The Konongo Gold Project, Ghana: An Example of How Geology Makes All the Difference to a Resource Estimate

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A B S T R A C T

The Konongo Gold Project is located on the western margin of the 125 Moz Ashanti Gold Belt in Ghana, West Africa. It is situated 60 km along strike of the world-class mineral system at Obuasi and is interpreted to lie on the same controlling regional shear system.

The project is operated by Signature Metals, a subsidiary of the Liongold Corporation, and is managed and funded by the Liongold Corporation.

Historic underground operations at Konongo produced 1.6 Moz Au at a head grade of 11.8 g/t Au, from eight operations spread along 16 km of the shear system. Mining focused almost exclusively on free-milling gold in quartz, ignoring the gold-bearing sulphide mineralisation associated with the quartz veins. Underground mining ceased in 1986.

In 2013, Signature Metals re-focused the programme at Konongo to assess the viability of mining the sulphide ore sustainably. This led to the first campaign review of the historic underground data and resource potential since mine closure. The Obenemase mine was the first of the eight operations to be assessed as part of this campaign.

Large amounts of legacy data have survived for Obenemase and several historic resource estimations have been completed based on these data. The data typically consisted of hand-drawn sections and plans, and ledgers of commonly incomplete drilling and sampling data. Some drill core have been lost over time, but a large amount of quarter- and half-core as well as pulps and rejects are still available. Previous resource estimates had a low confidence value because all the available assay and geological data were integrated effectively with the estimates, resulting in a lack of understanding of both grade and geological continuity.

This project built a new geological model for Obenemase that greatly enhances the understanding of the controls on mineralisation using a thorough approach of re-surveying, re-cataloguing and re-logging. This model led to an increased degree of confidence and a subsequent upgrade of resource classification, and created several previously unrecognised strong exploration targets. The resulting resource estimates increased the value of the project by 100%.

This paper emphasises and highlights the importance of a well-understood geological model on the confidence of a resource estimate and how this may directly impact on the project's "bottom line".

INTRODUCTION

The Konongo Gold Project is situated on the western margin of the 125 Moz Ashanti Gold Belt in Ghana, located 60 km along strike from the world-class mineral system at Obuasi. It lies on the same controlling regional shear system.

Managed and funded by the Liongold Corporation, the project is operated by its subsidiary, Signature Metals.

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Underground mining ended at Konongo in 1986. Historic underground operations produced 1.6 Moz Au at a head grade of 11.8 g/t Au, from eight operations spread along 16 km of the shear system. Mining was focused almost exclusively on free-milling gold in quartz, rather than the gold-bearing sulphide mineralisation associated with the quartz veins.

Signature Metals re-examined the programme at Konongo in 1986 to assess the viability of sustainably mining the sulphide ore. This resulted in the first campaign review of the historic underground data and resource potential since the mine was closed.

As part of the campaign the Obenemase operation is the first of the eight main operations within the Konongo Gold Project to be assessed. It was exploited underground up to the late 1970s with a total estimated production from free-milling gold in quartz of 29 500 ounces at a head grade of 8.5 g/t Au. Production from an open pit yielded 140 000 ounces of gold at a head grade of 4.7 g/t Au between 1988 and 1992.

At Obenemase, Signature drilled a total of 20 000 m of diamond, reverse circulation and aircore holes, complementing an existing 111 000 m of RAB, diamond, and reverse circulation holes drilled between 1972 and 2009 by previous operators. More than 5250 m of underground channel sampling and drilling was completed mainly in the 1950s and 1970s. Spacing between drill lines was 20 m for the entire length of the deposit (~1000 m).

Previous Mineral Resource estimations for Obenemase were completed by Mackay and Schnellmann (1986), Obenemase Gold (1995), RSG Global (2006) and Resolute Mining (2000). The last Mineral Resource was completed by Ball (2010) who reported a Mineral Resource of 6 875 500 tonnes at an average grade of 2.5 g/t for a total contained 552 693 oz Au.

GEOLOGY – REGIONAL

The Ashanti Belt is a well-studied orogenic belt and the most prominent gold-bearing structure of the Paleoproterozoic in West Africa (Figure 1). It marks the boundary between a continental domain (Archaean craton) and an oceanic domain (Birimian crust) (Feybesse, et al., 2006) and consists of the volcano-sedimentary rocks of the Birimian Supergroup and Tarkwaian Group which have both been intruded by granitoids.

The Birimian Supergroup consists of the Sefwi Group (composed of alternating micaschists, metavolcanics and intrusive rocks) and the Kumasi Group (metasediments, volcaniclastics and phyllites that are locally rich in graphite) (Adadey, et al., 2009; Perrouty, et al., 2012). The Tarkwaian Group consists of a variety of sandstones (quartzites), conglomerates, argillites and phyllites (Griffis, et al., 2002).

The belt's genesis is generally related to two phases of the Eburnean orogeny 2.19–1.98 Ga (Perrouty, et al., 2012). Some parts of the timing and subdivision of the various deformation, sedimentation, mineralisation and intrusion events are the subject of debate with Allibone et al. (2002a) proposing five deformation phases between 2.20 and 2.09 Ga; Feybesse et al. (2006) proposing three deformation events between 2.13 and 1.98 Ga; and Perrouty et al. (2012) proposing six deformation phases between 2.19 and 2.05 Ga. The understanding of the main deformation phases in most recent studies appears to be largely aligned; however, the timing of gold mineralisation also remains somewhat contentious. Oberthür et al. (1994), Blenkinsop et al. (1994) and Perrouty et al. (2012) suggest that mineralisation occurred during all stages of deformation. Allibone et al. (2002b) suggest timing of mineralisation to be a late phase of ductile–brittle deformation. Feybesse et al. (2006) identify primary gold mineralisation emplaced during stage D2 while Mücke and Dzigbodi-Adjimah (1994) conclude that mineralisation was post-metamorphic (Berge, 2011).

Four major types of primary gold mineralisation are present in the Ashanti Belt: (1) mesothermal, generally steeply dipping quartz veins in shear zones; (2) sulphide ores with auriferous arsenopyrite and pyrite; (3) sulphide disseminations and stockworks in granitoids; and (4) paleoplacers of the Tarkwaian Group (Oberthür, et al., 1996).

GEOLOGY – PROJECT SCALE

Most of the rock types that make up the generic fabric of the Ashanti Belt can be found within the project area. The sequence within the project area comprises rocks of the Birimian Supergroup (Kumasi and Sefwi Groups), Tarkwaian Group, Voltaian Group and basin granitoids (Figure 2).

Birimian metavolcanics of the Sefwi Group are the oldest rocks in the area and include basalt flows, andesites, tuffs, and metasediments. They occur within two SW–NE trending subvertical to steeply west dipping corridors. They include what is typically described as the "Mine Sequence", which is a ~150 m

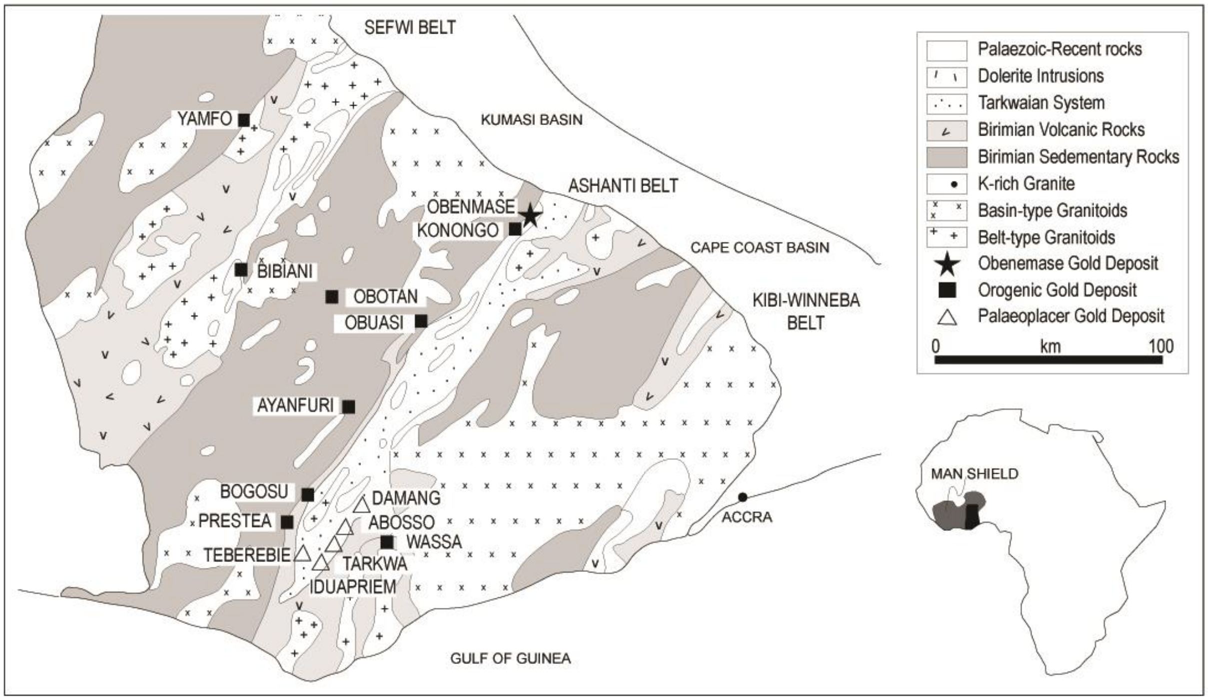

Figure 1 SW Ghana geology

package of tuffaceous and volcaniclastic metasediments in which most economic mineralisation within the project area occurs.

Sefwi Group rocks have been intruded by diorites and lamprophyres. Diorites occur as stocks and radial dyke swarms and have been observed to cross-cut stratigraphy and mineralisation at Obenemase and Kwakawkaw prospects (Wolff, 1993; Porter, 2006). These rocks are likely equivalent to those described by Feybesse et al. (2006) in a more regional context, where they were determined to have intruded around 2.16–2.15 Ga, marking the creation of the first segments of a Paleoproterozoic continental crust.

The Sefwi Group appears to be stratigraphically overlain by volcaniclastics of the Kumasi Group (Birimian) to the far west of the area (Wolff, 1993); however, Perrouty et al. (2012) have shown this contact to be regionally diachronous through a regional deformation event (D1, N–S shortening) commonly resulting in faulted and thrusted contacts.

Overlying Tarkwaian rocks consist of a series of conglomerates, coarse sandstones, well-sorted sandstones and siltstones that fine upwards. Within the area they have been interpreted to occur as an isoclinal syncline, which strikes in a northeasterly direction, and is overturned with both limbs dipping steeply to the northwest (Wolff, 1993). The contacts with the stratigraphically lower Birimian metavolcanics and metasediments corridors are structural.

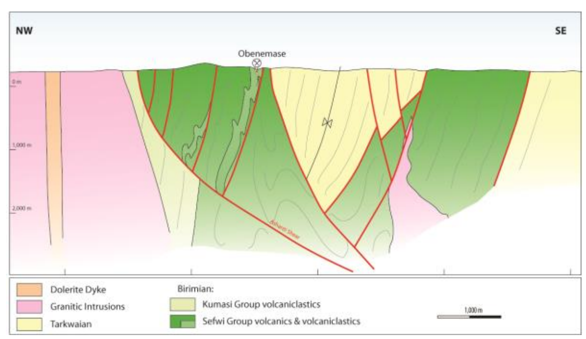

Figure 2 NW–SE section through the project area

Sefwi Group rocks have been intruded by a granodiorite sill to the south of the project area (Santreso prospect). The intrusion occurred along one of the bands of metasediments and volcaniclastics (Porter, 2006). Timing of the intrusion is not clear; however, comments in Griffis et al. (2002) suggest it is contemporaneous with Tarkwaian deposition. Regional work by Perrouty et al. (2012) broadly supports this, with the peak of Eburnean granitoid intrusions occurring around 2.10 Ga, which is during Tarkwaian deposition and the main D3 mineralising event (Perrouty, et al., 2012). Steeply dipping, low-

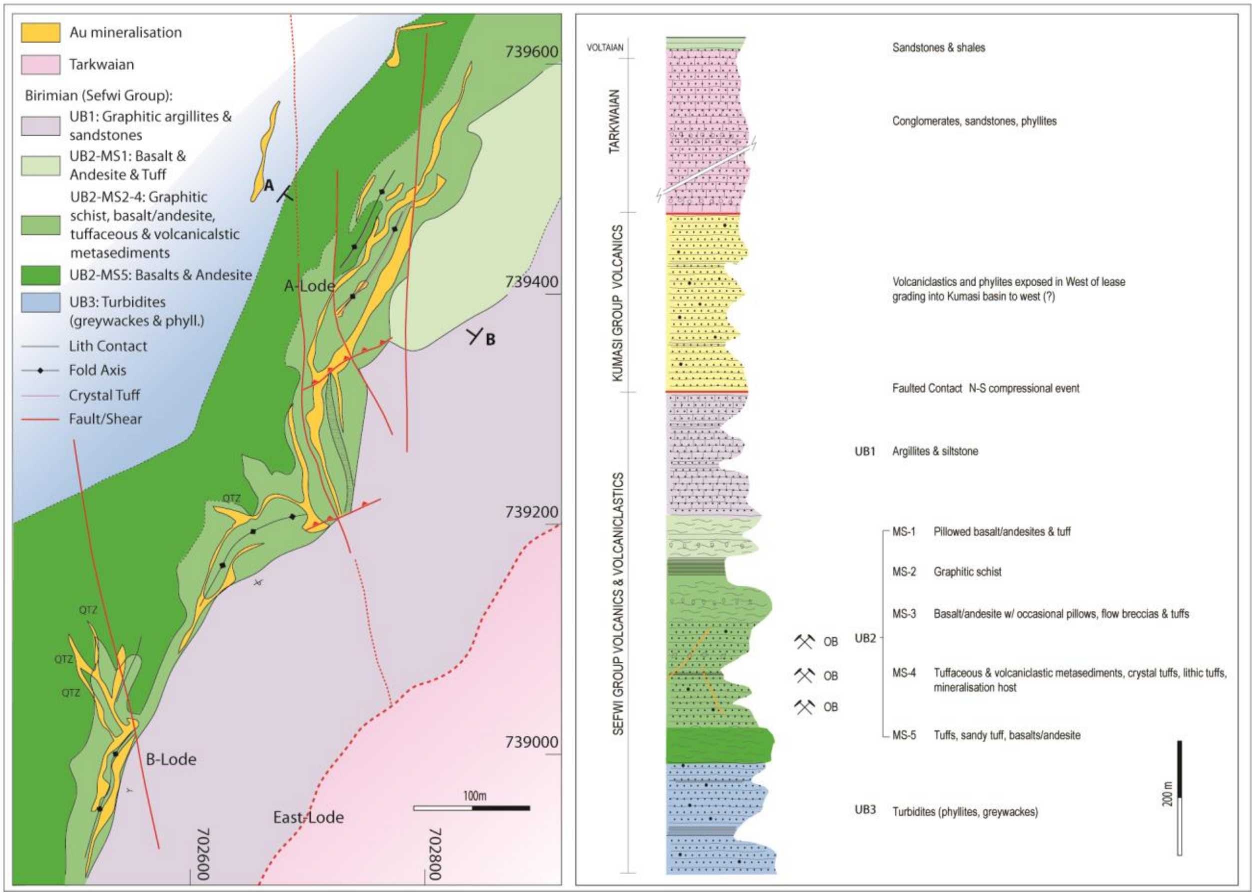

Figure 3 Obenemase geology, structure and stratigraphy for 250 mRL level (50 m below surface)

grade gold mineralised lenses occur within highly sheared, silica-ankeritie-chlorite altered granites (*sic*) (Reynolds, 1999).

Dolerite dykes of up to 300 m in width cross-cut the Birimian and Tarkwaian rocks within the project area. Regionally, they also cross-cut undeformed K-feldspar-rich granitoids that formed during the late Eburnean. Just outside the project area, to the north, they are overlain by younger Volta basin sediments.

Mineralisation predominantly occurs within the overturned western limb of the Sefwi Group metavolcanics and metasediments, with parasitic folds controlling the wider and higher grade mineralisation.

GEOLOGY – MINE SCALE

The Obenemase ore zones are hosted within Sefwi Group rocks. The stratigraphy has been described by Faulkner (1958) and Wolff (1993) as consisting of a lower turbidite member (UB-3), overlain by a volcanic-volcaniclastic "Mine Series" member (UB-2), which in turn is overlain by another turbidite member containing graphitic argillites and siltstones (UB-1). This sequence has been metamorphosed to amphibolite facies and intruded by diorites and lamprophyres which cross-cut the stratigraphy and mineralisation (Wolff, 1993). See Figure 3 for an overview of the geology.

The stratigraphic sequence is commonly overturned and steeply NW-dipping (younging towards the SE) to subvertical. It has been interpreted to represent the overturned NW limb of an isoclinal syncline that describes the overall geometry of the project area (Faulkner, 1958; Wolff, 1993). The sequence is wedged in between the main Ashanti shear to the NW and the Obenemase shear to the SE (the latter interpreted to be a lower-order back-thrust to the Ashanti shear zone, see Figure 2). The macroscopic isoclinal folding and shear zones are related to NW–SE thrusting at the onset of the Eburnean orogeny D1

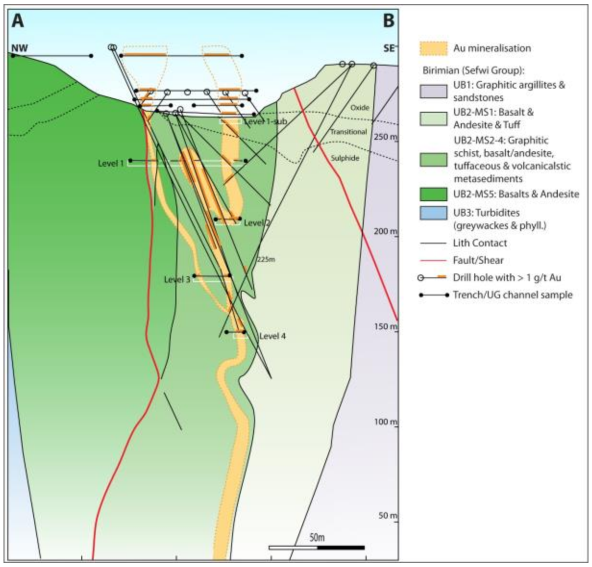

Figure 4 Obenemase cross section 10 020n

(Feybesse, et al., 2006); and D3 (Perrouty, et al., 2012).

Most economic mineralisation is controlled by parasitic and fault-drag folds. Parasitic folds are isoclinal and have a fold axis that plunges ~40 degrees to the NE. Geometries of both types of folds are controlled by the Obenemase shear zone as well as a pervasive set of N–S (350°) faults with oblique (sinistral-reverse) movement (Figure 4). These folds and faults were likely formed contemporaneously with the regional change in stress regime to NNW–SSE shortening and accompanying sinistral shearing on the main shear zones D2 (Feybesse, et al., 2006); and D4 (Perrouty, et al., 2012).

This change in stress regime, in combination with a preceding period of reduced tectonic activity between the two deformation events (stress quiescence) and uplift, led to increased crustal permeability and the main phase of circulation of gold-bearing fluids at Obenemase, similar to the nearby 60 Moz Obuasi mine.

Two styles of mineralisation are present at Obenemase: an early disseminated sulphide phase and a later quartz vein phase.

The preferred host rocks for disseminated mineralisation are the volcaniclastic and tuffaceous metasediments within the UB-2 member, which commonly display intense silica and carbonate alteration. They also contain disseminated, acicular arsenopyrite and subordinate pyrrhotite. The high-grade zones usually correlate with the most intensive alteration, which, although dominated by silica and carbonate (ankerite), also includes sericite and finely disseminated iron oxides (hematite). Finer grained sediments are better hosts for mineralisation. Fold hinges of isoclinal NE-plunging folds within volcaniclastic and tuffaceous metasediments are ideal hosts due to their dilation during deformation, leading to Bendigo-style saddle, neck and leg geometries.

These geometries also apply to quartz vein mineralisation, which occurs mostly parallel to foliation as well as cross-cutting stratigraphy. They contain high-grade gold values (often well over 10 g/t Au) and are commonly in the order of 1–1.5 m wide. Most of the gold in these vein systems, which produced by far the bulk of the gold from the underground operations, is non-refractory and occurs as very small grains within the quartz as well as on surfaces and fractures within sulphide grains (Griffis, et al., 2002).

APPROACH

In order to create accurate grade distribution and geological models, the data needed to be of optimal quality. This is often a problem when dealing with historic resources, and, depending on budget, understanding and vision, is achieved with varying degrees of success. Executing such a project of data reconciliation requires commitment and careful planning. Belabouring the obvious, “rubbish in leads to rubbish out” – the mineral resource will only be as good as the data upon which it is based.

For Obenemase, a large amount of original legacy data have survived the years, including stacks of lever arch folders (containing drill logs, assay sheets, reports), large amounts of A0, A1 and A2 maps, 41 090 m of diamond drill core and 1,480 m of reverse circulation pulps. As is often the case, these data were poorly organised, not catalogued and not properly validated.

A 12-month programme of data reconciliation focused on validating and correcting these data. The process included field checking and correcting location data, verifying assay and quality control data and verifying mine production data. In addition, all available core was re-logged and re-sampled where required. New data were recorded for recovery and density of all core.

Three-dimensional geological and grade shell models were subsequently constructed using the newly collected and validated data.

RESULTS

Location data

The location of old drill hole collars proved to be one of the main deficiencies in the dataset. Since a large proportion of holes were drilled before the onset of GPS, and various "local grids" had been used and abused by previous explorers, these required careful assessment and correction.

Using a digger, remnants of drill collars (PVC and steel pipe, cement plugs, etc.) were exposed and resurveyed. Since most collars were lost in the pit or had their PVC removed, care was taken to collect enough survey data from each drill campaign, across a good geographic spread of the drill area, and from each drill type, to assess the relative errors and their drift for each subset. Holes were surveyed on the WGS84 datum and subsequently converted to a new, corrected local mine grid.

The results showed errors of up to 12 m on the far ranges of the deposit (Figure 5). There were enough re-surveyed collars for each subset to determine the trend of the errors and therefore corrections could easily be made using second and third order conformal polynomial functions ("rubber band" correction). This resulted in a best-fit correction with a 30 cm standard deviation, which is considered a very good result, allowing all drill holes to be corrected with enough confidence to include them in the resource estimation process.

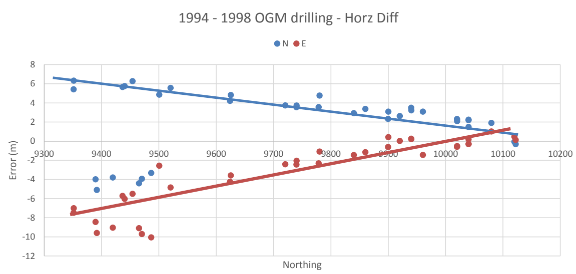

Figure 5 Error vs Northing for OGM series of drilling (1994–1998). The figure shows that the Easting values have an average error of 6–10 m at B-Lode (Northings of 9300–9500) which is furthest away from the local grid centre point of 10 000). Errors in both Easting and Northing diminish towards the centre of the grid, indicating a relatively consistent error. Note that the thick lines do not represent the second order conformal polynomial corrections and are only to indicate trend.

In addition to collar location data, downhole surveys can also influence the location accuracy of individual samples. Various previous operators or their consultants had made "corrections" to the original data, and by doing so, in almost all instances, in fact created more problems. To demonstrate the scale of the problem with an example, a series of 11 deep diamond holes were accidentally drilled towards 90 degrees east (WGS84) rather than the intended 90 degrees east *local* grid. It must have been assumed at some stage that this was an unlikely mistake to have been made and all figures were manually changed to 90 degrees towards *local* grid east (31 degree difference) both on original logs and in the database, resulting in ore intersections ending up 80 m in the wrong location for critical deeper parts of the ore body (Figure 6). The effect of these errors on interpretations and modelling, of course, is catastrophic. Errors such as these were only found by carefully double-checking the original single shot film discs for each hole in combination with exposing the collar in the field and re-surveying the azimuth of the collar. In similar fashion, important holes that were actually drilled down-dip of the ore body (perhaps intending to check for cross-structures) had been changed manually on the original paper logs by 90 degrees, as someone must have decided in hindsight that it was impossible to have drilled in that direction. Additionally, incorrect magnetic declination and angle conversions have been applied over the years. Hundreds of other issues were found and corrected.

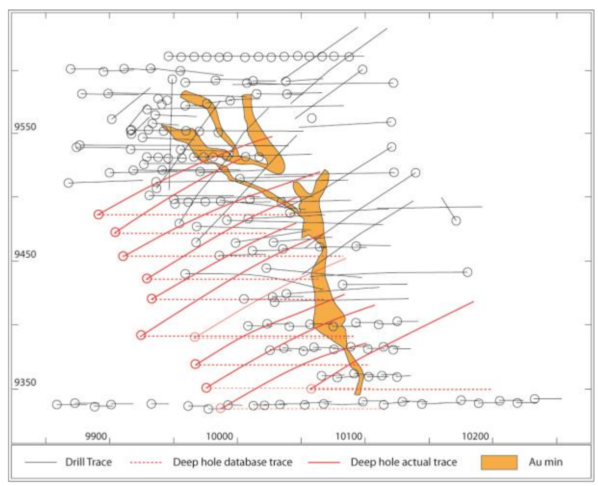

Figure 6 Incorrect azimuths for 11 deep diamond holes at Obenemase B lode.

Previous workers also noted that the uncertainty of the location of underground workings was an issue. Underground data such as underground sampling and geology had previously been dismissed as unlikely to add enough value in previous resource estimations. However, this study demonstrated that all available maps reviewed were, in fact, critical to establishing good variography from the close-spaced sampling data (~5000 m) as well as being important to establishing a sound geological model.

Rather than accepting the denoted grid lines to geo-reference the maps, for this study the two main shafts that occur on each map were located in the pit and re-surveyed, forming the base for all map geo-referencing. The result was that nearly all maps could now be brought into 3D geological software with great accuracy. This accuracy was verified by stope and drive intercepts in drill holes, which are now aligned almost perfectly with the locations as denoted on the maps. In some places the location error of underground drives compared to previous geo-referencing work was as large as 30 m.

Mine production data

Previously it was difficult to calculate the amount of stoped underground ore removed at this site, and all earlier applied solutions involved a compromise of some sort. This study's provision of accurate location data now allows for the construction of wireframes for stopes and drives based on a significant amount of information digitised from maps. The accuracy of the locations and shape of these voids can now be easily and accurately validated using the numerous intersections of stopes and drives in drill holes.

Assay data

A critical part of the data verification process included the verification of assay grades on which any resource estimations are based. This was carried out through: (A) visual validation of grades on sections; (B) checking of database values vs. original laboratory sheets or other hard-copy data; and (C) check-sampling a representative part of the available core and pulps to investigate bias.

The results revealed a large number of transcription errors that were easily rectified. Where errors were suspected but could not be rectified, holes were flagged to see if certain campaigns or series had systematic errors.

The check sampling programme did not reveal any bias above the cut-off grade; however, it did show a bias in the lower grade range (< ~0.6 g/t Au). The check samples clearly have lower grades than the original samples in this range. This can be attributed to the issues laboratories had at the time with accuracy close to detection limits. Even though at these low grades the resource models are hardly affected, it was decided to err on the side of caution and re-assay all samples in this range for which core was still available (~ 1800 samples).

Quantile-Quantile plots of distance-buffered sample data between good quality drill core and historic underground channel samples reveal a strong bias, with the channel samples producing consistently higher gold grades. These data were therefore used only to guide the wireframing and not for the estimation.

Density data

A total of 13 500 new density data samples were collected from the core using wet-dry water replacement techniques in a carefully controlled environment. Previous resource estimates were based on assumptions and poorly constrained values from unverifiable earlier work.

The resulting dataset is comprehensive and provides a representative spread of density data for all domains so that it can be properly estimated into the blocks. It also reveals a clear contrast in density between footwall sediments, the Mine Sequence and the hanging wall volcanic flows that supported the geological logging work.

Geological logging

Verification of the geology database formed a cornerstone of the work carried out for this study. Previous resource estimations were severely restricted by the lack of understanding of the geology. Geological continuity could not be properly demonstrated and grade continuity was also difficult to show due to the lack of knowledge on structure, lithology and mineralisation controls. This is directly apparent when looking at old sections, wireframes and interpretations; none showed any consistency, and when verifying the downhole geology data against any version of these interpretations it soon became clear that the geological database needed to be completely reconstructed.

The biggest problem with large projects that span many years and various drilling campaigns is that there have been many geologists involved with the logging and interpretation of them. No one single geologist will unconditionally log or interpret the geology 100% accurately and correctly. Coupled with this, the inclusion of a multitude of interpretations combined within the same database makes the data completely unreliable. Attempting to manipulate the data to fit (e.g. bulk changing logging codes) usually only makes matters worse and reconstruction from scratch is often the best solution.

Before re-logging started, a core library was constructed, consisting of two core trays containing type-pieces of specific lithologies, structures and mineralisation. These were photographed and printed along with descriptions on an A0 sheet. These formed the basis of, and quality control for, all logging.

The first few holes were logged “blind” by two geologists in order to remove bias and standardise the logging further. Both logs were kept as an indicator of quality control for later audits. Blind/cross-logging was repeated throughout the campaign to maintain quality control.

Geological interpretation & modelling

The results of the geological re-logging in combination with improved accuracy of location data allowed solid geological interpretations to be made, especially when combining the new data with properly geo-referenced underground mapping and pit mapping data. Additionally, the inclusion of 28 000 m of pit grade control trench samples enabled a very detailed impression of folding in the XY plane since the mineralisation is clearly controlled by lithology.

A 3D geological model was constructed for the entire deposit, with a specific focus on the features that most control the mineralisation: lithological contacts of the Mine Sequence host rocks, faults and parasitic folds. Both parasitic and fault-drag folds are clearly identifiable in the model and their northeasterly plunges conform to underground stoping.

Figure 7 shows an example of the difference between the new interpretation and an older one for section 9880N and the impact it has on geological continuity and grade continuity analyses.

Estimation domains

Using the 3D geological model as a main constraint, and using high-resolution grade control data from historic pit and underground operations, high-resolution grade shells have been constructed with significantly more detail than before, especially in the deeper parts of the model. The final wireframe consists of 11 000 manually triangulated planes. Because the structure is quite complex, with multiple orientation changes, faulting, folding and anastomosing patterns, “unfolding” as a preparation step for estimation has not been possible and the wireframe has been divided into several estimation domains depending on orientation.

Model & estimation

The Mineral Resource was estimated using 3D ordinary kriging and the estimation of domains grade shell wireframes to constrain the searches. This method was chosen because the nugget and coefficient of variation were quite low (~18% and <1.4, respectively) and domaining resulted in sound semi-stationary domains that were suitable for estimation using this method. A high-grade domain (following a plunging parasitic fold) was sub-domained for soft-boundary estimation. Block size and search parameters were optimised through Kriging Neighbourhood Analysis and estimation carried out in three passes, each one with looser search constraints on grade-capped data. Classification of the resource is shown in Table 1.

Table 1 Resource Statement

DRAFT FIGURES
TO BE CONFIRMED

	Inferred			Indicated			Measured			Total		
	Tonnes	Grade	Ounces	Tonnes	Grade	Ounces	Tonnes	Grade	Ounces	Tonnes	Grade	Ounces
Oxide				22,200	2.6	1,900	193,850	4.20	26,200	217,000	4.0	28,000
Transitional				70,000	2.9	6,600	317,200	4.09	41,700	391,000	3.9	48,500
Sulphide	435,000	3.0	41,000	2,183,000	3.3	229,500	2,374,250	3.84	293,150	4,991,250	3.5	563,300
Total	435,000	3.0	41,000	2,275,000	3.3	238,000	2,885,300	3.90	361,047	5,600,000	3.6	640,000

*Resources are reported at 0.5, 0.7 and 1.0 g/t cut-off for oxide, transitional and sulphide zones respectively.
**Inferred Resources exclude Indicated and Measured Resources.

SUMMARY & CONCLUSIONS

Evaluation of legacy data for the Obenemase project demonstrated that throughout its operating history there were significant flaws in data collection and interpretation, and, consequently, in the resource estimates. As a result, the project's potential has never been fully realised.

Unfortunately, for projects that are largely based on legacy data, these types of data collection and interpretation issues are common.

This paper emphasises that a thorough analysis of existing data, along with ground-truthing, re-logging and re-assaying can generate improved models as well as new exploration targets, and bring previously written-off projects back to life. It demonstrates that reworking the existing data leads to an increased understanding of the geology which is a critical ingredient for high-confidence resource estimates. In the case of this project, 12 months of work resulted in an estimated >100% increase in the value of the project.

Seemingly challenging projects like these can turn out to be significant opportunities when a company has the right vision, combined with a steady corporate strategy and the right technical expertise.

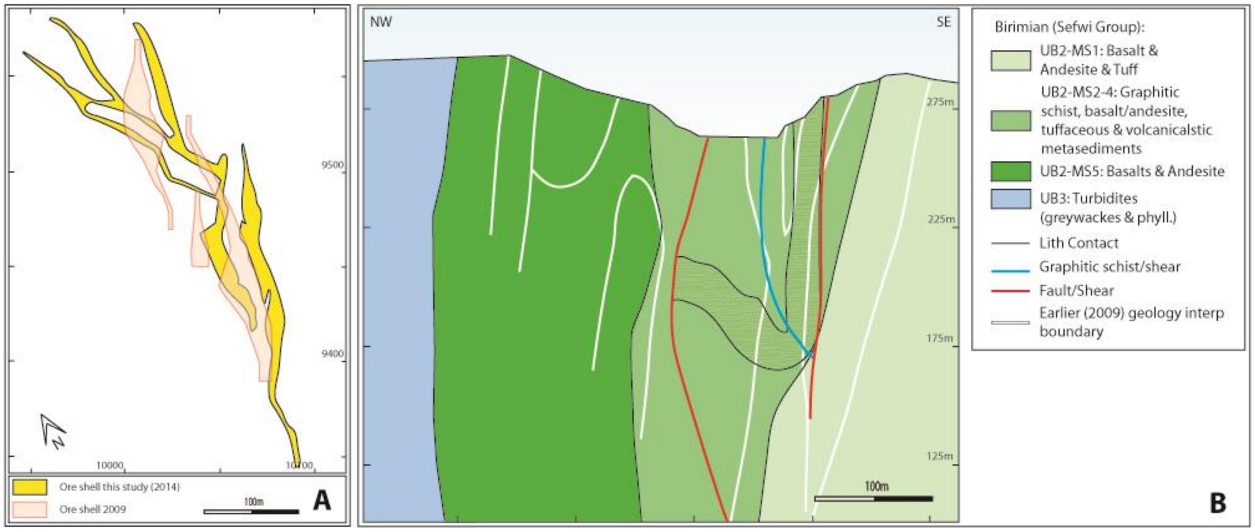

Figure 7 (A) Obenemase B-Lode ore shells in plan view: difference between 2009 and 2014 interpretations. (B) Transposition of previous geological section interpretation (white lines) on geological interpretation from this study (coloured polygons). Note the misalignment of most of the key boundaries and the lack of detail in interpretation of a clear fault drag fold.

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