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Hard Copy to Digital Transfer: 3D Models that Match 2D Maps

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Abstract

This research describes technical drawing techniques applied in a project involving digitizing of existing hard copy subsurface mapping for the preparation of three dimensional graphic and mathematical models. The intent of this research was to identify work flows that would support the project, ensure the accuracy of the digital data obtained, and provide a means of capturing, realizing, and extending the value of an existing investment in subsurface mapping. Mapping used in this project was in hard copy format. Control points for use in digitizing were converted from local coordinates to plane coordinates based on a defined map projection. Since mapping done in this work was to meet National Map Accuracy Standards, calculation of acceptable root mean square digitizing error was necessary and is demonstrated. Two methods are discussed to ensure quality control in digitizing. Preparation of base maps showing drilling data provides a means of estimating map *accuracy*. Map *precision*, however, is shown by comparing the congruence of contours as digitized and contours as obtained from the digital model. Where congruence is lacking, the digitizing of supplemental contours or direct editing of the grid itself is required to precisely constrain the 3D model. Efficient work in this project was heavily dependent on use of standard techniques of engineering graphics. To expedite digitizing, a common layering scheme was developed for all oil fields mapped. Control points used in digitizing were selected so as to be common to all mapping, even where multiple maps were involved. In addition, the use of a common map format, color scheme, lettering style, and included metadata materially expedited the work. Finally, the conduct of the work in defined stages provided immediate work products from the project. This facilitated identification of needed changes early in the project and supplied accurate data as soon as digitizing on a specific field was complete.

Introduction

Manual digitizing is a common task for any engineering graphics application where three dimensional (3D) models must be generated from existing hard-copy mapping. The use of digitizing is particularly appropriate where significant interpretative effort was necessary to develop the initial map. This would be so, for example, in the interpretation of subsurface structures from drilling logs used in energy exploration. Conceptually, there would seem to be little difficulty in digitizing; the drafter generates a set of x, y, z coordinates from either a scanned image or from a paper map affixed to a digitizing table. The set of coordinates so generated is then used for 3D modeling of the surface of interest.

Despite this conceptual simplicity, anyone who has digitized will readily attest to the difficulty of obtaining a mathematical model that closely matches the original image or map. Triaxial coordinates resulting from digitizing may produce questionable surfaces, innovative shapes, and spurious artifacts. Such results are especially frustrating when

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project planning assumes high production from digitizing and anticipates seamless data transfer into modeling. Further, because digitizing is the initial phase in much work, the project schedule can be immediately impacted when digitizing fails to proceed as planned.

A series of recent projects involving hard-copy-to-digital conversion of existing maps of oil and gas fields in the Illinois Basin provided an opportunity to study work flows, quality control methods, and engineering graphics techniques for manual tablet digitizing. The digitizing involved was designed to support the development of 3D models. Technically, digitizing and modeling in the subsurface must reflect the control on the model of faults within the structures mapped. This is because faults impact both digitizing itself and the model generated from the digital data set. Specifically, the following questions were addressed in this research:

(1) How can a common plane coordinate system be employed to facilitate large scale engineering mapping and yet provide for the use of specific map projections for small scale mapping?
(2) What techniques during digitizing are necessary to ensure an accurate data set? and
(3) How can faulting be accommodated during mapping and modeling?

Background

As noted by Bitters (2009), the use of existing information sources—including the digitizing of hard-copy mapping—is a common method of geospatial database development. Despite the availability of spatial data in the public domain, Lo and Yeung (2007) note that for much work in-house digitizing of existing maps continues to be an important part of system development, particularly where mapping is company-owned and proprietary.

Manual digitizing can be done using a digitizing table, or the image to be digitized can be scanned and then displayed and digitized on a computer screen. In either case, the map being digitized must be calibrated to known control points. Lo and Yeung (2007) describe the calibration process as a mathematical transformation that relates map to digitizer coordinates. Demers (2005) notes that digitizing software typically computes and displays calibration precision using the root-mean-square (RMS) error.

The numeric data resulting from digitizing are a marketable commodity. Large scale mapping for engineering purposes is distinctly different from the small or medium scale mapping available in the public domain. Prior to digitizing, industrial map products must be georeferenced to a defined map projection, plane coordinate system, and vertical datum. During digitizing Demers (2005) suggests use of a clear order for features to be digitized to ensure that omissions (and subsequent editing) are minimized. He also suggests using a defined list of attribute names to facilitate later data sorting. The importance of the projection, coordinate system, and vertical datum to later data users

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is recognized by Krygier and Wood (2005), who state that the drafter should include these in map metadata.

Digitizing hard-copy maps is a labor intensive and expensive process (Longley et al., 1999). Bitters (2009) states that the features and level of detail digitized depend not only on the level of detail resolvable, but on economics as well. Demers (2005) suggests that data digitized be limited to that necessary to the goals of the work being done, while Kellie (2010) notes that hard-copy-to-digital conversion provides additional return on investment by facilitating further use of existing mapping.

The labor intensive nature of digitizing makes it necessary to consider both methods of reducing the amount of digitizing and techniques for ensuring digitizing accuracy. Lo and Yeung (2007) prefer the use of point digitizing rather than data streaming because point digitizing enables the operator to select specific points to digitize, resulting in a smaller point set. Walsh and Brown (1992) discuss techniques for evaluating digitizing accuracy including (a) redigitizing, (b) use of a map overlay, and (c) volume computation using different algorithms. Kellie (2009; 2010) applied the graphic overlay technique—which he termed the congruence method—to subsurface mapping as a means of ensuring digitizing accuracy.

Faulting is a special problem that influences three dimensional modeling in the subsurface. Faulting controls the location of digitized contours and must itself be included in the data set produced. Kellie (2009) described the impact of faulting on digitizing and subsequent 3D modeling done on two Kentucky oil fields where structural contours being digitized terminated at the fault. The fault itself was digitized and used to blank cells in the 3D model prior to data gridding. The result was that structural contours were not extrapolated across the fault, and structure was modeled correctly.

Study Areas

Based on the above work, research was undertaken to address the three questions posed at the beginning of this paper. To do this, existing mapping was digitized for the Poole, Hanson, and Midland fields in the Illinois Basin of Kentucky. The outcome of this work for each study area included both the graphical result of the physical digitizing and a data file with a set of x,y,z coordinates that mathematically defined the surface mapped.

Coordinate Systems

The source maps used in this project were based on the Carter coordinate system used by the Kentucky Geological Survey (KGS) to archive oil and gas data. Vertical positions were defined by use of mean sea level (MSL), which usually referred to the National Geodetic Vertical Datum of 1929. The Carter coordinate system uses a number-letter-number system to specify location to a 1x1 minute grid; positions within each grid then are designated by the distances from the north (or south) and east (or west) grid lines

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(Nuttall, 2009). For example, a drilling location might be specified as 1000 FNL x 2000 FEL 3-G-38. This translates to "1000 feet from the north line by 2000 feet from the east line of 1 minute grid 3 in row G column 38". The Carter coordinate system mixes geodetic coordinates (latitude and longitude) and plane coordinates (distance in feet). This makes coordinate conversion necessary if a set of points is to be defined by a set of unique x,y,z coordinates.

In this research, all mapping was digitized using the Kentucky State Plane Coordinate System (SPCS), South Zone. To do this, Carter coordinates for a minimum of four control points on the each original map were expressed as x, y coordinates of the Kentucky SPCS using the Coordinate Conversion Tool of the Kentucky Geologic Survey (KGS) (KGS 2010; NGS, 2009).

All digitizing in this project was done using a Calcomp digitizing table and Didger software (Golden Software, 2001). The table was calibrated to each map so that digitized points represent real-world positions. Following calibration point digitizing, the Didger software displays the root mean square (RMS) error of the calibration.

The source maps used in this work were of unknown accuracy. Resulting map products were prepared to National Map Accuracy Standards (NMAS) (Ghilani & Wolf, 2008). These require that for map scales larger than 1:20,000 not more than 10 percent of points tested shall be in error by more than 1/30 inch at map scale. For maps smaller than 1:20,000 the limit of horizontal error is 1/50 inch at map scale. Then, mathematically,

$$E_{90} = E_{68} \cdot C_{90} \quad \text{……………………………………………….(1)}$$

where E_{90} = error at 90% confidence interval; E_{68} = RMS error; and C_{90} = 1.6449 the factor yielding 90% of the area under the normal distribution curve.

For example, the map of Poole Consolidated Field is at a scale of 1:12,000 (1 inch = 1000 feet). Then

$$E_{90} = 1{,}000 \cdot \left[\frac{1}{30}\right] = 33 \text{ feet} \quad \text{……………………………………..(2)}$$

$$E_{68} = \frac{33}{1.6449} = 20 \text{ feet} \quad \text{………………………………………….(3)}$$

For Poole, calibration was considered successful if RMS calibration error was less than 20 feet. There was little difficulty in obtaining the required calibration error; when RMS error exceeded that as computed above, the reason was usually a mistake in coordinate entry rather than digitizing problems. From an engineering graphics standpoint, if the

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RMS error in calibration is acceptable, data and graphics resulting will have correct position, orientation, and scale.

Quality Control for Digitizing

The first map digitized showed structural contours mapped at the Poole Consolidated Field, Webster County, Kentucky. Original field mapping was by Cowan (1988) at a scale of 1:12,000. For model calibration, Carter coordinates for four points on the map were converted to Kentucky SPCS positions as described above.

Standard graphic layers were created for (a) structural contours, (b) gas wells, (c) oil wells, (d) dry holes, (e) a mask, (f) a background, and (g) text. A supplemental contour layer was added following data export and a check of contour congruence. Experience in this project strongly reinforced the importance of using standard layers during data capture. This not only organizes digitized data, but minimizes editing of multiple data sets. Graphic results from digitizing are shown in figure 1.

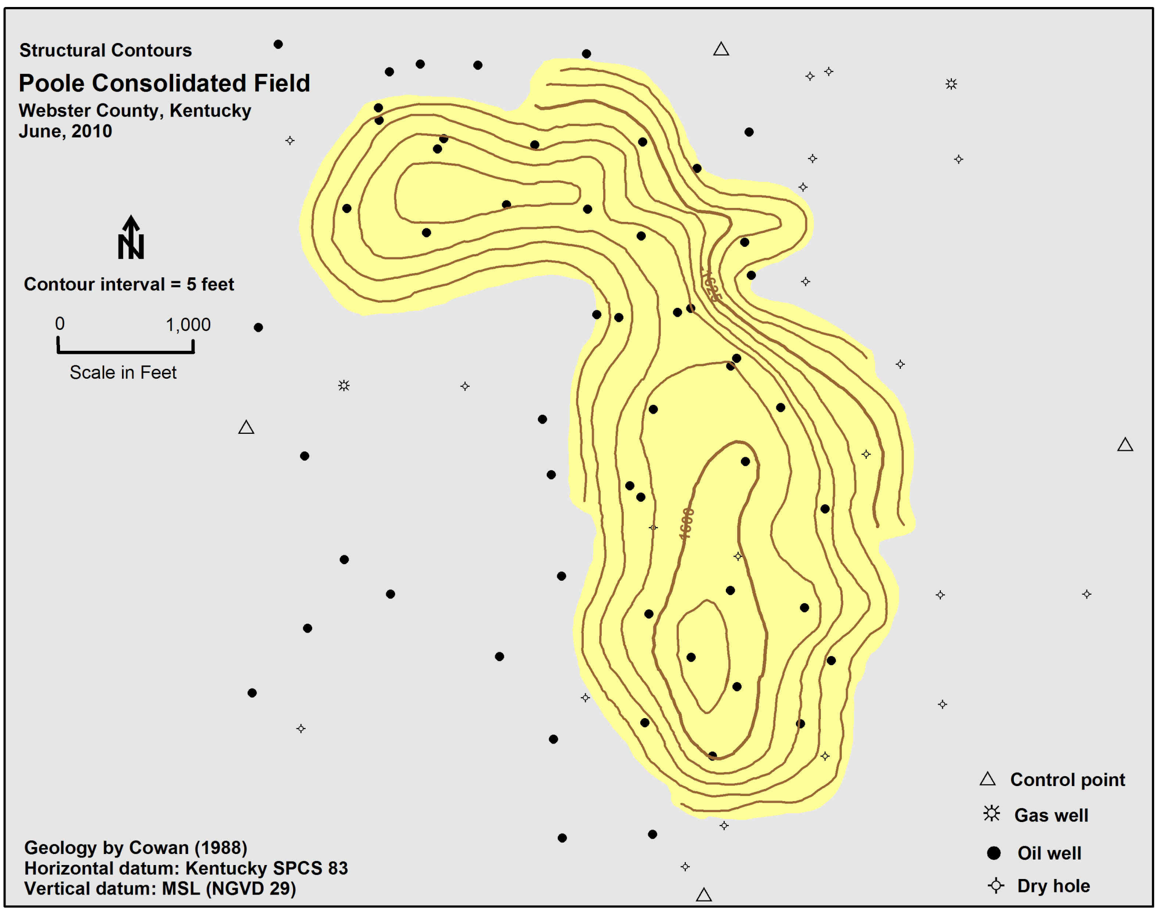

Figure 1. Results of digitizing at Poole Consolidated Field. Drilling data shown indicates extent and distribution of data used for contouring.

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After digitizing, structural contour data was exported to Surfer (Golden Software, 2002) mapping software as both coordinate (x,y,z) and graphics files. The coordinate data were gridded using the minimum curvature algorithm. The mask layer was used to blank gridded data outside the area mapped, and a structural contour map based on the gridded data was prepared.

Initial digitized data frequently result in artifacts that present as mislocated contours. This can be rectified by constraining gridding with additional data. To do this, a supplemental contour layer was created, and supplemental contours were digitizing. Original and supplemental elevations were then output as a data file, regridded, and plotted as a new contour map. The original graphic file was overlain once again to check congruence. The final result for Poole is shown in figure 2.

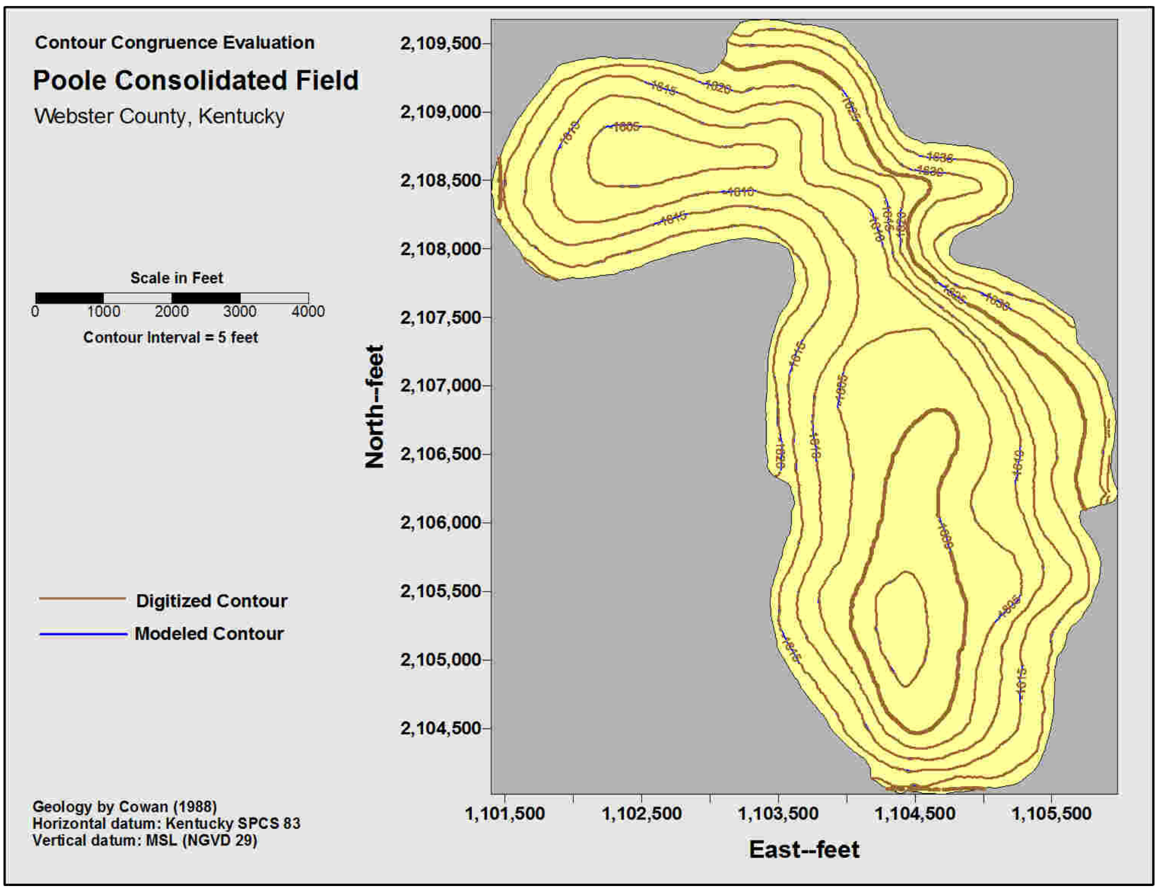

Figure 2. Results of digitizing, gridding, contouring, and editing for Poole Consolidated Field. Digitized and modeled contours are congruent, indicating a correct mathematical model.

The work above uses two quality control checks. First, *precision* of contouring was measured by the congruence of modeled and graphic contours. Second, map *accuracy* was evaluated by posting well locations on contour map. Because drilling was the basis

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for contouring, the density and distribution of drilling controls the amount of interpretation used in contouring.

The maps in figures 1 and 2 originally were intended as in-house map products, designed to be printed in C size format. Both are check maps. Figure 1 shows the location and extent of features digitized. By showing drilling, it helps the map user evaluate map accuracy. Figure 2 checks the precision of contouring by showing congruence of the digitized and modeled contours.

When the maps used for figures 1 and 2 were modified for use in this paper the standard title block was removed and replaced with the map title and purpose shown in at the upper left of each figure. A light gray background for the entire drawing and a pastel background for the map proper were selected to minimize eye fatigue. Lab standard color coding is used for digitized and modeled contours; industrial standard symbols are used for gas wells, oil wells, and dry holes. All lettering in this research uses an Arial (sans serif) font. A sans serif font was selected to avoid lost detail due to map reduction and screen resolution issues. Map metadata are included on each map.

A coordinate grid is not shown on figure 1 to limit clutter. Structural contours in figure 1 follow the convention of using a heavy line and label for index contours. A lighter, unlabeled line was used for intermediate contours. In Figure 2, every contour line is labeled with an elevation to facilitate editing. Drilling locations are not shown, having already been presented in figure 1.

The second set of maps digitized showed structural contours and isopachs (thickness contours) of the Tar Springs Sandstone at Hanson Field, Hopkins County, Kentucky. Here two different maps had to be overlain. The field itself and the area of the Tar Springs Sandstone (the principal petroleum reservoir) are shown in figure 3.

For model calibration, Carter coordinates for five points control points were converted to Kentucky State Plane Coordinates (1983) as described above. Control points were selected so that they could be used for both maps. Structural contour digitizing was generally unremarkable. Isopachs, however, had relatively wide spacing and required supplemental digitizing to constrain the mathematical model. Isopachs for Hanson Field are shown in figure 4.

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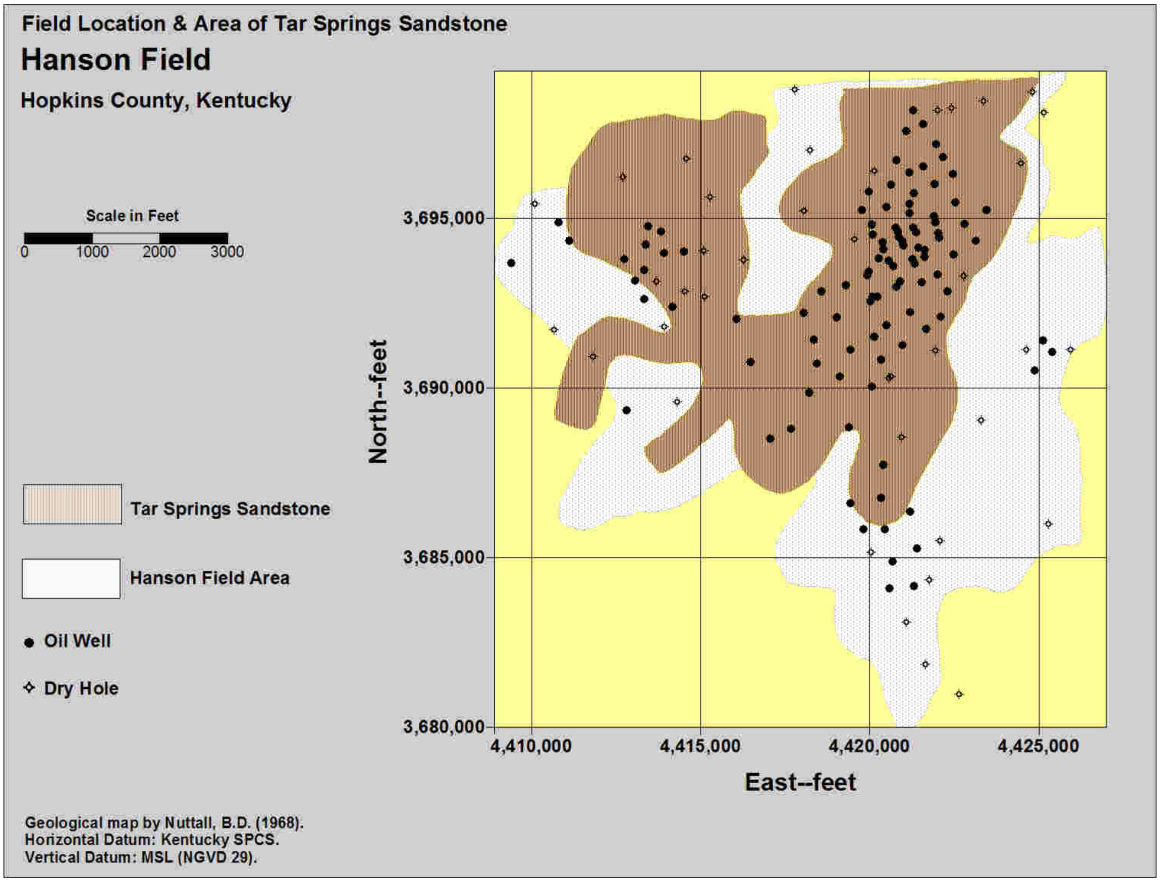

Figure 3. Hanson Field, showing total area and area of Tar Springs Sandstone reservoir.

Figure 3, which was prepared in Surfer (Golden Software, 2001), overlays the structural contour, isopach, oil well, and dry hole layers generated from digitizing. Field extent is shown with a light pattern on a pastel background. The area of the Tar Springs Sandstone Reservoir is shown using a significantly darker pattern. Colors represent those of the natural rock.

Figure 4, also prepared in Surfer (Golden Software, 2001), overlays graphic isopachs from digitizing with isopachs generated from the gridded data. Significant digitizing of supplemental contours was needed to obtain the congruence shown.

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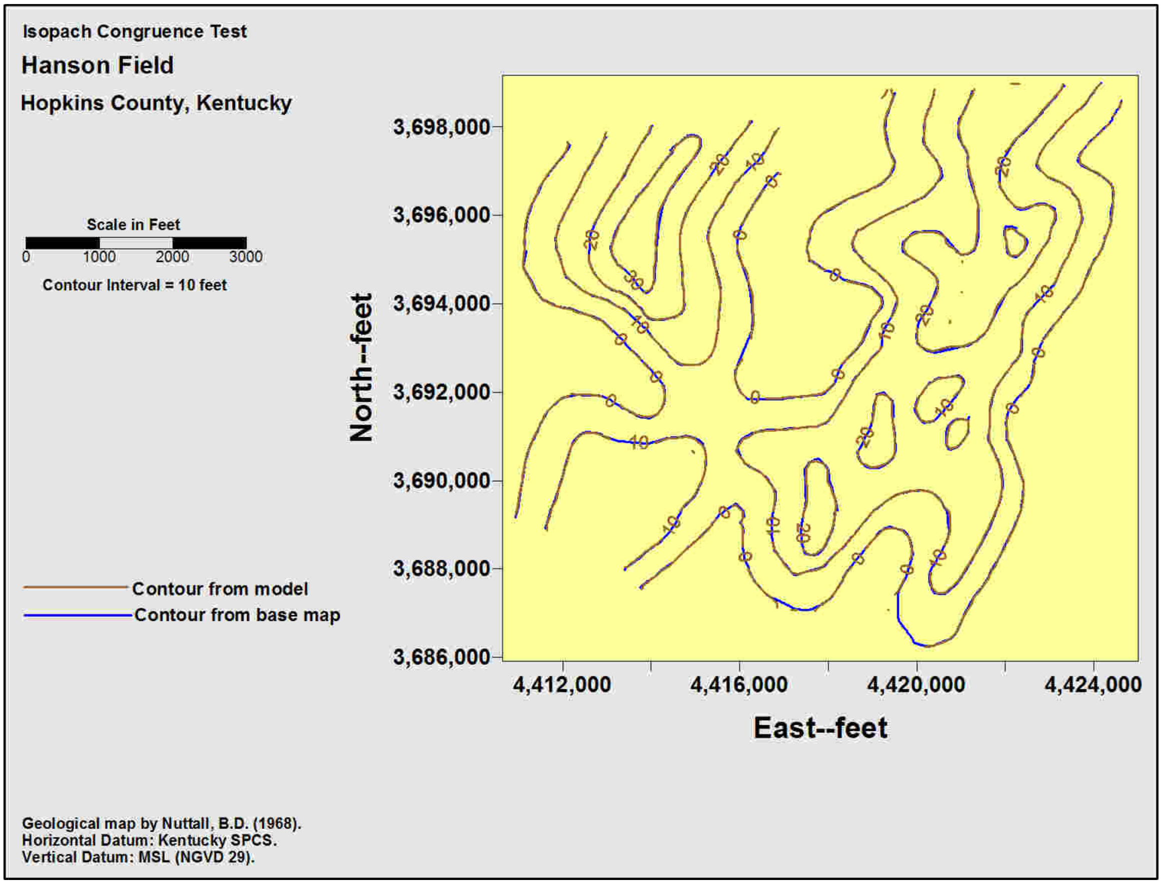

Figure 4. Isopachs of the Tar Springs Sandstone, Hanson Field, Hopkins County, Kentucky.

The final study area used in this research was the Midland Field, Hopkins County, Kentucky. This field was selected because it has faults that control structural contouring. Structural contours obtained from digitizing are shown in figure 5.

As figure 5 shows, mapping at Midland Field was based on drilling that had very irregular distribution. Contours are not continuous across the fault located in the center of the field, and contours terminate at the fault located in the southeast quadrant. During digitizing, a mask file was prepared to blank gridded data outside field boundaries. Fault lines were digitized and used to blank the grid cells along each fault. The blanked cells cause contours to terminate along the fault.

The congruence evaluation for Midland is shown in figure 6. This shows minor artifacts to be edited, but most of the contouring (including that along the faults) is congruent.

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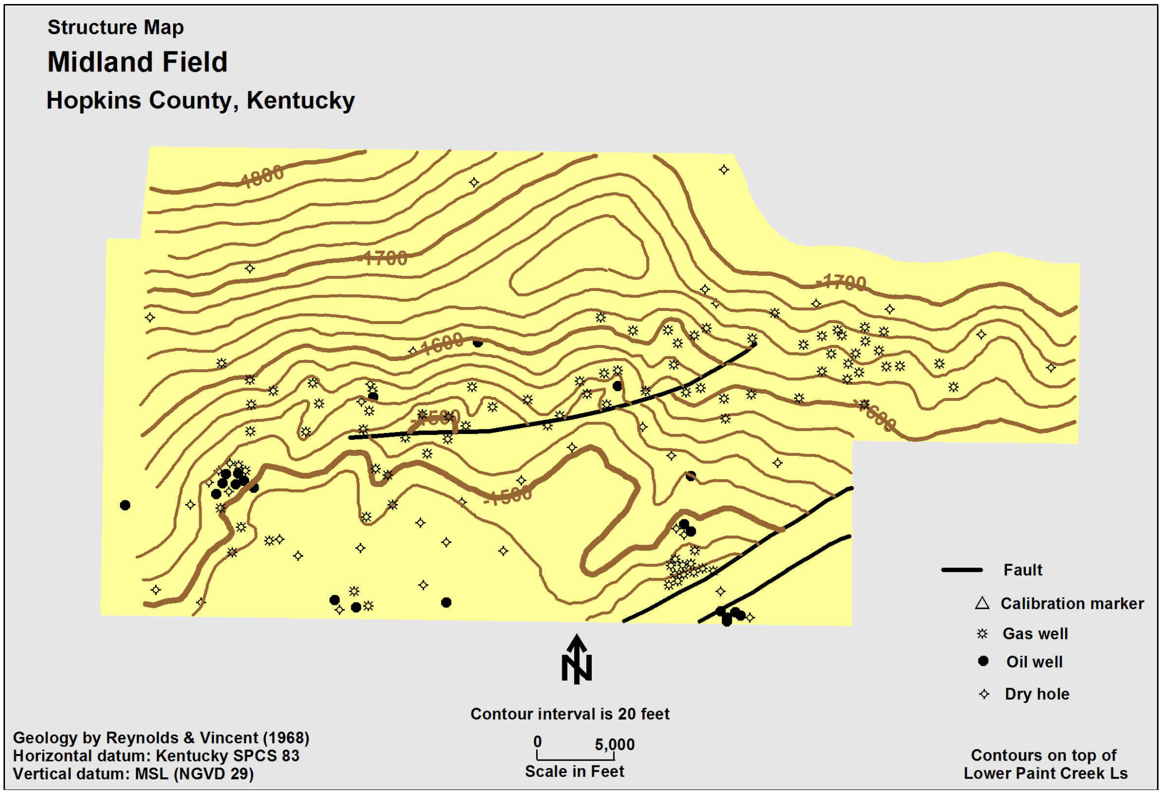

Figure 5. Structural contours at Midland Field, Hopkins County, Kentucky.

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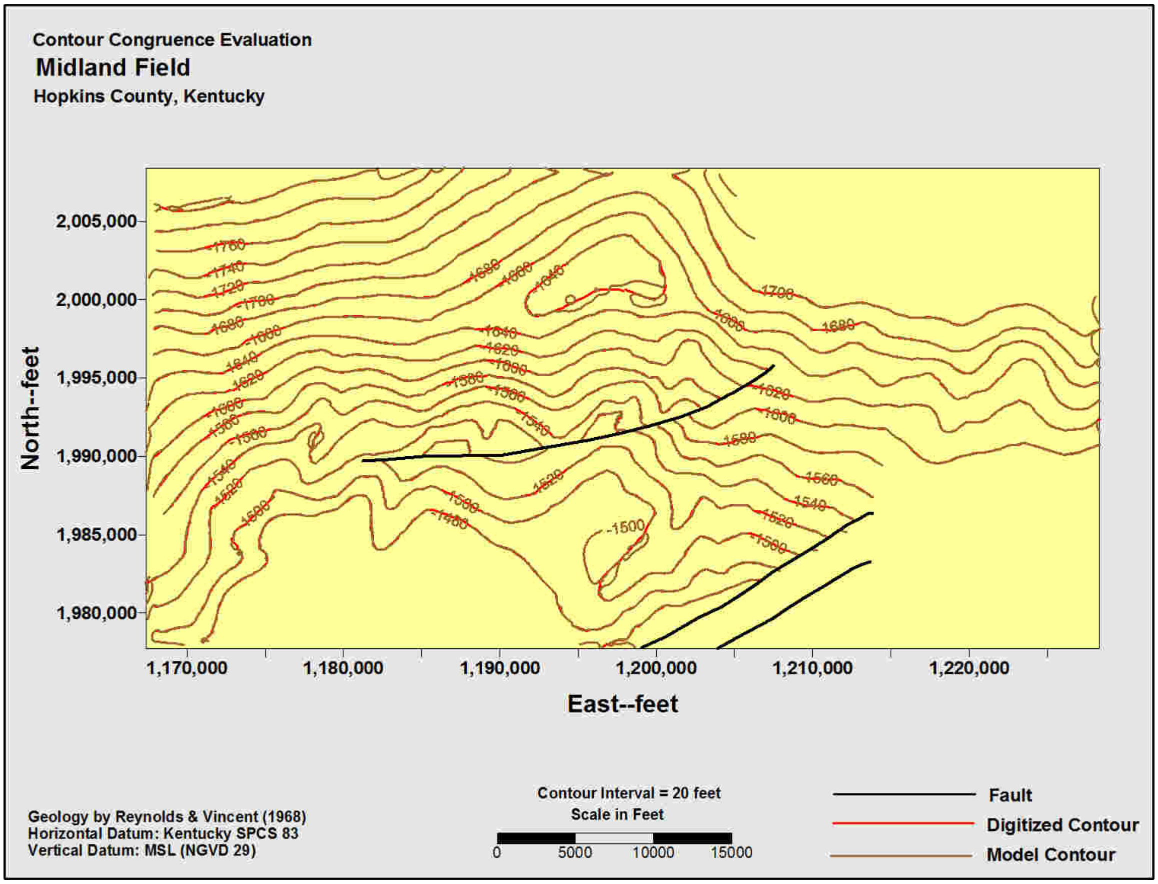

Figure 6. Congruence evaluation, Midland Field, Hopkins County, Kentucky.

Conclusions

The work done in this research demonstrated four things. First, despite the unique nature of subsurface mapping, the basic techniques of technical drawing were fundamental to the successful conduct of the work. These fundamentals included use of a standard layering scheme, standard map arrangement, uniform lettering styles and sizes, use of a bar scale and statement of contour interval, designation of orientation, and provision of map metadata including horizontal datum, vertical datum, and data source.

Second, use of a defined coordinate system provides map products with known distortion and a specified relationship to other coordinate systems. Calculation of acceptable calibration error for the project being digitized provides an immediate check on coordinate conversion, point identification, and digitizing precision. The work done in this project confirmed lab experience with digitizing error obtained in previous work: if the calibration error is larger than expected, something is wrong and correction is required before work proceeds.

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Third, quality control for digitized map products involves both accuracy and precision. A map is no more accurate than the data on which the map is based. For this reason, preparation of base map overlays showing drilling location and distribution is fundamental to understanding map accuracy. Comparison of the congruence of contouring obtained from digitizing with contours drawn from the gridded model tests mapping precision. Testing by congruence involves overlaying the digitized contour base map with contours generated from the gridded data file. Experience in this project showed that closely spaced, regular contours yielded models requiring little editing. Where contouring was widely spaced and irregular, supplemental contours had to be digitized in order to constrain the mathematical model.

Fourth, the constraints on contouring imposed by faulting and the potential for gridding routines to extrapolate beyond data limits must be recognized when 3D data is digitized. While this research employed a blanking method to control data expression in these cases, the specific technique employed is not as important as ensuring that the data produced for modeling accurately represents the surface being modeled.

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