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3D Visualization of Geothermal Features

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ABSTRACT

In this study, 3D visualization of temperature distribution in the Kizildere geothermal system and low resistvity distribution in Salavatli geothermal system were built using 3D interpolation and extrapolation techniques. The 3D visualisations are illustrated; cross-sections and 3D volume extractions from the main 3D visualization temperature and resistivity distributions were formed in different locations to illustrate better insight into the field. In addition, using a grid block system, better estimates of stored heat energy and heat volume for power generation from the Kizildere geothermal field and reservoir volume of Salavatli geothermal field were obtained. Moreover, model and measured temperature profiles of some wells are also shown. Furthermore, structural geology of Gonen geothermal field and hydrogeological model of the Balcova geothermal field are shown in 3D illustrations.

1. INTRODUCTION

Actual measurements of the properties of subsurface resources are very scattered and limited to the drilled wells and geophysical surveys. Their properties consist of features such as temperatures, pressures and geology. In addition, these natural properties do not have a normal distribution which complicates the interpretation and can make visualisation difficult. As a result, engineers and scientist sometimes have difficulty in conjecturing subsurface structures. Producing a three dimensional visualisation of these properties and features can help to overcome some of these difficulties. Three dimensional visualizations are not always available due to expensive software, difficulty in their use and require too much effort (Koorey, 2001). Recently, a state of art graphical 3D visualisation interface was also produced to integrate geothermal data base systems (Hochwimmer, et al., 2001).

Pure 3D visualisation only partly solves the problem; consequently, a way of mathematically expressing these properties and features must be found. In this study, 3D temperature and resistivity distributions were built by using initial temperature data obtained from the wells of a liquid dominated geothermal field (Kizildere) and resistivity data from Salavatli geothermal field by using “Inverse Distance” option of the used softwares; and the results are presented as coloured illustrations. Other features of the softwares utilized enabled us to estimate the stored heat energy and reservoir volume in a certain temperature and resistivity range, which is very important information about the resource. On the other hand, subsurface structural features of Gonen geothermal field are also shown in 3D form by using structural option of another software. The aim of the paper is to produce 3D illustrations at lowest cost by using available software and take advantage of their by product results.

2. METHODOLOGY

Two dimensional temperature distributions for geothermal fields had been routinely obtained by using 2D interpolation method of Kriging. As known, temperature distributions can be easily constructed in x-y, y-z and x-z plains in planes for 2D interpolation of Surfer software. However, the relationship between temperature or resistivity data across 3 dimensional is not appropriately presented in 2 dimensional interpolations. Two dimensional interpolations are conducted with the data available on a plane and they are not affected by the existing data outside of selected plane. Therefore, a 3 dimensional interpolation is needed to give a more realistic estimation of any property’s distribution. Two dimensional illustrations (cross-sections) obtained from 3D interpolations are more realistic ones. As a result, 3 dimensional interpolation and extrapolation techniques were used, cross sections have been taken in directions perpendicular to the axis, and cubic volumes were extracted from the main interpolated 3D property’s distribution cube. Property distributions can be presented visually using greyscale or colour options. The use of colour for the display allows the inter-relationships and patterns within the interpolation results to be easily observed, with colour acting like a forth dimension in the visualisations.

“Inverse Distance”, “Kriging” and “Triangulation” methods for interpolation were tested for this study. A comparison of these methods showed that the best results were obtained using the “Inverse Distance” method, which gives more weight to data from wells close to each other, and which have direct measurements. When using the Kriging method, it was difficult to define a 3 dimensional variogram model to present the existing property data, and significant differences were observed among the interpolations done by the accepted variogram model.

In this study, 3 dimensional Inverse Distance interpolation method is used. Hot, warm and cold areas or low and high resistivity areas within a geothermal system are defined by taking cross-sections in different directions from 3 dimensional temperature or resistivity distributions. Although there are similarities between previous 2 dimensional cross-sections produced by using Surfer software and 2 dimensional cross-sections obtained from 3D interpolations, it is believed that, if there are sufficient data in a given volume, 3D interpolation obtained by using Inverse Distance method provides more reliable results compared to those produced by 2D interpolations.

Geological structure can also be drawn as surfaces at boundaries between formations. The stratigraphic information about the boundaries is obtained from drilling logs. Well locations and boundary depths are used to produce surface contours of the formations. 3D drawing of stratigraphic and structural visualisation of the field was prepared by using RockWorks software. The illustrations of the known or conjectured faults are also added.

3. APPLICATIONS

3.1 Kizildere Geothermal Field

In this study, 3D temperature distribution profiles were built by using temperature data obtained from the wells of the Kizildere geothermal field, and the results were presented as coloured illustrations. Other features of the software enable to estimate the stored heat energy and reservoir volume in a certain temperature range. Techplot software was used to obtain 3D temperature distributions.

The temperature profiles of 22 wells were used, which are scattered over an area of about 15 km^2 within the Kizildere geothermal field. The wells are illustrated in Fig. 1. All profiles used the first temperature measurements of the wells, and therefore, a construction of original, or natural, temperature distributions was attempted. Nine of the wells are concentrated in the area, once considered to be main production section. The depths range from 300 m to 2300 m. Three-dimensional interpolations of the above mentioned data carried out by using inverse distance option of Techplot.

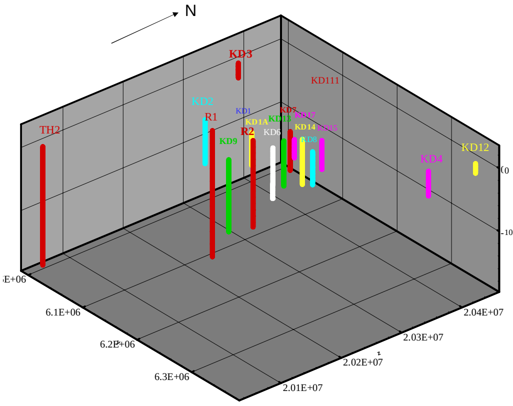

Figure 1: Kizildere well locations.

Figure 2 shows 3D interpolation of temperature distribution for Kizildere geothermal field. This cube can be turned over and can be viewed by any angle. Figure 3 illustrates 3D visualisation after extracting a prism with a depth of -500 m. Fig. 4 shows 3D visualisation with a cube extracted up to 1500 m. Several wells, including R-1, are seen in this figure. It can also be observed that hot water is rising from deeper horizon around the R-1 well where the highest temperature is found.

These observations extend the limits of the Kizildere geothermal field beyond the formerly known boundaries not only areawise, but also depthwise. Figures 5, 6 and 7 show cross-sections taken in N-S and E-W directions and also at different depths, respectively.

To check the validity of the interpolation results, temperature profiles in known points (well locations) are built after the interpolation with the model. Figures 8, 9, 10 and 11 illustrate comparative temperature profiles obtained from model and real measurements in wells KD-3, KD-6, KD-8 and KD-13, respectively. As seen in Fig.'s 9, 10 and 11, the model results match very well the measured results.

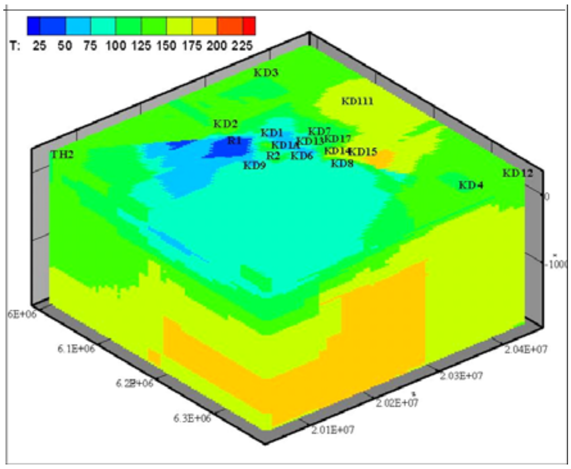

Figure 2: 3D interpolation of temperature distribution for Kizildere geothermal field.

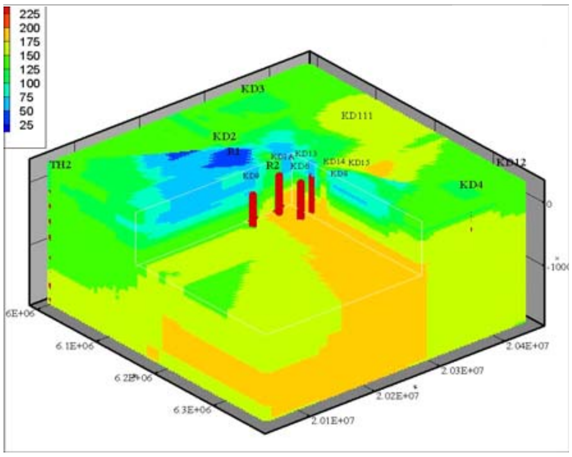

Figure 3: 3D visualisation after extracting a cube from 500 m.

As seen in well KD-3, the measured profile and the model profiles do not match at the upper section. This well is situated north-western part of the field, and it is situated at a topographically high location. At that section of the field not much data are available except for Wells KD-111, KD-4 and KD-12, which are situated at similar, distant, high locations (north eastern part). Techplot software estimates and assigns interpolation results for the grids in this vast area with few data points. As a result, the upper 200 m section of this well does not provide a good match due to insufficient data. Much better matches are obtained for the other wells that are situated in the central area of the field. On the other hand, the grid size selection influences the interpolation results. The smaller becomes the grid size the better matching is obtained. The software assigns interpolated values to the grid corners, and the interpolated value of our selected point assumes the interpolated value of the closest grid corner.

The cube shown in Figure 3 has a volume of approximately 30.2 km^3. By using grid numbers and their assigned temperatures, the stored heat for the indicated volume is calculated as 8.17 E15 kJ, which is in good agreement with the previously calculated value in study of Serpen et al., (2002). The porosity and reference temperature are assumed to be 6% and 50°C, respectively. Assuming a temperature sub limit of 175°C for conventional power generation, the stored heat is computed as 2.9 E14 kJ, and the volume for this temperature range is found as 6.78 km^3.

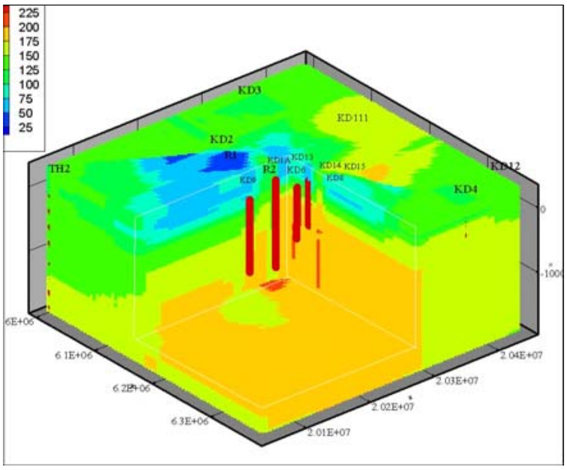

Figure 4: 3D visualisation after extracting a cube from 1500 m.

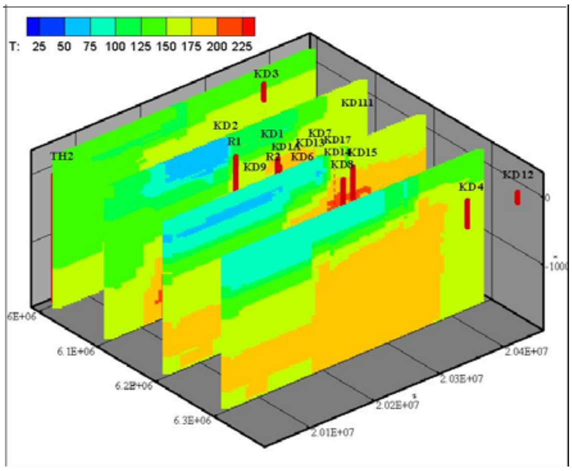

Figure 5: North – south cross-sections of the field

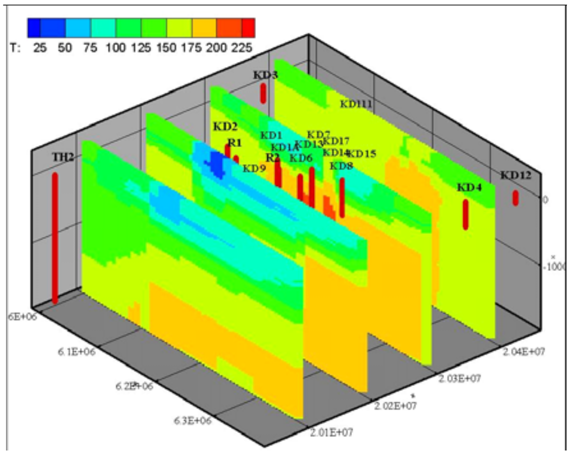

Figure 6: east –west cross-sections of the field

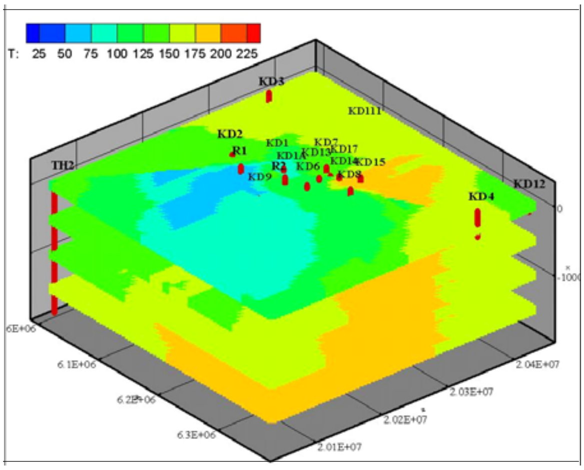

Figure 7: Horizontal cross-sections of the field

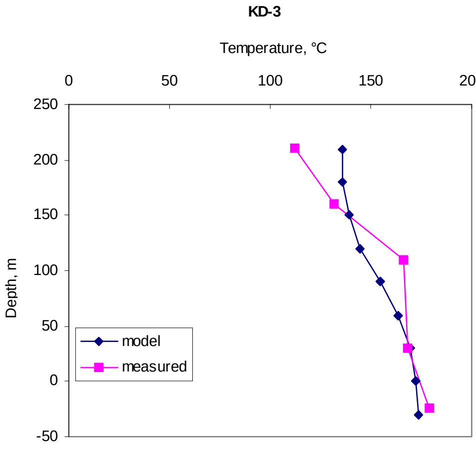

Figure 8: Measured and model temperatures for well KD-3.

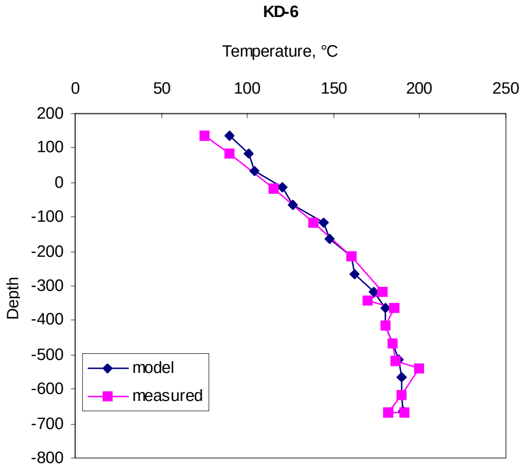

Figure 9: Measured and model temperatures for well KD-6.

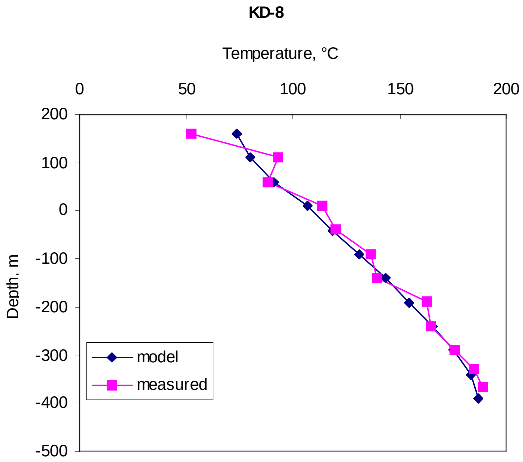

Figure 10: Measured and model temperatures for well KD-8.

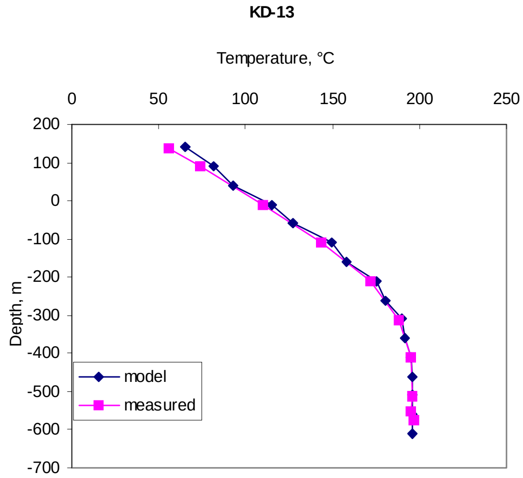

Figure 11: Measured and model temperatures for well KD-13

3.2 Salavatli Geothermal Field

The results of the resistivity survey in the Salavatli geothermal field indicated an unusually large low resistivity anomaly. As resistivity maps indicate, the lowest resistivity anomaly (5 Ωm) apparently begins at 300 m with a small area; it enlarges between 500 m and 700 m interval, it is reduced again at 1000 m depth, and goes on diminishing up to 1700 m. Its location can be observed in the three-dimensional illustration of the distributions of the low apparent resistivities, shown in Fig. 12, 13 and 14. In the B. Menderes geothermal region, 5 Ωm apparent resistivity is very characteristic one that could be directly related to the geothermal occurrences. A low 5 Ωm apparent resistivity volume of 3.5 km^3 was estimated from the 3D apparent resistivity distributions. Similarly, low resistivity volumes, having resistivities between 5-10 Ωm and 10-20 Ωm ranges are estimated as 16.4 km^3 and 54 km^3, respectively. The first 2 wells were drilled in 80'ies within an area with a resistivity range of 5-10 Ωm; and struck permeable zones at the same level, producing geothermal fluids with reasonably high temperatures (~170^{o}C). A third well has recently been drilled in the centre of 5 Ωm anomaly, and it also struck permeable zones with similar temperatures of the 2 previous wells at deeper zones. Drilled wells have validated the fact that the low resistivity anomaly correspond a huge hot thermal anomaly saturated with geothermal fluids.

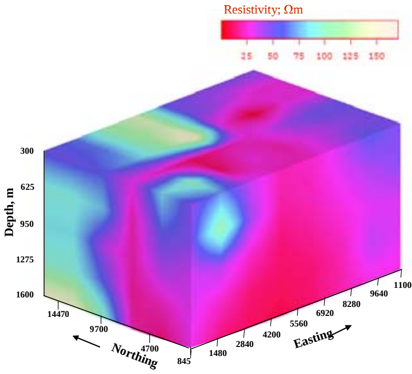

Figure 12: 3D visualization of resistivity distributions of the Salavatli geothermal field.

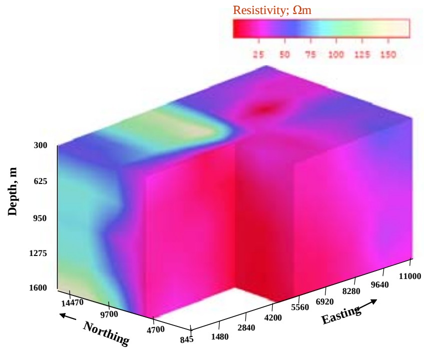

Figure 13: 3D resistivity distribution after extracting a cube in Salavatli field.

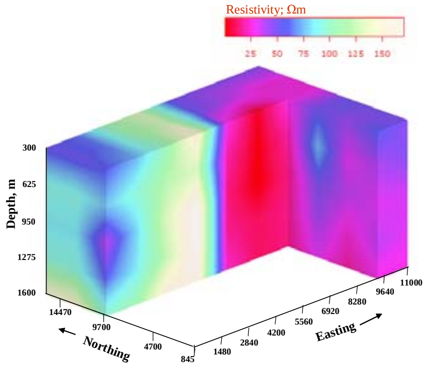

Figure 14: 3D resistivity distribution with deep insight of the Salavatli field

3.3 Gonen Geothermal Field

RockWorks software was used to form stratigraphic model of Gonen geothermal field. Inverse Distance model was used for the interpolations. Drilling logs of the wells display the depth of formation boundaries. As a result, well locations and boundary depths were used to generate formation boundary surfaces. Inferred faults were also illustrated in the Fig. 15. These faults were inferred by the drops of formation surfaces and were confirmed by the faults obtained from the geophysical studies. All indicated faults had also been identified in resistivity study conducted in this field (Ozen, 1995).

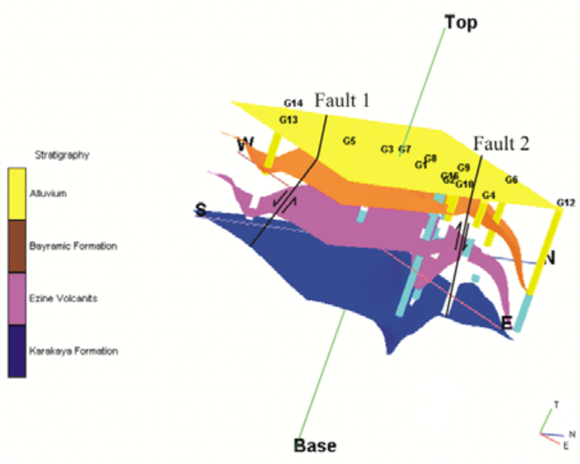

Figure 15: Stratigrahic and structural visualization of Gonen field.

3.4 Balcova Geothermal Field

Three dimensional illustrations are sometimes needed to present conceptual geological and/or hydrogeological models. Fig. 16 was drawn for this purpose, and it shows three dimensional visualization of hydrogeological model of the Balcova geothermal field which is obtained by using Surfer and Corel Draw softwares together. Digitized data were used to generate elevations in Surfer, which is coupled with the subsurface section drawn by Corel Draw.

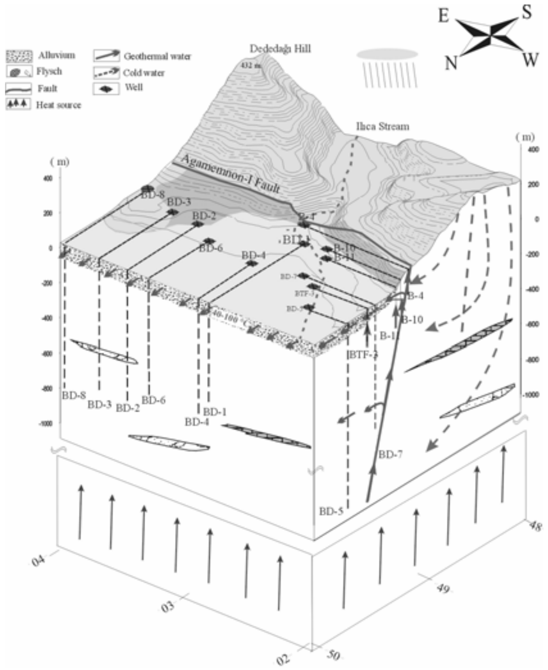

Figure 16: Hydrogeological model of the Balcova geothermal field (Aksoy 2001).

4. DISCUSSION AND CONCLUSION

As seen from the Kizildere geothermal field examples, 3D visualisations can be generated by using 3D interpolation and extrapolation techniques. The advantage of Techplot software is that it both interpolates the data giving information on the locations where no data are available and creates 3D images. Eventually, it provides better results in the interpolation of the data where more information is available.

Extrapolations should be treated with some degree of caution, but a recent similar study on the Balcova geothermal field (Satman et al., 2002) provided an excellent temperature profile match for an exploration well (BD-8) outside the known area. Similarly, promising new areas have been observed for new wells in our study of the Kizildere geothermal field. These areas should be further checked by deep geophysical surveys.

Until now, only deterministic and stochastic estimations of the stored heat energy in the Kizildere geothermal system have been made. For this type of estimations, either deterministic or distributions parameters, such as area, thickness and related temperatures of hot zones have been utilised. More realistic estimates of stored heat energy and their volumes are obtained with the use of Techplot software.

In addition to the geothermal properties, geological features were also presented using the surfer and Corel Draw softwares, and it was possible to produce the 3D visualisation of stratigraphy and structure of the Gonen geothermal field.

In summary, the following conclusions are reached:

- For creating and displaying 3D temperature distributions we use Techplot software. It has advantage of obtaining stored heat of the geothermal reservoirs.

- For creating and displaying 3D resistivity distributions we use RockWorks or Techplot softwares. They provide also resistive boundaries and hence reservoir volume.

- For interpolating structural data RockWorks software is used.

- For creating and displaying geological models Surfer and Corel Draw softwares are used.

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