Seam Modelling and Reserve Calculation for Lignite Field in Adana-Tufanbeyli (Turkey)

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Abstract: Since the first investment in mining operations is very high, so, it is absolutely important to model the field in three dimensions for appropriate planning and cost analysis. The whole data set belonging to the geological, geophysical and drilling exploration studies carried out in the field should be evaluated as a package. In the modelling phase, the computer-aided tri-dimensional mining software has been used instead of the classical reserve calculation methods being utilized in previous years. Thus, more realistic and shorter results are achieved. In the present work, three-dimensional seam modelling of the Adana-Tufanbeyli (Turkey) lignite field was carried out. In modelling, the coal horizon of the field was examined. Then, the sub-seam levels in the horizon were determined and after examining their geometric relationships with each other, three sub-seams were defined. Seam composites were prepared by the downhole method to make the analysis results of different sizes uniform. It is possible to make block quality estimations, which will be the basis for reserve calculations, by creating variograms in different directions. Variograms are first created in the vertical direction and then in the horizontal direction respectively, to obtain the necessary parameters. The nugget effect and structural distance parameters were obtained from the created variogram models. To assign quality estimation values on the block model, the Kriging method was used when the number of data was sufficient, and the inverse distance method was applied, when it was insufficient. As a result of this modelling study, a total of 355.617.194 tons of lignite reserves with an average calorific value of 1.153 Kcal/kg were determined in the field.

Keywords: Reserve estimation, Kriging method, variogram.

Introduction

Mineral reserve estimation involves forecasting the geometry, quantity, grade and distribution of a mineral resource from geological information and drilling data. The resource estimation process comprised of database formation, homogeneous geological solid modelling, block modelling grade estimation and resource model generation steps. The database is responsible for the management of data (geological maps, drilling logs, etc.) that are the basis for orebody modelling and quarry design. The conceptual geological solid model sets the resource estimation limits. It is necessary to define domains showing similar geological features and attribute distribution within these limits. Fixed or variable-sized blocks are created and the attributes of the blocks are estimated in these environments. In reality, homogeneous geological environment modelling and blocking are not independent but are complementary processes.A homogeneous environment in a mineral deposit should be determined and an estimation process should be followed according to the environmental conditions. When this is not done properly, substandard estimates are obtained and tonnage values below or above the normal are produced (Tercan et al., 2011; Tercan et al. 2013).

It is not possible to take samples from all points of a mineral deposit both physically and financially. For this reason, various approaches have been developed for the identification of the entire mineral deposit with the information obtained from the sampled locations. Polygon method, Inverse of Distance Weighting method, Kriging method and Geostatistical Simulation methods that perform this function. With these methods, estimations can be made regarding the grade and quantity of ore in a mineral deposit.

Materials and Methods

The Kriging method being used in the estimation process is a multiple regression method that gives the best linear and unbiased estimation results by weighting the relevant data appropriately in an ore block. The two main advantages of this method are (1) it avoids systematic bias (2) minimizes estimation errors (Krige, 1981). The Kriging method includes the following steps:

Identification of a homogeneous area that contains spatially related variables and can make the statistical mean concept for these variables meaningful.

Calculation of experimental variogram values for each direction to determine the variability depending on the distance by scanning all the data available within the area,

Creating a theoretical variogram model that describes the variation of the calculated experimental variogram values with distance,

Estimations at unsampled locations by Kriging method.

One of the most useful tools of geostatistical analysis is variograms, which calculate the relationship of samples

by considering the distance and angle between data pairs. Experimental semi variogram values are determined by the use of Equation 1.

$$\gamma(h) = \frac{1}{2N(h)} \sum_{k=1}^{N(h)} \left(Z(x_k) - Z(x_k + h) \right)^2 \quad (1)$$

In this equation;

h is the distance between the data pair,

Z (x) is the value of Z in position x,

Z (x + h) is the value of the Z variable at x + h,

y (h) is the semi-variogram

N (h) indicates the number of data pairs.

A typical variogram function is shown in Figure 1. Nugget effect value is the most important parameter of the variogram. This parameter gives a measure of the variable in short distances as the h value is closer to 0. Another experimental variogram parameter is structural distance. The threshold value is equal to the variance of the data used in calculating the variogram. If the ratio of the nugget effect value is close to 1, the variability between the data is largely independent of the distance. Figure 2 shows the commonly used variogram models and characteristics (Tercan and Saraç, 1998, Ünal et al., 2002).
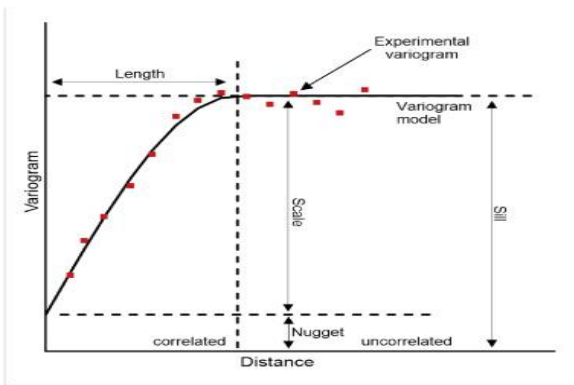

Fig. 1 Variogram parameters (structural distance, nugget effect and threshold value).
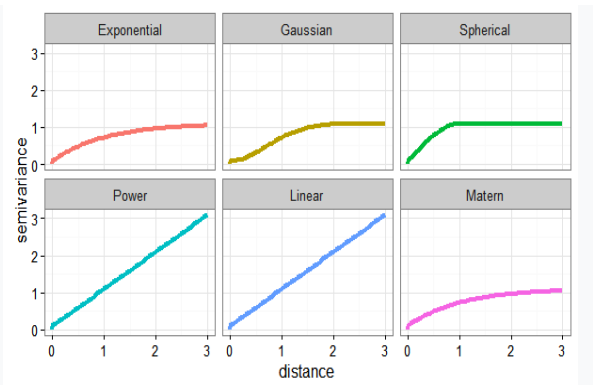

Fig. 2 Variogram models.

The accuracy of estimation by the Kriging method mainly depends on the following parameters:

1. Number of samples and data quality at each point.

2. Position of the samples in the deposit: Evenly spread samples represent the deposit more accurately than aggregated data.

3. The distance between the samples and the cut-off points. It is natural that in estimation, the close neighbouring sample is more efficient than the far one. Similarly, the estimation is expected to be more accurate around the samples, worsening away from the samples.

4. Continuity of variables depending on the distance: Variables that show a regular change are easier to predict than variables that change abruptly (Armstrong, 1998).

Results and Discussion

Adana-Tufanbeyli (Turkey) Lignite Field

The lignite basin, which spreads from the northeast to the southwest of the Tufanbeyli district of Adana province, is located 130 km from Adana. The lignite basin, which has the characteristics of an intermountain basin, extends approximately 6-7 km in the North-South direction. It is 3,5-4 km wide in the east-west direction. The average altitude above sea level is around 1400 m. The Sariz River, flowing in the northwest-southeast direction, passes through the lignite field. As a result of the geological studies carried out in the field, two units were determined in general. The Palaeozoic-Mesozoic aged basement unit; which forms the basis of the coaly unit, and the Upper Pliocene-Pleistocene unit; in which coal is included (Fig 3) (MRE, 1993).
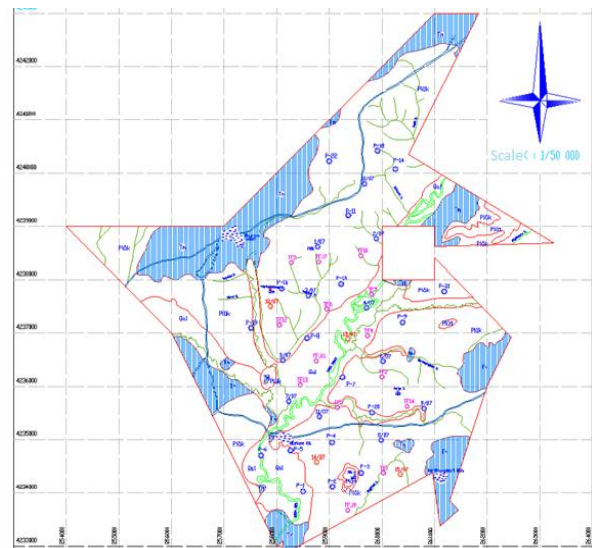

Fig. 3 Geological map of Adana-Tufanbeyli (Turkey) lignite field.

Apart from the main faults causing the formation of the basin, there is no faulting in the Upper Pliocene-Pleistocene units, which also contain coal-bearing units. Inclinations of 2-3° are due to the formation of the basin in the form of a bowl (MRE, 1993).

Faults affecting the basement rocks at the beginning of the Upper Pliocene contributed to the formation of the coal basin. After this formation, the basal conglomerates, in which the pebbles brought to the basin from the outer edges by gravity slides and rivers were formed, began to deposit. After a while, the basin became a shallow lake-swamp and the rocks in the coal-bearing unit began to precipitate. These formations continued until the middle of the Pleistocene. At the beginning of the Upper Pleistocene, the basin gained the characteristic of a fluvial-alluvial fan. In the meantime, upper conglomerates and tuffites, which are the product of Erciyes volcanism, were deposited (MRE, 1993).

Lignite is found within the clay-lignite gyttja unit having a thickness of 15-100 m. The thickness of the coal seams that meet the criteria is between 1.35 meters (P9) and 45 meters (T-15/07) meters. There are clay and gyttja layers of varying thickness between this coal seam. Coal seams contain abundant fossils in places. The lignite zone gets thinner from the middle of the basin towards the edges (MRE, 1993).

The drillings were carried out on different dates in the Tufanbeyli lignite basin. The total length of 57 drillings made in the field is 8.384 m (Fig 4), (MRE, 1993).
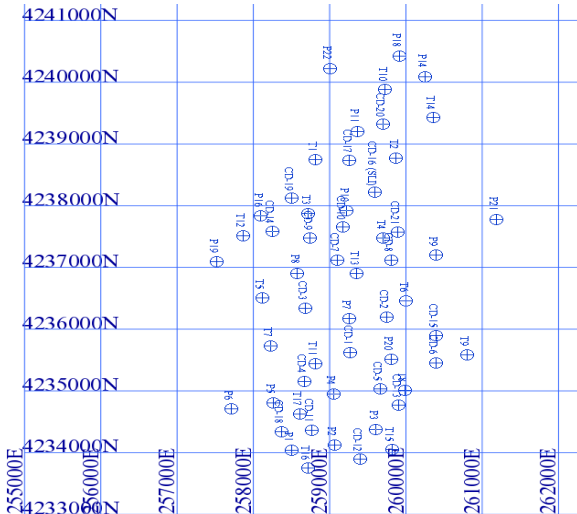

Fig. 4 Drilling location map of the site .

Fifty seven drillings have been made so far in Adana Tufanbeyli Lignite field evaluation on. These drillings are distributed in an area of 6795 m in the north-south direction and 3732 m in the east-west direction. The average drilling distance of the field is around 400 m. The deepest of the drillings made in the field is P2 at 237 m and the nearest to the surface is the drilling numbered as CD-15 with 73 m. From the drillings made; no coal seam came across in the drillings P22, T10, T1, T12, P19, CD15 and P21 (MRE, 1993).

Coal seam levels (below 750 kcal/kg) were not taken in the assessment, as can be seen in the CD-13 drilling stamp made in the east of Sariz River. It is due to the presence of very low calorific value coals in the drillings made in the Tufanbeyli field (Fig 5). As a result of the evaluation made in line with these assumptions, the spread limits of the defined seams were determined separately. Coal seams with a thickness of fewer than 0,50 m were not taken into account while evaluating the existing boreholes in the database. In addition, if the cut-off thickness is less than 0,50 m and is between two coal seam levels, these levels were added to the seam of coal and their average values were accepted as 25% humidity, 75% ash and 1 Kcal/kg calorific value. Density value is taken as 1,4 kg/cm^3 like coal density value.
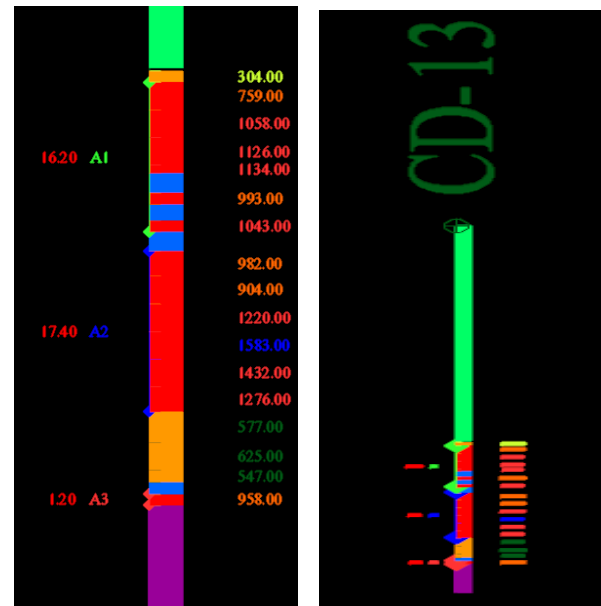

Fig. 5 Seam definitions used in drilling evaluation and modelling.

Reserve Evaluation Studies

No coal was encountered with the drillings P12, T10, T1, T12, P19, CD15 and P21 in the study area. Eight of the 57 drillings made in the field were excluded from the modelling and reserve studies were carried out while considering 49 of them. Firstly, the raw data prepared for the drilling evaluation were transferred to the computer, and a general evaluation was made in the three-dimensional environment.

Since the average drilling distance is greater than 400 m, and thus the separation of the coal horizon into lower seams and the correlations based three-dimensional modelling study will be insufficient, so studies were carried out to model the seams geometrically. Examination of the coal horizon in 3D revealed the presence of three different lower seams. Each of the coal seam levels with lower seam separation was modelled separately, and the intermediate cuts in the coal horizon were not added to the coal. Considering the geometric structure of the coal seam, geological structure of the field, thickness of the seams, operating method, and the excavation capacity of the vehicles to be used; the seam

models were formed with block dimensions of 40x40x5 m and sub-block dimensions of 20x20x1.25 m. The seam order is defined as A1, A2, and A3, from young to old. The SW-NE directional section of the seams is given in Figure 6.
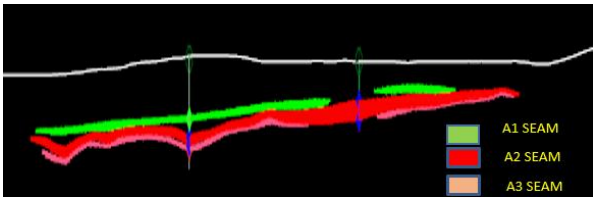

Fig. 6 Seam definitions used in drilling evaluation and modelling.

After the block models were created (Figs 7 - 12), composite data of each seam were formed to estimate the distribution of coal quality values.
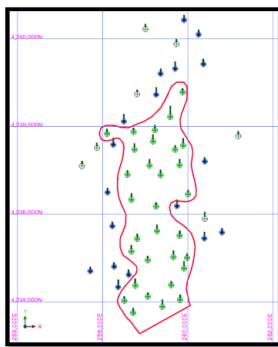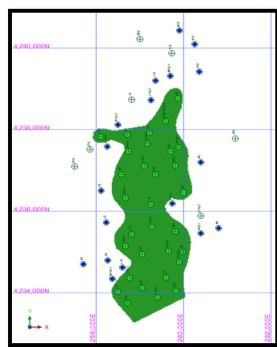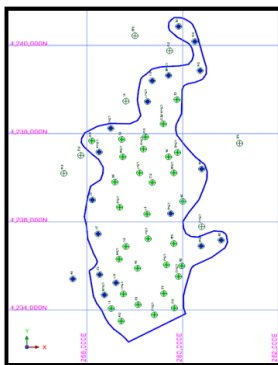

Fig. 7 A1 seam limit.   Fig. 8 A1 seam block model.
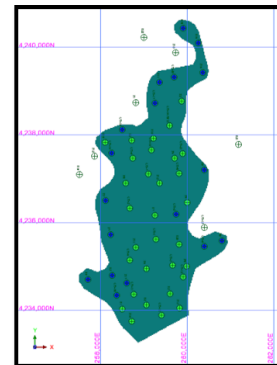
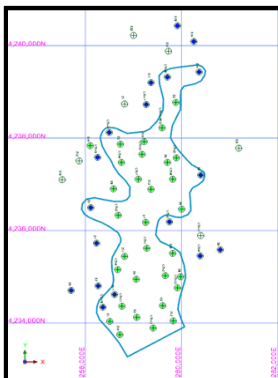Fig. 9 A2 seam limit.   Fig. 10 A2 seam block model.
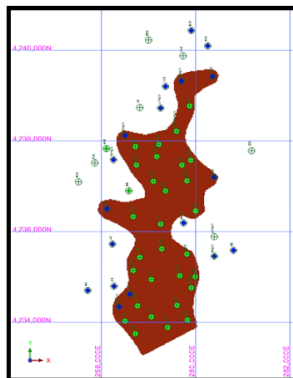

Fig. 11 A3 seam limit.   Fig. 12 A3 seam block model.

Using these composite data, variograms of the quality values were first generated. Then, suitable variogram models were produced on the said variograms with different methods. As a result, the parameters to be used in quality estimations (nugget effect, sill and structural distance) were obtained. These parameters were used for quality estimations with different algorithms as a variable of distance. Unknown values of the samples were used with known values on the block model with Kriging and Inverse distance methods (Figs 13, 21, Tables 1 - 3).

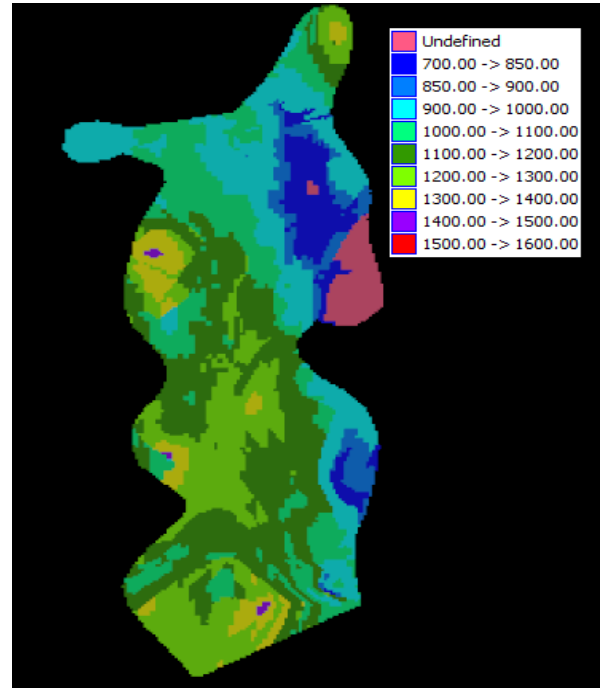**A1 Seam Quality Distribution**

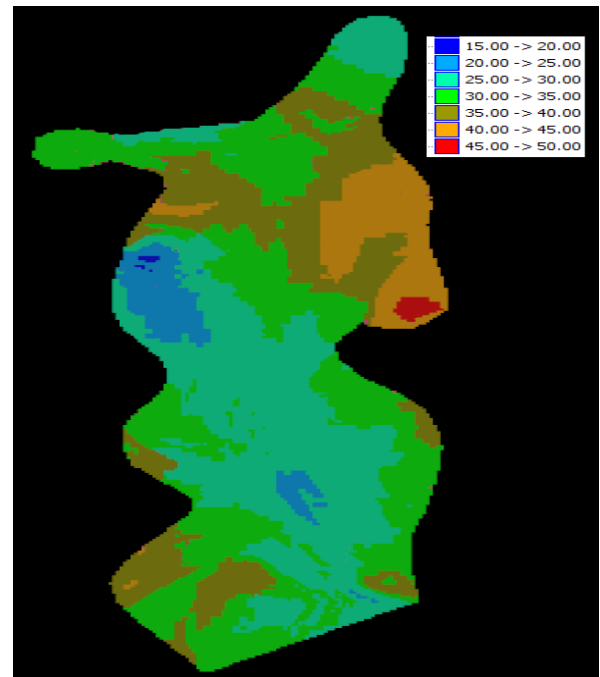Fig. 13 Calorific value distribution.
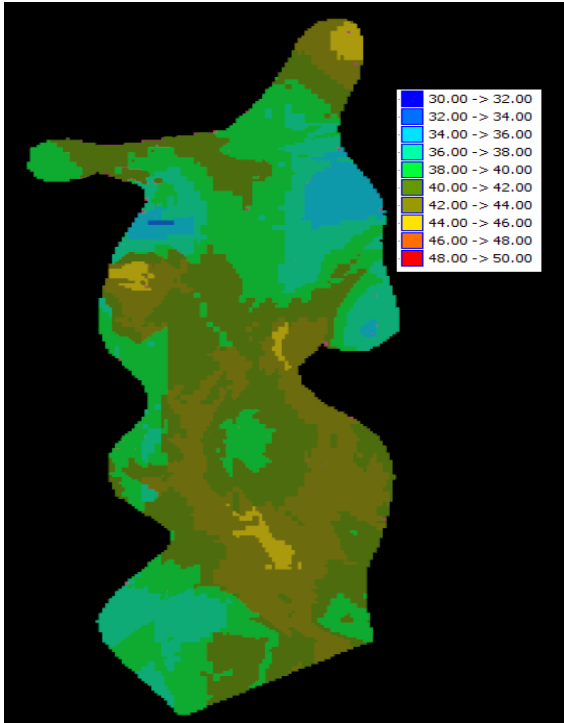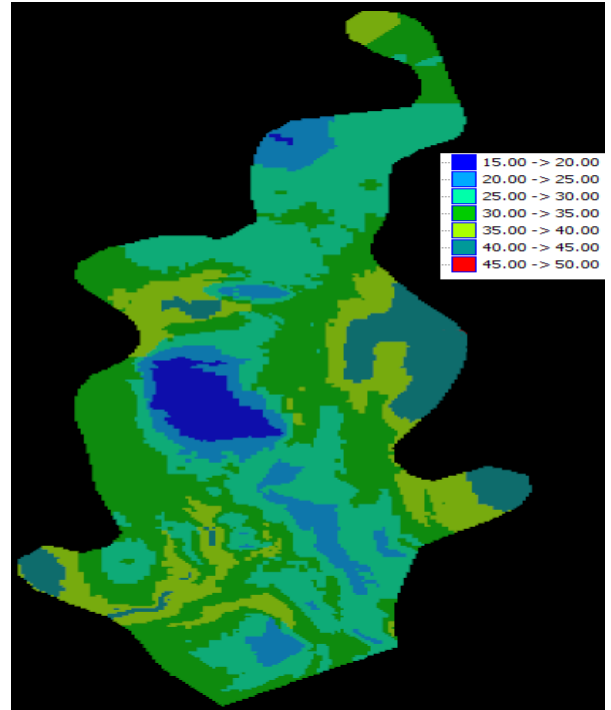

Fig. 14 % Moisture distribution.

Fig. 15 % Ash distribution.

Table 1. Calorie interval according to the A1 seam reserve distribution.

Seam	Calorie range		Volume (m³)	Reserve (tonnes)	Calorie (Kcal/kg)
A1	cv	> 700	50.916.875	71.283.625	1093
	cv	> 850	42.716.000	66.102.400	1116
	cv	> 900	44.367.313	62.114.238	1131

A2 Seam Quality Distribution
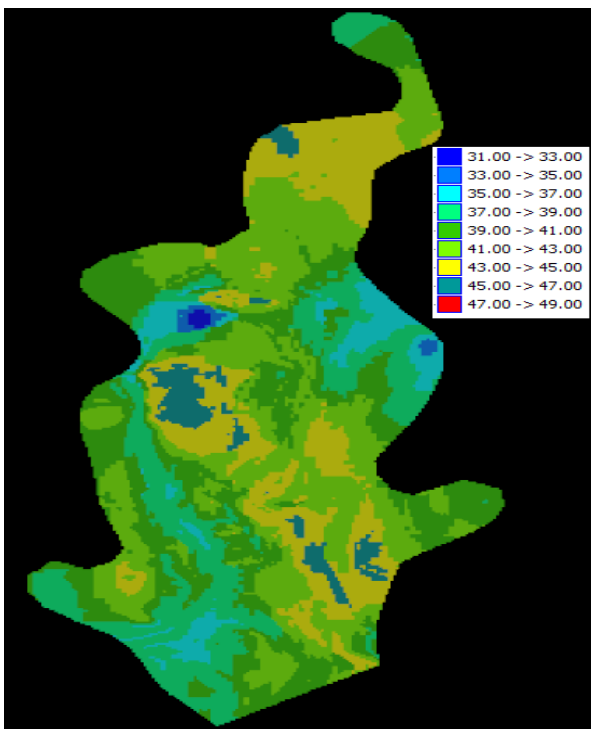

Fig. 16 % Sulphur distribution.
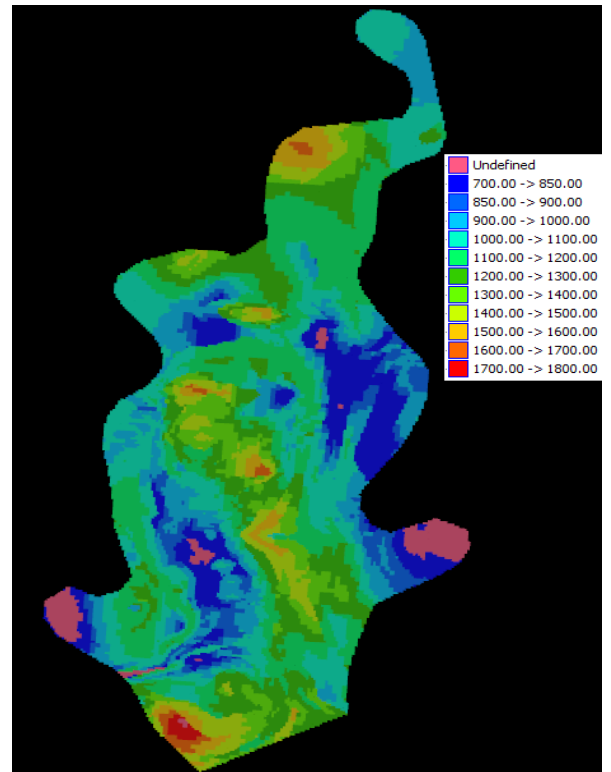

Fig. 17 % Moisture distribution.

Fig. 18 Calorific value distribution.

Table 2. Calorie interval according to the A2 seam reserve distribution

Seam	Calorie range		Volume (m³)	Reserve (tonnes)	Calorie (Kcal/kg)
A2	cv	> 700	169.275.969	236.986.356	1171
	cv	> 850	155.923.844	218.293.381	1204
	cv	> 900	147.951.625	207.132.275	1221

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A3 Seam Quality Distribution
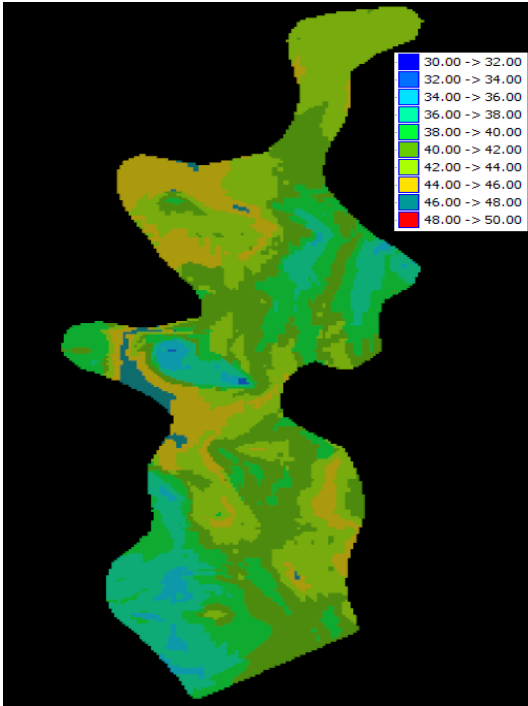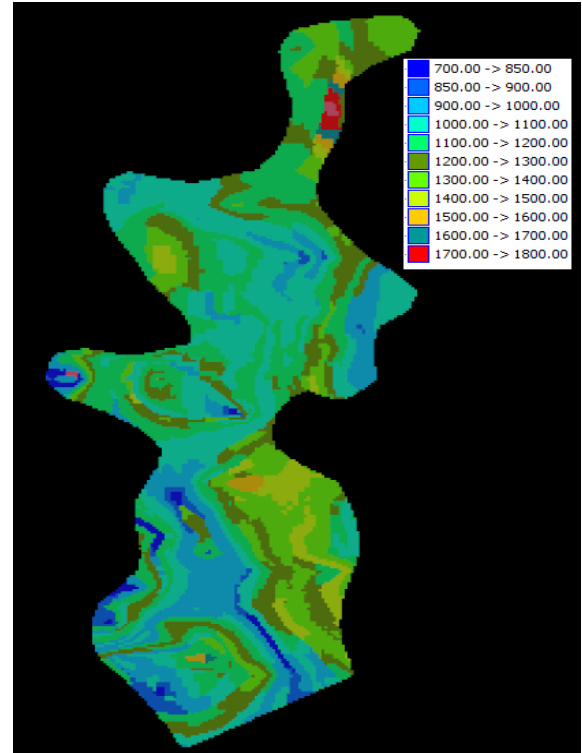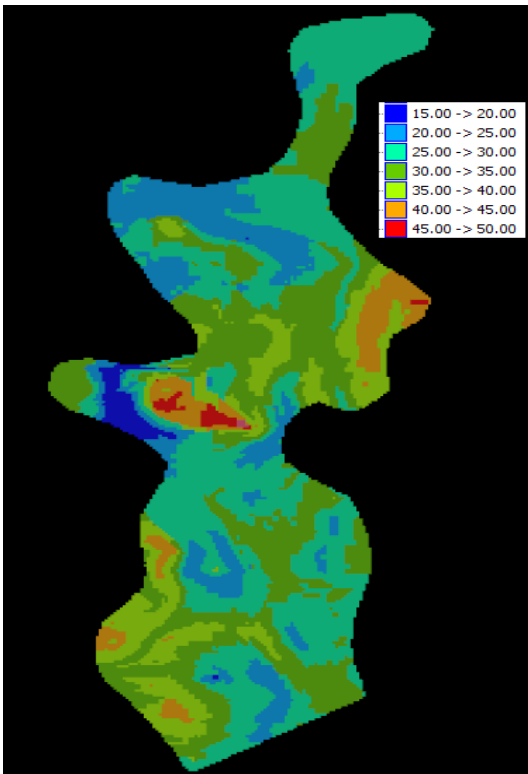

Fig. 19. % Sulphur distribution.

Fig. 20 % Moisture distribution.

Table 3. Calorie interval according to the A3 seam reserve distribution.

Seam	Calorie range	Volume (m³)	Reserve (tonnes)	Calorie (Kcal/kg)
A3	cv > 700	33.819.438	47.347.213	1154
	cv > 850	33.358.219	46.701.506	1159
	cv > 900	32.674.688	45.744.563	1165

Fig. 21 Calorific value distribution.

When Table 4 is examined, it has been determined that there is a total of 355.617.194 tons of lignite reserves based on an average calorific value of 1153 Kcal/kg, 331.097.287 tons of lignite reserves according to an average calorific value of 1180 Kcal/kg, and 314.991.076 tons of lignite reserves according to an average calorific value of 1195 Kcal/kg in the field of study.

Table 4. Distribution of all seams according to calorific value intervals

Calorie range	Seam	Volume (m³)	Reserve (tonnes)	Calorie (Kcal/kg)
>700	A1	50.916.875	71.283.625	1093
	A2	169.275.969	236.986.356	1171
	A3	33.819.438	47.347.213	1154
	Total	**254.012.282**	**355.617.194**	**1153**
>850	A1	42.716.000	66.102.400	1116
	A2	155.923.844	218.293.381	1204
	A3	33.358.219	46.701.506	1159
	Total	**231.998.063**	**331.097.287**	**1180**
>900	A1	44.367.313	62.114.238	1131
	A2	147.951.625	207.132.275	1221
	A3	32.674.688	45.744.563	1165
	Total	**224.993.626**	**314.991.076**	**1195**

Conclusion

Coal seams less thick than 0.50 m were not taken into account while modelling the site. If the thickness of clay bands is less than 0.50 m and is between two coal seam levels, these were added to the coal and their average values were accepted as 25% humidity, 75% ash and 1 Kcal/kg calorific value. Density value is taken as 1,4 Kg/cm³ like coal density value. Modelling of the field revealed a total of 355.617.194 tons of lignite reserves

with an average calorific value of 1153 Kcal/kg. For the work to continue smoothly and safely during operation, a 200 m safety pillar should be left between the river bed and the quarry slope in the east of Sariz river.

Considering the geometric structure of the coal seam, geological structure of the field, and thickness of the seams, the operating method to be applied and the capacities of the equipment to be used in the excavation, seam models were created with block dimensions of 40x40x5 m and sub-block dimensions of 20x20x1.25 m. The seam sequence is described as A1, A2, and A3, from young to old respectively.

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