Gold in Plant: A Biogeochemical Approach in Detecting Gold Anomalies Undercover- A Case Study at Pelangio Gold Project at Mamfo Area of Brong Ahafo, Ghana*

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Abstract

Many plants have the ability to take up gold from soils and accumulate them in their tissues. Their concentrations and distributions reflect the nearby gold deposits masked by complex regolith. The 50 vegetation samples collected at Pelangio Tepa concession recorded low and subtle gold (Au) concentrations of 0.2 to 10.4 ppb at Pokukrom target, 0.3 to 28.3 ppb at Nfante East target and 0.1 to 1.7 ppb at Subriso target. Each target area had different concentration populations enough to distinguish the anomalous areas from the background contrary to Au-geochemical expressions derived from the gold in soils. So many uncertainties were placed on the soil-Au-geochemistry because the defined anomalies were not strong and generally appear patchy, weak and subtle that led to the assumption of no associated bedrock mineralisation. The gold in plant samples confirmed the Pokukrom anomaly that has been drilled and known to relate to underlying mineralisation. Much better and robust anomaly was defined by the biogeochemical Au data in plants sampled and analysed for Au at Nfante East target and isolated high patchy anomalies were identified at Subriso area. The case study at Pelangio Mamfo project reveals and recommends the significant application of biogeochemistry in mineral exploration particularly in the field of gold prospecting at the regional exploration stage and endorses it as being practically feasible in regolith-dominated terrains where regolith-landform modifications may impact on the true geochemistry in anomaly delineation.

Keywords: Biogeochemistry, Regolith-Dominated-Terrain, Plant, Gold, Pelangio

1 Introduction

Weathering history complexities in many terrains impact on geochemical parameters used to detect mineral anomalies in surface soils. Plants with deep tap roots are able to penetrate beyond the complex regolith into the weathered materials and hence uptake signatures of the underlying minerals which are hosted in several parts of the tree (Erdman and Olson, 1985; Girling and Peterson, 1980).

Deeply weathered profiles, commonly ferruginous towards the surface, although in places buried by transported overburden, are widespread in Sefwi and the Lawra Birimian belts of Ghana. These situations are as a result of weathering and geomorphic history that can be simple or complex (Arhin *et al*., 2015). Where the weathering history is simple the geochemical expressions in surface samples relate to the underlying mineralisation but become complicated with terrains characterised by complex weathering histories. The weathered profiles which in this context will be referred to as the "regolith" in all climatic regions generally consist of many or all of the following horizons (from the base): saprock, saprolite, plasmic zone, mottled zone, ferruginous and/or aluminous duricrust or gravels, and soil (Anand and Butt, 1988, Costa, 1993; Porto and Hale, 1996; Tardy, 1997; Anand and Paine, 2002). There are many variations in the components of profiles, controlled by factors including lithology, topographic position and climatic history which invariably influence geochemical element concentrations and distribution. Works by Arhin and Nude (2009), Arhin *et al*. (2015) and Arhin and Zango (2015) all suggest the significance of regolith mapping towards successful geochemical exploration.

Nonetheless to discover hidden mineral anomalies particularly gold (Au) requires collecting samples from medium that will present realistic and more representative geochemical expression for the sampled environment. Results from such exploration technique will address the challenges of following geochemical 'false' anomalies where superimposed anomalies are considered as bedrock anomalies. There are testimonies to that, that biogeochemistry in mineral exploration can provide some answers towards our goal of discovering new gold deposit in complex regolith environment. Affam and Arhin (2010) suggested termite mound sampling can supplement soils in looking for gold anomalies.

Further evidence was provided by Arhin and Nude (2010) that termitaria can be used in surficial geochemical surveys and best gold results -125 µm size fractions can be used. The perception that the

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regolith-landforms has evolved and is still evolving made Arhin *et al*. (2015) use termite mound sampling results to identify pathfinder elements for gold exploration. The theoretical foundation of using termitaria is that termites are able to move large amounts of soil material, and thereby bring up anomalous materials from depth to the surface through bioturbation process. Similar attributes can also be assigned to plants as their roots may access buried weathered bedrock and deep groundwater. Sampling plants for metal geochemistry especially in transported overburden areas will contribute to the discovery of gold anomalies in such regolith environments. A survey of root penetration depth indicates that deep roots, especially sinkers, are ubiquitous with >10 m depths regularly reached and confirmed for several species in several climatic settings (Canadell *et al*., 1996).

Theoretically plants do not take up only gold during the mineral uptake by plant roots from the regolith but rather absorbs mineral nutrients as well from the weathered rock and mineralised body for the plant growth and development. The gold expressions obtained from plant barks and shoots are assumed to come from deeper regolith environments and represent undisturbed *in situ* weathered materials. This paper therefore demonstrates the use of biogeochemistry in gold exploration at Mamfo Gold project in southern Ghana.

1.1 Location and Local Geology

The study area is located in southwest Ghana, close to Newmont Ahafo and Kinross Chirano gold deposits. It is approximately 75 kilometres west-northwest of Kumasi, the second largest city in Ghana and approximately 270 kilometres northwest of Accra, the capital of Ghana (Fig. 1).

Local Geology

The Mamfo project is located along the eastern edge of the Paleoproterozoic Sefwi-Bibiani Belt. Along this contact, the belt is dominated by basalt and dolerite, with lesser gabbro, tonalite and diorite (Kesse, 1985). However, in the project area, the Sefwi-Bibiani Belt is underlain primarily by mafic metavolcanic, metasedimentary, volcanoclastic and granitoids, which is significantly simplified on the regional geological map of Ghana (Hirde *et al*., 1996, Fig. 2). A major north-northeast–striking fault corridor, approximately three kilometres wide, traverses the east side of the property (Leube *et al*., 1990). This fault corridor serves as the regional contact between the greenstone volcano-sedimentary package to the west and a regional synvolcanic intrusive to the east (Allibone *et al*. 2004).

Fig. 1 Location of Study Area shaded Red

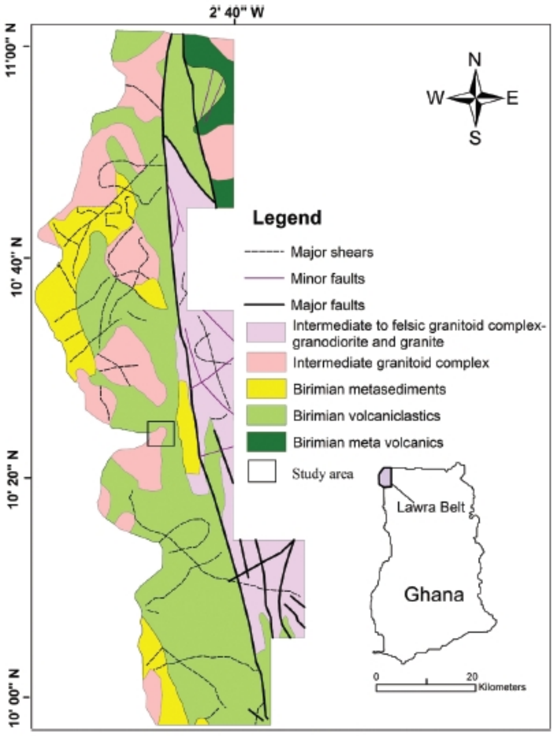

Fig. 2 Regional Geology of Study Area and the Surrounding (modified after Arhin *et al*., 2016)

Common mineralization and structural features found at some places particularly in the greenstone volcano-sedimentary rocks are wide zones of fracture-controlled quartz-sericite-carbonate-pyrite alteration overprinting an earlier phase of hematite alteration that are hosted typically in sheared and locally brecciated, altered granitoids and to a lesser extent brecciated hematite-altered mafic meta-volcanic rocks.

1.2 Uptake of Gold by Roots to Plant Barks and Shoots

Girling and Peterson (1980) work suggest plant roots have an ability to take up gold from soils and accumulate them in several parts of the plant. It is possible that plant secretions from the root systems aid the uptake of gold from the soil and that cyanide in some plants, in particular, render gold sufficiently soluble to enable plants to accumulate the metal. Plants that release cyanides are referred to as hyperaccumulators and those unable to release cyanides are non-hyperaccumulators.

Determination of trees sampled in this study did not investigate to know class of trees that fell within the two classes because the study was just an exploratory survey aimed to define hidden gold anomalies. This needs to be investigated in a future research. However cyanogenic plant species are known to produce free cyanide by hydrolysis of cyanogenic glycosides within their tissues (Girling and Peterson, 1980). This process allows many of the plants transport gold upwards via the macerated tissues of plants. And there are other mechanisms of gold uptake from underlying mineralisation in the regolith to the plants and these depend on chemical factors in the regolith profile or weathered profile. The gold in the soils form compounds with either chloride or cyanide and are taken up as soluble gold by the plant roots (Ryan and Peterson, 2012). The soluble gold species transported by the roots often accumulates in the plant shoots and are not present in the nutrient solution as the plants do not need gold in their food preparation. This thereby point to their possible production in the plant root.

2 Resources and Methods Used

2.1 Fieldwork

Fifty (50) vegetation samples were collected 1 m above the ground surface from the bark of the selected trees (Fig. 3).

Fig. 3 New-Scrapping Outer Skin of Tree Shoot to Collect Tree-Bark Sample (Sapele-Tree)

The dry-outer-skins of the trees were scrapped off until the fresh-inner-tissue is encountered. That was done to avoid possible contaminations from the atmosphere. Nominal slots at the bark of trees from which the cut materials were used as samples had dimensions 3 cm width and 10 cm depth cut round the circumferences of the trees. The 50 tree-bark samples collected were from three different target areas with different gold anomaly potentials. The targets were Pokukrom West, Nfante East and Subriso Main. Unequal amounts of samples were collected at the target areas. The breakdown of samples with respect to the studied targets was 10 samples from Pokukrom West, 14 from Nfante East and 26 from Subriso Main (Figs. 4 and 5).

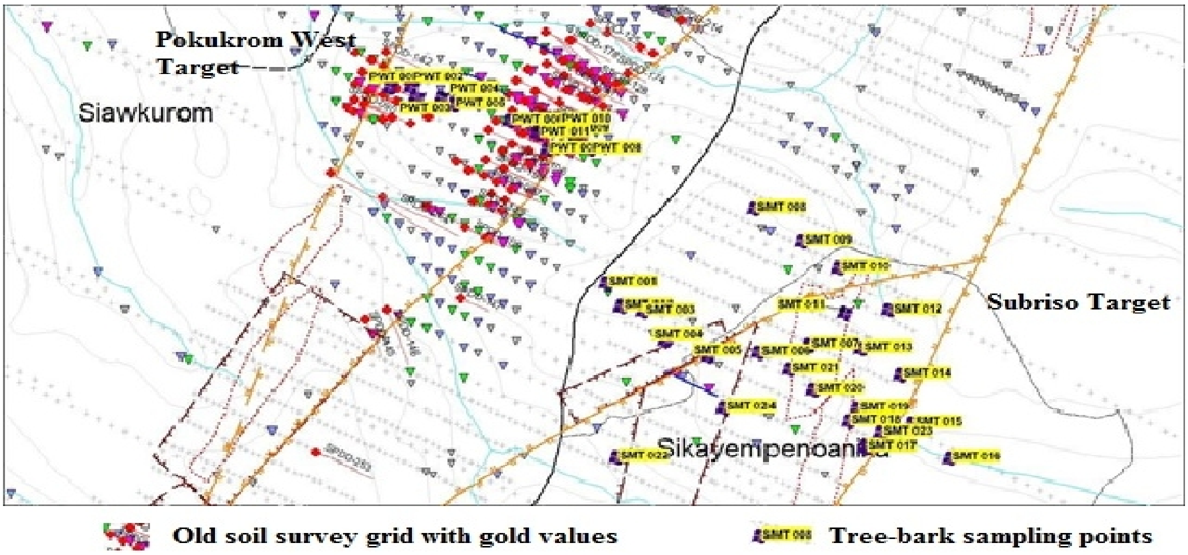

Fig. 4 Distribution points at Pokukrom

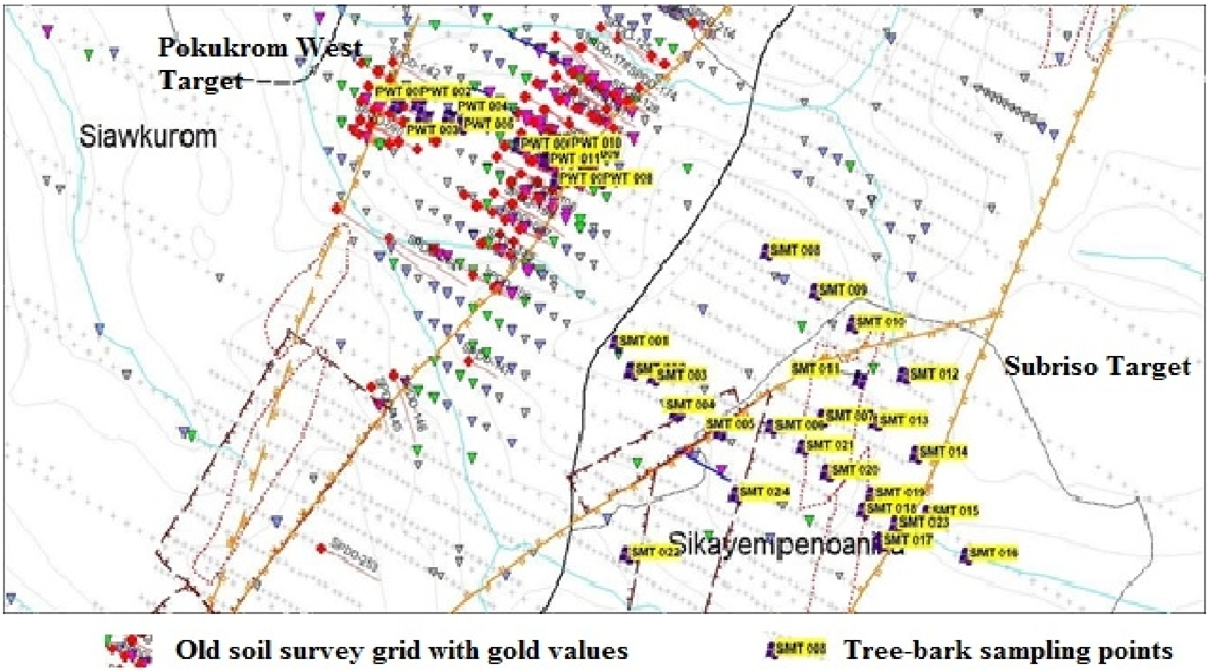

Fig 5 Distribution collars at Nfante

Six duplicates samples were taken from some of the trees and inserted in the batch of samples to the laboratory whose analytical results were used to monitor the quality of the analytical data. No certified sample was included in the study and different temperatures will be applied to examine the most appropriate temperature to result in best gold recovery.

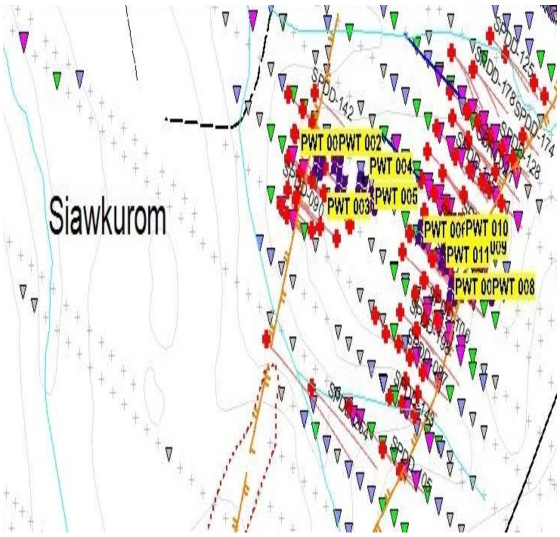

Fig. 6 Distribution collars at Pokukrom

2.2 Sample Preparation and Laboratory work

The raw-field-samples underwent some in-house sample preparation by ashing the field plant samples. This was carried out at the University for Development Studies; Multi-Purpose Laboratory in Navrongo. The sample preparation at the multi-purpose laboratory involved drying the fresh vegetation samples in an oven at a temperature of 105°C overnight. The dried barked samples were pounded to powder to pass through < 2mm mesh size fraction using pestle and mortar. The < 2 mm powdered samples were further sieved to < 125 µm size fraction. A 100 g weight portion of this size fraction were bagged in a Kraft paper, labelled and sent to ALS commercial laboratory in Kumasi. At the geochemical laboratory managed by ALS-Chemex; ME-VEG41A analysis that uses ICP-MS technique and designed by them was employed. Method precision of ± 10-15% on the super trace multi-element analysis expected from the ashed vegetation samples, determined via aqua regia digestion and ICP-AES and ICP-MS analysis were measured and recorded. The method detection limit for gold (Au) is 0.0002 ppm and hence could analyse for super trace elements in the samples.

3 Results and Discussion

The geochemical Au-expressions obtained in the tree-bark-samples though low in concentrations (Table 1) and incomparable to gold expressions normally in surface soil samples in terrains with bedrock mineralisation still seems to be useful in hidden anomaly detection. This technique eliminates nugget gold effects as pertains in the conventional gold exploration of sampling soils and rocks. In this method the plant root absorbs gold upwards to the stem bark and other parts of the plant.

Table 1 The Geochemical Au-Expressions obtained in the Tree-Bark-Samples

SAMPLE ID	GPS COORDINATE NORTH	EAST	ELEVATION	AU ppb	HEIGHT	WIDTH (CM)
SMT 001	755589	579679	253	0.2	12	10
SMT 002	755507	579730	261	0.4	11	10
SMT 003	755488	579804	251	1.6	12	10
SMT 004	755385	579877	261	0.6	12	10
SMT 005	755328	580024	247	0.2	10	10
SMT 006	755341	580198	268	0.4	11	10
SMT 007	755368	580365	273	0.2	12	10
SMT 008	755862	580183	262	1.2	12	10
SMT 009	755742	580340	261	0.4	12	10
SMT 010	755646	580466	254	0	11	10
SMT 011	755483	580488	257	0.8	10	10
SMT 012	755496	580635	248	0	12	10
SMT 013	755354	580543	260	1.3	12	10
SMT 014	755260	580675	255	0		10
SMT 015	755083	580712	249	0.3	11	10
SMT 016	754959	580848	238	0.3	12	10
SMT 017	754959	580848	238	0.28	12	10
SMT 018	755094	580501	256	0	12	10
SMT 019	755138	580532	267	0.7	12	10
SMT 020	755206	580380	268	0	11	10
SMT 021	755280	580296	279	0	11	10
SMT 022	754962	579717	237	0.5	11	10
SMT 023	755051	580609	257	0	12	10
SMT 024	755140	580075	260	1.2	12	10
SMT025	755140	580075	260	1.1	12	10
SMT 026	753701	579999	262	1.7	12	10
SMT 027	753750	579679	275	0.3	12	
SMT028	753750	579679	275	0.25	12	
SMT029	755206	580380	268	0.5	12	
SMT 030	755206	580380	268	0	12	10
NET 001	752162	578417	248	1.1	11	10
NET 002	752183	578502	254	1.36	12	10
NET 003	752212	578625	276	0.7	12	10
NET 004	752062	578583	250	9.4	12	10
NET 005	751991	578722	251	0.3	12	10
NET 006	751974	578881	242	0.4	12	10
NET 007	752060	578499	255	1.12	12	10
NET 008	752013	578435	243	4.3	12	10
NET 009	752374	578319	250	0.7	12	10
NET 010	752348	578487	265	1.6	12	10
NET 011	752265	578508	267	2.83	12	10

There is a school of thought that gold found in plants are adsorbed gold and could be as a result of abiotic process probably from aeolian contamination. However, in sampling the stem barks the outermost skin of the tree is scrapped off. It is believed that any gold particle adsorbed to the surface will be scrapped off during that time. Additionally, sampled trees were of about equal heights and circumference. Similar types of tree species in this exploratory survey ‘Sapele’ were mostly sampled. Geochemical gold expressions obtained were different even for same tree species in and outside the concealed gold mineralisation areas. This research was done at the background that the deep-rooted trees can penetrate the weathered materials and absorbed trace elements including Au if present and will be translocated to the other parts of the tree. The results of gold expressions in the stem bark samples conclusively demonstrate active biogeochemical absorption of Au via the plants roots and their subsequent translocation through the plant tissues.

The biotic process that support the plant roots to mobilise gold upwards is not properly understood at this stage but the lack of nugget effects in the results suggest the uptake of gold by plant roots and the translocation of Au and other elements to the other parts of the plant do so in solution form and not as detrital gold particles. This however confirms the observations by Johnston *et al.* (2013); Lintern (2007) and Eisler (2004) the roots of trees are able to take up gold from the mineralised source rock through the soils to certain parts of plants including the leaves, flowers, foliage and bark of the shoot.

The coincidence and confirmation of biogeochemical samples from tree-barks defining the hidden anomaly demonstrate the uptake of gold at depth by tree-roots even though the biotic mechanisms of Au migration are poorly understood. The gold geochemical results from this study suggests and reaffirms the knowledge that gold can accumulate in plants and as confirmed at Pokukrom tree-bark sample results reveal biogeochemical absorption of Au between tree-roots and the underlying gold mineralisation beyond the complex regolith. So the gold in the tree-bark may be an absorbed gold in solution translocated to other parts of the plant via the root system. Plant in the process of obtaining nutrients for its growth take up gold which is considered probably toxic to plants and in so doing expel or move the contain gold absorbed by the plant roots to its extremities (Girling and Peterson, 1980) (such as leaves) or in preferential zones (Gardea-Torresdey *et al* (2002) within cells in order to reduce deleterious biochemical reactions. As seen in Fig. 3 bark of trees sampled did not include the outermost skins of the plant where adsorbed gold may tend to reside as they were scrapped off until the inner fibrous tissue of the plant is reached. The portions collected as samples can be said to be devoid of gold particles adsorbing onto the plant surfaces and thus rule out any incidence of aeolian contamination. The 55 plant samples collected at different target areas with different style of soil anomalies returned variable gold geochemical anomalies reflecting the conditions of the underlying mineralisation (Figs. 6-8). Plants close to concealed mineralisation returned significant gold values after ICP-MS analysis using ME-VEG41A technique developed by ALS-Chemex.

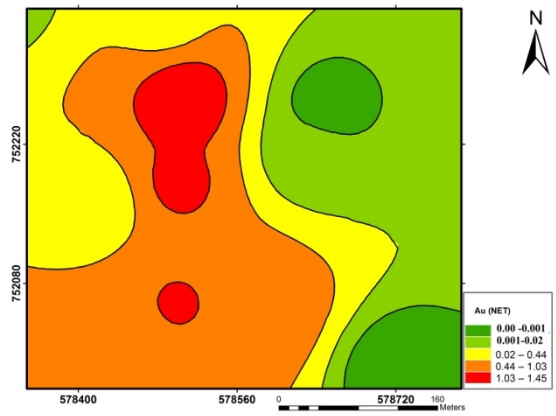

Fig 7 Gold expressions in tree-bark samples at Nfante Target

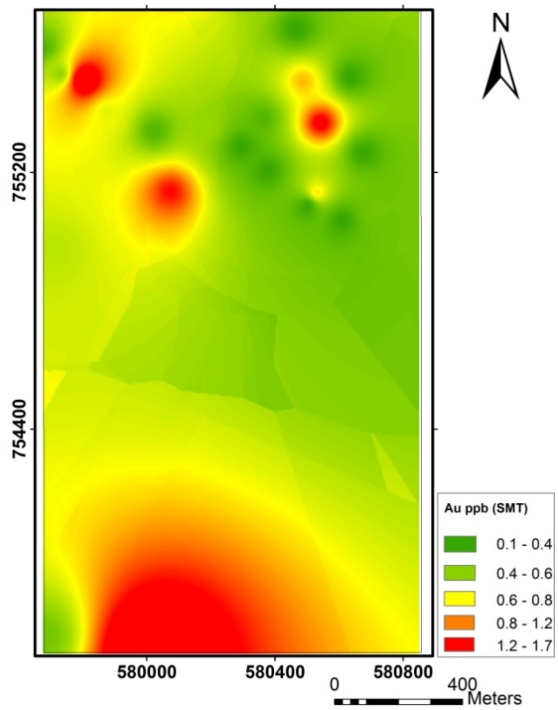

Fig 8 Gold expressions at Subriso Target

Tree bark samples located away from hidden mineralisation had insignificant and subtle assay results (Figs. 6-8). Plots of these results showed clearly where the hidden gold are in an area considered not to host any gold anomaly when surface soil samples were used as a geochemical exploration tool to detect gold anomalies.

Typifying the biogeochemical gold expressions at Pokukrom West target (Fig. 6); the gold results from similar trees growing about 250 m radius from a previously drilled RC hole by Pelangio Gold recorded varying degree of Au assays with respect to the bedrock mineralisation (Fig. 9). The observations of gold geochemistry in tree-barks of plants sampled overwhelmingly demonstrate that the trees sampled close to drill holes measured 52 times more gold than the background gold concentration of 0.02 ppb found in tree samples away from the mineralised area. Similar surveys conducted at Nfante (Fig. 7) and Subriso (Fig. 8) targets characterised by subtle and discontinuous geochemical gold signatures in soil samples also indicated gold in trees and reconfirmed it use as an exploration tool particularly for regolith complex terrains where soil geochemical surveys are unable to detect hidden anomalies. Though the biotic mechanism of gold migration from the sub surface environment to the plants currently not well understood but the synthesis of results obtained for Pokukrom West, Nfante East and Subriso Main suggest the super trace Au contents in tree-barks can identify hidden Au anomalies. It is imperative from the study that biogeochemical surveys where tree-barks are sampled for its gold content though normally characterise by low and weak assays can still provide insight into its behaviour in environmentally friendly natural samples for gold exploration. The confirmation of biogeochemical absorption of Au engineered by plant roots, and of a possible link with biotic processes, whose mechanism of gold transport from the orebody supports and provides confidence in the developing biogeochemical exploration techniques.

The gold expressions in tree-barks sampled at Pokukrom West returned significant gold values particularly in areas with bedrock mineralisation (Fig. 9) and decayed off away from the source orebody. The gold anomalous area defined by tree-bark samples at Pokukrom West target coincided in places where drill holes had good interception with bedrock mineralisation.

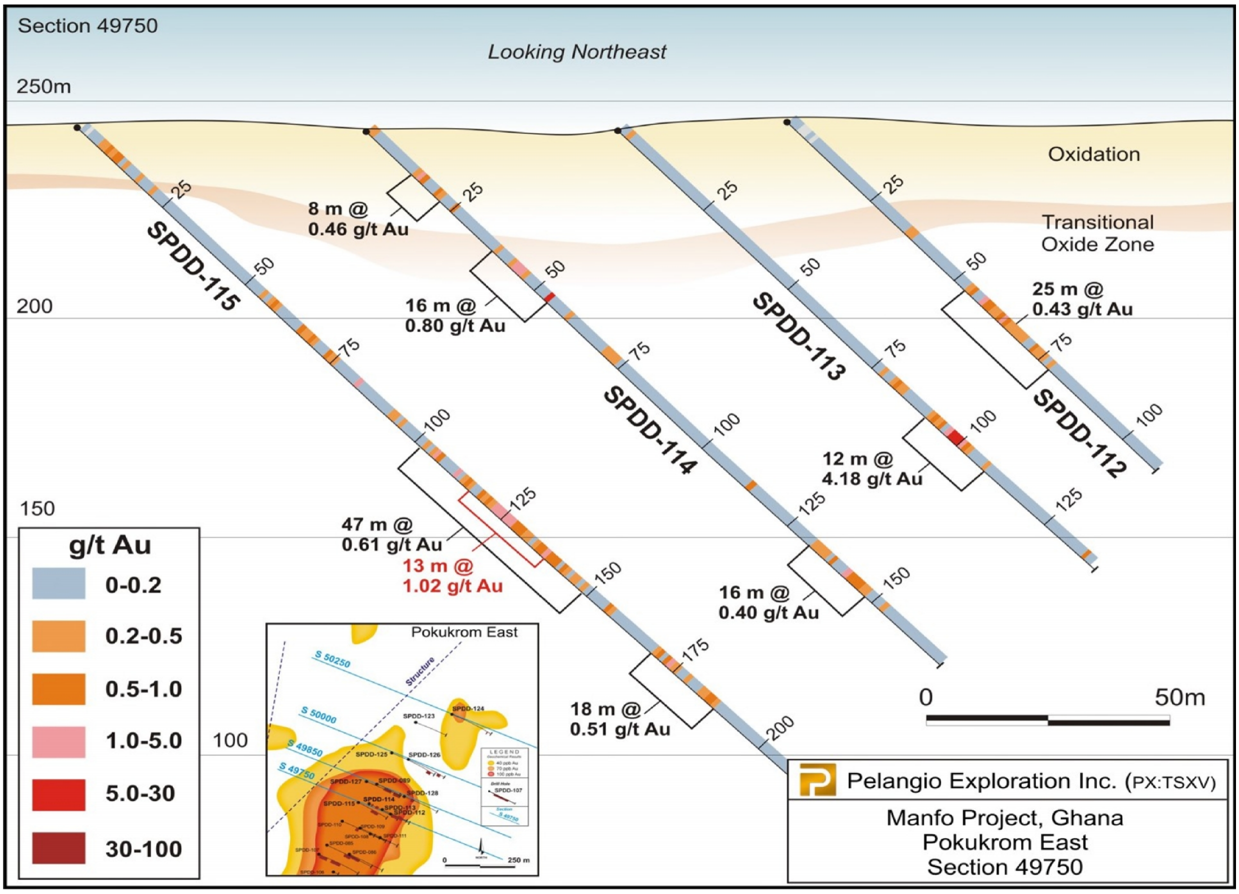

Fig 9 Bedrock Mineralisation Confirming the Effectiveness of Biogeochemical Survey

From Figs. 7 and 8 spot high gold anomalies were detected when the soil gold geochemical data were plotted, synthesised and interpreted. The gold in soils revealed no significant bedrock Au-mineralisation at these target areas. The data interpretation challenges were heightened because these targets seem to be on strike with the Pokukrom target. The variations between the areas were the regolith class. Whilst the Pokukrom West area is characterised by relict regolith; Nfante and Subriso targets have complex regolith consisting of the mixture of relict, erosional, ferruginous and depositional regoliths. This was not incorporated into the geochemical data interpretation as the processes that evolved the regolith and the landforms also impact on the element distributions and concentrations. The notion that most areas in the rainforest environments of southern Ghana has seen simple weathering process (Arhin and Nude, 2009) and for that reason the surface regolith geochemistry will relate to the bedrock and the concealed mineralisation was not correct in these study areas. Unearthing hidden anomalies in terrains characterised by unevenly distributed surface materials which superficially look alike and some formed from transported source or modified by lateritisation processes will have implications on the surface geochemistry. The regoliths in these areas are not formed only from simple weathering processes but some are from complex weathering processes. The resultant effect is the mix surface geochemical expressions which have serious implications on anomaly delineation (Arhin and Nude, 2009). The complex regolith masking potential anomalies is demonstrated at Nfante and Subriso targets (Figs. 4 and 5).

Detecting concealed anomalies from such regolith environments that are not properly classified into different regolith regimes require biogeochemical technique that can bring sample materials beyond the complex regolith. The plots of biogeochemical results presented the true gold anomalous status of the target areas. It confirmed the known bedrock mineralisation at Pokukrom West target (Fig. 6 and Fig. 9) and showed the gold prospectivity of Nfante target (Fig. 7) and showed succinctly the isolated high anomalies at Subriso area. As reported by Canadell *et al*. (1996) some plants can penetrate deeper beyond the complex regolith horizons into the residual weathered bedrock and are able to provide sub surface geochemical expressions consistent with the underlying mineralisation in the area. It has also been reported that trees with roots extending between 2-18 m are common in the tropical forest areas and roots of these trees can penetrate weathered rocks (Canadell *et al*. (1996). So in the event that the roots of the trees penetrate weathered materials that host bedrock mineralisation; it can absorb gold in solution while searching for water and micronutrients for its development. The revelations at Pokukrom West and particularly Nfante targets are clear testimonies that tree-barks as sample medium make economic sense to be used to search for gold especially in areas undercover or with complicated regoliths. This method would be more environmentally friendly than typical traditional prospecting methods of collecting soil samples that may be influenced by regolith and landscape evolution processes. The tree-bark sampling for gold can be sampled all year round and, in many environments, and that is its advantage over many of the conventional exploration methods.

4 Conclusions and Recommendations

The tree bark samples collected for their gold signatures at the three target areas in study area were able to define areas with concealed gold anomalies. Pokukrom target that had strong soil Au geochemistry and anomaly later confirmed by drilling results was detected by the plant sample results. Nfante and Subriso targets which hitherto were identified to be gold-poor-terrain because of the subtle, patchy and weak gold geochemical expressions in the soil samples showed coherent and robust anomaly at Nfante area and defined couple of isolated high anomalies at Subriso area. The findings in the study suggest plant samples as an appropriate sample medium for regional anomaly definition at the early stages of exploration because plants are able to defile the complex regolith, penetrate beyond it via the rooting system and through biotic mechanisms of gold migration transport gold as a nanoparticle to be stored at different parts of the plant. In conclusion the concealed gold undercover at Nfante and Subriso targets that the soil geochemical survey was unable to detect because of the regolith complexities were picked up by the tree bark samples and are classified as potential gold anomalous target earmarked for more systematic geochemical survey. The authors are of the believe that many similar anomalies like these have gone undetected because simple weathering processes were thought to characterise the rainforest environments leading to subtle, weak and discontinuous gold anomalous area concluded not to have any bedrock gold mineralisation. It is therefore being recommended that biogeochemical approach in mineral exploration be incorporated in all Greenfield exploration and in brownfield exploration if the regolith environment is not well understood. Finally, it is being endorsed for regolith dominated terrains where gold geochemistry in the overlying regolith materials can decouple from the underlying mineralisation.

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