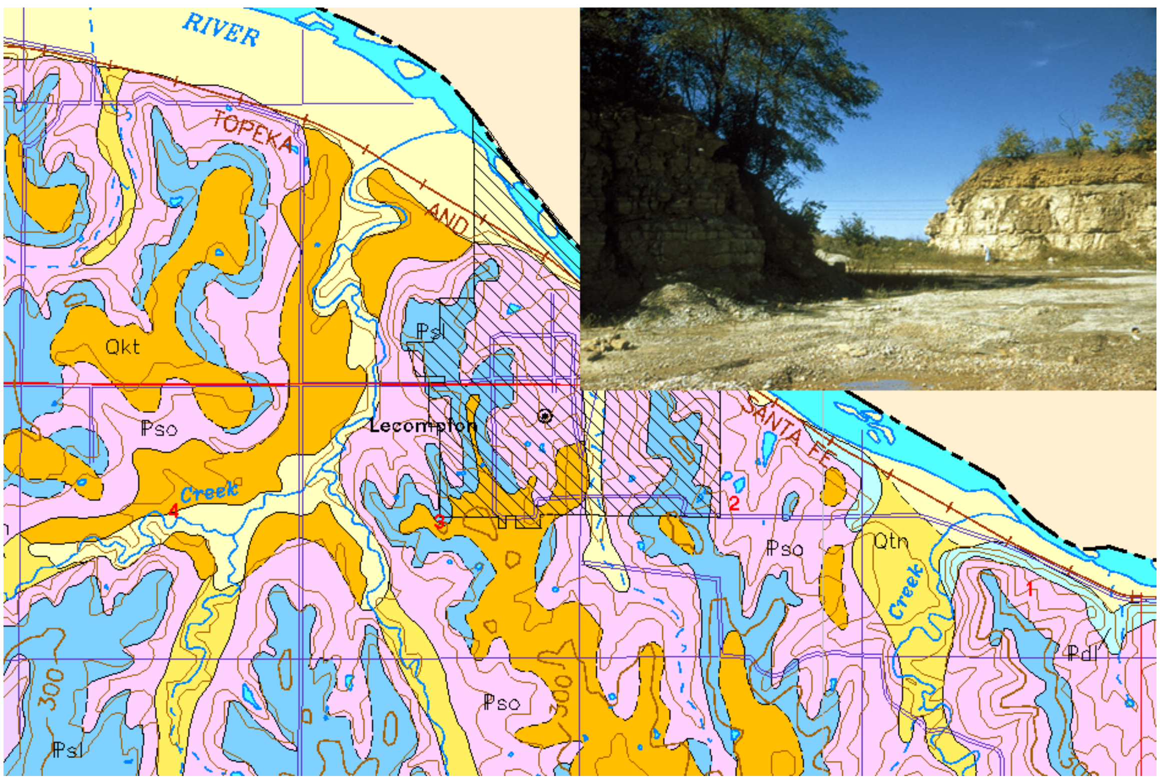
Kansas Geological Survey

Preliminary Development of a Digital Field Mapping Technique Including a Creative Field Trip Around the University of Nebraska Campus

Gregory C. Ohlmacher, Jeremy Bartley[1], Jorgina Ross, Ken Nelson[1], and Brett Bennett



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Introduction

The Kansas Geological Survey with the assistance of the Department of Geology at the University of Kansas has established a working group to develop a digital mapping technique to capture and edit geologic data in the field. The technique will support on-going geologic mapping at both organizations. The geologist will take a portable computer with an attached Global Positioning System (GPS) in the field and capture and attribute point, line, and polygon data including rock descriptions, contacts, unit polygons, and other data as needed by the project. The electronic files can be edited by the geologist both in the field and in the office on either a portable or desktop computer. Electronic data that are collected related to the Kansas Geological Survey's (KGS) mapping projects would be turned over to the automated cartography group for final map publication. Faculty and students in the Department of Geology would use desktop Geographic Information System (GIS) software to produce maps for publication and class assignments.

As part of the development of the digital mapping technique, the working group has identified the best hardware to use in the field and is currently developing the GIS procedures using the most recent ESRI GIS products including ArcPad 6 and ArcGIS 8 Desktop. The digital mapping technique needs to be flexible to allow for the changing needs of the KGS and Department of Geology mapping programs. As the digital mapping technique is developed, on-going mapping projects will be used to test the usefulness of the technique. The working group plans to promote the digital mapping technique and gradually phase it into projects where the geologists are receptive to using computers in the field.

This guide covers hardware and software considerations along with the structure for doing digital mapping and the knowledge required of the geologist. This guide represents the current status of the digital mapping technique and may not represent its final form. A six-stop walking demonstration of the current status of the digital mapping technique is included in the guide.

Hardware Device Considerations

Several types of portable computers were considered. The computers considered all have good and bad points. We have subdivided portable computers into three groups: mass-market laptop and tablet computers, handheld computers, and specialized laptop and tablet computers. The ESRI software products being considered require a computer running a Microsoft Windows operating system. Other considerations include a size and visibility of the display, GPS connectivity, battery life, weight, durability, and cost. Of these considerations the visibility of the display in bright sun was a major concern.

Mass-market laptops and tablet computers

Many companies manufacture laptop and tablet computers. These have the memory, speed, and storage capacity to run any ESRI GIS package. In general, these computers are lightweight, have reasonably large displays, and are relatively inexpensive. The main problem with these computers is that the displays are not visible in bright sunlight. Even on cloudy days the display is difficult to see. These computers are not rugged. They are not designed be used in the rain or other adverse conditions. GPS manufacturers offer plug in GPS devices if the computer has a special port; however, some GPS manufacturers indicate that interference between the GPS and the computer central processing unit (CPU) can lead to poor GPS results. Otherwise, a standard GPS can be attached via a cable to either the serial or universal serial bus (USB) port. Finally, the battery life is not good. Having the geologist to carry a spare battery solves the last item, provided that the battery can be installed easily. The working group felt that a geologist would not be interested in squinting at the display of these computers.

Handheld computers

Handheld computers are readily available, small, and lightweight; have a long battery life; and are relatively cheap. Some have displays that can be read in bright sunlight and backlit for viewing indoors. GPS attachments are available for handheld computers and one manufacturer has a slightly larger handheld device with a built-in GPS. You can buy GPS units that are wide area augmentation system (WAAS) compatible, which improves the horizontal accuracy to about 3 meters. The main problem is that the displays for these computers are tiny. The amount of memory in these computers is small, and they run a stripped down version of the Windows operating system. ESRI ArcPad is basic GIS software that is designed to run on handheld computers. None of the handheld computers can run the middle- or top-level GIS software. The inexpensive handheld computers are not rugged. However, if one gets damaged, it is relatively cheap to replace. The working group feels that handheld computers have a place in digital geologic field mapping, for example, when the geologist is collecting point data and not drawing and editing lines and polygons, a handheld device with a GPS unit may be the optimum approach.

Specialized laptops and tablets

Several manufacturers are making laptop and tablet computers that are rugged and have displays that are visible in bright sunlight. These computers have moderate-sized displays that range from 8.5 to 10.5 inches. These computers can be used in hot and cold weather,

and rain or shine. They can be dropped several feet without suffering damage. The amount of memory is sufficient (500 MB) to run any GIS software. The CPU speeds, about 800 MHz, are slow compared to mass-market laptops. Specialized computers are completely sealed and have no fans; thus, the heat generated by higher speed processors cannot be dissipated. Several manufactures are introducing units with either built-in or plug-in GPS units that are WAAS compatible. The disadvantages of the specialized laptops include cost, battery life, and weight. Because this is a limited market, the cost of specialized computers is high. Battery life is equivalent to a mass-market computer (3 to 4 hours) and the geologist would have to carry a spare battery. Many of the specialized computers are designed to be able to hot swap the batteries. Thus, the computer does not need to be shut down to change the batteries. These computers weight about 4 pounds, which is heavy compared to some mass-market tablet computers. With a larger display than the handheld computers and with a display that is daylight visible, the working group feels that these computers would work well in digital geologic mapping.

Software Considerations

Several ESRI GIS software options exist. The working group was interested in using the most up-to-date and functional software. The software needs to have the ability to collect and edit geologic data.

ArcView 3.x

A number of groups have used and are using ArcView 3.x for digital field mapping. The software is functional and has numerous editing tools. The Department of Geology at the University of Kansas developed a digital mapping technique using ArcView 3.x (Walker and Black, 2000). Further development of new tools in ArcView 3.x must be done in "Avenue" an obsolete ESRI scripting language. New ESRI products can use several programming languages including Visual Basic and Visual C++. The older Avenue scripts cannot be converted to Visual Basic or other scripts for the newer software. ArcView cannot use the newest ESRI data storage format. The working group felt that ArcView 3.x is obsolete software and was not selected for use.

ArcGIS 8 Desktop

ArcGIS 8 is the top-of-the-line ESRI GIS package. It offers the advantage of having a wide range of tools for capturing and editing data along with the geodatabase data storage format. Data capture tools include point, polyline (manually collected vertices), freehand line (machine generated vertices), and polygon collection. The edit tools include line/polygon clean up, joining and splitting lines and polygons, replacing line and polygon segments, creating polygons from lines, and other tools. The software offers exceptional data visualization tools including the ability to drape an orthophoto or geologic map on a shaded relief map creating a pseudo-3D view. ArcScene is optional with ArcGIS and allows the user to view and navigate (fly through) 3D views of the project. The user interface is fully customizable; buttons and menus can be added or removed as needed.

ArcGIS includes the ability to store data in a geodatabase. Geodatabases are relational databases that replace ArcInfo coverages and have increased functionality. Geodatabases can store both feature and tabular data. Raster data, however, cannot be stored in a geodatabase. Shapefiles are replaced with feature classes. Relationships can be established between feature classes and data tables. Linkages between polygon and line feature classes allow the user to edit a feature, for example a line, in one feature class and have the associated features (polygons) be automatically updated. Shapefiles and tables can be extracted from the geodatabase for use in other ESRI products.

ArcGIS is a top level GIS program and has lots of features. A geologist in the field does not need many of the features provided by the software. However, because the interface is customizable, the unnecessary features can be removed and more user-friendly buttons can be added. Additionally, the geodatabase structure does not store raster data like digital raster graphic (digital topographic maps), orthophotos, and photographs. Raster files would need to be organized into a folder that would be transferred with the geodatabase. The working group is actively developing a digital field mapping technique that uses ArcGIS 8.

ArcView 8.x

ArcView 8 is an upgraded version of ArcView3.x. Version 8 has more features and editing tools than version 3, allows for coordinate projection on the fly, and is customizable using Visual Basic Scripts as opposed to ESRI Avenue scripting language. Although ArcView 8 has many of the enhancements in ArcGIS, it lacks some of the advanced editing tools and cannot be used to edit complex geodatabases.

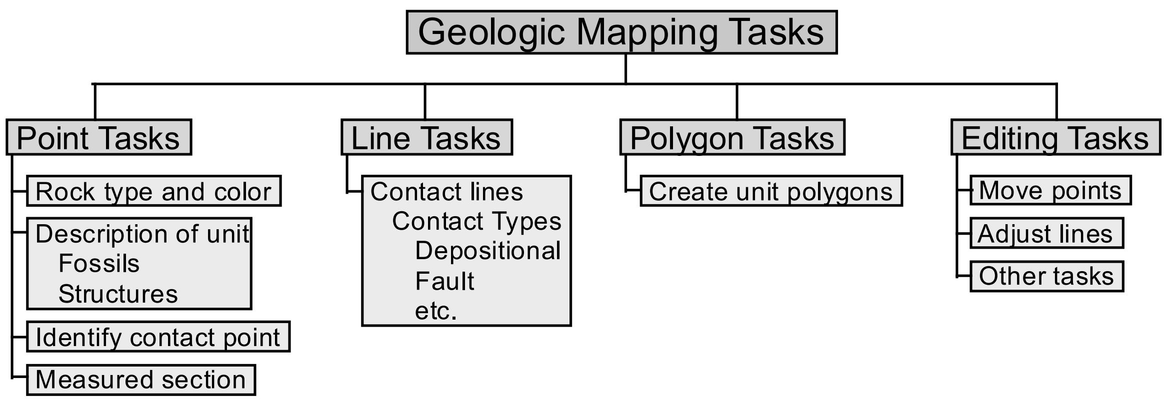
ArcPad 6.0

ArcPad 6 is a low-level GIS software package designed for data capture. It has tools for collecting point, polyline, freehand lines, and polygons. However, editing tools are lacking. The interface is customizable and forms can be developed to assist data input. The custom forms are written as Visual Basic scripts as opposed to ESRI Avenue scripts. ArcPad can be run on almost any computer with a Windows operating system. The program uses standard ESRI shapefiles along with MrSID and JPEG files. The software comes with extensions for both ArcGIS 8 and ArcView 3.x that will convert maps created in these formats to ones that can be used in ArcPad. The program is well suited for collecting point and possibly line data in the field.

The working group has several problems with ArcPad. The main issue is the lack of editing tools. The geologist would have few options in the field for correcting errors in points, lines and polygons. ArcPad has simple visualization tools lacking the advanced visualizations available in ArcGIS. For example, ArcPad cannot display DEM data. In the future, ESRI may address the visualization issue. ArcPad cannot use geodatabases, which forces the user to convert the geodatabase feature classes to shapefiles and then reconvert them back to the geodatabase format. The working group does feel that ArcPad on a handheld computer has a place in geologic field mapping. For example, when a geologist only wishes to collect point data and does not want to carry the tablet computer.

Digital Mapping Technique Structure

The basis for the digital field mapping technique is traditional geologic mapping. The idea is to implement digitally the same steps that geologists currently use in making a map. The fundamental steps in the process include gathering the background data, field data collection, and final map compilation. Field data collection can be subdivided into point tasks, line tasks, and polygon tasks. Point tasks including describing lithology, identifying the stratigraphic unit, identifying a contact, and describing a section. Line tasks include drawing contacts, faults, and fold traces. Polygon tasks include the creation of the unit polygons for the final map and specialized polygons like landslides. Final map compilation can be subdivided into clean up and editing tasks, developing tabular data, drawing stratigraphic sections, creating structure contours and other tasks. Most of these steps and their associated tasks can be computerized.



The overall structure of the digital mapping technique follows these steps and tasks. Initially, GIS specialists working with the geologist will assemble the data used in the mapping project and create the necessary geodatabases, shapefiles, and tables. These data might include digital raster graphics (DRG), digital elevation models (DEM), stratigraphic data, orthophotographs, satellite imagery, older geologic maps, soil maps, and other data. If the project involves specialized geologic mapping, for example hydrologic mapping, the GIS specialist will assist in developing specialized forms and tables needed to collect the data. At this point, the project will be transferred to the geologist's desktop computer.

The geologist will have a customized version of ArcGIS and will understand how to use the key features of the program. When the geologist goes in the field, the files will be copied onto the field computer(s). The main field computer is a specialized tablet computer running ArcGIS 8. Additionally, a geologist may take a handheld computer running ArcPad. The geologic mapping will be done in the field along with some editing. In the evening, the geologist transfers files between computers and edits the files as needed. Upon returning to the office, the geologist will transfer the data back to the desktop computer, back up all the files, and return the field computer(s) for others to use. On completion of the field mapping, the geologist will prepare the final shapefiles, maps, stratigraphic sections, explanatory text, and other items needed for map publication. At the Kansas Geological Survey, the data files will be turned over to the automated cartography group for review and final publication.

Required Knowledge

The geologist needs some GIS knowledge. The digital mapping technique requires the geologist to know how to plot points and lines and how to attribute the points and lines with the input buttons and forms. The knowledge required is dependent on what the geologist plans to map. A full understanding of the data structure is not required; however, the geologist must be familiar enough with the data structure to be able to perform tasks involving transfer of files. For example, if two computers (a tablet and a handheld computer) are used in the field, the geologist will have to be able to transfer files between the two units. The geologist may want to know how to add to the selections to the menus provided with the forms. The geologist will need to learn how to edit points and lines and may wish to learn how to create polygons.

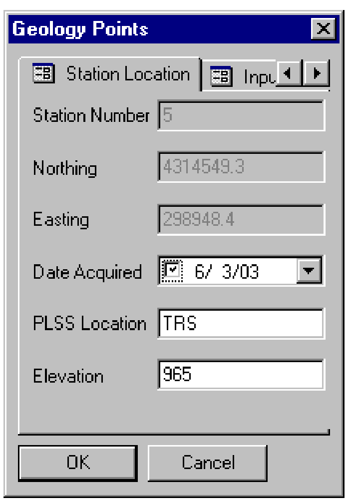
Practical Demonstration

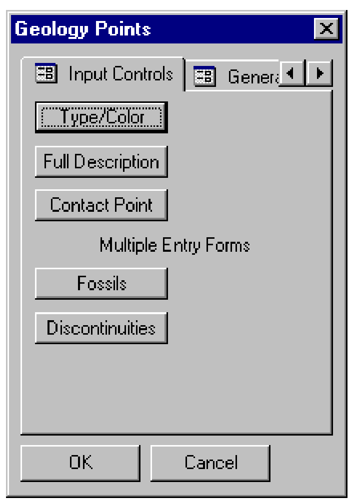
A brief walk across the University of Nebraska campus is planned to demonstrate the capabilities of the software and hardware options being considered. During this walk we will collect some geologic data and create a fictitious geologic map. The terrain covered is vertically challenged. While we are walking, imagine that you are in the gently rolling Flint Hills region of northeastern Kansas with Pennsylvanian and Permian limestone and shale exposures scattered along the hillsides. Because we are in Nebraska, we will generate some appropriate Nebraska names for the units we encounter. Along the walk we will demonstrate technique with both ArcGIS and ArcPad software packages. The stops will show basic input procedures for points and lines, the forms and menus developed to enter data, and some editing techniques. We will discuss the database structure and how we plan to input different types of geologic data. Additionally, we will demonstrate data input using a GPS. At the last stop we will demonstrate the creation of polygons from the lines we mapped and discuss the transfer of the geologic map data to the GIS cartographers.

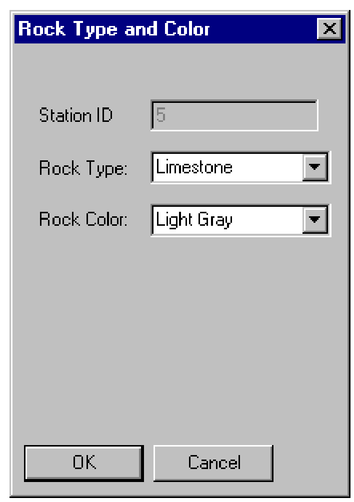
Stop 1: Simple data entry using ArcPad

At this stop we have an outcrop of pink gravel with granite fragments exposed around the statue. Many times when driving or hiking, a geologist will make a quick note of the general properties of the soil and rock, usually the type and color of the material. We have designed a simple form that allows the geologist to capture that data quickly, and not worry about more detailed description of the geologic unit. It may be that the geologist cannot identify the geologic unit or a simple note is all that is needed to keep track of a unit.

ArcPad is designed for collecting this type of data. One can collect a point, and attribute and store the results in a shapefile. Our design for the attribute collection is slightly more complex. For point data the geologist clicks on a point and a form (Geology Points) opens as shown below. This form is the gateway to a series of forms that allow the geologist to control the level of detail being collected. On the Geology Points form we automatically store a station number, the geographic coordinates of the point, the date the data was acquired. Three other fields (columns in a spreadsheet) of data exist that allow the geologist to store the Public Land Survey System (PLSS) location, the elevation of the point, and a field for the geologist to make some notes (not shown). These three fields have to be manually entered. The PLSS location and elevation can be read off or estimated from the DRG of the 7½' topographic quadrangle. Next the geologist can select from a number of options depending on the level of description needed at the location. Each option has a table associated with it. The option we will examine here is called "Type/Color" on the input controls page.





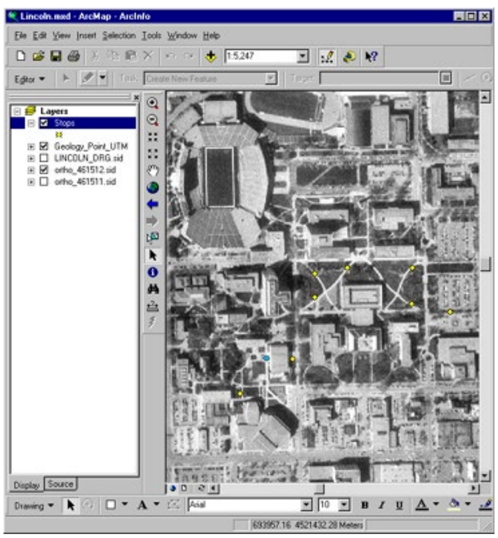


The "Type/Color" button opens to a new form (Rock Type and Color) that is linked to a spreadsheet file with three fields: station number, rock type, and rock color. The form can be used with both soils and rock information. The station number is automatically inserted and acts as the link between the Rock Type table and the Geology Points shapefile. The geologist can select from a menu of pre-entered choices or insert a new term.

As a geologist, I would arrive at this site and say to myself "Wow, I have a pink gravel with granite fragments." I would get out my field computer, turn it on, install the software, and add the point. In ArcPad as soon as the point is added the main form appears and the geologist can input the data. One advantage of ArcPad on a handheld device is the speed that the computer is ready and the software loads. The whole process for collecting simple data can be done in a few minutes. Another advantage is that ArcPad has a working GPS interface. Your GPS location is on the screen, you can center and zoom into the location, and then you can collect the point. ESRI is releasing a GPS interface for ArcGIS. If ArcPad is so easy, why not use it all the time? The editing tools in ArcPad are difficult to use. For example, if we plotted this point in the wrong place, it is easier to delete the point and all the records associated with that point and take a new point at the right location; whereas, ArcGIS has tools for moving the point.

Stop 2: Full Description of Geologic Unit

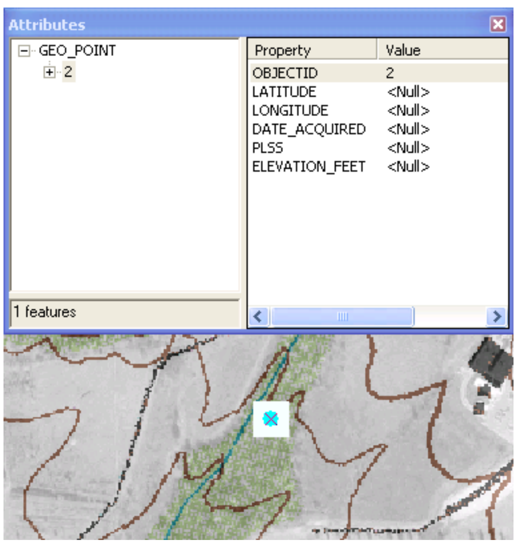
At this stop we have an outcrop of a white limestone that is exposed in the wall and steps of the Sheldon Gallery. The next type of data a geologist might collect is a description of a rock unit. We added a form that allows a geologist to collect some of the standard information used to describe a rock unit. Although, we have an ArcPad form that will collect these data, we will introduce the ArcGIS 8 techniques. Again, a geologist would click on a location to identify the point. The program automatically inserts the station number (Object ID), the location, and date of acquired. The geologist can open the attributes for this location and add the PLSS location and elevation from the DRG. With the point selected, the geologist can open any of a series of forms that collect the same data as in ArcPad. For example, a form exists that collects the rock type and color as was demonstrated at Stop 1. At this location, we want to do a more complete description of the geologic unit. First we select the Rock Soil button and enter the rock type (limestone) and rock color (white). After saving those values, we select the Full Description button. The form includes the following fields: station ID, thickness, stratigraphic name, internal bedding, bed uniformity, bed top direction, weathering, strike azimuth, dip angle, and dip direction. Other fields can be added to the form if necessary, and a field exists in the shapefile's attribute table for entering additional information.

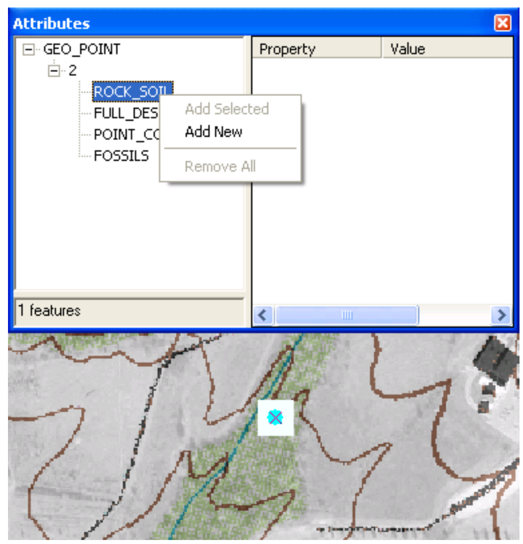


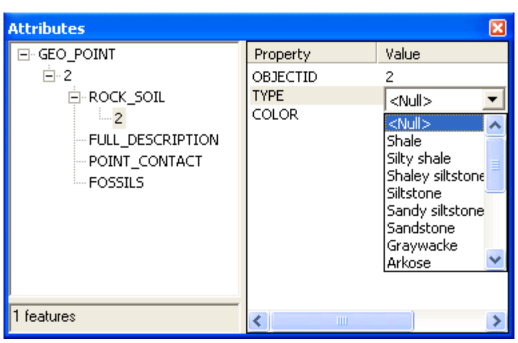
ArcGIS can use an ESRI geodatabase. A geodatabase is an object relational database that contains geographic information and provides services for managing GIS data. These services include validation rules (a dip angle can only be between 0 and 90 degrees) and relationships. In our digital mapping technique, the geodatabase contains a series of feature classes and tables. We will be using a point feature class at this stop. The attribute table for the point feature class has the same fields as the ArcPad shapefile viewed at Stop 1. Also within the geodatabase are tables for storing data depending on the level of description. These tables are related to each other via the Object ID, which you can think of as a station number. One advantage of geodatabase storage is the ability to search all the tables related to the feature class. For example, you could search the feature class for all the stations where a given formation is exposed; even though, the formation name is in a related table and not in the attribute table for the point feature class.

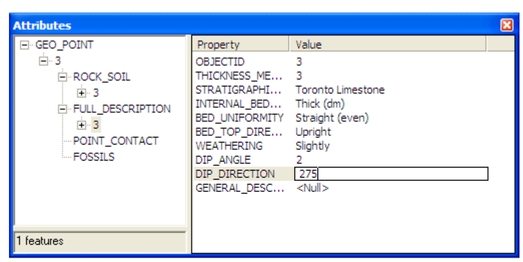
ArcGIS also has a wide variety of edit tools. If, for example, we misplace a point, you can click on the point and drag it to its proper location. The original geographic location stored in the attribute table will not be updated when the point is moved. However, tools are available in ArcGIS to update the attribute table after a point is moved.

As a field geologist I have located an outcrop of the Sheldon Gallery Limestone. First we will note that the unit is limestone and that the color is white. I did not measure the height of the building, so let's assume the Sheldon Gallery Limestone is 3-m thick. The unit is composed of thin beds and the bed surfaces are uneven. We will assume that the unit is upright and that the unit is fresh (no weathering). If we had a dipping unit, we could add the strike and dip, but I assume that it is horizontal in this outcrop.





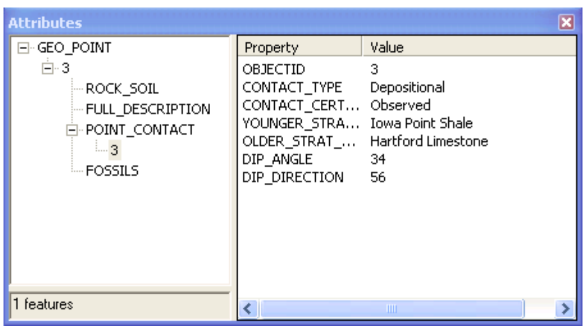




Stop 3: Contact between the Cornhusker Limestone and the Big Red Shale

As we walk over the hill we discover a depositional contact between two geologic units. At this location we have the fictitious Permian Cornhusker Limestone and the equally fictitious Permian Big Red Shale. Here, we have a different type of point. Several reasons

exist for taking this as a point as opposed to a line. This might be the only observed part of the contact at this map location. Additionally, when you finish your mapping, you might want to use this point and others similar to it to make a structure contour map of the bed surface. ArcGIS has tools for contouring data that would allow a geologist to create a structure contour map. The contouring tools in ArcGIS can allow for discontinuities in the contour pattern such as faults. When doing structure contouring, I prefer to have a number of control points where I am sure of the location and elevation as opposed to picking all my points off the contact lines back in the office. The contact point form has fields for object ID (station number), contact type, certainty, and the names of the two geologic units in contact. The contact types include deposition, fault, unconformity, and alluvial. The certainty levels are observed, inferred and concealed. Now clearly, one would not add a concealed contact as a point. However, situations may exist where a geologist might take a contact point that is inferred. The location is good enough to place a point, but not actually observed.

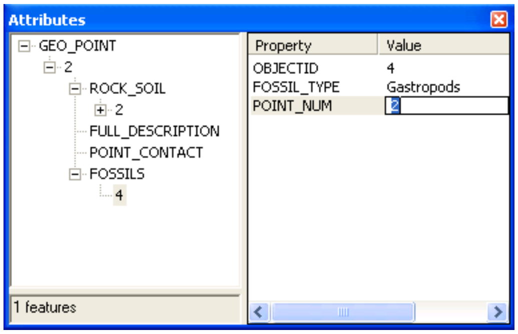


Structure contours require elevation data. At the earlier stops we added elevation data by reading values off the DRG. Although this is a viable method, we are investigating the possibility of getting the elevation from a level 2 Digital Elevation Model (DEM). It may be possible to have ArcGIS query the DEM layer and get the elevation for the 30-m DEM cell that contains the point. This value can then be automatically entered into the form. Again, an issue exists when the point is relocated. The elevation reading in the attribute cell will need to be updated.

We are standing near a contact between the Cornhusker Limestone and the Big Red Shale. The object ID is automatically entered into the form and table. The contact we have is a depositional contact. Someone might argue that the contact is 3 to 30 meters from the base of this outcrop, but I feel we are at an observed location. We enter the names of the younger and older units and we move on to the next location.

Stop 4. Fossils and Multiple Entry Data

Many situations exist where a geologist might wish to collect multiple data entries of a similar feature at the same station, for example, fossil identification. An outcrop might not have any fossils, or it could have a dozens of different fossils. One solution would be to add several fields to the attribute table and label them fossil one, fossil two, and so on. Our solution is to add another table and use a one to many relate. Each fossil entry has fields for the object ID (station number), point number, and fossil



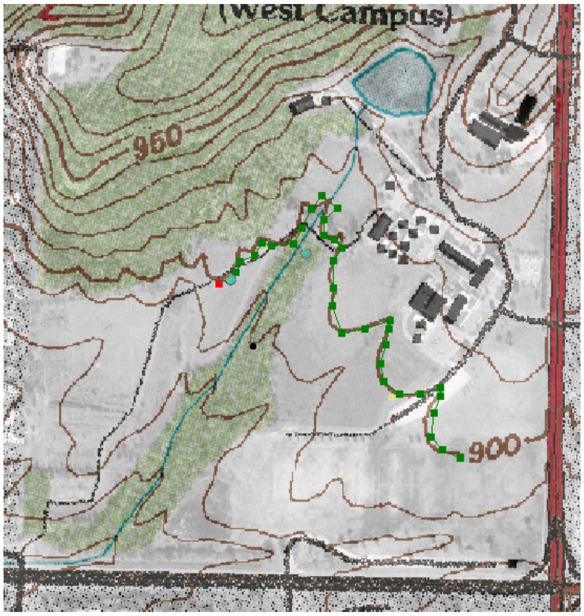
name where the point number is a count of the entries for the station. Other multiple entry features include minerals, and structures. Ohlmacher has a Student Mentor Grant from the AASG this summer and the student is collecting joint orientations in outcrops of the Cretaceous rocks. The student is collecting between 50 and 100 joint measurements per outcrop.

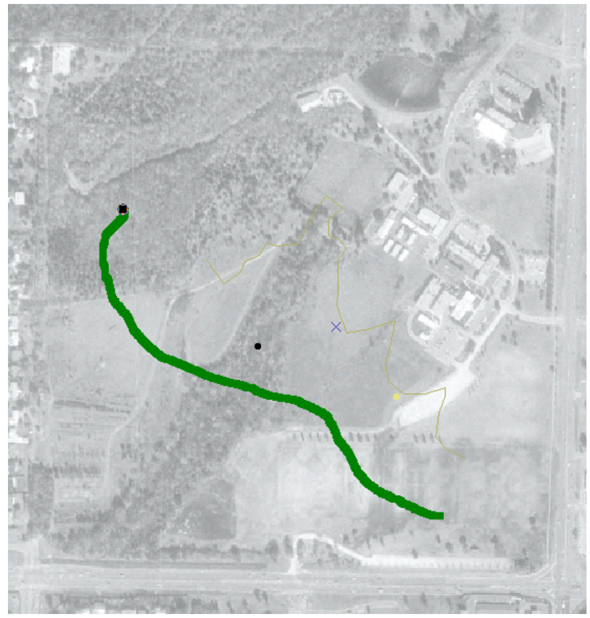
At this stop we will do a full description of the Cornhusker Limestone, some fossils, and record that this is also a contact between the Cornhusker Limestone and the Big Red Shale. This will require us to fill out four separate forms. The first ArcGIS form is the Station Location form where the data are stored in the shapefile's attribute table. We will enter the elevation prior to moving onto the Input Control form. In the input control form we will first select the Type/Color where we will enter the rock type and color (medium gray limestone). After closing the Type/Color form, we will next select the Full Description form and enter a thickness of about 1 meter, the unit name, the internal bedding is thick, the beds are upright, and they are slightly weathered. We will assume that the unit is horizontal. After adding the description of the Cornhusker Limestone, we will add several fossils to the data set. When you press the Fossil button, the fossil entry form opens. The top of the form is the data entry area. The station number is automatically loaded as is the element ID, which contains the next available number. The only entry value is the fossil name. We have seen some brachiopods, echinoderm fragments, and some crinoid stems in this unit. First, we will add the brachiopods. After entering the fossil name, we close the form. The form is then reopened to add the next fossil name and the procedure is repeated until we have entered all the fossils. Again we have another contact between the Cornhusker Shale and the Big Red Shale. So we will finish this station by adding the contact information. We went through the entire procedure here in order to demonstrate the amount of time required to complete a station at a moderate detail level.

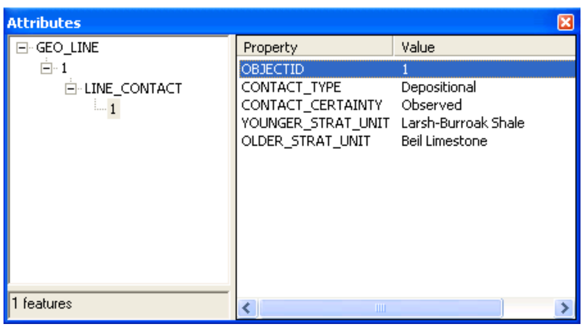
Stop 5: Contact Lines

We now have reached a third outcrop of the Cornhusker Limestone that exposes the contact with the Big Red Shale. At this point it is time to start drawing in a contact line. Two ways exist to draw lines in ArcGIS: point-by-point and freehand lines. The point-by-point method allows the user to place vertices where needed, whereas the freehand method is similar to writing and the program places the vertices. Freehand drawing tends to collect more vertices than necessary increasing the file size.

A wide variety of editing tools are available in ArcGIS. The user can highlight and move individual vertices or replace a line segment with a new segment. The program has an automatic line clean up option that repairs stray vertices and other helpful tools.

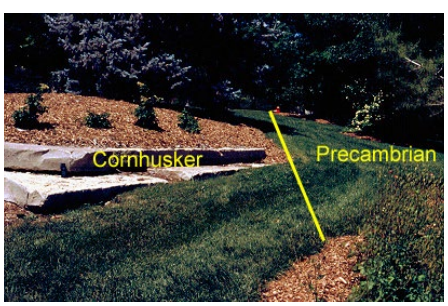




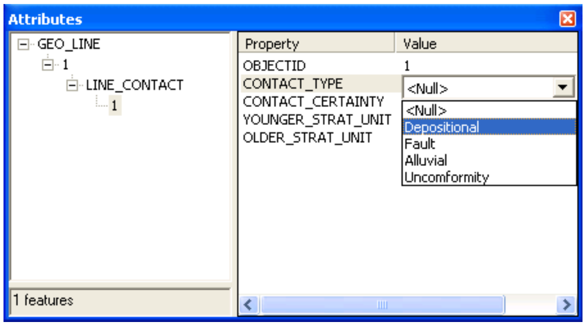


The last three stops have all had contacts between the Cornhusker Limestone and Big Red Shale. Now, it's time to draw and attribute the contact line. The attribute fields for contact lines are the same as those for contact points: line number, contact type, certainty, younger stratigraphic unit and older stratigraphic unit. The line number replaces a station number because lines are not stations. We have assumed that the contact type is depositional. And because the contact disappears between the outcrops we probably should term it inferred. From here the contact continues north around the library to stop 6.

Stop 6: Fault contact and creating polygons.



We have continued to follow along the Cornhusker Limestone contact with the Big Red Shale. However, at this location the outcrop of the Cornhusker Limestone comes to an end. To the east of the Cornhusker Limestone is an area of weathered Precambrian rift rocks and some granite. In the current version of the program, faults are treated as contacts. As work on the technique progresses, we plan to include more information on faults, for example, the fault type, rake of slickenlines, and amount of displacement. For this stop, we plan to use the contact line form and enter the contact type as a fault. We also will complete the contact of between the Cornhusker Limestone and the Big Red Shale. In ArcGIS, lines can be extended by selecting the current line feature and then selecting the modify feature option. Then vertices can be added to the end of the existing line. Another useful feature of ArcGIS is the snapping option. We



intentionally drew the fault in first. The snapping options of the contact line layer can be set so that as we draw the depositional contact line, the last point in the line will snap to the fault line. This provides closure for the contact line against the fault.

The last mapping step to be demonstrated is the creation of unit polygons. ArcGIS offers several ways to draw polygons. The easiest is to allow the program to draw the polygons. For this stop, we have outlined the mapping area with a rectangular polygon. By selecting the outline and the contact lines, the program has a routine that can generate the polygons. Another way to generate polygons is to use the trace tool. In this example the contact lines are selected along with the tracing tool button. The user can follow along the lines and the program uses the vertices of the line to create the polygon. At this point we have not decided how we will attribute the polygons.

For a Kansas Geological Survey project, after a geologist has finished field mapping and cleaned up the lines, the data will be turned over to the automated cartography group. The primary data that the automated cartography group wants are the attributed lines. They will create the polygons and final map. The geologist will use the additional data to create the stratigraphic section and the explanatory text that goes with the map. Additionally, the geologist may wish to write a report on the study area and will be able to refer to the data collected in the field.

Future Work

The digital field mapping technique demonstrated here is in its preliminary phase. A number of additions are planned. The first addition is to add and adjust the existing forms to include the data usually collected by geologist doing county or quadrangle geologic mapping. Next, we will develop specialized forms for different types of maps: landslide inventory maps, structure maps, geomorphology maps, and others. We would like to add the ability to link digital photographs and field sketches of geologic features in the study area to the geologic map files. We also are open to suggestions for additional data that should be collected in the field.

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References Cited

Walker, J. D., and Black, R. A., 2000. Mapping the outcrop. Geotimes, v. 45, no 11, p. 28-31.