Underground Mine Cost Control through Proper Mine Drainage- Bogala Mines

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Abstract: A Bogala graphite mine is located in the Kegalle district, Sri Lanka. Bogala mines has been experiencing a considerable water inflow during the past many years, involving a significant cost on mine dewatering compared to other production costs. Daily mine dewatering data shows that the average volume of water to be pumped out from the mine is approximately 1.5 million gallons per day and, the cost incurred for mine dewatering is approximately Rs. 1.3 million a month. This research focuses on identifying the interconnection between the leakage points in two levels, with major water seepage takes place above 72 fathom levels and significant intrusion is at 52 fathoms level. Environmental isotope analysis were carried out in underground seepage locations to identify the exact locations where water recharging takes place inside the mine. Water samples were collected from leakage locations. They were analysed to measure the Oxygen-18 and Deuterium contents. The local meteoric water line was drawn with the help of rain water samples. The Oxygen-18 and Deuterium content was plotted in a graph in various suspected combinations. The clustered locations were analysed in a graph and tried to identify the interconnection between leakage points in two levels. Some possible interconnections were identified between 52 and 72 fathom levels.

Keywords: Isotopes, Water seepage, Cost, Dewatering

1. Introduction

Water leakages in a mine are a complex and often a difficult problem to solve. The uncontrolled flows or leaking of water into underground excavations is one of the most annoying problems faced by the mine management. Bogala graphite mine is the largest underground mine in Sri Lanka, located in the Kegalle district, Sabaragamuwa province. Bogala mines produces high quality graphite and, it has a history of more than one and half centuries.

In early times people began mining the outcrops scattered in the area. At that

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time, mining was done in an unplanned manner A large number of pits are still visible in the vicinity of the area. These unplanned mining has led to several uncertainties. Bogala mine is experiencing considerable water seepage throughout the last 25 years, involving a significant cost for mine dewatering compared to other production costs. The most important observation on these areas is the visibility of incoming water seepages to the active mine areas from their reachable mouths and it's very difficult to understand the source of water entry due to uncertainty of those water paths. The upper levels of the mine are full of seepage water and most of the water is dewatered from the above 72 fathom level and some inflows pumped to the 72 fathom level and some from levels below. Highly fractured surrounding rocks are one of the major factors for seepage water entrance to the mine.

Mine Management firmly believed that the direct rainfall has a significant influence on water entry to the mine workings, since pumping data revealed a quantitative difference during dry period and rainy period. The results of isotope analysis carried out in the early research reveals that there is no significant direct connection between surface water bodies and underground water leakages. Management has now decided to locate the places where water leakages occur from one level to the other since stopping the water leakages in the upper levels can reduce the pumping cost rather than pumping it from the lower level.

This research is aimed at identifying the locations within underground levels where the water seepage is taking place between different levels. By identifying the leakage location a suitable method can be proposed to reduce the water seepage thus, reducing the dewatering cost on the mines production by pumping the water from upper level as much as possible. Hence, considerable amount of money can be saved and the company can increase the profitability.

Taking into consideration the fracture patterns, joints and vein systems in the mine connecting with resources at each level of the mine are important factors to identify the location of water seepage. Possible places from where water may flow into the mine have to be analysed and possible continuity of major joints, fractures inside mine levels to up to the surface also have to be predicted. Probable water leakage ways between levels of the mine have to be found out through environmental isotopic study and visually inspecting their water condition, continuity and density. Each level has a significant water spring, exact source for the springs have to be determined.

Fractures and joints in the underground mine tunnels may continue to the surface and may intersect the water bodies on and below the surface. Measurements of all significant fractures and joints in all the accessible tunnels above 72 fathom level would enable to identify the leakage points. Considering developing a "fracture model" for Bogala mine is not an easy task due to high fracture frequency, unpredictable fracture patterns and time constraints.

Isotope study is a popular method in identifying water leaking sources in modern world and, in Sri Lanka it was successfully carried out to identify the source of leakage in Samanalawewa dam. It was the main method used to accomplish the main objective of this study. The Atomic Energy Authority (AEA) of Sri Lanka comprises an "isotope hydrology study section" and has the technical ability to conduct laboratory testing on stable and radioactive isotope measurements and is equipped with required instruments. The technical support of the isotope hydrology section of AEA for isotope testing and analysing of water samples collected from the underground water seepages were needed throughout the study period.

2. Methodology

2.1 Measurement of fracture above 72 fathom levels

The fracture study was mainly concerned on the above 72 fathom level. The purpose of the study is to developing the joint/fracture network above the 72 fathom level. It would facilitate understanding about water paths that may continue from surface to 72 fathom level.

During the fracture survey underground, fractures and joints to be measured were selected by visual inspection. Fractures and joints which are continuous throughout the tunnel round or which are suspected to be continuous for a long distance towards surface were given more attention. Brunton compass, maps, notebook and measuring tape were used for this survey. In the case of Bogala mines, measuring all the fractures is impossible and the task is also unreliable. The fractures may be deviate to unanticipated or at a different direction.

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

For this isotope study of Oxygen-18 and Deuterium, water samples from underground levels were required. Sampling procedure for water sampling from one type of source is little different to another source. Methodology followed by us for water sampling from different sources are described below. Accurate location of the sampling point is important in this isotope study since in analysis of the isotope values, sample location plays major role. Underground AutoCAD maps were used to map the sample location in the each level.

Extreme care was taken during the sampling. Samples were collected using double-capped cleaned bottles. The main objective of sealing and capping the sample bottle was to avoid evaporation of the sample during storage and transportation to the laboratory. If evaporation takes place it would show a deviated result from the representative value. Samples were kept in a dark place to avoid direct sun light to prevent oxidization in the sample. Since the isotope is Oxygen-18, the results will not represent the actual isotope value at sampling.

In underground tunnels, water seepages were significant and in some locations insignificant amounting to droplets. Water samples were also taken from sumps from different levels. Rain water was collected at each fortnight period with a special arrangement to avoid evaporation and, 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 ^2H can be written as,

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

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

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

3. Results and Discussion

3.1 Analysis of the Isotope Values in the Water Samples

Environmental isotope analysis was done in order to track the seepage water paths to the mine through the bed rock. In the analysis, it was found that there was some interconnection between the levels where the leakage happens.

Analysis was performed using the available isotope data which was collected in the course of almost three months in three sampling sessions. But, it could not be assured since fracture patterns in the underground levels may influence the results. Actually with the available data during the period of study performed, a better conclusion of seepage paths could not be arrived at the underground.

"Local Meteoritic Water Line" for the Bogala area was developed by the available data. This line was drawn with the best fit of the available rain water sample data.

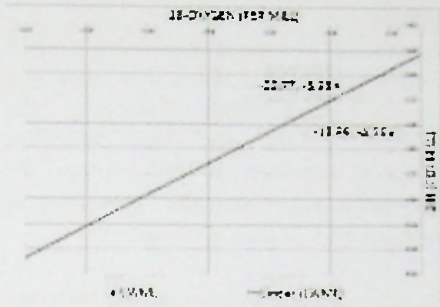

Figure 1: Relationship between $\delta(^2H)$ and $\delta(^{18}O)$ values

An average isotope value was taken by averaging the isotope values of three sampling sessions.Table-1 represents the average isotope values of different underground water samples taken during July to October, 2013.

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

Sample Code	d2H	d18O	Sample Code	d2H	d18O
72FM/SN01	-23.69	-4.57	40FM/SN24	-27.65	-5.13
72FM/SN02	-24.57	-4.78	27FM-SN25	-27.08	-5.00
72 FM/SN 03	-26.65	-5.04	27FM-SN26	-26.80	-5.05
72 FM/SN 04	-26.08	-4.78	40FM-SN27	-26.96	-4.82
72 FM- SN 05	-25.97	-4.74	90FM/SN28	-21.21	-4.12
72FM/SN06	-22.86	-4.65	90FM/SN29	-25.35	-4.81
72FM/SN07	-25.92	-4.86	90FM/SN30	-22.73	-4.70
72FM/SN08	-24.90	-5.05	90FM/SN31	-24.92	-4.83
52FM-SN09	-27.17	-5.01	90FM/SN32	-23.22	-4.51
52FM-SN10	-23.96	-4.55	126FM/SN33	-27.05	-5.19
40FM-SN11	-26.43	-5.02	126FM/SN34	-25.38	-4.81
52 FM- SN 12	-26.13	-4.94	170FM/SN35	-25.67	-4.92
52 FM- SN 13	-25.47	-4.68	205FM/SN36	-25.82	-4.75
52FM/SN14	-22.98	-4.64	205FM/SN37	-24.13	-4.56
52FM/SN15	-25.56	-4.60	240FM/SN38	-23.18	-4.58
47FM/SN16	-27.03	-5.00	240FM/SN39	-24.59	-4.84
47FM-SN17	-26.19	-4.81	240FM/SN40	-24.04	-4.78
47FM-SN18	-26.08	-4.79	90FM/SN41	-25.63	-4.72
47FM-SN19	-23.33	-4.55	126FM/SN42	-23.66	-4.58
43FM/SN20	-26.12	-4.70	205FM/SN43	-21.54	-4.42
40FM/SN21	-25.90	-4.76	275FM/SN44	-20.48	-4.23
40FM/SN22	-29.66	-5.24	170FM/SN45	-27.05	-5.12
40FM/SN23	-28.15	-5.28			

Isotope values of two levels were plotted in the graph. It can be noticed that the isotope values of water samples collected from leakage location shows similarity when it plotted in the graph. Also these locations were relatively closer to each other. So, this reveals that there is

interconnection between leakage points.
It can be observed from the graphs and underground maps that there is a strong relationship between the isotope values and the sampling location between 40 fathom and 72 fathom level especially between 52 fathom and 72 fathom level.

In some instances isotope values were approximately similar but the leakage locations in the underground map were far away from each other. Therefore, there may be an interconnection between two leakage points since fractures could link them

The analysis was carried out mainly considering the isotope values of the leakage location, but proper fracture analysis is much important in identification of water leakage location between levels. After identifying the leakage location it can be stopped at upper levels through applying a proper remedial plan, reducing the pumping cost.

4. Conclusions

Isotope studies confirm that there are interconnections between the seepage points in two levels. There is a strong relationship between the isotope values and the sampling location between 52 fathom and 72 fathom level. But there are some factors influencing the results. The first one is the mine area. As the underground mine area is small, there is a high chance for isotope values of several locations to come closer since the source for isotope is limited, hence we cannot find variation in the isotope values. It results in isotope values between the two locations to come closer when there are no connections. The other influencing factor is the presence of fractures. Even though fractures can be measured, they cannot be measured as they are in underground. In the analysis, fracture pattern was not considered. But fracture patterns play a major role in the isotope study. Therefore, it should be thoroughly studied and should have better understanding about that when analysing.

A well planned sampling programme is needed for better interpretation. The most suspected locations which show direct connection should be focused more and water samples should be collected on a weekly basis at least for two to three months to confirm the scenario.

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