Modelling and Resource Estimation of a Thin-Layered Lignite Deposit

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Abstract

The lignite deposits of the Kozani-Ptolemais-Amyntaio basin in western Macedonia (North-West Greece) present a difficult modelling problem. Each deposit consists of several thin lignite layers ranging from a few centimetres to a few tens of centimeters in thickness, and thin intercalated sterile layers of marly limestones, marls, clays, and sands. These layers are practically impossible to model individually due to fast lateral transition of lignite layers to humus clay and vice versa and the lack of reliable and detailed stratigraphic correlation, leading to compositing methods being applied prior to any interpolation and modelling. The complexity of the deposit is further increased by the presence of a number of faults. This paper presents the modelling and estimation procedures applied during the most recent study of the South Western Field – a new deposit that is considered for development and lignite production over the next years and will support the operation of a new power station in the area. Special focus is given to drillhole database structuring, fault modelling, stratigraphic correlation, mineable lignite intervals compositing, and resource estimation. The use of specialised mine planning software in all stages of modelling and estimation is thoroughly explained.

Introduction and Deposit Description

The study presented in this paper concerns the South Western Lignite Field (SW) located between Ptolemais and Kozani in North-West Greece. The SW Field is one of the “zebra” type lignite deposits of the Kozani-Ptolemais basin (Kolovos, 2006). The Public Power Corporation of Greece operates a number of surface lignite mines and power stations in the region. Bucket wheel excavators, belt conveyors and stackers are used as the main mining equipment. Shovels plus dumpers handle the hard overburden. PPC considers the development of the SW Field as an expansion to current operations.

The lignite bearing strata in the study area belong to the upper Pliocene. Overburden material belongs to the Pleistocene and Holocene (Anastopoulos et al., 1972). Over the lignite bearing strata lie a series of green-gray clay and marl layers - an alternation of mainly sandy clays, calcareous marls and silty clayish marls. A series of yellow-brown sandy layers follows, consisting of mainly calcareous sands with clay intercalations and occasionally sandy marls. In this formation, numerous lenticular intercalations of sandstones and conglomerates-consolidated pebbles exist. Over the yellow-brown layers lies a series of red-brown clays and conglomerates - an alternation of reddish sandy clays and loose conglomerates with clay-silica binding matter. The Proastion conglomerates are the most recent system of stream deposits consisting of loose conglomerates, sands and sandstones.

Software Used in the Study

Two software packages were used in this study. The first is an in-house package called METAL, programmed by PPC personnel, that allows mineable lignite intervals evaluation, resource and reserves estimation, hard rock reserves estimation, etc. (Karamalikis, 1992). The second is the well known Vulcan 3D software package built by Maptek Pty Ltd. Vulcan is one of the top general mine planning packages available, integrating specific coal oriented database and modelling sub-systems called ISIS and GridCalc (Lee and Kapageridis, 2004). ISIS is an interactive database editor used in conjunction with Vulcan databases. Grid Calc is a very powerful grid modelling and manipulation tool that provides both an interactive interface and a sophisticated macro command driven interface. Grid Calc provides facilities to generate grids from irregularly spaced data points.

Database Management

Raw data from more than 1500 drillholes covering the entire area of lignite deposits in Ptolemais were exported from METAL into an ISIS database. This data included collar information and lignite quality analyses (Ash, Lower Heating Value-Kcal, and Relative Humidity) on specific drillhole intervals. Average drillhole spacing was around 200m. A general description of the material in each interval (DESC) is included together with a number of coded descriptive fields (R1-R13) regarding parameters such as colour and texture. Table 1 presents the structure of the drillhole database built in Vulcan with a short explanation of each field. Only the first two tables (Collar and Raw) were filled directly from the information exported from METAL, and are discussed here. PPC drillholes have a unique CODE and PCODE field value corresponding to a numerical and an alphanumerical ID of each drillhole. CODE in particular is a combination of the X and Y coordinate of each hole allowing quick location of the collar on a map. The DESC field combined with a number of other descriptive fields (R1-R13) was used to calculate the COLOUR field that provides a specific colour to raw drillhole intervals for plotting purposes. An ISIS field calculation script was generated for this calculation.

Table 1: Database structure in ISIS

TABLE	FIELDS								
COLLAR	CODE	PCODE	X	Y	Z				
	hole code	*hole name*	*collar coordinates*						
RAW	FROM	TO	DESC	R1-R13	LENGTH	ASH	KCAL	RH	COLOUR
	top offset	*bottom offset*	*material type*	*descr. fields*	*thickness*	*ash*	*lower heating value*	*humidity*	*material colour*
COMPO	FROM	TO	DESC	LENGTH	ASH	KCAL	RH	SR	SG
	top offset	*bottom offset*	*composite type*	*thickness*	*ash*	*lower heating value*	*humidity*	*stripping ratio*	*specific gravity*
CORREL	DEPTH	CODE							
	bottom offset	*horizon*							
HARD	FROM	TO	THICK	ZONE					
	top offset	*bottom offset*	*length*	*overburden zone*					

Stratigraphic Correlation and Structural Modelling

Stratigraphic correlation of the SW Field deposit was performed by the Institute of Geology and Mineral Exploration (IGME) of Greece in order to study the tectonics of the deposit. Correlation was based on a number of drillhole section plots prepared in Vulcan, and the original drillhole logs. Plotting was performed using Vulcan's Batch Plotting utility which allowed quick generation of very complex plots combining information from multiple databases and tables.

Lignite seams were not modelled individually due to their excessive number and fast lateral transition of lignite layers to humus clay and vice versa, which makes practically impossible the development of a reliable correlation mechanism. Lignite seams were grouped in two main bands, the lower and the upper band. Three characteristic horizons that could be correlated were used for determining faults. The characteristic sand horizon is a very specific horizon of the Kozani-Ptolemais basin. It is light grey and 10-20cm thick, covering the entire basin. It consists mainly of feldspars (plagioclase), biotite, quartz and in smaller amounts crystals of hornblende, zircon, apatite and rutile. The Neritina horizon is another characteristic horizon of the basin that is found between the lower and upper lignite band. It consists of light coloured marls, ranging from a few centimetres to 9m thick, which contain fossils of gastropod Theodoxus (Calvertia) Macedonicus, mostly known from its older name Neritina. Final marl lies below the deepest lignite seam. It is a white-yellowish calcareous mud, 0.2-3m thick, with 92.1% $CaCO_3$ and 5.6% $MgCO_3$. The combined identification of the characteristic sand and final marl in a drillhole is a safe indication of where the lignite bearing strata end, and drilling should stop.

The roof and floor of each lignite band was also correlated and modelled. The section plots were produced in two directions, along and perpendicular to the long axis of the deposit. Drillhole columns were split in two parts - the left coloured and patterned according to the COLOUR field of the RAW table. The right part was coloured according to two of the R1-R13 fields that provide the actual material colour. The two corresponding colours were mixed into a single composite colour using special fill patterns. Not all drillholes had these two colour fields defined leading to some intervals showing white (Figure 1). The following horizons were marked on the sections and were used to fill the CORREL table of the ISIS database:

Table 2: Correlated and modelled surfaces and horizons

Surface - Horizon	Code in Database	Colour in Plots
Old mine dump areas	MD	Cyan
Recent dump areas	DND	Gray
Würm sediments	DV	Light blue
Proastio formations	DP	Red
Red-brown series	DR	Brown
Yellow-brown series	DY	Yellow
Green series	DG	Green
First Geological Roof	GO1	Black
First Geological Floor	GD1	Black
Second Geological Roof	GO2	Black
Neritina horizon	N	Dark blue
Characteristic sand horizon	F	Light green
Second Geological Floor	GD2	Black
Final Marl Roof	OM	Black
Base roof	BG	Dark cyan

Correlation and the study of faults were limited to an area extending around 500m outside of the SW Field. The surfaces listed in Table 2 were modelled in GridCalc originally as grid models and then converted to triangulation models for better visualisation and resource calculations.

As shown in Figure 2, the faults in the area follow a main direction NW - SE. This is the direction of the main faults that generated the large tectonic graben of Florina - Ptolemais. The main fault population is located at the West and North West limits of the deposit. The throw of the faults is NE and SW, leading to a compression in the NW limits of the deposit and the generation of faults vertical to the main direction.

The fault lines were combined into polygonal zones to be used in structural modelling of the deposit. Some of the originally designed fault lines had to be extended for the zones to close. Grid Calc builds a grid by modelling each zone independently and connecting the adjoining edges. Zones can also overlap in which case an average value is used as the final result. Each zone must contain at least three data points that define a plane. Inverse distance (ID^1) was used to model all structural surfaces (roofs and floors, Figure 3) while inverse distance squared (ID^2) was used to model thickness. Four samples were used for each estimation point within a search area of 300m radius.

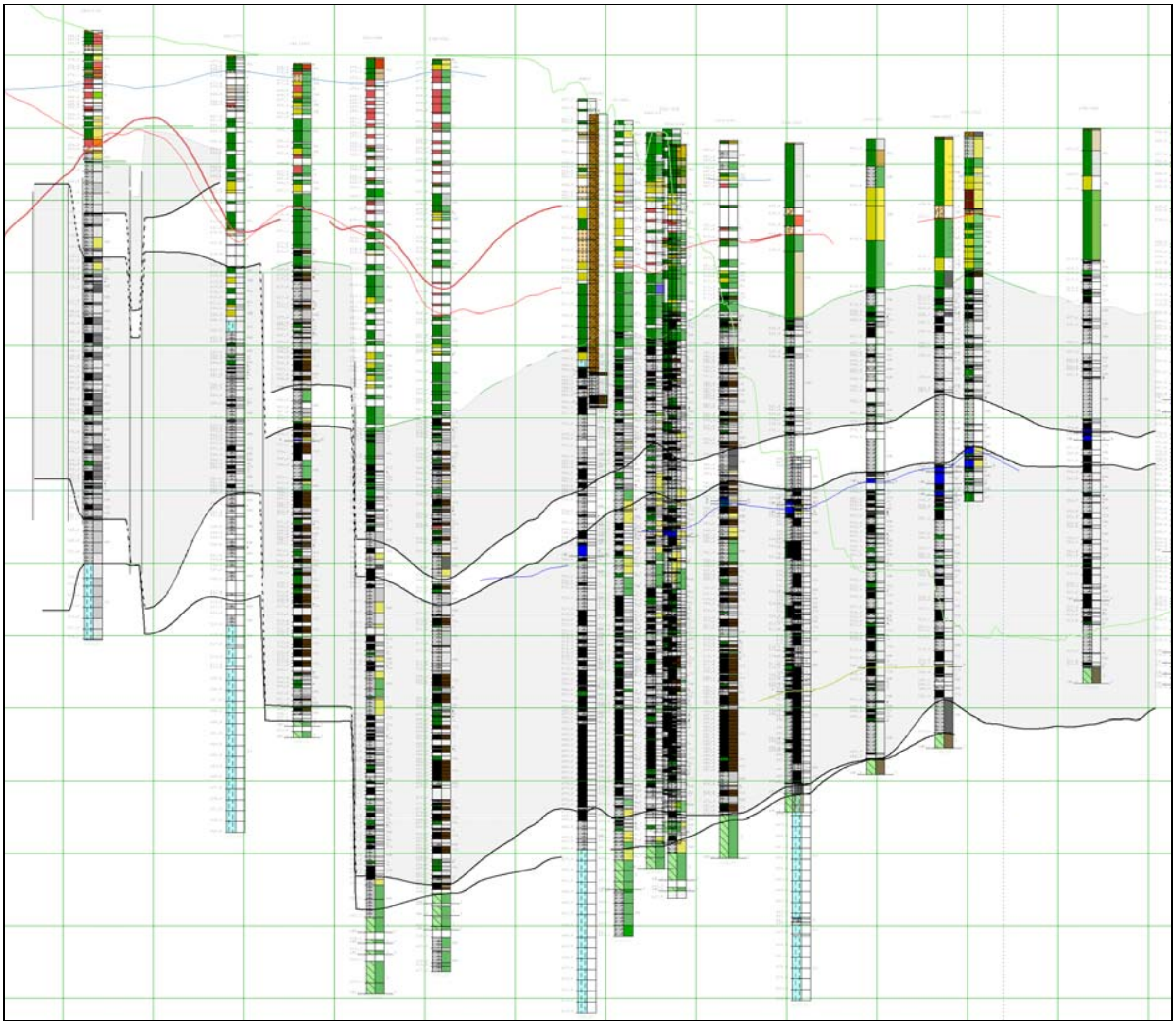

Figure 1: Typical section showing surface models based on stratigraphic correlation and fault modelling. Grey areas show the vertical extents of the lignite deposit

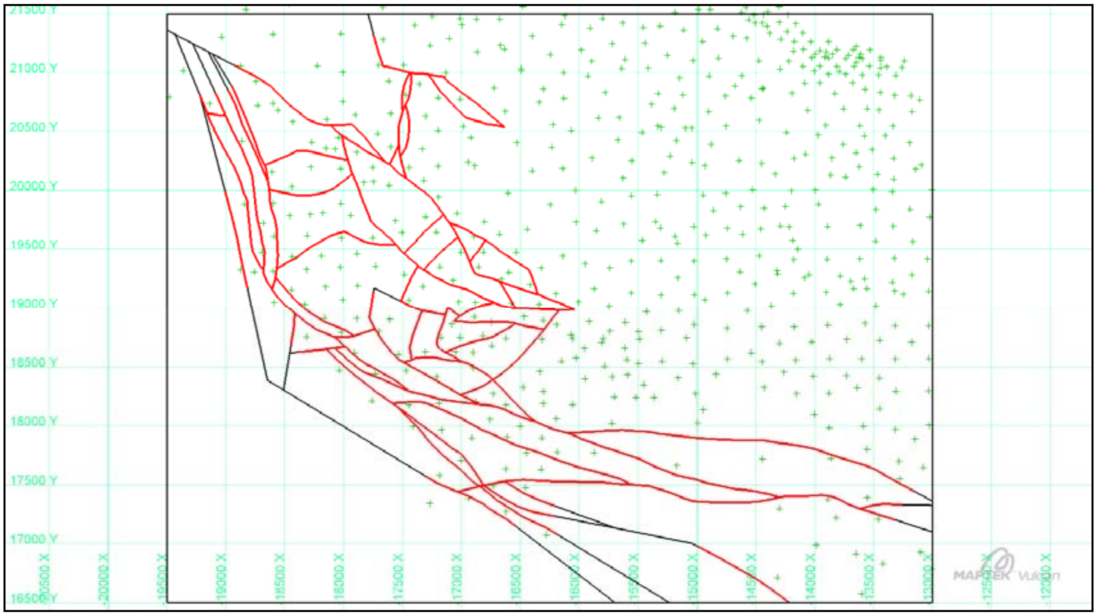

Figure 2: Plan view of faults and fault zones used for structural surfaces modelling. Red lines are the original faults and black lines are extensions for fault zone generation

Modelling of Lignite Quality Parameters

Three quality parameters were of interest in this study - ash, mean relative humidity, and mean calorific value of the mineable lignite intervals. A single grid model was generated for each of them using weighted average values from the composited drillhole intervals. In other words, a single ash, mean relative humidity, and mean calorific value was derived from each hole by weight averaging its mineable intervals. Inverse distance squared was used for generating the quality models and the same number of samples and search radius used for structural modelling. The quality estimates produced were only used to get a general picture of the resource quality. As lignite seams are not correlated, it was not possible at this stage to get a more detailed model of qualities and particularly their distribution along the Z axis. This will be possible once a reserves study is performed and the mineable lignite is modelled separately for each bench.

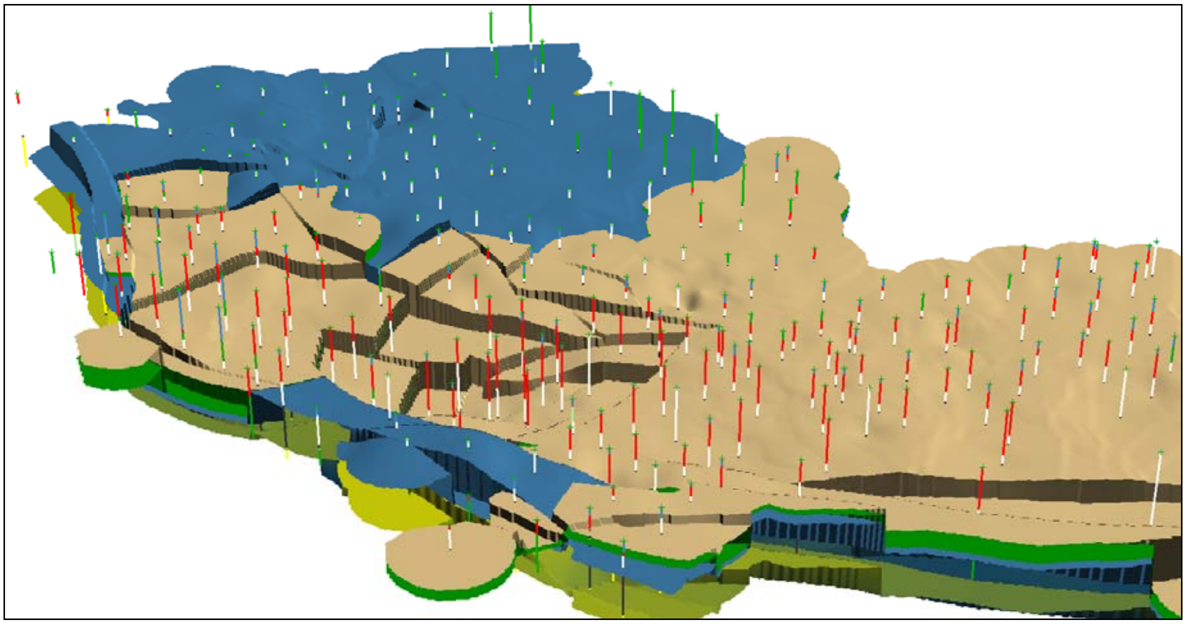

Figure 3: 3D view of the SW Field lignite deposit showing faulted models of geological roofs and floors of the two lignite bands

Modelling of Hard Formations

Hard formations within the overburden zones needed to be modelled for mining equipment selection and scheduling purposes. Definition of hard formations was based on an extensive search in the original drillhole logs. Hard horizons and their thickness were identified in the descriptions of drillhole intervals. The total thickness of these horizons varies from a few centimetres to more than 20m. Hard formation intervals were stored in the HARD table of the ISIS database. These intervals were also classified as per overburden zone. Separate models of hard formations within each overburden zone were generated in GridCalc and their volume and mass was calculated.

Evaluation of Mineable Lignite Thickness

The evaluation of raw lignite drillholes is a process of compositing seams into blocks of technically “recoverable lignite” and blocks of “barren (waste) material.” The borehole evaluation criteria were especially developed for the specific kind of deposit, exploited by the specific type and size of (existing) equipment and aiming to produce lignite quality acceptable by the power plant. In multi-layered lignite deposits, the blocks of “recoverable lignite” often include thin layers of barren rocks, having a thickness of some centimeters. Such waste layers are too thin to be selectively excavated by the bucket wheels, and constitute “pollution” to the original “geological” lignite. The average quality of the resulting blocks of “recoverable lignite” should meet certain specifications, depending on the requirement of each consumer. Evaluation of the average quality of blocks of “recoverable lignite” should take into account that, due to the geometry of the sickle-shaped cut, the bucket wheel will in fact co-excavate adjacent blocks of barren rocks. That imposes an additional source of “pollution” (or “dilution”). In a similar way, the blocks of “barren” material often contain thin layers of lignite, which cannot be selectively excavated. These layers constitute mining losses (Kolovos, 2007). The algorithm described here is implemented in the METAL package. The evaluation algorithm goes through the following main steps (Karamalikis, 1992):

1. *Initial raw seam coding* - all seams of a hole are characterised initially as waste if the ASH field is blank or the values of ASH field and seam thickness are greater than user defined limits. Seams not satisfying the above are temporarily considered as lignite.
2. *Waste seam compositing* - the algorithm composites consecutive waste seams derived from the first pass into "waste" blocks.
3. *Compositing lignite down to next parting* (Figure 4) - with the simplified picture of the hole generated after the first two steps, the algorithm goes into the main task of appropriate compositing seams into recoverable blocks of "lignite" and "waste". To achieve this, it scans the characterised lignite and waste seams of the hole until it finds a waste seam with thickness greater than the parting thickness defined by the user. The algorithm temporarily composites into one block the seams before the parting (the seven seams of Block A in Figure 4) and performs a number of calculations. These include the specific gravity in dry form that will be then used to calculate the mean ash value of the block, the subtraction of losses from the thickness of the first and last seam of Block A, the mean weighted values for moisture, ash, specific gravity and minimum calorific value of Block A. The algorithm can also take into account the increase of thickness due to "dilution"; however, introducing a "dilution" factor to the borehole evaluation software is not justified for the Greek multi-layered lignite deposits because it has resulted to an undesired and incontrollable alteration to the geometry of the pit and to the calculation of the reserves of "recoverable" lignite. (Kolovos, 2007). If the final mean ash of the block and the final block thickness (after dilution and losses) satisfy the requirements for recoverable lignite, the algorithm characterises the block as "lignite" and assigns to it the calculated final ash, moisture, calorific value and specific gravity. If the final mean ash of the block or the final block thickness does not satisfy the requirements for recoverable lignite then the algorithm removes the last seam of the block and repeats Step 3 until it finds a part of the block that will satisfy the requirements for recoverable lignite. This part is characterised as "lignite" and the process continues with all combinations of the remaining seams in the block.

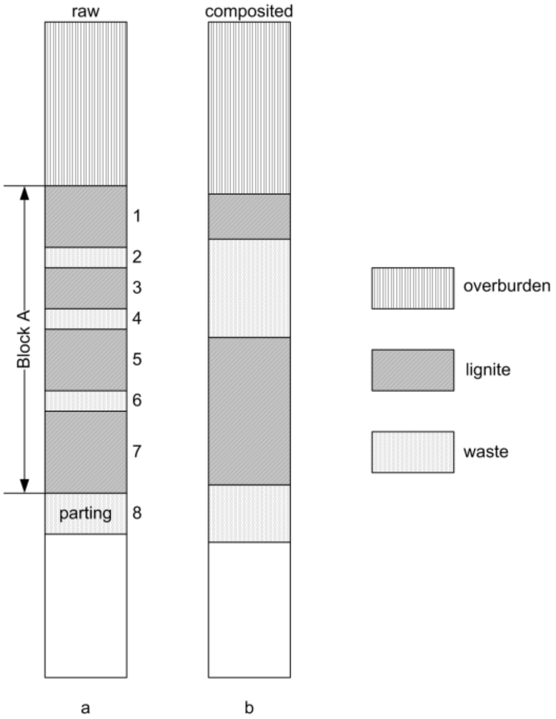

Figure 4: Example of mineable lignite intervals evaluation of a drillhole

4. *Compositing consecutive waste seams* - once the recoverable blocks of lignite are constructed, the program continues with the compositing of any consecutive waste blocks into composited waste blocks.

There are other steps that follow regarding drillhole totals. The evaluated drillhole intervals were imported into the COMPO table in ISIS which is used in the next stage of resource estimation.

Resource Estimation

Estimation of lignite resources for the SW Field was based on the structural floor and total thickness model of the mineable lignite intervals (Figure 5). The total thickness model was adjusted to exclude any lignite that is already mined or scheduled to be mined by existing operations. Similar models were developed for overburden (volume above the structural roof of the mineable lignite intervals) and intermediate intercalations (intervals classified as waste between mineable lignite). Figure 5 shows a mineable lignite thickness map. It is clear that the higher thickness appears in the deep area of the deposit where a number of faults bring the lower lignite band much deeper than usual. This is an area where the mining method will possibly have to differentiate from the common bucket wheel excavators used as the main excavating equipment in PPC lignite mining operations.

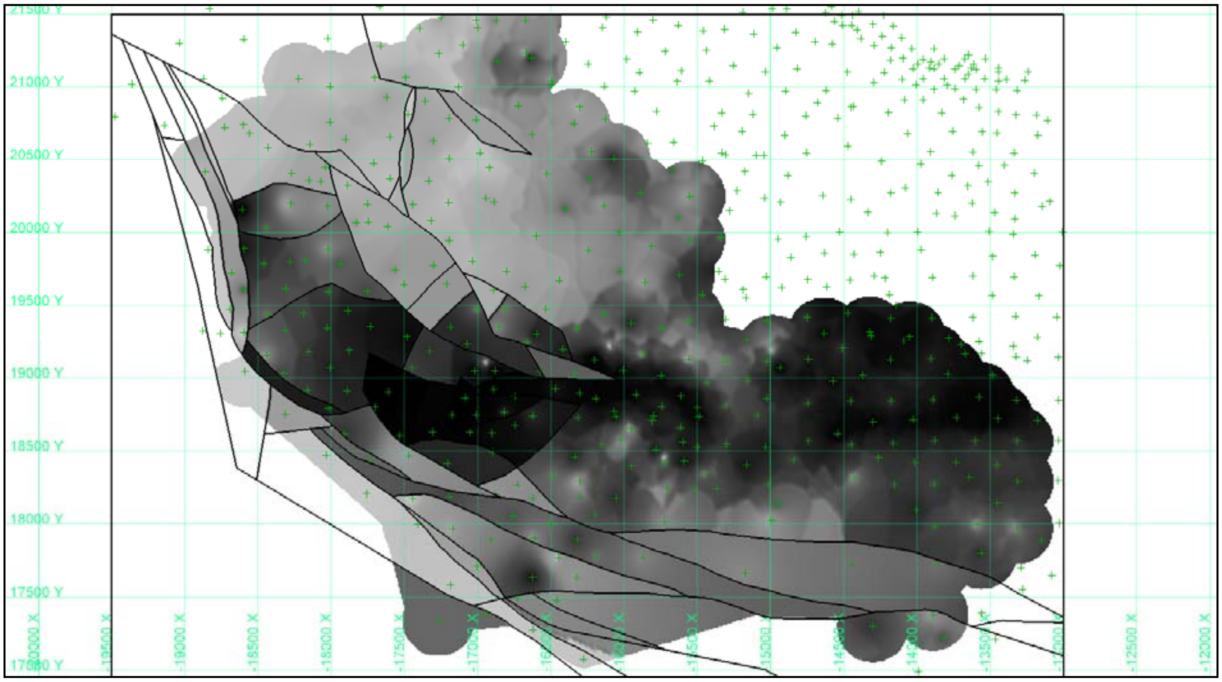

Figure 5: Mineable lignite thickness map of the SW Field (dark colours show areas of higher thickness)

Conclusions

This paper presented the stratigraphic modelling and resource estimation study of the South Western lignite field in North-West Greece. Data management and the evaluation of raw drillhole intervals to recoverable lignite blocks were critical aspects of the study. The data and methodology used in modelling the geometry and extents of this lignite deposit was thoroughly discussed. The particular problems arising from the deposit complexity and the given solutions were explained. The study also clarified the significance of the highly fragmented, deep area of the deposit as to the contained recoverable lignite and provided important information for further mine planning and development of the South Western field.

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