A method for three-dimensional mapping, merging geologic interpretation, and GIS computation


A cooperative geologic mapping project was conducted by the Illinois State Geological Survey (ISGS) and the United States Geological Survey (USGS) to map the Quaternary deposits in east-central Illinois (figure 1). This area provides an excellent geologic setting to develop and test new techniques for mapping Quaternary deposits in three dimensions (i.e., mapping the thickness and distribution of geologic materials both at land surface and in the subsurface), because it has diverse Quaternary geology and thick, regional sand and gravel aquifers within a buried bedrock valley system (the Mahomet Bedrock Valley). The Mahomet Sand, which fills the deepest portions of the bedrock valley, is the thickest and most widespread glacial aquifer in the system. In addition, overlying the Mahomet Sand (Mahomet Aquifer) are sand and gravel units intercalated with fine-grained deposits. Where the Mahomet Sand is absent, these aquifers are important sources of water for rural farmsteads, communities, and industries.

The Quaternary deposits of east-central Illinois are the product of multiple glaciations and three distinct bundles of Quaternary sediments are prevalent - those from the Wisconsin, Illinois, and pre-Illinois Episodes, all containing fine-grained diamicton and sand and gravel deposited by glacial ice. Because these sediments are relatively thin and, in places, discontinuous, they are a distinct challenge to map, especially in the subsurface. Traditionally, a map of the elevation of a subsurface unit has been drawn by the geologist, based on (usually sparse) outcrop and well data and a general model or understanding of how the unit came to be deposited and subsequently altered by erosion.

From the rapidly-growing field of Geographic Information System (GIS) science and software, automated methods have emerged for creating maps once produced only by the geologist’s hand. These computer-generated maps, however, have serious deficiencies especially in areas where data are sparse and/or of uneven quality. This presentation describes a method that combines the geologist’s knowledge of regional geology with the computational power of a GIS to create maps superior to those produced by either approach used alone.

Goal and products

The primary goal of our study was to build upon prior regional geologic investigations, using newly-refined stratigraphic data to produce updated, revised maps that could be used for various computer-aided applications such as groundwater modeling. Our second goal was to produce these maps using digital methods because county health and planning departments, state environmental, agricultural, and health agencies, water resource utilities, and other entities increasingly are using GIS to support decision making and planning.

Because computer-based mapping of deposits in three dimensions is not yet a common, well-established practice, we developed GIS-based methods to integrate point (key stratigraphic control data) and areal (geologic mapping) data. These methods are briefly described in Soller and others (1998 and 1999). With these methods, a set of geologic maps was produced that show the three-dimensional nature of the region’s Quaternary deposits and uppermost bedrock (Soller and others, 1999).

To help realize the second goal, we worked with local community and industry representatives to identify how 3-D geologic map information could help them model and manage the region’s groundwater resources. Partly as a result of those meetings, the Mahomet Aquifer Consortium was formed. As noted
at their Web site (http://www.MahometAquiferConsortium.org/), the Consortium’s goal is “to further study the Mahomet aquifer on a regional basis and to develop a plan for the management of this valuable resource.”

**Developing the stratigraphic database and maps**

The three-dimensional distribution of geological units cannot be properly mapped and understood without spending enough time and money to obtain the required high-quality stratigraphic information from boreholes and geophysical surveys. This is especially true for glacial deposits, as they commonly are thin (generally <200’) or patchy in distribution, and often have abrupt facies changes across short distances.

Over many years, the extensive ISGS collection of records from wells and borings has been used to interpret age relationships and lithology for geologic mapping and groundwater studies in cooperation with local, State, and Federal partners. A cornerstone in building our database was identifying a set of "key stratigraphic control points" (Kempton, 1990) from the ISGS collection of subsurface data. Key stratigraphic control points have high-quality data where samples have been described and/or well logs interpreted by geologists or engineers, and the locations of the data points are verified. From these control points, we built a stratigraphic database comprised of 177 such borehole records (about 1.5 per township, see figure 2). Included in these data were borehole logs and samples from six borings, to an average depth of 280 feet, done specifically for this study. Boring locations were in the presumed thalweg (deepest part) of the bedrock valley and in areas where data were sparse. Other key control points consisted of water wells with boring logs and sample sets of geologic materials (collected when the well was drilled). Representative well cuttings were described and samples assigned into various lithostratigraphic units.

Key stratigraphic control points served as principal data for constructing maps of each stratigraphic unit. These data were supplemented by more than 2000 secondary control points, mostly water-well drilling records having more generalized driller’s descriptions of the geologic materials. Water-well data provided additional mapping control, especially for units showing a strong lithologic contrast with adjacent units (for example, the bedrock surface, or the top of the Mahomet Sand).

From these data and an understanding of the geologic processes that prevailed in the region, a set of maps was produced, one for each stratigraphic unit. When the map of each geologic unit had been compared with those stratigraphically above and below, and all maps were found to nest properly, they were processed with EarthVision software, which is a high-quality software tool for geologic modeling. [For our purposes, it was preferable to generate each geologic map in ArcInfo software, and to import the file to EarthVision simply to create a three-dimensional visualization.] Apparent inconsistencies or errors in stratigraphic unit geometry were evaluated and, if necessary, the maps were revised in ArcInfo before completing the final set of 2-D and 3-D maps and images. In this way, the goal of producing an internally-consistent set of maps was realized. Finally, maps of unit thickness were computed in ArcInfo by calculating the difference in elevation between the top of the unit and the top of the underlying unit. In EarthVision, various 3-D perspective views, cross sections, fence diagrams, and vertical and horizontal slices through the deposits were generated for visual analysis (for example, see figure 3 and map images and animations at <http://pubs.usgs.gov/i-maps/i-2669/>).

**Summary**
An internally-consistent, three-dimensional geologic model was developed for a portion of east-central Illinois, including the Mahomet Bedrock Valley and surrounding uplands. Based on our experience, and the time needed to generate this model and set of maps, we advise that the planned and potential uses of the map products be carefully evaluated before a mapping project is begun. Providing an internally-consistent, three-dimensional model is essential if an analytical use is planned, such as development of a ground-water flow model. However, if adequate high-quality data are not available, or a raster-based analytical purpose not foreseen, these maps need not be developed. Instead, more conventional, vector-based methods for preparing maps of each surface may be used to provide a general, visual depiction of the geologic framework.

References


Figure 2. Perspective view of the map area showing the distribution of 177 key stratigraphic control points relative to the bedrock topographic surface. Viewpoint is from the south. Vertical exaggeration is approximately 30x.
Figure 1. Location of the map area, east-central Illinois

Figure 3. 3-D geologic maps showing the various geologic layers. The mostly discontinuous groundwater aquifers are shown in the images marked as “A”. The lowermost of these is the Mahomet Sand, an
important regional groundwater resource. Viewpoint is from the southeast. Vertical exaggeration is approximately 30x.