 

# Blast Induced Ore Movement Prediction Using Rock Strength Parameters – A Case Study

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**Abstract**
Blasting causes movement of rocks and so can be a nuisance in gold mines as it leads to ore loss or dilution. Auriferous ore at Golden Star Wassa Limited, Akyempim mine which is found in the Birimian Supergroup in Ghana is no exception to problems relating to blast movement. The ore comprises of altered mafic and felsic-metavolcanic rocks, diorite, feldspar porphyry, and phyllite. To track the ore after blasting in SAK-1 Pit, blast monitors measure the extent of blast induced movements which were parallel to strike and down dip of the orebody. Hence, graphs plotted from data collected in benches at 6 metres intervals were used to derive equations which relate movement of rock fragments, of diverse sizes up to boulders. These equations indicate that blast induced movement is dependent on rock structure - whether foliated or massive. Other parameters were rock density which is a controlling factor to the extent of movement and uniaxial compressive strength which influences breakage. Deductions show that at Akyempim mine, foliated rocks may have higher movement than massive rocks and so the equations should be used to plan adjustment of ore boundaries before blasting.
**Keywords**: Blast induced, Ore movement, Prediction, Birimian, Ghana

## 1. Introduction

Blasting is necessary to fragment rocks for efficient excavation. In gold mines, movement induced by blasting causes dilution of ore as the boundary of ore and waste was disturbed after the blast. Hence, knowledge of ore movement after a blast has been of interest to mine geologists, especially in areas where there is no clear distinction between ore and waste. Some geological factors that are out of control during blasting include the following:

- Rock Hardness/Brittleness
- Rock Strength (compressive and/or tensile strength)
- Rock Density
- Rock Porosity

Gilbride *et al*. (1995) reported that ore dilution due to blast-induced movement depends on several factors including blast design, free face conditions, rock mass properties and geology.

The objective of this paper is to calibrate using mathematical equations the movement of rock fragments, in a muck pile, after blasting, so that equations which were related to parameters of rock strength (compressive and/or tensile strength) and rock density for a particular rock structure would be deduced. These equations could help to predict similar rock movements away from *in-situ* locations with known rock parameters.

## 2. Field and Laboratory Work

The rocks at the Akyempim mine, which were exposed in benches of six (6) metres intervals, were mainly diorite and basalt, and were either massive or foliated (Kesse 1985 and Bardoux 2002) (Table 2). Weakly or strongly foliated rocks comprise of aligned fine grained to medium grained quartz, plagioclase, chlorite and amphibole while massive rocks were non-aligned medium to coarse grained, comprising of quartz, plagioclase, alkali-feldspar and amphibole.

An indispensable rock parameter which influences fragmentation is Uniaxial Compressive Strength. This is usually measured on a cylindrically shaped rock core which is loaded axially until failure of the rock. Subsequently, the maximum stress or load which each sample was subjected to failure represents the unconfined compressive strength ($S_c$) of that rock sample.

The compressive strength (Table 2) was then calculated using the following formula (after Braja 2002):

$$\sigma_c = \frac{P}{A}(kN) \qquad (1)$$

Where;
P = Applied compressive load at failure in *kN*
A = Area of the rock sample (in $m^2$)

Bulk density is another rock parameter which is dependent on mineral composition, porosity and degree of weathering. It helps to determine the extent of movement apart from its usage in the estimation of tonnage mined, blasted, or hauled. The procedure for measuring bulk density is to weigh a rock specimen on an electronic balance to the nearest 0.01g, coat it with paraffin wax and re-weigh. Subsequently, a piece of thread was tied around each specimen and gently lowered into two-third-filled beaker with distilled water. Measurement was done with an electronic balance that was set to read 0.00g when empty (Table 2).

Visual markers such as poly-pipes that could easily be located were buried in the block to be blasted. The blasting was facilitated in vertically drilled holes in a layout pattern, which was marked out based on rock type and structural weakness. Before blasting the monitors were activated and dropped into blast holes taking record of coordinates, depth and signal strength which were used in software to calculate movement. A blast monitor at Akyempim comprises of black high-density polyethylene (HDPE) pipe of pressure rating (PN) of 16, manufactured by Duraplast Ghana with external diameter of 7.5mm, internal diameter of 6.8mm and 9m long. The HDPE pipe is buried into a drilled hole (to a depth of 6m to conform with the planned mine bench height). The location of the bast monitor was planned by the Mine Geologist at the blast panel as the distances between the monitors (which were based on the blast panel area) were not constant. The blasting crew usually located the Ignition Point (IP) of blast towards a freeface and away from pit walls.

Visual markers enable after blast positions of blast monitors to be determined after the blast, as each poly-pipe was located using detectors. The coordinates of the blast monitors (before and after blast) were picked by surveyors and downloaded into Surpac software. The differences in locations were calculated by the mine geologist to determine the ore movement. The coordinates of movement, in x and y directions, were designed to be parallel to the strike and dip directions respectively.

The recorded movement in z-direction was not useful in this analysis which was two dimensional.


**Figure 1 Buried Blast Monitor (arrowed and labeled BM) at Akyempim**

## 3. Results and Analysis

**Table 1 Movement Distances as Recorded by various Blast Monitors**

| Blast Monitors | Bench | Movement (m) | | Blast Monitors | Bench | Movement (m) | |
|---|---|---|---|---|---|---|---|
| | | y | x | | | y | x |
| BM03 | 977 | 0.15 | 0.11 | BM14 | 956 | 1.12 | 3.56 |
| BM04 | 977 | 0.17 | 0.15 | BM04 | 956 | 1.69 | 2.82 |
| BM03 | 977 | 1.60 | 0.43 | BM07 | 956 | 0.47 | 0.72 |
| BM04 | 977 | 1.12 | 2.53 | BM08 | 956 | 0.80 | 2.57 |
| BM01 | 977 | 2.65 | 2.83 | BM04A | 959 | 1.32 | 2.62 |
| BM02 | 977 | 2.95 | 3.77 | BM02 | 959 | 1.71 | 0.82 |
| BM01 | 977 | 2.08 | 0.93 | BM01 | 959 | 1.49 | 1.20 |
| BM02 | 977 | 3.03 | 1.20 | BM02 | 959 | 0.54 | 0.03 |
| BM04 | 977 | 0.41 | 2.47 | BM03 | 959 | 1.05 | 0.54 |
| BM04A | 977 | 3.28 | 3.85 | BM01 | 959 | 2.13 | 1.36 |
| BM03 | 977 | 1.29 | 3.30 | BM03 | 959 | 3.25 | 1.19 |
| BM03 | 956 | 0.41 | 6.06 | BM02 | 959 | 2.23 | 0.70 |
| BM07 | 956 | 0.70 | 2.47 | BM01 | 959 | 2.44 | 0.11 |
| BM11 | 956 | 2.36 | 2.59 | BM01 | 959 | 0.20 | 3.01 |
| BM12 | 956 | 0.65 | 2.08 | BM08 | 959 | 1.49 | 1.93 |
| BM13 | 956 | 1.62 | 1.37 | | | | |

Table 1 illustrates movement of blocks as picked by various blast monitors mounted at selected benches on SAK-1 Pit. Assuming that the movement due to variation in individual fragment sizes was minimal in the blasted block, movements at the Pit range from 0.03 to 6.06 m. Table 2 shows average bulk density of all the rocks and ranges between 2.43 to 2.61. UCS values for massive basalt samples were generally higher (65.0-79.4 MPa) than values of weakly foliated or strongly foliated rocks (11.34–59.81 MPa). A. plot of rock movement after blast which was parallel to strike (x) and movement parallel to dip direction (y) failed to show any trend of deviation from *in-situ* locations at SAK-1 Pit of the mine (Fig. 2). However, UCS values which were plotted against bulk density show distinction particularly for massive rocks (Fig. 3 and 4) and foliated rocks (Fig. 5 and 6). These produce regression coefficients of 0.14 and 0.97 for massive and foliated rocks respectively. Usually hand-specimen identification of foliated rocks is more reliable than massive rocks which require a microscope to rule-out weak alignment of minerals as found in weakly foliated rocks.

Movement along x and y-directions were well defined when rock structures which occur at particular benches were considered. For instance definite trends (labeled A and B in Fig. 6) occur in plots using data from individual benches in SAK-1 Pit. This possibly was due to similarity in weather conditions during mining at a particular level which could either be in the wet or dry season. Temperature variation was from 18 to 36°C and at an average humidity of 960 mm. Another possibility was that movement of ore block due to blasting was dependent on depth of rocks even though rock characteristics were similar. Additional features such as faulting or significant veining probably imposed additional trend which was labeled as C (Fig. 7 and 8). Assuming availability of either foliated or massive textures, log plots showed various trends in x and y movement directions for foliated and massive rocks respectively (Fig. 9 and 10).

**Table 2 Rock Specimen Description, Bulk Density and Uniaxial Compressive Strength values.**

| Specimen No. | Rock Type | Description | Average Bulk Density | Uniaxial Compressive Strength (MPa) |
|---|---|---|---|---|
| 1 | Diorite | Strongly Foliated | 2.43 | 11.34 |
| 2 | Diorite | Strongly Foliated | 2.50 | 31.37 |
| 3 | Basalt | Massive | 2.48 | 75.70 |
| 4 | Diorite | Strongly Foliated | 2.49 | 35.70 |
| 5 | Diorite | Weakly foliated | 2.58 | 55.21 |
| 6 | Basalt | Massive with quartz veins | 2.53 | 79.36 |
| 7 | Basalt | Massive | 2.51 | 75.00 |
| 8 | Basalt | Weakly foliated | 2.61 | 59.81 |
| 9 | Basalt | Massive | 2.50 | 65.16 |

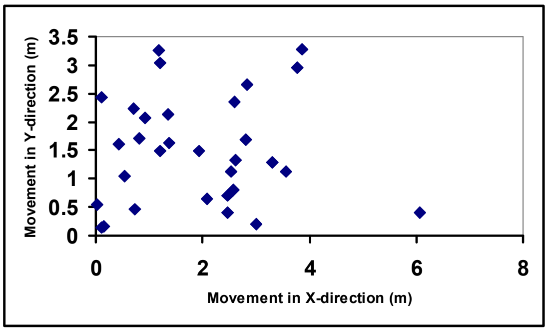


**Figure 2 Graph of Movement in Y Direction against Movement in X Direction at SAK-1 Pit Showing no Trend**

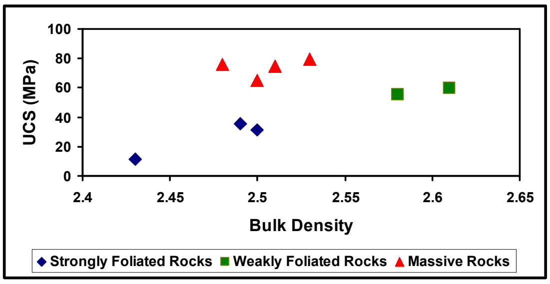


**Figure 3 Graph of UCS against Bulk Density of Diorite/Basalt (with Variation in Intensity of Foliation) Showing Two Sets of Trends**

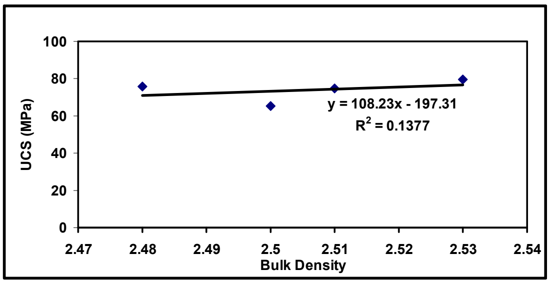


**Figure 4 Graph of UCS against Bulk Density for Massive Diorite/Basalt Rocks**

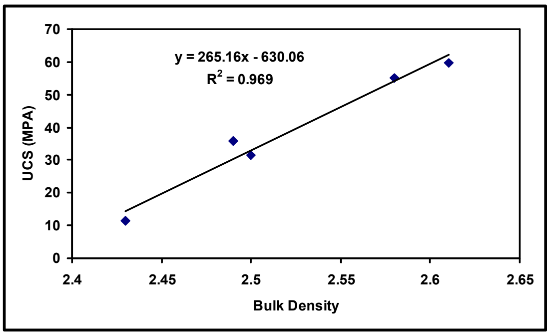


**Figure 5 Graph of UCS against Bulk Density for Foliated Diorite/Basalt Rocks**

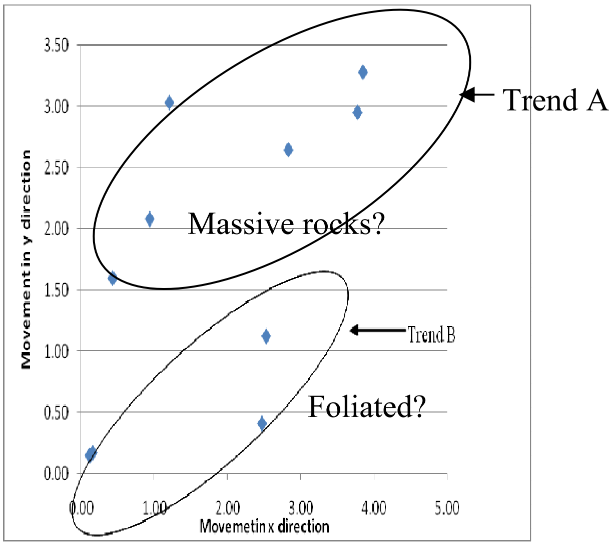


**Figure 6 Graph of Movement in the Y Direction against Movement in the X Direction for 977 Bench**

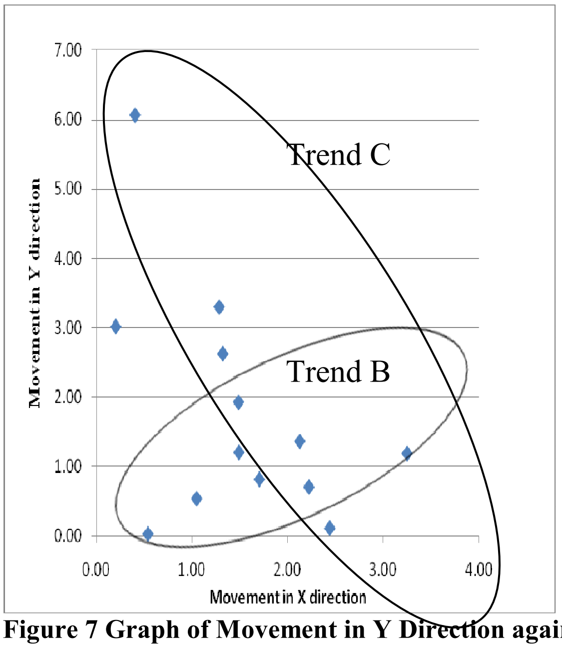


**Figure 7 Graph of Movement in Y Direction against Movement in the x Direction for 959 Bench**

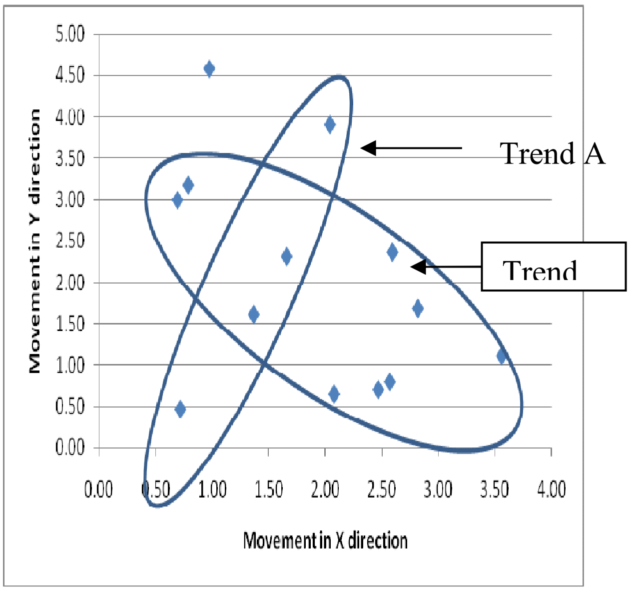


**Figure 8 Graph of Movement in the Y Direction against Movement in the X Direction for 956 Bench**

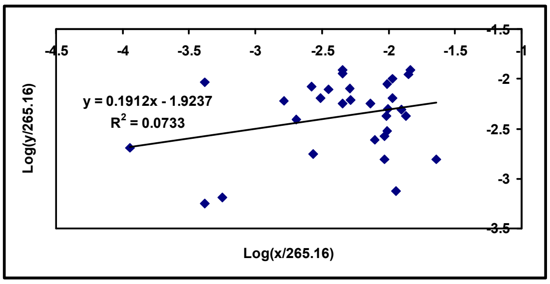


**Figure 9 Graph of Log $(y/265.16)$ against Log $(x/265.16)$ on the assumption that rocks at SAK-1 Pit were foliated.**

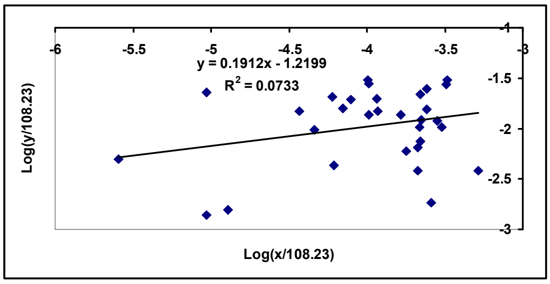


**Figure 10 Graph of Log $(y/108.23)$ against Log $(x/108.23)$ on the assumption that rocks at SAK-1 Pit were massive.**

## 4. Discussion

Metavolcanic rocks and metasedimentary rocks occur at Golden Star Wassa deposit, Akyempim mine in the Birimian of Ghana. Field names adopted by mine geologists for metavolcanic rocks were basalt, felsic-volcanic, feldspar porphyry and diorite while for metasedimentary rocks they were referred to as phyllite. Rock samples used in this report comprise of both massive and foliated varieties (Table 2).

Data recorded by blast monitors show no correlation of movement parallel to general dip direction (y-direction) against movement parallel to strike or x-direction (Fig. 2). However, locally, data from individual benches at SAK-1 Pit show three trends:

I. Positive correlation with intercept on y-axis ( Fig. 3 and 6)
II. Negative correlation with intercept on x-axis ( Fig. 7) and
III. Positive correlation with intercept on x-axis (Fig. 6 and 7)

Also massive and foliated rocks show different correlation coefficients on UCS against bulk density plots (Fig. 4

and 5). This relationship was observed again in graphs of the related log values (Fig. 9 and 10). Studies of intercept of the best fit lines suggest that movement of massive rocks correspond with correlation graph type-I and movement of foliated rocks to correlation graph type III. Correlation graph type II was possibly related to a fault which occurs at high angle to foliation. Such faults and shear zones are common on the mine area. With the exception of the negative correlated graph, all rocks with higher uniaxial compressive strength values also moved less distances from *in-situ* positions.

To better correlate all movement data, a log plot of the ratio of movement to correlation of UCS/Bulk Density was deduced as follows:

$$Log\left( y \Big/ \frac{\sigma}{\rho} \right) = mLog\left( x \Big/ \frac{\sigma}{\rho} \right) \text{............. (2)}$$

Where σ is UCS; ρ is bulk density; m is gradient of log graph; y is the vertical movement and x is the horizontal movement.

Let $k = \frac{\sigma}{\rho}$ .................................................. (3)

Then $Log\left(\frac{y}{k}\right) = mLog\left(\frac{x}{k}\right)$ ...................... (4)

$$Logy - Logk = mLog\left(\frac{x}{k}\right) \text{........................ (5)}$$

$$Logy = mLog\left(\frac{x}{k}\right) + Logk$$

$$Logy = Log\left(\frac{x}{k}\right)^m + Logk$$

$$Logy = Log\left[\left(\frac{x}{k}\right)^m \times k\right]$$

Then $y = \left( x \Big/ \frac{\sigma}{\rho} \right)^m \times \left(\frac{\sigma}{\rho}\right)$ ............................. (6)

Assuming rocks at SAK-1 Pit are massive, gradient of graph of UCS against bulk density would be 108.23 (Fig. 4). Using gradient of log graph of

$m = -0.1943$ (Fig. 10)

$$y = \left(\frac{x}{108.23}\right)^{-0.1943} \times 108.23 \text{.................... (7)}$$

$$y = 108.23\left(\frac{x}{108.23}\right)^{-0.1943} \text{........................ (8)}$$

If rocks at SAK-1 Pit were foliated, gradient of UCS against Bulk Density would be 265.16 (Fig. 5) and m = -0.2143 (Fig. 9); hence

$$y = \left(\frac{x}{265.16}\right)^{-0.2143} \times 265.16 \text{.................. (9)}$$

$$y = 265.16\left(\frac{x}{265.16}\right)^{-0.2143} \text{..................... (10)}$$

## 5. Conclusions

This work suggests that; even though no trend emerges when blast movement data were considered as a whole from SAK-1 Pit of Golden Star Wassa Limited, Akyempim mine, deductions from selected benches show three trends of blast induced block movement parallel to both strike and dip directions.

Deductions based on rock parameters show that movement was dependent on functions of rock strength (UCS) and bulk density. Characteristically, rocks with higher strength and higher densities move less than those with lower strength and lower densities.

Significant blast movements were dependent on the nature of the rocks, be it foliated or massive. Hence foliated rocks had higher movement values than massive rocks that had higher UCS values.

Further tests should be done to incorporate vertical movements in three-dimensional plots. In addition, the equations should be tested with the utilisation of rock mass strength, rock mass quality and rock mass rating.

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