

# Geological modeling of a stratified deposit with CAD-Based solid model automation

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## Abstract

The planning stages of mining activities require many comprehensive and detailed analyses. Determining the correct orebody model is the first stage and one of the most important. Three-dimensional solid modeling is one of the significant methods that can examine the position and shape of the ore deposit. Although there are many different types of mining software for determining a solid model, many users try to build geological models in the computer without knowing how these software packages work. As researchers on the subject, we wanted to answer the question “How would we do it?”. For this purpose, a system was developed for generating solid models using data obtained from boreholes. Obtaining this model in an AutoCAD environment will be important for geologists and engineers. Developed programs were first tested with virtual borehole data belonging to a virtual deposit. Then the real borehole data of a cement raw material site were successfully applied. This article allows readers not only to see a clear example of the programming approach to layered deposits but also to produce more complicated software in this context. Our study serves as a window to understanding the geological modeling process.

**Keywords:** geological modeling, orebody, AutoCAD solid model, SolidBox.

## 1. Introduction

Up until now ore deposits have often been modeled with different approaches. Geostatistical modeling techniques give very successful results in this sense. However, the ore deposit's ability to be defined in every sense depends on its ability to be represented as three dimensional beyond the reserve estimation. This issue will be solved partially by general computer-aided drawing systems (CADs) being available. Indeed, CAD applications have been used in pit design and planning processes for many years (Jiang, 1998). Solid models of geological structures are useful tools for engineers and geologists, especially by means of studies carried out in the modeling of geological features (faults, zone and ore deposits etc.) as they contribute to the improvement of applications by probing them with many different approaches (Jiang, 1998; Wu and Xu, 2003; Wu *et al.*, 2005; Webster and Oliver, 2007; Kaufmann and Martin, 2008; Calcagno *et al.*, 2008;

Lloyd, 2011; Tutmez *et al.*, 2012; Liu *et al.*, 2013, Dağ and Özdemir, 2013; Lad and Rao, 2014; Marschallinger and Jandrisevits, 2015). The solid model approach has entered into quite common modeling methods in parallel with developments in recent years. Another reason is that there are so many program options to be used. When viewed from a larger perspective, the used program and modeling methods may differ, even if the solid modeling approach merges under a certain roof.

The purpose of this study was to improve a system that produces solid models to be used in the evaluation of mineral deposits effectively in the light of recent developments. In accordance with this purpose, a two-step package in Visual Basic language was prepared due to the multitude of data entry and user options to form a solid model. There is BlockCAD in the first step of the system and with this program block data were obtained by evaluat-

ing a data file formed from three-dimensional borehole information. In the second step, a new program/macro was improved named SolidBox that can draw blocks from produced data. The program provides an opportunity to monitor the surfaces formed at the end of the triangulation process on the user form, as well as producing block data at the first stage. The second stage of the system forms an exact model in an improved macro and AutoCAD environment by spreading the block data to real space. The solid model formed at the end can be evaluated by taking advantage of all query tools provided by the drawing environment.

In order to test the outputs of developed computer programs, a virtual deposit and a cement raw material field were modeled. The aforementioned field was chosen due to the existence of more than one ore layer. Thus regardless of the number of the layers of the field, it should be turned into a representable

solid model with only one software program. We also tried to support the correctness of the solid model with

sections to prove the usability of the prepared system in all appropriate fields that may be encountered. Mistakes

that might occur were programmed to be monitored with the help of sections taken from the model.

## 2. Theory

### 2.1 Developed computer programs

The model developed to obtain a solid model of the mineral deposit about which borehole data is known in the AutoCAD environment consists of the following stages.

- Obtaining the solid box model data that are required for AutoCAD

- Obtaining an AutoCAD file including solid box models with developed VBA macro

- Obtaining the Solid Model by combining all solid boxes with AutoCAD tools
- Examining the desired information from the obtained solid model with

AutoCAD tools

The first two stages are performed with the two Visual Basic Application (VBA) programs developed. The program that performs the first stage is called BlockCAD and the macro that performs the second stage is SolidBox.

### 2.2 Data file creation for AutoCAD

A program has been developed to obtain the SolidBox model information drawn in the AutoCAD environment from borehole data. This program is called BlockCAD.

It is rather difficult to obtain complex data sets by classifying the simple borehole data taken randomly. Likewise,

arranging this data according to the intended purpose of another program requires a time-consuming series of operations. There is need for a set of values for box models to be drawn in the next stage. These values are  $X_{center}$ ,  $Y_{center}$ ,  $Z_{center}$ , and Height, Length and Width values for the box to be drawn. Large amounts of

data can be used. The only constraint on data size is the RAM capacity of the computer system used. The computational techniques used within the program will be explained in detail for the oncoming stages. At each stage, some data were arranged and/or formed for the following stage.

#### 2.2.1 Triangulation method and surface modeling

Triangulation creates surfaces by constructing triangles between borehole points and interpolating the surface from locations on the triangular mesh. The process of triangulation consists of determining the natural neighbors of successive points on a map. In particular, using triangulation to model 3D orebodies in the subsurface is recommended (Cauman *et al.*, 2009; Liu *et al.*, 2013). Even though there are different methods of forming these triangles, the basis of creating the triangulated surface from points or vertices is the same. (Zlatanova *et al.*, 2004; Zlatanova, 2006; Zlatano-

va and Prospero, 2006; Breunig and Zlatanova, 2011).

Two-dimensional values (X, Y) of each drilling are recognized as corner points of a triangle to be formed by drawing using the Delaunay Triangulation technique. This triangle is a triangle such that any drilling point will not fall. At the same time, this triangle is the triangle with the smallest area that can be formed when it is entered in combination with all points. When querying whether triangles possess these features or not in the Delaunay Triangulation technique, different mathematical processes are

taken advantage of. The clearest technique is the process that interrogates the equation of a circle whose two dimensions are known and pass through three points (Utrecht University, 2014). With the help of this equation, it is possible to fix characteristics (center, diameter) of the circle in a two dimensional plane whose three points (P1, P2, P3) are given (Figure 1).

Two lines can be formed from these three points. The first is a line passing from the first two points (P1 and P2); another is line b passing from P2 and P3. The equation of these two lines:

$$y_a = m_a (x - x_1) + y_1 \quad (1)$$

$$y_b = m_b (x - x_2) + y_2 \quad (2)$$

Where m is the slope of line given by the equation below:

$$m_a = (y_2 - y_1) / (x_2 - x_1) \quad (3)$$

$$m_b = (y_3 - y_2) / (x_3 - x_2) \quad (4)$$

The center of the circle is the intersection of the two lines perpendicular to and passing through the midpoints

of the lines P1-P2 and P2-P3. The perpendicular of a line with slope m has slope -1/m, thus equations of the lines

perpendicular to lines a and b and passing through the midpoints of P1-P2 and P2-P3 are:

$$y_a^1 = [-1/m_a(x - (x_1 + x_2)/2)] + (y_1 + y_2)/2 \quad (5)$$

$$y_b^1 = [-1/m_b(x - (x_2 + x_3)/2)] + (y_2 + y_3)/2 \quad (6)$$

These two lines intersect at the center and solving  $x$  gives:

$$x = [m_a m_b (y_1 - y_3) + m_b (x_1 + x_3) - m_a (x_2 + x_3)] / 2(m_b - m_a) \quad (7)$$

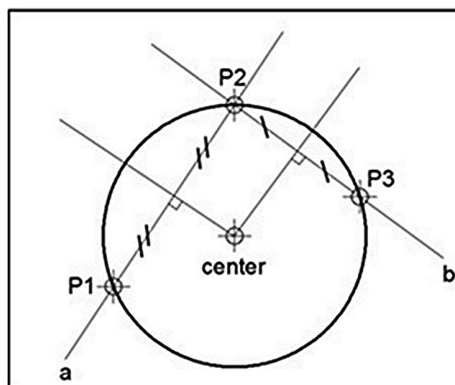


Figure 1  
Circle in three points (Bourke, 1990).

The  $Y$  coordinate can be calculated by replacing one of the vertical lines with the  $X$  value. At this stage, by considering that all lines drawn from known points to the center are equal in diameter, the distance between the center and these points can be easily calculated (Bourke, 1990).

The system primarily scans all points for each point and calculates center coordinates of all circles passed from the investigated point and another two points, after its radii. The location of other points is established by detecting the circle

with the smallest diameter by comparing formed circles and selected points. The circle detected in the last case is such a circle that it has only three points and there isn't any point within the area of the circle.

The program repeats the same processes for all points and in the meantime, it can again use the triangle points that were defined before. One point can be the corner point of many triangles. At the same time, elements of a triangle can form elements of other triangle groups. However, it should not be forgotten that

three elements of a triangle cannot be in the same group. This logical error leads to the formation of more than one of the same triangles, forcing the program's processing capacity and the creation of more objects in the last obtained drawings. To prevent this, the system defines the coordinate values of each of the triangle's three corners that it defined as one group and assigns a variable. All features of these coordinates grouped by the variable are defined as the elements of a matrix that is named as that variable.

### 2.2.2 Gridding of field

The division of the field into grids performs two important processes. Firstly, the grid system to be formed should pass from all defined points to use all elements of the obtained data from the field completely. Moreover, boundaries of the grid system play quite an important role because the grid system's intersections form the center of box models. When determining the boundaries, maximum and minimum values on  $x$  and  $y$  coordinate axes are detected by scanning the coordinate values ( $X$ ,  $Y$ ) automatically. Second is the grid width's selection that will affect the next stages of this program directly. When the program begins to work, it asks the user Width ( $W$ ) and Length ( $L$ ) values and these values are considered optionally by the user and intersections of drawn grids form one part of the box models' center coordinates at the last stage. Obtained intersections define center coordinates ( $X_{center}$ ,  $Y_{center}$ ) of cubes that will form our main model.

### 2.2.3. Value calculation of elevation

In previous sections, whether points in grid systems are in the formed triangle

The program first finds the border ( $X_{box}$  and  $Y_{box}$ ) lengths from the difference of coordinate values. During this process, it calculates how many boxes will be drawn using  $W$  and  $L$  value inputs. Width ( $W$ ) and Length ( $L$ ) of the box are defined again using  $X_{box}$  and  $Y_{box}$  numbers calculated at the first stage. The division process here is made with high precision. Thus losses were prevented by providing numerical precision to anticipated  $W$  and  $L$  values while the box number remained stable. The program appoints all calculations after this stage to the current point coordinates.

After calculating all grid coordinates, the grid system was defined so that it takes the biggest and smallest values of drilling locations. At this stage, it detected whether each intersection was in determined fields or not.

The logic that was used when the determination was made based on calculation of the three-sided polygon's area

simply and the algorithm of this logic is based on the rules below:

- One point can only be in one triangle's area.
- The sum of the intersection with the triangle's areas formed between the points that were defined before can be equal to only one of the triangle areas defined before. In this case intersection is replaced within that triangle.
- Otherwise intersection is outside the triangle

More clearly, the program assigns new triangles from each point to each corner of the calculated triangles before.

It is accepted that points that provide equality enter into the area of one triangle. The program investigates all triangular areas for all points and remaining points are determined. During the determination process, coordinates ( $x$ ,  $y$ ) of each point and the triangle's indices that are in it are defined and recorded at the same time.

surfaces or not was established. As seen in Figure 2a, all intersection points that

are in the closed area were formed from triangles from the center of box models.

In this logic, the ability of any box to be drawn depends on the condition of being central within the area of the triangle. It is accepted that the coordinates of the point where they intersect this surface with a line passing from Z axes direction within the surface of a triangle whose corner points are known are (x, y, z).

Three dimensions ( $X_{center}$ ,  $Y_{center}$  and Z) of the box models' center coordinates have been calculated by the program. But the main issue at this stage is finding which surface the "Z" value represents and the ability to be defined according to this. That the first formed triangular surface has to define the exit surface in

spite of its entry surface to the vein was accepted. In this case at least one series of Z enter ( $Z_{en}$ ) and Z exit ( $Z_{ex}$ ) values should be calculated.

When considered within the framework of this logic, the program forms a level for each obtained depth value from drilling data and the triangular surface at each level (Figure 2b). At each level, the rays that were assumed to pass through were accepted as a projection of each point defined before. Points that intersect the surface of these rays are calculated as explained above and  $Z_{en}$  (Z coordinate of entry of layer) and  $Z_{ex}$  (Z coordinate of exit of layer) values are assigned.

There are also points that intersect different numbers of triangular levels and come across the space between the points defined before (Figure 1b). For the prepared program to be usable in cases encountered with one or more intersection, it was provided with the capacity to be able to calculate more than one  $Z_{en}$  and  $Z_{ex}$  series.

At the end of the process, regular matrices belonging to each level, in other words triangle surfaces, are defined. It will even be possible to obtain real-like mathematical and visual data by classifying intersections, so intersections will be replaced within box models.

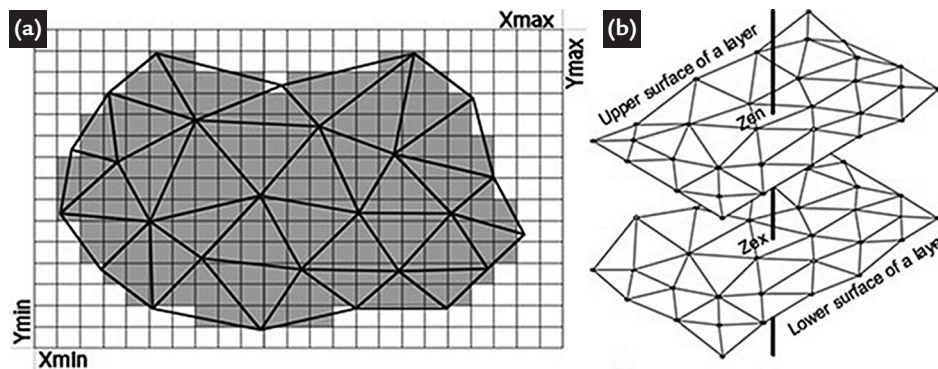


Figure 2  
Triangle surface: a) Grid system, b) The ray passed vertically through a point in the surface of a layer.

$X_{center}$ ,  $Y_{center}$ ,  $Z_{center}$ , coordinate values with length, width and height values belonging to each box must be known for box models that are planned to be formed in the last section of the program. Upper and lower surfaces of box models overlap with triangle surfaces formed before and levels where center rays passing from these surfaces are defined as  $Z_{en}$  and  $Z_{ex}$  values.

Then,  $Z_{center}$  is calculated from midpoint of  $Z_{en}$  and  $Z_{ex}$  by the program.

After all stages, all data obtained by the program are recorded in ".txt" file format and to this file the block information that will form the solid model in the AutoCAD environment is written. Drilling information obtained from the field consists of x and y coordinates and the cutting

depth of the vein. In this prepared program, data should be processed into ".txt" format file with the sequential file method. In the file should be X and Y coordinates and Z elevation values of enter and exit from all layers ( $Z_{en}$  and  $Z_{ex}$ ) belonging to each borehole respectively. This information should be recorded in order to be available for different processes within program.

### 2.3 Building a solid model in the AutoCAD Environment

In this study, three dimensional blocks are drawn using SolidBox data that were defined before with the help

of the Macro (SolidBox) developed with the Visual Basic editor in the AutoCAD drawing program. Each

block is formed easily using the Add-Box method (Sutphin, 2005) with the simple command below.

$$\text{Set3DSolidObject} = \text{Object.AddBox}(\text{BoxCenter}, \text{Length}, \text{Width}, \text{Height}) \quad (8)$$

The thing to be done after drawing the blocks that form the deposit's solid model and combining them, is to investigate the model by taking advantage of all AutoCAD's mathematical,

visual and digital query tools. The formed model can be perceived as a single solid object that can consist of more than one level. This body mass can be calculated. The section can be

taken from any points, and intersections can be followed. Because the processes appropriate to user requests are easily accessible, many stages of organization can be investigated.

## 3. Results

### 3.1 Testing with virtual borehole data

Developed programs and methodology were first tested with virtual borehole data belonging to a virtual deposit, and then they were successfully applied to real borehole data of

a cement raw material site. Figure 3a shows the AutoCAD 3D solid model of virtual ore deposit and 18 boreholes that are randomly scattered on the deposit and are constructed by Auto-

CAD. The 3D solid model was built using the programs and parameters (Figure 3b) on the basis of virtual borehole data (Figure 3c).

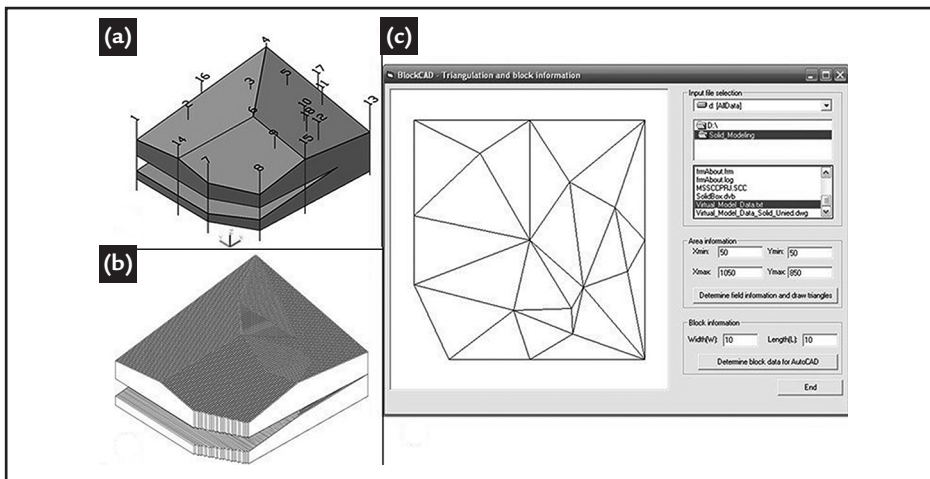


Figure 3  
 Program testing; a) AutoCAD solid model of virtual ore deposit and boreholes, b) The interface screen of the BlockCAD program and parameters, c) Constructed solid model of deposit using BlockCAD and the virtual boreholes

The effect of drill-hole spacing on the correctness of the solid model to be produced is indisputable. Basically, if the drilling distance gets smaller, the model accuracy increases. It was found that in testing, when the number of boreholes is increased, the

generated solid models are very similar to the real solid model in terms of shape and numerical characteristics. The constituted solid is similar to the real solid in respect of mass properties (Table 1). The difference is very small between the real solid model and

the generated solid model. X and Y coordinates have tiny changes. Likewise, generated Z coordinates tend to be lower than the real Z coordinates. It was observed that all difference values are less than 1%. The results are very acceptable for modeling techniques.

		Real solid model	Generated from borehole solid model	Difference	Difference %
Volume(m <sup>3</sup> )		223186198	221454767	1,731,431.00	0.78
Bounding box: (m)	X	50.0 - 1050.0	50.0 - 1050.0	0 - 0	0 - 0
	Y	50.0 - 850.0	50.0 - 850	0 - 0	0 - 0
	Z	25.0 - 425.0	25.2 - 425.1	0.2 - 0.1	0.80 - 0.02
Centroid: (m)	X	611.7	610.6	1.1	0.18
	Y	471.0	471.1	-0.1	-0.02
	Z	216.3	215.9	0.4	0.18

Table 1  
 Mass properties displayed for two 3D solids.

### 3.2 Application Real Field

It is now clear that our programs work with virtual borehole data. Let us turn our attention to real borehole data. A cement raw material field was chosen as the real application field. The triangle process belonging to borehole locations in

this field was made and the triangulated field is shown in Figure 4. This was right after solid models that were formed in different block dimensions were obtained.

A model was formed by using the block dimensions of the 15 m units (Figure

4). Thin deposit features belonging to marl attract attention. Slopes of the layers are recognized. Surface elevation difference changes in the formed solid model can be understood from location forms of the current blocks.

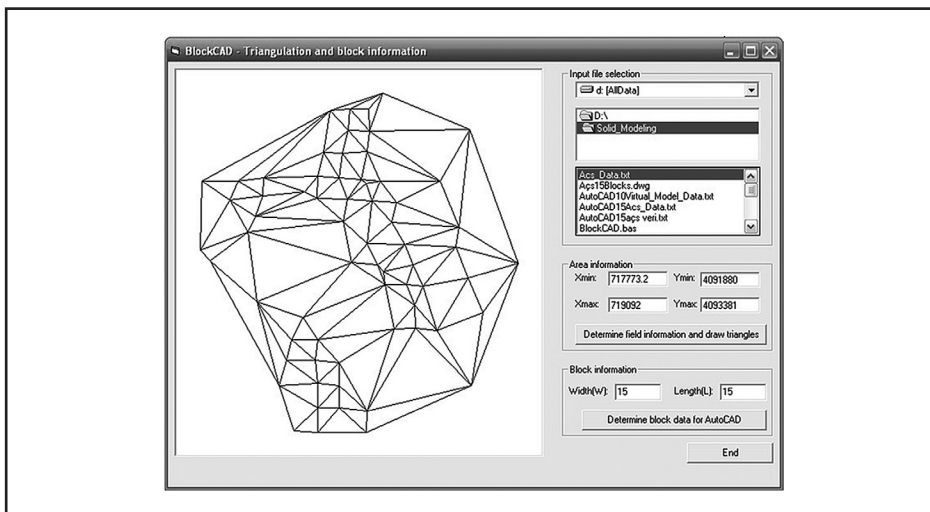


Figure 4  
 Triangulation of sample field and parameters.

Sectioning ease, which is one of the many advantages of the solid model approach, is also discussed there. This advantage becomes more accessible thanks to system tools. But the most sensitive point of the section process is the suitability of location form where the section will be taken. In this sense, the most appropriate section location is the regions where there are more changes. This is the reason for having a field with a variable number of layers and thicknesses. On the figure, N/S and E/W oriented sections can be seen. The aforementioned sections pass from marked lines.

The aforementioned obtained sections that pass from marked lines on Figure 5a are shown in Figure 4b and 4c. Sections show that there is no incorrect placement in terms of current ore location. No rupture was observed in internal parts of the layers.

Three layers observed at the northern end of the section were combined by getting thinner towards the middle sections of the ore body and becoming two layers (Figure 5b). This case reveals one of the advantages of the selected drawing environment and prepared program, as well as the fact that it is frequently encountered. As a result of this case, natural variables were presented by using combined data without loss. The aforementioned variability in the section was encountered in the eastern part of the deposit. As can be seen there, three layers become only one layer by combining (Figure 5c). This point can be made as a detailed image review, as well as a section examination. It can be comparatively complicated at first sight because it consists of smaller units visually, while it is more effective in showing the last model surface changes. By taking

advantage of the used system's simplicity, focusing tools that were made before were used. In this manner, it can be continued in the region marked in red in the investigation of the field's solid model. The field's layers can be seen easily in this section of the reflected model by getting close visions from the region marked in Figure 5a.

In particular, the slope, orientation and intersections of the layers can be selected easily. In the field, three layers and two intercalations attract attention. The first layer has quite thin deposits but just beneath comparatively thicker layers can be observed. Points of current intercalation thickness can be seen close to each other. Layer and intersection thickness can be assessed for investigation in detail. Mass properties of this solid are given in Table 2.

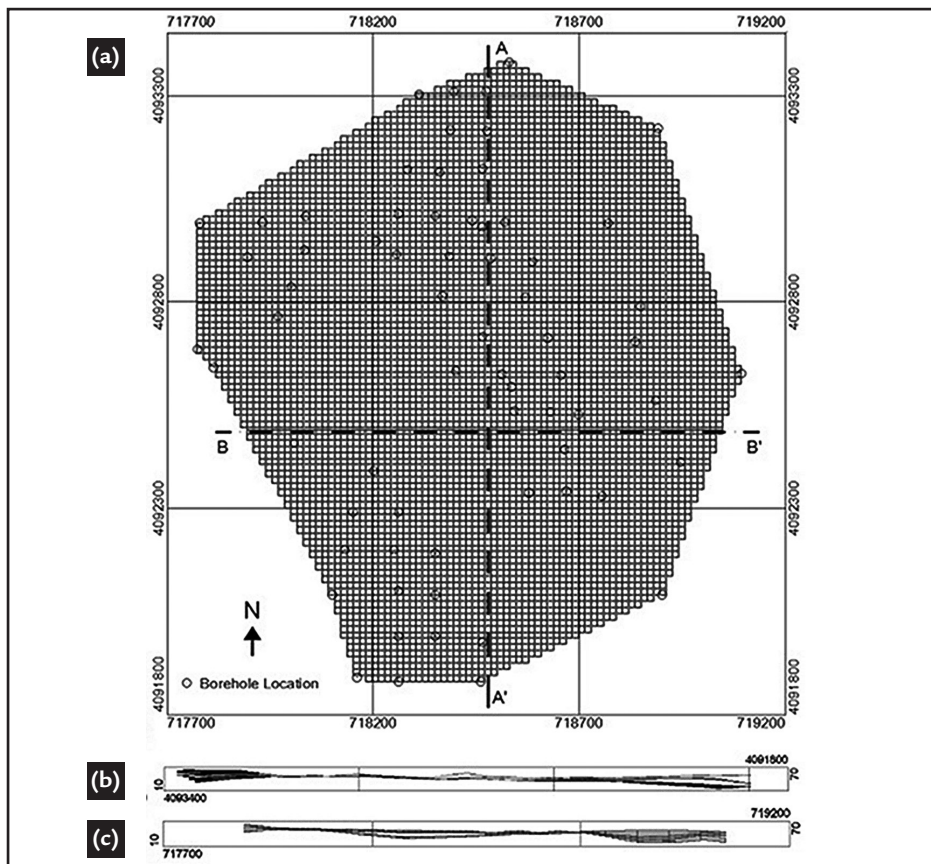


Figure 5  
Obtained models  
of Marl deposit; a) Solid model,  
b) A-A' section c) B-B' section.

		Marl solid model
Volume (m <sup>3</sup> )		17,596,625
Bounding box (m)	X	717773.2 - 719092.0
	Y	4091880.0 - 4093381.0
	Z	-3.517 - 68.4355.0
Centroid: (m)	X	718559.3842
	Y	4092648.3516
	Z	40.4664

Table 2  
Mass properties  
of solid model of Marl deposit.

## 4. Discussion and conclusions

In this study, developed programs intended to obtain the solid model of a deposit in the AutoCAD environment, which is a widely used design program, were developed and all stages of the programs have been explained in detail. Programs were tested in a virtual deposit and sample field and these two fields were modeled with the developed methodology. The sample field was observed with maximum three layers and different numbers of layers were determined from place to place. Layer slopes were monitored easily and presented in detail. The system produces successful results even in a stratified data environment.

Results of the obtained virtual deposit model indicate that the accuracy of the solid model depends on both large numbers and locations of boreholes. A more accurate model can be produced if the location of the borehole selected is on

the border exchange of the surface. Automation of user-defined options can be provided by preparing the procedure for the process that will provide optimization of the aforementioned block dimensions.

The BlockCAD program produces the data file in .txt format and the ability of this file to be used in AutoCAD will only be possible with a SolidBox macro prepared. In this way the process time can be shortened with the program that can be produced by drawing the file in dxf format instead of forming the drawing file with a macro. But forming such a file in dxf format is possible only by comparing thousands of codes to be obtained from the AutoCAD program.

In the program that was the subject of the study, the necessary block data for the solid model were obtained by three dimensional surface modeling only. Apart from this model, block data can also be obtained using geostatistical, inverse

distance, fuzzy logic and other modeling techniques. The package can be developed by adding the geostatistical estimation method as well as block geometry. Solid models are created using different methods in mining software, such as with the aid of two surfaces or cross-sections of ore deposits. In this study, this was created by combining three-dimensional boxes obtained between the surfaces. One of the greatest advantages of our program is that as this solid model was produced from boxes using common commercial software, it can be interpolated with various estimation techniques.

Clearly, some of the propositions that we have offered are not entirely unique but they are simple sample steps to understanding how common geological modeling software works. Furthermore, we feel that our study enhances academic understanding of the programming approaches for solid modeling.

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