Integrating Mine and Mine Map Databases with Georeferenced Maps to Provide a Mine Safety GIS for Southwestern Virginia[1]

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Abstract. Digital rendering of underground coal mine maps is a critical component of Virginia's commitment to enhance mine safety. The Virginia Department of Mines, Minerals, & Energy has identified over 20,000 coal mine maps from federal and state agencies, libraries, coal companies, and private collections. These maps are being scanned and cataloged into a comprehensive digital database that captures mine identification, elevation, roof falls, and flooding information. Using a geologic, topographic, and cultural framework, mine maps are assigned to the appropriate coal bed and georeferenced. Mine extents are then digitized from the georeferenced maps. The resulting integrated platform of spatial data, combined with the mine and mine map relational databases, enables a fully searchable, web-based geographic information system.

Additional Key Words: coal, coalfields, underground mines.

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[1]Paper was presented at the 2004 Advanced Integration of Geospatial Technologies in Mining and Reclamation, December 7 – 9, 2004, Atlanta, GA.

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Introduction

The Virginia Department of Mines, Minerals and Energy (DMME) is responsible for regulatory programs concerned with mine safety, mining-related public safety, and reclamation. Managing compliance with such programs requires knowledge of the spatial relationships between active mines, abandoned mines, and other man-made and natural features. Mine maps are a critical source for establishing such relationships. Beginning in the late 1950s, DMME and its predecessor agencies archived coal mine license maps on microfilm for use by regulators, industry, and the public. In recent years, DMME has committed to expanding its collection of mine maps and converting them to readily accessible digital images. Collaboration with other government agencies and coal companies has greatly expanded the number of maps available. To date, over 20,000 available mine maps have been identified. To manage such a large volume of maps, DMME has implemented a program of scanning, cataloging, and georeferencing (Figure 1). This digital archive serves as the foundation for building a spatial dataset of attributed mine polygons that can be integrated into a web-based geographic information system (GIS).

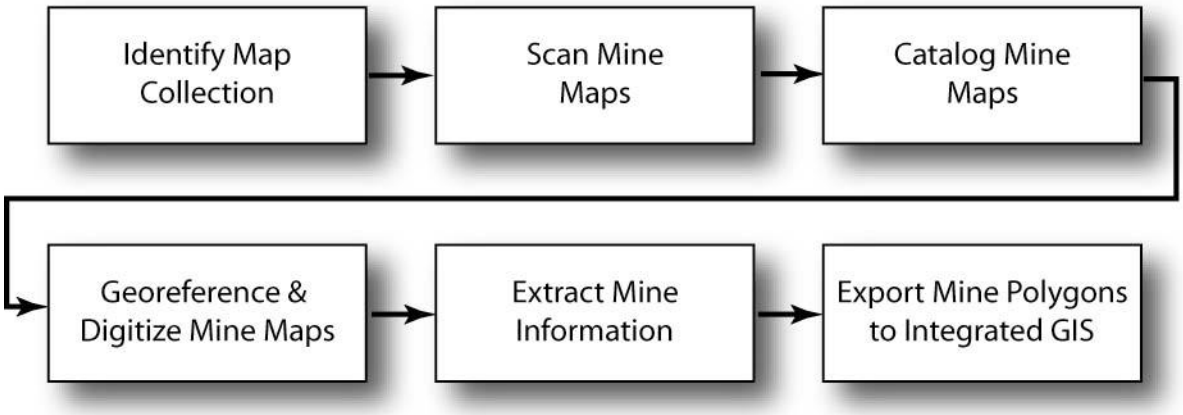

Figure 1. Flowchart of the DMME integrated mine mapping project.

Map Source Assessment

The first step in establishing DMME's integrated mine and mine map databases was to identify and locate all available mine maps. Two categories of map sources were identified: internal DMME collections and external collections. Five internal map collections represented

all maps submitted to DMME in order to meet the mine licensing requirements of State law. External mine map collections consisted of maps from other government agencies, coal companies, and libraries. DMME also launched an initiative to appeal directly to individual coal companies and to the public, asking for any old mine maps to be submitted for scanning. These collections are summarized in Table 1.

Source	Estimated # of Maps	Type of Maps	Estimated Age Range
State Library of Virginia	1866	Microfilms of closure maps	1958 to 2002
DMME Client Assistance Center	4848	Diazo duplicates of State Library microfilm	1907 to 2003
OSM National Mine Map Archive	3533	Microfilms	1910 to 1999
DMME Active Mines	461	Paper maps	1996 to 2004
DMME Division of Mineral Resources Archive	2515	Paper maps	1960 to 2002
DMME Previously Donated Map Collection	2277	Paper maps	Various
DMME Scanned Map Archives	821	Paper maps	1938 to 2003
Map Archives of Collaborating Mining and Land Companies	4221	Paper maps	Various

Table 1. Known sources of underground mine maps.

Mine maps collected range in quality from computer-drafted maps with abundant, detailed information to hand-drafted maps with little more than a mine outline. The dates of these maps range from 1907 to the present. Map format also varies depending upon the collection. Most of the collections arrived as paper maps and were scanned by DMME personnel using a large format scanner at a resolution of 200 dpi (dots per inch). Maps too large to fit through the large format scanner in one pass, were folded and scanned in sections. With a few external company

collections, DMME personnel scanned maps on-site in company vaults. Some of the older, internal collections existed only as microfilm images. Scanning of these microfilm maps was outsourced to a professional scanning consultant.

What appear to be duplicate mine maps are contained in the various collections; however, in many cases small differences in information between almost identical maps are significant. For example, maps dated a few months apart may show important differences in mined extents. These small, but significant differences make it essential that every attempt is made to collect all existing mine maps.

Database Development and Implementation

One of the key elements to this project was finding a way to store and serve the mine and mine map data so that it is readily accessible to all users. In order to capture and disseminate the important identification and safety information contained on the individual mine maps in our collections, a comprehensive database was designed. Initially, the database was created in Microsoft Access. However, it soon became clear that a project of this scale involving multiple users entering data required a more scalable, web-accessible database. Microsoft SQL Server was selected, and the Access database was migrated to the more robust platform. Rather than using Access or Visual Basic forms for data entry, browser-based Active Server Pages (ASPs) were developed (Figure 2). Making the application web-based enabled users in any of our offices across the Commonwealth to have access to the database without the need to install and support additional software.

Cataloging Mine Maps

Establishing a queriable database of mine map and mine information depends upon careful examination of each individual mine map. The cataloging process requires close attention to detail and basic knowledge of mining techniques. From each mine map, key data is captured using the previously discussed web-accessible SQL Server database, *Coal Mine and Mine Map Inventory System* (Figure 2). The captured data ranges from basic identification information about the mine to safety information, including the presence of water or roof problems.

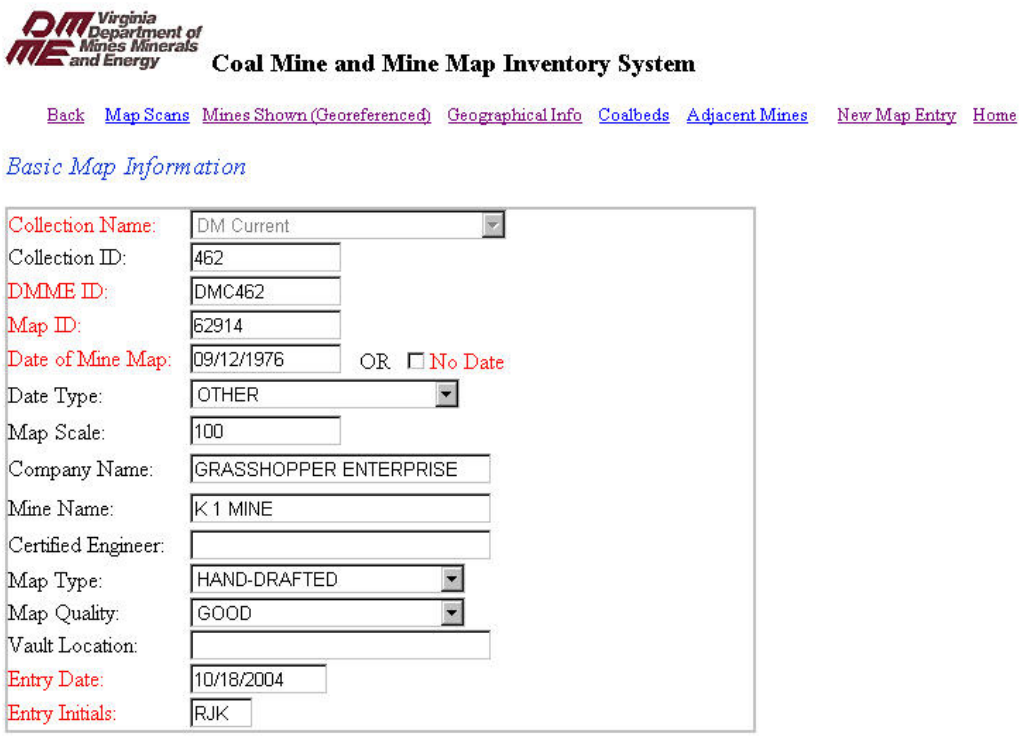

Figure 2. Screenshot of Coal Mine and Mine Map Inventory Active Server Page.

Basic mine map identification information recorded in the *Coal Mine and Mine Map Inventory System* includes data such as the mine name, company name, coal bed, map date, map scale and certified engineer. Other map items are captured in a series of check boxes such as the presence of adjacent mines, surface mines, gas wells, water in the mine, and adverse roof conditions. Finally, geographic information, such as mine map coordinates, drainage basin, county, and quadrangle, is recorded. For a detailed list of items captured from the mine maps, see Table 2. This information can be quickly and efficiently queried by any user to identify maps with specific qualities or maps in certain locations.

The majority of map cataloging takes place after the mine maps have been scanned. The cataloger has a dual monitor workstation. The scanned map image is displayed on one monitor and the data entry screen on the other. This workstation set-up saves time by allowing the cataloger to scroll through the map and enter data at the same time without having to maximize and minimize multiple applications.

Data Field	Data Entry Method	Brief Description
Collection Name	Dropdown list	Tracks source of maps
DMME ID	Automatically populated	Unique number used to identify maps
Map ID	Text entry box	Generally mine license number
Date of Mine Map	Text entry box	Date map was finalized
Map Scale	Text entry box	Scale of map
Company Name	Text entry box	Name of company who submitted the map
Thickness Data	Checkbox	Indicates coal thickness information is available
Elevation Data	Checkbox	Indicates elevation information is available
Surface Mines	Checkbox	Indicates surface mines are present on the map
Adjacent Mines	Checkbox	Indicates adjacent mines are present
Auger Mines	Checkbox	Indicates auger mines are present
Coreholes Present	Checkbox	Indicates corehole information is available
Gas Wells Present	Checkbox	Indicates gas wells are present
Water	Checkbox	Indicates water is in the mine
Roof Falls	Checkbox	Indicates a roof fall has occurred
Final Map	Checkbox	Indicates final map
Drains	Checkbox	Indicates drains are present
Crop Line	Checkbox	Indicates coal crop line is shown
Other Portals	Checkbox	Indicates other portals are shown
VVHs	Checkbox	Indicates vertical ventilation holes (VVHs) are shown on the map
Comments	Text entry box	Place for specific comments
Company Coalbed	Text entry box	Coal name company assigned
Scan Information	Text entry box	Hyperlink for the map image
Mines Shown	Text entry box	Lists all mines shown on map
Standard Coalbed	Dropdown list	DMR assigned coalbed
State Plane	Checkbox with text entry boxes	If map has state plane coordinates they are entered here
Lat/Long Point	Checkbox with text entry boxes	If map has latitude or longitude points they are entered here
Company Coordinates	Checkbox	Indicates company coordinates were used
Quadrangle	Dropdown list	Quadrangle(s) of map
County	Dropdown list	County(s) of map
General Location	Dropdown list	Lists names of streams, rivers, towns, valleys

Table 2. A list of data fields captured during cataloging and the method of data entry.

Georeferencing Mine Maps

Georeferencing is the groundwork for integrating the database with the spatial information, creating a GIS. Once maps have been georeferenced and vectorized, the resulting spatial data can be linked to the *Coal Mine and Mine Map Inventory System*. This kind of integration significantly improves the quality, searchability, distribution and manipulation of the data.

Due to the large volume of mine maps being addressed, priority areas had to be designated. Areas with active mining were identified as the first priority, with buffer zones generated around these areas. Georeferencing will continue in areas with the highest mining volume until the entire coalfield has been georeferenced. See Figure 3 for a map showing the locations of active mining areas.

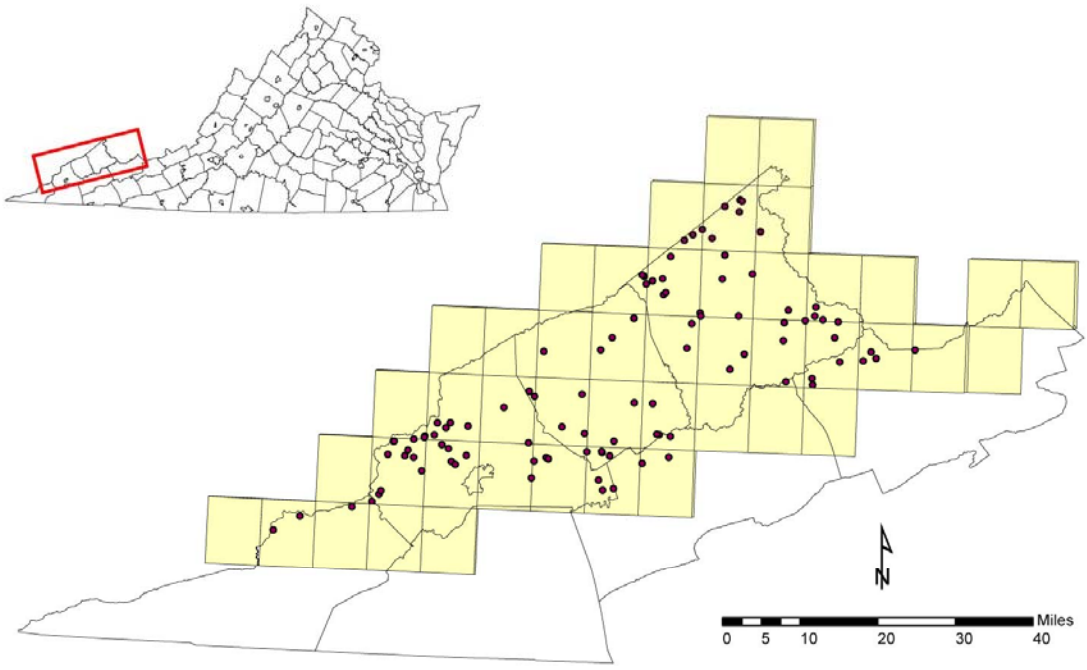

Figure 3. Map showing active underground coal mining locations in southwest Virginia.

Georeferencing map images begins with locating the map in the X and Y dimensions. This can be either relatively easy or impossible depending upon the information contained on the map. Some maps have a state plane coordinate grid or a point that has an assigned geographic coordinate. Many maps only have a named stream drawn or listed in the legend, while still others have little more than the coal outcrop line near the opening of the mine drawn. A preferred order for the method of georeferencing from a higher degree to lower degree of confidence has been established to ensure that the map is placed in the most accurate manner. The order of preference is: map placed using printed world coordinates; company planimetrics; natural and cultural features; relative to other mines; outcrop matching; and using general location description. The georeferencing method employed is recorded in the database.

In addition to georeferencing the mine maps in the X and Y dimensions, a Z dimension (elevation or coal bed in this case) must also be designated. Due to the many variations in local and regional coal bed names, close proximity of coal beds to one another, temporal name changes and the deliberate switching of coal bed names in order to market a more favorable coal, assigning a map to the proper coal bed can be one of the most difficult aspects of georeferencing. To address the local and regional naming issues, it was necessary to standardize and normalize the stratigraphic nomenclature of the region. Within this system, approximately 75 reference coal beds (coal zones) are recognized and named within the 5000 plus feet of coal-bearing strata. Of these reference beds, approximately 50 have been identified as key or primary coal beds that have either significant lateral extent and/or some record of underground mining. From this, a standardized list of reference coal beds and their aliases was developed. To date, more than 250 local and historical names have been correlated and normalized back to the standardized stratigraphic system. For example, some coal beds, such as the Upper Banner, have been consistently named and correlated within Virginia over the years; it has no secondary or local names that have been identified thus far. Conversely, the Imboden coal zone, an important historical and regional producer which extends beyond Virginia and into Kentucky and West Virginia, has more than 20 local names (including: Blue Gem, Burnwell, Campbell Creek, Freeburn, Lower Bolling, Lower Campbell Creek, Lower Elkhorn, Lower Marrowbone, Mason No. 2, Mason No. 3, No. 1, No. 2, No.3, No. 2 Gas, Path Fork, Pond Creek, Upper Bolling, Upper St. Charles, Upper War Eagle, and Warfield) in Virginia alone. To address other issues we have to rely on elevation data on the mine maps and correlate this to known elevations of

coal beds. Both the company-listed coal bed and the standardized coal bed names are captured in the database.

Capturing Mine Data

DMME is using AutoCAD to digitize and vectorize data on the maps. Once a map has been georeferenced in AutoCAD, the mine footprint (or outline) is digitized or updated. Coal thickness and elevation data are also captured at this time. Elevation data is usually presented as structural contours on the mine map; each contour is digitized as a polyline and assigned an elevation in AutoCAD. Coal thickness information is typically presented as a package of numbers (i.e., C=25, R=5, C=9). For capturing point thickness and elevation, DMME developed CoalPoint, a Visual Basic application that displays a form with text boxes for data input, then inserts an attributed symbol as a block into AutoCAD. ACAD_Extract, another in-house Visual Basic application, extracts the elevation and thickness data and exports it with coordinates to a spreadsheet. This data can then be imported into modeling software and used to generate three-dimensional models.

For every mine polygon that is digitized, a unique label is assigned. That label is either the DMME issued mine license number or, in the case of an unknown mine, an assigned label based on the three-letter abbreviation of the coal bed followed by a sequential three digit number (for example SPD_107). A record of each mine polygon is also entered into the *Coal Mine and Mine Map Inventory System*. This record contains information about the mine itself, including its name, license numbers, coal company, operator, coal bed, the presence of roof falls or flooding, and quadrangle and county location. Notes about any modifications to the mine polygons are also stored in the inventory system to track when and why a change was made. All mines present on the map are recorded in the *Coal Mine and Mine Map Inventory System*.

Generating Topology

In creating a GIS, topology is essential. Topology establishes the relationship of spatial elements to each other. To build the topology, the polygons digitized in AutoCAD have to be clean, e.g., no dangling lines, no undershoots and no overlapping polygons. The unique labels must also be linked to the specific polygons. After cleaning up the drawing, linking the labels and generating the topology, the polygons can be exported to GIS files (either being displayed

with ESRI software such as ArcGIS or with AutoDesk software such as MapGuide). The polygons have associated attributes including area and labels. The *Coal Mine and Mine Map Inventory System* can then be dynamically linked to these GIS features so that cataloged information is displayed and all associated scanned map images with this mine are also available for viewing.

Data Delivery

DMME is using AutoDesk's MapGuide to serve this dataset to internal users. MapGuide maps are viewed with a web browser, eliminating the need for GIS software on the client computers. It also allows for centralized data storage, so updates are available immediately to all users. Other data layers important to mine safety, such as topography, roads, gas wells, and aerial photographs, are also included in the MapGuide application. Currently, underground mine polygons are displayed on separate map layers, one for each mined coal bed. These mine polygons are linked to the *Coal Mine and Mine Map Inventory System*, enabling users to view all of the attributes of the source maps captured during the cataloging process. Reports from the database also include links to the scanned mine map images, so users can see the sources from which the map polygons were derived.

The Future of Mine Mapping at DMME

Current efforts are focused on the completion of scanning and cataloging an existing backlog of mine maps lent to DMME by cooperating coal companies. To provide the most immediate benefit to regulatory personnel, georeferencing is being focused on areas of active underground coal mining. Even though the project is not complete, important benefits have already been realized. Regulatory personnel reviewing mine license applications now have access to thousands of mine maps previously not available within the Department. The spatial relationships of active mines to abandoned mines, gas wells, and other facilities can be viewed from any desktop computer with a web browser. These capabilities will improve the Department's ability to administer its regulatory programs that assure the safety of miners and the public.

Much work remains to be done. New map collections are still being identified and targeted for scanning. At current staffing levels, we project that incorporating all of these maps

into the database and spatial data will take longer than two years. With over one hundred active underground mines, a portion of our resources must also be dedicated to updating their footprints as mining progresses. A related project within DMME is generating a three-dimensional digital coal elevation and thickness model of all mined coal beds. Future work will involve incorporating the three-dimensional mine outlines with the three-dimensional geologic and topographic model (Figure 4).

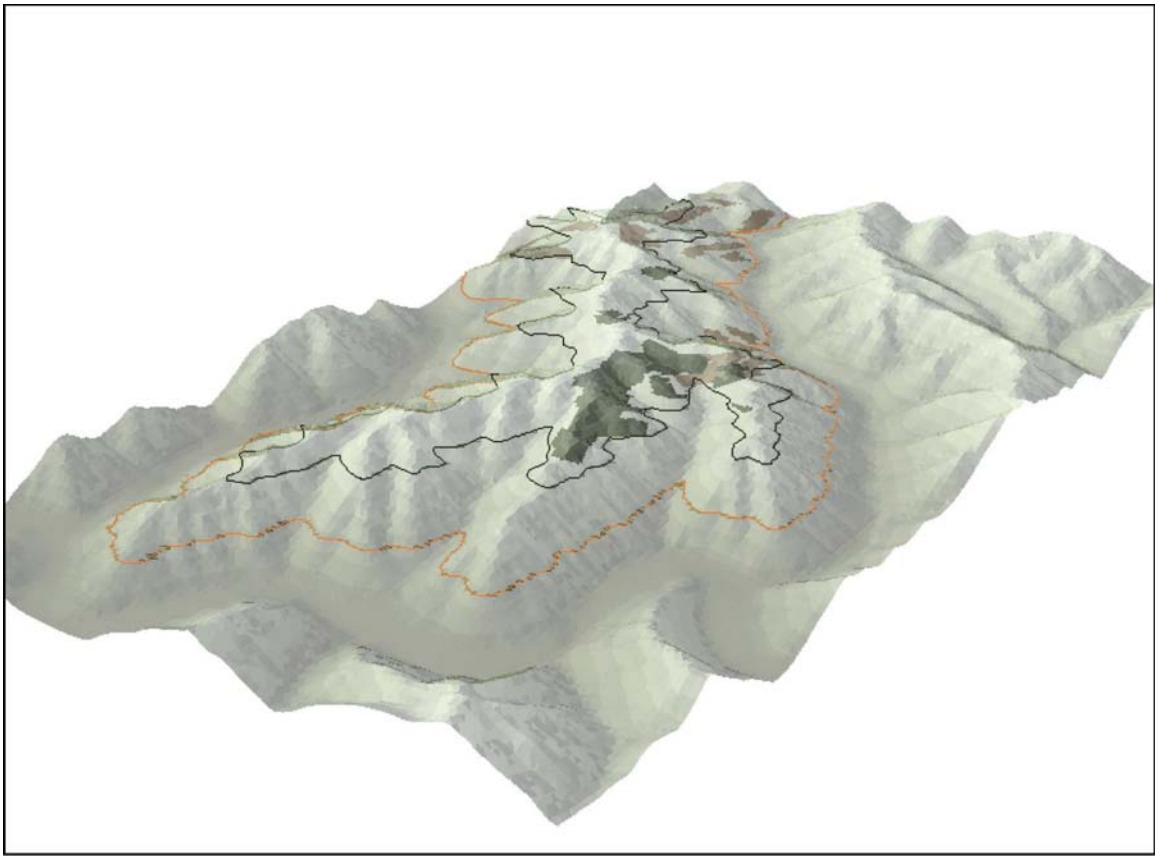

Figure 4. Three-dimensional model with underground mine polygons, coal crop lines and topography.