Mine Cost Control Through Effective Mine Drainage at Bogala Mines - Phase 1

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Abstract: The Bogala Graphite Mines in Sri Lanka is experiencing a considerable water flow problem for more than two decades which has resulted in increasing total production cost due to high dewatering cost. This case study was basically carried out to optimize the mine dewatering cost by preventing water inflow where possible. This paper describes only the phase 1 of the study, which is "The identification of water recharge sources in to the mine". Major water seepage takes place above 72 fathom (fm) levels and a significant inflow is at 52 fathoms level which discharges water at a rate of 8.5 liters/s. Initially, major joints/fractures above 72 fathom were measured and the fracture network in the problematic area of the mine was developed. Interpretation of the fracture model provided valuable data on water recharge locations. Simultaneously environmental isotopes (^2H and ^{18}O) analysis on surface, subsurface water bodies and underground seepage locations were carried out to identify the exact water recharge locations. The ^2H and ^{18}O contents were plotted in graphs in various suspected combinations with local meteoric water lineto identify interconnections. Even though, some solutions were presented to reduce the mine dewatering cost, further analysis is needed with continuous sampling of data to confirm the tentative conclusions.

Keywords: Cost, Dewatering, Fracture, Isotopes, Joints, Water intrusion

1. Introduction

Unforeseen conditions can occur at any time in an underground mine with its development and/or mining activities. Bogala mine is a shallow underground mine located in the Kegalle district; Sri Lanka and operated under "Graphite Kropfmühl" AMG group of companies. Company had to cope with significant water inflows throughout the past decades up to the present. Past unsystematic

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mining activities have created unsafe abandoned pits and huge open stopes throughout the mine and laterdevelopments irrespective of such informality have resulted in uncertain and uncontrollable water seepage areas with no solution.

Pumping data reveals a quantitative difference between amount of water pumped out during dry period and rainy period indicating that direct rainfall has a significant influence on water seepage into the mine and there exist interconnections between surface water accumulation paths and underground water seepages. Highly fractured, jointed and faulted surrounding rock mass further confirms the above argument.

Authors' attempt was to identify and estimate these interconnections and the influence of them for mine dewatering cost and also propose remedial measures in an economical manner in order to increase the profitability of the company. With the assumption of continuity of major joints/fractures in the tunnels up to the surface which may intersect the water bodies, paths on and below the surface enabled development of a three dimensional (3D) "fracture model" to understand the fracture concentrations on the surface to identify probable water leakage sources and pathways. Environmental isotopes study carried out with the collaboration of Atomic Energy Authority (AEA), Sri Lanka revealed more accurate data on interconnections between different surface water sources and underground seepage water.

It is noted that all the underground studies were limited to above 72 fathoms (fm) level.

2. Materials and Methods

2.1 Development of Fracture Network above 72 Fathom Levels.

Fracture/joint survey was carried out in 25 Fm, 27 Fm, 37 Fm, 40 Fm, 47 Fm, 52 Fm and 72 Fm levels and the fractures and joints to be measured were selected by visually inspecting their water condition, continuity and density. Dip and Strike of selected fractures were measured with a Brunton compass and tunnel maps and measuring tape were used to record their exact locations. AutoCAD drawing tool was used to locate the measured fractures/joints level wise. The drawn fractures were projected to each and every level above that particular level and it was assumed that fractures are continuous up to the surface and dip angle is constant throughout its length during the fracture projection. Similarly, all the fractures plotted in each tunnel were projected to each and every level above that particular level concerned. Finally AutoCAD file and surface coordinates were fed to "SURPAC" modeling software and to obtain a good fracture/joint model which enabled the interpretation of the water recharge locations and pathways. Refer Figure 1 below.

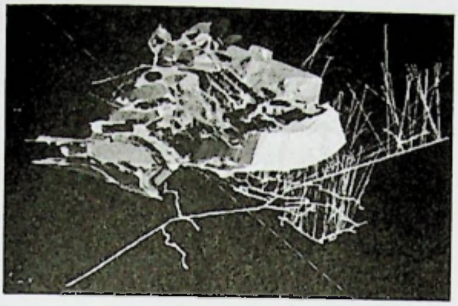

Figure 1: Final fracture model

2.2 Environmental Isotopes Analysis (^{18}O, ^{2}H and ^{3}H).

Deuterium (^{2}H), Tritium (^{3}H) and ^{18}O contents of water samples collected from different surface water accumulations, run off, rivers, dug wells, rain water and seepage water from underground were analyzed repetitively to identify any interconnection/s between surface and underground seepage water. Extreme care was taken during sampling, storing and transportation of each water sample to avoid any possible contamination and evaporation as it is critical to ensure high quality analysis and for reliable interpretation of data. All the samples were collected in double-capped clean bottles and sealed well to prevent the contact with external atmosphere. Rain water was collected each fortnight with a special arrangement to avoid evaporation. Their isotope values were used to construct the local meteoric water line (LMWL) for Bogala area.

2.2.1 The δ (delta) notation

When measuring isotope contents of different water samples, the values are expressed relative to the standard sample (Vienna Standard Mean Ocean Water) made averaging the ocean water composition in the world for measurement of water isotopes. The delta notation for ^{2}H can be written as,

$$\delta^{2}H = \frac{(^{2}H/^{1}H)_{sample} - (^{2}H/^{1}H)_{std}}{(^{2}H/^{1}H)_{std}} \times 1000 \quad \text{........(1)}$$

Then the equation for LMWL (a & b are constants.);

$$\delta(^{2}H) = a \cdot \delta(^{18}O) + b \quad \text{..........................(2)}$$

3. Results and Discussion

3.1 Interpretation of fracture survey data.

The fracture projection from 47 fm level to the surface indicates highly fracture-concentrated zone near the ventilation shaft area of the mine. The existing drain system in the mine lies within this area and it is neither concreted nor made water proof and one can observe during rainy season, a substantial reduction of rain water when in this area. This zone therefore can be identified as a main water recharge source to the mine.

A significant amount of water can be trapped at the surface if proper remedial action is taken resulting in a considerable decrease in the cost of dewatering. Also fracture model doesn't show any fracture concentration or major fractures in the surface paddy field area and the stream nearby, revealing that stream and paddy fields have no significant. influence on water inflows into the mine. However, a large number of fractures projected on the surface and upper levels were directed towards the mountain range which is the catchment area of the Haloluwa River, reflecting that, it is a possible area for water recharge to the mine. Water sampling for isotope study must be extended to this area.

3.2 Analysis of isotopes values for water recharge identification.

The line of best-fit for the data set was selected by regression method as;

$\delta(^{2}H) = 8.1 \; \delta(^{18}O) + 13.5$ ....(3)

Following graph depicts the relationship between $\delta(^{2}H)$ and $\delta(^{18}O)$ values of surface water samples in September and October,2012 and 52 fathom level main water leakage.

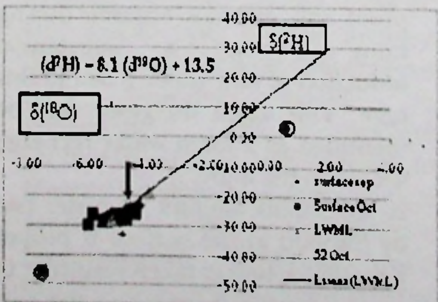

Figure 2: Relationship between $\delta(^{2}H)$ and $\delta(^{18}O)$ values.

It can be noticed that the values of main leakage (shown in arrow) lie on the clusters of surface water sample values. So, this reveals that the main water spring is recharged by surface or shallow ground water and neither from an underground aquifer nor surface accumulation like paddy field (shown in rounded points). The distinctive difference of same paddy field values in two months was due to dilution of isotopes by rain in October. Table 1 represent isotope value ranges of different underground and surface water samples taken during September and October, 2012.These values clearly indicate that the values of paddy field area are completely different from other sample values implying that there's no connection between paddy field and the underground seepage water.

Table 1: Isotope Values ($\delta^{2}H$&$\delta^{18}O$)

Sampl e	September		October	
	$\delta(^{18}O)$	$\delta(^{2}H)$ (‰)	$\delta(^{18}O)$(	$\delta(^{2}H)$ (‰)
52fm main	-5.08	- 27.09	-5.28	- 26.65
Strea	-4.85	-	-	-
Paddy	+0.5	+3.25	-7.50	-
Shallo	-	-	-	-
27fm	-	-	-	-
40 fm	-	-	-	-
47fm	-	-	-	-
52fm	-	-	-	-
72fm	-	-	-	-

It is observed that similarities exist between drain water in 27fm, 40fm levels and shallow ground water.

Hence, indicating that interconnection between shallow ground water, drain water in level 27 and 40 may be possible.

Individual isotope values also indicate similarities between 40fm and 52fm, 27fm & 52fm levels. However, repetitive sampling is required to confirm these valuable clues to identify surface water recharge locations and level wise leakages. The above facts investigated through both fracture analysis and the isotope values are very much important in identification of water recharge sources from the surface and leakages from upper levels to lower levels hence eliminate the problem through applying a suited remedial plan to reduce water intrusions to the mine.

4. Conclusions.

Seepage of water in the mine is local ground water and is mainly recharged by direct local rain fall and not from the surface accumulated water bodies. It is proved that the paddy field adjacent to the rock dumping yard is not the source of water that recharges water to the water spring at 52 fathom. Water seepage from upper tunnel levels to lower levels is confirmed from the isotope and fracture survey results up to now. For the exact identification of water recharge locations and the leakages at upper levels to lower levels, continuous and well planned sampling program is required to determine isotopic variations and similarities between water samples. However, a significant cost can be cut if the water is trapped at the source itself or in the higher access levels avoiding seepage in to deeper levels or locations.

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