Regional Prospectivity Modelling in Data-Poor Areas: The Kumasi Basin, Ghana

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Abstract

Here we present a case study of prospectivity modelling over a region with both data-rich and data-poor areas, in the Kumasi Basin, Ghana. Whilst a reasonable amount of geological, geochemical and geophysical data is available over much of the Asankrangwa Gold Belt, host of the large Nkran and Esaase gold deposits (measured, indicated and inferred resources >10 Moz Au), data availability over much of the remainder of the Kumasi Basin is generally poor and of much lower resolution. As part of a comprehensive prospectivity and targeting study undertaken by Corporate Geoscience Group for Asanko Gold, Kenex completed GIS-based prospectivity modelling using the weights of evidence (WoE) technique to delineate high priority targets for orogenic gold. WoE modelling provides a data-driven tool that combines relevant datasets, identifies anomalous thresholds in predictors of mineralisation and produces a map of geological potential. Statistical methods ensure that when the final geological potential grid is created, areas with missing data coverage are not significantly down-weighted relative to anomalous areas.

Areas of poor data coverage in the Kumasi Basin required creative examination to allow successful modelling. For example, Kumasi Basin orogenic deposits are often associated with broad zones of silicic alteration. Consequently, many deposits resist weathering and form topographic ridges, allowing analysis using detailed open-file DEM data. Ridges were extracted and attributed with scale, relative strength and orientation, all of which were tested for spatial correlation with known orogenic deposits. Another example involves limited coverage of available geophysical surveys. Scanned TMI image data was reclassified into a GIS and certain colour bands selected as most accurately representing TMI. Properties such as magnetic slope, a common predictor for orogenic mineralisation, could then be calculated. Many targets identified by the model were located in areas with high data density. By using data intelligently we have also identified targets in data-poor areas.

Keywords: prospectivity modelling, data-poor areas, Kumasi Basin, gold, Asankrangwa Belt, Ghana.

Introduction

Prospectivity modelling of mineralised systems using GIS (Bonham-Carter, 1994) is increasingly being used by geoscientists in industry, government and academia to assess exploration areas and identify targets for further investigation. A number of prospectivity modelling techniques have been developed, including weights of evidence (WoE), fuzzy logic and artificial neural networks. In recent times, prospectivity modelling has expanded into the 3D domain. The outputs of these models are mineral potential maps, which highlight areas containing the same geological attributes as known deposits. A key advantage of this type of modelling is that it can be applied to a wide range of mineral deposit types and used at prospect to regional scales. Importantly, prospectivity modelling can be applied to regions with an uneven distribution of input data, such as those containing data-rich areas (e.g. drilled and mapped prospects) and data-poor areas that have only been subject to geological reconnaissance.

In this paper we describe how GIS-based prospectivity models may be used in areas of mixed data distribution, without compromising the quality of the output. Examples will be taken from prospectivity modelling of orogenic gold mineral systems in the Kumasi Basin, southwest Ghana, using the WoE technique. This modelling was undertaken by Kenex Ltd as part of an extensive targeting study completed by Corporate Geoscience Group for Asanko Gold Inc (Chudasama et al, 2015). The prospectivity model uses the mineral systems approach (McCuaig et al., 2010) to determine key predictive variables that define the orogenic style of mineralisation. The mineral potential map has then been used to delineate the most prospective areas and define high priority exploration targets. The targets either represent existing prospects or mines or high probabilistic areas defined by the data-driven modelling where new gold mineralisation could be discovered through further exploration and development.

Regional Geology

The Kumasi Basin opened between 2150 and 2100 Ma under an extensional tectonic regime and is dominated by Palaeoproterozoic metasedimentary and metavolcanic rocks (Figure 1). The region evolved in a back-arc tectonic setting, with active volcanic arcs having developed above subduction zones both to the west (Sefwi-Bibiani volcanic belt) and to the east (Ashanti volcanic belt) (Leube et al, 1990).

The Birimian Supergroup basement outcrops over much of the Kumasi Basin, containing northeast striking mafic metavolcanic belts separated from intervening turbiditic units by major faults. Birimian rocks are overlain by slightly younger rocks of the Tarkwaian Group that include metasedimentary rocks such as conglomerates, sandstones, siltstones and minor shales. These rocks were originally laid down in a shallow marine environment floored by thinned continental crust, interpreted as a foreland basin. Tarkwaian rocks generally occur as either fault-bounded slices or unconformably overlying the basement, and are therefore interpreted to be erosion products of the Birimian Supergroup that infill late basinal structures. Concurrent thinning of the crust and the arrival of a mantle plume beneath the Kumasi Basin caused underplating of the thinned crust by mafic magmas. The resultant intermediate to felsic melts produced in the lower crust were emplaced into the upper crust as belt-type granitoids of the Eburnian Plutonic Suite, intruding Birimian and Tarkwaian lithologies shortly after they were deposited. The second and most extensive period of orogenesis in the Kumasi Basin occurred at this time, resulting in the deformation (phases D1-D5) of all Birimian and Tarkwaian rocks and the intrusion of the basin-type granitoids.

Gold Mineralisation

Orogenic gold deposits, including vein systems and mineralised shear zones, are an integral component of many metamorphic belts (Groves et al., 2003). These deposits are believed to form from late-stage fluids mobilised by metamorphic dehydration reactions, specifically across the greenschist-amphibolite facies boundary. Deposits are diverse in terms of their geometry, structural controls, host rocks, temperature and pressure of formation and, consequently, with respect to alteration assemblages and metal associations. In the Kumasi Basin, orogenic gold deposition was temporally, spatially and most likely genetically associated with metamorphism of the Birimian Supergroup and emplacement of Eburnian granitoids. The most significant gold deposits in the Kumasi Basin are Asanko Gold’s Nkran and Esaase (measured, indicated and inferred resources >10 Moz Au), and the Edikan gold deposit cluster (measured, indicated and inferred resources >7 Moz Au). The Edikan deposits (formerly the Ayanfuri project) are located on the eastern flank of the Kumasi Basin and are owned by Perseus Mining Ltd.

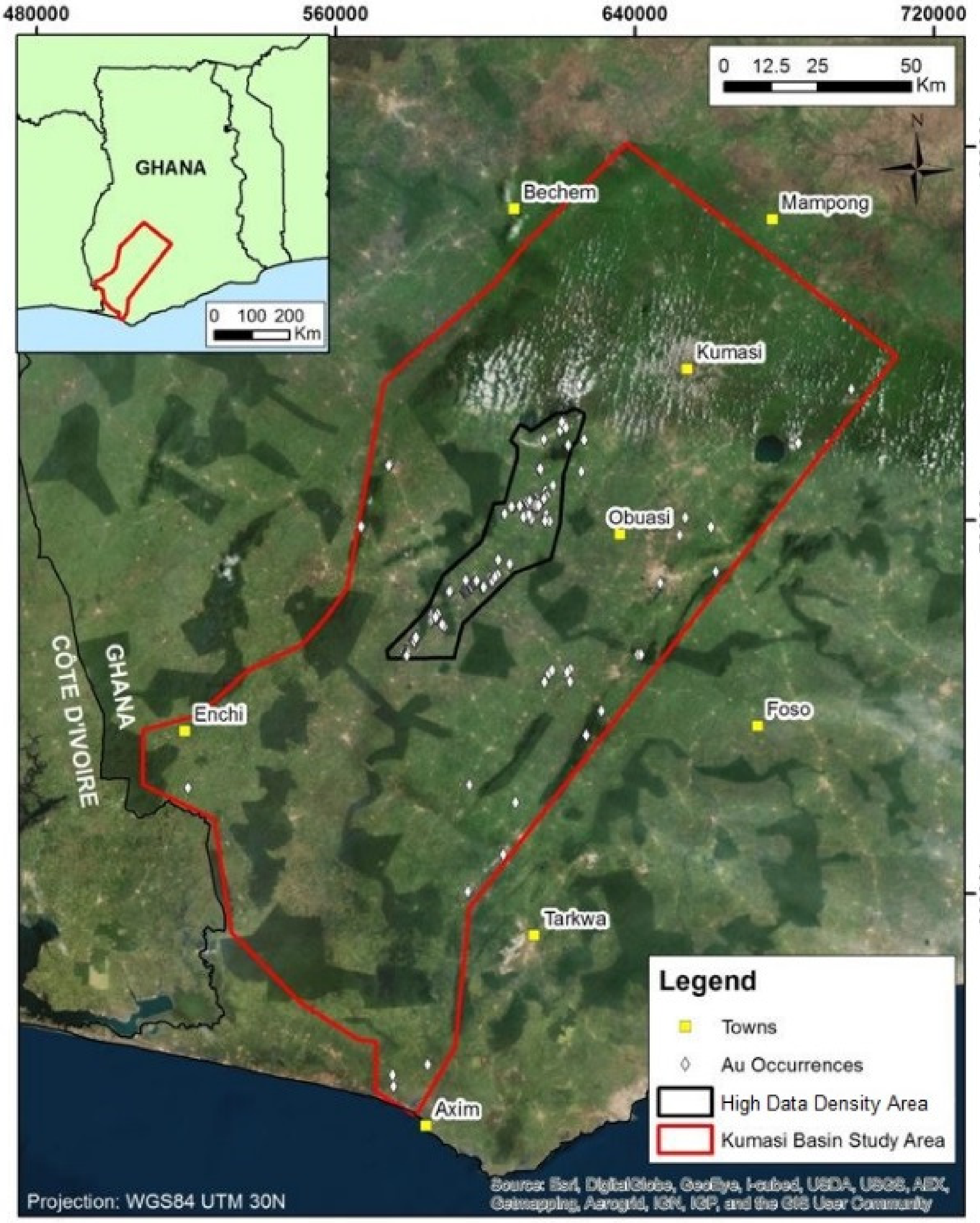

Figure 1. Location of modelling area.

Orogenic gold mineralisation is hosted in Birimian metasediments and basin type granites, and is believed to have been deposited between 2110-2090 Ma (Hirdes and Leube, 1989). Within the Kumasi Basin, the area containing the highest density of known orogenic gold deposits is the Asankrangwa Belt, a complex northeast-trending shear zone system (high data density area in Figure 1). This belt lies along the central axis of the Kumasi Basin, bearing strongly deformed metasedimentary rocks, granitic intrusives and quartz reefs, within a zone approximately 15 km wide and 150 km in length. Gold was deposited near the brittle-ductile transition, most likely at depths of 6 to 12 km, pressures between 1-3 kbar and temperatures from 200-400˚C.

Specific characteristics of orogenic gold deposits in the Kumasi Basin include:

- Mineralisation is controlled by and has been deposited adjacent to major northeast-striking shear zones and splays, which are interpreted as reactivated basin growth faults.
- Auriferous veining is preferentially developed at lithological contacts where competency contrasts exist, such as between metasediments and intrusive dykes, plugs or stocks.
- Alteration is indicated by outcropping K/Th anomalies and negative magnetic anomalies due to magnetite destruction.
- Elevated values of Au, Ag and As in stream sediments and soils samples.

Mineral Systems Approach

This study uses a mineral systems approach to represent all the elements and processes that are necessary to generate and preserve mineral deposits (Wyborn et al., 1994). These are sources of energy to drive the system, as well as fluids, metals and ligands; transport pathways along which fluids containing ore components can migrate towards trap zones; trap zones along which fluid flow becomes focused into channels; deposition of ore components from fluids passing through the trap zones; and outflow zones for discharge of residual fluids and melts. Results of the above processes can often be mapped directly or identified indirectly using geoscience datasets, and are perfectly suited for analysis and display using GIS. Predictive maps of individual variables serve as proxies for each element of the mineral system, allowing the critical ore-forming processes to be mapped. Ore deposit formation is precluded in an area that lacks one or more of these essential components.

Following significant additional work by the authors to build a coherent geological model and make the data useable for modelling in a GIS framework, predictive maps have been developed that describe possible source, transport, trap and metal deposition. In the Kumasi Basin, each of these criteria has been mapped using various geological, geophysical and geochemical data supplied by Asanko Gold Inc. Complete coverage of geological mapping at a scale of 1:250,000 was used extensively in this study, in conjunction with compiled mineral occurrence and geochemical data and more detailed structural information for the Asankrangwa Gold Belt. A DEM for the study area with a resolution of 90 m was sourced from CGIAR-CSI.

Weights of Evidence Method

For this prospectivity analysis, a study area of the Kumasi Basin was defined and, following validation, training data were selected for the orogenic gold mineral system from the supplied mineral occurrence database. The training data were selected to include a representative selection of historical and current orogenic gold mines and mineral occurrences, with priority given to those with recorded production. The study area was gridded according to the maximum data resolution, and a unit cell size of 0.7 km^2 assigned that represents the approximate size of an orogenic gold deposit. This allowed the prior probability to be calculated, which indicates the probability of a deposit existing in a predetermined area before applying any knowledge about geology or geochemistry.

Spatial analysis was carried out using the weights of evidence technique developed by Bonham-Carter (1994), using the Spatial Data Modeller extension developed for ESRI's ArcGIS software. To summarise, Deng (2009) explained the WoE modelling method as the creation of numerous binary predictive maps of geological variables and their spatial comparison with known mineral deposits, also known as training data. Selected predictive maps are combined

into one final prospectivity map of estimated posterior probabilities of the occurrence of known or unknown ore deposits of the targeted mineral system.

The predictive maps used in the final prospectivity model were chosen mainly due to their high contrast (C) weighting coefficient, indicating a close spatial relationship between the variable and the training data. The studentised contrast value (StudC) is another important value, calculating the ratio of the standard deviation of the contrast to the contrast value itself, and gives an informal test of the uncertainty. If the ratio is relatively large then the contrast is more likely to be real. Other factors were considered, including good regional data coverage and minimal duplication of predictive map patterns, although particular predictive maps can introduce an element of bias to the analysis because of conditional dependence issues.

Prospectivity Modelling

Sixty binary and multiclass predictive maps of geological variables were tested for their spatial associations with the training data. Evidence for sources of heat and mineralised fluids comes from dyke structures that are used here as a proxy for deep crustal cracks that existed well before Mesozoic dyke emplacement and most likely were present at the time of gold mineralisation. Metallogenic trends delineated by statistical analysis of mineral occurrences also provided evidence for the source of heat and fluids. Fluid transport proxies were identified to be closely associated with faults and shear zones, with different fault orientations and lengths analysed for correlation with known deposits. Another indicator of fluid pathways is silicification, mapped indirectly using the DEM (see section below).

Table 1. Predictive maps used in the orogenic gold prospectivity model.

Mineral System	Description	Variable	C	StudC
Source of energy and fluids	Proximity to dyke structures	750 m buffer	2.1	4.9
	Proximity to metallogenic trends	100 m buffer	3.0	6.9
Migration pathways	Proximity to thrust (D2) faults	200 m buffer	2.7	6.1
	High fault density	High	1.3	2.9
	Proximity to large scale topographic ridges	1600 m buffer	1.3	2.9
Formation of trap	Proximity to high lithological competency contrasts	300 m buffer	2.4	5.5
	Proximity to fault bends	1100 m / 550 m buffer	2.5	5.7
	Proximity to fault intersections	1850 m / 450 m buffer	2.3	5.2
Deposition of metal and outflow of fluids	Proximity to graphitic alteration	1950 m buffer	1.7	2.3
	Proximity to high lithological reactivity contrasts	300 m buffer	2.8	5.9
	Proximity to granite contacts	300 m buffer	2.1	4.6
	Proximity to mafic contacts	550 m buffer	1.9	4.2
	Anomalous Au in soil	> 100 ppb	4.8	4.7
	Proximity to high magnetic slope	350 m buffer	1.9	2.5

Trap formation (e.g., formation of a highly effective fluid channel) is one of the most important variables in any hydrothermal mineral system as the trap will determine the size and continuity of any resulting ore body. Zones of relative dilation mapped from fault data are found to occur at fault intersections and bends. Lithological trap and deposition controls occur where contrasts in rock competency and chemical reactivity result in metal deposition, which have been identified using geological mapping to distinguish brittle-ductile rock unit contacts. Good

evidence for the efficiency of metal deposition comes from geochemical anomalism for gold. Soil samples provide reasonable geochemical coverage in the Kumasi Basin and have a good correlation with the training data. A high gradient within regional magnetic data also proved valuable by identifying the presence of alteration and ore deposition.

The selected predictive maps (Table 1) were combined into a single prospectivity map to give a spatial representation of the geological potential of the entire Kumasi Basin. Each grid cell in the map contains a posterior probability value that is a unique combination of the input map variables. The prospectivity map for a small section of the Kumasi Basin is shown in Figure 2.

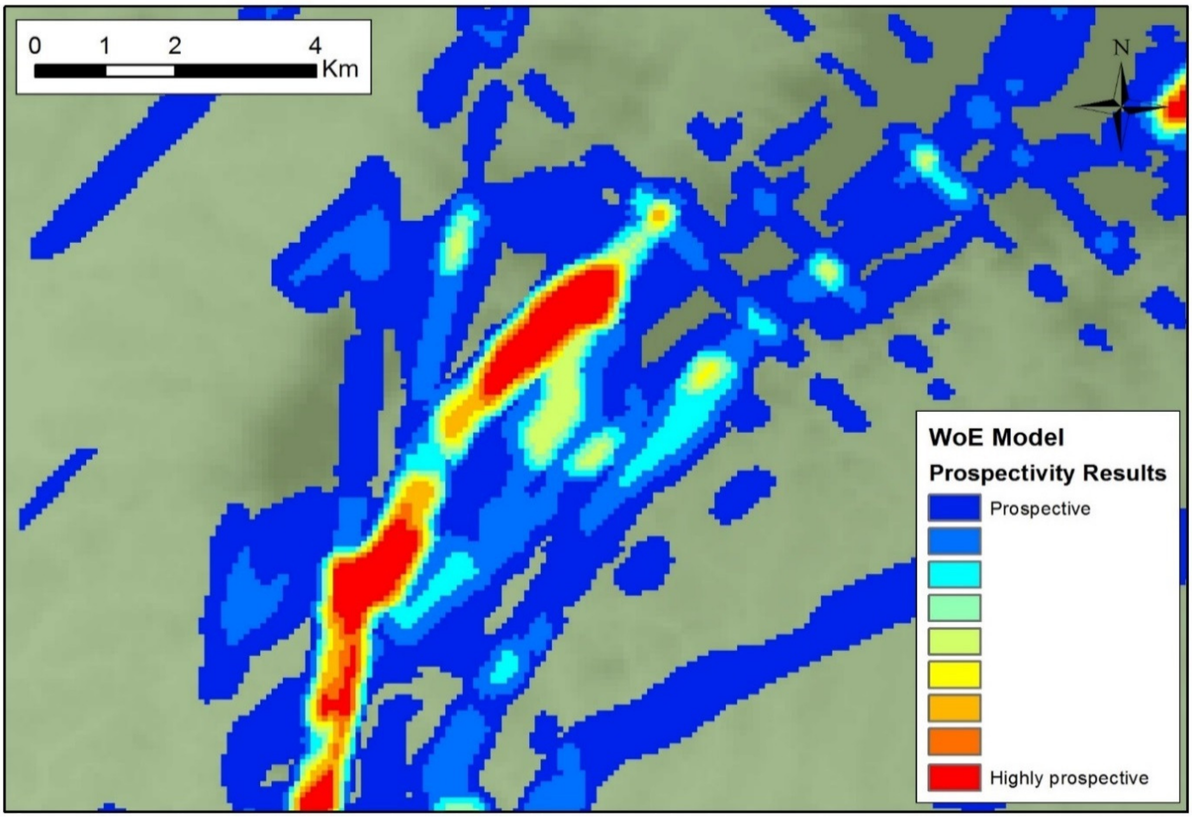

Figure 2. WoE prospectivity model result over a small area of the Kumasi Basin. This map of geological potential highlights areas ranging from blue (prospective) to red (highly prospective).

Missing Data

A key advantage of WoE prospectivity modelling is that statistical methods ensure that when the final geological potential grid is created, areas with missing data coverage are not significantly down-weighted relative to areas known to be anomalous. This is important in regions with uneven data distribution, such as the Kumasi Basin, as it prevents data-poor areas from being classified by the model as unprospective, and thus be written off for future exploration. In addition, it is not always the targets with the highest geological potential values that offer the best chance for discovery, but also targets with moderate geological potential values due to missing data that has not yet been collected. If the missing data is acquired and contains positive indicators for mineralisation, the prospectivity of these exploration targets would be upgraded. Conversely, if missing data were not anomalous, targets would be down-graded in their priority. Although the prohibitive cost and resulting lack of gridded geophysical data in the Kumasi Basin is a drawback, the effect of this on modelling prospectivity can be minimised by using the WoE method, which statistically compensates for this missing data.

Methods of Analysis

Geological and geophysical data covering the Kumasi Basin has broad, low resolution coverage over the majority of the basin, however all of the obtainable high resolution data is focussed on the central Asankrangwa Belt. High resolution data also exists over Perseus Mining's Edikan gold deposit in the eastern Kumasi Basin but this data is not available for analysis. The available data required creative analysis to extract as many useful aspects as possible in order to create a successful prospectivity model. Some of these analysis methods are described below.

Topographical Data

Orogenic gold deposits in the Kumasi Basin are commonly more resistant to weathering and form ridges, suggesting the presence of broad zones of silica flooding into possibly hidden fault systems. Topographic data has been used to map ridges and high points, which are believed to reflect a mappable expression of the fault systems that played a critical role in the transport of the gold-bearing fluids. Geophysical software was used to extract and analyse linework from the DEM open-file data (Figure 3). Ridges were extracted as polylines at more and less detailed scales and attributed with relative strengths and orientations. Each subset was tested for correlation with the training data. Major northeast-trending ridges had a good spatial association with gold mineralisation, but the best correlation was with the major topographic ridges in the Kumasi Basin, identified as those attributed with high strength values at the less detailed scale.

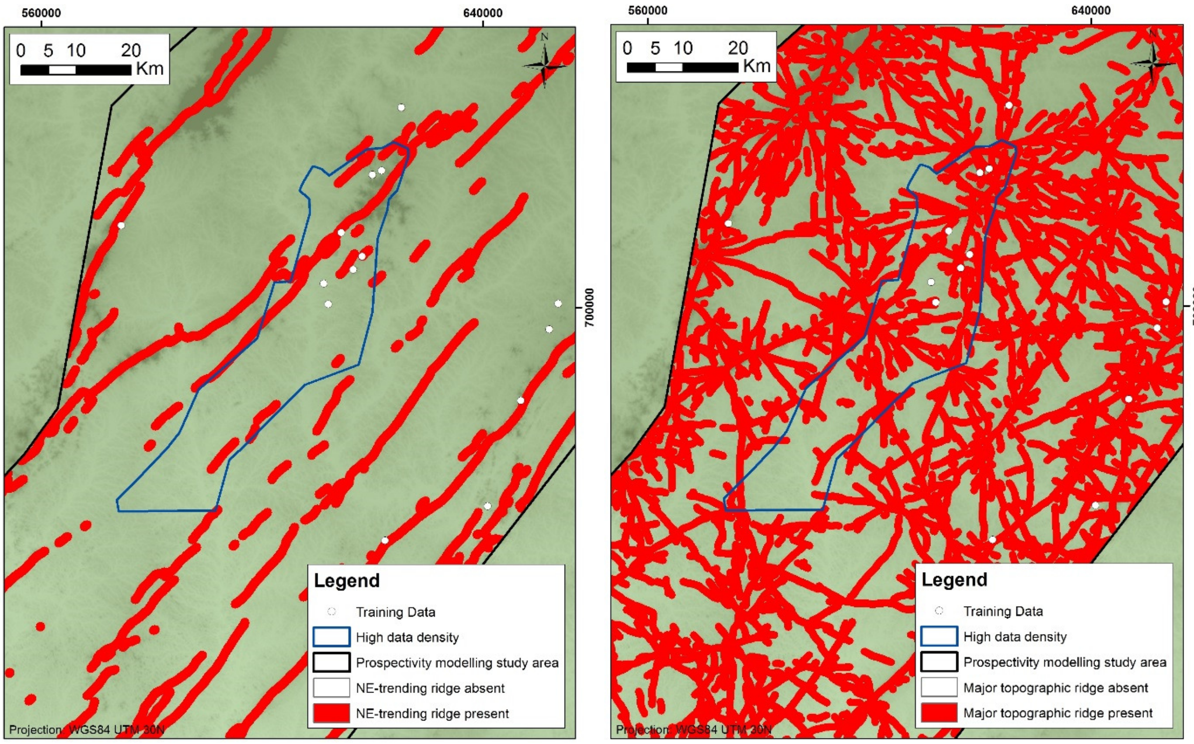

Figure 3. Predictive maps displaying only northeast-trending topographic ridges (left) and all high-strength topographic ridges (right). Both at the less detailed scale.

Geophysical Data

Multiple high resolution geophysical grids cover the Asankrangwa Gold Belt within the study area, including radiometrics, EM, TMI as well as a number of filtered derivative grids generated within the current study. A lower resolution GeoTIFF image of RTP magnetics covers the entire

study area but is not digitally attributed to allow full analysis. Magnetic highs often represent particular lithologies or alteration zones, while high gradients in magnetic intensity can be used to map buried contacts and structures. Spatial analysis of the regional TMI revealed the red colour band as the best available proxy for magnetic signal (Figure 4). The image was reclassified into a GIS grid, allowing the correlations with training data to be tested without the need for acquiring expensive gridded TMI data. While the high and low magnetic values did not have a strong association with potential mineralisation, areas with a high magnetic gradient demonstrated a significant correlation with orogenic gold training data.

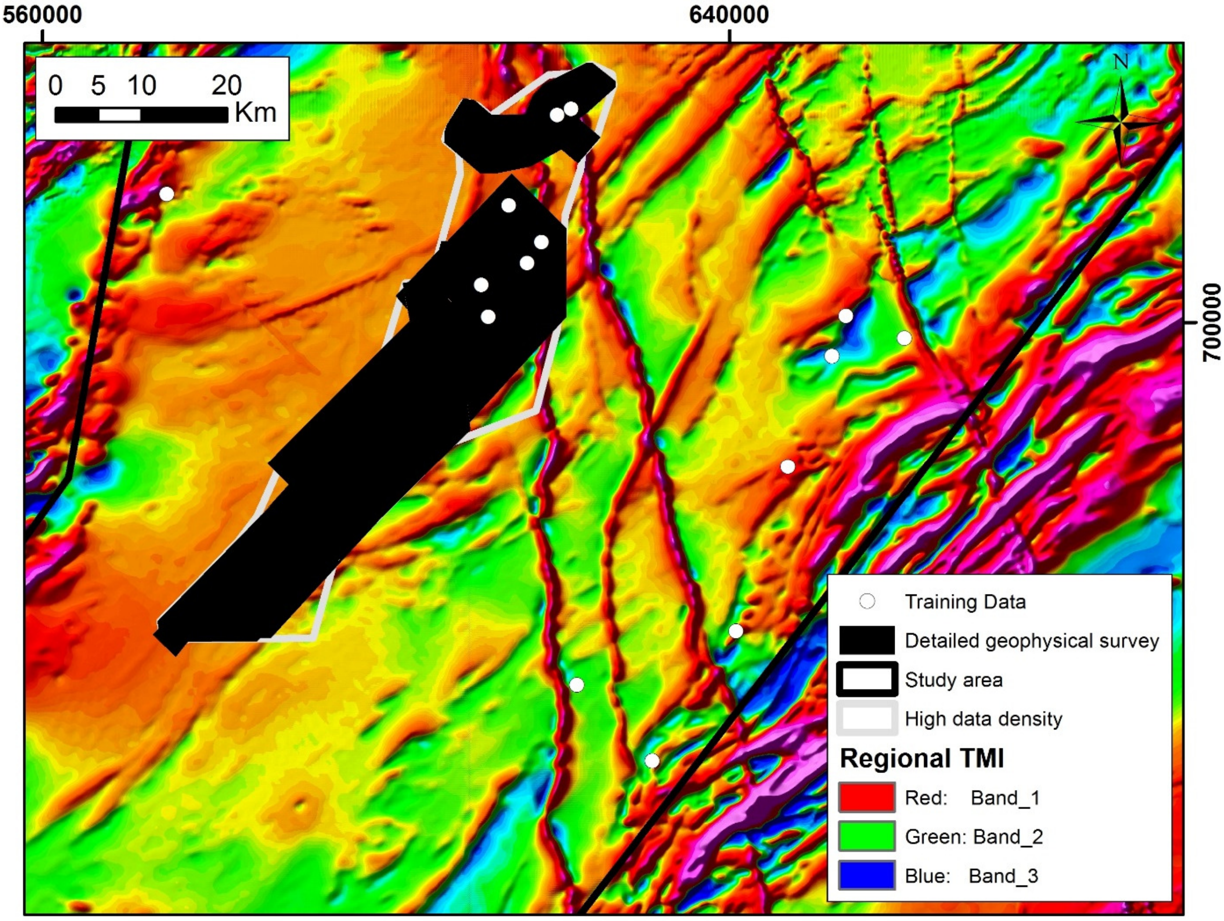

Figure 4. Coverage of detailed geophysical surveys underlain by regional aeromagnetic GeoTIFF. Detailed company geophysics is not shown due to the sensitive nature of the data.

Lithology Data

Regional lithological control on mineralisation is an important predictor for orogenic gold systems in the Kumasi Basin. The lithology data supplied by Asanko and significantly enhanced through a structural interpretation by the authors was further updated to include attribute fields for main lithology, competency and reactivity, allowing spatial analysis based on the dominant lithological characteristics of each region. A map of competency contrast could then be created (Figure 5), displaying areas where lithology varied to different degrees across a contact, from highly competent (e.g. granite) to less competent (e.g. phyllite). Contacts between lithologies with widely different competencies are often important indicators for mineralisation, rather than lithologies attributed with absolute high or low competency values. This same process was undertaken to map the contrast between lithological reactivity values. A good correlation with known mineralisation was achieved, showing that mapping the contacts between rocks of low

reactivity (e.g. quartzite) and high reactivity (e.g. carbonates) is successful in identifying the locations of possible chemical gradients that create a trap for mineralised fluids.

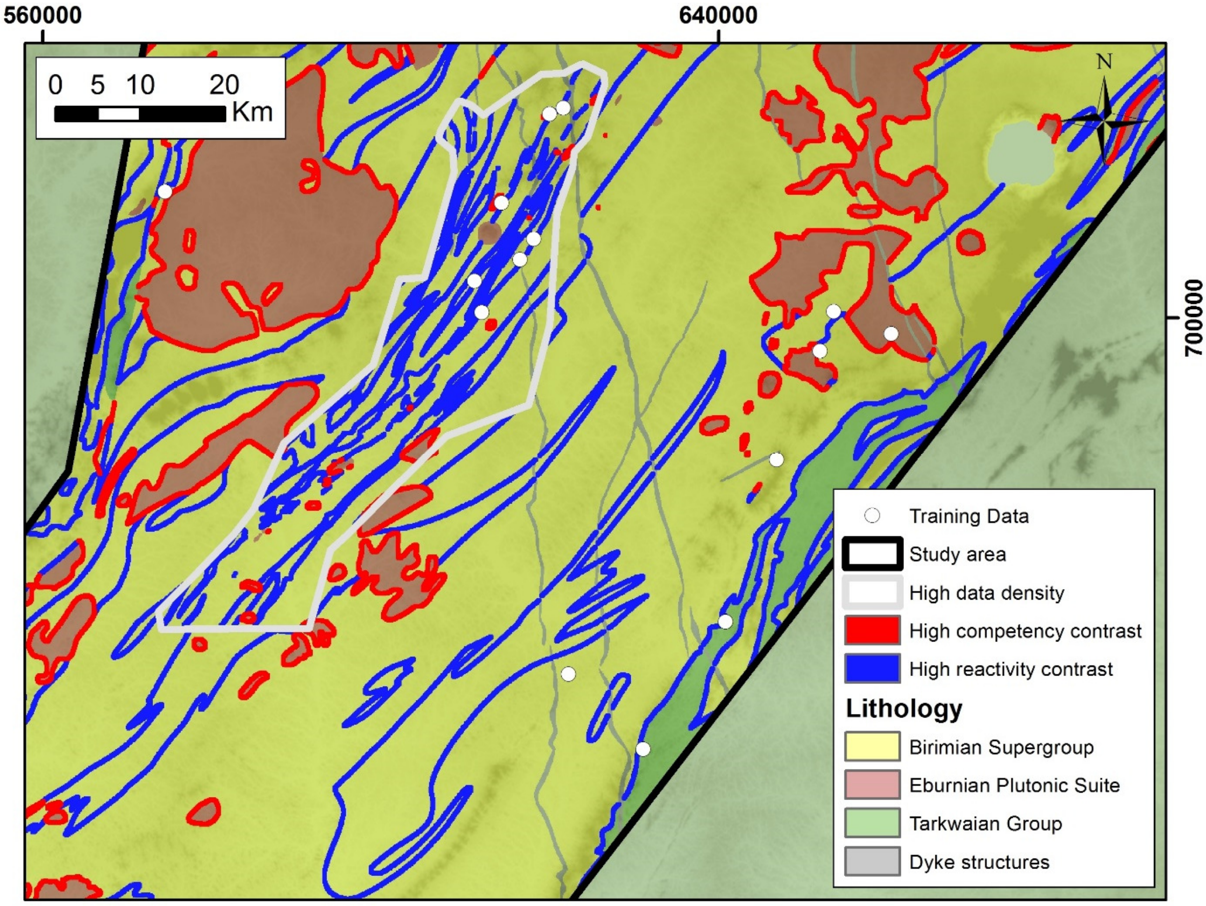

Figure 5. Map highlighting areas of high contrast in lithology competency and reactivity values, overlying the three main geological formations in the Kumasi Basin.

Geochemical Data

The predictive geochemical layers in the GIS were created based on gold-in-soil assay data, the only pathfinder element described from the mineral system model that is currently available. 1169 orogenic gold mineral occurrences, including many placer deposits, were added to the 79,505 soil data points. One mineral occurrence was deliberately assigned a low soil gold value of 5 ppb to statistically balance the geochemical predictive map and prohibit a perfect correlation with the training data, which would have significantly skewed the prospectivity model. The Bokrobo mineral occurrence was chosen as it coincides with most other predictive variables that have good spatial correlations with mineralisation indicators, so its geological potential was not down-weighted significantly in the final model.

A second gold-in-soil value was assigned to each sample location based on a weighting system, designed to favour samples located on topographic highs (associated with silicic alteration and major faults) and coinciding with mapped outcrop or saprolite over those located within alluvial domains. Gold-in-soil values less than 200 m from ridges identified from DEM data kept their value, whereas gold-in-soil sample points located (i) more than 200 m from ridges but over mapped outcrop or saprolite were applied a 0.7 weight, and (ii) more than 200 m from ridges mapped over alluvium were applied a 0.2 weight. Weighting classes within data layers in this

manner adds a fuzzy logic methodology component (Carranza, 2008) to the model and results in an excellent indicator of potential mineralisation in this hilly terrain with broad alluvial valleys.

Conclusions

Mineral prospectivity modelling using the WoE technique identified numerous areas with high geological potential for orogenic gold in the Kumasi Basin. The resultant prospectivity map illustrates the probability of finding a gold deposit based on input predictive maps that represent the mappable proxies of the underlying orogenic mineral systems model. The prospectivity map has been reclassified above the prior probability to define and rank targets that are highly prospective for gold mineralisation. The model has successfully identified areas of known gold mineralisation in the Asankrangwa Belt, an area of high data density within the Kumasi Basin, validating the results.

The uneven distribution of available geoscience and exploration data in the Kumasi Basin posed a challenge with respect to identification of targets in data-poor areas beyond the Asankrangwa Belt. The WoE method proved to be an ideal tool for handling this challenge because it can (i) statistically compensate for areas of missing data, (ii) prevent dismissal of potential targets whose lower prospectivity values are solely due to lack of data, and (iii) ensure that the weighting of predictive features is not heavily influenced by areas possessing missing data. Additional techniques, such as astute use of DEM data and GIS tools for spatial analysis, considerably add to the ability of prospectivity modelling to evaluate comparatively poorly-explored areas. Therefore, through creative use of all the available data, targets could also be defined in the very large data-poor domains of the Kumasi Basin.

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