Converting Legacy Maps into 3D Models

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Abstract
This research investigates methods and work flows for the conversion of legacy mapping to digital format. Study areas for the work included three oil fields in the Illinois Basin for which legacy mapping was available. The research identified specific workflows for digitizing, a defined suite of maps and digital products as project deliverables, and development of three dimensional models for management presentation. The outcome of this work demonstrated a relatively low cost method for increasing the return on monies invested in subsurface exploration.

Introduction
Legacy mapping refers to existing hardcopy maps and map products showing past work. Such mapping is often the result of significant field work and intellectual effort; as such, it represents a substantial monetary investment. A significant amount of legacy mapping currently exists as proprietary industrial information, and in the absence of new exploratory data, this mapping may still be current, even if completed decades ago. Current use of legacy map data represents a further return on the original investment. This use is facilitated when legacy map data are available in digital format.

Hard copy-to-digital conversion typically involves digitizing of a hardcopy map. In theory, digitizing is simple and straightforward; in practice, it can be time consuming and expensive. Digitizing needs thoughtful planning and careful execution to ensure that digital products retain original mapping precision and meet management expectations for data use. When the digitizing process is directly followed by the development of basic digital mapping products, data from legacy mapping can be used immediately for asset management and presentation graphics. Basic mapping from the digitizing process provides a basis for enhanced geological interpretation, three dimensional (3D) subsurface modeling, and plotting of the 3D relative location of adjacent fields.

This research describes experience in the hardcopy-to-digital conversion of legacy mapping and the presentation of these data as standard, 3D map products. Mapping used is that of oil and gas fields located in the Illinois Basin. The work done is intended to support the location of by-passed hydrocarbon resources in the basin. The U.S. Geological Survey estimates these as including 214 million barrels of oil and 4.65 trillion cubic feet of natural gas (Swezey, 2007). Specifically, this work addresses the following questions: (1) How can digitizing work flow be organized to decrease cost and time? (2) What basic work products can be directly output during legacy map conversion? (3) How can legacy map conversion deliver immediate utility?

Previous Work
The digitizing process is well known and is discussed at length by a number of authors (Krygier, J. & Wood, D., (2005); Lo, C.P. & Yeung, A.K.W. (2007); Longley, P.A., Goodchild, M.F., Maguire, D.J., & Rhind, D.W. eds. (1999); Demers, M.N. (2005); and Kellie, (2010b). Digitizing typically proceeds in three steps: map calibration using georeferenced coordinates, the digitizing process itself, and quality control and data export to the mapping or modeling program.

Legacy mapping may employ almost any datum as a geometric basis for mapping. Regardless of the current coordinate system, legacy mapping needs to be georeferenced to a defined coordinate system prior to digitizing so that a consistent mapping system results. Once mapping is available in geodetic coordinates, conversion is possible to any map projection. Conduct of the digitizing program is described by Demers (2005). He suggests use of a defined order for digitizing features and use of common feature (attribute) names. Kellie (2010b) states that features should be digitized using standard layers to facilitate export.

Quality control for the digitizing process is discussed by Lo and Yeung (2007), and Kellie (2009; 2010; 2011). Lo and Yeung (2007) suggest digitizing discrete points as opposed to streaming data to minimize data set size. For quality control, Walsh and Brown (1992) propose redigitizing and volume computation, while Kellie (2011) suggests using RMS error to ensure calibration quality, and using the congruence method for evaluating digitizing precision.

Delay in receipt of deliverables is a common complaint by persons contracting for, or directing, legacy map conversion. Immediate delivery of a standard map set for each field directly following digitizing makes completed mapping available for both technical and management use. Map types to be included as deliverables depend on the intended use, but examination of current technical reports show use of traditional planimetric maps, structural contour and isopach maps, stratigraphic sections, cross sections and 3D block diagrams (Ciftci, et al. (2004); Dull (2004); French & Kearns (2004); Matsuda, et al. (2004); McNeill, et al. (2004).)

Procedure

Based on the above, work was undertaken to address the questions posed at the beginning of this paper. Three existing oil and gas fields for which legacy mapping was available were selected as study areas. These were: Apex Consolidated (Rose ,1968); Kincaid Consolidated (Dean, 1988); and Mode (Zuppann & Kerrigan, 1988). Figure 1 shows the location of each oil field.

Figure 1. Study area location map.

Prior to beginning work, digitizing protocols were developed, standard map deliverables were identified, and methods for generating immediate return on the digitizing effort were examined. Digitizing protocols specify procedures intended to organize the conduct of work, ensure work quality, and minimize errors and omissions. The protocols used in this work were: (a) use of the state plane coordinate system for all georeferencing; (b) employment of a layering scheme for all digitizing; (c) use of the congruence method for quality control.

Deliverables for each field included: (a) traditional two dimensional structural contour and/or isopach maps with longitudinal and lateral sections; (b) three dimensional surface and/or isopach models; and (c) a three dimensional polychromatic wireframe model for use in technical presentations. A common mapping format was developed. This included a standard title block, listing of map type, location map, company name, and map metadata (horizontal datum, vertical datum, and map source).

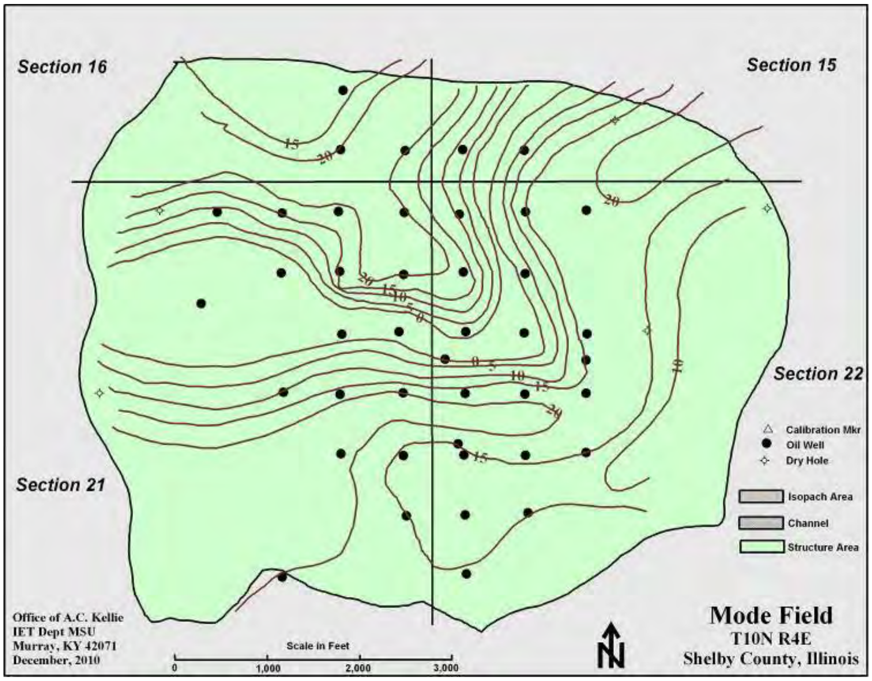
Results

Results from this research addressed the three questions posed at the beginning of this research: (1) How can digitizing work flow be organized to decrease cost and time? (2) What basic work products can be directly output during legacy map conversion? (3) How can legacy map conversion deliver immediate utility? These are addressed by topic below.

Work flow

Didger software (Golden Software, 2001) and a CalComp digitizing table were used for all digitizing in this project. Digitizing employed the protocols described.

Figure 2. Results of digitizing for Mode Field.



Georeferencing for all mapping used the appropriate state plane coordinate system. The Coordinate Conversion Tool of the Kentucky Geological Survey provided geodetic coordinates for Apex Consolidated (Kentucky Geological Survey, 2010). Earthpoint (2010) provided geodetic coordinates for Kincaid Consolidated and Mode fields. The Geodetic Toolkit of the National was used to convert geodetic to state plane coordinates (National Geodetic Survey, 2010).

The standard layering scheme included contours, isopachs, oil wells, dry holes, faults, gas wells, land system, text, and blanking area. Additional layers were generated as needed by the specific field. Figure 2 shows some of the results of digitizing at the Mode field. Because of data density, only selected layers of the map are shown.

Data from digitizing were exported as both (x,y,z) data files and graphics files to Surfer (Golden Software, 2002) software. Surfer gridded the x,y,z data for use in contouring and modeling. To test model quality, contours from gridding were overlain on graphic contours to test the degree of congruence.

Figure 3. Congruence test for Apex Consolidated.

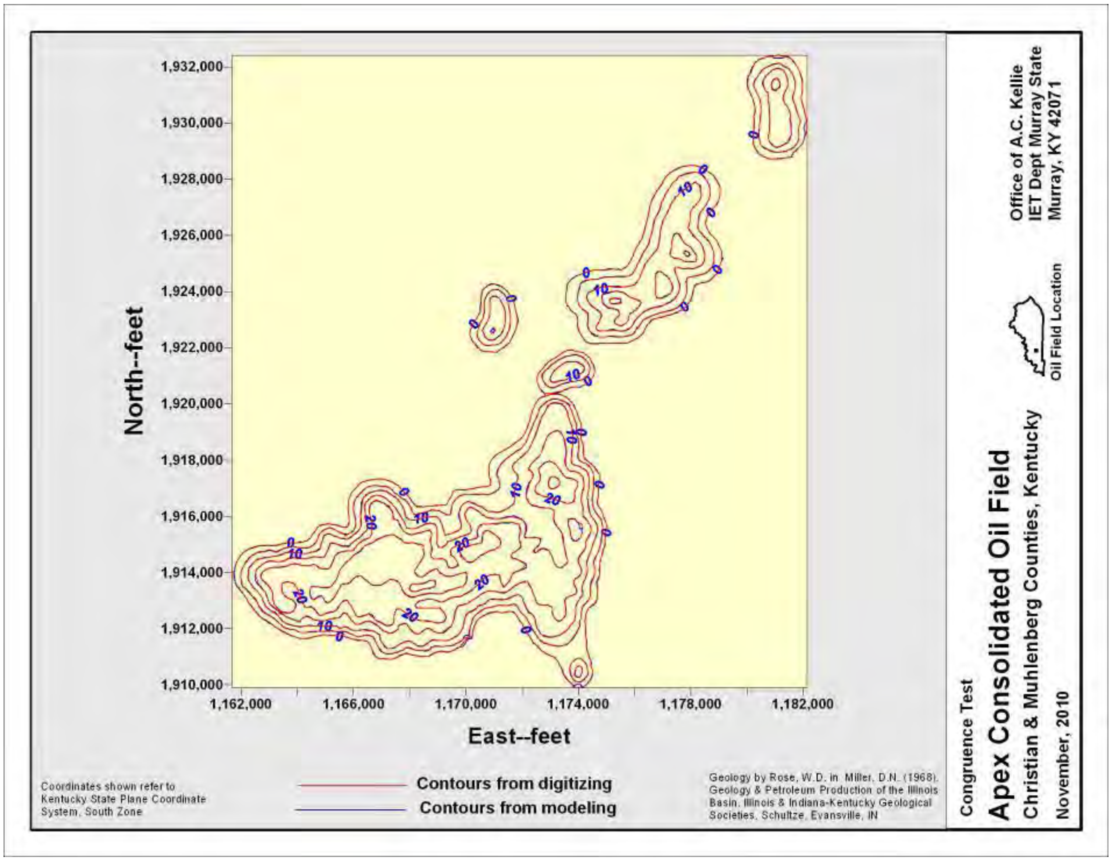


Figure 3 shows a typical contour validation map. If gridding and graphic contours were not congruent, supplemental contours or spot elevations were digitized on the legacy map. The process was repeated until the two sets of contours matched.

Work products

Preparation of a digital data file and map template for each field facilitates development of a suite of map products for immediate use. In this research, three map products were developed for each field: (a) a standard 2D structural contour or isopach map; (b) a 3D subsurface model with isoline drape; and (c) a 3D polychromatic wireframe model intended for technical presentation.

Figure 4 shows a standard isopach map for Apex Consolidated. This map employs a digital image map as a background. Isopachs are draped over the image map. A brown hue is used to show the Jackson sandstone and the standard pattern for sandstone is used for the sections. Because the features mapped are interpreted as barrier islands, blue is used for the map background. Although figure 4 shows a traditional map product, the use of tint, color, and pattern aids interpretation, and because the image is available in digital format, revision or editing is facilitated.

Figure 4. Standard isopach map and sections for the Apex Consolidated field.

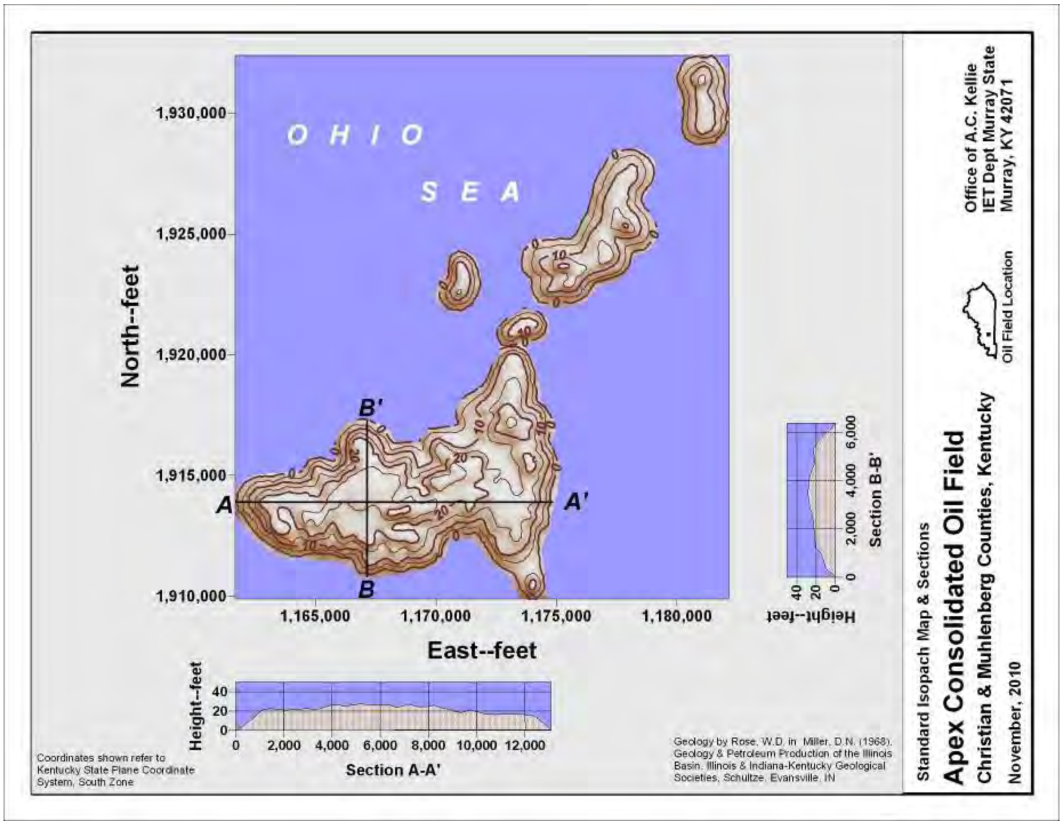
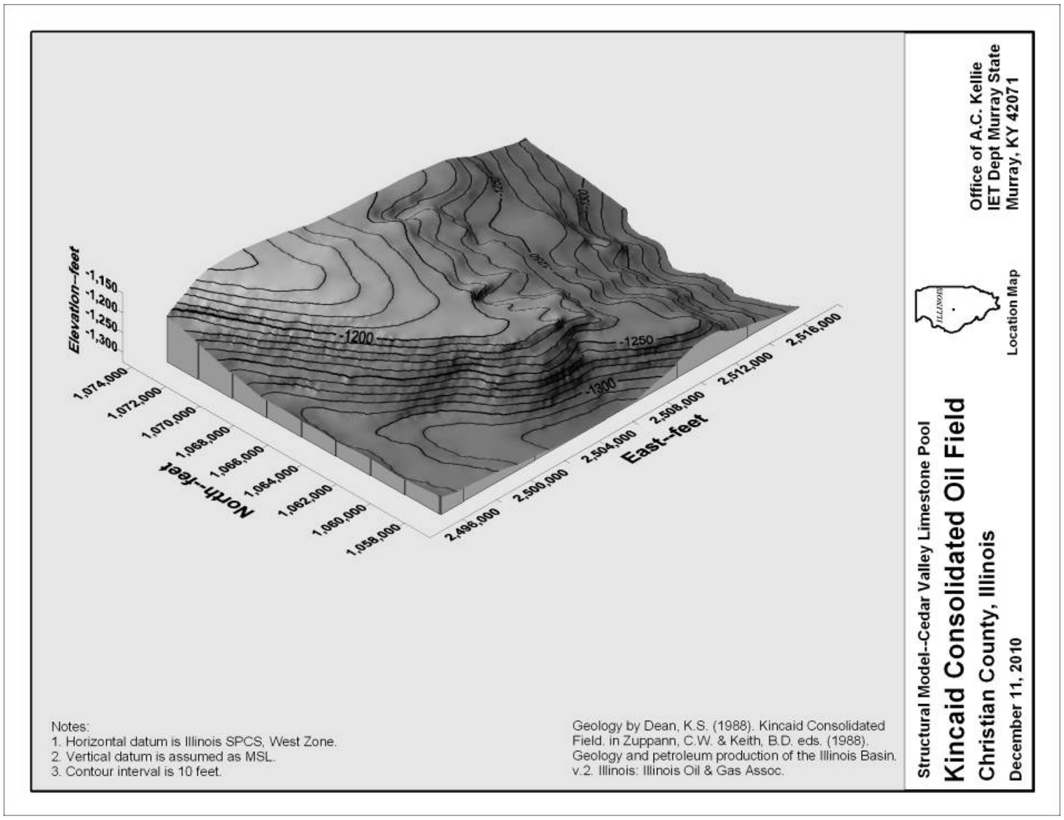


Figure 5 shows an example of a 3D structural model for Kincaid Consolidated. A gray color is used to represent limestone on what is interpreted as an anticlinal nose.

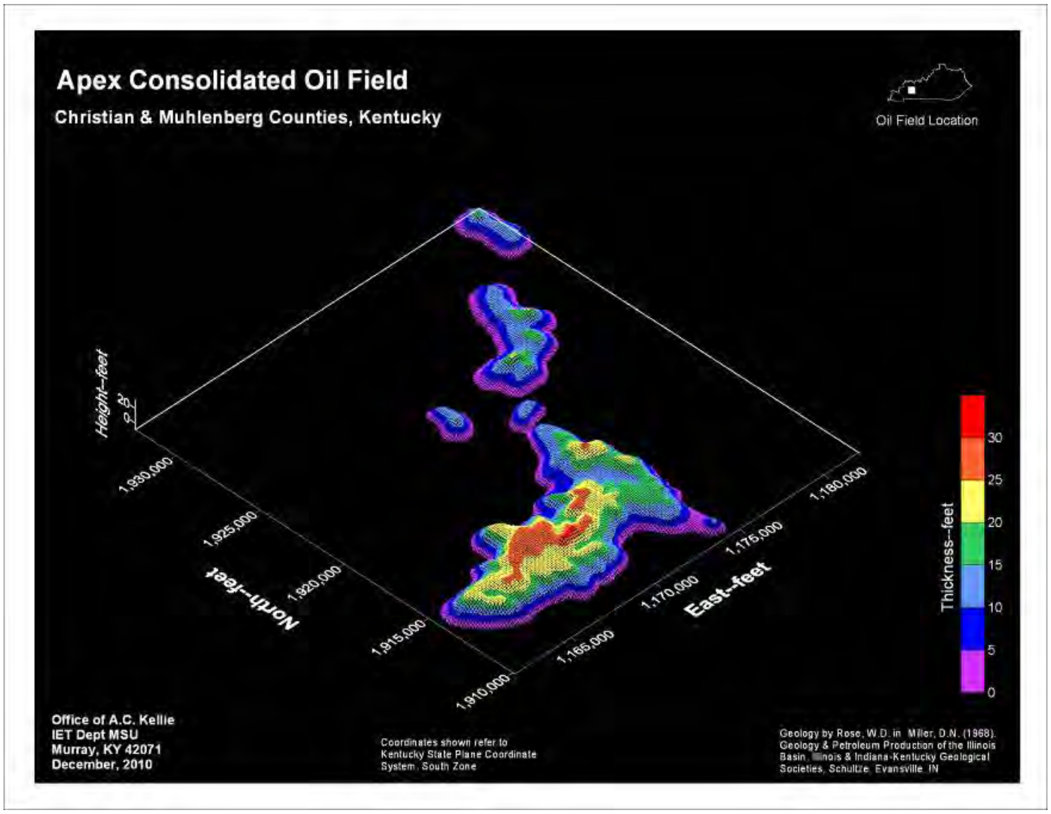
Figure 5. Three dimensional structural model of the Kincaid Field.



Contours are used to show surface elevation below sea level. An orthographic projection is employed with a model rotation of 45 degrees and a tilt of 35 degrees. The resulting view is from the southwest corner of the site.

Figure 6 shows the polychromatic wireframe model developed for Apex Consolidated. Unlike the other products developed in this work, the wireframe model was intended for use in technical presentations that would be projected in a darkened room. A polychromatic color scheme on a black background focuses attention on the model. An orthogonal projection is used with a model rotation of 45 degrees and a tilt of 40 degrees. The view shown is from the southwest corner of the field.

Figure 6. Polychromatic wireframe model of the Apex Consolidated Field.



Immediate utility
A map conversion project involves an investment of time, money, and resources. Outcomes should support both technical and management objectives. This research suggests two methods for doing this.

First, the conversion project should be conducted incrementally, i.e., on a field-by-field basis. There are two reasons for this. First, digitizing results require verification before being accepted as precise models of legacy map data. For example, this research showed a routine need for supplemental digitizing in areas of low relief. Digitizer recalibration and setup time for supplemental digitizing can be avoided by verifying digitizing quality before moving on to the digitizing of another field. Second, repetitive elements in the conversion process can be identified and automated early in the project. For example, in this research the need for standard graphic elements—title block, company logo, location map, map metadata—wasn't apparent until the deliverables were being prepared.

Second, outcomes from the conversion should include both data and graphic products. These should be posted to the company server or project website immediately after being completed and verified. Digital data can be used by engineers and scientists for work at a project level. The scientist or engineer will manipulate the data as needed. Graphic outcomes can be used by management to support work at a strategic level. The difference in the deliverable must be recognized during the conversion process. For example, this project used a different graphic format—background, arrangement, and color—for presentation graphics than for standard mapping.

Conclusions
This research showed that legacy map conversion can provide accurate digital information from existing hard copy mapping in a timely manner. Experience with this work resulted in the following conclusions: First, digitized data must be validated prior to use in modeling. This prevents use of incorrect data in mapping, modeling, and decision making. Second, the conversion project should be conducted in an incremental, field-by-field, manner. Working thus facilitates data validation and identifies process work flow problems. Third, conversion results should be posted immediately for use by others. The posting should include digital data, a limited suite of standard map products, and presentation graphics.

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