Visualization in the Subsurface: Oil Field Modeling in 3D

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Abstract *- This research describes engineering graphics techniques used for three dimensional modeling of oil fields. Three dimensional data were obtained by digitizing existing mapping using specific quality control techniques. Using these data, a variety of three dimensional graphic models then were prepared to evaluate engineering graphics techniques for use in subsurface mapping. Graphic products used in this study included wireframe models, vector maps, shaded renderings, filled contour maps, and stacked surface models. Color and illumination were examined, and examples of each type of model investigated are provided.*

I. Introduction

Three dimensional graphic modeling for describing and characterizing an oil field is a typical part of petroleum exploration. Mathematical models developed are based on drilling and seismic data and then used in three dimensional graphics to show subsurface structure. Portraying the oil field model effectively requires extensive expertise in engineering graphics.

Graphic techniques used in oil field modeling include sections, isoline (contour) maps, wireframe and surface models, and block diagrams. Subsurface graphics may employ either isometric or perspective projections, and graphic models are frequently colored, rotated, tilted, and illuminated to emphasize field features. Because formations at different elevations may be included in mapping, it may be necessary to overlay, vertically stack, or combine individual graphic models to display information in the correct relative position.

This research describes the use of graphic modeling techniques for portraying subsurface structure in the Illinois Basin. In this work, existing maps of specific oil fields were digitized and the resulting data were used to prepare a series of graphic products. Specifically, this work was used to address the following questions:

(1) What procedures ensure the quality of data digitized from existing mapping?

(2) What techniques of engineering graphics can be effectively employed to enhance three dimensional modeling of subsurface structures? and

(3) How can existing subsurface mapping be effectively presented in three dimensional format?

II. Previous Work

General subsurface mapping techniques are discussed by a number of authors including Jones, et al. (1986), Barnes and Lisle (2004), Kellie (2009), Kellie, et al. (2007), and Tearpock and Bischke (1991). Mapping of features in the subsurface is unique because the features being mapped are known only indirectly, and then from a sparse data set. Subsurface mapping frequently employs the use of color and pattern omitted from mapping at the surface (Kellie, et al., 2007).

III. Methods and Procedures

This research prepared graphic models of four oil fields in the Illinois Basin for which maps were available in the public domain. The fields selected were intended to include the different subsurface structures typical in the basin, including coral atolls, offshore sandbars, and faulted anticlines. This was important as each of these structures poses specific problems in graphical modeling.

Digitizing and Validation. Work began by manually digitizing existing maps of each field. A CalComp Drawing Board IV digitizing table and Didger software were used to do this (Golden Software, 2001). Tablet calibration was based on the local coordinate system shown on the existing mapping. Data digitized included structural contours, faults, and drill hole (oil well, gas well, and dry hole) locations.

Figure 1 shows digitizing results for a typical oil field (Plummer Field, Greene County, Indiana). Separate graphic layers were used for the structural contours, drill holes (oil wells, gas wells and dry holes), and the area to be blanked in the mathematical model. Data contained on each layer was exported separately in a file format compatible with the software.

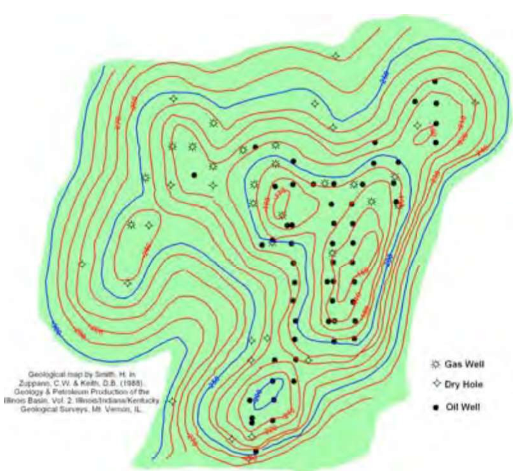

Figure 1. Plummer Field. Digitized line drawing of existing structure and wells. Area to be blanked is outside green tint.

The random x,y,z data resulting from digitizing were gridded using Surfer software (Golden Software, 2002). The gridding algorithm generates elevations on a regular grid from the randomly positioned points obtained from digitizing. Different gridding algorithms generate slightly different elevations, and this is reflected in automated contouring. In this research, the Kriging algorithm was used for gridding three of the fields mapped; data for the fourth field were gridded using the inverse distance squared algorithm. Grid files were blanked in areas for which there was no contour data on the original mapping. The blanking avoided extrapolation of mapping beyond the source data.

As a check on data quality, contours generated from grid data were overlain on the graphic contour files obtained directly from digitizing. Grid data were then edited until contours matched. Grid editing was necessary for quality assurance because grid files form the basis for three dimensional modeling. A good match between contours from digitizing and contours generated from gridded data can be particularly difficult to obtain in areas of widely spaced contours, or where change in contour direction is abrupt. Widely spaced contours and abrupt change in contour direction can result from the sparse data sets employed in subsurface mapping.

Following grid editing, a contour map of each field was prepared and drill hole locations were posted on the map. Since drill hole data were used to prepare the original maps, posting drilling locations enables the map user to evaluate the data density on which interpretation was based.

Figure 2a (Iuka Field, Marion County, Indiana) shows contours prepared directly from digitized data. This is a relatively "clean" data set that resulted from a regular subsurface structure with closely spaced

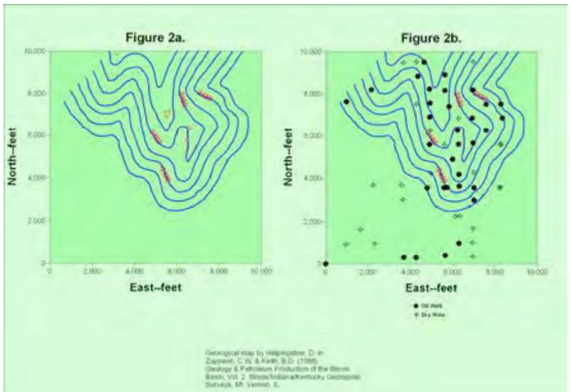

Figure 2. Iuka Field. Original (2a) and edited (2b) grid files.

contours. However, digitizing artifacts are apparent on the -2460 contour and between the -2440 and -2450 contours.

Figure 2b shows contouring based on the edited data set. The coincidence between the digitized contours and those developed for the three dimensional model are now relatively close. The graphical solution and the mathematical model of the field match the original map closely, i.e., the mathematical model is precise.

A precise model still may not be accurate. Accuracy in modeling depends on data density and data quality. In Figure 2b, well locations have been posted on the contour map so that the map user can evaluate map accuracy from the number and location of wells posted.

Three Dimensional Modeling. It was unclear at the beginning of this work which modeling techniques would best show subsurface characteristics. The fields mapped had varying orientation, elevation range, area, and subsurface expression, and they represented different topographic features. It was hypothesized that specific field characteristics might influence the graphic techniques need for effective modeling.

The use of wireframe techniques for modeling was investigated at Iuka Field as shown in Figure 3. This field has an area of approximately two square miles, and elevations range from -2440 to -2500 feet. The wireframe models used in three dimensional mapping at this field were drawn with perspective projection, 45 degrees of rotation, and 30 degrees of tilt.

Figure 3a is a wireframe model that shows elevation by use of standard color coding (blue though red hues as shown). A color scale facilitates matching of color and elevation.

Figure 3b uses a shaded contour map draped over the wireframe model. The shaded contours employed indicate elevation qualitatively by changes in color value and quantitatively by labeled contours. From a graphics perspective, varying color value traditionally has been preferred to varying hue. In Figure 3b, varying the value to show elevation enables use of a brown hue that matches the color of the rock being modeled.

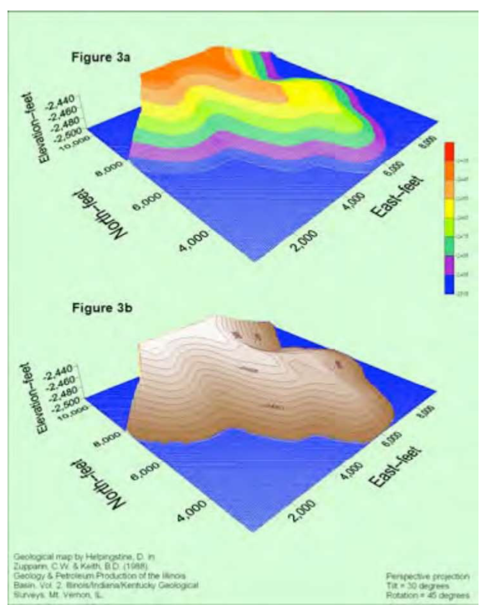

Figure 3. Iuka Field. Wire frame model with color zones (3a) and draped with shaded contour map (3b).

The use of a surface model and vector map for subsurface mapping was investigated at Plummer Field as shown in figure 4. This field has an area of approximately eight square miles, and elevations range from -300 to -170 feet.

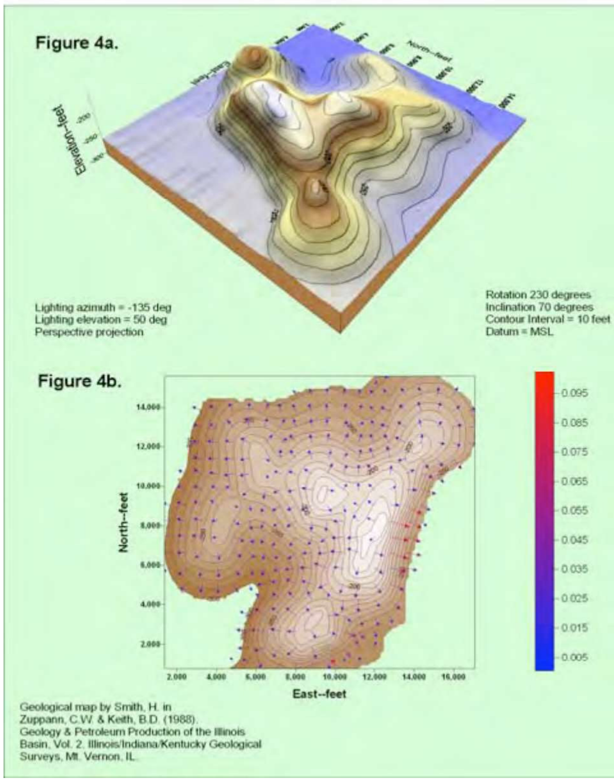

Figure 4. Plummer Field. Draped surface model (figure 4a) and vector map (figure 4b).

Graphically, the surface models used in this research are three-dimensional shaded renderings of a grid file (Surfer, 2002). Use of the surface model enables the drafter to employ lighting that can be varied in orientation and elevation.

The surface model of the Plummer field shown in figure 4a employs perspective projection, is rotated 230 degrees, and is tilted 70 degrees. Lighting is at -135 degrees (southwest quadrant) and at an elevation of 50 degrees. The surface model is draped with a contour map, but the contours were not filled. This enables the model surface to be seen while adding the additional component of the contours.

Examination of the three dimensional model of the Plummer Field showed the east and south sides to be steeper than the west and north sides. This was of interest geologically, and so a vector map was prepared to quantify slope. This is shown in figure 4b. Vectors shown in 4b are oriented perpendicular to maximum slope and the graphic symbols used are scaled to reflect the steepness of the slope.

The use of a surface model for three dimensional mapping also was applied at the Wilfred Field (Sullivan County, Indiana) as shown in figure 5. This field has an area of approximately 1.5 square miles, and elevations range from -1575 to -1370 feet.

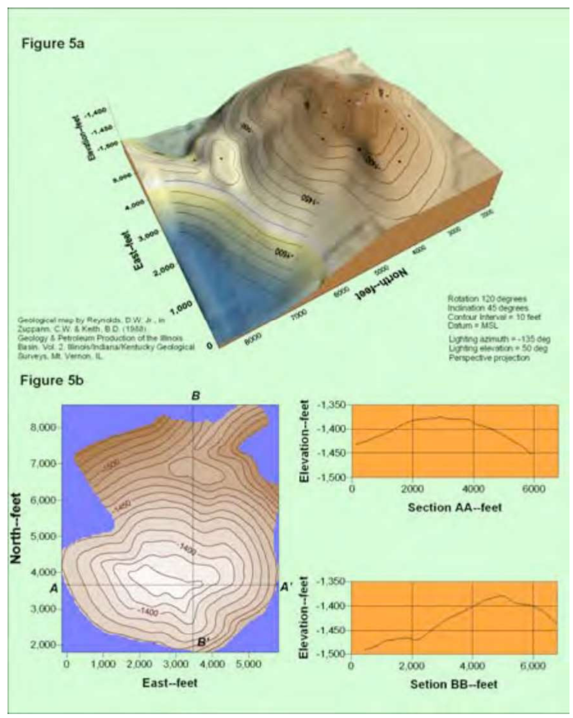

Figure 5. Wilfred Field. Contour draped surface model with posted wells (figure 5a) and contour map with sections (figure 5b).

The three dimensional surface model prepared for Wilfred incorporated a draped contour map and used perspective projection. Rotation was 120 degrees, and tilt of was 45 degrees. Lighting was at -135 degrees (southwest quadrant) and at an elevation of 50 degrees. Unlike the mapping for the other fields, well locations were posted on the surface as shown in figure 5a. This was because of a very uneven distribution of data points on which to base mapping.

To contrast the three dimensional model of Wilfred with traditional mapping, a contour map and two sections were prepared as shown in figure 5b. With the exception of the posted well locations, data shown by the contours and sections are comparable to the three dimensional model.

The effect of a faulted surface on mapping and the use of a stacked surface model were investigated on the Smith Mills North and Geneva combined fields (Henderson County, Kentucky; hereinafter referred to as Smith Mills North). These fields have a combined area of 22 square miles and are separated by a fault having vertical displacement of 120 feet.

To investigate the use of stacked, 3D surface models, modeling was done for the top of the Barlow limestone (elevation -2030 to -1810 feet), Vienna limestone (elevation -1620 to -1440 feet), and West Kentucky No. 9 coal (elevation -90 to +60 feet). Because multiple surfaces were included in the mapping, it was necessary to separately digitize, grid, and edit each of the surfaces involved.

Faulting made it necessary to use the inverse distance gridding algorithm to enable blanking of the grid file along the fault. As a result, contours generated from the gridded data end at the fault. Extensive editing of grid files was necessary because of the flat areas within the oil field.

Modeling at Smith Mills North began with a contour draped surface model for the Barlow limestone. Oil well and dry hole locations were posted on the model. Perspective projection was used, rotation was 15 degrees, and tilt was 35 degrees. Lighting was at -135 degrees (southwest quadrant) and at an elevation of 50 degrees as shown in figure 6a.

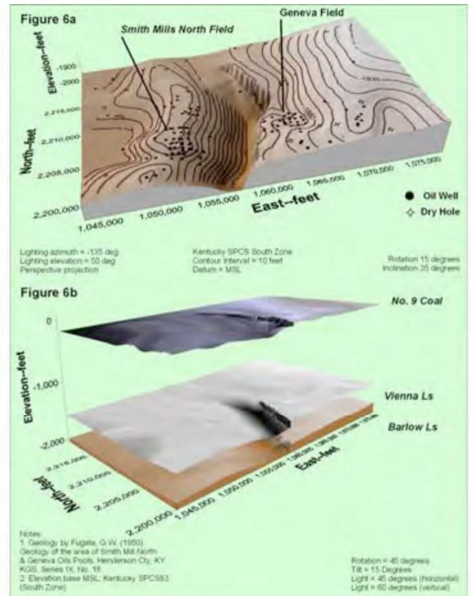

Figure 6. Smith Mills North Field. Contour draped surface model (figure 6a) and stacked surface models showing the Barlow and Vienna limestones and number 9 coal (figure 6b).

Because multiple surfaces describe this field, a stacked surface model was prepared next to show the relationship between the surfaces mapped. The stacked surface model used perspective projection, a rotation of 45 degrees, and tilt of 15 degrees. Illumination was selected to emphasize faulting and used an orientation of 45 degrees (northeast quadrant) and an elevation of 60 degrees. The stacked model is shown in figure 6b.

IV. Results and Conclusions

Results from the mapping described above provide answers to the questions posed at the beginning of this paper. These are discussed specifically, below.

Quality Control. The first question posed was, "What procedures ensure the quality of data digitized from existing mapping?" This research suggests two procedures. First, use direct comparison of the contour map generated from the gridded model with the graphic file for the digitized contours. This quickly identifies areas needing revision or editing. Edit the grid file and/or perform additional digitizing until the two sets of contours coincide. This procedure is simply the geometrical technique of showing congruence by figure overlay; it was used for all digitizing and gridding in the project.

Second, post drilling locations on project mapping. This shows the density of drilling on which interpretation is based. This is important for quality control because sparse data may indicate uncertain interpretation that will not be improved by advanced techniques of graphical presentation.

Graphical Techniques. The second question posed in this research was, "What techniques of engineering graphics can be effectively employed to enhance three dimensional modeling of subsurface structures?" This research suggested two methods. First, use three dimensional graphics to produce images that are useful to both the technical and non-technical user. For example, the arcuate, atoll-like structure of the Plummer and Wilfred Fields as well as the humped, elongated structure of the Iuka and Smith Mills North fields are apparent on the original, 2D mapping. But this is true only if the observer understands topographic mapping conventions and recognizes the graphic signatures of the structures involved. To even a non-technical user, however, a three dimensional, low relief structure having a light brown shading set on a blue base looks strikingly like a coral atoll (if arcuate) or offshore sandbar (if elongated). One function of engineering graphics is to communicate information. This communication is enhanced when the graphic products are developed for the people using the information rather than solely for the technical community.

Second, use careful color selection to enhance interpretation and understanding. This can be done by use of natural colors to mimic reality. In interpretation, the color of individual rock units is suggestive, and specific hues are associated with specific rocks. This means that color selection must be thoughtfully and realistically applied, perhaps by reference to the color of surface exposures of the rock units being mapped in the subsurface.

In addition to color, structural perception appears to be enhanced by shading and illumination. Use shading and illumination to clearly show the existence of a fault or the steepness of a surface.

Effective Presentation. The third question posed by this research was, "How can existing subsurface mapping be effectively presented in three dimensional format?" This research suggests two techniques. First, rotate and incline the surfaces modeled to provide different ways of viewing data than are possible with a 2D map. In preparing reports and presentations, use available engineering graphics tools to show 3D surfaces in a variety of attitudes.

Second, use the full range of graphics techniques available for mapping; do not constrain subsurface mapping to simple automation of traditional plan and section views. For example, the use of vector mapping, as done in this research for the Plummer Field, can assist in distinguishing offshore and onshore sides of the structures mapped. Similarly, the stacked model of mapped surfaces, as done in this research for the Smith Mills North Field, graphically shows relative vertical position.

In conclusion, the ability of engineering graphics to display, quantify, and summarize is of significant value in subsurface mapping provided that the techniques available are intelligently used. Graphics that are accurate, realistic, and complete aid interpretation and understanding and provide the best return available on the data investment.

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