Determination of coal seam thickness in blast holes utilizing geophysical well logging data and its use in short term mine planning

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Abstract

The use of geophysical well logging data can help to solve problems related to the loss and absence of core samples in a coal deposit, providing extremely valuable information and at the same time reducing exploration cost. In this context, blast holes drilled in a total area of 50x50m, were logged with a geophysical probe in a coal deposit. The geophysical parameters measured in the blast holes were natural gamma radiation and resistivity. Bibliographically, it is known that coal as a mineral exhibits low natural gamma radiation emissions and high resistivity values respectively. The coal seams were easily identified from the other lithotypes in the deposit since the measured parameters varied in recorded values when in the coal seam regions with respect to other lithological regions down the blast holes. As a result of the variations in the measured parameters in regards to coal, the thickness of the coal seams present in the deposit were able to be determined using the logs obtained down the blast holes. This study was able to compare the mass of the mined coal seams to the mass calculated using data obtained from geophysical logs and the relative error did not exceed ±12% with an insignificant global difference of less than 2.5%.

Introduction

Geophysical well logging practices are becoming more important in the mining sector. In successful cases, they can be used to replace core sample recovery surveys, which can be quite expensive. Through these techniques, physical and chemical properties of minerals in exploration, important parameters used in the implementation of mine planning and mineral processing can be determined. When properly applied, it is an economical and efficient way to increase the quality and quantity of information about mineral deposits in exploration, modelling and estimation of resources/reserves (Bond et al. 1971). These techniques can also be used to preview the quantitative parameters, helping to delineate mineral/waste interfaces (Borsaru and Asfahania, 2007). It also can be very advantageous to solve problems related to the low core sample recovery or its absence (Reeves, D.R. 1976).

Parameters like ash content and density reflect the mineralogical composition of the coal in association with natural gamma and backscattered radiation of rocks (Borsaru et al., 1985). When there is a strong correlation between these parameters and the geophysical readings obtained by determined probes and techniques, we can determine the quality of coal with a very high precision.

The principal objective of this study is to determine coal seam thicknesses in blast holes utilizing geophysical well logging data and show its use in short term mine planning.

Method

Data acquisition

This work was realized in the state of Rio Grande do Sul which is situated in the southern region of Brazil. Geophysical logging data was obtained in 35 blastholes situated in a total area of 50x50m with spacing of approximately 10m between holes. The blastholes were logged with a natural gamma and resistivity probe, which measures the natural emission of gamma radiation, by rocks and resistivity of the rock formation respectively. The depths of the blastholes were between 18 to 20m and no core samples were recovered during drilling. The time taken to log a blasthole took more or less 15 minutes, performing the profiling of the blasthole at a speed of 3 meters per minute. It was also noted that there were three coal seams in the area of study (S, M and I) with primarily siltstone in between them. The coal seams in this deposit were known to be small in thickness, which makes the accuracy of thickness determination highly important in terms of production calculations.

During mining, the area of study was sub-divided into three parts with about 10 to 11 blastholes in each part. The extraction scheme for the M coal seam is shown in Figure 1 as an example.

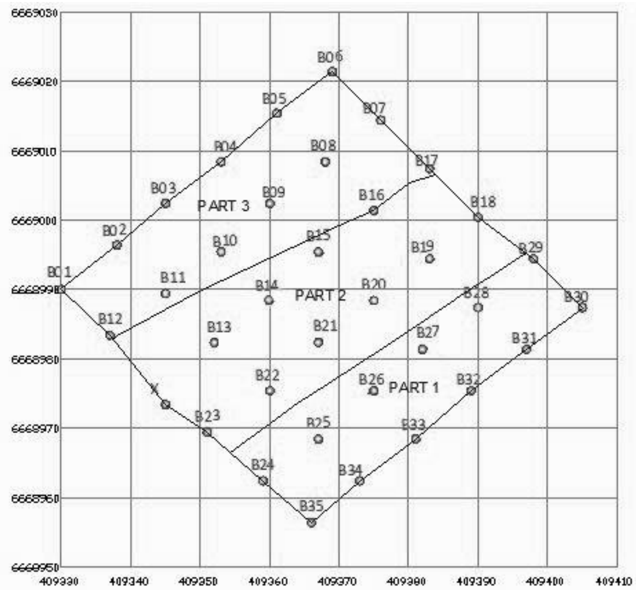

Figure 1: A map showing the positions of the blastholes and the extraction scheme for the M1 coal seam as an example.

Each coal seam was mined in three parts, except for the I coal seam, which had only two parts extracted due to operational problems. Each mined digline was weighed and stockpiled. The area of study was georeferenced, before and after mining of each part (digline) with reference to each coal seam, enabling the possibility of mass extracted reconciliation. Area (calculated) occupied by each part of the extracted coal seams and the weighed values for the extracted mass are shown in Table 1.

Table 1. Area occupied by extracted coal seams and their weighed masses

Seam	**Part**	**Area (m^2)**	**Mass (t)**
S	1	672	1875
S	2	882	1938
S	3	896	1718
M	1	657	1171
M	2	1008	1271
M	3	785	1838
I	1	686	1168
I	2	926	1983

Interpretation and lithotype recognition

In well logging, various parameters can be measured depending on the probe utilized. The behavior and variations in measured values of these parameters depend on the physical and chemical properties of the rock type. Natural gamma radiation and resistivity are the measured parameters in this case. Coal tends to exhibit low natural gamma emission values because it has very low constituent of radioactive elements (uranium, thorium and potassium), making it easier to be identified from other lithotypes within its vicinity or formation. Resistivity values are relatively high; this is as a result of compactness and low porosity which is common in coal. Siltstone is the opposite, high natural gamma emission and low resistivity values. In this case study scenario, it was relatively easy to distinguish coal seams from siltstone. However, it should be noted that this is not always the case, as some rock types exhibit the same characteristics as coal, for example, sandstone. In these cases, another probe is mandatory in order to avoid classification and identification errors. The figure below shows one of the 35 logs obtained in the blastholes with its corresponding geological description. The practice of determining the top and base of the coal seam in order to be able to determine the coal seam thickness rests on a fundamental rule. Each is determined as a midpoint between two inflection points on the resistivity anomaly at the beginning and at the end of the coal seam. This is adopted to avoid wrong interpretation due to the interference from the hanging wall and footwall lithology in the geophysical records and taking into account the volume of investigation given by the used probe. Sometimes there could be some deviation from this rule but this is based on the discretion of the log interpreter.

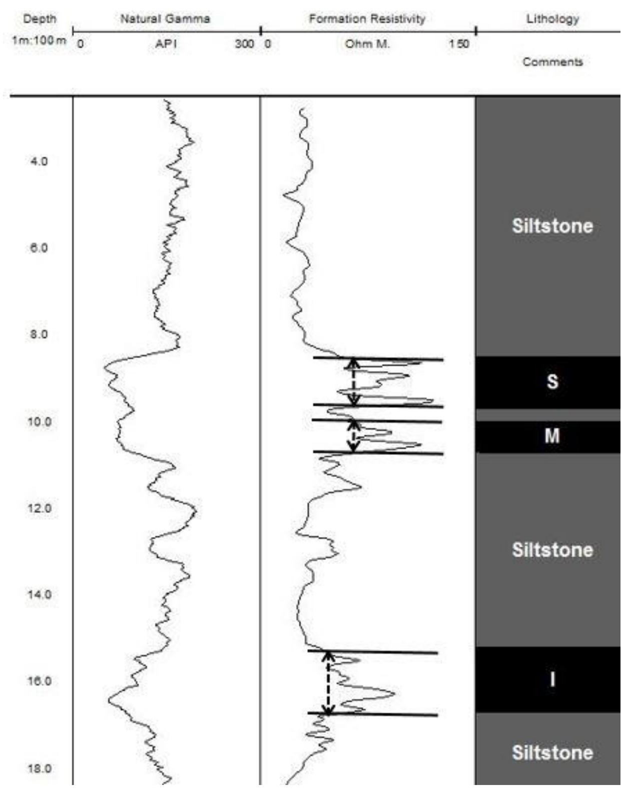

Figure 2: Typical geophysical log (natural gamma on the left and resistivity on the right).

However, it should be noted that it is not in all cases that the determination of coal seam thickness is so straightforward or possible. In the case of this deposit, in certain situations, geophysical logs give the impression that the S and M seams merge into a single seam, making it extremely difficult to determine the lithological boundaries of both seams (Figure 3).

A simple solution could be to examine other logs within the vicinity (top, bottom, left and right) of the log in question, which could be very helpful to arrive at a conclusion in terms of the thickness of the seams. Obviously, there will be some error involved, which is inevitable because of the situation at hand.

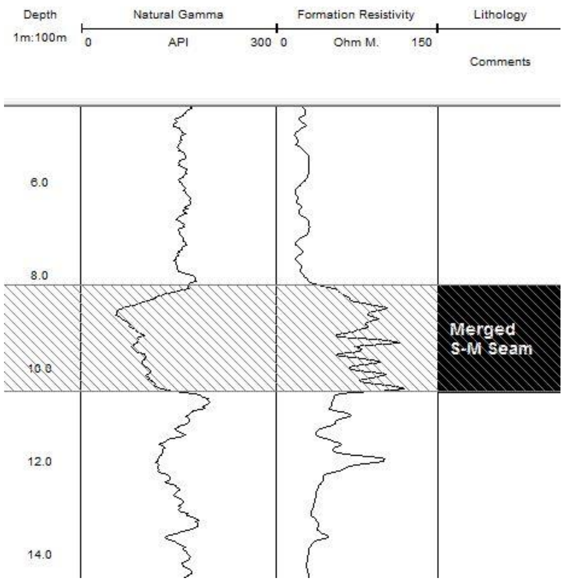

Figure 3: Log of blast hole B05 showing the S and M seam merged into a single seam (natural gamma on the left and resistivity on the right).

In addition, it was noticed that there were differences in thickness values determined for seams when the logs were interpreted. This can be explained as variations in lithology limits over distances along the deposit (Figure 4). However, these variations are not extreme since the sample grid is dense.

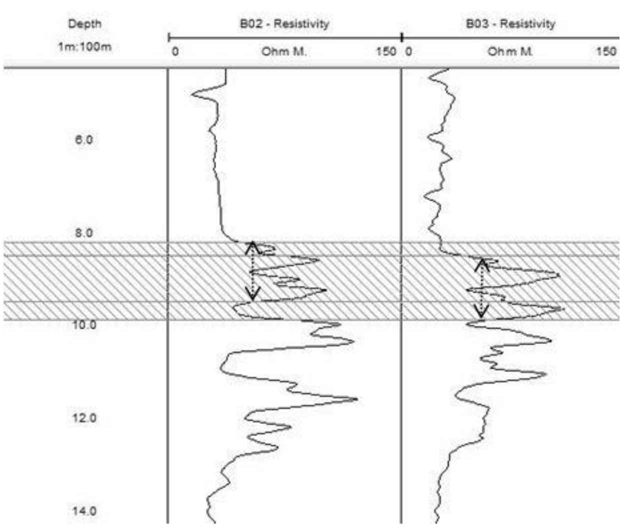

Figure 4: Comparing the S seam limits utilizing the resistivity parameter in logs of B02 and B03 with seam thickness of 1.30m and 1.40m respectively.

Dilution factor

During the extraction process, part of the waste material is extracted with the coal seam. This is referred to as dilution and a dilution factor has to be computed into the calculated extracted mass. In order to arrive at a value for the dilution factor, core samples at the top of the S coal seam, between the S-M, M-I coal seams and at the base of I coal seam were obtained and sent to the laboratory for analysis. Density values of these samples varied between 1.9 to 2.2 g/cm^3 with a mean value of 2 g/cm^3. Also an average addition thickness of 0.1 m for the waste material mined together with the coal seam is also taken into consideration. Therefore, resulting in an equation for calculated extracted mass:

$$(A^* Esp_c{}^*\rho_c) + (A^* Esp_w{}^*\rho_w) \qquad (1)$$

where: A is the area occupied by the part extracted, Esp_c is the average thickness of the coal seam in the part extracted, ρ_c is density of the coal seam, Esp_w is the average thickness of the waste material (0.1 m) and ρ_w is the average density of the waste material (2 g/cm^3).

Results

Mass calculation

Coal seam thicknesses were determined in each blast hole for all three coal seams (S, M and I). As already stated, each seam was extracted in three parts with 10 to 11 blast holes situated in each part, leading to 10 to 11 thickness values in each extracted part. It was observed in the results that small variations in thickness values occurred over short distances (intervals of 10 m). However, there was no need for any geostatistical processing since the sampling grid was considered to be dense and also variations in thickness were relatively small. An average thickness value was assigned to each extracted part. The results are shown in Table 2.

Table 2: Coal seams and their average thickness values

Seam	Part	Average seam thickness (m)
S	1	1.47
S	2	1.23
S	3	1.10
M	1	0.91
M	2	0.66
M	3	1.10
I	1	0.82
I	2	1.02

The determined thicknesses were applied in equation one to calculate the extracted mass. An average density value was assigned to all eight parts, ρ_c = 1.7 g/cm^3. This value was given by the mine's laboratory. The correct procedure would have been to acquire samples from each pile and send them to the laboratory to determine the density value for each extracted part but this was not possible at that time. It should be noted that this will definitely have a small effect on the mass calculation results because each coal seam is different from the other in terms of composition. For example, density values are severely affected by ash content. The higher the ash content, the higher the density value of the coal in question. The table below shows the results from the calculations and also the respective errors.

Table 3: Reconciliation between extracted mass and calculated mass for each seam

Seam	Part	Mass extracted (t)	Mass Calculated (t)*	Absolute Error (t)	Relative Error (%)
S	1	1875	1814	-61	-3
S	2	1938	2021	83	4
S	3	1718	1855	137	8
M	1	1171	1148	-23	-2
M	2	1271	1315	44	3
M	3	1838	1625	-213	-12
I	1	1168	1093	-75	-6
I	2	1983	1791	-192	-10
	Total (t)	12962	12662		

average density value of 1.7 g/cm3 was used in the mass calculation for each part and also included were masses calculated as a result of dilution for each part.

The relative error for the estimates of mass did not exceed ± 12%, taking into account all 8 parts. The weighed value for the total mined mass was 12,962 t, while the total calculated mass was 12,662 t, which resulted in an insignificant overall global difference of less than 2.5%.

Mine planning

Core sample recovery in drill holes is a common and highly important practice in the mining industry. Mining exploration and mine planning are extremely dependent on core sample recovery, which are very expensive. It is the backbone of these processes. The information obtained is frequently applied in short term mine planning but at times it is not very reliable. Drill holes for sample recovery are executed at very large spacing distances, which is not compatible with the resolution focus in short, term mine planning since variations in mineral composition and lithotypes from one point to another over long distances can only increase. The population at one point could be entirely different from the other. Therefore, well logging is an extremely good alternative when a dense sampling grid is required which is the case of short term mine planning. Besides well logging operational costs are very low compared to core sample surveys. Data acquisition is easy and fast. It could be carried out hand in hand with blasting and extraction operations. For example, in this case study, a 20 m blast hole was being logged in less than 15 minutes, logging at a speed of 3 meters per minutes more or less.

Looking back at table above and comparing the resulting values from the calculated extracted mass to the weighed extracted mass, the differences between them were not high. It seems that geophysical well logging (an indirect sampling method) in a dense sampling grid is able to produce results close to results in reality.

Conclusion

Geophysical well logging, utilizing resistivity and natural gamma radiation parameters, permits the identification of lithological contacts in a formation, especially in situations in which core sample recovery is absent which is the case in this study. The technique being able to be applied in blast holes situated in a dense sampling grid, assists in the rapid calculation of the volume of material contained in the area to be mined in question.

The reconciliation between extracted mass and calculated mass using estimates based on geophysical well logging was well conducted and the results were more than satisfactory. The relative error of the estimates with respect to the extracted masses did not exceed ± 12% with an insignificant global difference of less than 2.5%.

Geophysical logging data acquisition is easy and fast. Its operational cost is nothing compared to core sample recovery in boreholes. In proper combination with core sample recovery, exploration cost can be greatly reduced.

Acknowledgments

The authors would like to thank Copelmi Mineração, Brazil for allowing the realization of this study in their mine and their total and undivided attention during the whole process including the liberation of vital mine production information.

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