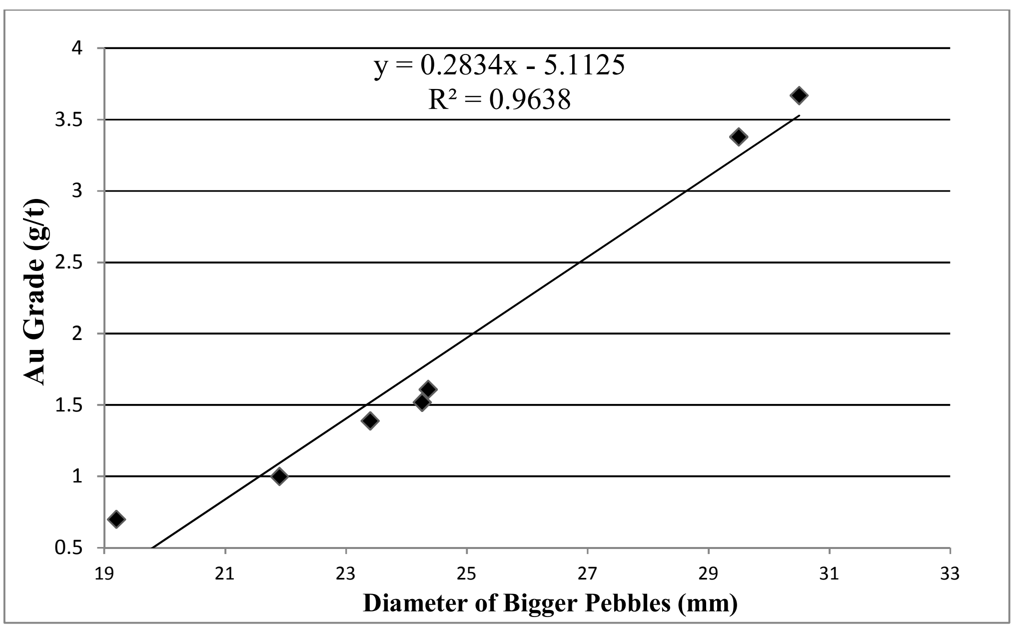

Fig. 6. Scatter plot of the bigger pebbles against high grade

Table 4. Average diameter of bigger pebbles and corresponding low grades in the borehole

Sample ID	Depth (m)	Average diameter of bigger pebbles (mm)	Grade (g/t)
21	31.17	10.60	0.06
22	32.00	8.80	0.04
23	33.00	9.88	0.05
24	34.00	10.98	0.07
25	35.00	15.06	0.30
26	36.00	15.50	0.35
27	37.00	14.60	0.26
30	40.15	12.20	0.17
31	41.00	10.90	0.08
32	42.00	11.88	0.15
33	43.00	14.20	0.23
35	44.00	15.70	0.37
36	44.91	6.70	0.01
49	73.27	10.88	0.08
50	74.00	10.46	0.06
51	75.00	11.40	0.12
52	76.00	8.50	0.03
53	77.00	9.80	0.04
54	78.00	10.72	0.09
55	79.00	15.98	0.46
60	84.00	17.10	0.28
62	86.00	17.06	0.50
63	87.29	11.33	0.11
64	97.26	9.00	0.04
76	98.00	11.20	0.11
77	99.00	9.90	0.06
78	100.0	15.20	0.38
79	101.0	14.90	0.26
80	102.0	9.40	0.04
81	103.0	10.00	0.07

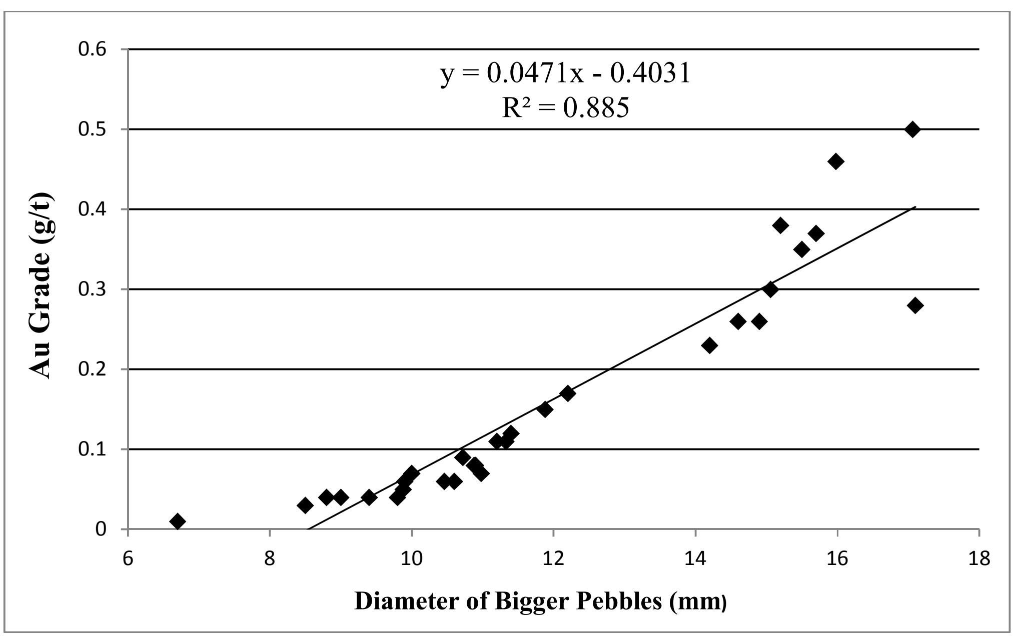

Fig. 7. Scatter plot of bigger pebbles versus low grade

Table 5. Diameter of larger grains in the matrix (mm) and corresponding high grades in the borehole

Sample ID	Depth (m)	Larger grains in matrix (mm)	Grade (g/t)
28	38	3.10	0.70
29	39	3.88	1.61
56	80	3.30	1.00
57	81	4.21	3.38
58	82	4.35	3.67
59	83	3.61	1.39
61	85	3.71	1.52

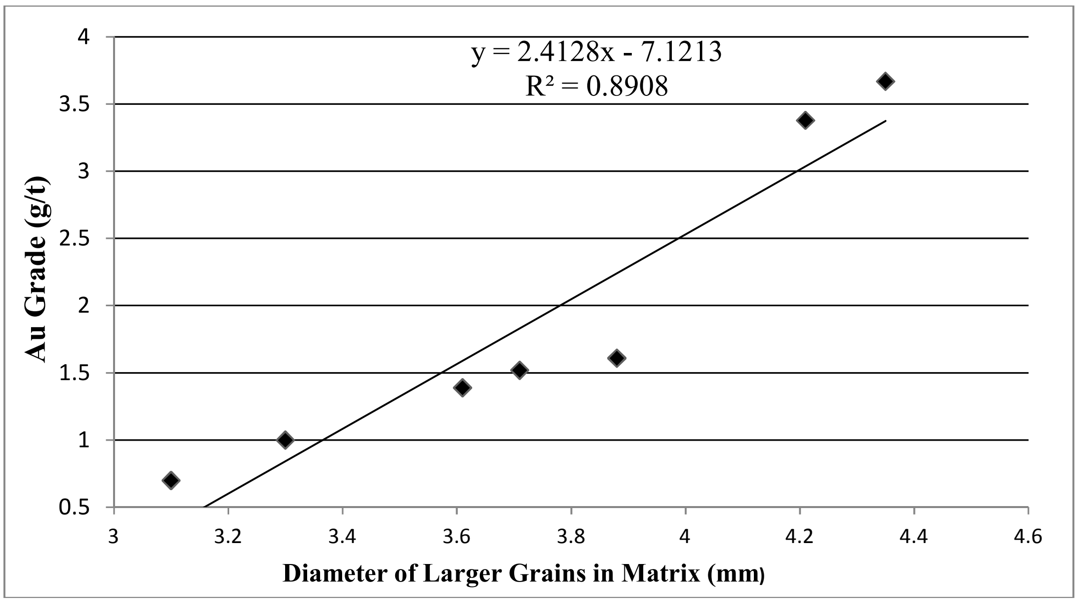

Fig. 8. Scatter plot of the larger grains in the matrix against high grade

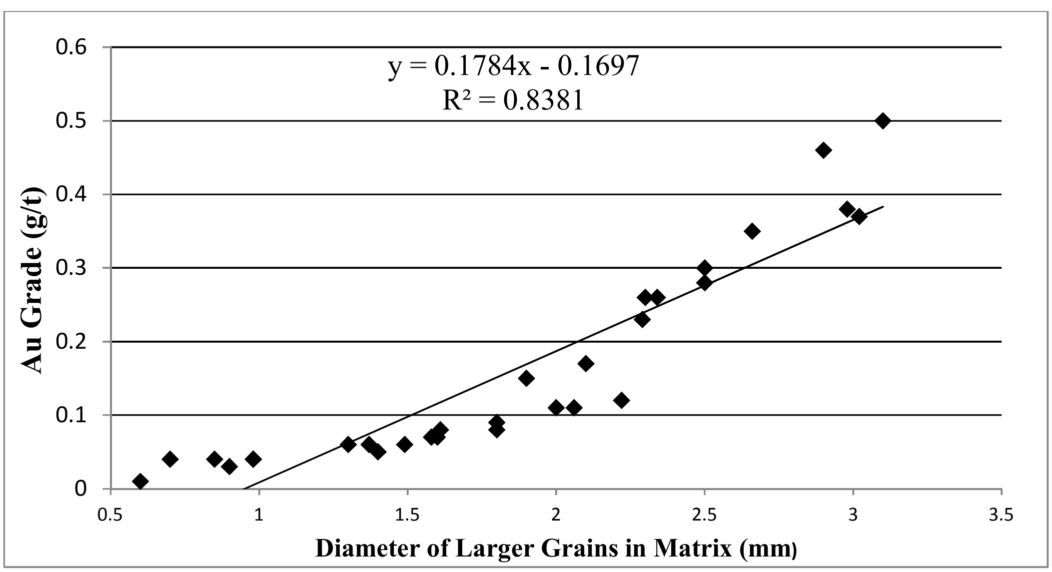

Fig. 9. Scatter plot of larger grains in the matrix against low grade

Table 6. Average diameter of larger grains in matrix and corresponding low grades in the borehole

Sample ID	Depth (m)	Larger grains in matrix (mm)	Grade (g/t)
21	31.17	1.49	0.06
22	32.00	0.98	0.04
23	33.00	1.40	0.05
24	34.00	1.58	0.07
25	35.00	2.50	0.30
26	36.00	2.66	0.35
27	37.00	2.34	0.26
30	40.15	2.10	0.17
31	41.00	1.61	0.08
32	42.00	1.90	0.15
33	43.00	2.29	0.23
35	44.00	3.02	0.37
36	44.91	0.60	0.01
49	73.27	1.80	0.08
50	74.00	1.37	0.06
51	75.00	2.22	0.12
52	76.00	0.90	0.03
53	77.00	0.85	0.04
54	78.00	1.80	0.09
55	79.00	2.90	0.46
60	84.00	2.50	0.28
62	86.00	3.10	0.50
63	87.29	2.06	0.11
64	97.26	0.70	0.04
76	98.00	2.00	0.11
77	99.00	1.30	0.06
78	100.0	2.98	0.38
79	101.0	2.30	0.26
80	102.0	0.98	0.04
81	103.0	1.60	0.07

3.2 Discussion

Banket conglomerate, which is a palaeoplacer gold-bearing deposit in the Tarkwaian Group, is also found at the Ajopa pit near the Tarkwa area in Ghana. The conglomerate, which is the richest gold-bearing unit of the Tarkwaian Group according to [2], was deposited in an alluvial fan, with evidence of sedimentary structures of current bedding, with subrounded to rounded, moderately sorted, and medium packed pebble textures. These textures are due to distal transport from the Birimian Supergroup [34]. Later, [35] supported this with the observation of high-density CO_2 inclusions of primary and pre-sedimentary origin, which were absent in post-depositional quartz veins in the Tarkwaian Group. High-density characteristics constrain their source to be the Birimian gold-bearing quartz veins. These quartz pebbles are absent in the basal unit of the Tarkwaian Group, which is the Kawere conglomerate. The Kawere conglomerate, which contains a major tholeiitic basalt pebble component, contains virtually no gold (Au ≤ 50 ppb) [4]. According to [17], quartz veins (cherts) carry the highest gold grade, particularly the variety associated with sulfides, followed by carbonaceous schists, with granitoids being the lowest in gold-bearing rocks. The main gold mineralizations in the Birimian Supergroup are the quartz-vein type, with shear zone mineralizations commonly associated with quartz veins [30,31,27]. Usually fractured white, smoky, bluish or grey to black quartz veins are richer in gold, which is microscopic [32]. Native gold occurs along cracks and grain boundaries of arsenopyrite, with sulfosalts along grain boundaries or precipitated in quartz fractures in disseminated-sulfide type gold mineralizations [36]. According to [37], arsenopyrite form 60-94% of the ore mineralogy, and associated with pyrite, pyrrhotite, marcasite and sfalerite. They are proposed of a synchronous, two-stage quartz vein and sulfide mineralization, which embraces sulfidization of country rocks with a distinct mineralogical and geochemical signature (As, S, Au), and emplacement of gold quartz veins, characterized by Ag-rich gold and Pb, Cu, Sb, Zn-sulfides. On the age of gold mineralization in the Birimian, syntectonic gold mineralization in the Birimian Supergroup was estimated from detrital zircon in the Tarkwaian conglomerate, as 2132 Ma and age determined from late kinematic basin granitoid was 2116 Ma [37]. Early sources of gold for the Tarkwaian, possibly Eoeburnean mineralized quartz veins in southwestern Ghana are suggested by [2] and [1]. An Eoeburnean gold source is also in agreement with palaeo-flow indicators that suggest the Banket conglomerate derivation from Birimian schist and volcano-sedimentary rocks to the east of the Ashanti Belt [38].

The pebbles in the banket conglomerate at the Ajopa pit are made up of quartz, either milky or vitreous whitish grey, coarse-grained, rounded, well to moderately sorted, and closely packed with the matrix composed of fine-grained quartz, chlorite, and sericite with magnetite and hematite [2,4]. According to [4], various quartz pebbles dominate, with a mean of 95% to 97%, minor chert with traces of metavolcanic rock and foliated quartzite. The pebble sizes vary with depth and range from 8.50 to 30.50 mm. The larger pebble sizes found in the matrix, ranging from 0.60 to 4.35 mm (Tables 1-6). The bigger these larger quartz pebbles are, the higher the gold grade (Table 5, Fig. 7). Though these bigger quartz pebbles recrystallized with triple junctions into medium grains, the secondary quartz grains aggregate and bounded by sericite and chlorite (Fig. 3). The conglomerate grades were grouped into low grade (below 0.01 g/t to 0.70 g/t), and high grade (above 0.70 g/t) (Tables 3 and 4 respectively). From Fig. 4, gold grade increases with increasing diameter of bigger pebbles, and beyond a pebble size of 19.20 mm, higher grades over 0.70 (g/t) occur. Correlation between the average diameter of larger grains and gold grade was also very strong (correlation coefficient, r = 0.96). This closely corresponded to the correlation between the average diameter of bigger pebbles in the matrix and gold grade (correlation coefficient, r = 0.94) (Fig. 7). As with the bigger pebbles, gold increased significantly beyond 0.70 (g/t), above 3.0 mm pebble diameter in the matrix (Fig. 5). The gold grade linked to quartz pebble size was also related to larger grains in the matrix (Figs. 4 and 5). These results relatively apply to higher and lower gold grade groupings (Tables 3 to 6; Figs. 6 to 9).

4. CONCLUSION

This study aimed at finding a complementary guide to recognize relatively high gold grades of the palaeoplacer banket conglomerate of the Tarkwaian Group in southwestern Ghana, West Africa, using pebbles in the matrix. The conglomerate, which is the main gold-bearing unit of the Tarkwaian Group deposited with sedimentary structures of current bedding and pebble textures. In the banket conglomerate at the Ajopa pit, rounded, closely packed quartz pebbles and cobbles, which are matrix supported with larger pebble sizes that range from coarse sand to pebble sizes occur. The study highlights that there is a relationship between matrix pebble grain sizes in the conglomerate and gold grades. The findings outline alternative criteria for identifying higher grade ore which up till now had been linked with the bigger pebbles. Gold grades in the conglomerate increase with increasing pebble size particularly above 19.20 mm, where higher grades over 0.70 (g/t) turned out in the analyzed portion at the Ajopa pit. Gold grades also increase with increasing diameter of larger quartz grains in the matrix, especially above 3.00 mm pebble diameter.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/24043