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Research Article

Integrating Geoscience Data for Delineating Potential Gold Targets-a Case Study from Sian Goldfields Limited, Ghana

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Abstract: Sian Goldfields Limited (SGL) recently re-examined its concession by integrating data in a GIS environment for the improvement of the mapping of the local geology as well as for delineating potential gold targets. Data employed included geochemical, topographic, geological and aerial photographic information. The geochemical data included 5660 soil samples collected over a terrain underlain by six different lithologies namely, rhyolites, greenstones, sheared greenstones, phyllites, sandstones and granites. The various lithologies and their boundaries were obtained from the shaded relief map derived from the topographic information whilst "ground truthing" confirmed and established the other geological contacts. The updated geology map generated from the geosciences data was superimposed on the soil gold geochemical plot. The integration of these datasets in the form of maps resulted in the easy definition of anomalous gold targets. The targets were delineated using background and threshold values of 30 ppb and 50 ppb respectively. The integration model approach portrayed many of the geological boundaries to have relations with mineralization. The use of the MapInfo-Discover GIS markedly aided to ascertain the geological contacts in areas where outcrops were uncommon. The re-analysis of the remote-sensed data and the ground truthing showed the clear contact between the Birimian system and the Voltaian units at the north eastern side of the concession. The integration of this information with soil geochemical gold results highlighted the most prospective gold targets. It is recommended that the granite-sheared greenstones/sheared greenstone-massive greenstones contacts and areas with defined soil anomalies should be subjected to further exploration works.

Keywords: Data-driven, exploration, geoscience data, knowledge-driven, mineralization

INTRODUCTION

Soil geochemical survey has widely been used as first phase exploration tool for gold (Au) in tropical rainforest regions where soils are considered residual in character. However, despite the residual characteristics of soils in these areas there are numerous associated exploration problems. Some of the problems are naturally low gold concentrations in some regolith materials, especially the depositional and lateritized environments. This renders uneven distribution of gold in surface samples as the landforms are not uniform hence creating isolated high and subtle gold assay values in soil anomalies that are not representative samples for areas analyzed. The continuous modifications of landscape also results in both nugget effects and sample dilution that create a random phenomenon that masks the true geochemical signal. Generally, the collection and analysis of representative samples require large volume of materials and specific size fractions as well as appropriate analytical method.

Successful gold exploration surveys are achieved depending on the reliability of samples collected. The probability of obtaining and recognizing that a mineralized body may be present or absent within a surveyed area should be inferred from the interpreted data. The indications, if strong, invariably are characterized by an increase in the abundance of one or more elements of economic importance in the media sampled (Owusu, 2001) or as a result of landform modifications (Bolster, 1999; Arhin and Nude, 2009).

Fletcher *et al.* (1986) are of the view that the first phase of interpretation of geochemical survey results is to condense large numerical data and extract the essential information from them. The interpretation should involve both geological and statistical inferences

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and although their relative importance varies from one situation to another neither can be totally ignored (Joyce, 1974). But the most commonly used method by exploration companies is through statistics which is seen to be subjective criterion (Lepeltier, 1969). However, during the past one and a half decades, systematic exploration for gold through the integration of geosciences data revealed not only new economic gold deposits but also grades of minerals of economic interest, which were hitherto unknown especially in cases where multi-media and multi-element chemical analyses were the geochemical tools employed. Woodall (1993) also observed that modern exploration techniques consist of two components, namely, early generative and subsequent systematic stages. Meanwhile the ultimate objective of mineral exploration is to delimit economic mineral deposit in a cost effective manner. It is thus envisaged that discovering new deposits requires integration of ground-collected and remotely-sensed data.

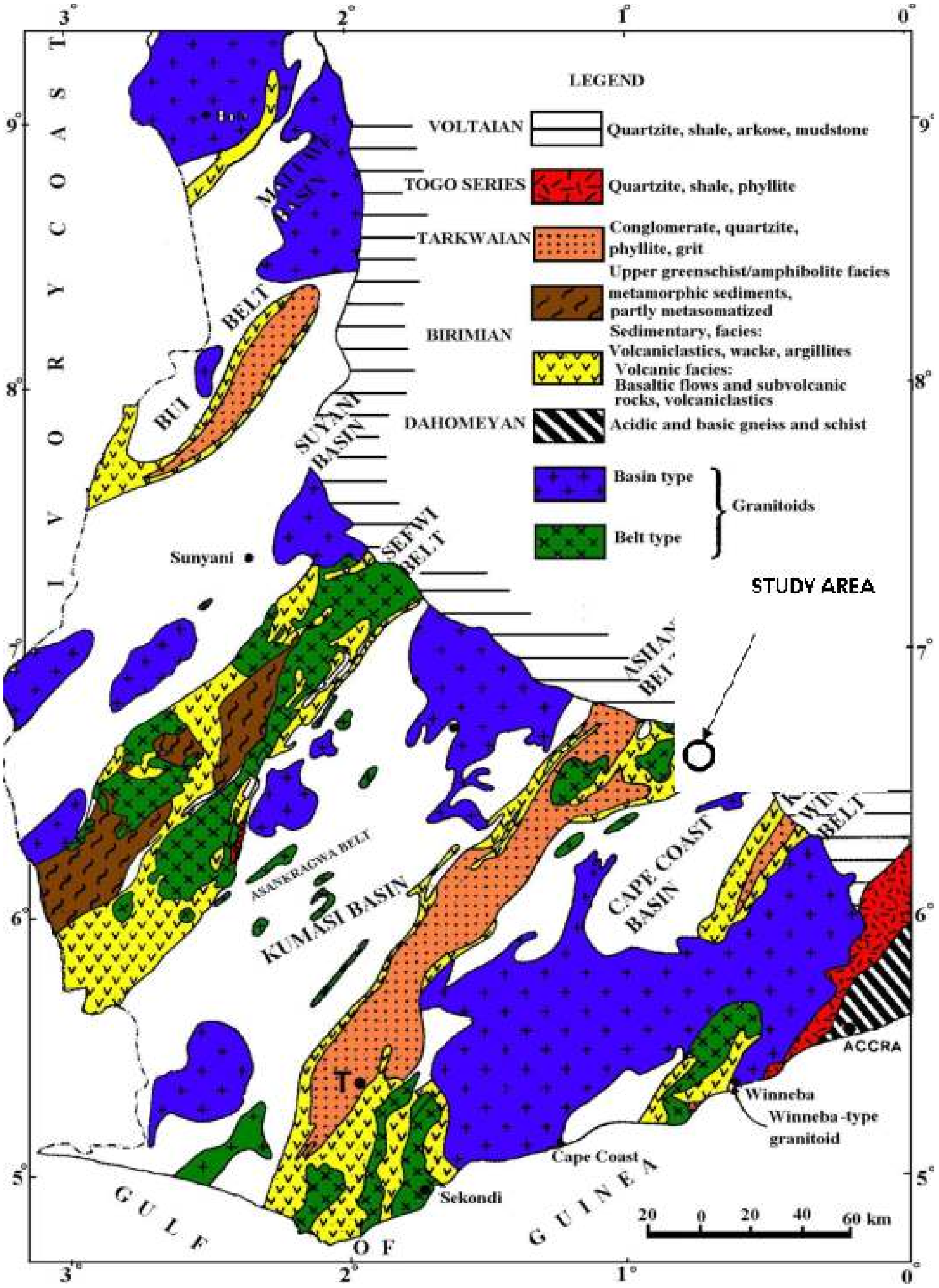

Fig. 1: The geology of Southern Ghana and location of the study area (modified after Kesse, 1985)

Geographical Information Systems (GIS) are now routinely used for the management, manipulation, processing and integration of voluminous spatial exploration datasets to improve exploration and detection of mineral deposits (Ott *et al*., 2006). According to Sabins (1986) remote sensing and GIS have proven valuable for mineral exploration in several ways. These include mapping of regional lineaments, mapping of local fracture patterns that may control ore deposits, detection of hydrothermally altered rocks associated with ore deposits and providing basic geologic data at low costs within a short time.

In light of these developments Sian Goldfields Limited (SGL) decided to further explore its entire concession by employing data-driven and knowledge-driven methods. The objective was to undertake image-based favorability mapping to delineate potential gold mineralization targets by applied GIS-based analysis of ground-collected, geochemical and remotely-sensed data to improve exploration for buried deposits. This study demonstrates GIS-based predictive spatial analysis technique used to integrate multiple exploration datasets and map displaying favourability for the occurrence of the mineral deposit.

Geology and mineralization: The SGL concession is located at the northeastern margin of the Ashanti Birimian gold belt with the general geology as shown in Fig. 1. The concession area is underlain by the Birimian rocks with their associated granitic intrusions and the Voltaian sandstones. The Birimian rocks regionally trend northeasterly with steep dip angles ranging between 65° and 80°. These rocks consist of metavolcanic and metasedimentary units (Kesse, 1985). The metavolcanic unit consists mainly of basic volcanics (also known as “greenstones”) rich in pyrites and typically gabbroic in composition. Two types of greenstones are differentiated; the sheared greenstones (SGrst) and the massive greenstones (MGrst). Texturally, the greenstones are generally medium to coarse grained, dark green and pyritised. The metasedimentary sequence consists of tuffaceous and carbonaceous phyllites (PH) commonly associated with quartz veining. Belt and Basin intrusives intrude the metavolcanics, granites (GR) rhyolite (RH) etc. Arenaceous rocks, generally sandstones (Sst), mark the beginning of the Voltaian rocks and they form an escarpment at the northeastern part of the concession. A period of structural deformation is evidenced by a number of northeast trending shear structures. These are hosted by the Birimian rocks and appear to be particularly well developed within the basic metavolcanics unit. These shear zones are highly altered-silicic and potassic in their central parts grading outward into the host rock. The shear zones tend to be intruded by northeast trending quartz-feldspar dykes of which albite appears to be the main alteration.

Later structural deformation is also evident in a number of northwest trending zones which appear to terminate and/or offset the northeast trending shear zones. In all, seven mineralized shear structures are known to be inferred within the concession. These structural units host principal mineralization at Esaase village where SGL has open pit mining. Alteration effects range from silicification and pyritisation (in the directions with highest gold grades) to chloritisation and sericitisation and finally to carbonation in sections with lesser grades. In addition, epidotised alteration is present except that it is not normally associated with significant gold mineralization. The general mineralization is in lenses, which pinch and swell both along strike and down dip.

MATERIALS AND METHODS

Materials: Topographical sheet (scale 1: 50, 000) and aerial photographs (scale 1:25, 000), prepared in January 1974, were acquired from the Ghana Survey Department. Various themes (elevation and contour, town/village locations, road and rail line, etc) were extracted and stored in a Geographic Information System (GIS) environment after demarcation, scanning and geo-referencing. The digital elevation contours together with their elevation values were used for the generation of surface and shaded relief map of the study area using MapInfo-Discover software. Not all aerial photographs covering the concession were obtained for the study. The lineaments extracted from the aerial photographs were combined with those extracted from the shaded relief and digital elevation maps. The hard copy geological map was also scanned, geo-referenced and captured digitally.

Methods: The conceptual methodology implemented to achieve the research objectives is illustrated in a simplified form in Fig. 2. Ground-collected and remotely-sensed geosciences data were assembled in digital form and co-registered to a common projection to build a geospatial database in which the various spatial components overlap properly.

Geochemistry: Based on an earlier orientation survey, soils from the B-horizon were sampled over the entire concession along 300° bearing profiles normal to suspected trends of gold mineralization. The profiles which have a total of 275 km line were set at 500 m apart and sampling points were at 50 m intervals. A total of 5660 samples were collected with spatial and non-spatial information registered (Owusu *et al*., 2003). The samples were analyzed using calorimetric method in an in-house laboratory. Twenty certified reference samples, 50 duplicate and 10 blank samples were inserted in the samples to control and monitor the in-

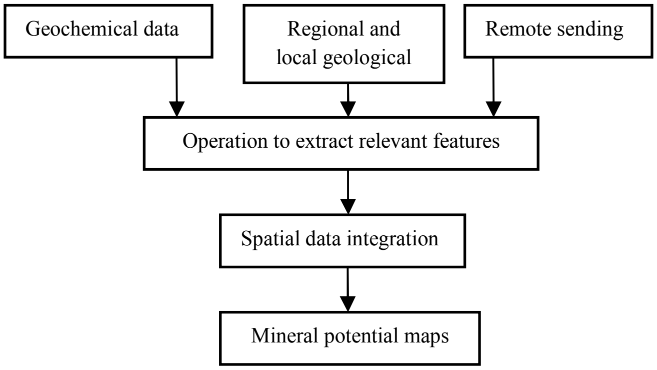

Fig. 2: Flowchart of the conceptual methodology for the research

Table 1: Statistical parameters of Au (ppb) in six lithologies

Gold descriptive statistics	RH	PH	GR	SGrst	MGrst	Sst
Mean	26.3	26	23.1	25.8	34.7	33.8
Standard Error	1.2	1.1	0.4	0.4	1.8	3.7
Median	20	20	20	20	20	30
Mode	10	20	20	20	20	60
Standard Deviation	30.6	21.5	14.7	15.1	79.2	17.9
Sample variance	939.3	462	217.4	227.7	6276.6	320.1
Kurtosis	24.9	9.3	2.1	3.4	163.7	-1.2
Skewness	4.5	2.8	1.5	1.7	10.8	0.3
Range	240	120	80	110	1740	50
Minimum	10	10	10	10	10	10
Maximum	250	130	90	120	1750	60
Count	680	380	1151	1164	1951	24

Table 2: Summary of estimated background and threshold for the various lithologies

Lithology	Estimated background (ppb)	Estimated threshold (ppb)
Granit (GR)	40	55
Massive Greenstone (MGrst)	40	53
Sheared Greenstone (SGrst)	41	56
Phyllites (PH)	35	49
Rhyollite (RH)	38	56
Sandstones (Sst)	25	33

house laboratory analysis. In addition to that 10% of split samples from the 5660 samples were re-analyzed at different laboratories to validate the bulk results from the in-house laboratory. In addition to the primary data that were obtained from the geochemical survey, secondary data were extracted and processed from remotely-sensed data.

All acquired geo-scientific datasets (geochemical, geological, topographical, lineaments, etc.) on the concession were entered into MapInfo-Discover (GIS) software were manipulated to generate a favourability map for the concession. This map composed of series of overlays, displayed geological phenomena, such as the locations of mineral occurrences, spatial distributions of these occurrences, their association with specific geological units, structures (shear zones, faults and contacts) from the real world. The favourability map provides useful information for prediction of where to explore on the concession.

A similar approach was used and reported by numerous researchers like Bonham-Carter (1996), Brabb (1984), Carrara *et al*. (1991), Van Western (1993) and Leroi (1996).

RESULTS

Descriptive statistics: For reliable statistical parameters to be established the extremely high gold values were not considered for the statistical exercise due to their unwarranted influences. They were observed to produce single point anomalies. The statistical parameters of gold values in six lithologies present in the SGL concession are presented in Table 1.

The above table shows low assay gold values for the six lithologies from the bulk of the results (about 95% of each lithology). The modal value of 20 ppb accounts for more than 40% for each lithology except for sandstone. Based on Lepeltier's method (Lepeltier, 1969) the background and threshold for gold were established for the various lithologies (Table 2).

The observed similarities in the statistical parameters hint at possible multitude of interference

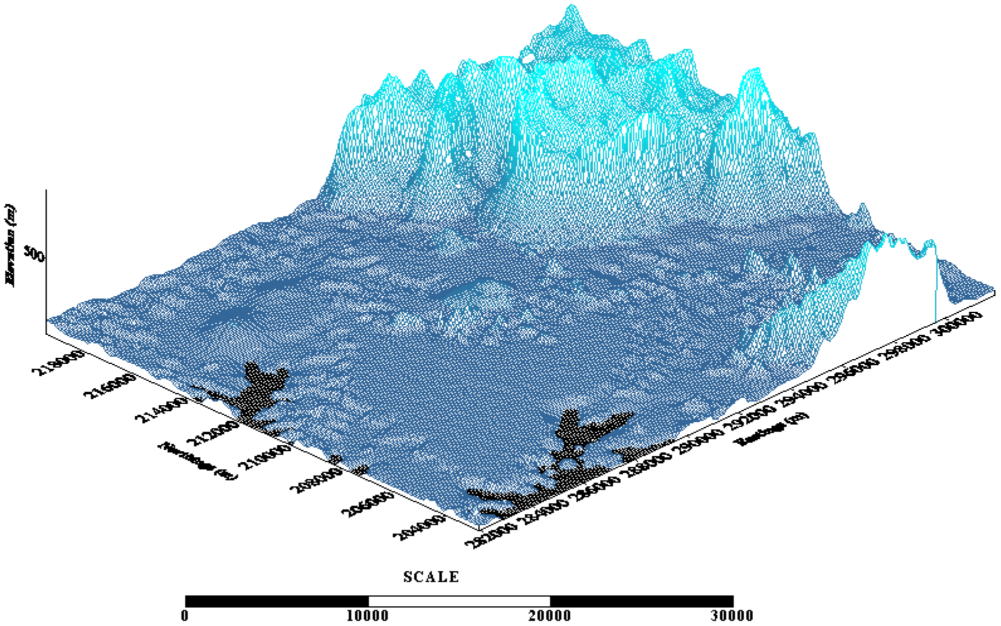

Fig. 3: Digital elevation model of the study area

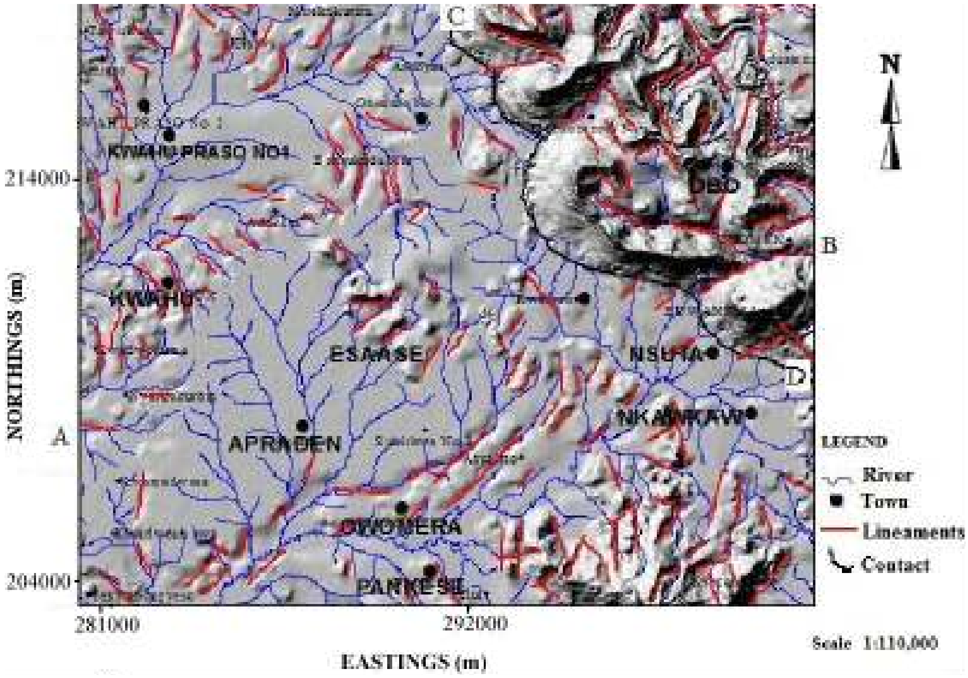

Fig. 4: Shaded relief map and lineaments of the study area (CD is a geological contact between the Birimian System and Voltaian Supergroup)

which may be attributed to any of the following four factors; the presence of thin mineralized quartz veins of varying grades; varying rock composition of each lithology; imprecision of identified lithological boundaries to a lesser extent and possible analytical errors (Owusu, 2002).

In view of the above and also for the fact that geological contacts are potential targets for gold mineralization, a background and threshold of 30 and 50 ppb respectively were used for target generation on the SGL concession.

Two landform features; low lying terrain and highlands (Fig. 3 and 4) occur on the concession. The south western section of the concession is characterized predominantly by lowlands rising up to 200 m with some isolated hills with elevations up to about 300 m. The northeastern portion comprise of hilly landscape with steep slopes.

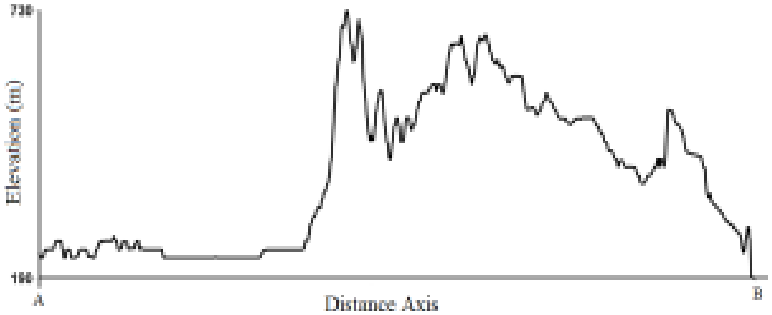

Fig. 5: Profile AB showing the nature of the topography

The highest point of the concession as profiled in Fig. 5 has an elevation of about 700 m.

DISCUSSION

From the GIS interpretation of the geo-scientific datasets, the geological boundaries of lithologies and structures were clearly defined (Fig. 6). However 'ground truthing' carried out at some localities during the soil sampling to ascertain the geological contacts observed on the generated favourability map were not conspicuously seen. The contact between the Voltaian Super Group and the Birimian System was difficult to discern in the field, though the analysis of the digitalelevation model (Fig. 3) and the shaded relief map (Fig. 4) show the geographical location of the geologic contact. The shaded relief map defined proximally the location of the inferred contact marked CD on Fig. 4.

The sudden rise of land observed in the profile (Fig. 5) was confirmed as scrap landform of the Voltaian Super Group uncomformably overlying the Birimain System during the 'ground truthing'. The superimposition of the shaded relief map over the geology map in the same spatial frame work confirmed the existence of the contact of the Birimian System and the Voltaian Super Group. The Voltaian Super Group cover towns like Obomen, Obo, Aduamoa etc.

Though phyllites tend to be a common rock unit in the Birimian System metasedimentary rocks, only few bands of phyllites were encountered during the ground truthing survey and these were observed within the sheared greenstones (Fig. 6). Their thicknesses seldom exceed 10 m over maximum strike length of about 50 m. The massive greenstones which outcrop in Nkawkaw area also form a rim almost enclosing the sheared greenstones except where the rhyolite. The granites is at the centre (Fig. 6). These contacts were ascertained during the soil geochemical sampling. The geology and contacts at the northwestern corner of the area were easily mapped from the processed remotely sensed data and were confirmed by "ground truthing".

The mineralization on the concession occurs mainly in sheared greenstones and phyllites (Fig. 6). However few weak individual mineralizations are scattered in massive greenstone, granite and rhyolite especially along lithologic contacts. In the Birimian System some gold occurrences display a close spatial relationship with granitoid plutons either being hosted in intrusive bodies, at the contact with the country rock or in close proximity to an intrusive body (Kesse 1985). It is proposed that intrusion of granitoids may have generated hydrothermal systems at and within the margins of plutons, mobilizing fluids from within the country rocks (Naden and Caulfield, 1989). Though spatial association with intrusives is evident at some gold occurrences on the concession, it is not a universal feature and the genetic relationships remain unclear (Gunn and Plant, 1998). Steed and Morris (1986) suggested the association between gold mineralization and intrusions may solely reflect zones of structural anisotropy developed around intrusions, facilitating the development of brittle fracture systems.

Lineaments are found to be widespread in the concession (Fig. 4 and 6). Generally the lineaments in the Birimian System are in two directions; NE-SW and N-S in the greenstones (sheared and massive) and phyllites to a large extent. However there are a few NW-SE trending lineaments in the Kwahu environs (Fig. 4). The granites and the rhyolite appear structureless, hence very few lineaments were mapped within these lithologies. But sometimes some lineaments straddle the granites and rhyolite. Within the Voltaian Super Group lineaments are variedly oriented and extensive compared to those in the Birimian System. Goldfarb *et al.* (2005) are of the view that significant gold provinces in metallogenetic belts are related to first-order, major crustal structures, which represent pathways for large volumes of ore-forming fluids. This assertion holds almost true for the occurrence of gold deposits on the SGL concession. All the major identified deposits occur in the sheared greenstones. These brittle-ductile broad shear zones are due to regional faulting and fracturing that deformed the greenstones. The fault and fracture planes within the broad shear zones were indicated by the lineaments interpreted from the aerial photographs. The deposits north and east of Esaase community (Fig. 6) clearly demonstrate scenario. The parallel lineaments trending approximately NE-SW are sites that host significant gold mineralizations in the sheared greenstones and phyllite formations. The strike lengths of these

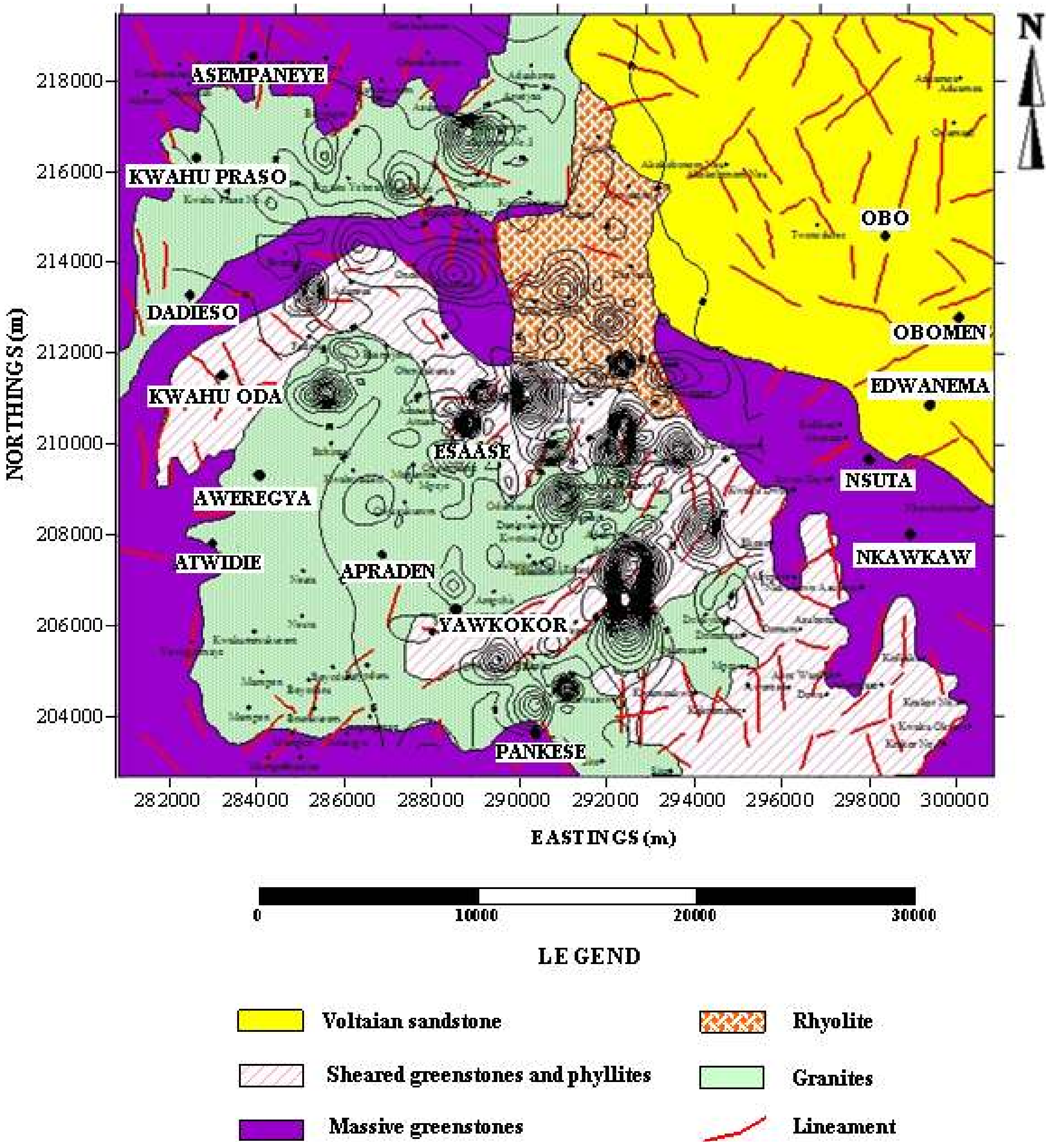

Fig. 6: Improved geology of the study area with overlays of lineaments and soil contours

lineaments appeared to have been shortened by the rhyolitic intrusions north of the sheared greenstones. Comparatively the rhyolitic intrusion is weakly mineralized like the sheared greenstone because it consists of less major crustal structures. The only major mineralization found in the rhyolitic intrusion is found at the contact with the sheared greenstone. This could be attributed to fracturing that affected the boundary of the intrusion.

Though the Voltaian rocks have lineaments in them yet no indications of any significant gold mineralization occur in them. It could be argued out that they were deposited after the mineralization episode within the environment that affected the Birimian System.

Apart from controlling mineralization, lineaments had strongly influenced the drainage patterns on the concession. Major rivers and streams courses are along the orientations of lineaments (Fig. 4). The drainage patterns can be described as dendritic.

Relationship between geochemical patterns and geology: Deposit mineralogy has a direct bearing on identifying the correct geochemical criteria to use in mineral exploration. Throughout the Birimian metallogenic province gold occurs in association with arsenopyrite and pyrite. Litho geochemical studies indicate a consistent positive relationship between arsenic and gold values. Arsenopyrite and pyrite-bearing samples are enriched in gold, sphalerite and to a lesser extent nickel, copper and zinc. These associations reflect the mineralogy of the deposit with minor bismuth present in arsenopyrite and nickel in pyrite and copper and zinc resulting from inclusions of chalcopyrite, tetrahedrite and sphalerite in pyrite. Using a threshold of 50 ppb for gold geochemical anomalous zones was defined on the concession. Correlation of geochemical and geological data for delineation of altered rocks and mineralization had revealed strong soil-gold anomalies at lithological contacts, especially along the granite and sheared greenstones, sheared greenstones and massive greenstones and then the massive greenstones and rhyolite contact (Fig. 6). There are however some weak soil anomalies that are found within the granites and the rhyolite. The trends of almost all the strong anomalous soil-gold contours follow either NE-SW or N-S lineaments (Fig. 6), especially along lithologic contacts and within the sheared greenstones and phyllite. In localities where no orientation is well defined, it is very that possible geochemical elements dispersal may have accounted for this scenario mostly in the granites and rhyolite.

Exploration model: Based on the general characteristics of gold mineralization displayed on the generated favourability map, a range of exploration criteria was defined for use on the SGL concession. The sheared greenstones and phyllites with NE-SW and N-S trending lineaments on account of their favourability for hosting gold mineralization were allocated the greatest significance in the model. The next in terms of favourability for mineralization is the lithological boundaries that coincide NE-SW and N-S trending lineaments. The granitic intrusions that are fractured are considered as the next prospectivity area. As a result of its complex geological history a large number of structures occur in the Birimian System. Therefore lineaments are perceived to have regional influence and potential control on the location of mineralization as noted above. The orientations of these lineaments are very important. The lineaments trending NW-SE in lithologies are allocated the least favourability for mineralization.

CONCLUSION

Various data sets were integrated to improve the geological contacts and delineate potential gold targets. The integration model approach portrayed many of the geological boundaries to have relations with mineralization. Also improved geological contacts resulting from the integration enabled more appropriate background and threshold values to be selected. Background values are computed by establishing some form of average that can be meaningless since geochemical data are rarely drawn from a single population so that the average computed does not fit any of constituent populations.

From the processed shaded relief map the Voltaian sandstones, sheared greenstones and their respective boundaries were easily mapped. The “ground truthing” helped in establishing the other geological contacts. However, the phyllites contacts were not clearly established due to very few outcrop observation points.

Mapped lineaments within the Birimian were of two directions, NE-SW and NW-SE with the sheared greenstones hosting most of the NE-SW trending lineaments to a large extent.

Areas northwest of Esaase as well as those on the southeast which host NE-SW lineaments are potential structural targets of gold mineralization and this must be of highest priority in further exploration. Other areas of interest for possible granite-hosted gold mineralization are Apradan, Nsuta and Aweregya area. These areas must also be considered for further exploration.

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