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The Importance of Integrating Geological Mapping Information with Validated Assay Data for Generating Accurate Geological Wireframes in Orebody Modelling of Mineral Deposit in Mineral Resource Estimation: A Case Study in AngloGold Ashanti, Obuasi Mine

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Abstract

The basis of accurate mineral resource estimates is to have a geological model which replicates the nature and style of the orebody. Key inputs into the generation of a good geological model are the sample data and mapping information. The Obuasi Mine sample data with a lot of legacy issues were subjected to a robust validation process and integrated with mapping information to generate an accurate geological orebody model for mineral resource estimation in Block 8 Lower. Validation of the sample data focused on replacing missing collar coordinates, missing assays, and correcting magnetic declination that was used to convert the downhole surveys from true to magnetic, fix missing lithology and finally assign confidence numbers to all the sample data. The missing coordinates which were replaced ensured that the sample data plotted at their correct location in space as intended from the planning stage. Magnetic declination data, which was maintained constant throughout all the years even though it changes every year, was also corrected in the validation project. The corrected magnetic declination ensured that the drillholes were plotted on their accurate trajectory as per the planned azimuth and also reflected the true position of the intercepted mineralized fissure(s) which was previously not the case and marked a major blot in the modelling of the Obuasi orebody. The incorporation of mapped data with the validated sample data in the wireframes resulted in a better interpretation of the orebody. The updated mineral resource generated by domaining quartz from the sulphides and compared with the old resource showed that the sulphide tonnes in the old resource estimates were overestimated by 1% and the grade overestimated by 8.5%.

Keywords

Mineral Resource Estimation, Geological Models, Sample Data, Validation, Assay Data, Geological Mapping

1. Introduction

One of the most important steps in mineral resource estimation is the generation of accurate geological wireframes. For any mineral resource estimation process, geology is fundamental key to establishing good estimates without any issues [1]. In extreme situations, poor geological models can lead to resource downgrades. The development of a good geological model takes into consideration the limits and geometry of the mineralization, mineralization control and internal waste structures in the deposit [1]. The use of mapping data from underground, especially in a structurally controlled mineralization like the deposit in Obuasi Mine, is key to ensuring the style of mineralization, the geometry of the orebody, the limits of mineralization and orientation of the mineralized structures are fully replicated in the geological model.

Sample data validation plays an important role in the generation of wireframes and ensuring subsequent robust mineral resource estimation. The Obuasi Mine has been in existence for more than 100 years and had acquired enormous sample data enshrined with several legacy issues. This situation impacted early mineral resource estimations and mining operations. The mine sample data over the period actually require very rigorous validation to rid the data of all inconsistencies to ensure an accurate geological orebody modelling and mineral resource estimation. The purpose of this research work is to bring to light the importance of vigorously cleaning sample data which forms the foundation for resource estimation. Again, the research seeks to also highlight the importance of incorporating mapping information with sample data to generate wireframes for accurate resource estimation. The focus of this article is to illustrate the importance of sample data validation and the subsequent integration of the validated sample data with underground mapping information to generate accurate geological models that truly replicate the geometries, mineralization styles and orientations of the ore shoots in the mineral deposit. These geological models will then be used for resource estimations.

2. Geology of the Area of Study

The rocks within the Obuasi Mine (**Figure 1** and **Figure 3**) consists of basin

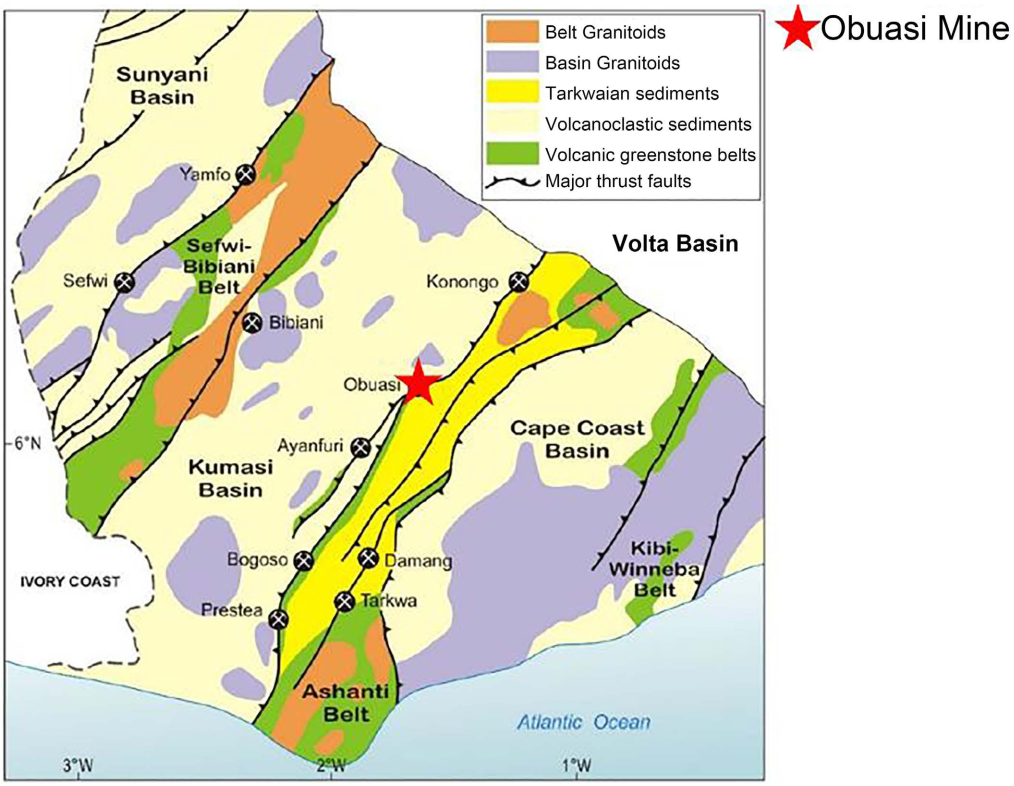

Figure 1. Location map of the mine.

volcano-sedimentary materials in contact with the greenstone belt rocks [2]. The major rock units of the study area include phyllites, greywacke and schist (meta-sedimentary) as well as meta-volcanics with limited linear features. Dolerite dykes crosscut the other rock units. The phyllites are slabby with strong foliations while the greywackes are massive with minor foliations. The schists are sheared with crenulation foliations. Graphitic schist is black friable schist with high carbon content that tend to soil the hand.

The rocks have undergone multistage deformation history with three main deformation events identified. The first deformational event (D1: Deformation 1) are rare bedding parallel shearing preserved as early foliations in the hinges of later folds. These foliations are folded and transposed by later structures and fabrics [3]. The second deformation event (D2) was related to regional NW-SE shortening [2]. Folds formed during this deformation event are called F2 folds. The F2 folds correlate with the first major phase of gold mineralization. Major laminated quartz veins developed within graphitic shear zones with disseminated gold-bearing arsenopyrite in the wall rock sediment [2]. This phase of gold defined as the sulphide ore. The latter stage of the D2 is marked by flattening and boudinaging of the early stage veins. The final major stage of deformation (D3) is marked by NW-SE shortening with the development of cross-cutting F3 folds (folds formed during D3 deformation) with axial planar S_3 crenulation cleavages. The high grade ore shoots with visible gold are located in the F3 fold hinges overprinting the quartz veins during the D3 deformation. Five major shear zones have been identified within Obuasi Mine, with the main prominent mineralized shear system showing anastomising structural pattern [4]. It extends roughly NE-SW over a strike length of about 8 kilometres and dipping largely to the northwest at between 65˚ to 90˚ [5].

Mineral deposits in the main shear system are characterized by strong pinch and swell geometries [3]. There are variations in thickness, continuity, dip and strike of mineralised deposits, thus presenting complex unpredictable geological geometries and grade distribution [5]. Other identifiable mineralised structures splay off the main shear also in an anastomosing structural pattern. The gold mineralisation in Obuasi Mine has a proven continuous lateral extent of about 8 km along strike and continues to an explored depth of over 1.5 km below surface. The meta-sedimentary rocks host the bulk of sulphide mineralization because they are more susceptible to ductile and brittle deformation. The ore zones are defined by the presence of mineralised quartz or presence of sulphides. The ore zones dip steeply to the northwest, comprising a thick mineralized quartz vein on the western side and sulphide ores disseminated between two graphitic shears, as shown in **Figure 2**. The main source of high-grade ore in Obuasi Mine is from quartz veins associated with coarse, visible free gold [4]. The second type is the disseminated sulphides (arsenopyrite predominant) in meta-sedimentary/metavolcanic rocks. The sulphide ores are of increasing importance, representing approximately half of the gold production, with typical gold grades in the range 4 g/t to 7 g/t.

The ore mineralogy in the area is dominated by arsenopyrites (60% - 95%) with lesser amount of pyrite, pyrrhotite, marcasite, chalcopyrite, and micro-grains of native gold [6]. The percentage of arsenopyrites increases with proximity to the quartz veins and graphite-rich shear zones. Petrography and micro-structural studies show that a large proportion of the gold-bearing arsenopyrites are disseminated in the meta-sedimentary rocks and aligned with S_2 crenulation cleavage [2]. The S_2 are crenulation cleavages produced from the second stage of

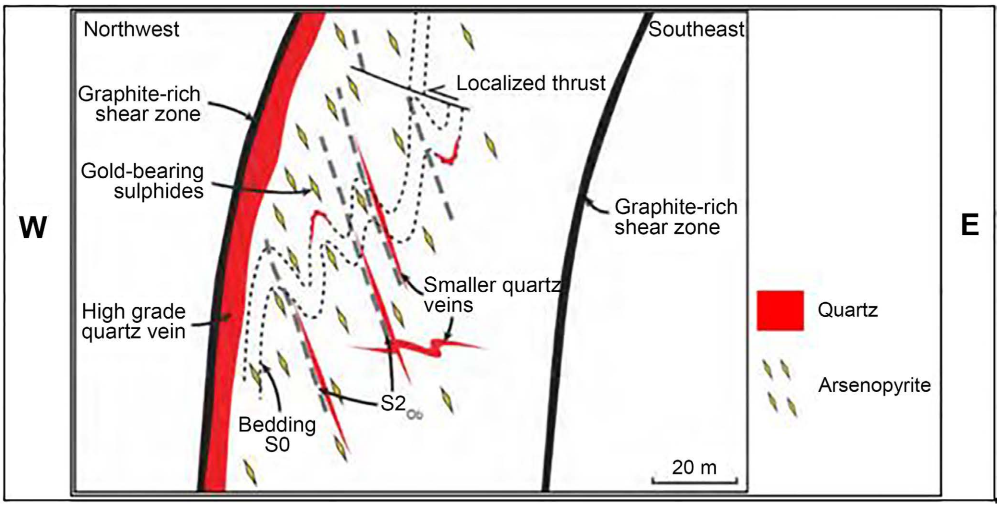

Figure 2. Schematic cross section through a typical ore in Obuasi Mine (after Fougerouse, 2014).

deformation in Obuasi Mine. This generation of gold-bearing sulphides is associated with quartz strain shadows parallel to S_2 crenulation cleavages.

3. Methodology

3.1. Validation of the Database

1) The very old drill holes information in the database have either missing collar coordinates or wrong downhole survey data or inputs of wrong collar coordinates or missing data on lithology or inaccurate entries of lithologies. Thus, the database was vigorously validated to clean it, for the geological wireframes. The strategy employed for this database clean-up, was to compare the information on the existing geology log sheets for all the drill holes to be used for the modelling with the data in the database. This ensured that collar coordinates, downhole surveys, assays and lithology information on the hard copy of drillhole log sheets matched with the electronic version of the same drillholes in the database. This was necessary especially for the collars in order to ensure the holes plotted correctly in space.

2) Metric conversion of assay values

Assay values which were entered as penny weight were converted to grams per tonne in the database. These conversions were necessitated as the mine migrated from imperial system to that of metric some years back, all previous imperial information had to be converted to metric. This was also achieved by comparing the original hard copy log sheets with the electronic data.

3) Magnetic declination of downhole Surveys

The main issue with most of the drill holes in the Obuasi Mine was that a constant magnetic declination of 10 degrees had been used since 1961 and had not been changed ever since. As the magnetic declination changes yearly, these changes should have been used in the planning of the drillholes. This was never done. Therefore, magnetic declination for all the drillholes in the sample data was corrected to match their respective drilling year.

4) Missing Data Issues

Missing data on lithology, mineralization and recovery tables was widespread in the database. The lithology code in particular is important as the de-survey function in Datamine software takes its primary downhole points from the lithology table. Due to the missing lithology in the database, de-surveyed holes always displayed gaps in drillhole traces. This situation is not ideal for modelling. The missing lithologies in the electronic database were fixed by using the lithologies provided in the descriptive field on the old hard copy log sheet. Some few instances of missing assay records were also encountered in the validation. The main source of reference again was the old hard copy log sheet. Inconsistencies found between the hard copy log sheets and the new database were flagged and fixed.

5) Confidence levels for all drillholes in new database

Confidence levels were assigned to all the sample data as part of the validation process. The drillholes and channel samples as part of the validation process were assigned confidence levels from one (1) which is the highest to five (5) which is the least. Drillholes and channel samples in the database which had their log sheets available and had the collar, surveys, assays and lithologies verified against the hard copy log sheet were considered as confidence one (1) holes. Those that did not have their hard copy log sheets available, in addition to missing collars, surveys and lithology information were considered as confidence five (5) holes. These confidence levels were used to measure the integrity of the sample data, while in modelling a quick appreciation of which data has the most and least confidence. This helped in making critical decisions with regards to geological interpretations in the modelling process. A confidence 1 sample data will always take precedence over a confidence 5 sample data while making interpretation in modelling of the orebody.

3.2. Geological Mapping

The mineralization style in Obuasi Mine is marked by strong pinch and swells with waste bands occurring within the broad mineralized zone. Underground mapping was carried out in existing crosscuts and reef drives in the study area to delineate graphitic shears within the fault zones. The graphitic shears at the Hanging Wall and Footwall contacts marking the main shear zone hosting the mineralization were clearly demarcated. The strike, dip and dip directions of the graphitic shears were recorded and plotted on the geology plan shown in Figure 3. The strike, dip and dip direction for the quartz veins in area in addition to the Footwall and Hanging wall contacts of the sulphide mineralization were also recorded and plotted on the geology level plans. Also, lithological contacts were mapped by differentiating greywackes and phyllites (meta-sedimentary rocks) dominant in the area and represented with the yellow colour as shown on the found. The geology plan generated from the mapping in addition to the sample

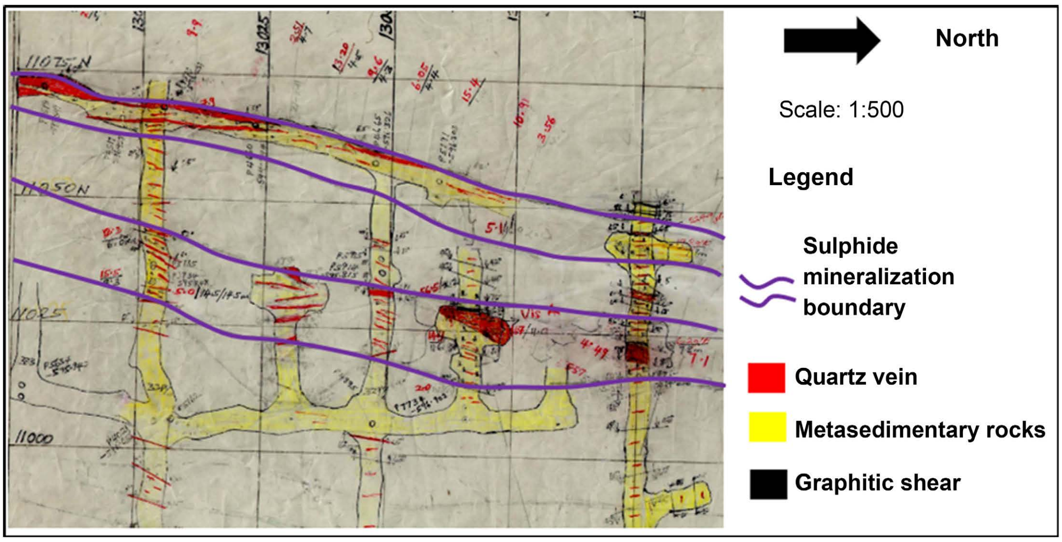

Figure 3. Geological plan showing key structures and lithologies that were mapped.

level plan shown in Figure 3 from meta-volcanics represented as green where data was uploaded in leapfrog software for the wireframes to be generated (Figure 4).

3.3. Wireframing Process in Leapfrog Software

Three dimensional wireframe of the orebody in Block 8 Lower in Obuasi Mine was generated with the uploaded mapping and validated sample data in leapfrog. The key principle followed in this process was always honouring the mapping data any time the drillhole data did not agree with the mapping interpretation as demonstrated. The drillhole data shown in Figure 5, by the red arrow indicated mineralization outside the main mineralized zone. The mapped crosscuts data was rather considered than the drillhole information, hence the mineralization boundary restricted to the mapped contacts. This borehole also turned out to be a confidence Five (5) hole which means that the data in the database could not

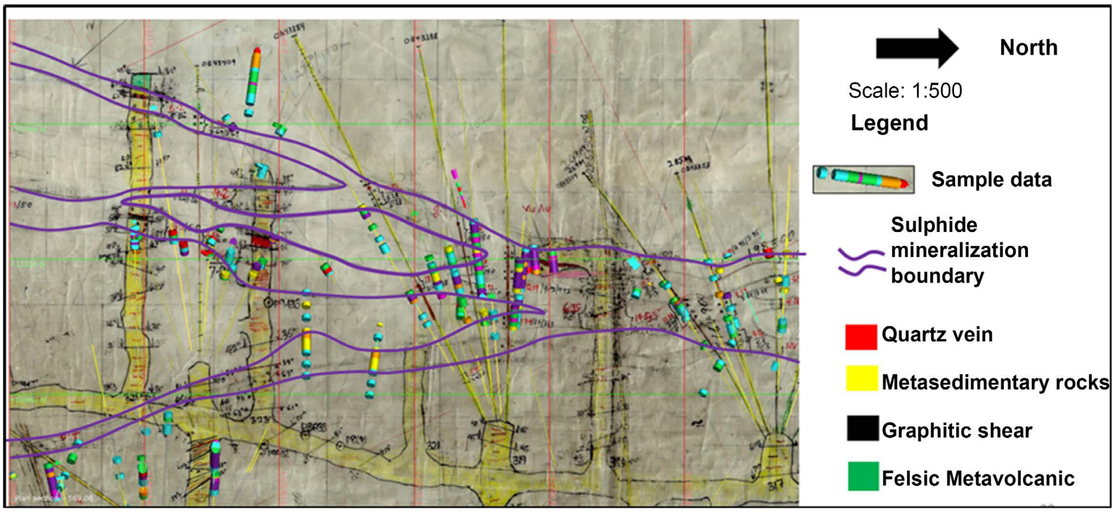

Figure 4. Geological plan superimposed with sample data in leapfrog for modeling.

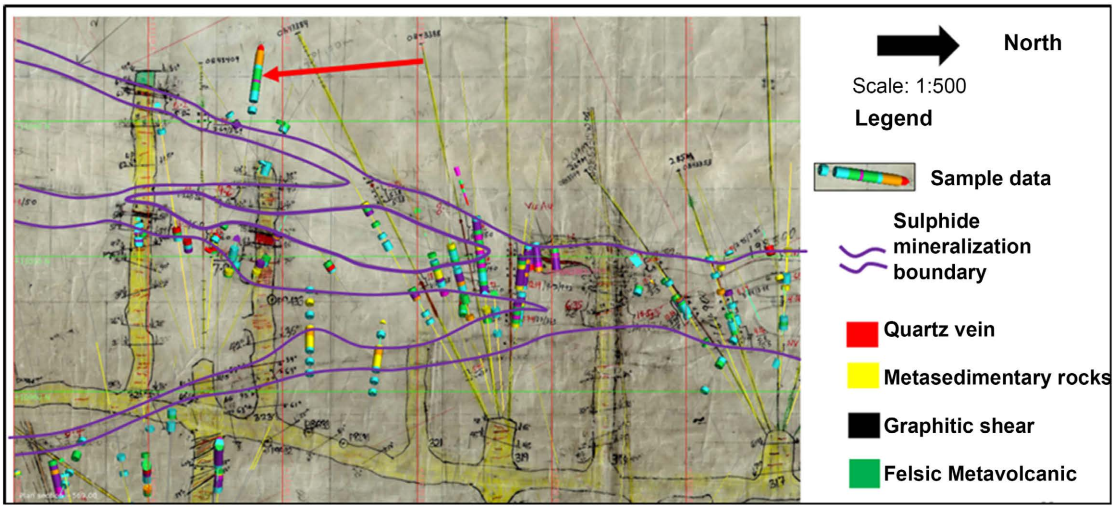

Figure 5. Geology plan showing a sample data plotting outside the main mineralized boundary (Red arrow).

be verified with a hard copy log sheet. The pinch and swell nature of the quartz vein coupled with the internal waste architecture in the sulphide mineralization, posed a difficult challenge in the modelling of the orebody. This difficulty was only managed by using the mapped data on all the elevations in tandem with sample data both in plan and section. The graphitic shears themselves are not mineralized, but an important control of mineralization in the study area was modelled mainly by making use of the graphitic shear exposures mapped underground. The mapped graphitic contacts were used because the graphite intervals in the drillholes are in most cases not very accurate. The inaccuracies in the thickness of the graphite in the drillholes arose from the fact that graphite tends to be washed during the drilling process because of its softness. This presents a difficult challenge in getting accurate graphite intervals from drillholes for modelling.

The wireframing followed a systematic process where broad outline sulphide mineralization envelope was developed, then shears that concentrated the mineralization within the sulphide mineralization envelope were developed. The metavolcanic intrusives were separately wireframed before wireframing the various sulphide mineralised lodes, the Main Lode, Hanging Wall and Footwall Lodes. The Hanging Wall and Footwall Lodes are mostly within the shears while some discontinuous lodes were modelled outside of the shears. In the course of wireframing the sulphide mineralised lodes, the quartz veins occurring within these mineralisations were separately wireframed. Sample data which were de-surveyed and imported into leapfrog were complete, with all the lithological data having no gaps in them as it had been the case for some of the sample data before validation. The lithology data played a vital role in the modelling process more especially in areas where quartz veins existed. Due to the pinch and swell nature of the quartz veins, absent lithological data made it difficult wireframing the quartz veins along strike and down dip. Nevertheless, the sample data in most situations related well with the mapping data.

4. Results

4.1. Wireframed Domains in Block 8 Lower

The plan and section views of the geological model for the sulphide and quartz domains, the main mineralized domains in the study area are shown in **Figure 6**. With the incorporation of the mapping information in the modelling process, an accurate model which depicts the pinch and swells characteristics of the orebody was generated. The sectional view of the orebody, which was taken along line AB, shows the orebody having an average dip of 70˚ to the west. This dip direction conforms with the general dip of the structures which were mapped underground.

4.2. Tonnes and Grade Estimates for Quartz and Sulphide Domains

The mineral resource in Block 8 Lower generated without domaining the Quartz veins from the Sulphide mineralization is compared with the updated Mineral

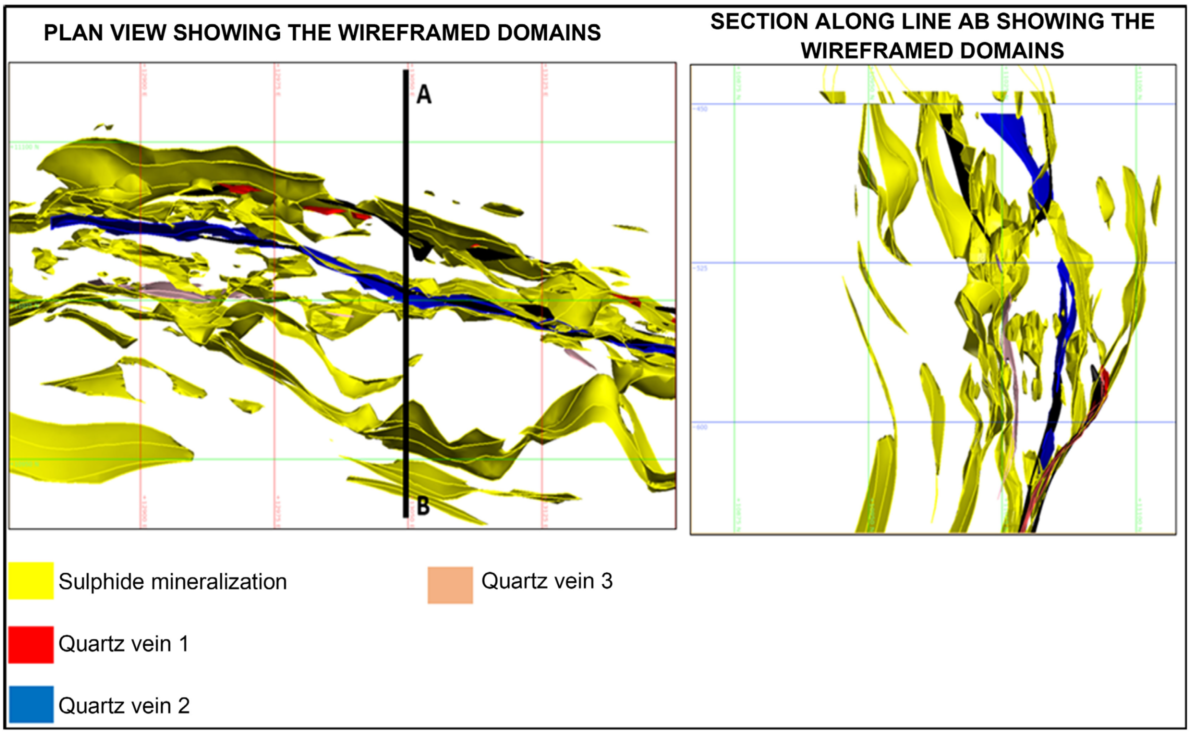

Figure 6. Plan and section views showing the wireframed domains in Obuasi Mine.

Resource which was generated by domaining the Quartz veins from the Sulphide mineralization (Table 1). The total tonnes for the Sulphide mineralization without domaining the Quartz veins is 8.039 Mt at a grade of 6.33 g/t. When this is compared with the updated Mineral Resource estimated with the Quartz veins domained separately from the Sulphide mineralization, there is a reduction in the tonnes and grade to 7.995 Mt at a grade of 5.79 g/t This clearly shows that when the Quartz veins are not domained separately from the Sulphide mineralization, the Sulphide mineralization ends up being over estimated. The overestimation of the Sulphide mineralization results in inaccurate monthly and quarterly grade forecasting. The actual grades of mined stopes end up being lower than the forecast grade due to the over estimation of the Sulphide domains.

The updated Mineral Resource estimates generated by domaining Quartz and Sulphide mineralization separately arrived at a total tonnes and grade for the Quartz domains as 0.818 Mt at a grade of 17.35 g/t. This shows that the Quartz domains are significantly higher than the Sulphide domains even though they are lower in tonnes compared to the Sulphide domains.

5. Discussion

Rigorous sample data validation and underground mapping were critical in generating accurate geological models that represent the nature and style of mineralization. The constant magnetic declination of 10˚ used for all the years potentially caused deviations with the actual position of the mineralized fissures thus

Table 1. Resource estimates in Block 8 Lower showing Sulphides only and Quartz domained numbers.

Mineral Resource in Block 8 Lower estimated with only Sulphides					Updated Mineral Resource in Block 8 Lower estimated by domaining Quartz and Sulphides				
Domain	**Tonnes (Mt)**	**Grade (g/t)**	**Ounces (Moz)**	**Classification**	**Domain**	**Tonnes (Mt)**	**Grade (g/t)**	**Ounces (Moz)**	**Classification**
Sulphide (71)	1.378	0.81	0.036	Indicated	Sulphide (71)	1.682	0.73	0.039	Indicated
Sulphide (72)	4.806	4.84	0.748	Indicated	Sulphide (72)	4.738	4.76	0.725	Indicated
Sulphide (73)	1.856	14.28	0.852	Indicated	Sulphide (73)	1.575	14.32	0.725	Indicated
					Total	7.995	5.79	1.489	
					20 (Quartz 1)	0.280	14.25	0.128	Indicated
					21 (Quartz 2)	0.456	19.29	0.283	Indicated
					22 (Quartz 3)	0.082	17.17	0.456	Indicated
Total	**8.039**	**6.33**	**1.636**		**Total**	**0.818**	**17.35**	**0.456**	
Grand Total	**8.039**	**6.33**	**1.636**		**Grand Total**	**8.811**	**6.86**	**1.945**	

displacing the locations of the mineral deposits. [7] recommends that checks be carried out on both the raw database tables and the final desurveyed data before commencing any mineral resource estimation project. This underscores the importance of validation process in generating accurate wireframes for mineral resource estimation. When dealing with situations where the sample data have been in existence for more than 20 years and also with issues of sample data transitioning from imperial to metric, thorough validation process is very imperative to deal with all legacy issues in order to guarantee the integrity of the sample data.

The validation work mainly centred on fixing all missing pieces of information in the database left over the years and finally assigning confidence numbers to the sample data. The validation avoided plotting of sample data at different locations instead of their accurate positions. Wrong coordinates have the tendency to cause wrong interpretation of the mineralized zone to miss the mineral deposit. The unchanged magnetic declinations and downhole surveys would have affected the azimuth of the drill holes. Though the unchanged magnetic declinations value of 10˚ will not be too much of a problem with holes less than 60 m depth, the adverse effect becomes every obvious with holes in excess of 60 m deep. A one-degree deviation in azimuth in a drill hole is magnified with increase in hole depth. The magnetic declination corresponding to the year the holes were drilled was used to correct the azimuths of the drill holes. The entire validation exercise provided database devoid of inconsistencies, thereby taking away any data integrity risk associated with the geological database. This is expected to lead to a high confidence geological data for orebody wireframing.

Confidence numbers between 1 and 5 were assigned to all the sample data based on the amount of data which were verified against the hardcopy log sheets. Sample data which had the collar, assay, lithology, and downhole surveys verified against the hard copy log sheet were assigned confidence one (1) which represents the highest confidence. This means that a confidence one (1) hole used in the modelling process is less likely to be error ridden. Holes with missing coordinates, assays and surveys and also with no hard copy log sheets were assigned confidence value of two (2) to five (5) which represents the lowest confidence. This critical piece of information requires extra circumspection in the course modelling. Also, there would be the need to validate the sample data information assigned low confidence values (2 to 5) with mapping information in the vicinity of those sample data. The confidence value numbers are therefore used as a first pass validation tool which prior to the validation work was non-existent.

Underground mapping had been shown to have a positive impact on resource estimation. [1] stated that mapping of drives and raises are of equal importance as rapid variations in detailed geology need to be tracked. It is important and applicable to the characteristic pinch and swells orebody in tandem with changing strike of the mineralized Fissure of the Obuasi Mine. The detailed underground mapping guided the generation of strings which were subsequently used for the wireframes. In areas where the mapping information did not tie in with sample data, the mapping information was considered instead of the drillhole. This was because the physically exposed mineralised materials were mapped and deemed more accurate than the drillhole data.

Resource estimates which were generated for the Quartz and Sulphide mineralization separately are 7.995 million tonnes at a grade of 5.79 g/t and 0.818 million tonnes at a grade of 17.35 g/t respectively. The tonnes and grade for the Sulphide mineralization which was generated by domaining the quartz veins separately from the Sulphides was then compared with the old Resource estimates where there was no domaining of the Quartz veins. The Sulphide tonnes and grade from the old Resource estimates was 8.039 Mt at a grade of 6.33 g/t, this when compared with the new estimates of 7.995 million tonnes at a grade of 5.79, shows that in the old Resource estimates, the tonnes of the Sulphide mineralization were overestimated by 1%. The grade was also overestimated by 8.5%. This increase in grade is due to the influence of the Quartz domains which have high grade and as a result pushing up the grades of the Sulphide domains. Theoretically, a comparison between the old Resource estimates and the Updated Resource estimates shows overestimation of the Sulphide domains if the Quartz veins are not domained separately.

This position is corroborated by the Resource estimates for the domained Quartz veins in the updated Mineral Resource estimates with the Quartz having 0.818 million tonnes at a grade of 17.35 g/t which is significantly higher than the grade of the Sulphide mineralization.

Accordingly, the separation of the Quartz and Sulphide domains will help improve stope grade prediction and more importantly in areas where the Sulphide mineralization is proximal to quartz veins as the influence of the quartz veins on the grades of the Sulphide mineralization would be very minimal. This will also allow for better monthly stope reconciliation as actual grades realized from the mill head at the processing plant would be close to the predicted grades.

6. Conclusion

Effective geological mapping and validation of all sample data is key to generating a good geological model, which reflects the nature and style of mineralization of an orebody. This will also help in generating accurate wireframes for all domains which are key controls of mineralization in a deposit and subsequently accurate resource estimates. Also, in situations where there is the need to use old data in modelling, all the legacy issues associated with the sample data must be duly corrected. Where possible, in situ mineral exposures must be mapped and the mapping data were used to validate the interpretations made with the sample data.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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