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Fundamentals of 3D modelling and resource estimation in coal mining

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Abstract

The prerequisite of maintaining an efficient and safe mining operation is the proper design of a mine by considering all aspects. The first step in a coal mine design is a realistic geometrical modelling of the coal seam(s). The structural features such as faults and folding must be reliably implemented in 3D seam models. Upon having a consistent seam model, the attributes such as calorific value, ash and moisture contents, volatile matter, and sulfur must be estimated in the block model. Considering the geotechnical and hydrogeological conditions, the most appropriate mine design strategy can be selected and implemented. Application of the above steps to three coal basins in Turkey are presented in this paper. The Soma-Eynez and Tunçbilek-Ömerler basins are the two most important lignite resources having an on-going production and prospect for future underground mining. Comprehensive 3D coal seam modelling is carried out at both basins. As both are extensively faulted due to tectonism, it is a challenging task to realistically model their structures. On the other hand, the Karapınar basin has a considerably different geological, structural, and coal measure rock conditions in comparison to the Eynez-Ömerler basin. The Karapınar basin is a relatively recently explored brown field site suitable mainly for surface mining. Coal seam(s) geometry and quality-related attributes certainly play the most important role for production planning and mining activities. The influence of the inherent characteristics of each site on the modelling and mine design strategy are also briefly discussed. This paper presents the fundamentals of coal seam modelling at various geological and structural conditions. It is believed that the methodology presented in this paper can be considered as a guiding example for a comprehensive 3D modelling and resource estimation of coal seams around the world.

Keywords: *Coal Seam Modelling, 3D Seam Modelling, Coal Mine Design, Resource Estimation.*

1. Introduction

There are numerous lignite deposits in Turkey, namely Soma, Tunçbilek, Seyitömer, Yatağan, Eskişehir, Konya, Beypazarı, Tracia, and Elbistan. Apart from Soma, all of the other deposits are of mainly low heating value lignite. The author of this paper has taken part in the coal seam modelling and mine design of nearly all of these sites. This paper presents information on the research works carried out at the Soma-Eynez, Tunçbilek-Ömerler, and Konya Karapınar coal basins. While coal has been produced in the Soma and Tunçbilek basins since 1940's, the Karapınar basin is in the development stage. Locations of the coal basins are marked in Figure 1.

Coal horizons in Anatolia are mainly formed in coal-bearing Neogene basins, which have been developed as a result of extensional tectonism commenced during Miocene. The Soma and Tunçbilek basins are among them, and contain mainly fluvial–lacustrine lignite that is of Miocene age. In these coalfields, coal has been produced mostly by open-pit mining since 1940 and utilized for domestic use, and mainly as feed coal to the power plants constructed in their respective regions. Coal resources suitable for open-pit mining in the Soma and Tunçbilek coalfields are currently nearing depletion, and underground coal resources are under consideration. These coalfields include several sectors such as Eynez, Işıklar–Kısrakdere, Evciler, Deniş in Soma, and Ömerler in Tunçbilek. The present work involves modelling and estimating underground coal resources in the Eynez and Ömerler sectors. The coal deposits in these sectors present difficult modeling and estimation problems. In particular, the coal seams in Eynez and Ömerler are frequently faulted due to severe tectonic movements. In addition, the quality of the seams is highly variable: the quality of the 25 m thick Eynez seam systematically decreases from the top to the bottom. The Ömerler coal includes a number of rock partings in various thicknesses.

Figure 1. Locations of Soma, Tunçbilek, and Karapınar basins.

The Karapınar coal deposit is located in the inner Anatolia near Konya. It is a brown field project under development. Exploration works have commenced in 2007. By the time of this work, 408 exploration boreholes were sunk between 2007 and 2010. However, advanced exploration has been in progress up to the present time.

The design of a mine is a difficult task. If a major problem is encountered during the production stage of a mine arising due to erroneous determination of the geometry of orebody or coal seam, the consequences would be catastrophic. Therefore, the extension and boundaries of orebody or coal seam must be reliably determined before mine planning. It is very risky and almost impossible to carry out an efficient and safe mining operation without a proper coal seam modelling and resource estimation in comply with the world standards. This paper presents a modern modeling and estimating methodologies carried out in these sectors with a special focus on the building drill-hole database. The 3D faulted seam modelling and block modelling were performed in the Soma-Eynez and Tunçbilek-Ömerler basins. However, seam modelling had to be performed in 2D in the Karapınar basin. This paper briefly presents the methodology applied and the results obtained.

A number of coal seam modeling and resource estimation studies (Siddiqui et al., 2015 [1], Tercan et al., 2013 [2]; Saikia and Sarkar, 2013 [3]; Deutsch and Wilde, 2013 [4]; Hatton and Fardell, 2012 [5]; Heriawan and Koike, 2008a [6], 2008b [7]; Hindistan et al., 2010 [8]; Kapageridis and Kolovos, 2009 [9]; Olea et al., 2011 [10]; Tercan and Karayiğit, 2001 [11]) are available on the practical and theoretical basis in the literature. Tercan and Karayiğit (2001) have addressed a case study on the global estimation of tonnage, thickness, and quality parameters in the Kalburçayırı field of the Sivas–Kangal (Turkey) basin [11]. Heriawan and Koike (2008a) have estimated the thickness, ash, sodium, total sulfur, and calorific value in a multi-layer coal deposit in East Kalimantan (Borneo, Indonesia) using ordinary kriging, cokriging, and factorial kriging [6]. Heriawan and Koike (2008b) have presented an approach for the assessment of coal resource uncertainty associated with tonnage and coal quality based on spatial modeling of seam distribution and coal quality [7].

Kapageridis and Kolovos (2009) have presented a stratigraphic modelling and resource estimation study of the SW lignite field in NW Greece [9]. Hindistan et al. (2010) have geo-statistically estimated the calorific value in an underground lignite mine to help a short-term planning of coal production. Olea et al. (2011) have illustrated the inherent limitations of the distance methods in classifying resources, and have proposed a combination of several geo-statistical methods for appraisal of the uncertainty associated with resource estimation [10]. Hatton and Fardell (2012) have described the structural and coal seam qualities of the Zambezi basin (Mozambique) and its impact on determining coal resource and reserve estimates to the international resource and reserve reporting standards [5]. A detailed explanation of the geo-statistical tools such as variogram, kriging, and conditional simulation has been given by Srivastava (2013) [12]. Deutsch and Wilde (2013) have used global kriging to preserve the continuity and complex nature of the coal seams [4]. Saikia and Sarkar (2013) have applied an integrated exploration modelling approach with statistical and geo-statistical modelling parameters to Jharia coalfield, India [3]. Tercan et al. (2013) have made note of the importance of modelling the coal fields in Western Anatolia [2]. Siddiqui et al. (2015) have produced spatial distribution maps for various coal quality attributes by ordinary kriging on the generated 3D model of lignite resource in Thar Field, Pakistan [1].

2. Field description and geological setting

The coal basins under consideration lie within the Aegean Region and inner Anatolia (Figure 1). Soma Manisa is located over the Akhisar-Bergama highway in the Aegean region. The Eynez sector lies about 10 km SW of Soma. Tunçbilek is a district of Tavşanlı–Kütahya, and the Ömerler coalfield is located in the northern part of Tunçbilek. Exploration and operation permits in the studied fields have been held by the Turkish Coal Enterprises (TKI), which is the leading state-owned coal mining company in Turkey. The size of the Eynez sector is approximately 30 km^2 (3 km in the EW direction and 10 km in the NS direction), the Ömerler sector is 24 km^2 (6 km in the NS direction and 4 km in the EW direction). Karapınar is located at 120 km west of the Konya province.

The lignite-bearing sedimentary basins in western Anatolia arose as a result of intra-continental extensional tectonic regime developing in Miocene. Yağmurlu et al. (2004) have divided these basins into three groups based on their formation of time, tectonic setting, and sedimentary facies: the NE, NW, and EW trending basins. These lignite basins are bound by growth faults, and contain sedimentary and volcanic rock assemblages that are locally more than 1000 m thick. Yağmurlu et al. (2004) have pointed out that the sedimentary sequences of the continental basins mainly consist of alluvial-clastic sediments directly overlying the basement [13]. The stratigraphic sections of the sites are presented in Figure 2.

Coal seams are formed in Pliocene age Hotamış formation. Coal seams in Karapınar basin are formed in a continuously changing condition due to the unstable nature of the area, intermittent variations in the settlement regime, tectonism, and relatively fast changing of coal formation swamp geometry. Consequently, there is a great variation in the number, thickness, and extent of seams. Coal seams are formed along the NE-SW direction as the length of the zone in the NS and EW directions are 9 km and 17 km, respectively. Hence, the extent of coal is around 107 km^2. The thickness and depth of the coal-bearing horizon decrease towards the boundary of the basin. While the coal-bearing horizon is located at around 170-180 m below surface in the central region, it is around 110-120 m at sides. Similarly, the coal-bearing horizon thickness reaches 170-180 m, and it decreases to 10-20 m towards borders.

In general, there are sandstone, siltstone, mudstone, claystone, gyttia having abundant fossils, clays with organic coloring, and coal seams in the coal horizon. There are siltstone, mudstone, clay, and claystone strata on top of the horizon. Partings between coal seams are mainly sandstone, siltstone, organic colored clay bands and gyttia with abundant fossils. There are clay, claystone with fossils, and clayey limestone at the bottom part of the coal-bearing horizon.

Anatolia comprises both metamorphic and non-metamorphic basement rocks. The main metamorphic basement is formed by the Menderes, Sandıklı, and Sakarya massifs. Non-metamorphic basement rocks mainly include ophiolite, flysch, and platform-type limestones. Figure 2 shows the generalized stratigraphic sections of the three coal basins. The following descriptions of the Soma and Tunçbilek basins are largely based on İnci (1998 and 2002) [17, 18] and Karayiğit and Çelik (2003) [19]. İnci (1998 and 2002) indicates that the Soma basin contains Miocene alluvial/fluvial–lacustrine deposits composed of three lignite successions: the lower, middle, and upper coal successions. Only the lower coal succession includes an exploitable seam [17, 18]. It generally strikes NE–SW, and dips 5° in a SW direction. The seams in the middle and upper successions are not of sufficient thickness and good quality. The total thickness of the coal successions is about 900 m, and they rest unconformably on the Mesozoic carbonate/siliciclastic basement rocks. Lower Coal succession was deposited in an alluvial fan to plain and perennial forest mire system resulting in a subbituminous lignitic coal (KM2) that is on average 20 m thick and lies between the basal unit and the marlstone unit. In contrast, the middle lignite succession includes several lignite beds, ranging in thickness from 10 to 250 cm, which alternate with fine-grained siliciclastic rocks and biogenic/clastic limestones. Freshwater carbonate-dominated middle coal succession was formed in floodplain environment including shallow freshwater carbonate lakes and/or ponds, and frequently drying poor forest mires of an anastomosed river system. In the region, the volcanism in calc-alkaline character was in effect throughout Eocene to Plio-Quaternary periods and caused local contact metamorphism of the lower lignite seam (KM2) and middle lignite succession (Karayiğit and Whateley, 1997) [20]. Volcanism-induced upper coal succession was deposited in fluvial channel, floodplain, and probably in allochthonous peat mires of a braided river system (İnci, 2002) [18].

The Tunçbilek Neogene basin is situated between Tunçbilek and Domaniç (Kütahya) in the NE part of a horst–graben system in western Turkey. The metamorphic and ophiolitic rocks and granites of the Pre-Neogene age form the basement of the basin. The coal-bearing Tunçbilek Formation in the basin was conformably underlain by fluvial deposits of the Miocene Beke Formation and conformably overlain by sandstone–tuffite of the Miocene Besiktepe Formation and Pliocene volcanics, fluvial–lacustrine deposits (Karayiğit and Çelik, 2003) [19]. The coal-bearing Tunçbilek Formation was developed in lacustrine facies (mudstone, claystone, coal, and marl), continental deltaic conglomerate–sandstone, continental fan deltaic conglomerate–sandstone–mudstone, and lacustrine limestone. The overall thickness of the Miocene–Pliocene formations in the basin is above 1 km (Karayiğit and Çelik, 2003) [19]. An average 7 m thick coal bed lies at the base of the Tunçbilek Formation. The coal bed lies between the marl and conglomerate–sandstone units and includes dirt bands as claystone with coal traces, marls, and alternations of coal and claystone (Karayiğit and Çelik, 2003) [19]. The coal seam dips with 7° in the NE direction.

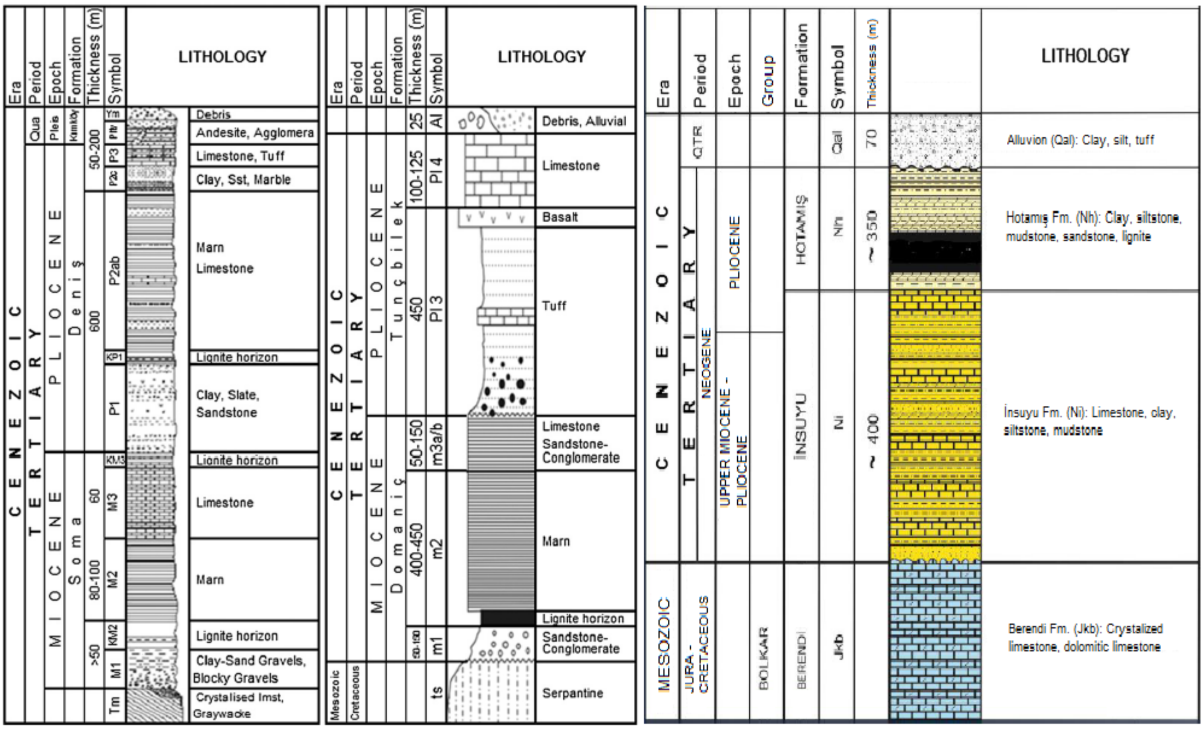
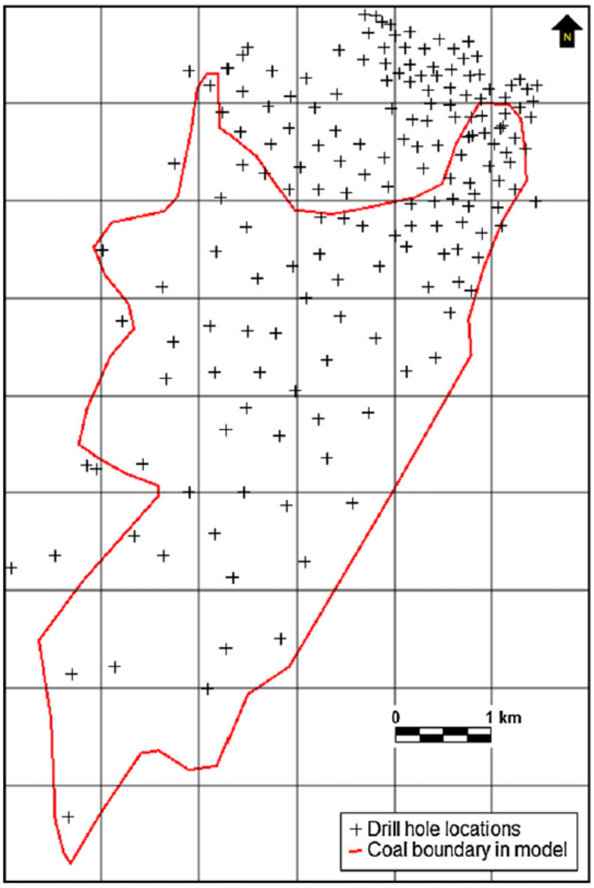


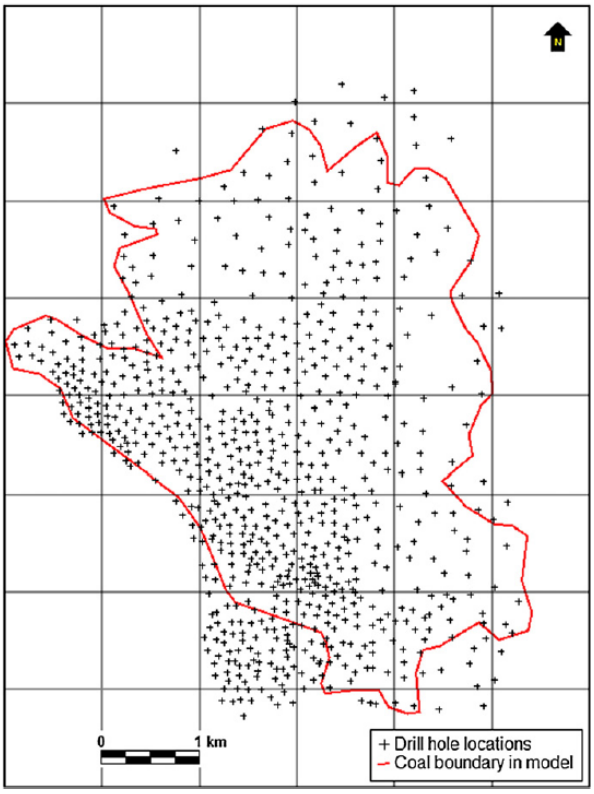
Figure 2. Generalized stratigraphic sections of Soma (left; modified from Nebert, 1978 [14]), Tunçbilek (middle; modified from Nebert, 1960 [15]), and Karapınar basins (Murat et al., 2007 [16]).

3. Database used in modeling and estimation

The data is based upon the information obtained from drilling, lithological logging, sampling, and analyzing a number of diamond core holes conducted by various bodies from the 1960s to present in the Soma and Tunçbilek basins. On the other hand, exploration drilling has started in 2007 in Karapınar. Drill hole locations at all sites can be seen in Figure 3. This data includes collar information of drill holes, lithology, coal seam intercepts, and coal quality information.

A drilling summary for both sectors is presented in Table 1.





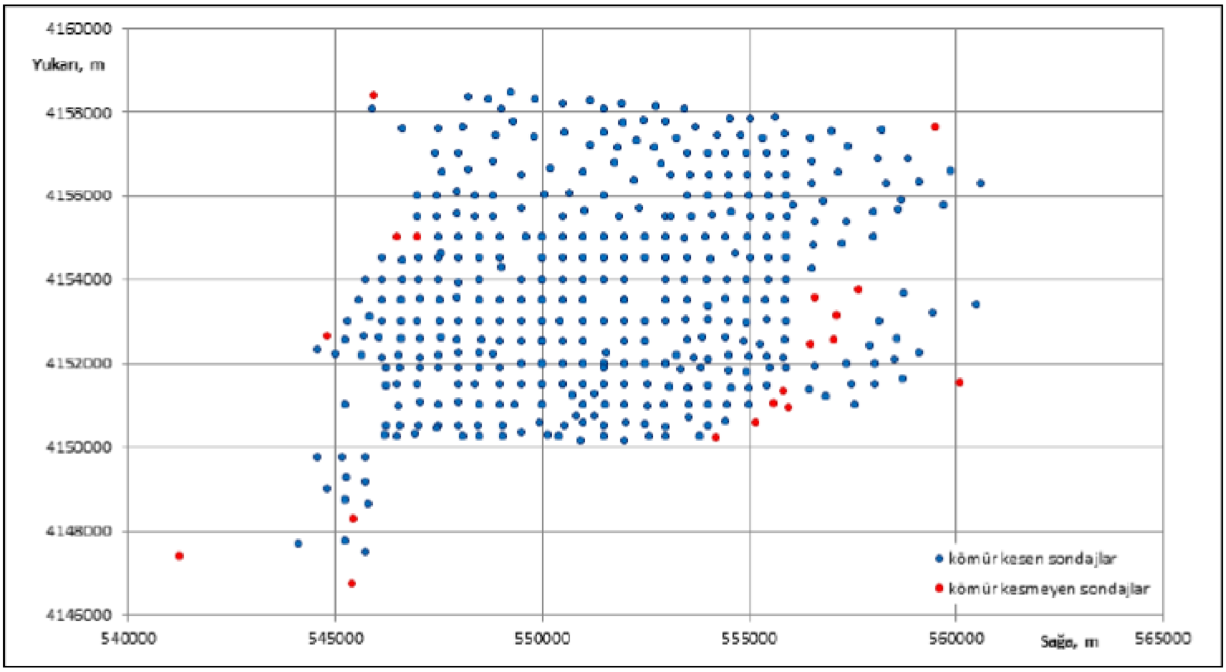


Figure 3. Drill hole locations at all sites.

Table 1. Summary of exploration drilling activities.

	Number of drill-holes	Total length drilled (m)	Minimum depth (m)	Maximum depth (m)	Average drill-hole spacing (m)
Soma-Eynez	293	95,000	25	1274	335
Tunçbilek-Ömerler	706	185,000	29	850	163
Karapınar	408	105,000	79	426	498

All geologic and sampling data (x, y, z coordinates and dip and azimuth angles of drill holes, lithological definitions of samples taken from drill holes, lower calorific value (LCV), ash content (AC), moisture content (MC) on an as-received basis, core recovery) is entered and maintained in an electronic database. The following checks are performed to identify the incorrectly entered data. The summary statistics (minimum, average, maximum, standard deviation, and number) of each quality variable are calculated and histograms are drawn. Outlier values are reviewed based on box-plots. It is checked to see whether the sum of attribute values (volatile matter, ash content, moisture content, and sulfur content) are 100%. The summary statistics of core sample intervals are calculated, and their histograms are drawn. Excessively large lengths are checked. Scatter diagrams are drawn between quality variables (for example LCV *vs.* AC, LCV *vs.* MC, and AC *vs.* MC). The incorrectly entered values are observed on these diagrams, and they are removed from the database. After correcting all the errors determined at each step, the drill holes are indicated with lithological colors. Based on this colored lithology, the coal thickness at each drill-hole is checked visually. The core samples are taken at various intervals from horizons, where the drill holes cut the coal. The samples are analyzed for LCV, AC, MC, and other variables such as volatile matter, fixed carbon, and sulfur content on an as-received basis. In this work, only LCV, AC, and MC are considered.

In the Karapınar basin, exploration and drilling have started in 2007 including geological mapping, geophysical borehole logging, and diamond core drilling. 408 boreholes had been opened until 2010, and lithological descriptions of the core obtained had been carried out. 4813 coal samples were obtained with an average sampling length of 1.41 m. Tests were performed on as-received (original) and dry samples for determination of moisture, ash, volatile matter, fixed carbon, lower heating value, and organic and inorganic sulfur contents. Density tests were carried out on 425 samples. The raw coal average values for LCV, AC, and MC for the three basins are presented in Table 2.

Analyses of the test results indicate that moisture, and organic and total sulfur contents decrease steadily from roof to floor of the coal horizon, whereas there is no change in the ash content. However, the heating value of coal increase up to the altitude of +870; from this level downward, there is no change observed until +750, starting to increase below this level. Similarly, as the heating value and sulfur content increase towards basin boundaries, the ash content increase, as expected.

Table 2. Average values for lower heating value, ash, and moisture content of raw coal.

	LCV (kcal/kg)	Ash Content (%)	Moisture Content (%)
Soma Eynez	3483	39.68	13.18
Tunçbilek Ömerler	3802	30.67	14.60
Karapınar	1357	19.57	47.19

4. Brief description of seam modelling procedure

Generating a 3D solid model of the coal seams subject to severe tectonic movement is one of the most challenging tasks of resource modelling. Approaches used in modelling can be broadly divided into two groups: the section method and the top–bottom surface method. In the section method, coal is outlined in vertical sections, and these sections are then combined to construct a 3D solid model. In the top–bottom surface method, the roof and floor surfaces of a coal seam are triangulated or interpolated and then combined. In the present work, a combination of both methods is used to detect the faults and to construct a 3D solid model. This is rather a difficult task, and requires the involvement of a mine planner. We believe that the 3D solid modelling is not a process that only the geological features of a coal deposit such as thickness and dip of the formations above the coal seam and the structural information are considered. It is also a process where a mine planner is involved with the minimum mineable coal thickness and rock parting thickness. The Eynez and Ömerler basins are suitable for underground mining due to their depths. In this work, for Eynez and Ömerler, the minimum mineable seam thickness is assumed to be 130 cm and the rock parting thickness with less than 50 cm is included with the coal seam. Karapınar is to be exploited by means of the surface mining method. Therefore, the minimum coal thickness that can be produced is taken as less than 50 cm.

A simple illustration of the approach in the 3D modelling of a single coal block is given as follows (Tercan et al., 2013) [2]:

i. Examine each drill hole data and cores. This would give an insight into the dip of stratification at drill hole locations.

ii. Take a number of vertical sections outlining the coal in such a way that the sections cover the whole coal field uniformly (Figure 4a). This stage allows forming a rough idea about the local tectonic structure, and uses information such as coal seam intercepts, thickness, and dip of the strata above the coal seam. At this stage, it is assumed that the change in the dip of the seam or differences in level of the coal seam are indications of faulting (Figure 4b). Due to consideration of the coal seam dip, there must be at least 3 drill holes in the section, and these drill holes must be on the same line. As seen in Figure 4b, the drill hole coal intercepts suggest two possible faults: one is between the drill holes 6 and 7 and the other one between 3 and 4.

iii. Build a coal seam roof surface by triangulating the coal roof intercepts of the drill holes falling inside a coal block and check the continuity of coal roof elevation contours (Figures 4c and 4d).

iv. Extend the contours for coal roof elevation to fault boundary and triangulate this additional area (Figures 4e and 4f). Extension of roof surface is carried out by considering all sections. Fault lines separating the blocks are drawn by considering the general and local tectonics observed in the area.

v. Follow the same procedure (steps ii–iv) to build the coal seam floor surface, and then combine the roof and floor surfaces to construct a 3D solid model of the coal seam block.

vi. Repeat the above steps for all the other blocks in the field.

5. Results of solid and block models of coal seams

5.1. Soma-Eynez and Tunçbilek-Ömerler

The Eynez and Ömerler basins are greatly affected by tectonism, and there are abundant faulting in both them. Isometric views of the coal seam models can be seen in Figure 5.

The 3D solid models for the Eynez and Ömerler coal fields are generated manually by applying the above explained approach. Upon completion of the first draft 3D model, an arduous and meticulous work is done in corporation with the experienced field engineers. The model is updated in comply with critics and suggestions. Due to the size and complex tectonics encountered in the areas, this validation and correction procedure is repeated for 8 times. Finally, the 3D model on which everybody agrees is obtained. The Eynez solid model (Figure 5) covers only the license area of the Turkish Coal Enterprises. The northern part is currently exploited by private sector companies, and this part is omitted from the model. Eynez includes 20 faulted coal blocks separated by the NE–SW and NW–SE trending faults. The throws range from 10 m to 200 m between the faulted blocks that strike N30°E and dip 5° to SW. The total volume of these blocks is 263,600,000 m^3. The Ömerler coalfield is divided into 129 faulted coal blocks due to a severe tectonic movement (Figure 5). The faults are NW–SE, NW–SW, and N–S trending faults, which have throws of up to 20 m. The coal seam strikes N52°W and dips 7°NE. The total volume of the blocks is 105,000,000 m^3.

In Eynez, the average thickness of coal seam is about 25 m. There are 80 m and 100 m thick marl and limestone strata above the seam. They are exceptionally thick and strong layer in comparison with the conditions encountered for coal measure strata around the world. The floor is weak clay. Due to the presence of strong and thick roof strata having brittle characteristics in the roof, tectonism mainly resulted in faulting instead of folding. As a result, coal seam in the Eynez site is mainly divided into sectors by means of faulting. The coal seam is produced using the longwall with top coal caving (LTCC) method, and insufficient caving characteristics of roof strata creates a lot of problems (Ünver, 1995a [21], Ünver, 1995b [22], Ünver, 1996 [23], Ünver, 1997 [24], Ünver and Yaşıtlı, 2006 [25], Ünver et al., 2015 [26], Yaşıtlı and Ünver, 2004 [27], Yaşıtlı and Ünver, 2005 [28]).

The Ömerler site is also extensively faulted, as shown in Figure 5. About 7 m thick coal seam is also produced using the LTCC method (Hindistan et al., 2010) [8].

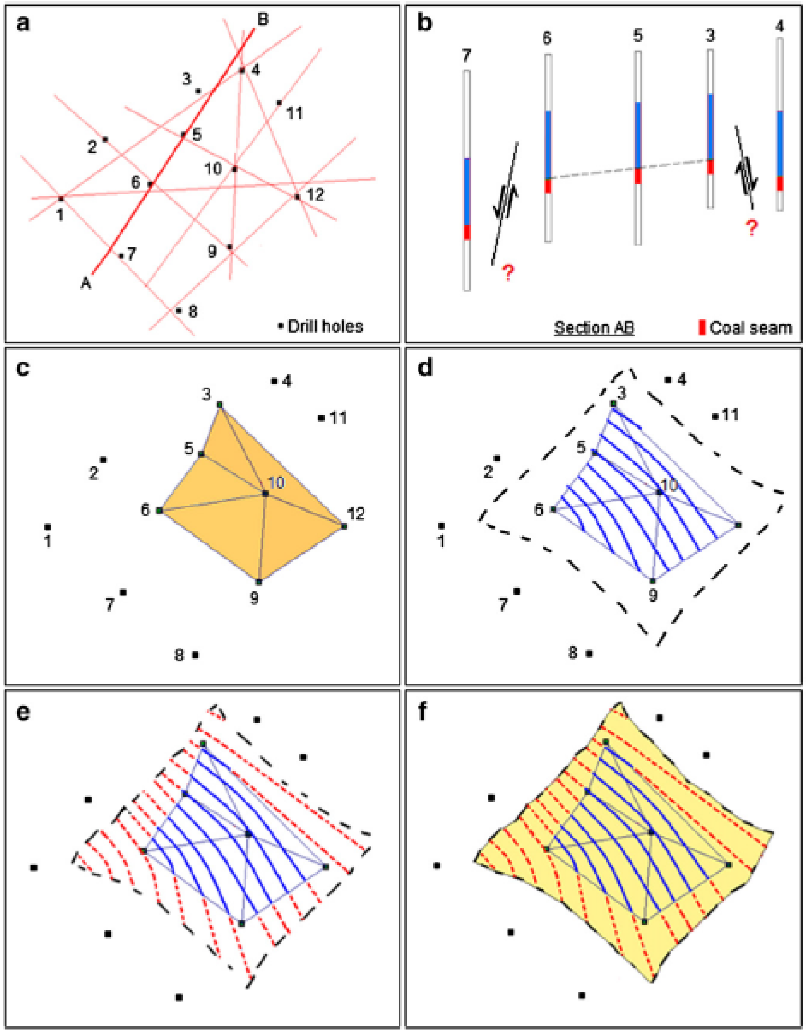


Figure 4. 3D modelling procedure utilized in this work (Tercan et al., 2013) [2].

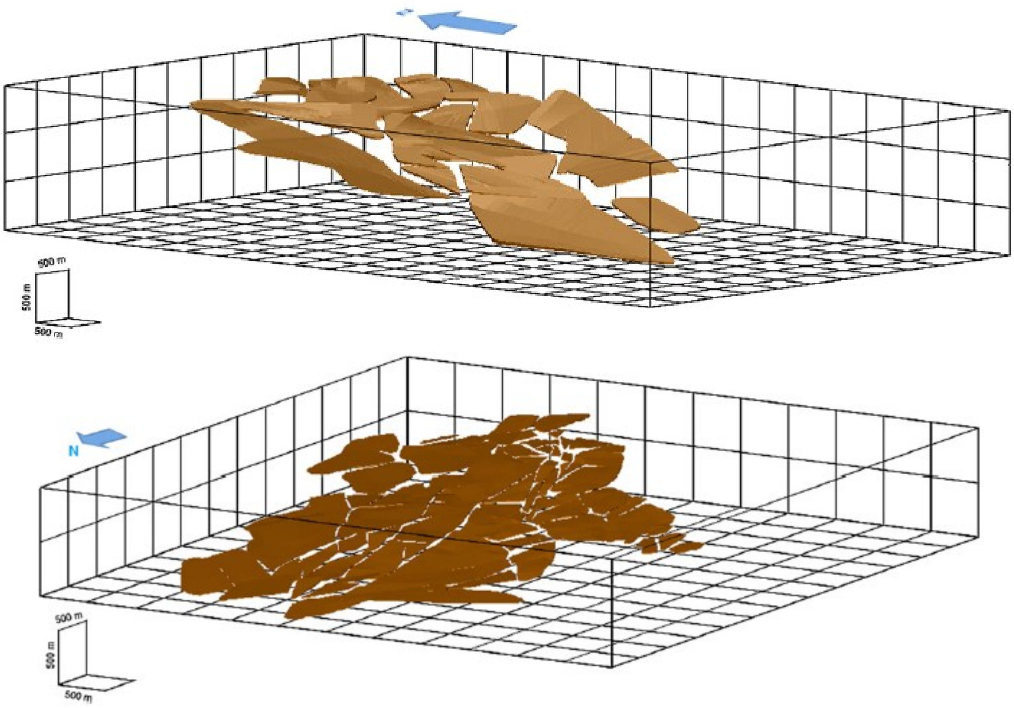


Figure 5. Isometric views of 3D seam model for Eynez (above) and Ömerler (below).

5.2. Block models

Resource estimates are produced from the block model of 3D solids for the coal seams. For this purpose, the solid model is divided into a number of small mining blocks, and the mean qualities of these blocks are estimated from the composited data using ordinary kriging. The block size is chosen to be 50 m × 50 m × 2 m in Eynez and 50 m × 50 m × 1 m in Ömerler, depending on the geometry of the solid model, mining method, composite interval, average spacing of drill holes and spatial relation of the quality variables. The block models are rotated according to strike and dip of the corresponding solid models. The total number of blocks is 52,720 in Eynez and 41,974 in Ömerler.

The coal seam thickness is derived from the block model by summing up the individual block thicknesses in each block column in downwards z direction. Figures 6 and 7 show the spatial distributions of coal thickness in Eynez and Ömerler, respectively. Note that the seam thickness decreases towards the eastern and western part in both coalfields.

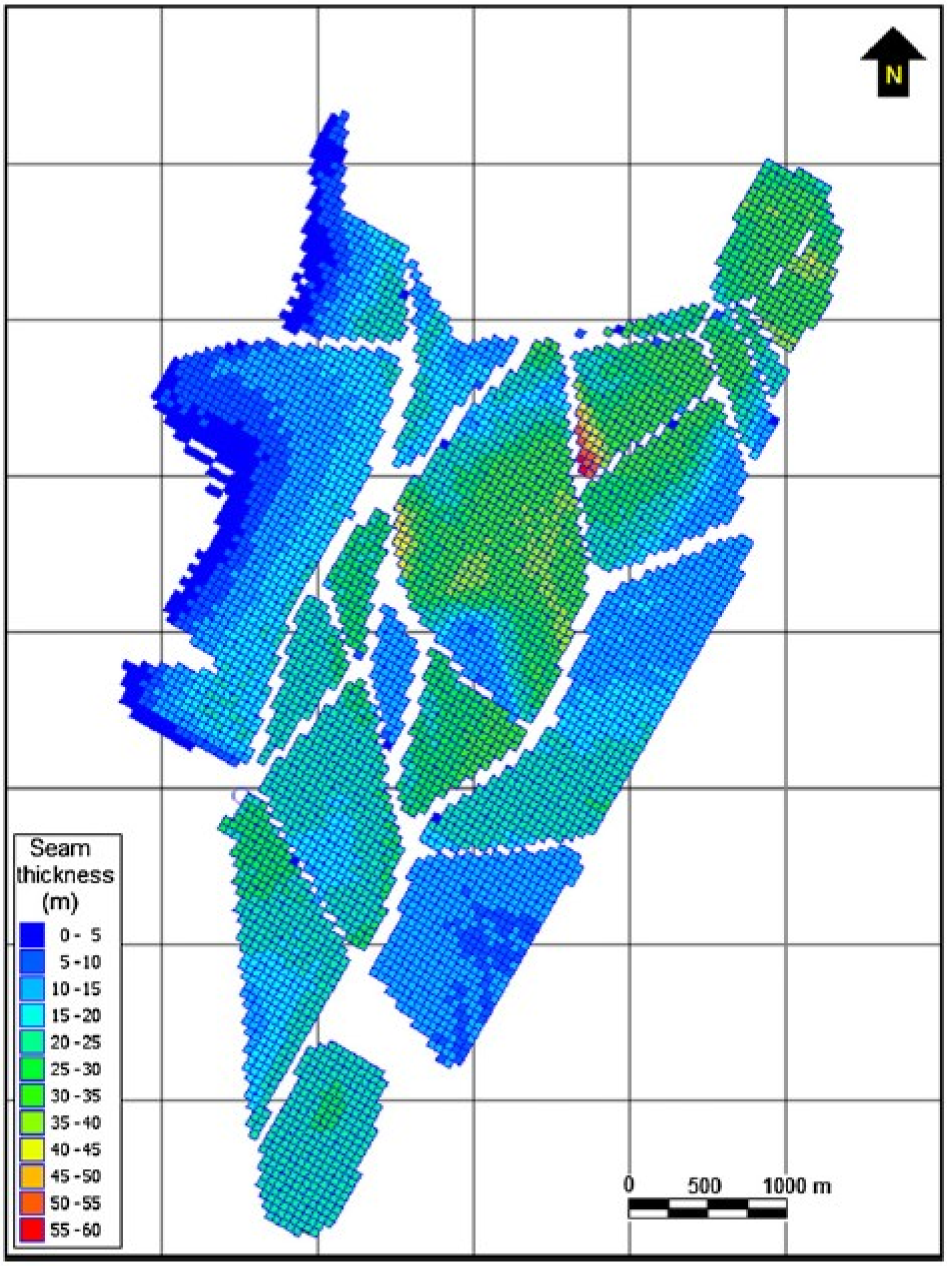


Figure 6. Spatial distribution of Eynez seam thickness (Tercan et al., 2013) [2].

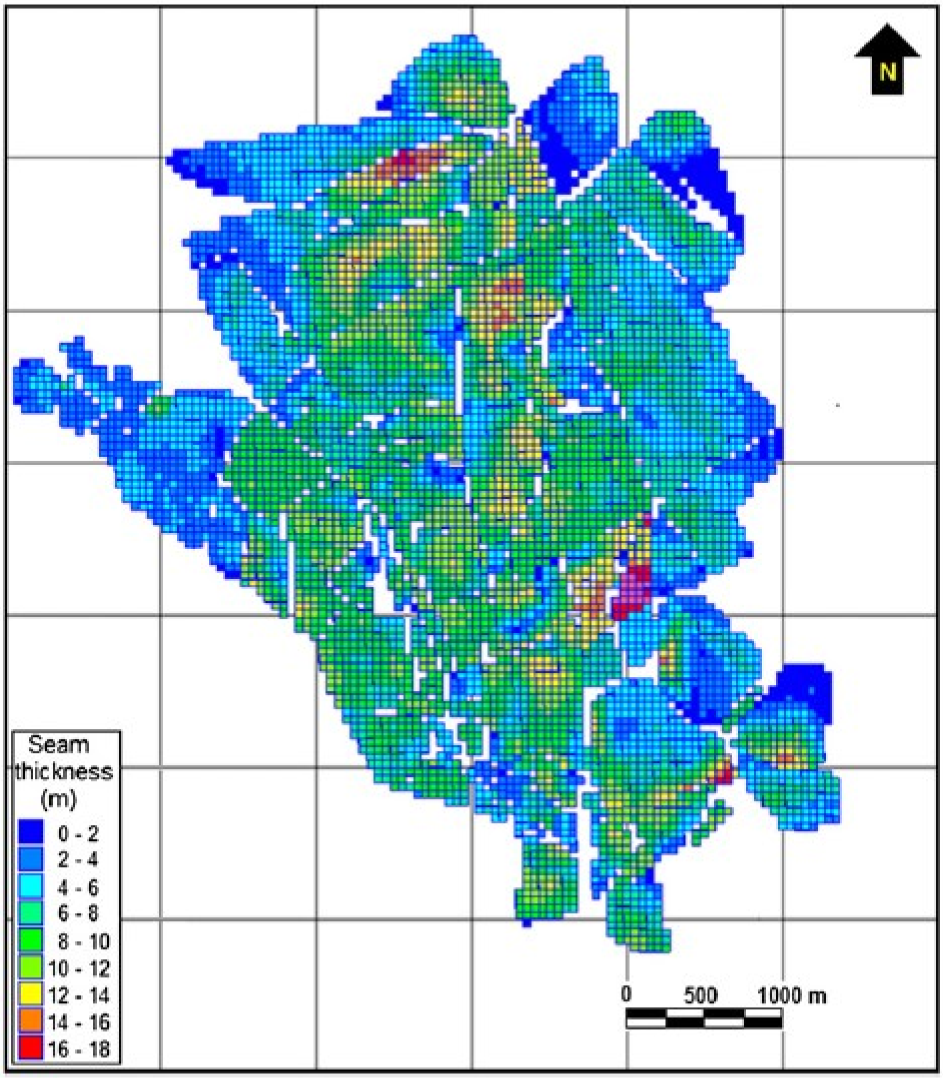


Figure 7. Spatial distribution of Ömerler seam thickness (Tercan et al., 2013) [2].

Estimation of a number of coal blocks separated by a series of faults with high throws is relatively difficult. In order to ease and improve the block estimation, the blocks and composites are projected into a flat plain, being a procedure known as unwrinkling, whereby only the z-coordinate of spatially located data is moved to maintain the correct spatial relationship (Carew, 2001) [29].

A simple unwrinkling transformation suggested by Tercan et al. (2011) is used in estimating the lignite resources [30]. A schematic representation of the method is given in Figure 8. Using this method, the block centroids and composited data are transformed into an unwrinkled space. Estimation is made on this space, and the estimated values are finally back-transformed into an original space. This simple transformation can only be used when seam inclination is relatively low and regular. In case of high seam inclination, the x and y coordinates of the block centroids should be considered in transformation together with the z coordinate.

A swath plot is a graphical display of the grade distribution derived from a series of slices or swaths generated in several directions through the deposit. The coal seam is divided into slices along with the direction under consideration, and the weighted average of each slice for the respective quality variable is calculated. The averages are plotted against the slice number. Figure 9 shows some of the swath plots in various directions in the original space rather than the unwrinkled space (not all plots shown here). As expected, the block model averages are smoother than the corresponding composite averages since the block values are estimated by ordinary kriging. There is generally a good match between the block models and the composites.

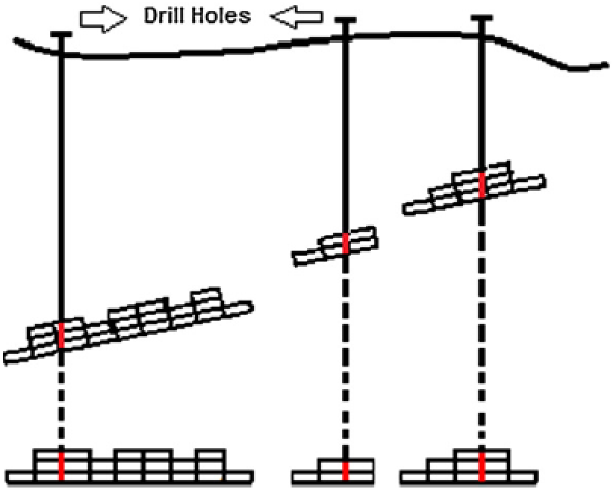


Figure 8. A schematic representation of unwrinkling blocks and composites. Red lines show composites (Tercan et al., 2013) [2].

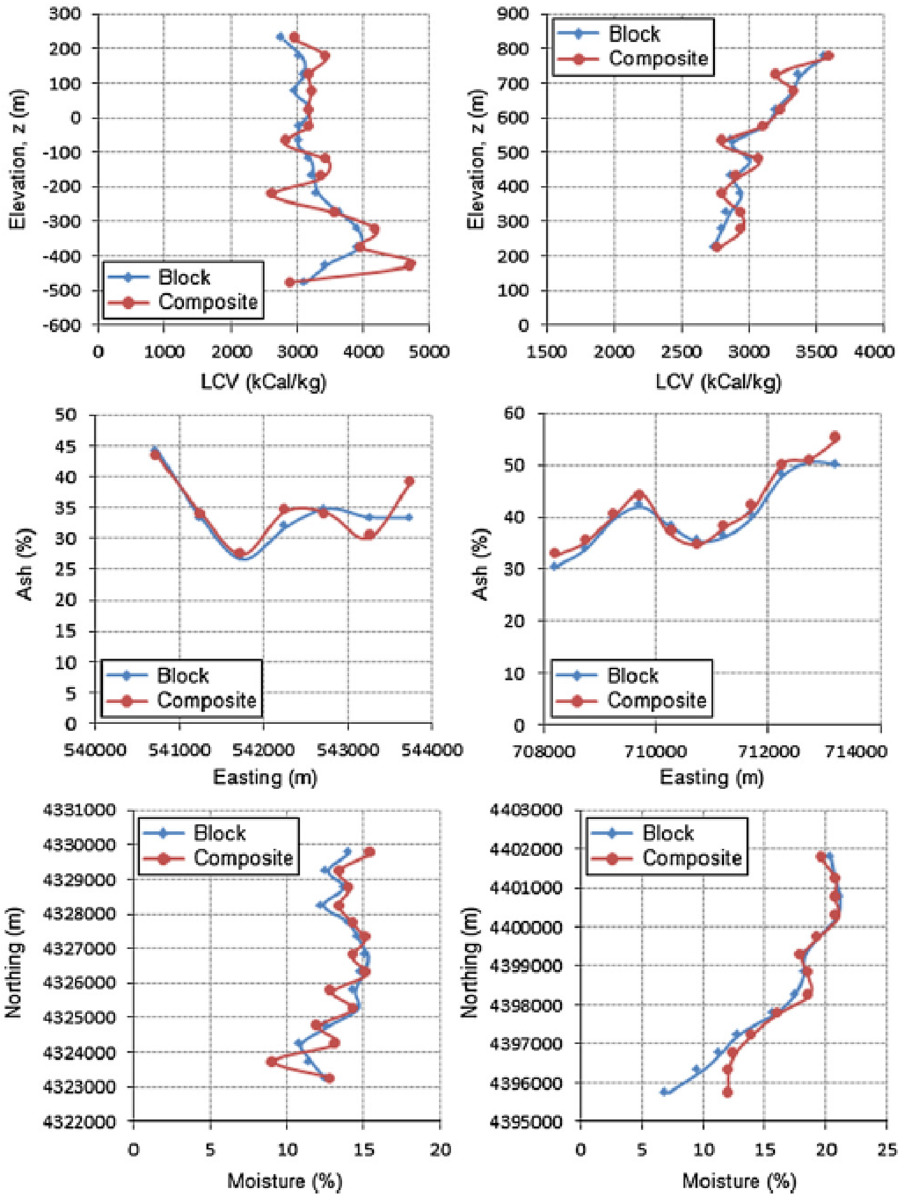


Figure 9. Swath plots: elevation *vs.* LCV (upper), easting *vs.* AC (middle) northing *vs.* MC (lower). The left figures belong to Ömerler, and the right ones to Eynez (Tercan et al., 2013) [2].

The spatial distribution of LCV and cross-sections at the Eynez and Ömerler coal fields can be seen in Figures 10 and 11. The LCV of coal seam at Eynez is high at the roof, and steadily decreases towards the floor. Cross-sections clearly reveal the successful modelling of this quality change over the stamp of the coal seam. Therefore, application of the unwrinkling process has proved to be successful, resulting in a realistic modelling of coal quality over its thickness.

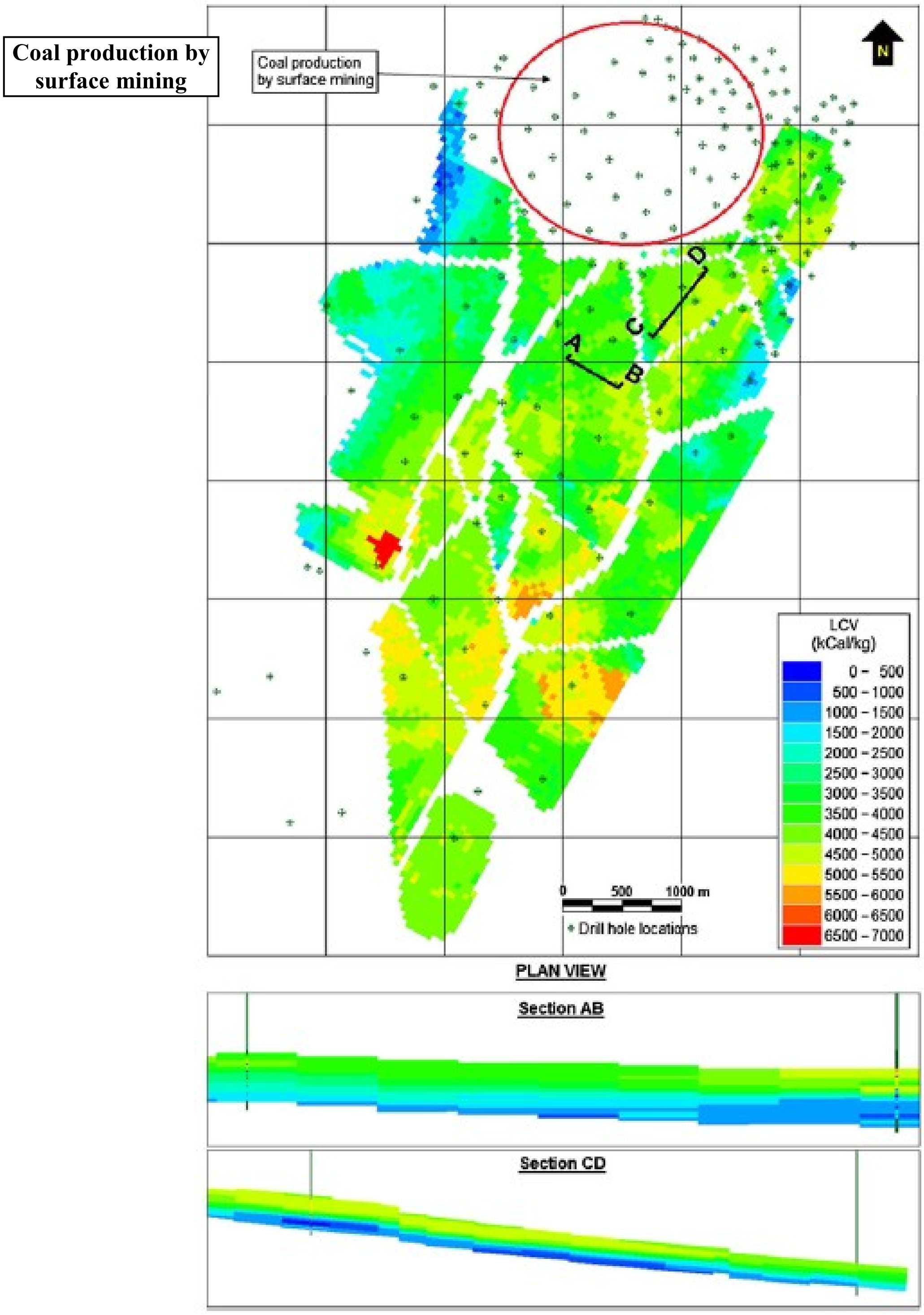


Figure 10. The spatial distribution of LCV and cross-sections at Eynez (Tercan et al., 2013) [2].

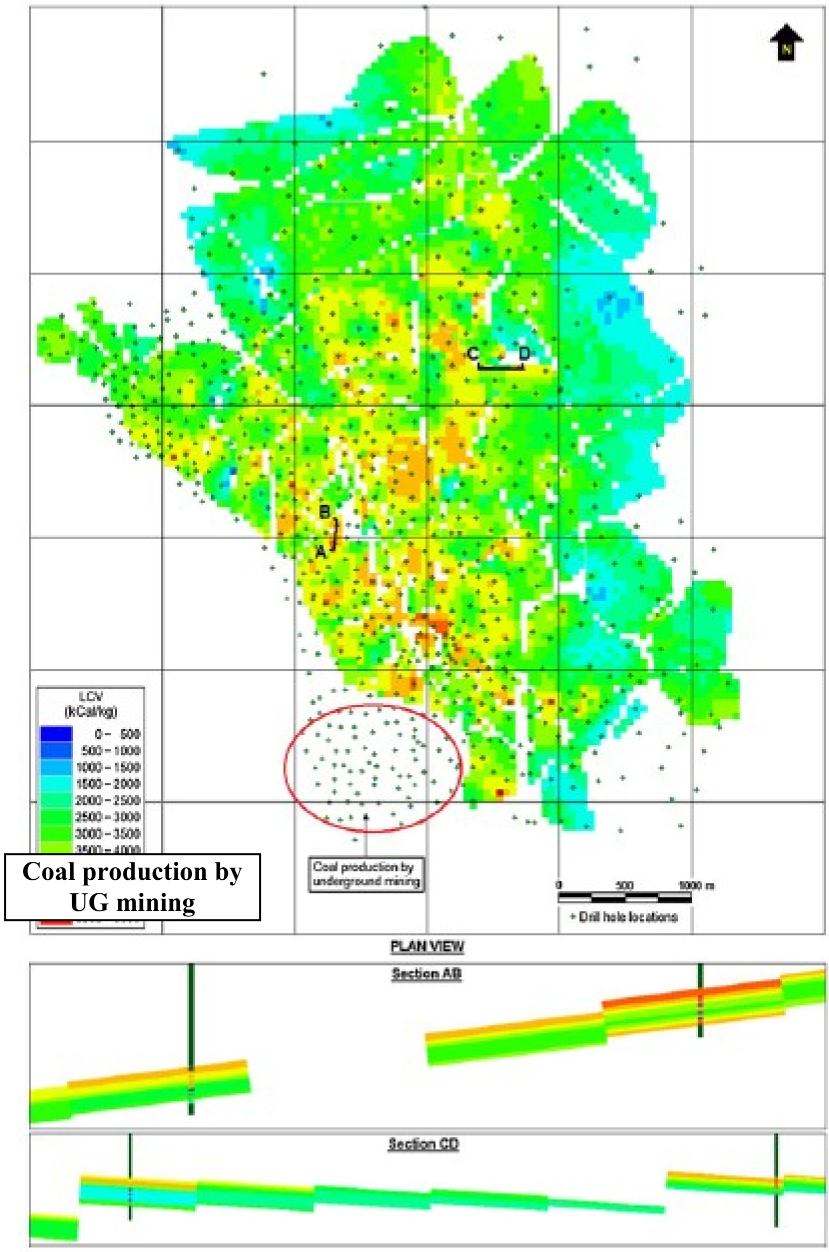


Figure 11. The spatial distribution of LCV and cross-sections at Eynez (Tercan et al., 2013) [2].

5.3. Coal seam models of Karapınar

The unstable conditions present in the environment during seam deposition resulted in the formation of many individual coal seams having various thicknesses (Figure 12). Hence, connection of coal seams encountered at adjacent boreholes could not be performed.

Therefore, it was not possible to create a 3D solid model of the coal seams with the present dataset.

Therefore, it was decided to divide the coal horizon into 6 horizontal slices resembling similar properties. These slices are: 1) Level > 870, 2) 850 < Level < 870, 3) 820 < Level < 850, 4) 790 < Level < 820, 5) 750 < Level < 790, and 6) Level < 750. Each slice is modelled separately.

The stripping ratios are calculated on individual boreholes to estimate the boundary of open-pit mines. Counter-plots of stripping ratios are drawn to visualize the pit geometry alternatives. As a results, 5 different pit geometries were selected for analysis. Pit geometry enabling the highest amount of production was selected for the detailed calculations.

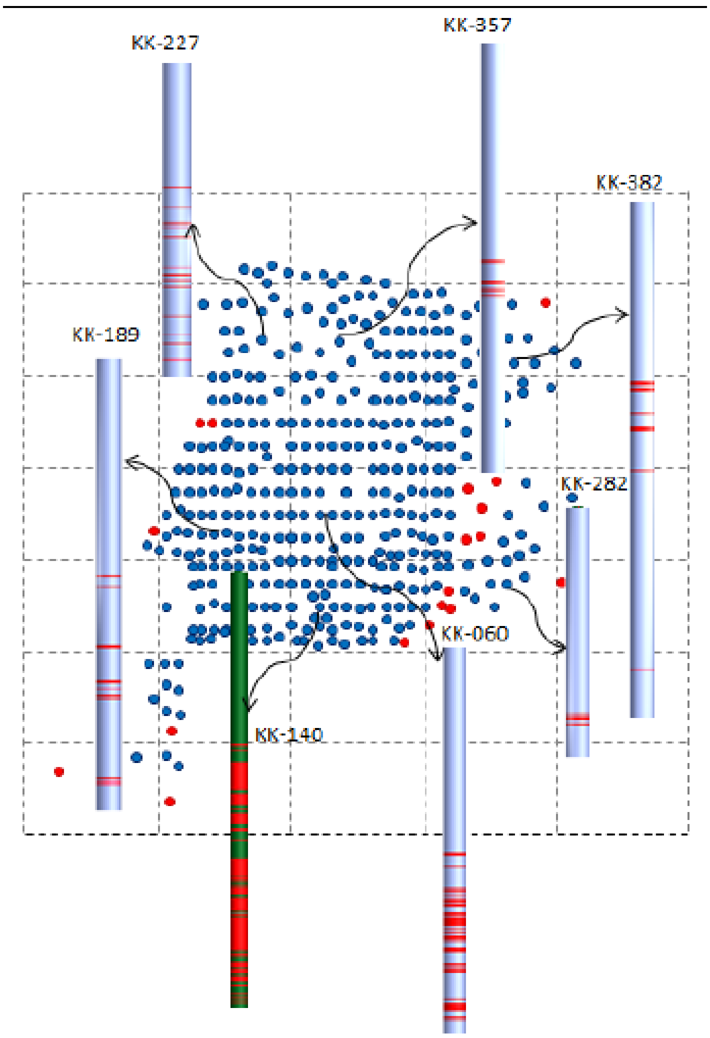


Figure 12. Boreholes and variation of coal seam encountered at selected locations (red stripes are coal seams) (Ünver et al., 2014) [31].

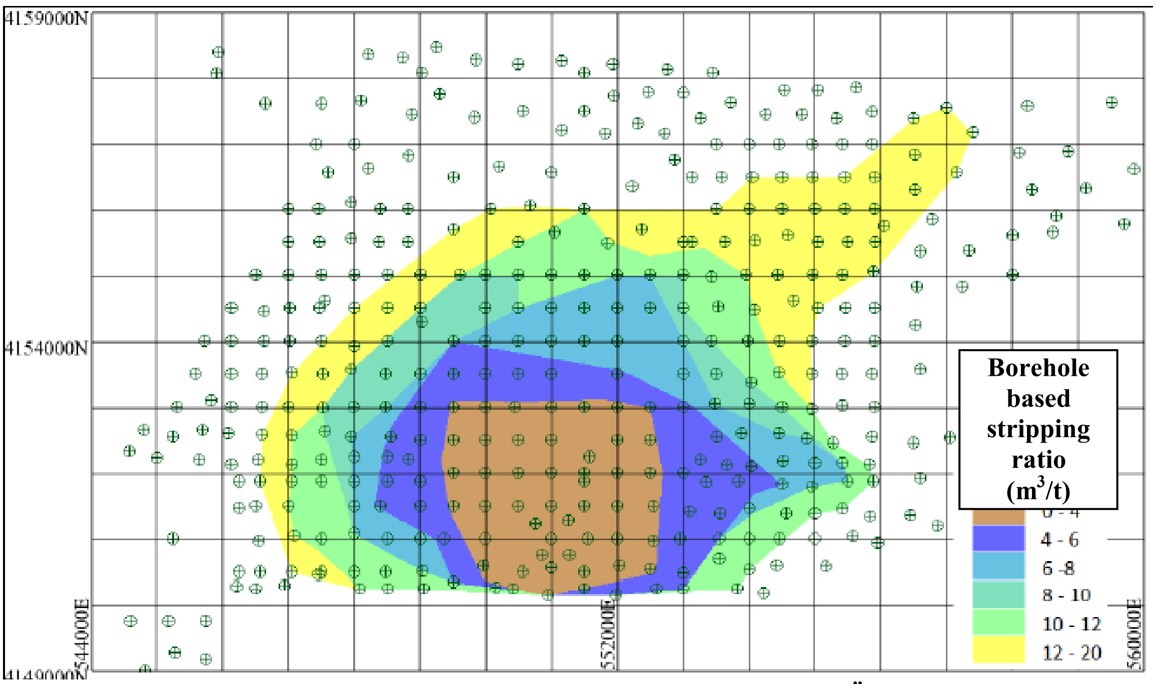


Figure 13. Stripping ratio contours calculated for individual boreholes (Ünver et al., 2014) [31].

5.4. Block modelling

Each slice was divided into 500 m × 500 m blocks. The block size was selected as 250 m × 250 m around the boundary to enable a better modelling. The block models of each slice were carried out within the pit-slice intersection.

The analysis results of the samples within the slices were used for estimation of the block average values. Attributes such as the lower heating value, thickness, ash, moisture, and organic and total sulfur contents were by using ordinary kriging. Figure 14 presents the overall thickness block model of the deposit. The southern part of the deposit is licensed by a private company, and therefore, extension on this part could not be included in modelling.

The total amount of coal in the Karapınar site is about 2 billion tons. However, the amount of coal suitable for production by means of open-pit mining with a stripping ratio of 7 m^3/ton is around 1.55 billion tons with an average lower heating value of 1357 kcal/kg. Although a detailed study has been completed on the Karapınar basin, because of the fact that the studies are in progress at the present time and the site has just been tendered, the other details are not given in this paper.

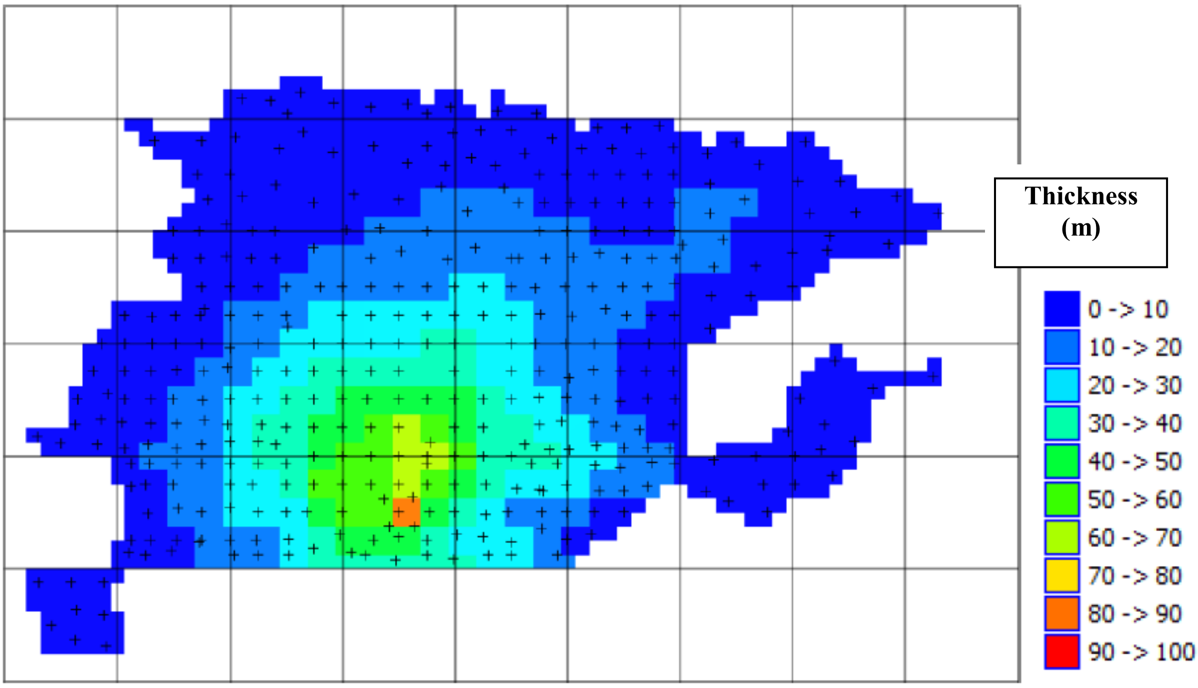


Figure 14. Total coal seam thickness block model of Karapınar basin (Ünver et al., 2014) [31].

6. Conclusions

The Soma- Eynez and Tunçbilek- Ömerler coal fields are the major lignite production locations in Turkey. A relatively good quality lignite has been produced from these fields over fifty years. A majority of coals produced from Eynez and Ömerler have been utilized to fuel thermal power plants. The need for energy at an affordable price has been increasing in Turkey at an accelerated rate during the last decade. Especially, the Eynez region has a significant potential in terms of resource for building new thermal power plants. Therefore, it is of high importance to model coal seam in terms of geometry and quality distribution. The Eynez and Ömerler coalfields are influenced by immense tectonic activities leading to the formation of adverse geological conditions for underground production. Considering the potential of a relatively high amount of production from these fields, the mechanized coal production methods will have to be implemented. Obviously, risks related to production should be lowered to acceptable levels by careful modeling of both coal seam geometry and coal quality related attributes.

The Karapınar basin is somehow different from Eynez and Ömerler. Quality of coal is lower and geological; the hydrogeological and structural characteristics are important characteristics for both resource modelling and pit planning. There are multiple inconsistent coal seams in the region. Therefore, 3D seam models could not be formed with the available data. However, as the exploration has been in progress, a more realistic

seam modelling would be made in the future. The novel methodology developed for the Karapınar region enabled a realistic initial evaluation of both coal resource and production possibilities.
As a conclusion, the methodology applied at the three coal regions in Turkey can be considered as a guiding example for other coal regions in the world.

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References

[1]. Siddiqui, F.I., Pathan, A.G., Ünver, B., Tercan, A.E., Hindistan, M.A., Ertunç, G., Atalay, F., Ünal, S. and Kıllıoğlu, Y. (2015). Lignite resource estimations and seam modeling of Thar Field, Pakistan. International Journal of Coal Geology. 140: 84-96.

[2]. Tercan, A.E., Ünver, B., Hindistan, M.A., Ertunç, G., Atalay, F., Ünal, M.S. and Kıllıoğlu, S.Y. (2013). Seam modeling and resource estimation in the coalfields of western Anatolia, western Anatolia. International Journal of Coal Geology. 112 (2013): 94-106.

[3]. Saikia, K. and Sarkar, B.C. (2013). Coal exploration modelling using geostatistics in Jharia coalfield, India. International Journal of Coal Geology. 112: 36-52.

[4]. Deutsch, C.V. and Wilde, B.J. (2013). Modeling multiple coal seams using signed distance functions and global kriging. International Journal of Coal Geology. 112: 87-93.

[5]. Hatton, W. and Fardell, A. (2012). New discoveries of coal in Mozambique- development of the coal resource estimation methodology for International Resource Reporting Standards. International Journal of Coal Geology. 89 (1): 2-12.

[6]. Heriawan, M.N. and Koike, K. (2008 a). Identifying spatial heterogeneity of coal resource quality in a multilayer coal deposit by multivariate geostatistics. International Journal of Coal Geology. 73 (3-4): 307-330.

[7]. Heriawan, M.N. and Koike, K. (2008 b). Uncertainty assessment of coal tonnage by spatial modelling of seam distribution and coal quality. International Journal of Coal Geology. 76 (3): 217-226.

[8]. Hindistan, M.A., Tercan, A.E. and Unver, B. (2010). Geostatistical coal quality control in longwall mining. International Journal of Coal Geology. 81 (3): 139-150.

[9]. Kapageridis, I.K. and Kolovos, C.J. (2009). Modelling and resource estimation of a thin layered lignite deposit. APCOM 2009 Proceedings, Vancouver, Canada. pp. 95-103.

[10]. Olea, R.A., Luppens, J.A. and Tewalt, S.J. (2011). Methodology for quantifying uncertainty in coal assessments with an application to a Texas lignite deposit. International Journal of Coal Geology. 85 (1): 78-90.

[11]. Tercan, A.E. and Karayiğit, A.İ. (2001). Estimation of lignite reserve in the Kalburçayırı field, Kangal basin, Sivas, Turkey. International Journal of Coal Geology. 47 (2): 91-100.

[12]. Srivastava, R.M. (2013). Geostatistics: a toolkit for data analysis, spatial prediction and risk management in the coal industry. International Journal of Coal Geology. 112: 2-13.

[13]. Yağmurlu, F., İnaner, H., Nakoman, E. and İnci, U. (2004). Age, tectonic setting and quality distribution of the Neogene lignite deposits of western Anatolia. Geologica Belgica. 7 (3-4): 251-258.

[14]. Nebert, K. (1978). Linyit içeren Soma Neojen bölgesi, Batı Anadolu. MTA Dergisi 90. pp. 20-69 (in Turkish).

[15]. Nebert, K. (1960). Tavşanlı'nın batı ve kuzeyindeki linyit ihtiva eden Neojen sahasının mukayeseli strarigrafisi ve tektoniği. MTA Dergisi 54. pp. 7-35 (in Turkish).

[16]. Murat, A., Kadınkız, G. and Yiğit, E. (2007). Karapınar-Ayrancı (Konya-Karaman) Neojen. Havzasında Yeni Belirlenen Linyitlerin Jeolojisi ve Ekonomik Potansiyeli, 60. Türkiye Jeoloji Kurultayı, 16-22 Nisan 2007. Ankara.

[17]. İnci, U. (1998). Lignite and carbonate deposition in Middle lignite succession of the Soma Formation, Soma coalfield, western Turkey. International Journal of Coal Geology. 37 (3-4): 287-313.

[18]. İnci, U. (2002). Depositional evolution of Miocene coal successions in the Soma coalfield, western Turkey. International Journal of Coal Geology. 51 (1): 1-29.

[19]. Karayiğit, A.İ. and Çelik, Y. (2003). Mineral matter and trace elements in Miocene coals of the Tunçbilek–Domanic Basin, Kutahya, Turkey. Energy Sources. 25 (4): 339-355.

[20]. Karayiğit, A.İ. and Whateley, M.K.G. (1997). Properties of a lacustrine subbituminous (k1) seam, with special reference to the contact metamorphism, Soma-Turkey. International Journal of Coal Geology. 34: 131-155.

[21]. Ünver, B. (1995 a). Kalın damar kömür madenciliğinde tabaka kontrolu ve göçme mekanizmasına pratik bir yaklaşım. Türkiye 14. Madencilik Kongresi Bildiriler Kitabı. pp. 15-22. Ankara.

[22]. Ünver, B. (1995 b). Eynez yeraltı ocağının yapısal jeoloji ve jeoteknik açıdan incelenmesi. TUKMD Bülteni, Haziran. pp. 27-40.

[23]. Ünver, B. (1996). Possibility of efficient application of semi-mechanization in longwall mining in thick seams. Journal of Mines Metals and Fuels. pp. 223-230. India.

[24]. Ünver, B. (1997). Arakatlı göçertme uygulanan kalın kömür damarlarında işletme veriminin artırılması. Türkiye 15. Madencilik Kongresi Bildiriler Kitabı. pp. 179-183. Ankara.

[25]. Ünver, B. and Yasitli, N.E. (2006). Modelling of strata movement with a special reference to cavingmechanism in thick seam coal mining. International Journal of Coal Geology. 66: 227-252.

[26]. Ünver, B., Hindistan, M.A., Tercan, A.E., Ertunç, G., Ünal, M.S., Kıllıoğlu, S.Y. and Atalay, F. (2015). Soma Eynez Kömür Sahası İçin Farklı Bir Üretim Yöntemi Önerisi. Türkiye 24. Uluslararası Madencilik Kongresi ve Sergisi (IMCET 2015), 14-17 Nisan 2015, Bildiriler Kitabı. pp. 363-371. Antalya.

[27]. Yaşıtlı, N.E. and Unver, B. (2004). Numerical modelling of top coal caving in thick seam coal mining. EUROCK 2004 & 53rd Geomechanics Colloquium. Schubert (ed.).

[28]. Yaşıtlı, N.E. and Unver, B. (2005). 3D numerical modeling of longwall with top coal caving. Int. J. of Roch Mech. and Min. Sci. 42 (2): 219-235.

[29]. Carew, T.J. (2001). Unfold and unwrinkle-Gemcom irons out the problem. Internal Report.

[30]. Tercan, A.E., Ünver, B. and Hindistan, M.A. (2011). Lignite resource estimation by unwrinkling. 22nd World Mining Congress and Exh., 11-16 September 2011: Proceedings Book, vol. II. Aydoğdu ofset, Ankara-Turkey. pp. 139-142.

[31]. Ünver, B., Tercan, A.E., Hindistan, M.A., Ertunç, G., Atalay, F., Ünal, M.S. and Kıllıoğlu, S.Y. (2014). Resource Estimation Report of Karapınar-Ayrancı Coal Basin, EÜAŞ. 145 P (unpublished).

اصول مدل‌سازی سه‌بعدی و تخمین منابع در معدنکاری زغال‌سنگ

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چکیده:

پیش‌نیاز عملیات معدنکاری کارآمد و ایمن، طراحی مناسب معدن با توجه به تمامی جنبه‌ها است. اولین گام در طراحی معدن زغال‌سنگ، مدل‌سازی هندسی واقعی از لایه (های) زغال‌سنگ است. ویژگی‌های ساختاری مانند گسل‌ها و شکستگی‌ها باید به طور قابل اعتمادی در مدل‌های سه‌بعدی اجرا شود. برای داشتن یک مدل همسان و سازگار، ویژگی‌هایی مانند ارزش حرارتی، خاکستر، رطوبت، مواد فرار و گوگرد باید در مدل بلوکی تخمین زده شود. همچنین با توجه به شرایط ژئوتکنیکی و هیدروژئولوژی، مناسب‌ترین استراتژی طراحی معدن می‌تواند انتخاب و اجرا شود. در این پژوهش، استفاده از مراحل فوق در سه حوزه زغالی در کشور ترکیه ارائه شده است. حوزه‌های Soma-Eynez و Tunçbilek-Öermler دو منبع مهم از زغال‌سنگ‌های لیگنیتی هستند که دارای تولید و چشم‌انداز خوبی در آینده معدنکاری زیرزمینی می‌باشند. در این پژوهش، مدل‌سازی جامع سه‌بعدی از لایه‌های زغال‌سنگ در هر دو حوضه انجام شده است. از آنجایی که هر دو حوزه زغالی، به علت تکتونیک به شدت گسله هستند، این یک کار چالش‌برانگیز است که ساختار واقعی آن‌ها را مدل می‌کند. از سوی دیگر، حوزه Karapınar در مقایسه با حوزه Eynez-Öermler دارای شرایط زمین‌شناسی، ساختاری و سنگی بسیار متفاوت است. حوزه Karapınar که اخیراً مورد اکتشاف قرار گرفته است، عمدتاً برای معدنکاری سطحی مناسب است. هندسه لایه (های) زغال‌سنگ و ویژگی‌های کیفی آن‌ها قطعاً نقش مهمی را در برنامه‌ریزی تولید و فعالیت‌های معدنی ایفا می‌کنند. تأثیر ویژگی‌های ذاتی هر حوزه در مدل‌سازی و استراتژی طراحی معدن نیز به طور خلاصه مورد بحث قرار گرفته است. در این پژوهش، مبانی مدل‌سازی لایه (های) زغال‌سنگ در شرایط مختلف زمین‌شناسی و ساختاری ارائه شده است. اعتقاد بر این است که روش ارائه شده در این پژوهش می‌تواند به عنوان مثال کاربردی برای مدل‌سازی جامع سه‌بعدی و تخمین منابع لایه‌های زغال‌سنگ در سراسر جهان در نظر گرفته شود.

کلمات کلیدی: مدل‌سازی لایه زغال‌سنگ، مدل‌سازی سه‌بعدی لایه، طراحی معدن زغال‌سنگ، تخمین منابع.