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Innuendoes of Sterilisation Drilling in Surface Mining Operations—A Case Study

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Abstract

Surface mining operations play a crucial role in meeting the world's increasing demand for mineral resources for the advancement of technology and debauched expansion of economies. The search for and exploitation of these mineral resources are therefore important for the sustainability of the mineral extraction industry. To this end, efficient mine planning must incorporate sterilisation drilling and effective waste rock management principles in the search and exploitation of these minerals. In this article, sterilisation drilling is being reviewed *vis-a-vis* the establishment of waste and tailings dump locations, backfilling of open pit excavations and mine closure giving critical attention to the minerals and mining laws of Ghana. Subsequently, a detailed case study of a surface mining operation that successfully incorporated sterilisation drilling in determining waste dump location in its mine planning process has been presented in this study. The findings indicate that the proposed waste dump location could present a potential mining prospect in the future based on enhanced milling capacity/technology and improved mineral commodity price; underscoring the significance of sterilization drilling in the sustainability of the mining industry.

Keywords

Sterilisation, Exploration, Backfilling, Waste Dump, Cutoff Grade

1. Introduction

Mining operations involve the extraction of precious minerals in the form of ore reserves from the earth for both commercial and non-commercial purposes. These reserves can only be properly delineated and estimated through detailed exploration processes [1] [2]. Exploration activities including soil/rock sampling, trenching and especially drilling facilitate the retrieval of drill cores for the study of rock properties such as density, grade, dip and color [3]. These exploration activities constitute the geophysical and geochemical testing which lead to the identification of the minerals by means of their natural, magnetic or/and electric characteristics.

In surface mining operations, before the ore is mined, the overburden would have to be stripped to access the ore. The stripped overburden is normally called waste material. Large volumes of waste materials are generated during the stripping of the overburden and mining in order to mine the precious ore. These waste materials (overburden, low mineral content or barren material) are then disposed into mine waste dumps. Also, during the processing of the mined ore, liquid waste in the form of tailings/slurry is generated which is dumped separately from the solid rock waste [4]. It costs mining companies significant amount of dollars to re-handle and transport mine wastes, thus affecting the financial sustainability of companies. Mine rock waste and tailings could be of most life-threatening issue in mining milieu. Rock waste (otherwise commonly termed as waste rock) and tailings storage around mine locations remain a long-lasting environmental problem. As a result, deleterious environmental pollution has ensued due to failed systems used for storing mine wastes in general [5] [6].

In addition, the manner in which the mine waste (rock and tailings) is handled could be of major sustainability concern in the mining industry to the stakeholders such as mine planners, government agencies, local communities, etc if not properly managed. Subsequently, it is imperative to conduct sterilization drilling to confirm the bareness or otherwise of the waste dumping location to prevent inappropriate dumping of waste rock, tailings or backfilling of abandoned pits. This is because if the waste material is not handled properly it could cost a company several millions of dollars, considering the fact that the cost of handling waste material is almost half of the mining costs [4].

Moreover, location analysis is an integral part of rehabilitation planning and must be considered prior to the beginning of mining operations due to the fact that when the mining operation is completed, the mined out areas and mine waste dumps need to be rehabilitated. Therefore, cost effective and efficient methods for the selection of optimal site(s) for waste dumps in the mine is thus of significant concern to management and stakeholders of surface mines [7]. It's important to restate that before any form of waste dumping or backfilling occurs, the location for such an exercise must be thoroughly evaluated to ascertain the suitability (occurrence of no mineralization) of the location through sterilization drilling. Though the mining laws of Ghana propose that backfilling, for instance, be done when mined out pits are abandoned [8], caution should be taken to ensure that detailed geological study and sterilization are conducted to give an indication of uneconomic deposits at the level of abandonment and results of the study also presented to the Minerals Commission.

Now, the major factors that are considered during the location selection process for the establishment of waste dump include financial, environmental, geological, land-use and safety requirements. These factors are combined simultaneously to avoid potential losses. Some of the environmental factors are land, air and water pollution, forest destruction, etc. For instance, the mining laws of Ghana prohibit the establishment of a rock waste dump to water bodies closer than 100 m [8]. The stability of the dump location must also be considered during mine planning and mine waste dump site designs. Most mine waste dump storage systems are designed to minimise the inhibition of future mining prospects, effect on the environment due to acid rock drainage, surface water run-off, dust emissions and visual pollution and haulage cost [9].

Modern mine waste management requires mine waste to be placed on specially prepared sites that satisfy all the major factors [10]. Failure to include these factors or non-assessment of these factors during the early stages of the site selection procedure often results in severe negative implications such as fines, mine closure, protests, relocation of dumps and environmental pollution. Most mining companies use different methods for selecting sites for dumping of waste. However, there is no standard model which combines these constraints and factors for selecting sites for waste dump. The improved capabilities of information technology have brought about these possibilities.

There is an increased societal awareness of the impact of mining and environmental concerns have become a growing challenge for all the agents within the sector. The social demand has increased for the sustainable development of all the activities related to mining, particularly the adequate management of waste products during each phase of the mining process, including prospection and exploration, development, extraction, transport and treatment of product obtained. Energy requirements, environmental and human health risks, demands on water resources, and the required technology must all be taken into account [11] [12] [13].

Repeatedly, mining industries are condemned for dumping waste without taking the required precautions. Hazardous materials that are generated from mining operations are mainly wastes that have reactive minerals such like pyrites and pyrrhotite. They could be seen in places such as open cuts, waste dumps, pit walls, impoundments, leach pads, tailings disposal amenities, tailings spillage locations, remaining footprints at the end of re-mining of tailing and the fall of a waste mix within the borders of previous mine properties [14].

In this paper, waste dump location and sterilisation drilling are being reviewed with particular attention to investigating the economic potential (sterilization/exploration) of the Essikuma area.

2. Resources and Methods Used

2.1. Resources

Secondary data from sterilization drilling (**Figure 1**) at Essikuma of Ghana

Manganese Company (GMC) was used for this work. Drill cores from diamond drill (DD) were used and the Champ ORI tool used for core orientation. Core boxes used by GMC used are indicated in **Figure 2**. All information relating to the diamond drilling holes, including hard copies of logs, photographs, down-hole survey shots and assay reports were filed and processed in arriving at the economic potential of the Essikuma area.

2.2. Study Area

The Ghana Manganese Company at Nsuta is an open pit mine located in the Tarkwa/Nsuaem Municipality of the Western Region of Ghana. The mine is about 4 km south-east of the town of Tarkwa. It lies on the Takoradi-Kumasi railway line, about 60 km inland from the port of Takoradi by rail and 80 km by road. It is on longitude 1˚58’32’’W and latitude 5˚16’5’’N as shown in **Figure 3**.

Figure 1. Sandvik DE710 drill rig.

Figure 2. Loaded drill core boxes.

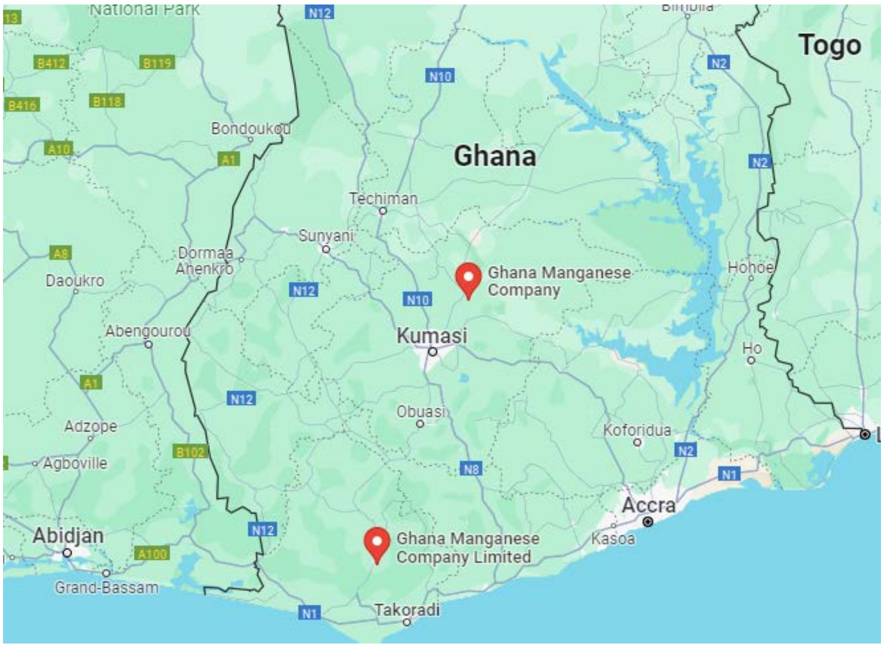

Figure 3. Location of Nsuta GMC.

2.3. Methods

A review of waste dump location and establishment is conducted giving critical attention to the minerals and mining laws of Ghana using GMC, which successfully used sterilisation drilling in determining waste dump location in its mine planning process, as a case study. In this study, sterilization drilling is applied, as a very subtle process of the entire sustainability chain.

2.3.1. Waste Dump Location

Waste dump site selection must be done taking into consideration economic, technical and environmental concerns. The location needs to be substructure resistant while respecting technical and economic issues such as proximity to the pit. The road properties factor, such as distance, is of particular importance between others, like geotechnical characteristics, final pit limit, and landform, due to their long-term and indirect impact on the productivity of mine. Traveling cycle time of mine fleet is undeviatingly linked to traversing distance. According to the typical classification of mine haul road, main hauling distances are from pit extraction face toward, crusher, processing plant, and mine facilities [15]. In summary, waste dump site selection will depend on a number of factors such as:

1) Pit location and size through time;
2) Topography;
3) Waste rock volumes by time and source;
4) Property boundaries;
5) Existing drainage routes;
6) Reclamation requirements;
7) Foundation conditions;
8) Material handling equipment.

In determining waste dump location, sufficient information about the proposed area must establiblished including the geotechnical conditions of the area, environmental implications (nearness to water bodies or habitation), economic potential of the proposed location and subsequently cycle time analysis arising from haul route profiles between mucking points and the waste dump. Sterilization drilling, as an exploratory process, is useful in determining the mineralization of the area and hence possible future mining of the proposed dumping site. Thus, to establish the economic potential of the proposed dump, sterilization must be done. The area for waste dumping by the mining laws of Ghana, must be within the limits of the concession. It is important to state that, it would be absurd to establish the waste dump on very high topography since that will lead to lesser volume of dumping relative to flat and low tarains. This is because the mining laws of Ghana also prohibit dump heights beyond the highest topography of the vicinity [8]. In this study the suggested cycle of waste dump location process is shown in **Figure 4**.

2.3.2. Environment

Environmental protection and public health considerations should be the principal concerns in site selection. Selection of an appropriate site will minimize potential environmental impacts and provide a sound basis for effective management. The factors which need to be addressed during site selection include the potential for the creation of public health hazards or nuisance, the potential for the pollution of water bodies, local topography and soil erosion risk, the suitability of soils for earthworks and containment of leachates, the adjacent land uses and the accessibility of the site to users. Some waste generated by mining operations, due to the mass it represents or to its chemical (or physical) nature, can pollute the environment, in particular media as water, soil, vegetation, and targets like the fauna and human.

2.3.3. Hydrology

Pollution of surface and ground water resources by leachates is a principle concern in relation to landfill location. Leachates are generated by water passing through waste materials in landfills and becoming exposed to and mobilizing a range of contaminants. Contaminants may be removed or reduced in concentration

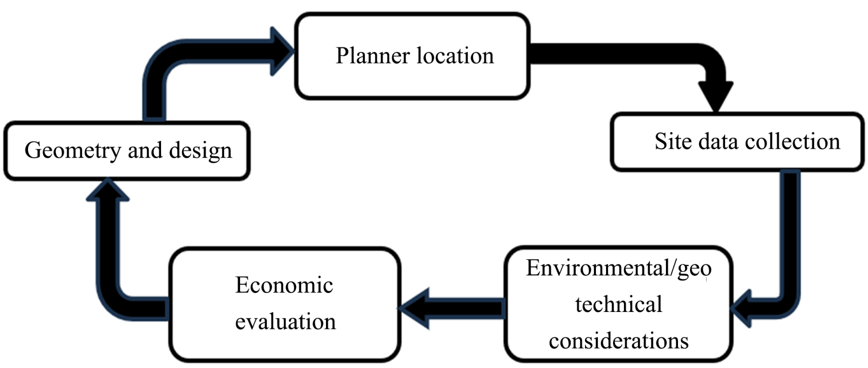

Figure 4. Waste dump location process.

as they pass through soil surrounding the landfill, by processes involving filtration, dilution, absorption and microbial decomposition [16]. In many cases the presence of water courses, drainage lines and underground aquifers will limit the utility of sites. Although site design and management can reduce the potential for water pollution, some sites are not suitable due to the potential for inundation by floodwaters and/or the proximity to water bodies.

2.3.4. Technical Factors Affecting Dump Site Selection

The location of waste dump site significantly influences both the capital and operating costs at a mine. Post practice has been carried out to optimize the site selection based largely on criteria of economics and ease of operation resulting in a relatively simple selection process. This selection process has now become more complex as a result of the numerous environmental concerns that limit the suitability of many sites. Various factors should be considered in the selection of a waste dump site. Some of the most significant of these factors can be defined as:

1) The waste rock volume removed through the exploitation period;

2) The dump capacity;

3) The horizontal and vertical distance between the source and the dump location;

4) The cost and type of waste rock haulage from the source to the dump site;

5) The effect exerted by waste rock disposal on the environment;

6) The final boundaries of the pit and methods of ore mining;

7) The ground condition of the dump site;

8) The chemical and physical properties of the waste rock;

9) Time, methods and cost of dump site preparation;

10) Demand for mine working reclamation;

11) The filtration effect of surface and ground water;

Under the equal conditions of selecting the location of the waste dump site, the preference is given to the sites ensuring the minimal expenditure for haulage and storing of waste rocks and the least negative influence on the nearby environment [17]. Because of the long-term nature of the pollution and environmental impact of the waste materials, the selected site and engineering respects must serve as an effective contaminated facility not only in the short term but also in the long term. Such long-term stability is an extremely difficult task to engineer into a facility subject to the slow but perpendicular geological processes such as wind and water erosion, chemical and physical weathering, seepage and leaching.

The mine engineers and environmental agencies usually have different objectives which come from their job and organization purposes. Engineers are often interested in increasing the productivity, decreasing the costs and maximizing the profit, while environmental societies believe that public health is the highest goal. The distinctions between the mining operation participants and such agencies are neither possible to solve nor eliminate completely. Therefore, the best site is a location which meets both objectives. **Table 1** presents a summary of the essential factors that should be considered in dump site selection.

Table 1. Essential factors to consider in waste dump selection.

Criteria	Sub Criteria
Topographical conditions	Landform, Dump capacity, Dump area, Haulage distance
Hydrology and climate	Precipitation, Windspeed and direction, Acid mine drainage (AMD), Hydrologic regime, Surface water runoff and Quality downstream condition.
Hydrogeology	Groundwater quality, Groundwater table, Drainage rate
Geology and Geotechnology	Foundation condition, Seepage and porosity, Active faulting, Waste material strength, Repose angle of waste material, Earthquake/blasting vibration
Technical aspects	Mining method, Final pit limit, Haulage system, Waste rock volume
Environmental aspects	Chemical and physical properties of waste, Filtration effects of surface and groundwater, Reclamation regulations, and biotypes.
Economical features	Capital and operating costs, Closure costs, Economic risks.

2.3.5. Design and Regulation and Legal Framework

The construction of waste rock dumps is a crucial component in surface mines for the storage of the large volumes of waste rock mined from open pit mines. Depending on the nature of the deposit, stripping ratio could be as high as 15:1 waste to ore in volume [18]. Unfortunately, many waste dumps have failed geotechnically through the use of inappropriate design or construction techniques. Inappropriate handling of acid waste rock can also lead to the contamination of the environment [19].

Legal consequences play a critical role in instituting new standards and consenting to novel approaches to be implemented. In the absence of an appropriate understanding of the legislative and regulatory context, solutions that will be feasible to provide improved results could technically fail [20]. Hence, the operation of mining activities has been impinged to a body of national legislation recognized as the mining code. Every country has her own national legislation and by convention, the state makes and enforces laws within the country. The principal role of governments through its policy framework will provide a successful feasible solution [21].

The mine site physiographic and climatic constraints must be carefully considered to ensure that the waste dump can be constructed correctly. This is an approach that requires a conceptual design to be developed during initial mine feasibility and material characterization studies. The conceptual model must then be revisited regularly, and refined as necessary, to ensure that the mining operations continue to manage the onsite materials and achieve any closure criteria that have been initially proposed or any necessary deviations are properly evaluated and documented. If this process is applied any alteration to the anticipated conditions, or misinterpreted geochemical data, can be managed as the mining life progresses, rather than at the end of operations when costs to rectify any issues will be far greater than what had been initially estimated.

It is important that waste storage facilities (wheather waste dump or TSF) be designed and built incorporating the site-wide closure plan; and considering the overall surface and groundwater management plans. To achieve these goals, the regulatory requirements are relevant. Researches on slope stability using systematic geotechnical engineering principles have been conducted [22], establishing the necessary factors affecting dump stability to be considered at the design stage [23]. These factors include the floor dip and foundation strength, from which the dump stability is highly sensitive [24]. Along with the geotechnical factors, several other parameters, such as the topography (environmental), final pit limit, haul road distances, landform, among others, have been ranked, by multi-criteria decision methods with the specific aim of selecting the dump location [25]. Waste dump lift height should necessarily be constant, though is restricted to prevent shear stresses on the foundation and is a factor to control consolidations and permeability variations [26]. The mining laws of Ghana also restricts the lift height to a maximum of 15 m. Though the total height of the dump is also restricted by formation mechanism [27] and carrying capacity limitations [28], the Ghanaian mining code limits the maximum dump height to the height of the highest topography in the vicinity. Also, the berm distance is petched at a minimum of 10 m to allow for battering before rehabliatiton such that the batter angle (θ_1) is less than the angle of repose (θ). **Figure 5** gives an illustration of a waste dump design configuration.

In dump designing, costs may be governed by any or all the following factors:

1) Geometry: Usually designed to handle a total capacity throughout the life-of-mine. Over-dimensioning can cause underutilization of valuable areas. Under dimensioning can result in the increase of the total haulage distances.

2) Operating costs: Costs resulting from fuel, energy, maintenance and labour of the haul trucks.

3) Haulage distances: Minimizing the total haulage distance while meeting the required capacity by strategic placing of the ramps, exits, entrances and dumping sequence.

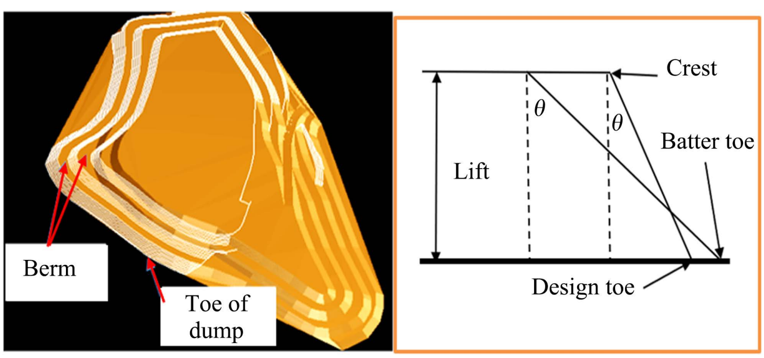

Figure 5. Waste dump design configuration.

4) Stability control: It will define the angle of repose and the nature of the underlying material. Maintaining the stability of the dump may require relocation of weathered rock or material blending, especially if water is present [29].

5) If it is a dump leach, a leaching cycle time will define the mining delivery rate and dumping schedule. Ideally, deliveries rate from the mine should match the leaching cycle times of the dump. Otherwise, there is a risk of short cycling and losing on mineral recoveries. In addition, costs of building the leaching facilities must be catered for [30].

6) Environmental factors: costs of implementing and maintaining effective systems to reduce and eliminate loses and contamination.

7) Design considerations for reclamation and closure to maintain long-term stability, erosion control and to avoid re-handling costs [31].

Although every dump is unique and some of its cost maybe be given by its own factors, the above description includes all the general concerns one would have to elaborate the most economical dump design [32]. In the past, several mining companies just dumped waste rocks and tailings in the nearest convenient place, such as nearby rivers and streams. This was done before the implementation of environmental laws and standards. Some of the most awful environmental consequences of mining have been linked with the open dumping of tailings, a practice that nearly all the universe now rejected [33].

Legal frameworks should offer a standard for evolving adapted management systems, revealing gaps in the midst of the available procedures, relating with all stake holders, gaining necessary permits, conducting internal audits, and aiding compliance and considering sustainability, at all phases of the mining life cycle [33]. It is important to note that the current mining code of Ghana maintains that an exhausted or abandoned pit should be back-filled with waste roack which implies an *old pit* could be located as a waste dump. In this study it is propsed that before such an abandoned pit is backfilled, geological investigations must be done to declare the area sterile.

2.3.6. Sterilisation Drilling

Sterilization drilling tests areas of a mine site to be sure there are no valuable minerals there, so that waste rock, buildings, roads, power lines, pipelines, tailings disposal areas, etc. can be built on the areas that have been sterilized or condemned. Every mine site has at least one mineral deposit and infrastructure, and you need to be sure they don't conflict with each other [34].

Sterilisation drilling is especially important for proposed waste dump locations to ensure that waste rock is not dumped on areas where grades could be of economic value under current market conditions as well as future metal price or improved extractive technology. Sterilisation drilling is very critical in the establishment of waste dumps to avoid cut-backs after longer periods of dumping when it is later established that mineral deposits of economic value is deeply seated under it. It helps reduce operational costs which might be incurred if such activities are not undertaken before waste dumps are established.

2.4. Consideration of Cut-off Grade

The cut-off grade is therefore a strategic variable that determines the economic viability of a mine, and hence return on investment. It is critical that the cut-off grade is optimal so as to maximize the net present value. This algorithm is flexible and can be adjusted to include other factors specific to a mine. Cut-off grade is the minimum grade required in order for a mineral or metal to be economically mined (or processed). Material found to be above this grade is considered to be ore, while material below this grade is considered to be waste. The Cut-off grade can be determined through a variety of methods, each of varying complexity. Cut-off grades are selected to achieve a certain objective, such as resource utilization or economic benefit. Dividing these objectives even further gives way to specific goals such as the maximization of total profits, immediate profits, and present value.

It is important to recognize that the cut-off grade is not simply calculated to a definitive answer. It is in fact a strategic variable that has major implications on material categorisation and mine design. The cut-off grade is adapted as the economic environment changes with regard to metal prices and mining costs and is therefore constantly changing. Metal value is not the only factor affecting the profitability of an ore block. The presence of unwanted material in an ore block may increase the processing cost. This is also considered when classifying waste rock and ore [35]. Essentially, mining is a multidisciplinary knowledge of three scientific fields consists of geology, mining engineering, and economics [36]. Mineral mining is a complex process technique and can last for decades [37]. There are two kind of mining methods widely used, namely open pit mining and underground mining. One of the challenges faced by open pit mining industry is determining the optimal cut-off grade of the mine to be processed. Thus, it is important for the engineer to determine whether a parcel of land with grades below the cut-off could be considered for waste dumping or not.

The metal fraction contained in a rock mass is used by mining engineers to describe the term of grade. Cut-off grade is the minimum grade required in a certain rock mass to be considered as ore [38]. Material that does not exceed this minimum criterion is defined as waste. Mining companies must be smart enough to decide the optimal cut-off grade since the cut-off grade value will affect the cost and revenue components of the company. Several studies have been conducted to find the optimal cut-off grade in open pit mining. The first basic model of determining cut-off grade through the breakeven approach was introduced followed by an algorithmic/heuristic approach by engineers [39] [40].

In addition to using the two approaches above, several researches have been conducted in open pit mining to determine the optimal cut-off grade using a mathematical approach through analytic solutions. Exploration and exploitation will directly affect the depletion of natural resources and the surrounding environment such as air, water, land, flora and fauna which should continue to be preserved and utilized optimally. Therefore, the company has an obligation to carry out the land reclamation. The purpose of reclamation according to is to achieve stability, security for humans and animals, recovery of landscape aesthetics, eliminate risks, increase the economic value of final land formation and improve company image.

Nowadays, one of the important issues to be considered by the company is the use of the mining area after reclamation (post mining activities). Research shows that post-mining land uses can be grouped into eight possibilities (forestry, construction, agriculture, intensive recreation, non-intensive recreation, lake or pool, conservation, and backfilling) [41]. The type of utilization above will certainly provide additional economic value to the area after the mining process is completed and provides a higher investment value in mining projects [41].

3. Results and Discussions

3.1. Borehole Logging

All diamond drilling conducted by GMC was supervised by a geologist and a qualified technician who frequently visited the drilling site while drilling was in progress. The locations for the plan holes were set up by a surveyor and the shift geologist responsible for the drill rig alignment and orientation. All drill holes were geologically logged. Also, geological codes for rock-type and colour were developed to establish consistency in logging.

In the core shed, protocols on mark-up, core loss, logging, sampling, and photography are performed. It is appropriate to retain a complete core sample to aid in visual examination of the core and at the same time have, a portion of the core analysed at the laboratory. For this purpose, an effective new core cutter is being used to split the core into two halves. Half of the split core is assayed while the other half is permanently stored for future use and re-assaying if necessary.

Sampling is carried out on the outlined carbonate ore zones after thorough logging and the samples are collected every 1 m. The individual 1 m sampling intervals are composited to 3 m which are then sent for analysis and should any 3 m composite sample return a significant carbonate grade assay, the individual 1 m samples will be sent separately along with those from the immediately adjacent samples. The samples are defined by a sample tag placed within the plastic sample bag, with the sample ID's clearly written on the plastic bags as an added precaution.

3.2. Assays

The assay laboratory provides single and multi-element analyses by a variety of methods. The assay lab in Ghana Manganese Company Limited is divided into two sections namely sample preparation (sample preps) section and wet chemistry section.

Sample preparation unit

This is the section of the assay lab where samples are first received. These samples are mostly the Manganese Carbonate ores from the carbonate plant, trucks, trains, shipment or grade control and diamond drill samples from the geology department.

The preparatory stages of sample preparation are numerated as:

1) The sampled samples are crushed with a jaw crusher to about 10 mm.

2) The crushed sample is split with a riffle splitter to obtain approximately 400 - 500 g quality sample, the remaining is discarded.

3) The 400 - 500 g of the sample is dried in an oven at 105˚C for 2 - 3 hours.

4) It is then pulverized with a disc and ring mill to an analytical fineness (<106 micrometre).

5) The pulverized sample is then split with micro riffle splitter to obtain approximately 200 g.

6) The 200 g sample is then bagged into envelopes and sent to wet chemistry for analysis. The reject is discarded.

Wet Chemistry Section

In the wet chemistry section, qualitative and quantitative analyses are carried out for all samples received.

The three (3) types of analysis carried out are:

Volumetric Analysis (redox reaction): This method is used to determine the percentage manganese in the sample.

Atomic Absorption Spectrometer (AAS): This method is used to determine the percentage of manganese, calcium, iron, magnesium in the sample (ore).

Gravimetric Analysis: This analysis is used to determine the silica (SiO_2) and alumina (Al_2O_3) contents in the sample.

3.3. Section Creation

The geological database profile is opened in Geovia Surpac 2022 and the holes are being displayed using the display panel. Define option is selected from the section panel on the menu bar. The section planes are then defined by entering the necessary requirement of the sections to be created which includes the section method (Example, Northing, Easting, Graphically select section etc.), distances between section planes, and the range of values.

The quick plane dialogue box is opened from the plane toolbar and the plane specifications (orientation, plane position, plane corridor and plane output) are applied. The created section planes are opened from the planes panel.

3.3.1. Drill Hole Data Validation

For the purpose of standard work of this mineral resource estimation, all the drill hole data in the excel format (csv), consisting of assays, collar, lithology and topography were imported into Geovia Surpac software. An oxidation table, which explains the weathering profile was also constructed and imported in Geovia Surpac database for the construction of an oxide seam surface. Using the standard tools in Geovia Surpac, the imported drill holes (database) were validated and all associated errors corrected. The validation of the drill holes was relatively easier as much of this work has been done by the database and resource geologist in the geology department. The total number of drill holes, were 10 and the total metres drilled were 3960.2 m.

3.3.2. Drill Hole Collars and Downhole Surveys

The coordinate system used for all drill holes are the local Mine Grid. The coordinate of all the drill holes were determined using handheld Garmin GPS unit and sited for direction with a compass. Subsequently, the collar locations were collected using GMC's differential GPS unit calibrated to Nsuta Mine Grid. Champ ORI was the downhole survey tool used. The diamond drill cores are oriented for structural measurement, by the use of Champ ORI electronic core orientation tool for orienting and marking core as indicated in Figure 6 and Figure 7. The Champ ORI completely integrates with existing coring hardware by replacing standard components of commonly used inner-tube head assemblies. The ORI tool remains within the head assembly to communicate, mark drill core and drill the next run seamlessly. This tool was employed because system does not require outer-tube extensions thereby reducing the risk of costly extension failure downhole and resulting hazards.

Figure 6. Core orientation procedure.

Figure 7. Marking and orienting of core.

The hole collars and down-hole survey data were loaded into Surpac software together with the assay and lithology data to generate a drill hole database. Validation of data confirms no survey data exceeds final depth of hole. Examples of Surpac data structure for collars and down-hole survey data are presented in Table 2 and Table 3 respectively.

3.4. Assay Results

Assay results provide an early indication of the potential value of a mineral or ore body, and therefore they are closely monitored by investors in mining companies of which GMC does same. The average assay results for the respective boreholes are presented in Table 4 and graphical illustrated Figure 8.

Table 2. Sample of Surpac file structure for assay data.

Date	Hole Id	Sample ID	Depth (m)		Mn %	Fe %
			From	To		
13/01/2022	ES8053	ES8053_01	157.6	158.6	0.1	0.5
13/01/2022	ES8053	ES8053_02	158.6	159.6	0.1	0.4
13/01/2022	ES8053	ES8053_03	159.6	160.6	0.3	0.6
13/01/2022	ES8053	ES8053_04	160.6	163.6	0.1	0.3
13/01/2022	ES8053	ES8053_05	163.6	166.6	0.1	0.5
13/01/2022	ES8053	ES8053_06	166.6	169.6	0.4	0.3
13/01/2022	ES8053	ES8053_07	169.6	172.6	0.8	0.2
13/01/2022	ES8053	ES8053_08	172.6	175.6	0.4	0
13/01/2022	ES8053	ES8053_09	175.6	178.6	0.8	0.5
13/01/2022	ES8053	ES8053_10	178.6	181.6	0.3	0.4

Table 3. Sample of gem file structure for drill hole collars.

Date	Hole Id	Hole Path	Hole Type	X	Y	Z	Depth
20-Jan-22	ES8062	CURVED	DD	5067.75	4574.58	241.299	430.9
28-Dec-21	ES8055	CURVED	DD	4927.23	4951.36	240.374	453.1
10-Nov-21	ES8048	CURVED	DD	5277.98	4595.06	215.562	466.6
12-Nov-21	ES8049	CURVED	DD	5230.92	5361	211.952	457.5
14-Nov-21	ES8050	CURVED	DD	5232.79	6243.33	230.747	199.9
17-Nov-21	ES8051	CURVED	DD	5012.18	6220.11	205.347	430.5
14-Dec-21	ES8052	CURVED	DD	5011.82	6553.08	220.548	447.4
17-Dec-21	ES8053	CURVED	DD	5109.82	4971.35	192.547	445.6
15-Dec-21	ES8054	CURVED	DD	5067.75	4574.58	213.533	444.8

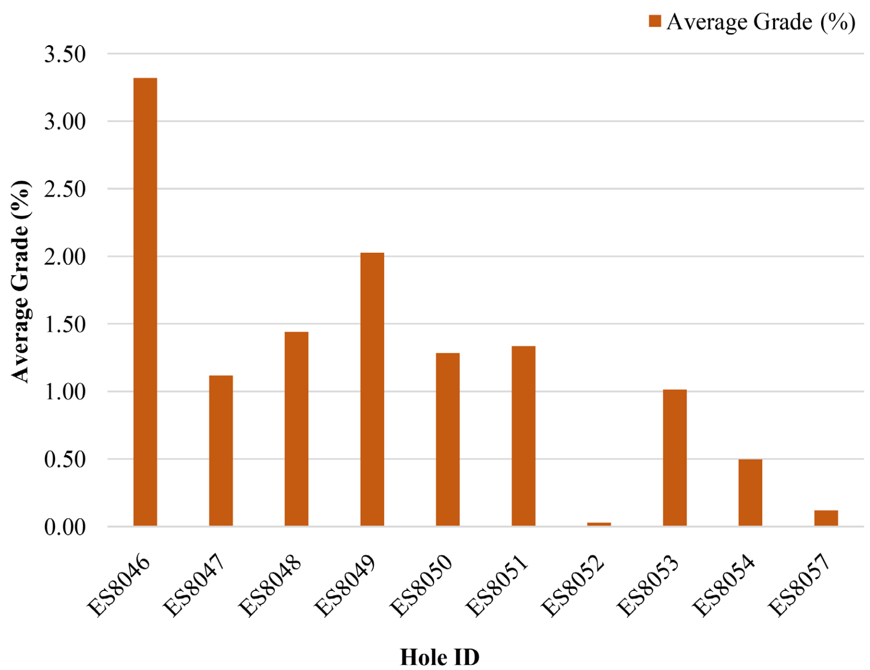

Figure 8. Average grades of drill holes.

Table 4. Average grades of drill holes.

Hole ID	Total Distance (m)	Average Grade (%)
ES8046	36.4	3.32
ES8047	32.8	1.12
ES8048	64.6	1.44
ES8049	97.7	2.03
ES8050	81.7	1.28
ES8051	136.9	1.34
ES8052	94.6	0.03
ES8053	64.6	1.01
ES8054	24	0.50
ES8057	95.4	0.12

Generally, material found to be above the cut-off grade is often considered to be ore, while material below this grade is considered to be waste. For this study, a comparison of the average grades was made with the cut-off grades as shown in Table 5. The comparison indicates that the average grades fell below the company's accepted (economic) grade to be in sustainable operation since the cut-off grade is set upon which the mine operates to generate positive net present value. At GMC, the current cut-off grade is 14% Mn.

Table 5. Average grades compared with the cut-off grade.

Hole ID	Average Grade (%)	Cut of Grade (%)	Variance (%)
ES8046	3.32	14	−10.68
ES8047	1.12	14	−12.88
ES8048	1.44	14	−12.56
ES8049	2.03	14	−11.97
ES8050	1.28	14	−12.72
ES8051	1.34	14	−12.66
ES8052	0.03	14	−13.97
ES8053	1.01	14	−12.99
ES8054	0.50	14	−13.50
ES8057	0.12	14	−13.88

4. Conclusions and Recommendations

The average grades of the drill holes were less than the cut-off grade decided on by the mine. However, it was noted that some boreholes recorded high values of Manganese oxides namely; ES8046, ES8047, ES8048, ES8050, ES8050, ES8051 and ES8053 respectively. These values were recorded in the detrital zones as a result of geological activities. This is an indication that the area may not wholly be sterile (baren) and probably not the best location for waste dumping. It is thus recommended that further in-fill drilling be conducted to gain more information about the mineralization of the Essikuma area. Due to the fact that commodity prices and technology can be improved in future, it is recommended that GMC locates an alternative area for waste dumping since there are pockets of good grades of manganese showing in some boreholes.

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Authors' Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Mr. Isaac Ekow Anaman, Dr Festus Kunkyin-Saadaari and Dr Richard Gyebuni. The first draft of the manuscript was written by Dr Richard Gyebuni and all authors commented on previous versions of the manuscript. All authors reviewed and approved the final manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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