Digital Conversion of Geologic Maps
Pendleton County, West Virginia
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GIS Layer Specifications and Project Technical Report

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Table of Contents

Appendices

Introduction

<u>Purpose</u>
This document describes the procedures and specifications for the conversion of hand drawn geologic maps into a geographic information system (GIS). The West Virginia GIS Technical Center (WVGISTC) performed the digital map conversion (Figure 1b) of geologic features drawn by the West Virginia Geological and Economic Survey (WVGES) on U.S. Geological Survey (USGS) 1:24,000-scale maps (Figure 1a).

Figure 1a: Hand drawn geologic features on USGS 1:24,000-scale topographic map

Figure 1b: Geologic map digital conversion

<u>Scope</u>
This project involved seven Pendleton County, West Virginia geologic quadrangles produced under the federal 1:24,000-scale STATEMAP project: Brandywine, Doe Hill, Moatstown, Palo Alto, Snowy Mountain, Spruce Knob and Sugar Grove. This region is significant because igneous intrusions are found in the area.

Need for Better Resolution Geologic Maps
The 1968 geological map of West Virginia is the only seamless geology GIS file that exists for the entire State. Because of its poor spatial resolution and generalized geologic unit representation, it was determined that this 1:250,000-scale geologic map should be updated with more accurate 1:24,000-scale geologic data (Figure 2).

GIS Software
WVGISTC used ESRI ArcGIS version 8.2 software, along with various vector (e.g., ArcInfo coverages, shapefiles, and geodatabase) data formats and raster images (ArcGrid, TIFF) to perform the conversion. During the completion of the project, geodatabase topological tools were under development by ESRI. Therefore, ArcGIS 8.2 topology was built using the ArcInfo coverages format. Newer geodatabase software tools might be used to implement this project in the future, but the conceptual framework remains the same.
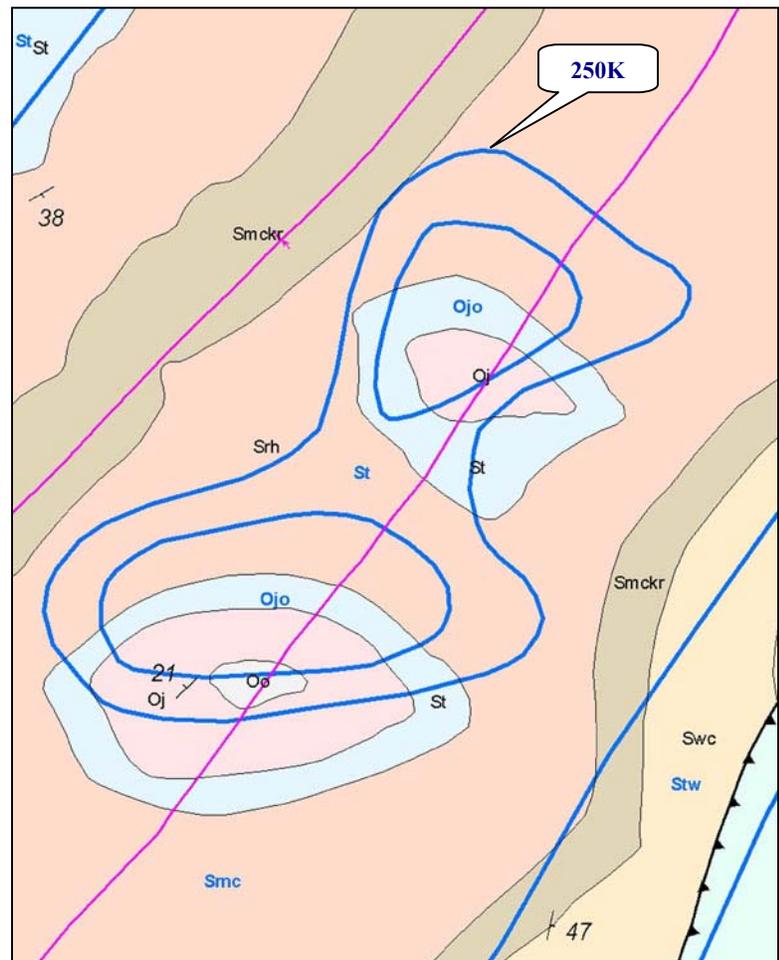
Coordinate System
All GIS layers were cast on the Universal Transverse Mercator (UTM) projection, Zone 17, datum NAD 27, with units in meters.

Figure 2: Comparison of 1:250,000-scale geologic map (dark blue lines and labels) with more accurate 1:24,000-scale geologic map.

Product Deliverables (for WVGES)
1) GIS coverages / shapefiles for layers described below. Layers were named according to feature type and the USGS topographic quads from which they were drawn.
2) Hardcopy plots for quality checking by the WVGES
3) Georeferenced scanned images of topo maps (source data)
4) Georeferenced images of final GIS maps
5) A final report summarizing procedures and accomplishments of the project (this document)

Ownership

All digital and hardcopy products are the property of the WVGES and will be distributed by them on a request basis. This document, which describes methods that may be applicable to other similar projects, is publicly available from the WVGISTC website at http://wvgis.wvu.edu.

Conversion Process

The initial steps of the digital conversion required that the geological information on the topographic map be scanned and georeferenced. Heads up digitizing then captured the vector geological features such as faults, folds, and contacts. After linear or polygon topology was created, features were attributed. Next, attributed features were edgematched to corresponding features of adjacent quadrangles. In the cartographic map production phase, hardcopy or print-ready electronic versions were made with the appropriate symbols and annotation. Throughout the conversion process quality control checks were done (Figure 3).
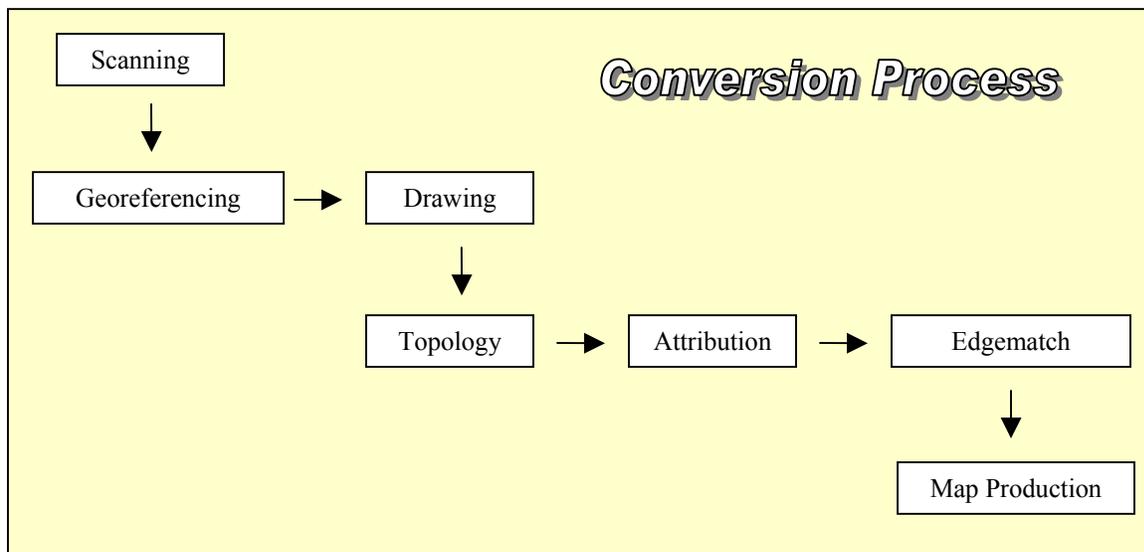

Figure 3: Flowchart of digital conversion process

I. Scanning and Georeferencing 1:24,000 Geologic Quadrangles

A. *Scanning*

Paper topographic quadrangles with hand drawn geologic information, supplied by the WVGES, were scanned directly to RGB color TIFF files using a high-resolution, large format drum scanner at an optical resolution of 250 pixels per inch (Figure 1a).

B. *Georeferencing in ArcMap*

<u>Neatline</u>: The first step in georeferencing, or warping, the TIFF was to generate a neatline coverage with precise corner coordinates. A pre-existing neatline or index grid could also be used as a reference.

Neatline generation involves the following steps:
1) Obtain the coordinates from the topo map corners and convert the latitude and longitude values to decimal degrees.
2) Open *ArcGIS | ArcToolbox* and select *Conversion Tools | Import to Coverage | Generate to Coverage Wizard*. Select the *user input* option and specify *Lines* as the feature class to generate.
3) Assign line ID numbers and enter the corner coordinates in decimal degrees as vertex coordinates, including the minus sign for the longitude (X coordinate).

Once the coverage was generated *ArcToolbox | Define Projection Wizard (coverages, grids, TINs)* was used to set the projection information explicitly to geographic, decimal degrees, NAD 1927. Then the *ArcToolbox | Project Wizard (coverages, grids)* was used to re-project the coverage to Universal Transverse Mercator (UTM), North American Datum (NAD) 1927 to match the native projection of the topo map.

Note: Re-projecting introduced small positional offsets of 0.2 – 2.0 meters in the corner / edge positions. It may be desirable to use a seamless index grid for the entire mapping area rather than a quad-by-quad approach for georeferencing. However, appending single quads into a mosaic, using a fuzzy and snap tolerances of 1.0 meters, should eliminate the corner / edge offsets. The integration and cluster tolerance settings available with geodatabases should also be effective in matching up coincident features.

<u>Georeferencing</u>: The scanned geologic quadrangle map was georeferenced in the ArcMap environment to the UTM NAD 1927 neatline coverage in a new map project (see instructions given in ArcMap Help for "*Georeferencing a raster dataset")*. The "Autoadjust" feature in ArcMap | Georeferencing was deactivated while establishing links for corner placement. It was reactivated once the links were in place and we were ready to move the georeferenced raster.

II. Capturing Geologic Features

A. *Preparation*

A blank shapefile was created for every geologic GIS layer before digitizing began. This is done in ArcCatalog by browsing to the appropriate (e.g. same as quad name) directory, right clicking and selecting *New | Shapefile,* filling in an appropriate label / name, setting the feature type (i.e. polyline) and editing the coordinate system to UTM NAD27.

Notes: A neatline boundary was required to close the polygons at the USGS 7.5-minute quadrangle boundary.

Consult ArcMap Help under the topic "Creating lines and polygons" for specifics on digitizing features, while following the feature sequence discussed below. Collect all linear features by placing vertices close enough to smoothly follow the original curves and minimize the jagged appearance that can result from too few vertices.

Digitizing Tips
  ➢ Use Ctrl + C and the left mouse button to pan while drawing.

  ➢ Snapping environment: Make sure that end and / or vertex snapping, where appropriate, is on in the *ArcEdit | Snapping* menu to reduce the likelihood of undershoots or dangles, or to maintain coincidence between features.

  ➢ Outside Edge: Extending the lines outside of the neatline when drawing will allow for them to later be clipped and snapped exactly to the neatline coverage. If they are drawn exactly to the neatline it is important that snapping be set to "edge."

  ➢ Arc Directionality: Direction matters! Arcs for linear features such as faults and folds have a directional component to correspond with the correct mapping symbols for printed maps. Note that some feature symbols are not symmetrical, e.g. thrust faults with "saw teeth" to one side only, or have directionality, e.g. plunging fold axes. Features can be flipped after drawing using the Editor, or they can initially be drawn in the correct direction to save the extra step.

  ➢ Pseudonodes: Keep pseudonodes to a minimum to accelerate topology building. Add pseudo nodes at intentional locations to aid in the logical placement of map labels.

B. *Feature Collection Sequence*

1. Faults (Line features)
Faults, which often are coincidental with geologic formation contacts, were collected first. The fault vectors were then copied to a new layer and extended, split or trimmed to form complete contact arcs. This method ensured that the coincident faults and contacts have the same vertex coordinates. Faults were drawn on the paper maps as solid, dashed, or dotted lines to indicate the confidence in their placement. Thrust faults were distinguished from others by the added "saw tooth" line decoration (Figure 4). Relative motion along fault lines was indicated by 'U' (up) or 'D' (down) on the map. This motion was included in the final map as annotation.

2. Geologic Formation Contacts (Line and Polygon)

Surface bedrock geology was mapped according to its geologic time period, i.e. Eocene, Mississippian, Devonian, Silurian or Ordovician, and geographic type location, i.e. Marcellus shale, Oriskany sandstone, Tonoloway limestone, or Juniata formation (a group of several related rock types). The "contacts," lines separating different geologic units, were drawn solid, dashed or dotted, according to confidence, as with faults. Care was used in interpreting the confidence value of contact lines that coincide with faults. Geologic formation contacts were collected as lines, which were then used to create formation polygons during the topology building and attribution phases. The polygons formed by the contacts were labeled with the letter symbols used to represent the geologic units, i.e. "Do", for Devonian Oriskany, or "Sto" for Silurian Tonoloway limestone.

3. Folds (Line)

Fold axes were distinguished from other lines by their double-headed arrow symbols; arrows pointing out for anticlines (convex upward folds) and in, toward the axis line, for synclines (concave upward folds). A terminal arrow on one or both ends of the axis line itself indicates plunge. The confidence symbology used for faults and contacts applies to this layer.

4. Bedding Orientation (Point)

The orientation of rock layers was measured at various outcrops and depicted on the geology maps using strike and dip symbols. These points were first given arbitrary station numbers on paper, beginning at the north end of the quadrangle and proceeding south, left to right. Station numbers and dip angles were typed into the appropriate fields in the shapefile attribute table. Once the points were collected, the table was opened in a spreadsheet application (Excel), edited to remove extraneous fields, and then delivered to WVGES for a quality check of the azimuth and dip angle and direction data.

Figure 4: Digitized geologic features: formation units, faults, folds, dikes, strike/dip measurements, and cross-sectional lines.

5. Cross Sections (Line)

These lines were drawn where geologists plan to make more extensive subsurface interpretations of the surface geology. They are marked with letters at each end, e.g. A—A', B—B'. Confidence levels do not apply to these features.
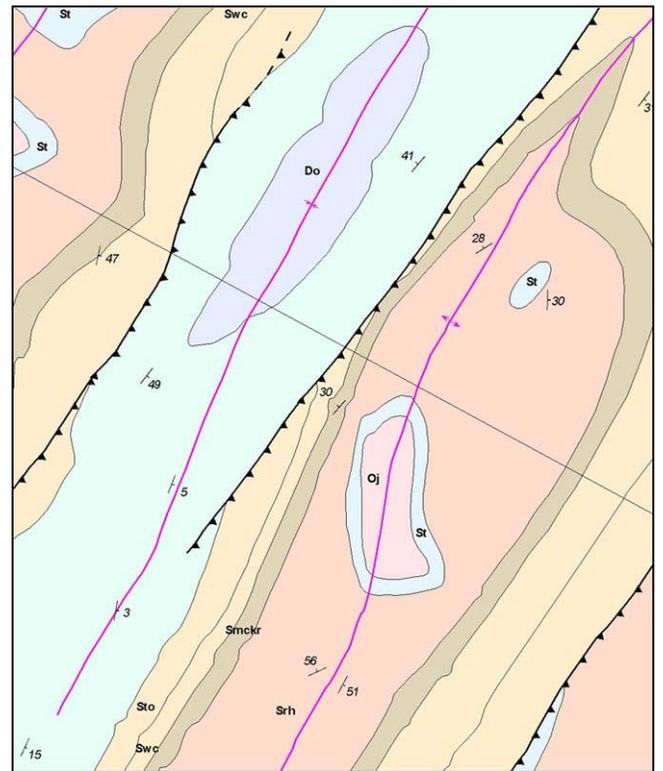
C. *Building Topology and Resolving Geometric Errors*

Topological association is the spatial relationship between features that share geometry such as boundaries and vertices. If topological associations are defined, for example, before you do an edit of a shared boundary between a fault and geologic contact, then the shapes of each of those features is updated.

Before attribution began, "clean" topology was built for all adjacent linear and polygon features using specified tolerances. Faults and folds have linear topology while contacts have both linear and polygon topology.

GIS layers were checked using topological tools in order to detect problems such as duplicate features, line under-shoots, dangles and missing or duplicate polygon labels. ArcInfo routines were employed to detect and fix topological errors. Listed below are the ArcInfo commands used for building topological associations, checking for geometric or attribute errors, and creating new fields for attribution:

1) Combine the neatline coverage with the converted contacts coverage using APPEND with the NOTEST switch, since the contact lines shapefile lacks attributes.

2) Run the CLEAN and BUILD commands, then select the dangles in ArcEdit and delete them. Check visually to make sure that only dangles outside the neatline are selected before deleting. Re-run BUILD after deleting dangles. There should be no dangle errors after the above steps. Check this with NODEERRORS.

3) For polygon topology, add label points to the formation polygons using CREATELABELS. New fields can be added to the attribute table using ADDITEM. The field name, width, output and type are specified as arguments to the command. It may be useful to assign the name of a formation found frequently throughout the quad map to all polygons initially, then update the name in the ArcMap environment. This is accomplished in the ArcEdit environment using "SELECT" and "CALC".

4) If necessary, build line topology (Arc: BUILD line) to enable the addition of attribute fields for line TYPE, i.e. neatline (-99) and CONFIDENCE (1-4) using the ArcInfo ADDITEM command.

5) Copy the coverage, if necessary, to the ArcMap workspace using ArcCatalog and add the appropriate feature classes, e.g. line, polygon, to the ArcMap project.

Notes:

ArcInfo workwas done in a separate workspace from that in which the ArcMap project was built, to reduce the likelihood of corrupting current coverage versions. The corrected coverages then were copied to the ArcMap workspace using ArcCatalog.

The newer ArcGIS version 8.3 has topological tools in the ArcMap Editior so that ArcInfo topological tools are no longer needed. Because version 8.3 was not available at the start of this project, shapefiles generated for this project were converted to coverages for topological processing in ArcInfo. Use the SHAPEARC command or ArcToolbox |Conversion Tools | Shapefile to coverage for this purpose. Also note that coverages cannot be edited in ArcGIS 8.3.

III. Feature Attribution and Associated Symbols

Map features were first drawn and "cleaned" before adding attributes. Certain features like faults and geologic contacts had to be collected in the proper sequence because of shared locations.

A crucial element in the processing and representation of abstracted map data through a GIS is the assignment of attributes to spatial features. Attributes function directly when querying features on-line and indirectly by controlling cartographic symbol styles in electronic and hardcopy maps. See the GIS layer descriptions (GIS data dictionary) in Appendix I for a full list of attribute fields, data types and value ranges.

Attribute fields can be added to feature attribute tables (and initially populated) using appropriate commands in ArcInfo, or by using the ArcMap and / or ArcCatalog table editing tools. Coverage tables in this project were set up initially in the ArcInfo environment but most table editing was done in ArcMap. Once the fields were established they were populated in one of several ways:

1) Select records in command line Arcedit and CALCulate values en mass

2) Select features in an ArcEditor session, open the attribute table and type in values, the method used for most features

3) Import data from an external table (JOIN). This method was used for bedding point data

The methods described below use modified versions of the Geology 24K symbol set included as part of ArcGIS / ArcMap 8.x.

A. *Polygon Features*

Attribution
The "NAME" attribute field was added to the contact coverage polygon feature class in ArcInfo and all polygons were assigned the name of a frequently occurring formation (see Section II above). To change the polygon name to the correct value we used the Editor toolbar in ArcMap (see the stratigraphic column legend in the Appendices for a list of formations in the study area):

1) Start editing and choose the appropriate target edit layer (this should be an ArcInfo workspace) in the selection dialog.

2) Use the Edit arrow tool to select individual polygons.

3) Open the attribute table using the "Attributes" icon on the Editor toolbar. Make sure you have selected a polygon and not an arc (line). The attribute fields will be different.

4) Select the current value in the "NAME" field and type in the correct (text) value specified in the original geologic quadrangle. Hit Enter to accept the value.

Symbology
Polygons were labeled in the maps with the "NAME" field. The scale in ArcMap was set to the nominal value of 1:24,000 before applying the font style and size of Arial 8pt bold.

Polygon color assignment was generally based upon the 1968 (1:250,000 scale) Geologic Map of West Virginia, when formations matched those of the new 1:24,000 scale geologic maps. Units unique to the 1:24,000 maps were assigned colors according to the Federal Geographic Data Committee (FGDC) Public Review Draft – Digital Cartographic Standard for Geologic Map Symbolization. Color CMYK values were adjusted where necessary to create a sufficient number of gradations within given geologic systems (Appendix II).

B. *Arc (line) Features*

Attribution
The process for adding attribute values to lines was similar to that for attributing polygons. Contact, fault and fold line features have several fields related to confidence and symbol style. These fields are short integer with, in the case of CONFIDENCE, increasing values indicating greater uncertainty, e.g. 1 = certain, 2 = approximately located, 3 = inferred, 4 = inferred, queried. The TYPE field in the contact arc feature class is used to distinguish neatline (-99) from contact (1). Symbol field values were compiled from one or more other fields. For example, the contact arc symbol field may

have a value of 12, indicating type = 1 (contact) and confidence = 2 (approximately located).

Symbology
Line features were symbolized according to the confidence associated with the original geologic map features. Solid lines indicate a confidence level of "certain," while dashed, dotted and question mark ('?') symbols indicate "approximately located," "inferred" and "inferred, queried," respectively.

C. *Point Features*

Attribution
Bedding orientation was the only user-attributed point in the geology GIS project. These points were identified after collection using arbitrarily assigned (by WVGISTC) station numbers. The numbers generally trend left - right, top – bottom across the original geologic quadrangle. Rock type and bedding orientation were recorded by WVGES field geologists at the point locations. The horizontal direction, or strike, of the rock layer is recorded as an AZIMUTH value, which was used in the advanced symbol properties of ArcMap to rotate the bedding symbol in the map. DIP_ANGLE, a measure of the rock's tilt downward and perpendicular to strike, was displayed in the map as a feature label, though it was first converted to annotation in order to position it correctly relative to the bedding symbol. The SYMBOL field contains one of four values: 1 = horizontal, 2 = inclined, 3 = vertical and 4 = overturned.

Symbology
The ArcMap Geology 24K symbol set contains icons for the four bedding orientations (see Point Features, Attribution, above) used in the geologic quadrangles. The size of all symbols used in this project was adjusted for greater cartographic clarity.

D. *Annotation Hints*

Portability and long-term usefulness of the annotation and symbols related to the GIS map files, are enhanced by following these steps:

1) Convert labels to annotation feature classes that are separate of the map files
2) Create ESRI Layer files that store legend and symbol information
3) Use templates to transfer the textual and graphical information in the map collars from one map to another

IV. Edgematching

Geologic features were mapped by the WVGES and digitized by the WVGISTC in discrete quadrangles. Polygons and linear geological features should, however, match seamlessly across quad boundaries. The 1:24,000-scale geological GIS files will eventually cover all of West Virginia, further emphasizing the need for seamless integration of all quadrangles.

WVGES personnel edgematched the original hardcopy maps and provided, in some instances, additional hard copy overlays for areas extensively re-drawn. The WVGISTC edgematched the digital files by opening the matching arc or poly line layers for adjacent quadrangles, zooming in to lines that cross boundaries, and using spatial adjustment tools in ArcEditor to select arcs and adjust vertices. In Figure 4, polygons intersect the quadrangle boundary; the center polygon is offset to the east (right) in the upper quadrangle, relative to the lower one. The figure shows the quadrangle vectors drawn to meet approximately half-way between the original map lines.
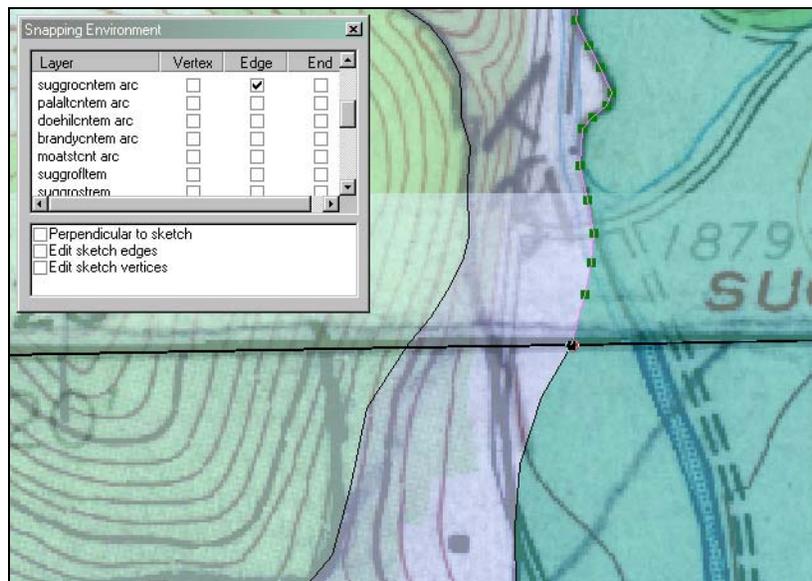

Figure 4: Shared edit of an arc representing a geological formation contact. Upper quad contact arcs are east relative to matching arcs of lower quad. Note "edge" snapping is "on" for editing layer to prevent undershoot / dangle.

Multiple geological formations have, in some cases, been separated by geologists in one quadrangle but mapped in adjacent quads as a single, combined unit. Figure 5 is an example of this. The same polygon color can be used for both the combined and separated formations, thus simplifying the visual aspect of the map while preserving geological detail in the GIS. The neatline edge will serve as the boundary between two different geological contact units.
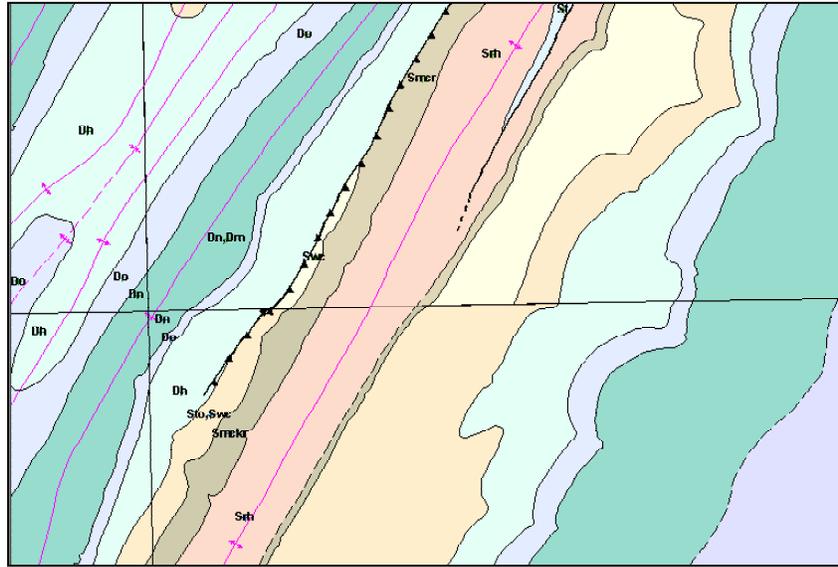
Figure 5: Combined Sto, Swc (lower) and separated Sto and Swc formation polygons (above) at quadrangle boundary.

V. Coincidental Features

Geological features such as folds and faults share common boundaries (Figure 6). Special consideration must be given to the sequence of digitizing (Section III-B) and subsequent editing of coincidental layers. Coincidental features can be moved a number of ways.

1) *Snapping Environment:* Snapping is the process of moving a feature to coincide exactly with coordinates of another feature within a specified snapping distance or tolerance during an edit session. Set the snapping properties in the Editor tool bar so that the vertices of one feature class can snap to those of another. To move coincident features, first move the vertices of one feature to the new location, then adjust those of the other feature until they "snap" to the first.

2) *Map Topology:* A topology that you can impose upon simple features (shapefiles or geodatabases) on a map during an edit session. Set up temporary relationships between coincidental parts of features based on the cluster tolerance, the distance within which features will be shared.

Figure 6: Shared boundary between thrust fault and geologic contacts.

3) *Geodatabase Topology:* Set up permanent spatial relationship rules between feature classes in a feature dataset. This option requires ArcGIS version 8.3.
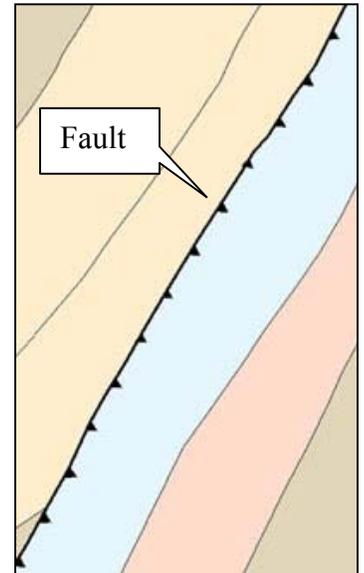
GIS tools are available to edit shared or unshared geometry while maintaining attributes. For example, the Shared Edit tool is used for changes affecting multiple layers, whereas the Edit tool works for features on a single layer (Figure 7).
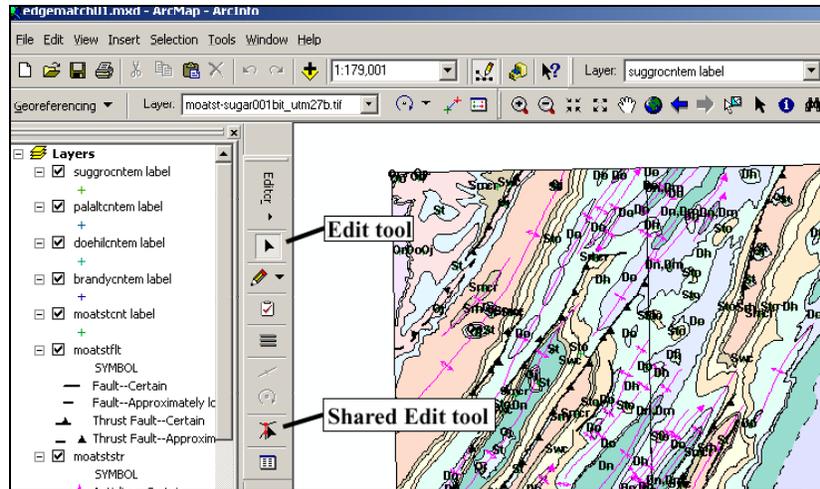

Figure 7: ArcEditor 8.2 Shared Edit tool

VI. Printing

Both hardcopy and print-ready electronic versions (e.g., Adobe .PDF, TIFF) of the geologic maps were made. Electronic versions include the map collar information and can be georeferenced and utilized in a geographic information system.

The hardcopy maps created during this project were printed directly from ArcMap to Hewlett-Packard 5500 or 3500CP large-format color printers using PostScript drivers. Some trial and error may be necessary to obtain the desired quality in printer output. The symbol styles and sizes used in the maps were adjusted with print quality in mind after reviewing test copy.

After mapping has been finished, the client may want to export the data layers to a graphical editing package for publishing. Vector graphical software like Adobe Illustrator may allow the user more control over colors and symbols (Figure 8). Since illustrator packages do not recognize georeferencing, layers must be exported with a cross-hair or some
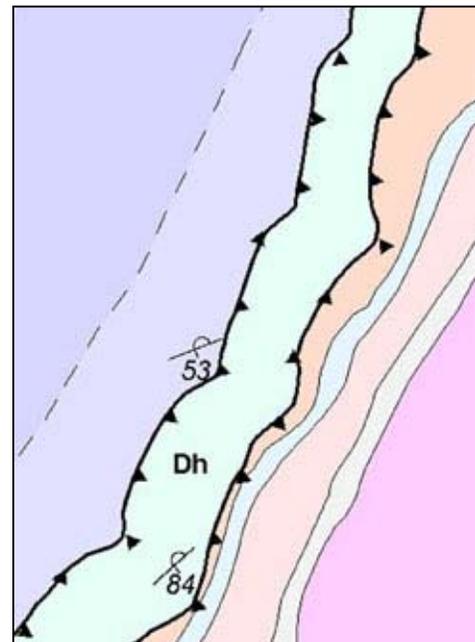

Figure 8: Computer artifact? Occasionally saw teeth of ArcGIS thrust fault symbol become detached.

other identifying mark to align the layers together in the graphical software.

The transparency property for layers in ArcGIS is quite useful for reducing the intensity of all polygon colors without re-adjusting each one separately. Transparent hillshading is another way to enhance map topography (Figure 9) and its relation to the surface geology.
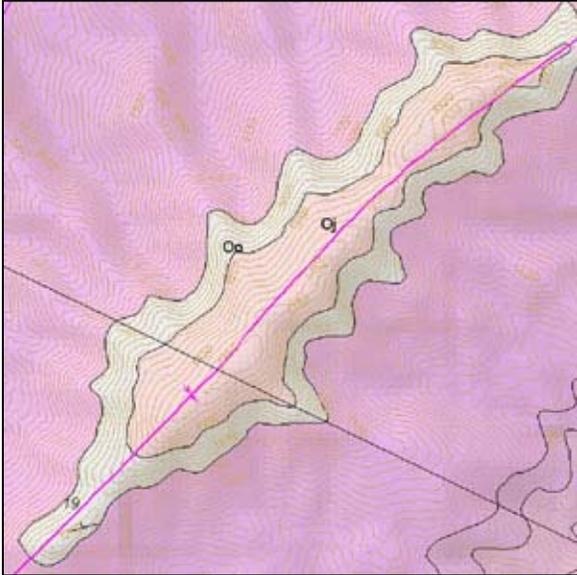
Figure 9: Geological map with hillshading to enhance relief.

VII. Quality Control

The following quality control measures were undertaken during the conversion process:

Positional Accuracy: Verified that scanned geological maps were georeferenced correctly with other correctly referenced layers such as digital topographic rasters or quadrangle index layers.

Topology: Linear and polygon geometric errors (e.g., undershoots, dangles) and polygon label errors (e.g., duplicate or missing labels) were checked and fixed.

Content:
Digitized overlays were checked with scanned source material. Hardcopy check plots were printed using paper or transparent media

Edgematch: Visual check of edge-matched layers

Database Integration: Merge all quads together using the APPEND function to verify database fields are compatible.

VIII. Future Directions

Suggestions for future geological conversion projects:

- Migrate to an ESRI Geodatabase format for enhanced topological and shared editing functions. Another advantage of the geodatabase is that it models complex behaviors of objects better than the coverage format through the implementation of domains, subtypes, and validation rules.

- Store annotation in separate layers than geographic data to improve portability of symbols and text (Appendix III). Annotation stored in a separate layer refreshes more quickly on the computer screen.

- Integrate 1:24,000-scale (24k) geologic layers into the 1:250,000-scale (250k) statewide geological statewide spatial database. Suggested steps:

  1. Standardize 24k and 250k spatial databases for conflation.

  2. Mosaic (append) contiguous 24k quads together.

  3. Dissolve quadrangle boundary lines. The user may choose to keep a linear boundary separating the 24k and 250k data.

  4. Build clean topology for all adjacent linear and polygon features using one-meter tolerances.

  5. Replace (erase and copy) 250k spatial data with 24k data.

  6. Edgematch geometry and attributes between 24k and 250k spatial data.

  7. Build clean topology for all adjacent linear and polygon features using one-meter tolerances.

- Consider maintaining geographic data sets in double precision coordinates and a single format (e.g., geodatabase) through all stages of the digital conversion to minimize the introduction of positional errors.

Appendices

Appendix I: Geology GIS layer descriptions (Data Dictionary)

The various data layers of the Geology GIS are described below. Rigorous topological analysis was performed only for the geological contacts coverages.

Note: The first six characters of the quad name plus a three-character layer descriptor were used to form layer filenames.

A. Features with polygon and line topology

Layer: **Geological Formation Contacts**
Layer file name: BRANDYCNT
Layer type: ESRI Coverage
Arc attributes:
       TYPE: i4
           -99 = neatline
           1 = Contact
       CONFIDENCE i4
           1 = Certain
           2 = Approximately located
           3 = Inferred
           4 = Inferred, Queried
       SYMBOL i4
           -99 = neatline
           11 = Contact, Certain
           12 = Contact, Approximately located
           13 = Contact, Inferred
           14 = Contact, Inferred, Queried
Polygon attributes:
       NAME c16

B. Features with line topology

Layer: **Faults**
Layer file name: BRANDYFLT
Layer type: ESRI Shapefile
Arc (Line) attributes:
       NAME c24
       TYPE i4
           1 = Normal
           2 = Thrust
       CONFIDENCE i4
           1 = Certain
           2 = Approximately located
           3 = Inferred

        4 = Inferred, Queried
SYMBOL i4
        11 = Normal, Certain
        12 = Normal, Approximately located
        13 = Normal, Inferred
        14 = Normal, Inferred, Queried
        21 = Thrust, Certain
        22 = Thrust, Approximately located
        23 = Thrust, Inferred
        24 = Thrust, Inferred, Queried

Layer: **Structural Axes**
Layer file name: BRANDYSTR
Layer type: ESRI Shapefile
Arc attributes:
    NAME c24
    TYPE i4
        1 = Anticline
        2 = Syncline
        3 = Anticline, Overturned
        4 = Syncline, Overturned
    CONFIDENCE i4
        1 = Certain
        2 = Approximately located
        3 = Inferred
        4 = Inferred, Queried
    PLUNGE i4
        0 = Non-Plunging
        1 = Plunging
    SYMBOL i4
        110 = Anticline, Certain
        120 = Anticline, Approximately located
        130 = Anticline, Inferred
        140 = Anticline, Inferred, Queried
        111 = Plunging Anticline, Certain
        121 = Plunging Anticline, Approximately located
        131 = Plunging Anticline, Inferred
        141 = Plunging Anticline, Inferred, Queried
        210 = Syncline, Certain
        220 = Syncline, Approximately located
        230 = Syncline, Inferred
        240 = Syncline, Inferred, Queried
        211 = Plunging Syncline, Certain
        221 = Plunging Syncline, Approximately located
        231 = Plunging Syncline, Inferred
        241 = Plunging Syncline, Inferred, Queried
        310 = Overturned Anticline, Certain
        320 = Overturned Anticline, Approximately located
        330 = Overturned Anticline, Inferred
        340 = Overturned Anticline, Inferred, Queried
        410 = Overturned Syncline, Certain
        420 = Overturned Syncline, Approximately located
        430 = Overturned Syncline, Inferred
        340 = Overturned Syncline, Inferred, Queried

Layer: **Igneous Intrusive Features**
Topology: line
Layer file name: BRANDYILN
Line attributes:
        CONFIDENCE i4
                1 = Certain
                2 = Approximately located
                3 = Inferred
                4 = Inferred, Queried

Layer: **Cross Section**
Layer file name: BRANDYXSC
Arc attributes:
        NAME c9 (sample:brandy001)

C. Features with point topology

Layer: **Bedding Strike and Dip**
Topology: point
Layer file name: BRANDYBED
Point attributes:
        STATION i4
        AZIMUTH i4
        DIP_ANGLE i4
        DIP_DIRECTION i4
        SYMBOL i4
                1 = Inclined
                2 = Horizontal
                3 = Vertical
                4 = Overturned

Appendix II. Cartographic symbol legend

Legend

NAME

▮	Ei
▮	Pp
▮	Mmc
▮	Mg
▮	Mp
▮	Dhs
▮	Df
▮	Db
▮	Dn,Dm
▮	Do
▮	Dh
▮	Sto
▮	Stowc
▮	Swc
▮	Smcrk
▮	Srh
▮	St
▮	Oj
▮	Oo
▮	Or
▮	Odr
▮	On
▮	Ou
▮	Onm
▮	Ob

Bedding Orientation

⊕   Horizontal

├   Inclined

┼   Vertical

⸶   Overturned

Faults

——— Fault--Certain

– – – Fault--Approximately located

- - - - - Fault--Inferred

- - -?- - Fault--Queried

▲——▲ Thrust Fault--Certain

▃ ▲ ▃ Thrust Fault--Approximately located

▃▲- -▲ Thrust Fault--Inferred

▃▲-?-▲ Thrust Fault--Queried

Structural Axes

——╪— Anticline--Certain

– ╪ – Anticline--Approximately located

- -╪- - Anticline--Inferred

——ᴜ— Overturned Anticline--Certain

——╪— Syncline--Certain

– ╪ – Syncline--Approximately located

- -╪- - Syncline--Queried

——╪—▶ Plunging Anticline--Certain

——╪—▶ Plunging Syncline--Certain

Formation Contacts

– - – - – Neat Line

——— Contact--Certain

– – – Contact--Approximately located

Intrusive Features

——— Dike--Certain

– – – – Dike--Approximately located

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Appendix III. Feature Linked Annotation

A. Attribute field-based annotation

Below is a review of the steps used to create standalone annotation feature classes that are independent from the ArcMap project in which they are created. Storing annotation in this manner allows the same annotation to be used, with some limitations, in multiple maps. Refer to these ESRI publications and online help for more information: *Building a Geodatabase* and *Geodatabase Workbook*.

1. Create a new empty geodatabase in ArcCatalog by right-clicking in the desired folder and selecting New | Personal Geodatabase from the menu.

2. Import a layer to the new geodatabase (or export a layer to it) with an extent large enough to include all data that you plan to add. A 1:24,000-scale quadrangle index for all of West Virginia was used for this project. There are several import/export wizards to facilitate adding data to a geodatabase.

3. Import (or export) the layer you wish to annotate to the geodatabase as a standalone feature class. Default options in the wizard are generally correct.

4. Open ArcMap and add the feature class created above.

5. Zoom to this layer in ArcMap, then set the scale to the intended reference scale for the annotation, i.e. 1:24,000. Be sure to use the same scale each time you create annotation that you want to look the same in the final map(s).

6. Open the properties for the target layer and set the appropriate label options, i.e font, style, position, overlap. Click the label check box on and click OK (alternately turn on labels using the right-click menu.

7. Once you have the labels displayed correctly, right-click the layer in the ArcMap table of contents and choose "Convert labels to annotation..." Click the option to place the annotation "In the same data base as the features and automatically linked to them". Edit the default feature class name, if desired, then click OK to complete the process.

B. Feature annotation unrelated to attribute fields

The procedure for creating annotation that is not derived from existing feature attributes, such as indicators of relative fault block motion ('U', 'D'), differs somewhat from the steps listed above. Follow the steps below to create non-feature linked annotation:

1. Consider closing ArcCatalog before you proceed as it may hinder the process of creating and accessing the annotation feature classes you create. Set a "New

Annotation Target" in the Drawing menu on the left end of the tool bar at the bottom of the ArcMap window. Choose the option to store the annotation in a database, not in the map, then navigate to the correct geodatabase, select it, enter an appropriate name for the new feature class (i.e. "moatstflt) and set the reference scale (24,000). When you click OK the annotation feature class should appear in the ArcMap table of contents.

2. Set the "Active annotation target" in the Drawing menu to the layer that you created.

3. Start editing the layer in ArcMap.

4. Open the Text tool from the lower tool bar. Make sure that the correct layer is selected in the Edit menu, and that "Create new feature" is selected in the Edit Task menu. Pick up the Text tool from the tool bar, place its cursor where you want text to appear and type in the desired text. Hit the return key to finish typing and click Edit | Save Edits.

5. Use the manipulation tools from the Edit tool bar to position and rotate the text object.