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Creating Geologic Maps for the Appalachian Plateau in a GIS Environment

By Jane S. McColloch and Gayle H. McColloch, Jr.

West Virginia Geological and Economic Survey
1 Mont Chateau Road
Morgantown, WV 26508-8079
Telephone: (304) 594-2331
Fax: (304) 594-2575
email: *janemc@geosrv.wvnet.edu*, *mccolloch@geosrv.wvnet.edu*

Introduction

West Virginia Geological and Economic Survey (WVGES) has been collecting, archiving, and, more recently, developing digital databases of geologic and mineral resource data in West Virginia for many years. The extraction of petroleum resources in West Virginia began in 1859, and development of a digital oil and gas database at WVGES was initiated in the 1960s. Large-scale coal mining began in West Virginia immediately following the Civil War, and it has generated a wealth of coal resources and mining information. The Coal Bed Mapping Program (CBMP) and its predecessor the Coal Resources and Pollution Potential Study are sources of much pre-interpreted mineral resource information that has provided a starting point for our mapping. The structure of the Pittsburgh coal, shown in Figure 1, is an example of the large amount of coal resource information available at WVGES. Coal resource maps and GIS coverages have been created for 42 minable or potentially mineable coal beds in West Virginia. The WVGES Oil and Gas database, which contains information about more than 140,000 oil and gas wells, is another useful source of data. Locations of wells included in this digital database are shown in Figure 2. This information has enabled us to complete two or three quadrangles per year in data-dense areas. Even without this preprocessed information, given reasonable data density, the procedures described below represent a reasonable strategy to develop geologic maps in a GIS environment.

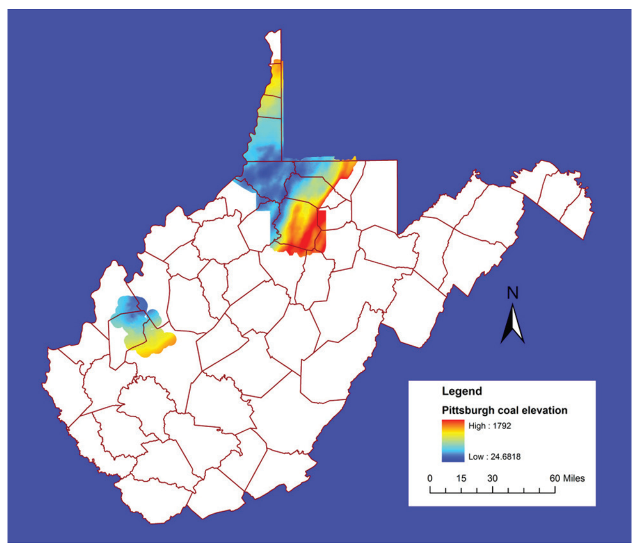

Figure 1. Structure of the Pittsburgh coal, which forms the base of the Upper Pennsylvanian Monongahela Group. The colors represent elevation of the base of the coal. Elevations range from less than 24 feet above sea level in the center of the basin (represented by the deepest blue) to 1792 feet above sea level (represented by the brightest red). Only those data from the minable extent of this coal are shown; the apparent gap in data in western West Virginia is because this coal is not economically minable there.

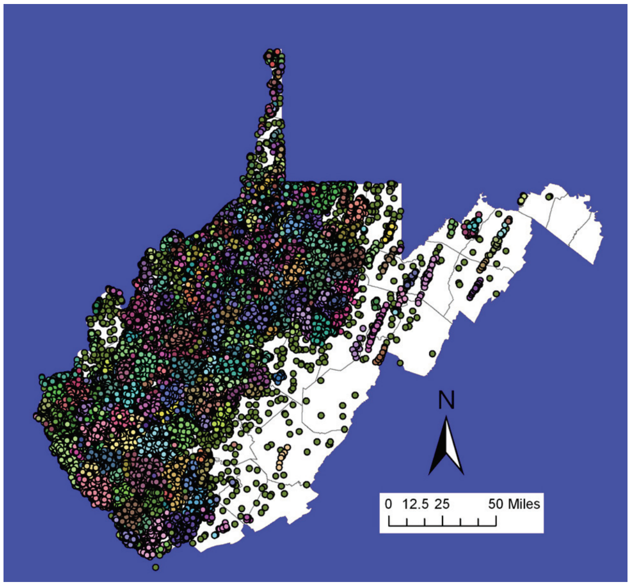

Figure 2. Locations of the more than 140,000 oil and gas wells contained in the WVGES Oil and Gas database.

Methodology

Geologic mapping in relatively flat-lying rocks of the Appalachian Plateau involves tracing important marker beds that are coals, sandstones, or other geographically extensive units. Pennsylvanian unit boundaries are frequently associated with coal beds. For example, the base of the Upper Pennsylvanian Monongahela Group is the base of the Pittsburgh coal bed (Figure 1) and the boundary between the Washington and Greene Formations of the transitional Upper Pennsylvanian-Lower Permian Dunkard Group is the base of the Jollytown coal bed (Figure 3).

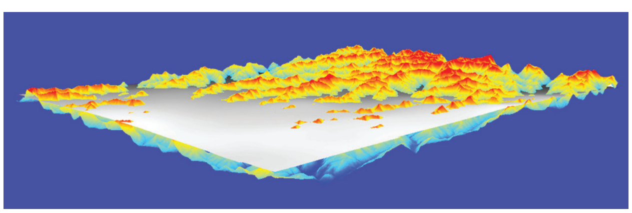

Figure 3. The Jollytown coal bed is the horizon that divides the Washington and Greene Formations of the transitional Upper Pennsylvanian-Permian Dunkard Group. The Jollytown coal bed structure on the Mannington 7.5-minute quadrangle is represented as the gray surface. This horizon was extrapolated above the underlying Washington coal bed by adding a fixed interval to the elevation grid. (A more sophisticated approach would be to record the interval at observation points and to compute the irregular surface.) The colored surface is the 1/9 arc-second-resolution digital elevation model; warm colors represent higher elevations and cooler colors represent lower elevations (vertical exaggeration is 3x). By definition, the cropline is the intersection of these two surfaces.

The first priority during a mapping project is to examine coal resources information produced by the CBMP and to identify gaps in data coverage where the important marker beds do not represent economically important resources. Oil and gas data, other data from WVGES files, and collection of additional field data are used to eliminate these gaps. Oil and gas data also provide subsurface information for improving the detail of cross sections.

Croplines of important beds are automatically generated by intersecting the grids representing structure of each bed with the grid representing the topography. This process is accomplished by subtracting the two grid surfaces and generating a zero contour line that denotes the cropline (Figure 3).

Preliminary field maps include the croplines of all critical horizons, as shown in Figure 4, which is a representation of part of the field map for the Mannington 7.5-minute quadrangle. In creating the preliminary field map, three-dimensional geologic data have in effect been reduced to two dimensions. After field maps are generated, the GIS-generated croplines are field checked to verify contacts. During the field check, additional field data are collected for our use and entered into field volumes and databases for future use.

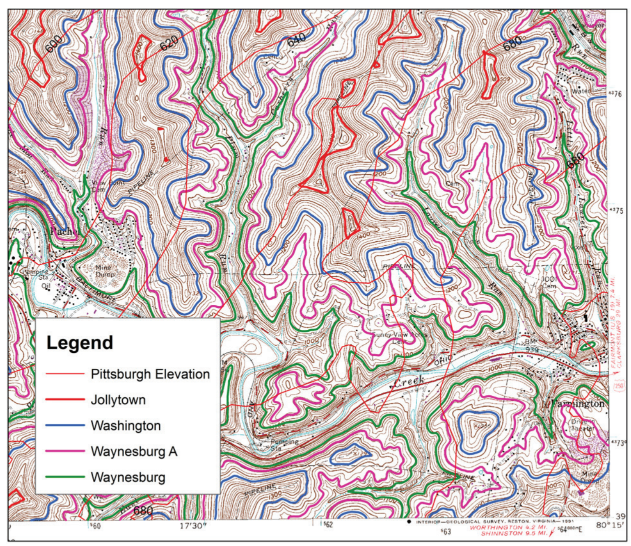

Figure 4. Part of the preliminary field map of the Mannington 7.5-minute quadrangle, showing croplines of critical horizons and the structure of the Pittsburgh coal that is thick and minable but does not cropout on the Mannington quadrangle.

After fieldwork is completed, the linework used to construct field maps is modified as needed, attributed, and built into final GIS datasets that are used to produce geologic maps (Figure 5). Cartalinx, an application produced by Clark Labs in Worchester, MA (*http://www.idrisi.com/products/cartalinx.cfm*), was used for editing, although other GIS editors could also be used. Cartalinx is our preferred editor because it is easy to use and it supports a version of the arc-node topology made popular by ArcInfo. This allows us to create outcrop

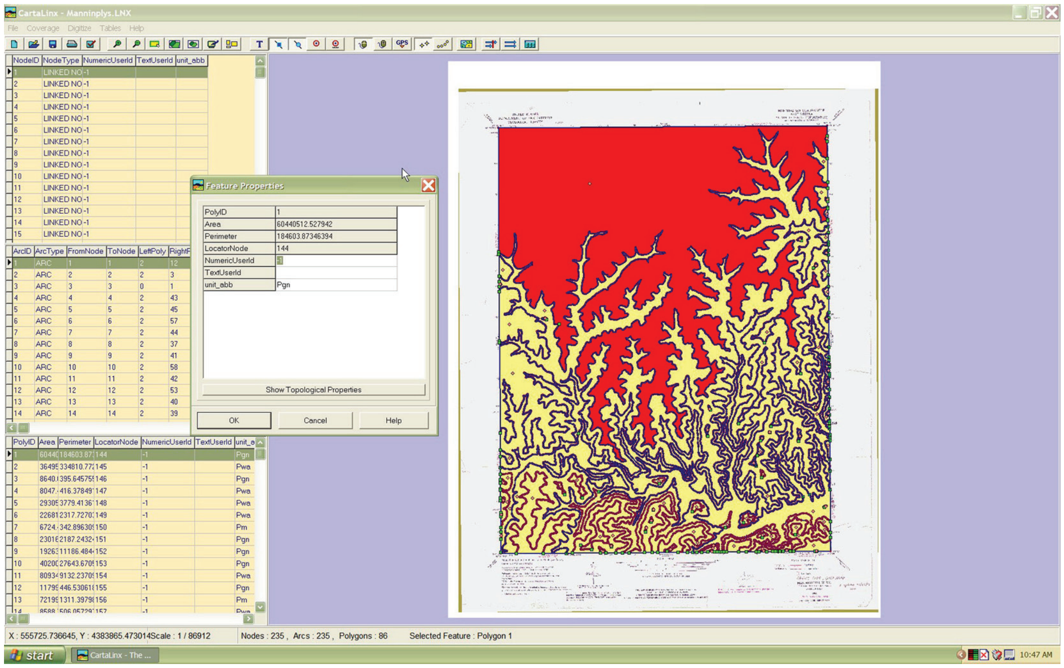

Figure 5. Cartalinx display of outcrop polygons on the Mannington 7.5-minute quadrangle.

lines that can be added to a coverage initially composed of a quadrangle border. The Cartalinx data model also supports distinct polygon locators that facilitate attributing the outcrop polygon coverage. The complete set of structure grids and the DEM enable the sampling of grids along profiles, and the sampled profiles are used to generate cross sections (Figure 6). Open-File Report maps are produced utilizing Adobe Illustrator with the MAPublisher plug-in (Figure 7).

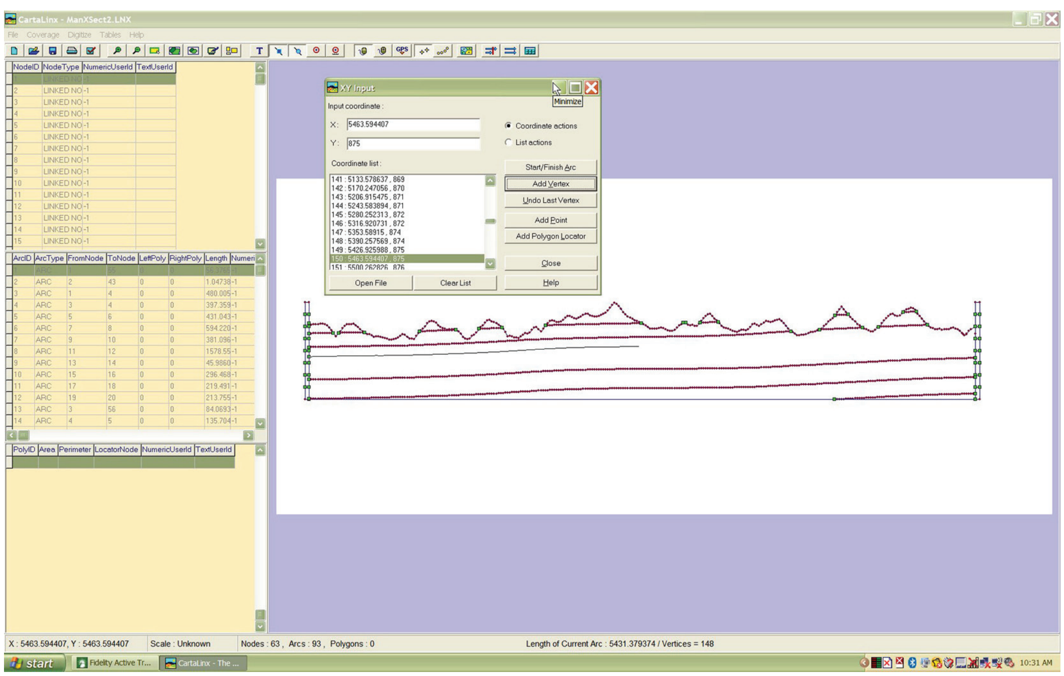

Figure 6. The cross section accompanying the preliminary geologic map of the Mannington 7.5-minute quadrangle is generated by sampling structure grids of critical horizons and the topographic grid along a profile. The incomplete line is in the process of being plotted using individual points from the elevation grid of the Waynesburg coal sampled along the cross-section line. The coordinates of the line being plotted can be seen in the window above the cross section in the illustration.

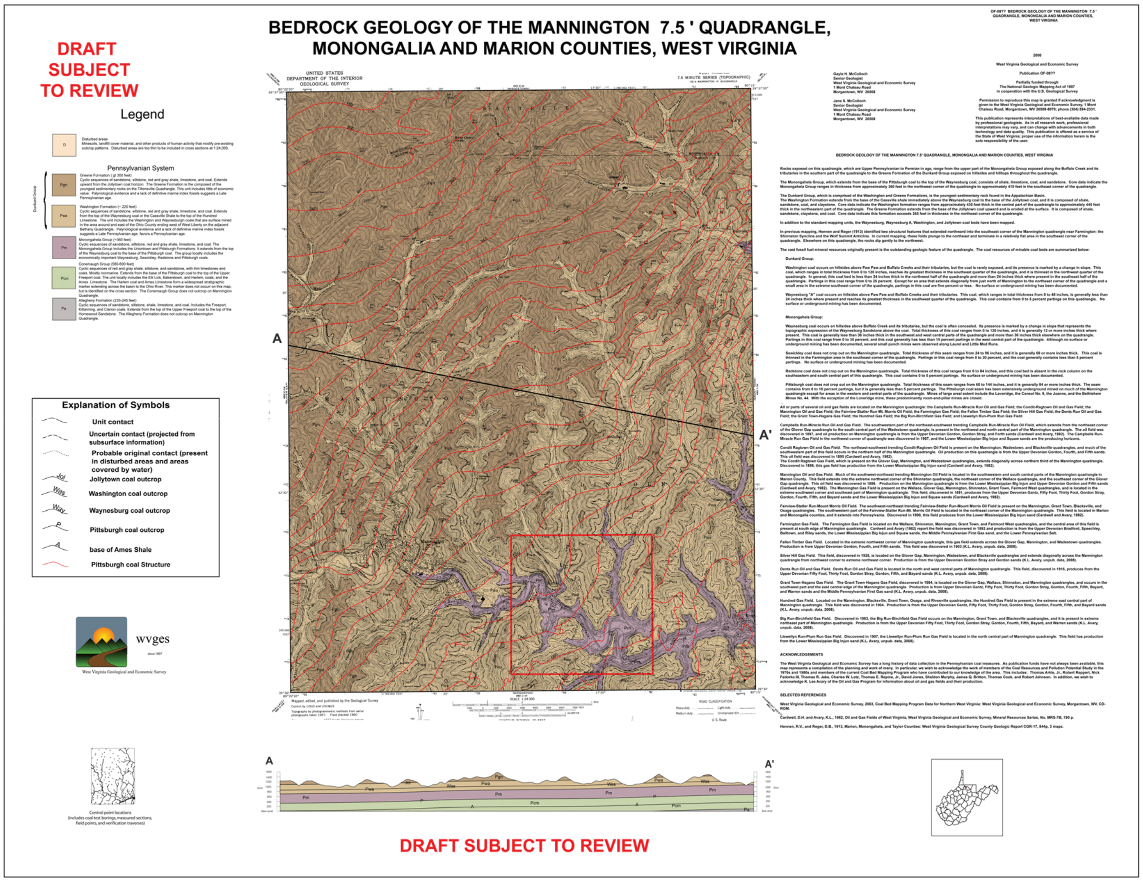

Figure 7. A reduced-size version of the open file Mannington 7.5-minute Geologic Quadrangle Map produced utilizing Adobe Illustrator with the MAPublisher plug-in.

Developing a New Base Map

A recent decision to produce a new West Virginia State Geologic Map has generated discussion of several issues including obtaining modern base maps for use in preparing new geologic maps of all scales.

The planned State Geologic Map is to be a living document representing the current state of knowledge about West Virginia geology. A robust data model and an accurate scalable base map are two tools that will make this possible. The North American Geologic Map Data Model Steering Committee has provided a suitable data model. Regarding the base map, the previous state geologic map (printed in 1968, with minor updates in 1986) uses the 1:250,000-scale Army Map Service 2-degree quadrangle series. A more suitable base map is being sought because this older series has a well-documented minor projection error (Snyder, 1987), it has become outdated, and there are no plans to produce an updated base at 1:250,000 scale. Ideally, the new base map would be a flexible statewide digital vector base, usable for scales ranging from 1:4800 to 1:250,000.

One possibility results from a data collection effort begun in 2003 when the West Virginia State Addressing and Mapping Board (SAMB) flew digital imagery of the state and subsequently made it available as state plane coordinate tiles (WVSAMB, 2004). In 2005, cooperative projects between the USGS, SAMB, and the West Virginia GIS Technical Center reformatted this imagery from state plane coordinates to digital orthophotoquads (DOQQs) (Figure 8) (USGS and WVSAMB, 2005) and produced 1/9 arc second digital elevation models (DEMs) (Figure 9) (USGS, 2005). In 2006, the West Virginia GIS Technical Center contoured the DEMs to produce a uniform statewide set of attributed shapefiles of 20-foot contours (WVGISTC, 2006). Figure 10 shows an unannotated base map of part of the Mannington 7.5-minute quadrangle that was produced using these contours and the new 2007 Census Bureau TIGER files (U.S. Census Bureau, 2007). In order to support the new West Virginia State Geologic Map, it will be necessary to first test whether current geologic mapping at 1:24,000 will fit the new base. Figure 11A shows part of the Mannington 7.5-Minute Geologic Quadrangle map that has a backdrop of scanned separates from the Mannington 7.5-minute topographic quadrangle produced in 1960 and photorevised in 1976. Figure 11B shows the same area using the linework from Figure 10 as a base map for comparison. Much additional testing will be necessary before a decision about this approach to a new base map is made, but this preliminary test is promising.

Figure 8. Digital orthophotoquad, with 2-foot resolution. The red box on Figure 7 delineates the area covered.

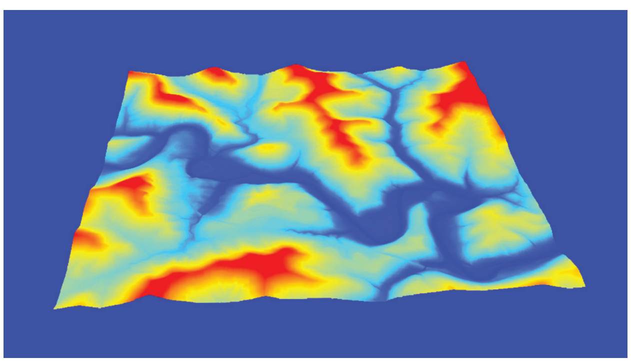

Figure 9. 1/9 arc-second Digital Elevation Model, produced from digital orthophotoquad imagery for area shown in Figure 8, looking north.

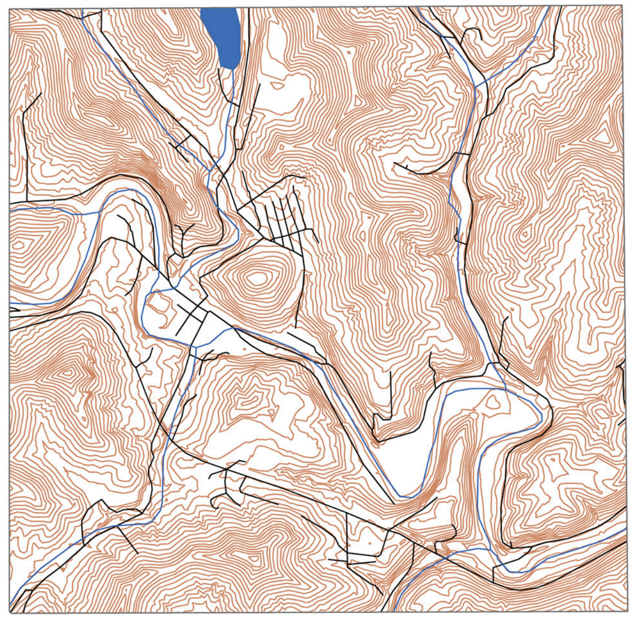

Figure 10. Twenty-foot contours produced from the DEM, and 2006 second edition Census Bureau TIGER files, used for a simplified unannotated base map.

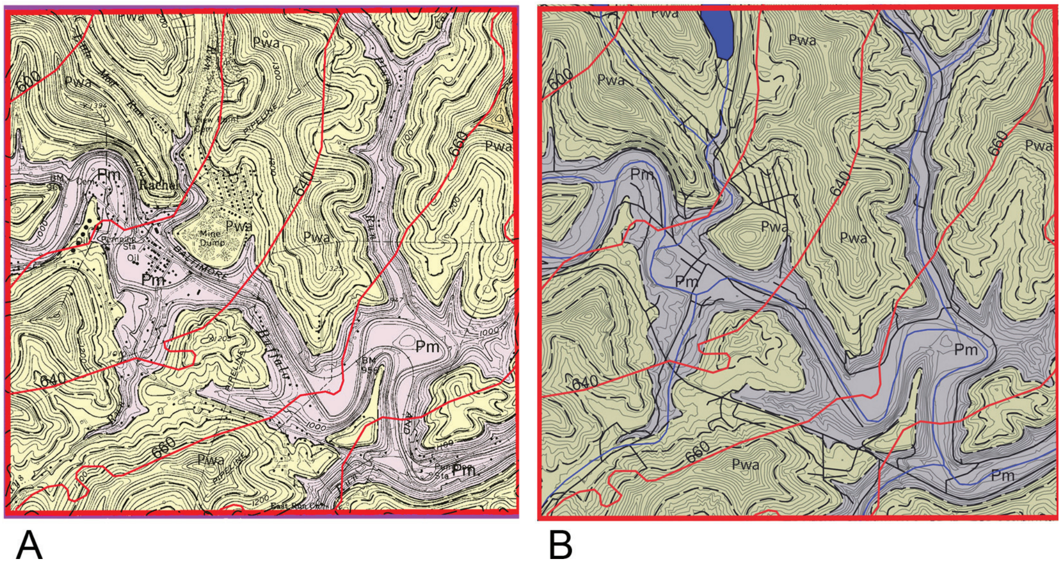

Figure 11. Mannington quadrangle geology at 1:24,000 from the draft open-file report, plotted on (A) scanned quadrangle separates and (B) the simplified base map shown in Figure 10.

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