## GIS Tools for 3-D Surficial Mapping in Ohio

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## ABSTRACT

The Ohio Department of Natural Resources, Division of Geological Survey is currently mapping the surficial geology of Ohio in three dimensions (3-D) using a modified version of the stack-mapping technique of Kempton (1981).  The stack-mapping technique depicts the geology for an area in 3-D by listing the unconsolidated (mostly glacial) geologic units from the surface to bedrock, the thickness of each unit, and the underlying bedrock unit.  The new mapping of the surficial geology is intended to replace the older and smaller-scale mapping that was based upon generalized, two-dimensional mapping techniques.

Three ArcMap-based software applications were developed to assist with the stack-unit mapping program.  The first software application uses the lithologies from water wells to create on-screen graphics representing the stratigraphic columns for each well record.  These stratigraphic columns are interpreted by the geologist to assign a generalized stack unit for each polygon.  The second software application consists of two tools used to attribute and label the stack-map polygons, which will capture the information in the GIS and for cartographic display. The first tool attributes a one-to-many relationship between a surficial-geology polygon and the lithology table.  The second tool labels the surficial-geology polygons with the stack text for use in map publishing.  The third application performs custom queries against the lithology table that can be used to create derivative mapping products, such as location and thickness of sand and gravel resources.  These three applications allow the efficient creation of 3-D surficial-geology polygons and labels within a GIS database, and provide analysis tools to facilitate the use of the 3-D surficial geology maps for specific applications.

## INTRODUCTION

The Ohio Department of Natural Resources, Division of Geological Survey (ODGS) is involved in a program, partially supported by the U.S. Geological Survey STATEMAP program, to map the unconsolidated-surficial sediments of Ohio in three dimensions (3-D).  It is important to characterize and understand these surficial, mostly glacial, materials because more than two-thirds of Ohio is covered by them.  Mapping of the surficial geology is conducted using the stack-mapping technique of Kempton (1981).  In Ohio, this technique has been modified to depict the primary lithologies of the materials and their thickness.  These 3-D maps will allow geoscientists and the public to more effectively use geologic information for land-use planning,

resource exploration, hydrogeologic investigations, and geohazard identification (Swinford and others, 2007).

The mapping methodology is summarized below, while a more comprehensive description of the mapping methods used to create the stack maps is found in Swinford and others (2007) and Venteris (2007). There are a number of different data sources used to conduct the mapping, including maps of soil parent materials, drift thickness, bedrock geology, and legacy (previously published) glacial-geologic maps. In addition, boring data from water wells from the Ohio Department of Natural Resources, Division of Water (ODW) (Jones and Barrett, 2007), bridge borings from the Ohio Department of Transportation, engineering boring logs, maps, field notes, and seismic-refraction lines (Swinford and others, 2007), and boring data from environmental studies of the Ohio Environmental Protection Agency are also used to help delineate the stack-unit polygons in the subsurface (Venteris, 2007). The delineation of the stack-unit polygons is generally a two-step process. First, the surface mapping units (lithologies) are derived from county-scale soils maps and digital elevation models (DEMs). The polygons of surface features are drawn by generalizing the parent material polygons from the soil surveys and interpreting geomorphic features on the DEMs. Second, subsurface polygons are delineated using the drift thickness maps and depths to bedrock from boring logs. These subsurface polygons delineate broad areas of like thicknesses. When the areas of like thicknesses are delineated, the stratigraphic model for that polygon is then assigned a stack sequence using borehole information from bridge borings and environmental site studies as a starting point. After the initial conceptual framework has been developed, the model is verified and extended using the water-well logs from the ODW (Venteris, 2007). Polygon and stack-unit information are hand-drawn on 1:24,000-scale Mylar overlays registered to the 1:24,000-scale topographic maps (Swinford and others, 2007).

Once the polygons have been drawn by a geologist on the Mylar overlay, the maps are digitized. The maps are scanned and georeferenced to the appropriate 7.5-minute quadrangle. The lines are then digitized into an ArcGIS geodatabase feature class, where the 7.5-minute quadrangles are mosaiced into a 30 x 60-minute quadrangle for plotting at 1:100,000 scale. Several iterations of quality control are conducted to ensure that stack-unit polygons are edge-matched between quadrangles (Swinford and others, 2007). After the lines are digitized, polygons and topology are created in the GIS. The polygons are assigned a unique polygon ID, known as the GEOID, which is based upon a unique sequence number for each 7.5-minute quadrangle. Finally, the polygons are attributed with the correct three-dimensional stack-unit lithologies using the stack-map application. In Figure 1, these stack units are shown for the Peninsula, Ohio, 7.5-minute quadrangle. Once the GIS data are created for the project, they are given to a cartographer to create a finished print-on-demand map at 1:100,000 scale that the public can purchase.

The ODGS program to map the surficial geology began in 1997. To date, the ODGS has mapped 17 of the thirty-four 30 x 60-minute quadrangles covering the State of Ohio (Figure 2). Each year, a 1:100,000-scale quadrangle is selected for mapping and four to five geologists are assigned to the task. At the beginning of the program, the geologists mapping the 1:100,000-scale quadrangle used traditional techniques, such as drawing the map units onto Mylar overlays and using paper topographic base maps. In the last few years, there has been a transition from using traditional techniques to using a mixture of traditional and GIS techniques. This paper describes the first GIS tools developed to assist automating the stack-mapping process in a GIS

environment.  These tools allow for the more rapid mapping of surficial geology in three dimensions.


**GIS TOOLS**


**Stick Figure Application**


In order to create the stack-unit polygons, many different sources of information are used. The most abundant source is the water-well logs from the Ohio Department of Natural Resources, Division of Water (Jones and Barrett, 2007).  To help the geologist interpret and map the stratigraphy for the stack units, a VBA application for ArcMap was written that draws a stratigraphic column for selected water wells based on the lithology information from the water-well logs.  In this 3-D mapping program, these stratigraphic columns are called stick-figures. Stick figures changes an overwhelming amount of written lithology information into a more easily decipherable set of colorized graphics which speeds interpretation.

To create stick-figure stratigraphic columns, a geologist selects a series of wells using the native *Selection Set* tool in ArcMap (Figure 3).  Once the desired wells have been selected, the geologist activates the *Stick-Figure* application, which draws a stratigraphic column for each well.  The geologist can then begin to use these stratigraphic columns as an aid in the delineation of the stack-unit polygons.  Before this application was created, four geologists required approximately twelve weeks to transcribe lithologic records from water wells and draw the stick-figures.  Using this application, the amount of time necessary to create the stick figures has decreased to approximately 1 week.  Most of this time is spent on generating the stick-figures for each 7.5-minute quadrangle, removing stick-figures for wells with suspect information, removing stick-figures in areas of dense drilling to improve readability and interpretation, and plotting the 7.5-minute quadrangles.

The creation of stick figures utilizes the one-to-many relationship between a water-well location and the water-well lithology table.  During the drilling of a water well, one or more lithologies are encountered downhole; in the database, this is managed as a one-to-many relationship.  This is illustrated in Figure 4, whereby a water well has been selected and the corresponding lithology records of the water well are displayed in a separate table.  The upper table is the feature-attribute table of the water-well location, showing the selected record of the water well (near the bottom left of the map).  The other table is the water-well lithology table, which shows the five stratigraphic records related to the selected water-well location. In the geodatabase, there is a feature class for the water wells, a table for the lithologic descriptions, and a relationship class.  The relationship class provides the link for the one-to-many relationship between the water wells and the table of lithologic descriptions.  The primary key between the water well feature class and the lithology table is the WELL_LOG_N field, which is the unique identification number for the water wells.  During execution of the stick-figure application, the VBA code cycles through all of the selected water wells and identifies the corresponding lithologic units that are associated with each selected water-well location.  The VBA application then builds graphic polygons at the location of the water well.  The polygon has a constant width and the height is defined as the along-hole depth of the lithologic unit encountered during the drilling of the water well.  The application creates a stack of polygons that represent the lithology encountered during drilling of the water well.

The polygons are symbolized based on a lookup field.  The original lithologic descriptions provided by the water-well drillers were reclassified into eight standard lithologies that can be displayed by the stick-figure polygons.  These lithologies include clay, silt, sand, gravel, diamict, peat/muck, soil, and bedrock.  These reclassified values are stored in a reclassification lookup field.  The VBA application reads the value from the reclassification field, and then assigns the appropriate color and symbol pattern to the polygon.  The entire process takes about 1 minute for a few thousand wells found in a quadrangle.

For each stick figure, the graphics polygons are grouped together so they can be moved and placed cartographically on the map.  In some areas the density of water well drilling is very high, particularly in urban areas.  In these areas, the density of the stick-figures can make it almost impossible to read and interpret them.  At any time, a geologist can delete individual stick figures, reselect individual well locations and generate new stick figures, all of which can improve the readability of the map.  This ability also allows the geologist to omit from consideration, and from display, those well logs found to contain unreliable information.

**Stack Map Application**

Currently, the stack-map process requires both GIS software and traditional methods of drawing the polygon boundaries using pen, paper, and Mylar.  Once the maps have been drawn using traditional methods, the maps are then digitized into the GIS database.  Finally, the stack-map application is used to attribute the newly digitized polygons in the GIS database.

The stack-map application consists of three different toolbars in ArcMap; each toolbar has a number of different tools (Figure 5).  The first toolbar is *Surface Geology*; it is used to attribute the surface-geology polygons and their associated one-to-many relationship lithology table.  The second toolbar, *Geology Annotation Editing*, is used to label the surface geology polygons by reading the associated one-to-many relationship lithology table and creating the stacked text labels shown on the map.  The third toolbar, *Geology Query*, is used to create custom queries using the one-to-many relationship lithology table.

The primary tool used to list and edit the lithology attributes is the *Edit Surface Geology* tool on the *Surface Geology* toolbar (Figure 6).  By selecting the tool and then selecting the desired polygon, different forms will appear that will either list the stack-unit lithologies in stratigraphic order or allow the GIS user to attribute one or more of the stack-units for the selected surface-geology polygon.  In figure 6, the selected surface-geology polygon has been attributed, and the *Edit Surface Geology* tool will activate the *List Stack Lithologies* form.  This form lists all the stack-unit lithologies and the name of the GIS user who has edited the stack-unit lithology and the date and time the last edit has occurred.  The name of the GIS user and the date and time of the last edit are a form of feature-level metadata.  This feature level metadata is stored in the database and is currently used for project-management quality control of the GIS conversion and editing.

Similar to the relationship between the stick-figure stratigraphic columns and the lithology table, the surface-geology polygon and the lithology table is a one-to-many relationship (Figure 7).  The upper table is the feature-attribute table of the surface-geology polygon, showing the selected record of the selected polygon.  The other table is the lithology table, showing the four records related to the selected surface-geology polygon.

To edit any of the stack-unit lithologies, the **Surface Geology Input** form is used (Figure 8).  This form is accessed automatically if a surface-geology polygon has not been attributed, or it can be accessed through a command button ("Update…") on the **List Stack Lithologies** form (see Figure 6).  Once the form has been activated, the GIS user can select the stack-unit sequence number, select a new lithology, input the thickness of the stack-unit and, optionally, select a unit modifier for the stack unit.  In this figure, the topmost unit is being edited (Layer 1).  The lithology is till (T), thickness is 40 feet, and the minus sign modifier indicates that this is the maximum thickness for the unit.

The labels for the surface-geology polygons can be placed using the **Geology Annotation Editing** toolbar (Figure 9).  This toolbar uses the **Annotation Editing** tool along with a custom **Add Lithology Annotation** tool to place the labels for the polygons.  The GIS user first turns on the annotation editing using the **Annotation Editing** tool.  Next, they select the **Add Lithology Annotation** tool and then select the surface-geology polygon to be labeled.  The custom **Add Lithology Annotation** tool, using the GEOID for the polygon, reads the related records for the polygon in the lithology table.  The tool then finds the center of the polygon, builds the text and separating lines for the label in correct stratigraphic order, and then snaps the label to the center of the polygon.  Placing the label semi-automatically in the polygons, which can number between 1,500 to 2,000 per 30 x 60 minute quadrangle, creates significant time savings.

## Query Toolbar

Complex queries can be generated using the **Lithology Query** toolbar, which has two tools within its dropdown menu.  The first tool, shown on the left side of the toolbar in Figure 10, can select polygons that have one type of lithology overtop another type of lithology.  The second tool, which is not shown in Figure 10, can select polygons that have a combination of thicknesses and lithologies overlying one another.  In Figure 10, a query was generated for Sand and Gravel (SG) overlying Lake Clays (LC).  The selected polygons are then highlighted in red.  The query tools allow for easy extraction of specific data for a map area and allow the user to transition data from a surficial-geology map to a more user-specific derivative map that a layperson can comprehend.

The Lithology Query toolbar has been set up to perform some very simple queries.  The query tools use the depth sequence ID number to identify the stack-unit sequence with depth.  For the first query, one type of lithology above another, the SQL SELECT WHERE clause is

WHERE  (LITH = "1$^{st}$ Lithology" AND LITH = "2$^{nd}$ Lithology") and (SEQID of 1$^{st}$ Lithology > SEQID of 2$^{nd}$ Lithology)

This SQL statement identifies stack-unit polygons that have both 1$^{st}$ Lithology and 2$^{nd}$ Lithology, and where the 1$^{st}$ Lithology overlies the 2$^{nd}$ Lithology.  One disadvantage of this type of query is that it will also identify multiple-selected lithologic records within a polygon of 1$^{st}$ Lithology overlying the 2$^{nd}$ Lithology.  For example, take a stack-unit polygon that has a lithologic sequence from the surface of till, sand, lake clay, till, sand, and bedrock.  If a query was generated to identify till over sand, the SQL query above will select both till over sand units.  The query will select multiple units and can not specify as to which till over sand unit we would

like to select.  Future enhancements of this type of query and the VBA code must be modified to refine the query for depth, thickness, and the selection of a single lithologic record per polygon.


**CONCLUSIONS**

      Three new GIS applications have been created for the 3-D stack-unit mapping program at the Ohio Geological Survey.  Two GIS applications are used to assist with the stack-unit mapping.  The stick-figure application is used to draw stratigraphic columns of boreholes, adjacent to the location of the borehole.  The stratigraphic columns are then used to delineate the subsurface polygons on the stack-units maps.  The second application is used to attribute the one-to-many relationships between the polygons and the related attribute table; it also is used to edit and label the stack-unit polygons.  These two applications have greatly increased the productivity of the geologists, reducing the amount of time it takes to produce a map.  The third application queries the stack-unit polygons, allowing geologists to perform map analysis and to ask questions using the GIS database.  The query tools are a first generation attempt to provide answers to typical questions that might be asked of the GIS database.  These query tools will form the basis of future derivative mapping at the ODGS.


**ACKNOWLEDGEMENTS**

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Figure 1.  Map showing the surficial geology of the Peninsula Quadrangle, Cuyahoga and Summit Counties, Ohio.  The topmost unit is symbolized, by color.  Till units are colored green

(T), Ice-contact units are colored orange (IC), Lake clay units are colored tan (LC), Alluvium and Organic units are colored blue (A and O), Sand and gravel units are colored dark blue (SG), and Pennsylvanian Pottsville Group sandstones are colored purple (Ss).
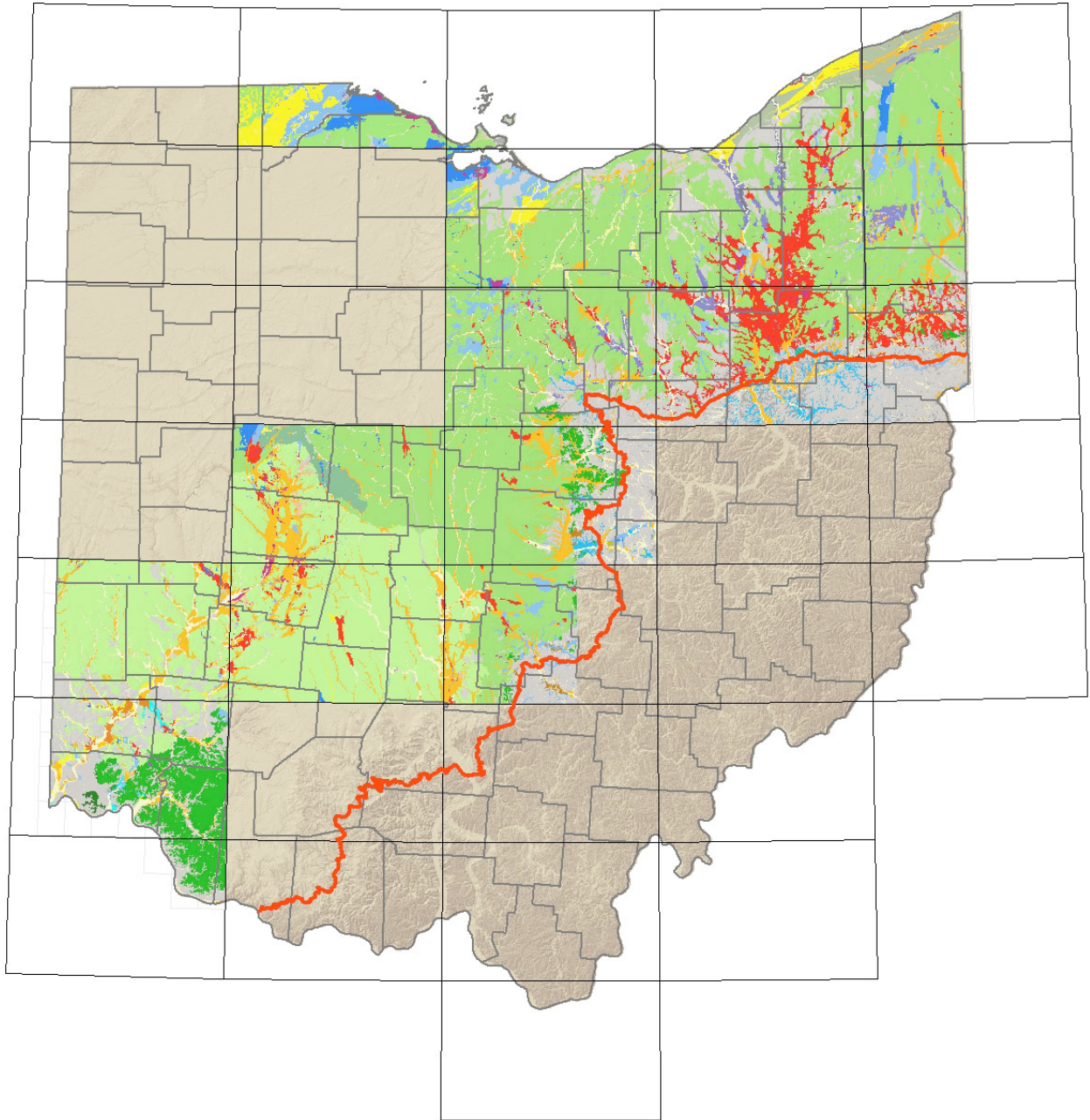
Figure 2.  Map showing the completed 1:100,000-scale 3D surficial geology mapping in Ohio. This figure shows the topmost surficial geologic units, and can be compared to the *Quaternary Geology Map of Ohio* (Pavey and others, 1999) to show the similarities and differences between the two mapping techniques.  The red line is the generalized glacial boundary in Ohio.
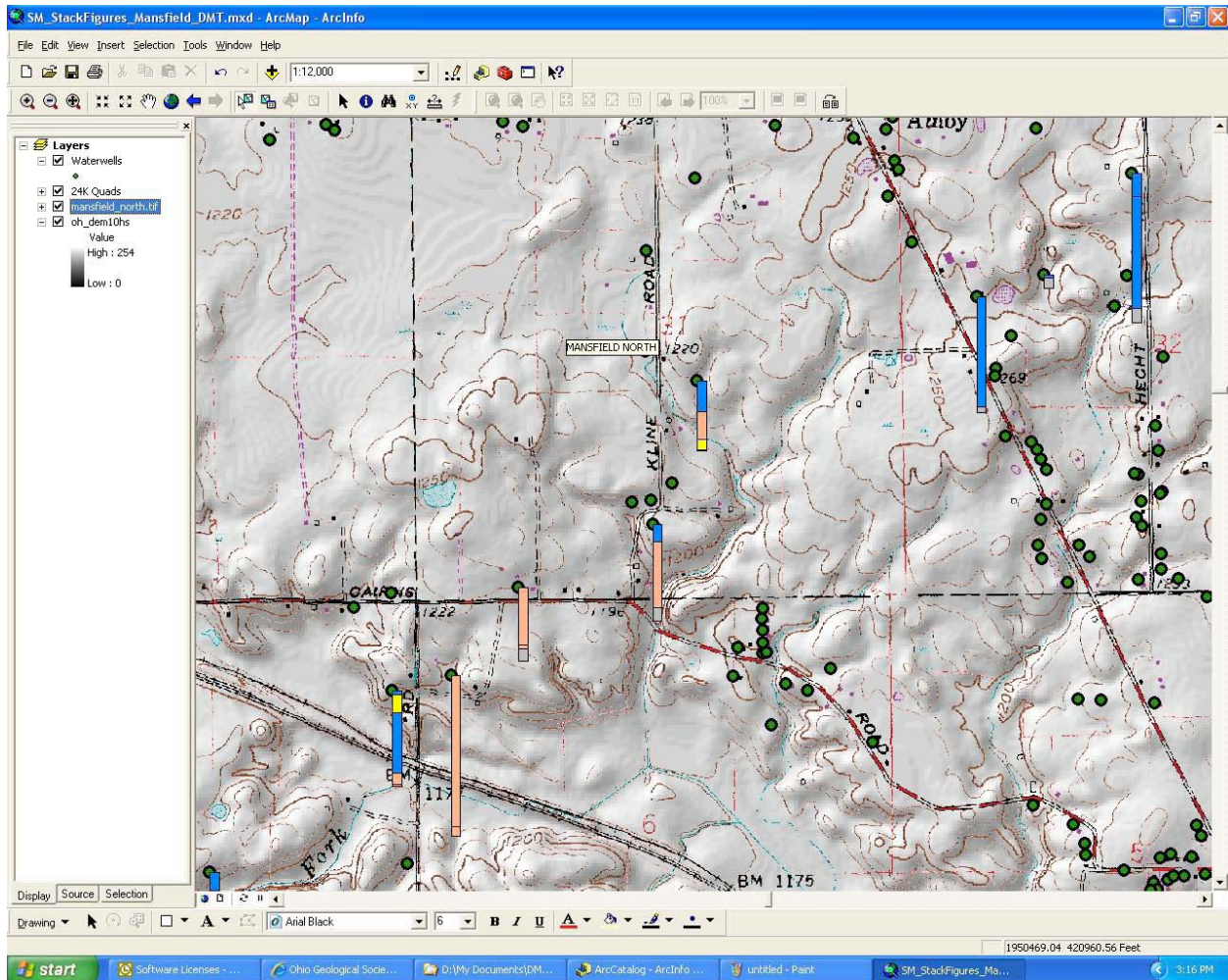
Figure 3. Selected water wells whose lithologic column is generated using the *Stick-Figures Application*. Colors in the stick figures represent various lithologies. Length of the stick figures corresponds to depth of the well, with deeper wells resulting in longer stick figures.
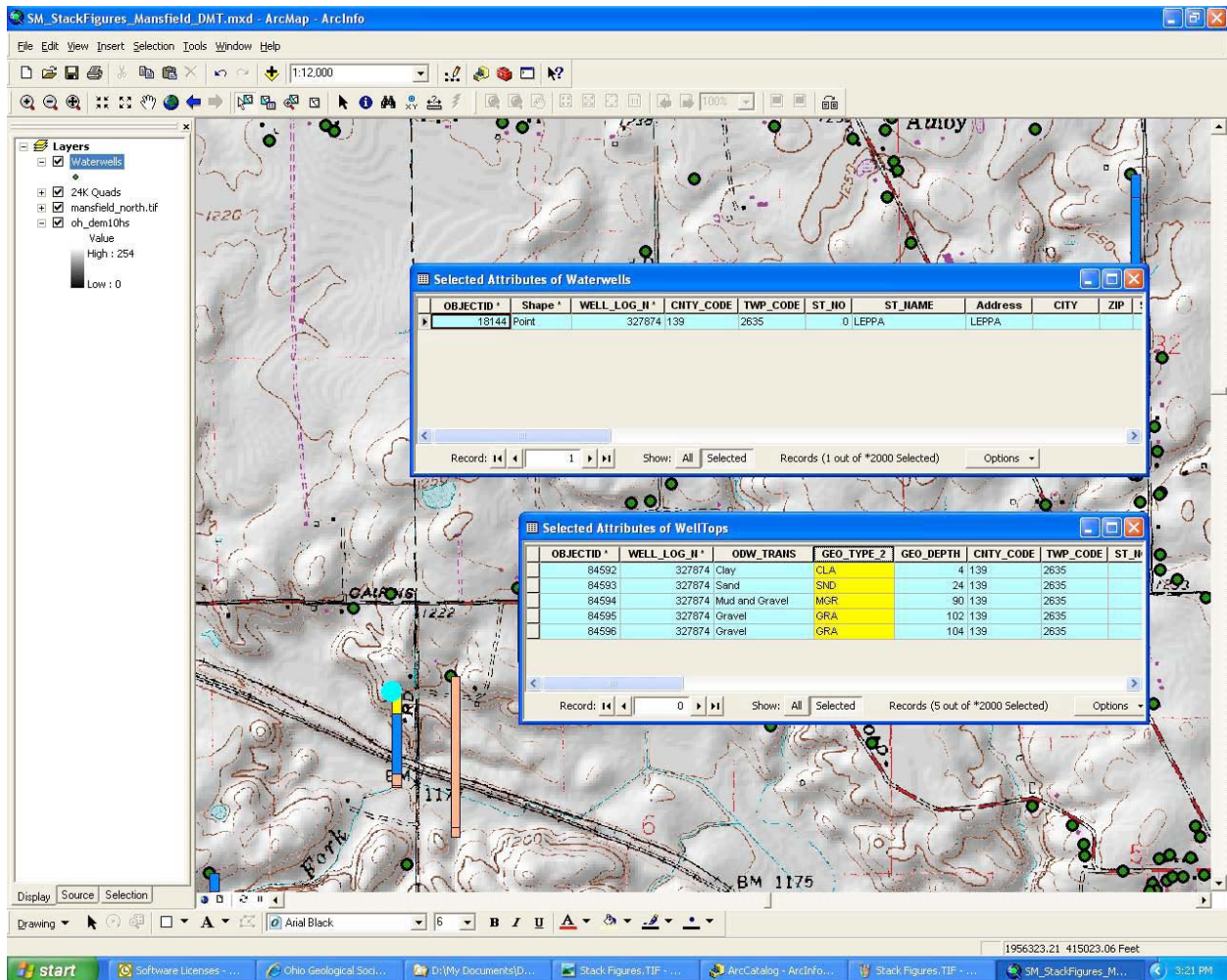
Figure 4.  Example of the one-to-many relationship between the water-well location and the water-well log table.  The well log record (upper table) is linked by WELL_LOG_N to the lithologies encountered downhole (lower table).  The selected well is in the lower left-hand corner.
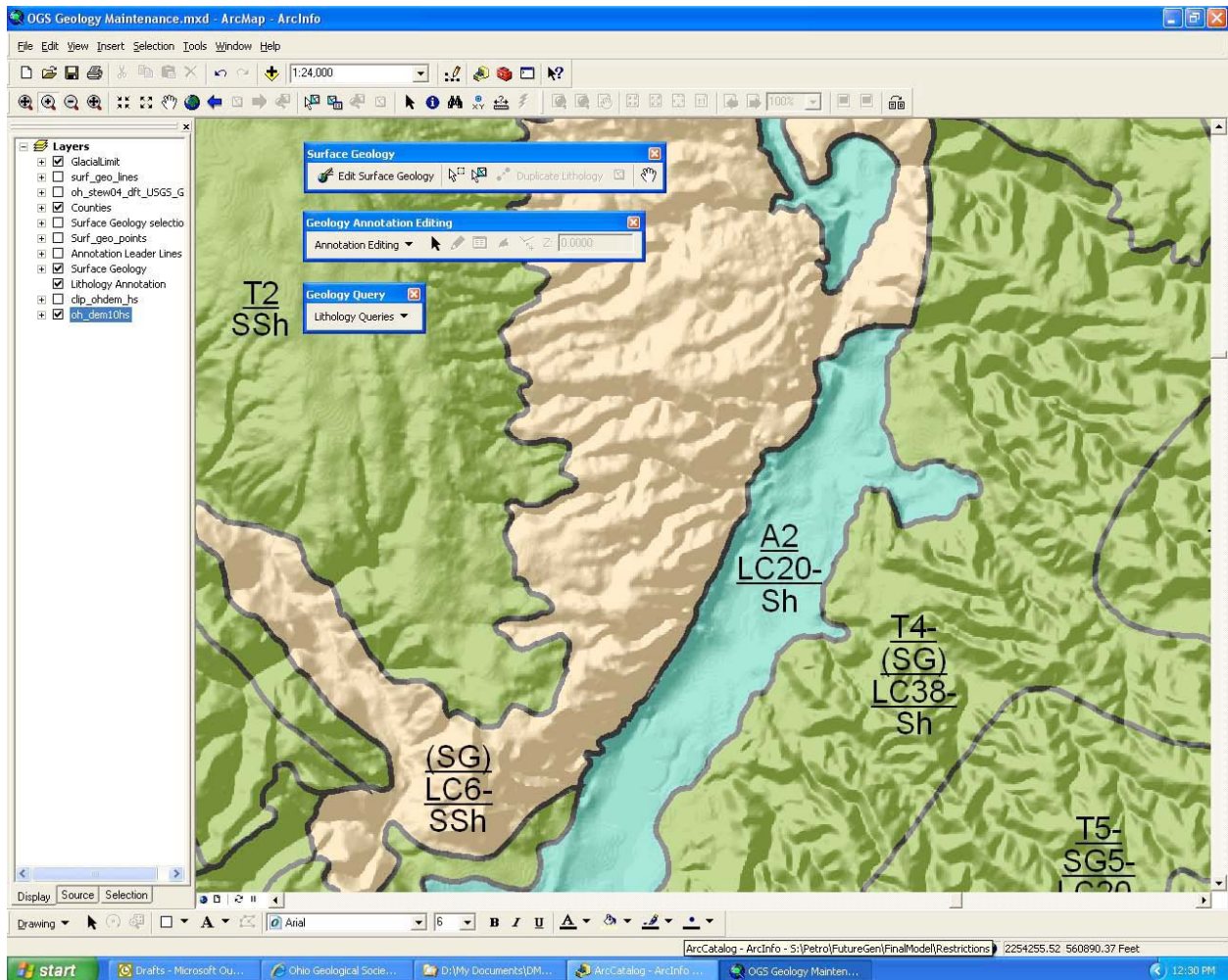
Figure 5.  The three toolbars of the stack-map application: The *Surface Geology* toolbar, the *Geology Annotation Editing* toolbar, and the *Geology Query* toolbar.
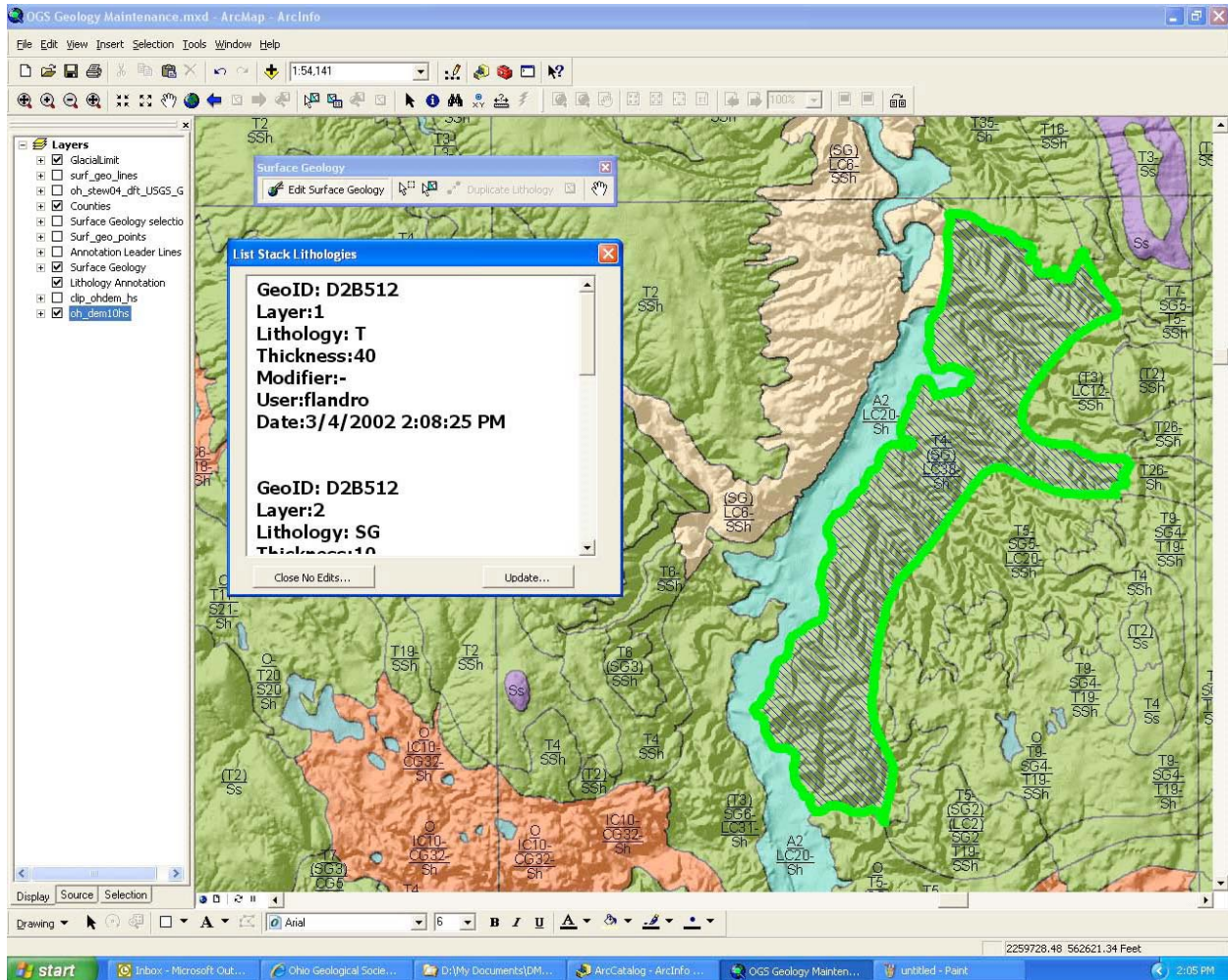
Figure 6. The *Edit Surface Geology* tool, and its *List Stack Lithologies* display. Polygon selected is in the right side of the figure and is outlined in a bold green line and has a hatchured interior.
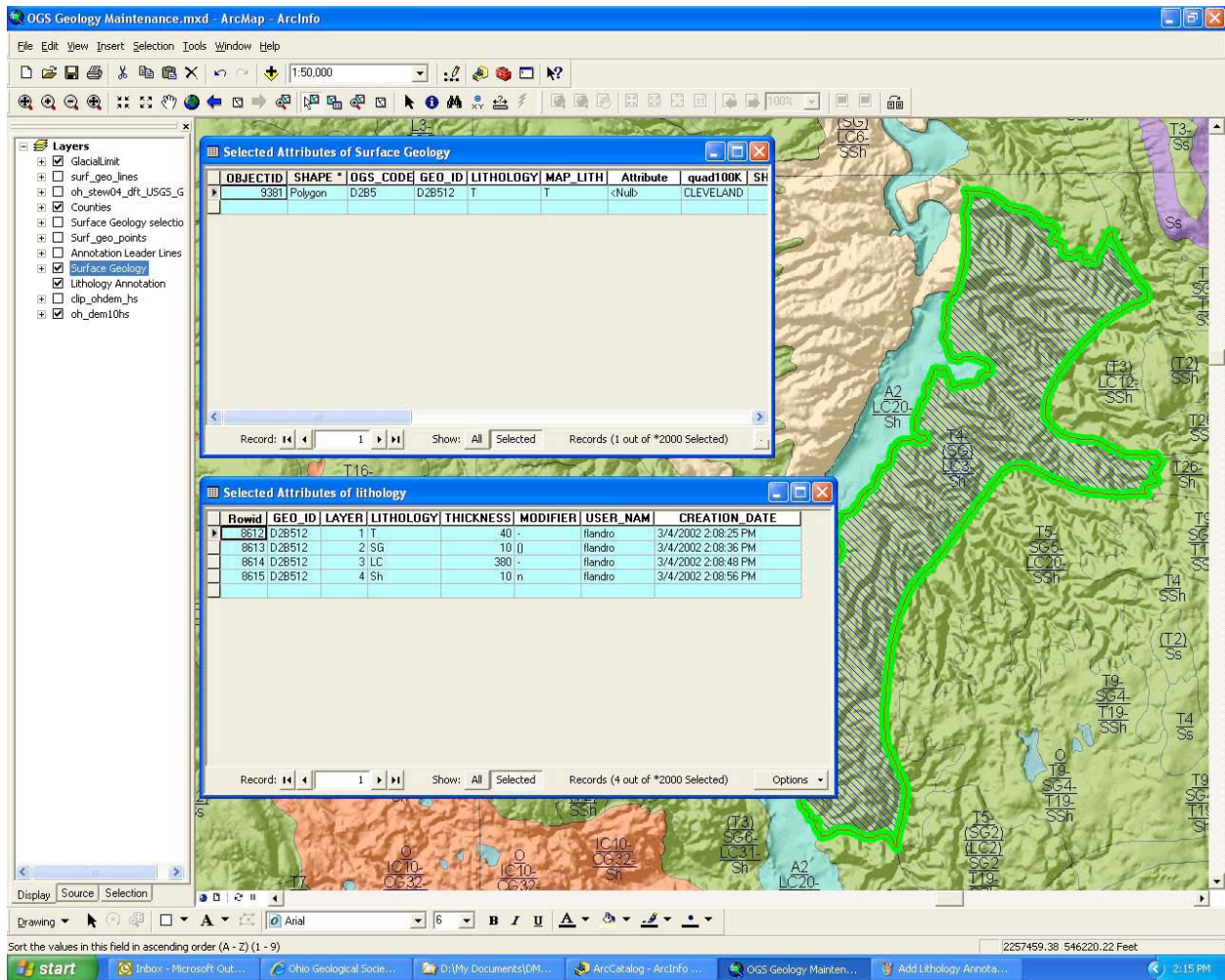
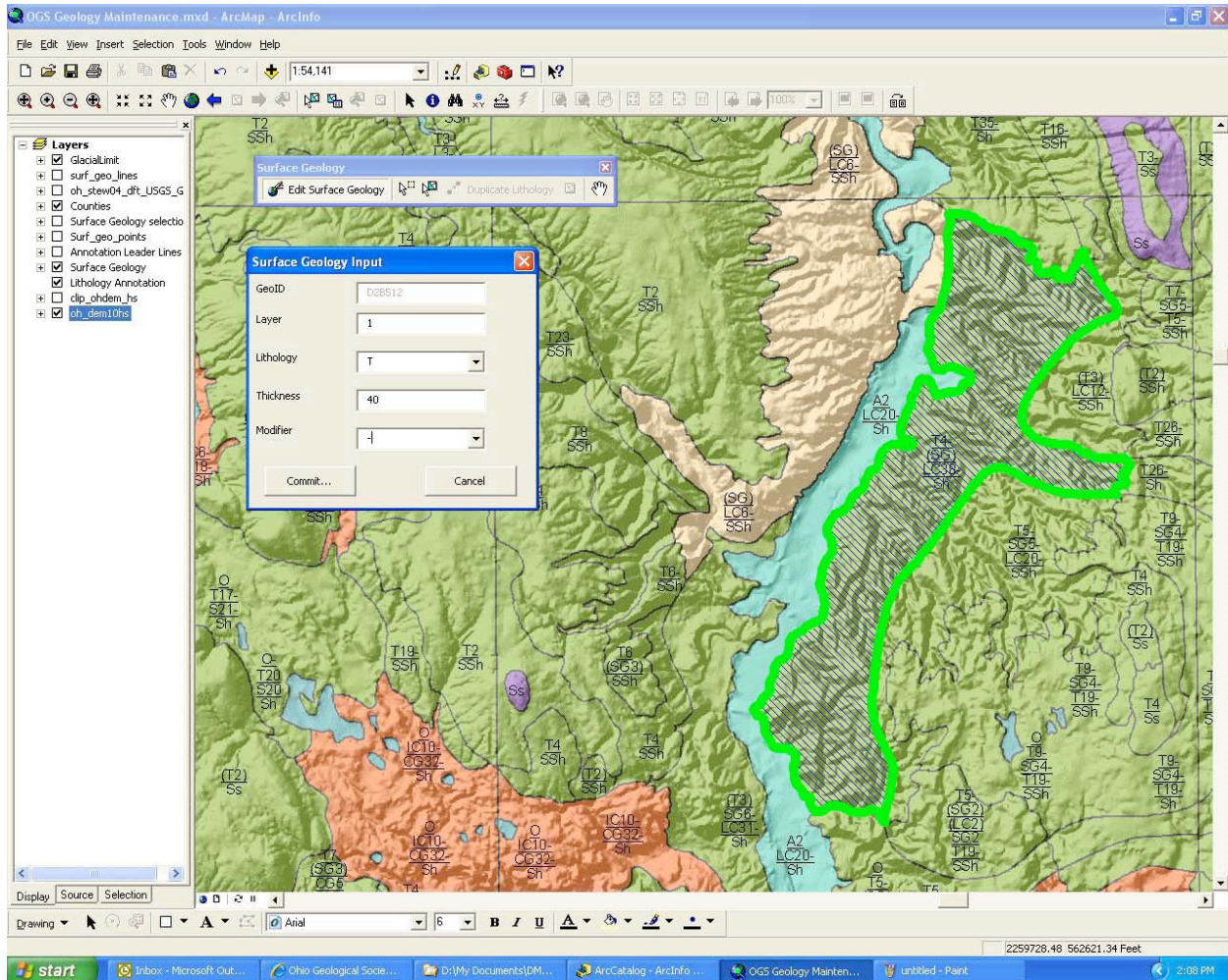Figure 7. Example of the one-to-many relationship between the surface-geology polygon and the lithology table.

Figure 8. The **Surface Geology Input** form for the top layer (1) containing a lithology of till (T), a thickness of 40 feet, and a modifier of minus (-) meaning maximum thickness.
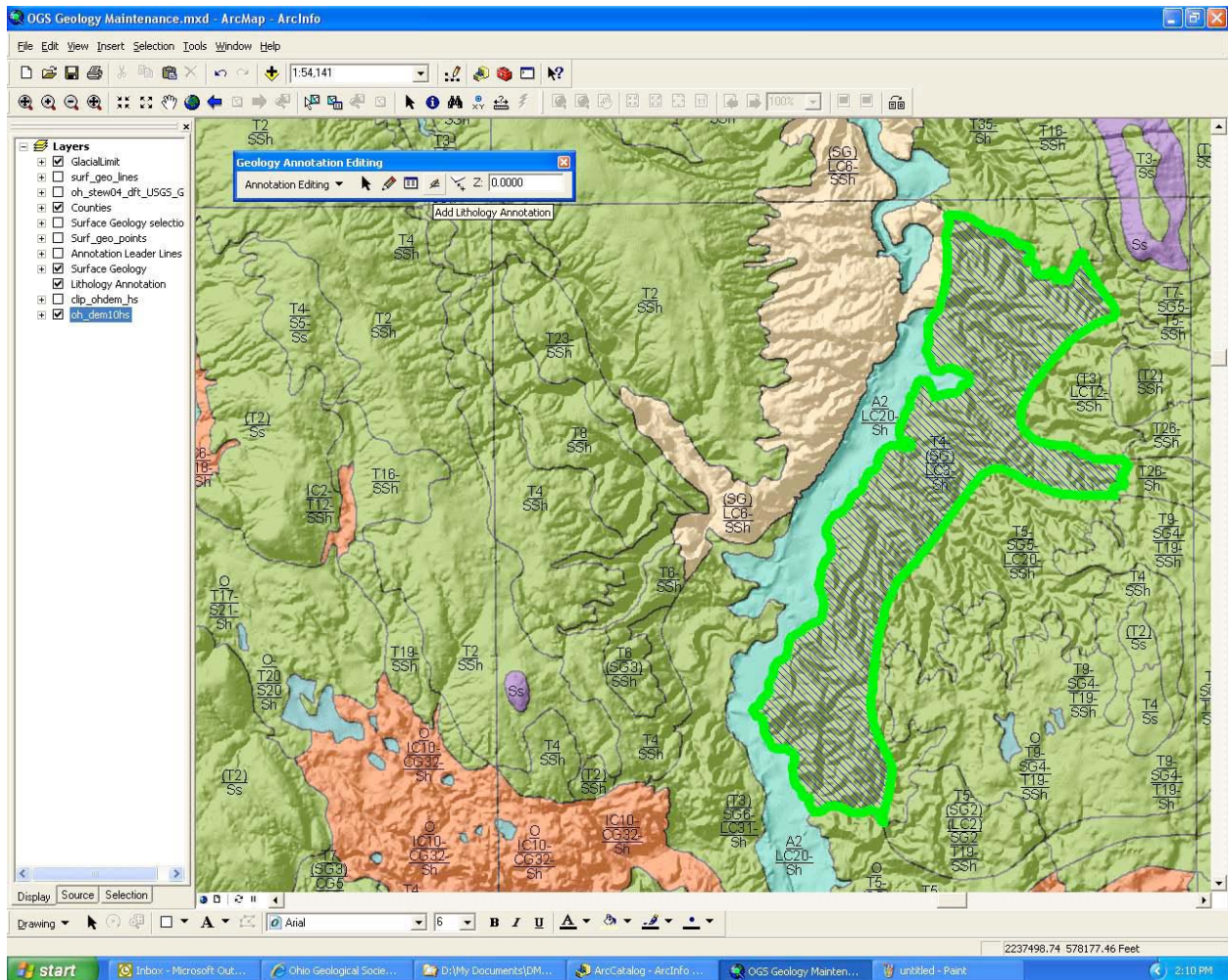
Figure 9.  The *Geology Annotation Editing* toolbar.  This toolbar contains the *Annotation Editing* tool and the custom *Add Lithology Annotation* tool.
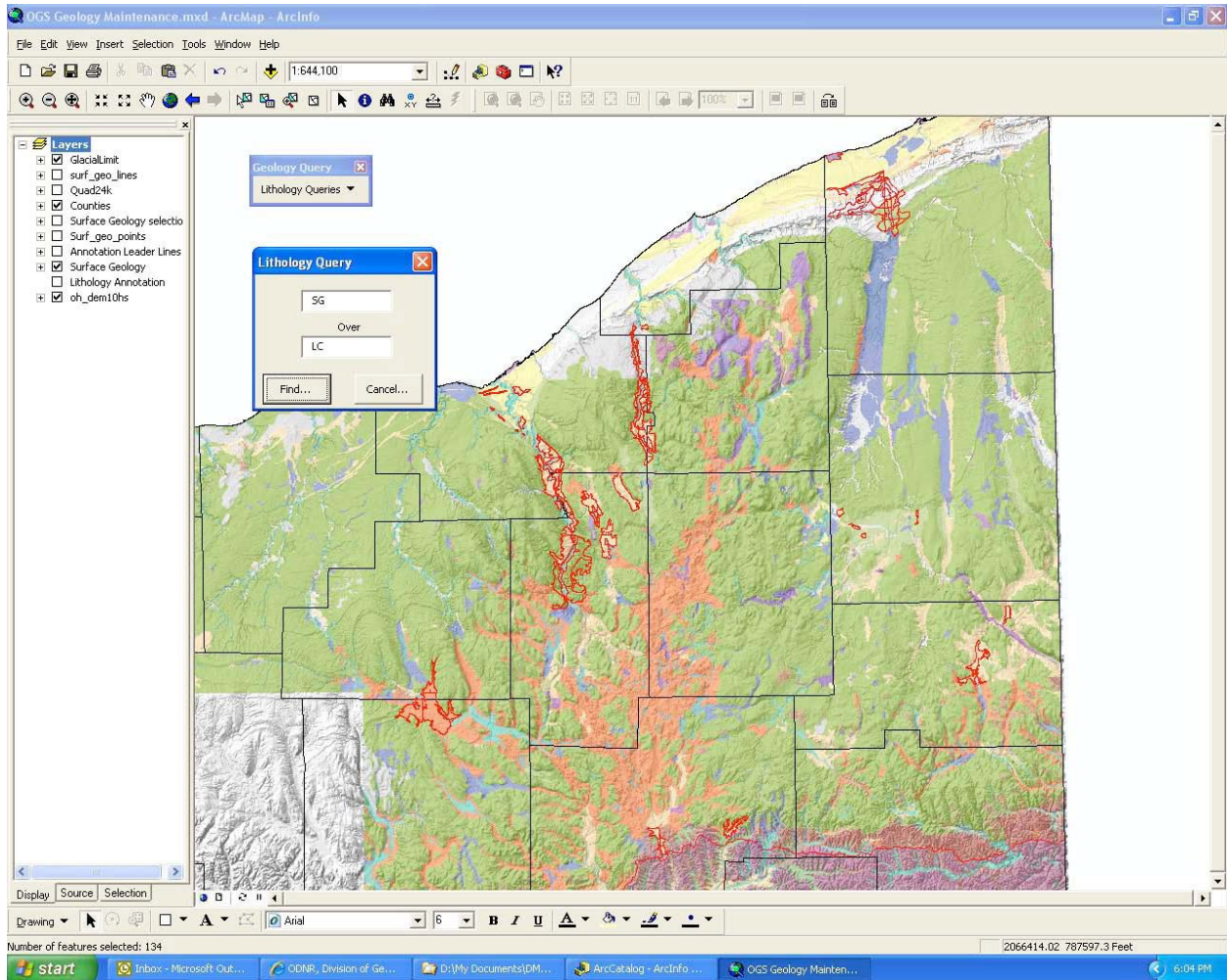
Figure 10.  The *Lithology Query* toolbar with areas of sand and gravel (SG) over lake clay (LC) selected and outlined in red.